Hybrid Intelligent Decision Support System for Distributed Detection Based on Ad hoc Integrated WSN & RFID

A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy (PhD)

By

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Abstract

The real time monitoring of environment context aware activities, based on distributed detection, is becoming a standard in public safety and service delivery in a wide range of domains (child and elderly care and supervision, logistics, circulation, and other). The safety of people, goods and premises depends on the prompt immediate reaction to potential hazards identified in real time, at an early stage to engage appropriate control actions. Effective emergency response can be supported only by available and acquired expertise or elaborate collaborative knowledge in the domain of distributed detection that include indoor sensing, tracking and localizing.

This research proposes a hybrid conceptual multi-agent framework for the acquisition of collaborative knowledge in dynamic complex context aware environments for distributed detection. This framework has been applied for the design and development of a hybrid intelligent multi-agent decision system (HIDSS) that supports a decentralized active sensing, tracking and localizing strategy, and the deployment and configuration of smart detection devices associated to active sensor nodes wirelessly connected in a network topology to configure, deploy and control ad hoc wireless sensor networks (WSNs). This system, which is based on the interactive use of data, models and knowledge base, has been implemented to support fire detection and control access fusion functions aimed at elaborating:

- An integrated data model, grouping the building information data and WSN-RFID database, composed of the network configuration and captured data,
- A virtual layout configuration of the controlled premises, based on using a building information model,
- A knowledge-based support for the design of generic detection devices,
- A multi-criteria decision making model for generic detection devices distribution, ad hoc WSNs configuration, clustering and deployment, and
- Predictive data models for evacuation planning, and fire and evacuation simulation.

An evaluation of the system prototype has been carried out to enrich information and knowledge fusion requirements and show the scope of the concepts used in data and process

modelling. It has shown the practicability of hybrid solutions grouping generic homogeneous smart detection devices enhanced by heterogeneous support devices in their deployment, forming ad hoc networks that integrate WSNs and radio frequency identification (RFID) technology.

The novelty in this work is the web-based support system architecture proposed in this framework that is based on the use of intelligent agent modelling and multi-agent systems, and the decoupling of the processes supporting the multi-sensor data fusion from those supporting different context applications. Although this decoupling is essential to appropriately distribute the different fusion functions, the integration of several dimensions of policy settings for the modelling of knowledge processes, and intelligent and pro-active decision making activities, requires the organisation of interactive fusion functions deployed upstream to a safety and emergency response.

Publication List

- ***Conference Publications:***

1. F. Alshahrany, H. Zedan, and I. Moualek, " A conceptual framework for Small WSN Configuration using Intelligent Decision Support Systems for Emergency Preparedness and Response," in Innovative Computing Technology (INTECH), Third International Conference, London, 2013.

2. F. Alshahrany, M. Abbod and I. Moualek, "WSN and RFID integration to support intelligent monitoring in smart buildings using hybrid intelligent decision support systems," International Conference on Computational and Experimental Science and Engineering (ICCESEN 2014), Turkey, Antalya.

- ***Journal Publications***

1. F. Alshahrany, H. Zedan, and I. Moualek, " A conceptual framework for Small WSN Configuration using Intelligent Decision Support Systems for Emergency Preparedness and Response," IEEE,2013, DOI: 10.1109/INTECH.2013.6653726

2. F. Alshahrany, M. Abbod, A. Alshahrani and K. Alshahrani, "How WSN can be designed to be Efficient, Journal of Multidisciplinary Engineering Science and Technology (JMEST), December – 2014, Vol. 1 Issue 5, ISSN: 3159-0040.

3. F. Alshahrany, H. Zedan, and I. Moualek, " WSN Configuration using Agent Modelling and Hybrid Intelligent Decision Support System “International Journal of Sciences: Basic and Applied Research (IJSBAR) (2014) Volume 14, No 2, pp 67-90, ISSN 2307-4531

4. F. Alshahrany, M. Abbod and I. Moualek, "WSN and RFID integration to support intelligent monitoring in smart buildings using hybrid intelligent decision support systems," Acta Physica Polonica A ,2015 ,vol. 128 ,issue 2B B-152-B-160

5. F. Alshahrany, M. Abbod, J. Alshahrani and A. Alshahrani, "Intelligent Networks Data Fusion Web-based Services for Ad hoc Integrated WSNs-RFID”, International Journal of Engineering and Technology Innovation, Feb 2016, ISSN: 2223-5329

- ***Poster Publications:***

1. Falah Alshahrany,"WSN configuration for Smart buildings: Devices Localisation and deployment" the 7th Saudi Scientific International Conferences 1-2 February 2014, Edinburgh

2. Falah Alshahrany and Maysam Abbod, "Using hybrid WSN approach and intelligent decision support systems for fire detection and mitigation in smart buildings" the 8th Saudi Students Conference (SSC2015), 31st Jan _1st Feb 2015, London.

Dedication

My special thanks go to:

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- My beloved father (Allah's Mercy) on his soul passed away during the course of this research,
- My mother and my sister Haya for their unconditional support and encouragement, and
- My son Abdullah for taking me off lots of family responsibility.

I dedicate this work to all of them, showing my gratitude to them, and I am saying to them thank you for enabling my PhD dream become a reality.

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Declaration

This is to certify that:

i. The thesis comprises only my original work towards the Ph.D. except where indicated.

ii. Due acknowledgement has been made in the text to all other material used.

Falah Alshahrany

Table of Content

List of Figures

List of Tables

List of Abbreviations

ABM	Agent-Based Modelling
AHP	Analytic Hierarchical Process
AIDC	Automatic Identification Data Collection
CC	Cloud Computing
CLDs	Causal Loop Diagrams
CM	Cognitive Maps
CN	Coordinator Node
CVWE	Collaborative Virtual Work Environment
DASH	Desktop Management
DCOM	Distributed Component Object Module
DoS	Denial-of-Service
DPM	Dynamic Power Management
DSB	Domain Service Bus
DSS	Decision Support Systems
EBL	Enquiry-Based Learning
EDN	End Device Node
EEPROM	Electrically Erasable Programmable Read-Only Memory
EP	Ending Point
ESUP	Energy Supply Use Points
ETL	Extraction-Transformation-and Loading
FODA	Feature Oriented Domain Analysis
G	Gateway
GDSS	Group Decision Support Systems
GSS	Group Support Systems
HIDSS	Hybrid Intelligent Decision Support System
HSB	Health Service Base
HTTP	Hyper Text Transfer Protocol
IC	Integrated Circuit
ISR	Intelligence, Surveillance and Reconnaissance
KB	Knowledge-Based
KIIDSS	by Knowledge-Intensive Intelligent Decision Support Systems
KM	Knowledge Management
LMS	Learning Management Systems
LNA	Low Noise Amplifier
MADM	Multiple Attribute Decision-Making
MAS	Multi-Agent System
MB	Model-Based
MDM	Master Data Management
NetMan	Network Management
NLDP	Node Location Distribution Patterns
OLAP	On-Line Analytical Processing
OLTP	On-Line Transactional Processing
PA	Power Amplifier
PDAs	Personal Digital Assistants
PR	Procedural Reasoning
QoD	Quality of Data
R	Router

RBR	Ruled-Based Reasoning
RFID	Radio Frequency IDentification
RN	Router Node
SC	Soft Computing
SD	Spacing Distance
S_l	Segment Length
SM	Spatial Multiplexing
SMI	Storage Management
SNC	Sensor Nodes Clusters
SOA	Service-Oriented Architecture
SOAP	Simple Object Access Protocol
SP	Starting Point
SSD	Sensing Spacing Distance
SSN	Sensor Semantic Network
UART	Universal Asynchronous Receiver/Transmitter
UPC	Unique Product Code
VMAN	Virtualization Management
WBKBS	Web-Based Knowledge-Based System
WBKBSS	Web-Based Knowledge Support System
WBSS	Web-Based Support Systems
WSAM	Web Services Architecture Model
WSDL	Web Services Description Language
WSDL	Web Service Description Language
WSMN	Wireless Sensor Multimedia Network
WSN	Wireless Sensor Network

Chapter 1: Introduction

1.1 Introduction

The emerging field of pervasive computing is imposing new research challenges for the generic design of context aware computer systems needed to implement intelligent solutions for the configuration, support and effective use of smart spaces characterised by their location, content, and environmental and data-aware attributes. These challenges concern the validity, durability and quality of solutions that integrate varied individual and group knowledge activities, supported by an increasing complex seamless interaction of people, smart devices, intelligent agents and services interoperating in these smart places and configured in information and knowledge context applications. The context aware property of these systems which originated from the emerging ubiquitous or pervasive computing, relates to linking changes in the environment with computer systems; these changes being induced by the dynamic behaviour of people, devices and software agents. However, Textaware capabilities dealing with instant text in terms of very fast entry text, is not considered in this research.

The implementation of these solutions poses difficult infrastructure challenges such as integration and interoperability, devices power supply and communication protocols, intermittent and variable-bandwidth connectivity, and other concerns that standards, regulation and security considerations impose. The nature of such applications that adapt to the user's context and needs, and configured in proactive and self-tuning distributed systems is changing to reduce human involvement in their management, and better respond to highly dynamic information context environments involving wireless communication and mobile computing. These systems are required to work autonomously and integrate the different infrastructure aspects needed to capture and process multi-sensor heterogeneous data, and create the information required for the knowledge domains analysis. The study of these aspects, with a focus on the development of generic real-time solutions for integrated context management infrastructure, and the design of hybrid intelligent decision support systems based on the use of appropriate context modelling concepts is presented in this research.

1.2 Research Motivations

The study of several problems that include real-time predictions and decision making, maximizing the scope of multi-agent interaction, aggregation of decision making models, integrated web-based services composed of intelligent agents and smart devices, is the focus point of the new generation of intelligent solutions and systems successfully integrating communication, information, computing and other advanced technologies.

Of great interest in the research domain considered, is the development of advanced hardware and software intelligent agents, in the sense of pervasive computing that extends further the multi-agent interaction scope. The involvement of humans in knowledge elicitation, discovery and extraction has led to their incorporation as additional agents in the multi-agent framework. They are represented by individual and collective processes describing their roles and functions. Their involvement poses the problem of the representation of cognitive differences reflected in individual agent roles and behaviours that might affect their group interaction.

Interoperable dynamic web services of a good quality service level enabling the internet to play a preponderant role in the design and implementation of self-turning distributed multi-agent systems, is an essential aspect of edge computing. The agent coordination required to facilitate the interaction within the system is supported by the hybrid support service composition rules which structure the agent service configuration depending on the agents roles, behaviours, and influence on each other.

The study of these problems is based on the modelling of intelligent agents organised as hierarchical collections of knowledge functions identified, analysed, structured and configured in a programmable coordination and cooperation constructed as multi-agent systems. Such systems support the agent interaction and exploration of the knowledge domain following the strategy of decoupling the data capture and processing from information and knowledge fusion.

The research motivation can be presented succinctly as follows:

- Real-time predictions and decision making:
    - Heterogeneous raw soft and hard big data from different sources.
    - Data fusion complexity and predictive data modelling.

- Intelligent agent modelling, interaction and distributed multi-agent systems, and self-turning multi-distributed systems.
- Collaborative and group decision making, and decision aggregation.
- Agent based service configuration and composition.

- Data fusion decoupling in fusion processing.
- Information fusion and knowledge discovery and extraction.

1.3 Research Aim and Objectives

The aim of this research is the study of the design of a hybrid intelligent decision support system for data, information and knowledge fusion. This study includes the following:

- Discovery of knowledge about distributed detection: indoor sensing, tracking and localising, and requirements elicitation.
- Identification of distributed detection knowledge processes and fusion functions.
- Elaboration of intelligent distributed detection solutions using advanced technologies.
- Definition of specifications for a hybrid intelligent decision system to support the activities of indoor sensing, tracking, localising and monitoring.
- Development, implementation and evaluation of a support tool for ad hoc WSN-RFID configuration, deployment and control.

The hybrid intelligent decision system should support the following features:

- Sensing, tracking, localising and monitoring knowledge requirements elicitation as part of domain analysis,
- Detection sensor node design, that identify functions and allocate components,
- Integrated WSN-RFID configuration & deployment, and
- Context aware real-time multi-sensor and WSN data Fusion.

The proposed research illustrated in the conceptual framework shown in Figure 1.1, focuses on hybrid intelligent context aware systems that can provide a reliable and responsive support to knowledge activities. This framework supports the study of knowledge domain context aware real-time data, information and knowledge fusion, and multi-agent interaction based on collaborative decision making.

The complexity in designing and programming such systems involves the exploration of several research domains for the understanding of the development of context modelling concepts needed to support data-aware context capture and processing, and information and knowledge fusion. These domains are examined to elicit the key requirements for intelligent agents to reason about information context, interact with each other to enable knowledge sharing in open and dynamic information context environments.

The computer hardware dimension, platforms and the technical services supporting the business processes implementing the knowledge functions are not included in this research to limit the diversity of research concerns.

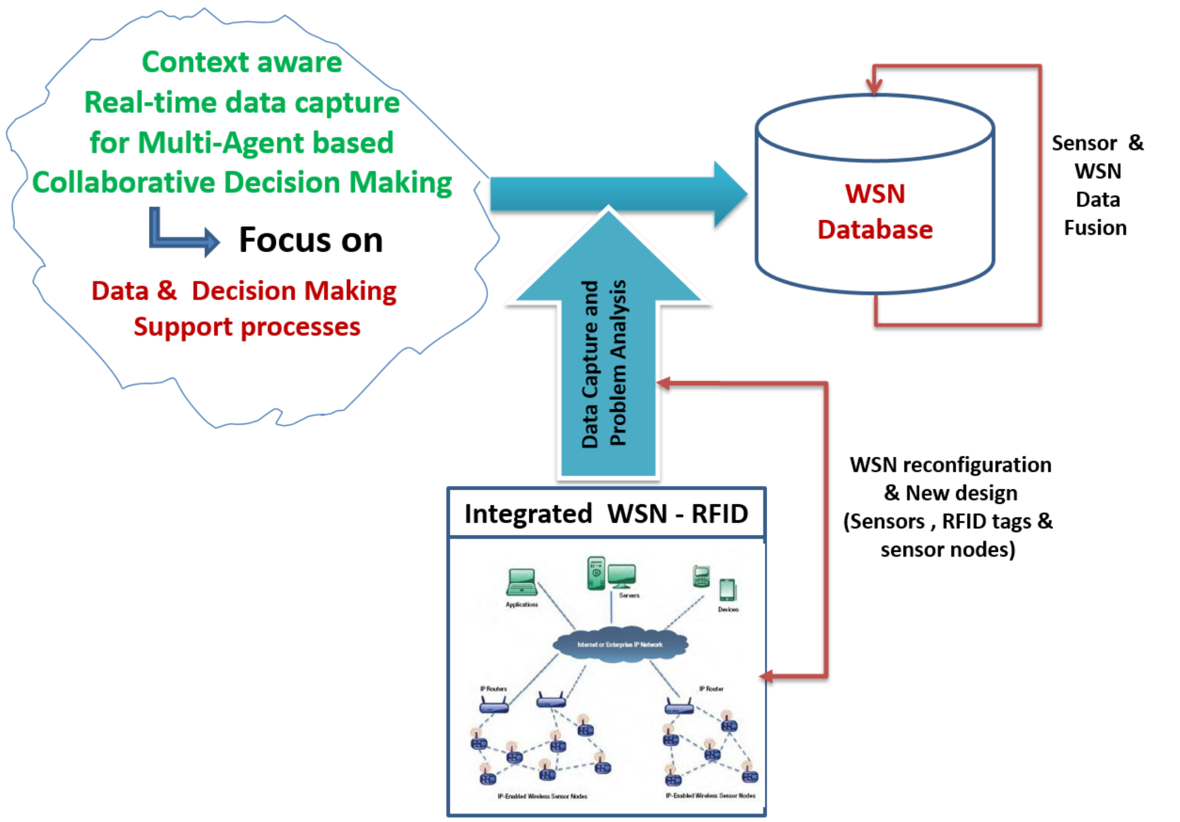

Figure 1.1: Research Problem 1

The research aim can be achieved by the following objectives:

- A good understanding of indoor sensing and monitoring requirements, in the context of surveillance activities as part of civil defence,

- The definition of specifications for an intelligent solution for distributed detection, particularly indoor sensing and monitoring activities, and other applications of the domain context,

- The design, development and implementation of a hybrid intelligent decision support system for distributed detection based on the use of integrated WSN-RFID, and

- The implementation of a case study to validate the concepts developed in this research that include:

  - Distributed detection knowledge processes & data fusion functions,
  - Virtual layout generation for smart buildings,
  - Optimal distribution of detection and support devices,
  - Generic detection sensor node design,
  - Integrated WSN-RFID configuration, deployment and control,
  - Real-time data capture, and WSN data fusion, and
  - Predictive data for evacuation planning, fire detection and evacuation simulation.

1.4 Research Methodology

The research methodology adopted in this work and shown in Figure 1.2, is a constructive research method based on the use of a hybrid approach that:

- Integrates the three domains of the study: problem analysis, solution design and system development, and

- Composes different classes of support system capabilities (data, model, knowledge) to achieve more deterministic and optimized results. The results evaluated are obtained from the modelling and implementation of several knowledge processes related to the deployment of objects and agents controlling an integrated WSN-RFID.

The constructive method used in this research methodology, has focused on the use of:

- A hybrid approach to compose entities at different conceptual levels,
- Requirements elicitation for the knowledge domain analysis,
- Knowledge processes modelling and specifications derivation for the solution design,
- Fusion processing for the service composition and distribution,
- Different classes of support capabilities for the support system structure, and
- Real time predictive data and decisions for the system outputs.

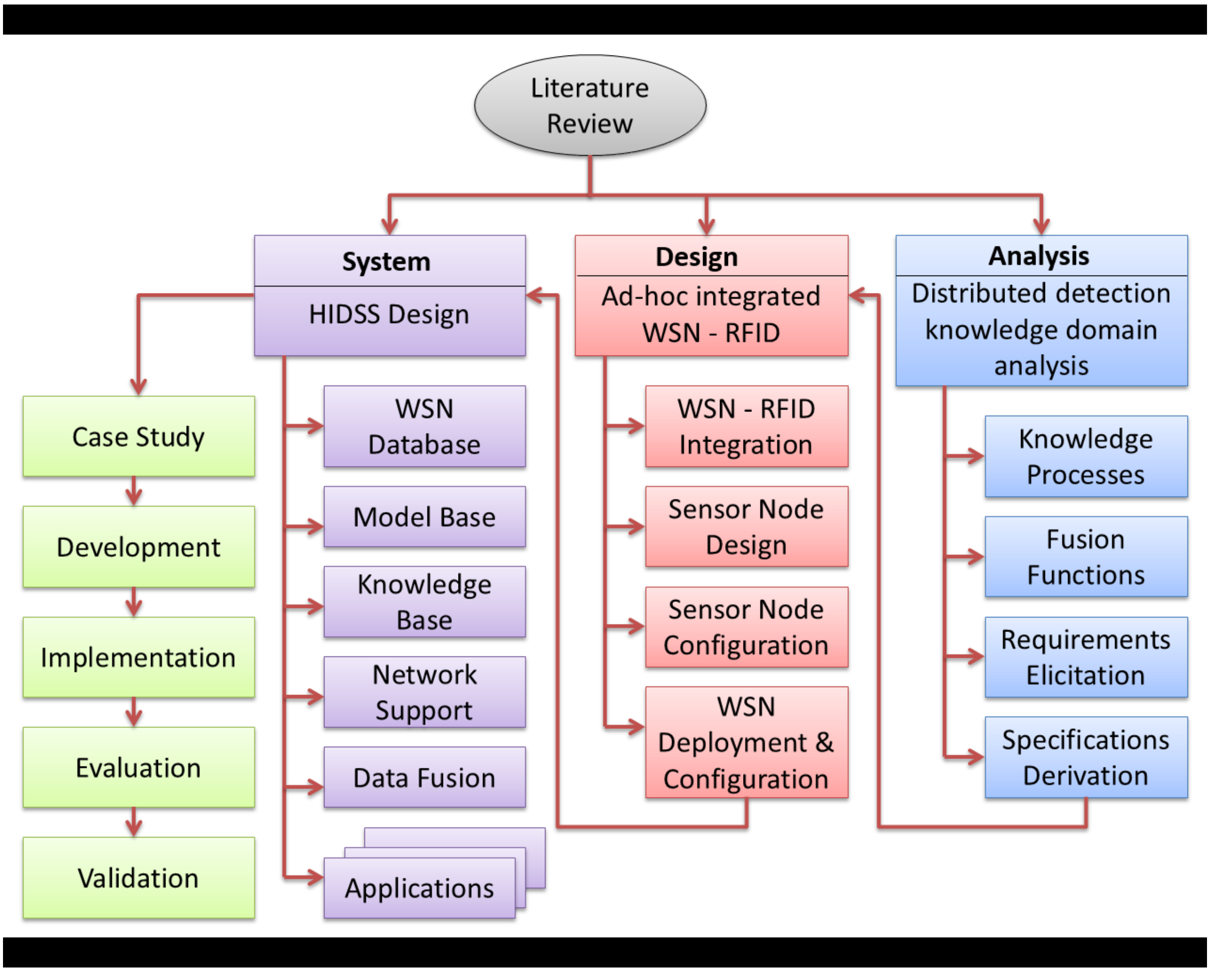

Figure 1.2: Research methodology 1

This research includes the following steps:

- The state of the art of surveillance and indoor sensing, WSNs, RFID, WSN and RFID integration, and hybrid intelligent decision support systems that include intelligent agents and agent modelling, multi-agent systems, decision support systems and group decision making.

- The integration of WSN and RFID technologies.
- The design and the configuration of ad hoc WSNs.
- The design and the implementation of the application context (Emergency preparedness and surveillance).
- The design and implementation of the HIDSS, as the pilot system supporting the case study.
- The evaluation of the system prototype.

The testing of the system prototype requires a case study aimed at designing an integrated WSN-RFID, based on a virtual building layout, to support:

- Emergency preparedness and fire simulation, and
- Building control access and evacuation simulation.

1.5 Conceptual Solution

The conceptual solution presented in Chapter 4, has been designed around the integration of the different functional components that include data capture and processing, the multi-sensor data fusion, information and knowledge fusion, and the inferring mechanism linking predictions and decisions to knowledge and explanations through the use of a wide variety of models. The design of the conceptual solution has been based on resolving the following issues:

1) The tasks organisation in a multi-agent distributed system environment, by:

    a) Separating the capture and communication of data and its processing performed at both the network level and the client system, and

    b) Turning the real time data into knowledge, and decisions using a hybrid intelligent decision support system to model the integration of predictive data, knowledge and explanations.

2) The optimization of WSN issues to facilitate intelligent real time decision making in disaster management, mainly:

a) The distinctive use and importance between heterogeneous and homogeneous devices for integrated and aggregated decisions,

b) The importance of local data processing at the node level (in-networking), and its implication on the WSN performance in terms of network congestion avoidance,

c) The reduction of redundancy of devices, data and messages,

d) The improvement of the message routing mechanisms addressing specifically the key problems of:

- Energy consumption and residual energy in sensor nodes,
- Routing path communication link quality requiring a thorough instantaneous monitoring of the ad hoc WSN performance, and

e) The evaluation of the ad hoc WSN and WSN-RFID integration design in terms of:

- Configuration, reconfiguration, optimal deployment, and
- The impact on the network performance measured by an enabling tool to adapt automatically to the external environmental events in the context of deploying web-based proactive and self-turning distributed systems.

3) The implementation issues of the system prototype aimed at integrating several technologies controlled by composed intelligent agents and services using a hybrid approach.

1.6 Measures of success

The research presented in this thesis relates to a project development aimed at supporting the real-time capture of big data inherent to real time predictions and decision making using ad-hoc wireless sensor networks. The corresponding measures of success are the efficiency and effectiveness of:

– The generic design of surveillance domain contexts applications using the same integrated computer based support for real time big data capture, and predictions and decision making,

- The optimal sensing coverage,
- The full integration of RFID and WSN technologies,
- The appropriate use of heterogeneous devices to enhance the configuration and deployment of homogeneous devices,
- The degree increase of hybridness of devices, intelligent agents and communication networks,
- The increase of intelligent agents collaboration, and
- The decoupling of fusion functions separating the processing of data from the elaboration of information and knowledge.

1.7 Research Contributions

The significance of the problem tackled in this research relates to the feasibility of defining generic design principles for web-based hybrid intelligent multi-agent solutions that are based on integrating sensing and tracking, and data communication technologies for solving different context problems. The solution to the research problem is based on satisfying the measures of success above listed in the previous section, and the research contribution to knowledge includes the provision of a generic recursive design conceptual framework that provides researchers and practitioners with a full understanding of the research approach proposed for the requirements elicitation and the specifications definitions to design and develop hybrid intelligent decision support systems.

The proposed generic recursive design conceptual framework is the research contribution in the following knowledge areas:

Enhancement of the integration of RFID and WSN technologies: The generic design conceptual framework presented in this research is a contribution to the enhancement of the integration of RFID and WSN technologies to extend ad-hoc wireless sensor networks. Such configurations which are supported by hybrid intelligent decision support systems, contribute to better configure and manage ad-hoc networks, and extend identification, tracking and sensing capabilities required for intelligent monitoring of activities and interaction support to people in emergency response when evacuating after a hazard occurrence. The scope of this contribution includes enabling these two technologies to extend the penetration of pervasive computing in every domain of context aware environment, and reducing the boundaries of informal big data and decision making processes to reflect real time situations and instantaneous decision making.

Large-scale realisation of multi-agent applications composed in intelligent services: The proposed conceptual framework has been designed for the study of knowledge domain requirements elicitation and specification derivation, and the development of a hybrid intelligent decision system to support the physical dynamic context aware environment and generic easy way to deploy context applications. This support system aims at integrating data, knowledge and models, and decoupling the real time data capture and processing from information and knowledge fusion. This is a contribution in large-scale realisation of multi-agent applications composed in intelligent web-based services for real-time decisions at the point of interaction, using self-adaptive processes.

Service oriented architecture integration: This contribution is also in the domain of service oriented architecture, integrating different computing techniques to support the service provision and composition that requires the development of intelligent agents including both intelligent devices and software agents. These intelligent agents are the vectors of the collaborative knowledge discovery and computational intelligence required by adaptive and flexible decision models for the processing of context-aware data using the mutual benefits of the varied service access devices. They integrate intelligence and generate a variety of solutions into decision processes using predictive analytics automation.

Distributed detection based on small ad hoc networks: The major benefit of this framework is the control of distributed small ad hoc networks of activity surveillance in a fully automated setting required for the optimal use of emergency response resources. The use of both physical and logical clustering levels procures a flexible and adaptable policy making support to various organizational scenarios for different types of emergency responses.

1.8 Thesis Structure

The domain theory is presented in Chapter 3, in relation with the definition of the problem after a literature review. Then the design of the solution, presented in Chapter 4, has been detailed, focusing on both organizational and technical perspectives in the context of inter-organizational activities performed in a complex and dynamic management environment. In this solution, a conceptual framework is proposed for the knowledge domain study, the elicitation of domain requirements and the specifications for the generic integrated design of a hybrid intelligent decision system to support sensing-monitoring knowledge domain analysis, sensor node design, integrated WSN-RFID configuration and deployment, and context aware real-time data capture and sensor node and WSN data fusion. These requirements which include indoor sensing, localising and tracking of people and goods, are used for the homogenous and heterogeneous sensor node specifications.

This integration is then illustrated in Chapter 5, describing the functional components of a prototype system to implement emergency preparedness that includes the implementation of the building information model, the sensor nodes location and identification of motion and control access in a smart building using a room capacity model for occupancy and evacuation, access rights and a navigation map automatically generated by the system. The configuration characteristics of the homogenous and heterogeneous sensor nodes are presented in terms of policy settings for the definition of the WSN architecture.

Results from the case study are finally presented in Chapter 6 to show the practicality of the conceptual framework, and illustrate the implementation of the solution in emergency preparedness for fire detection.

This research focuses on hybrid intelligent context aware systems that can provide a reliable and responsive support to knowledge activities. The complexity in designing and programming such systems involves the exploration of several research domains to understand the development of context modelling concepts needed to identify, structure and deploy data-aware context capture and processing, and information and knowledge fusion. These domains are examined to elicit the key requirements for intelligent agents to reason about information context, interact with each other to enable knowledge sharing in open and dynamic information context environments.

The computer hardware dimension, platforms and the technical services supporting the business processes implementing the knowledge functions are not included in this research to limit the diversity of research concerns.

Chapter 2: Literature Review

2.1 Introduction

This research aims at studying the design requirements and specifications for a real time decision surveillance system for detecting and tracking multiple people and monitoring their activities in an indoor environment. This monitoring includes analysing events such as interaction between people and objects, management access control, fire detection and people and objects evacuation.

Problems inherent to the capture of real time context environment data required for intelligent instantaneous decision making are examined in the light of the new hardware and software developments, integrating a panoply of technologies which include WSN, RFID, smart detectors, intelligent agents, web-based services, multi-agents distributed architectures and hybrid intelligent decision support systems to translate sensing and identification activities into services.

The requirements elicitation for a cooperative control model which involves a dynamic configuration of decision-making components is an essential step within the design process of hybrid intelligent decision support systems in the domain of sensing and monitoring. These components with limited processing capabilities, locally sensed information, and limited inter-component communications, are associated to a wide variety of homogenous and heterogeneous devices, basic or smart or intelligent, all interconnected in panoply of networks.

Of great importance in the design process of hybrid intelligent decision support systems are the components of the decision making process needed to support automatically a cooperative model aimed at processing the events inherent to the configuration and management of the network and its environment. These components are the problem definition, the design of the solution, the elaboration of the decision alternatives, and the evaluation of the decisions outcomes.

The participation of all these elements is determinant in the contribution to the collective goal of a controlled environment in terms of network congestion control and routing. The resulting global decision making process which requires a complex management, is characterised by the distributed nature of data storage and processing, sensing, and actuation within the network, and also the necessary back end support structured in a distributed multi-agent systems architecture and delivered in the form of cloud web-based composite services and applications.

This global problem covers complex networks of interacting intelligent agents, dynamic systems, and hybrid humans-machines appearing in broad applications in scientific, engineering, biological, environmental and social systems supporting research and real life activities.

2.2 Surveillance

Surveillance is the activity of monitoring environmental changes and a panoply of processes showing the behaviour of entities (people, goods, species and elements of the natural environment) interacting over a period of time in a defined space [1]. There are several types of surveillance, and among the main ones are:

- Acoustic surveillance: Audio, Infra/Ultrasound and Sonar,
- Electromagnetic Surveillance: Infrared, Visual, and Ultraviolet, Light or Optical, Visual and Aerial,
- Radar Surveillance: Radio and Radar,
- Chemical and Biological Surveillance, and
- Magnetic, Cryptologic and Computer surveillance.

This research is concerned with indoor spatially distributed sensor nodes wirelessly connecting integrated devices containing sensors and RFID tags and readers to monitor physical and environmental conditions, and process captured real time data in the ad hoc network and/or a main location. This type of surveillance is important for the activity of monitoring environmental changes that is necessary to support the detection and mitigation of events causing a panoply of damages to people and the environment, and prevent these potential hazards to occur.

Surveillance requires adequate resources which result from diverse technologies that are developing rapidly and generally combined with high-tech materials for use in every aspect of daily life. These are changing our approach to surveillance solutions to gather intelligence in several security domains: military, border, retail, and residential security, by governments and corporations. This work focuses on the context of hazard assessment and emergency response.

2.2.1 Surveillance Definition

The surveillance literature is abundant, and this work is limited only to the configuration of smart devices to design robust and effective surveillance and monitoring solutions for domestic and corporate applications. It focuses on how technology has changed our approach to real time information and intelligence gathering and how it is used instantaneously to react to environmental changes.

Technological surveillance is "the use of technological techniques or devices to detect attributes, activities, people, trends, or events" [2]. Surveillance activities require the use of different technologies which can be configured depending on the nature of the surveillance activity, the type and format of the derived data, and the physical nature of the technology.

2.2.2 Surveillance Evolution

As part of the responsibility and social evolution, surveillance scrutiny from increased use of surveillance devices is clearly evident. The fantasist suggestion of humans implanted with radio devices and microchips for all sorts of purposes may become a reality, and this will extend further the limits of man-machine interaction, creating the concept of human-machine hybrids [3]. On the other hand, the tasks of overcoming the machines lack of capabilities are extensively developed to effectively implement intelligent agent software by encoding more of the cognitive abilities attributed to humans into them, in the context of machine agency, using the technologies of neural networks, genetic algorithms and situated robots [4, 5].

Surveillance technologies have changed the way surveillance is perceived in ensuring people and goods safety and security, shifting from the individual responsibility to the corporative duty and responsibility in the health and safety management to curtail illegal or intrusive behaviour against others as mandated by the law.

Rapid advances in digital and communications technologies have made a wide range of theoretical capabilities practical with sensing and data processing. Tremendous research and development work has been undertaken over the last two decades on pervasive ubiquitous communication and computing systems, suggesting more elaborated physical configurations of a very fast growing number of varied objects of life, wirelessly connected, precisely identified and tracked or located, with a log of their behavioural changes. This has resulted in significant changes in network system architectures being needed to support a virtually unlimited application potential that includes predominantly surveillance, monitoring and assessment.

2.2.3 Surveillance Technologies and Systems

This research focuses on multimodal surveillances technologies and systems that have been developed for the perception of people, activities and their interactions, involving a varied range of domains for surveillance data, including the automatic detection and track keeping of faces visible in a video sequence, establishing their positions and movements. Some technologies are based on the use of a 3D tracking audio system that employs audio and video sensors, integrating miniaturization and emerging wireless systems, creating an increasing number of sophisticated devices [6]. Surveillance resources include smart devices that aid to effectively capture, process and assess information in a data aware context using intelligent configurations and mechanisms.

Surveillance and monitoring are used for a variety of applications in the dynamically changing civilian, industrial and military environments. This has led to a great demand for a wide range of innovative elaborate sensors requiring sensing data and rules for their location, deployment and connection to form adaptive sensor configurations. The design of support to surveillance and monitoring activities involve cutting-edge technologies, which include knowledge-based (KB) signal and data processing, model-based (MB) sensing rules and surveillance models, waveform diversity, wireless networking, mobile and smart devices, advanced computer architectures, and modelling and supporting software languages [7].

Knowledge-based techniques have been used to support sensing and data processing within and between platforms of sensors and communication systems and the resulting activities in terms of surveillance, monitoring imaging and communications within the networks environment are similarly supported**.** In network configurations, sensors cooperate with other users and sensors, sharing information and data, and their performance can be enhanced by changing their configuration as the environment changes [8, 9].

2.2.4 Surveillance Planning

Surveillance is very context sensitive and requires planning strategies, data analysis, and accurate interpretation of the results.

Monitoring differentiates in terms of framework between policy-based and targeted monitoring. Generated events against defined security policies require analysis in the environment context, using monitoring resources that condition the monitoring system. Concrete and precise acceptable behaviours and/or standards are coded as security policies defined to support monitoring procedures, and require evaluating their compliance in the context of surveillance management.

Of great importance in surveillance management is the existence of plausible behaviours and/or standards which cannot be monitored. It is thus of interest to focus on policy setting to appropriately support the surveillance monitoring.

2.2.5 Surveillance Monitoring

All companies and organisations are bound by security legislation of their activities translated into policies. Two types of policies are used for surveillance monitoring: external policies which deal with regulatory compliance consisting of adherence to externally enforced controls, and internal policies which deal with internally implemented controls and control the employee's security. Regulatory compliance covers all security aspects which require real time verifiable compliance with sets of best practice elaborated using control objectives in the context of the configuration control monitoring to set up the acceptable behaviours and/or standards. The development of monitoring procedures is required to maintain compliance, ensuring that changes operated on the surveillance resources are updated in the surveillance control system, and also privacy of personal information is protected [10]. The violation of standards requires reconciling detected changes to critical systems values for each standard attribute with the records in the configuration control repository. The surveillance resources logs are an essential part of the configuration control system.

2.2.6 Surveillance Intelligence

Surveillance results in intelligence gathering and requires among other monitoring resources, different devices depending on the activities to be watched over. These distributed devices grouped in a network configuration could be employed to monitor physical and environmental conditions in real time, and used in the control of instruments to provide efficient reliable communications with the network.

Surveillance activities and devices are an extensive domain characterised by the integration of panoply of technologies used in the design of smart surveillance, monitoring and tracking devices and accessories. Their diversity has made them become an intrinsic part of domestic, governmental, corporate, retail, and residential security. These devices which are fixed or portable are used in a wide range of field endeavour to continuously extend the limits of real-time applications and knowledge engineering needed to support the globalisation of geographical and socioeconomic information. The access to this information and its dissemination is enhanced by the increasing availability of more elaborated web services supported by multi-distributed agent systems configured with satellites and network channels [11]. These services support intelligent domestic and corporate applications, search and rescue operations, people and objects tracking and monitoring.

It has been established in the context of the Actor Network Theory [12] that agencies exist only relationally in and through process networks involving close interaction of humans and intelligent agents, including both smart surveillance and monitoring devices and software agents.

2.3 Wireless Sensor Networks

The continuous development of wireless sensor networks has resulted in the development of a variety of communication configurations enabling a tremendous information exchange growth between every location on the face of the earth using indoor and outdoor wireless networks. Their emergence has enabled practitioners to integrate wireless tethering to deliver sensing, localising, monitoring and tracking everywhere on earth and beyond, and within our own bodies, and their continuous development is based on chronological advancements in telecommunications.

2.3.1 WSN Definition

A wireless sensor network is "*a collection of low-powered, physically tiny devices, called sensor nodes, which are capable of sensing the physical environment, collecting and processing sensed data, and communicating with each other in order to accomplish certain common tasks*" [13]. This collection, defined as a configuration, requires a central gathering point for the storage of the collected data. This point is called the sink or base station.

WSNs support wireless communication, coordinated sensor nodes operations and reporting to sink(s), maintaining energy efficient control in all WSN protocols... They are used as effective measurement tools to observe the environment, and make decisions to enhance the processes of monitoring environmental changes or exercise some control on the surrounding environment by responding to these changes. The decision making aspect can be included inside the network or left outside.

2.3.2 WSNs Evolution

The most remarkable development has resulted in the emergence of more elaborate wireless networks: wireless LANs (WLANs) and mobile ad hoc networks (MANets) where IEEE 802.11 provides full scale connectivity, and small and low-cost computation and communication devices called sensor nodes to compose wireless sensor networks (WSN) [14]. These devices, which originally had a very basic sensing role, enhance their catalyst role for a major change in how we communicate and interact with the environment, mainly when real time decisions require real time data in a context aware environment. They are grouped and configured in networks organising the cooperation among composed nodes grouped into clusters to deliver real-time sensed data for analysis and measurement. Although the capability of each individual sensor node is limited in terms of storage capacity and processing capabilities, and energy power, the aggregate performance of the entire network with a wide range of multifunctional wireless sensor nodes, with more elaborate sensing, wireless communications and computation capabilities is sufficient for the support of a profusion of applications [15].

2.3.3 Network Architectures

Designed originally from a flat topology made of homogeneous wireless sensor devices measuring a single variable, WSN architectures continue to evolve over time as new smart devices and intelligent capabilities are becoming increasingly available, enabling support to a profusion of multi-distributed applications in the civil and military using ubiquitous and mobile computing, for the efficient exchange of data with sensor nodes clustered in different network topologies designed to include multiple sinks [16]. Furthermore, these network configurations evolved to support the interconnection of WSNs with the internet, private networks, cellular networks and wireless ad hoc networks, requiring the design of elaborate communication protocols to enable an efficient exchange of data between them.

2.3.4 Multi-Function Sensors Nodes

Sensor nodes forming WSNs, self-organise appropriate network configurations after their initial deployment regardless of the dispatching method used: planned or typically ad hoc. They create multi-hop connections between themselves. They also contain on-board sensors aimed at sensing, i.e. collecting environmental data, including acoustic, seismic, infrared or magnetic information about the environment, using either continuous or event driven working modes. Additional location and positioning information can also be obtained through the incorporation of global positioning devices or using local positioning algorithms and the computing devices inside the network [15].

On-board sensors are located in a sensor module which provides a plurality of parameter sensors and can interface with external control operations of one or more processor control systems located inside or outside the network. The sensor node is equipped with single or multiple integrated circuit boards integrating embedded microprocessors, radio receivers, RFID tags, and power components that enable sensing, computing, communication, and actuation. Additionally, a storage capacity is included to contain internal configuration and computational rules, and data collected by the sensors when it is not relayed in real time to processing devices inside and outside the network. These capabilities are needed for the dynamic access by others sensor nodes and the back end system queries from users [17].

2.3.5 Multipurpose WSNs

A multipurpose WSN consists of using a single sensor network for multiple concurrent distributed applications, ensuring the delimitation of each application to its specific set of relevant nodes based on the design of a modular multi-purpose WSN infrastructure. The research challenge insists on the fact that the desired behaviour of WSNs is to be achieved by distinct local algorithms implemented on each sensor node of the application cluster, with very limited knowledge about the whole sensor network. This is supported by the modular separation of different tasks both at node and networking level, extending the multipurpose context by introducing multitasking at the sensor node level [18] and outside the network where the data distribution is organised by the implementation clustering mechanisms in multi-agent systems. These mechanisms are required for WSNs configuration, in terms of selection and discovery of these clusters of nodes.

The concept of scoping as a middleware building block and abstraction layer for these tasks in the WSN infrastructure has been used in the design of modular architecture in order to meet the requirements of multi-purpose WSNs [19]. Sensor nodes can be pre-programmed for a number of roles with associated tasks, and their roles selected following event conditions at runtime, ensuring to reduce or eliminate the proliferation of components with functional overlap. This has opened a new research direction for the design of middleware for resource sharing in multi-purpose WSNs [20] to meet the varying Quality of Data (QoD) requirements of the multiple concurrent applications, and improve configuration, adaptability and customize-ability of WSNs [21].

2.4 Radio Frequency Identification

Radio Frequency Identification (RFID) is the technology based on the use of electromagnetic waves, precisely radio waves [22, 23] to transfer data within the process of automatically identifying and tracking tags attached to objects. Although Near-Field Communication (NFC) is defined as one among ubiquitous computing enablers, it is a similar communication technology that can links two smart devices; and its short-range wireless communication requiring a separation of ten centimetres or less, would impose more spatial requirements such as the reading distance, for the use of these devices.

The first RFID had emerged in the 1940s as a spying device energized and activated by waves from an external source [24] before a passive radio transponder with memory was presented as the first RFID ancestor in the 1970s, with a 16 bit memory used as a toll device [25] .The first modern RFID system emerged a decade later [26].

The radio wave development has led to the design of Radio Detection And Ranging (Radar) on the principle of radio waves reflect off an object, enabling their range, height, and bearing to be determined. The radio wave, communication and integrated circuit technologies developed further to create the transponder, a device that emits an identifying signal in response to an interrogating received signal, to provide real-time monitoring and identification of mobile objects. This enabled later the development of RFID systems based on far field systems. RFID continues to play a vital role in the technological revolution along with WSNs, smart mobile devices, web-based services and other technologies to gradually inter-connect the real world [27].

The RFID identification process is based on the use of a two-way radio transmitter-receivers called interrogators or readers activated by the presence of a magnetic field to send a signal to the tag or label and read its response. A RFID system is made up of three components: RFID readers or interrogators, RFID tags, and a backend system which is connected to a database containing information about tagged objects.

RFID supports the Automatic Identification Data Collection (AIDC) and is constantly making inroads in offering greater flexibility, higher data storage capacities, increased data collection throughput, greater immediacy and accuracy of data collection, enhanced accuracy and security, and an ideal data collection platform for a wide range of applications.

2.4.1 RFID Tags

A RFID system uses identification devices (tags) or labels (smart labels) attached to the objects to be identified. The RFID tag is composed of an integrated circuit (IC) embedded in a thin film medium to store information stored in the memory of the RFID chip. This information is transmitted to an RFID reader by the means of an antenna circuit embedded in the RFID inlay using the mechanism of radio frequencies. The data stored normally represents a unique serial number which is associated to a RFID reader, and used as a reference to lookup in a host system database more details about the object attached to the tag.

Of great importance in a RFID tag is its non-volatile memory to retain the tag identifier, the tag identity information when the tag is not powered. Similarly the tag size benefited from the tremendous integrated circuits developments, to enable their miniaturisation for incorporating digital and analogue components in the same physical chip. An approximate size of a RFID chip is approximately one square millimetre.

2.4.1.1 RFID Smart Labels

RFID enabled "smart labels" have the same reading property as they can be read even if the label is not in the line of sight of the reader. Reading operations are performed automatically, and the encoded information can be changed during their lifetime eliminating the need to remove and re-label items.

Smart label printing is a two-step process supported by RFID printers with embedded RFID encoders and readers. Firstly, it consists of simultaneously printing bar codes, text, and graphics on the surface of the label. Then the RF tag embedded in the label is encoded: read, programmed, and verified the RFID data is encoded, copied to and from printed and non-printed fields in the label templates [28].

2.4.1.2 RFID Tags Read-Only versus Read/Write

The information stored in RFID tags can be written in two ways depending on the RFID tag type. RFID can be Read-only or Read/Write. Read-only tags have their information recorded during the manufacturing process and this information cannot be typically modified or erased during their lifetime. With greater flexibility, intelligence and ease of use, data can be written and erased on demand at the point of application in read/write tags which provide better traceability and updated information, and offer advanced features for locking, encryption and disabling the RFID tag [29]. The interrogator read rate is a determinant performance factor for applications supporting monitoring of activities involving rapid localisation or environmental changes.

2.4.1.3 Data-On-Network

Data-on-network is a data storage approach used in distributed applications where there is no access to a network database and application, by reading and writing data in/from the tag additional memory. Data on RFID tags other than the ID tag (EPC) can be updated through local in-network processing, using coding algorithms and pre-defined values, and compression techniques to avoid accessing a database or network connectivity. This data is stored in the additional limited memory on the tag called Electrically Erasable Programmable Read-Only Memory (EEPROM). This memory is associated in most of tags with CMOS integrated circuits to facilitate the reading and writing of additional data in the tag [30]. The ID tag and the additional data stored in the tag additional memory are read separately.

Indirect addressing is proposed to overcome the limitation of the additional memory. The storage strategy consists of storing an internet address (URL) in the tag through which the data related to the person or goods connected to the tag could be looked up in the database server and not stored in the tag itself using the backend system services [31].

2.4.1.4 RFID Tags Operating Frequency

RFID tags and readers have to be tuned to the same frequency in order to communicate, similarly to how a radio must be tuned to different frequencies to hear different channels. There are several different frequencies an RFID system can use.

RFID tags operate at four different frequency ranges: low, high, ultra-high and microwave frequency. In the electromagnetic spectrum, the higher the frequency range is, the longer the reading range, the higher speed and more interference from metal. The lower the frequency range is, the shorter the signal range, the slower the reading, less impact from the metal presence and less absorption by moisture [32] . The RFID tag frequency can be chosen depending on its use and the specificity of automatic identification and data capture (AIDC) applications. A key principle observed in the tag frequency selection is that RFID systems listen before transmitting data to reduce collisions in the network and general interference with other WSNs, but adversely reducing the data rate.

2.4.1.5 RFID Tags Key Factors

The design of RFID specifications for application development aims at searching to find the optimal tag, taking into account the tag specific attributes that define its limitations physically, environmentally, and mechanically. These specifications are the translations of the application RFID requirements. The tag attributes are: frequency range, environment, mounting surface, attachment method, read range, custom printing encoding and others [33].

2.4.2 RFID Tags Passive vs Active

A RFID tag can be passive or active or semi-passive or semi-active. The basic difference between RFID tags resides in the tag’s source of power and way of communication. With no battery on-board, passive tags use the radio energy transmitted by the RFID reader and communicate through backscatter, whereas active tags transmit periodically their ID signal using an on-board battery and a receiver-transmitter. Passive tags communicate with less interference than active ones. Backscatter is a passive tag communication with the interrogator based on a radio frequency wave reflected from the tag. Several properties determine the performance of RFID tags. They are the type of IC used, the read/write capability, the radio frequency, the power settings, and its deployment environment.

RFID tags can incorporate sensors. Semi-passive and semi-active tags have similarly a battery on board powering a micro-chip, and a receiver. Semi-active tags communicate via a transmitter whereas semi-passive via backscatter. Semi passive tags are still in the development stage, their deployment is just beginning. Semi active tags are efficient in noisy environments [29].

Universal communication systems require interoperability between interrogators and tags developed by different companies, needed to provide a standard communication protocol worldwide. This requirement is met via a standardised communication method between readers and tags, based on a role distribution: readers acting as masters and tags as slaves. Of similar importance to the tag size is the energy reduction needed for the tag to operate, mainly for passive tags that must harvest energy from the signal transmitted by the RFID reader. The maximum theoretical power that can be harvested is inversely proportional to the RFID tag range, defined as the distance between the RFID reader or interrogator and the tag. This distance which is used as a performance metric, becomes higher as the amount of energy required for integrated circuit operation is lowered.

RFID tags became prominent because a direct connection or a line of sight is not needed during the tag interrogation, and more importantly identification and critical data can be stored in their non-volatile memory. Active tags supported by a battery can store a large amount of data, and the tag range and life time can be limited by the amount of data they store.

2.4.2.1 RFID Passive Tags

Passive tags predominate (several billions in the world) and have a unique identification code similar to the Unique Product Code (UPC) readable by any UPC scanner. Both work on the same principle, UPC code items must be scanned individually whereas RFID tags or labels are read together. Portals with embedded RFID interrogators can be set up to read RFID tags. Passive tags which do not have an integrated power source and are powered from the signal carried by the RFID reader, operate in three frequency ranges: low, high and ultra-high. The higher the tag frequency range is, the higher the amount of information the tag could modulate, theoretically a maximum of millions of bits of data per second for an ultra-high frequency [34].

Passive tags have three components: the chip, the strap and the antenna. Their performance is higher when the attachments of the chip to the strap and of the strap to the antenna are more resistant. It can be affected by the tags shape, in terms of their minimal cylinder diameter required to encase them: the lower the cylinder diameter reduction, the more resistance is required for both attachments of the chip and the strap. These tags have a short read range, and even shorter write range. Unreliable in radio frequency challenging environments, they have no sensor support [35].

The major development challenges of passive tags are: size reduction, cost lowering, read range and rate increase, and security improvement. This research focuses mainly on the read range which is the absolute maximal distance a tag can be read by a RFID interrogator, and the read rate which is the maximal number of tags that can be read by a RFID interrogator.

2.4.2.2 RFID Active Tags

Active tags have a built-in power source, and their behaviour can be compared to a beacon. They use their powered transmitter and receiver for long distance communication and at higher data rates. They can operate more effectively in less favourable communication environments than passive tags in which the presence of metal results in communication interference. Due the existence of multiple level communication interference, regulation has been put in place to reduce the interference impact in terms of collisions and general interference with wireless networks and systems. This regulation consisted of requiring that ultra-frequency RFID systems listen before transmitting (so called listen before talk) not allowing simultaneous reception and transmission of data, and resulted in the reduction of the maximum available data rate of these systems [36].

Active tags have a considerable advantage on other tags due their ability to perform tasks even when a reader is not interrogating the active tag, also to enter a low power sleep mode using the mechanism of a burst switch. This mechanism, which aims at keeping the receiver active but reducing its power to nearly zero to listen for the wake-up command, detects the presence of certain forms of energy using an ultra-low power processor to decode the presence of energy to check if it resembles the wake-up code.

2.4.2.3 Semi-Passive Tags

Semi-passive tags, which are also called battery assisted passive tags, are more fragile and larger than passive tags. They have a small battery on board that enables them to deliver a greater reading range and reliability than passive tags. They also present similar functionality than active tags. The price is in the same order of passive tags and lower than active tags. However, they are incapable of initiating the data transmission from their location because they require a reader to interrogate them first [27, 37].

The main challenge of semi-passive tags remains the maximisation of the backscatter efficiency on the tag side to provide a high sensitivity on the reader side because they do not actively send RF power back to the RFID reader. This result in an incomplete reading of sensing values stored in the semi-passive sensor tag [38]. Semi-passive tags are best used in situations where there is no or just a little metal interference making reading not difficult, and on-board sensors aimed at tracking.

2.4.2.4 Semi-Active Tags

Semi-active tags can be considered as a combined manner of working between active and passive tags, working as passive tags when the generated RF-power is sufficient to operate. In a passive mode, low noise amplifier (LNA), oscillator (OSC) and power amplifier (PA) are cut off to save the whole chip power consumption. In the active mode, semi-active tags use battery power and the use of the power amplifier increases both the read and write range distance [39]. The use semi-active RFID tags is recommended for tracking items in extremely noisy environments that prevent passive or semi-passive tags from communicating with the reader.

2.4.3 RFID Readers

RFID readers support Automatic Identification Data Collection (AIDC). They are installed at read points, permanently fixed RFID, or handheld for on-the-spot reading of specific tags. The tag reading visibility has been extended to include a new type of moving read points to allow the expansion of RFID applications through additional optimal tag reading capabilities. This has resulted in the design of mobile wirelessly connected RFID readers that enable the deployment of RFID read points at virtually every key junction of movement, and the utilisation of a single mobile RFID reader in different areas throughout the work process.

RFID readers can be integrated into WSNs by connecting the RFID node to one of the WSN nodes to authorize or keep track of people or objects carrying RFID tags [40].

For a read/write tag, data can be written and erased on demand at the point of application. Since a rewriteable tag can be updated numerous times, its reusability can help to reduce the number of tags that need to be purchased and add greater flexibility and intelligence to the application. Additionally, data can be added as the item moves through the supply chain, providing better traceability and updated information. Advanced features also include locking, encryption and disabling the RFID tag.

2.4.4 RFID Security

Clandestine reading is an important security issue in RFID systems, and encryption mechanisms are used to effectively and strongly protect the data stored in RFID tags. However, an encrypted tag ID can be maliciously tracked without being prevented. Locking mechanisms can be used to lock the RFID tag, enabling the tag not to respond to some fraudulent commands, allowing the reading of the memory using the collection with data command [41, 42]. Additionally, password protection is introduced in RFID systems to prevent changing existing or writing new data or operational parameters of the tag, or prevent the active RFID tag from responding for a certain length of time, switching off the tag during this time. Long length passwords are required (32 bits) to complicate the access to the command disengaging password protection. Public and private key-based encryption reinforce the system security requiring to obtain the key set from a central server, limiting the RFID system in terms of reducing the read rate and requiring the RFID system to have a connection to the central server or Internet. Finally, the tag protection can be increased by requiring a password to access the database on the server containing the tag data linked by an internet address (URL) to the tag ID [43].

The encryption mechanisms require additional in-networking computing resources (software or hardware) to support the latency of the key lookup used in public and private key-based encryption techniques. Hardware enhancements on the RFID tag lead to reducing the power consumption required by the data encryption which is better supported by active RFID tags, and significantly reduces their lifetime.

2.5 Integrated RFID-WSN

The integration of RFID and WSNs along other advanced technologies is essential in procuring enhanced and extended sensing and tracking capabilities in a variety of integrated devices, and extending the range of applications for people and/or object presence detection. The taxonomy integrated RFID-WSNs include four classes of integration [44], which are integrating:

- RFID tags with nodes,
- RFID tags with wireless sensor network nodes and other wireless devices,
- RFID readers with sensor nodes and other wireless devices, and
- A mix of RFID tags, readers and wireless sensor nodes.

Although their design is based on meeting simultaneously sensing and tracking requirements, their integration aims at using them in:

- a user-programmed mode enabled by the reconfiguration of their firmware, and
- An interaction mode enabled by the RFID tags and the sensor nodes communication.

An extensive literature has been devoted to the hardware integration of RFID and WSN, and our research interest includes:

- the mode of hardware integration and the resulting data fusion [45],
- the allocation of specific tasks to RFID and WSN devices [46], and
- The classification of both RFID and WSN devices to create similarity classes of their deployment attributes [47].

The functional RFID-WSN integration [44] is summarized in Table 2.1 shown below.

	Object and/or Person				Environment Sensing
	Attached	Sensing	Identification	Localised	
WSN	1	2	4,6	5	3
RFID	1,2,3		4,5	6	

Table 2.1: Functional RFID-WSN integration 1

2.6 Ad hoc Networks

In this research, ad hoc networks are varied configuration of WSNs formed of sensor nodes wirelessly connecting fix and mobile smart devices containing a variety of sensors and/or RFID tags and readers.

An important development in WSNs is the integration of heterogeneous devices in the network enabled by the incorporation and interconnection of multiple sinks to support complex data control functions, integrating active sensor nodes with storage and processing capabilities for data aggregation. These nodes are selected in their respective clusters to play the role of cluster head, to perform the deployment and configuration node functions. The selection of appropriate cluster heads (CHs) for prolonging the network lifetime remains one of the major WSNs challenges. Several techniques have been proposed, and among them the fuzzy multiple attribute decision-making (MADM) and analytic hierarchical process (AHP) approaches are based on three criteria including residual energy, number of neighbours, and the distance from the base station of the nodes [9, 48].

Current research and development is concentrating on the generalisation of the heterogeneous devices interconnection in different network configurations to relax the communication existing constraints for the design of a new network architecture called a wireless sensor multimedia network (WSMN). These architectures which are advocated for multimedia in-network processing, are comprised of small embedded video motes capable of extracting the surrounding environmental information, locally processing it in the network at the node level and then wirelessly transmitting it to parent node or sink [49]. They link networks of wirelessly interconnected smart heterogeneous devices integrating medical, acoustic, video and audio sensors along with advanced signal processing and computer vision techniques. They aim at providing capabilities to ubiquitously retrieve from the environment rich varied multimedia content which includes video and audio streams, still images, and scalar sensor data, and process in real-time, store, correlate, and fuse multimedia streams originated from heterogeneous sources [50]. They support sensor network applications developed in the domains of tracking, home automation, and environmental monitoring. WMSNs are enablers for applications including video surveillance, storage and subsequent retrieval of potent.

2.6.1 WSN Typology

Wireless networks can be terrestrial, underground, underwater, multi-media, and mobile depending on where they are deployed. There are two types of wireless networks:

– cellular networks characterised by centralised communication defined as several users grouped in a cell communicating with a base-station controlling the transmitted and received data to and from users, and
– ad hoc networks characterised by a configuration of terminals which are on an equal footing, receiving and transmitting data to a base-station or another terminal and acting as a relay for ?

Both terminals use distributed multiple radio links in multiple out technology (MIMO) which is based on a method for multiplexing to increase wireless bandwidth and range by multiplying the capacity of a radio link to exploit multipath propagation, and has become an essential element of wireless communication standards used in Wi-Fi, 3G and 4G. This technology relies on the use of multiple, smart transmitters and receivers to support three activities: pre-coding, spatial multiplexing (SM), and diversity coding [51].

2.6.2 WSN Major Challenges

WSNs major research challenges aim at relaxing existing constraints that enable increasing of the network performance, lifetime and interconnectivity with other networks, and constantly improving the networks self-deployment. These challenges depend on whether WSNs are deployed on land, underground, and underwater. Depending on the environment, a sensor network faces different challenges and constraints [49].

When deployed, autonomous sensor nodes wirelessly in WSNs face communication link failures, memory and computational constraints, and limited energy. These issues may affect WSNs key performance criteria such as optimal deployment, node localization, clustering, data aggregation, and in-network processing [52].

2.6.2.1 WSNs Performance

WSNs optimisation techniques have received a lot of interest from researchers and practitioners, considering the minimisation of energy consuming and latency, miniaturisation of the components, and discovery of information from unaware locations [53]. Flexibility in sensor nodes configuration can make them able to wake up and turn to active mode in only a few milliseconds only when sensing, working in a virtual sleeping mode during the node listening period. Of similar importance in increasing the performance of WSNs is the use of multiple and alternative communication paths, in conjunction with reliable and robust solutions for message routing and flooding of the network.

The support to WSN sensor nodes receives increasing research attention with the aim to increase their performance by pre-programming them for a number of roles with associated tasks. Their roles can change and be selected following event conditions at runtime for a better control resource allocation, and decrease resource competition within the network when fulfilling allocated services.

This design requirement is another research challenge to improve WNSs performance in terms of reducing application reaction times and decreasing overall transmission overheads, and pushing intelligence into the network [54]. This can be achieved by using a flexible service platform to provide reusable services for multiple concurrent distributed applications. The focus on the efficient management of shared resources and application-specific data quality properties that include reliability and resolution (QoD), and context aware operations. This focus aims at identifying the middleware requirements to translate into specifications for the definition of the sensor nodes roles and associated tasks.

2.6.2.2 WSNs Lifetime

WSNs when deployed in outdoor environments have their lifetime more likely to be limited because they are battery powered. The replacement of the sensor nodes batteries can be considered only for those physically reachable, with exact location known and in non-hostile environments. The lifetime of WSNs is an important research issue, and several strategies have been explored. Of great simplicity is the creation of a hierarchy of nodes in the network architecture where these primary nodes with renewable energy sources carry out most message delivery tasks, and other nodes with less communication demands are equipped with conventional chemical batteries [55].

The functional use of WSNs is an essential requirement in their design. The sensor nodes lifetime can be extended considerably when their configuration is based on operating the sensors in a very low duty cycle using duplicate nodes, synchronised sensing within the sensor nodes clusters and sleeping using dual switching mode on and off. Of great interest in the energy saving challenge is the use of the microcontroller and transceiver sleeping modes.

The activation of these two components is energy consuming for the execution of a long operation of WSNs. In WSN applications with user-specified delay requirements, the dynamic tuning of the sensor nodes duty cycle is systematically activated to achieve the desired end-to-end delay guarantees [56]. More importantly, the use of intelligent middleware aims at using less consequential resources to serve additional service requests. The focus is mainly on monitoring the energy level and adapting system behaviour to select the available energy levels that allows the application to achieve its targets [57].

A planning mechanism based on the use of a resource engine can interactively calculate energy levels and reserve the required consequential resources needed to successfully support each application service request allocated in the network. This mechanism aims at developing resource distribution strategies needed to provide efficient system adaptation of the network, and effectively achieve the desired trade-off between end-to-end delay and energy conservation [20].

2.6.2.3 WSNs Interconnectivity

WSNs full interconnectivity has been always a major research and development challenge. Interconnectivity concerns first a fully functional network of sensor nodes connecting wirelessly homogeneous and heterogeneous devices organised into clusters using different communication protocols to transmit data via gateways to base stations, ensuring that data reaches the desired destination inside or outside the network for storage, event analysis, and actions to identified event conditions. WSNs are also designed to be interconnected with many different networking technologies.

The future internetworking aims at interconnecting all physical worlds, creating autonomous interaction based on a full interoperability with the commodity internet using seamless interconnection between remote WSNs with web servers and IP Networks to create hybrid networks [58]. This seamless interconnection can be done by using a dynamic service in the form of a WSN middleware to enable IP-based hosts considered as external agents, to gather sensed data from one or more remote WSNs through application-layer gateways [59]. IP-based hosts can access and manipulate IP-enabled WSNs which are part of the WSN, and extract data from remote dynamic services enabled in WSNs.

The deployment of autonomous sensor nodes before their aggregation into clusters is performed either in an ad hoc fashion or with careful planning and engineering. When deployed outdoor in an ad hoc way, they autonomously organize themselves into a network by wirelessly connecting with each other and to a base station via gateways, similarly when they are deployed indoor with planning their exact locations.

2.6.3 WSNs Domains of Use

The use of WSNs depends on the type of sensors embedded in the sensor nodes. Sensors can be classified in five categories: environmental, gas, physical, optical and biometric, and have two design use characteristics: field-readiness and scalability. These sensors can be hardware, software, and virtual. Specific software can be used for the configuration and management of sensors, providing a comprehensive interface for enhanced representation of their key elements and measurements, their location and configuration, their alert thresholds, and their decision rules that associated to their different behaviours or states changes.

A different variety of software are embedded in enhanced hardware sensors to compose what is so-called software sensors increasing the sensing intelligence required by the sensing accuracy. This intelligence can be extended outside hardware sensors in the form of intelligent agent software in what so-called virtual sensors.

WSNs have been widely and extensively used primarily for research purposes to demonstrate the development of new technologies and the exploration of remaining limitations of existing ones. Their first application area is the military surveillance for the tracking of enemy forces [60, 61] to study the complexity of robust tracking of people and vehicles moving in the proximity of a WSN and the requirements of in-network processing of the sensed data. The first significant application deployment of a WSN occurred in 2002 [62] to monitor the environmental conditions around the nests of storm petrels on a small island with the aim of examining the nesting behaviour of birds.

2.6.4 WSNs Applications

There is a wide broad range of WSN applications. Their feasibility has been demonstrated by either a prototype or a real-world deployment. The WSN technology is used for many purposes. Most of WSN applications are aimed at pure data measurement. The collected data is relayed to a server for processing. The type of collected data can differ depending on the application purpose: Low-Rate Data Collection, High-Rate Data Collection and On-Demand Data Collection. The difference between these three types resides in the involvement of the user who triggers the collection of data on-demand, whereas different types of homogeneous devices with different configuration of sensors generate the low or high rate collected data [63].

Several types of WSN applications have been developed in the following domains:

- Healthcare and structural health monitoring, radiation prevention and control,
- Smart agriculture, metering, cities and homes, intelligent buildings and energy saving smart grids,
- Traffic flow and congestion control, enhanced safety and security, and transport and asset tracking
- Enablement of new knowledge and improvement of productivity, logistics and high-confidence
- Predictive maintenance, surveillance, disaster surveillance and emergency response,
- Industrial chemical and military fields.

The number of WSNs deployed has tremendously increased due to the efforts consented due to maturing software infrastructures (e.g., TinyOS, TinyDB), the increasing robustness of networking protocols and support systems [64]. Their use has been extended to cover several domains, a myriad of applications, including structural monitoring [65], cold chain management [66], precision agriculture [67], emergency response [68], and health care [69, 70].

The tremendous implementation success of WSNs in a wide range of domains has created the need for their integration or combined use with other technologies to support unconventional and real-world applications involving smart devices such as RFID [71, 72], mobile robots, and smart phones and cameras. WSNs perform on-node processing and event detection or it even classifies the observed data within the network.

2.6.5 WSNs Deployment

Of great importance in the deployment and maintenance of WSNs is to prolong network lifetime and enhance the routing inside the network by the removal of the performance bottlenecks and the avoidance of the single point of failure of a centralized node. This is addressed in terms of discovering spatial relationships in sensor nodes data through the identification of clusters, using in-network distributed algorithms [73].

2.6.5.1 WSN Sensor Nodes Clustering

Spatial clustering consists of identifying a set of cluster representatives showing that they follow the same data trends using, for example, the time series analysis, to reduce data acquisition and transmission times, and consumption power [74, 75] in a sensor network configuration with limited storage and communication capabilities, and power resources, mainly in the case of generalised passive nodes use. Other considerations including sensor nodes deployment and communication characteristics are also used for spatial clustering.

The sensor nodes clustering can be done off-line at the base station or inside the network. Off-line clustering consists of the sensor node data transmission to the central base station and can lead to heavy traffic in the network, augmenting the processing time. In-network clustering consists of grouping sensor nodes in a network on the basis of their data characteristics by using data regression analysis for each node and configuring a node model called the communication graph associated to a distance matrix measuring the distance between the graph nodes [76]. Different techniques using specific algorithms have been suggested to solve this complex sensor nodes clustering problem, and significant changes in the nodes data will result in the reconfiguration of the communication graph, called the sensor nodes clustering maintenance.

2.6.5.2 WSN Security

WSNs are application-specific networks which process large scale real time data in complex environments. They face critical security challenges due to their vulnerability characterised by network attacks causing serious performance degradations which could result sometimes in the network breakdown. There are three common security requirements for WSNs. These are confidentiality, data integrity and service availability [77].

a) Confidentiality

Sensor nodes use symmetric key encryption to provide confidentiality [78]. Strong authentication and encryption mechanisms are used to protect data confidentiality in all the network levels and outside to ensure that data is accessed by the intended recipient only, and free from malicious attacks, referred in the literature as untrusted third party.

The risk of confidentiality violations can be increased by sensor nodes which can mislead the base station by gaining access to a sensor node keying material for inserting modified or inaccurate data into the network when forwarding and aggregating the data. These violations also occur when sensor nodes are corrupted affecting the data aggregation during the in-network processing. Data aggregation consists of collecting data generated by sensor nodes at each intermediate node en route to the sink in order to reduce the volume of messages transmitted in the network. These sensor nodes can also fail due to random and non-malicious causes which include sensor malfunctioning, battery exhaustion, and device disconnection from the network or inability to properly execute the protocol due to hardware or software failures.

The protection against these violations is developed in mechanisms that provide both confidentiality and integrity of the aggregated data using the data from the same sensor nodes cluster of the compromised node using the concept of delayed aggregation and peer monitoring based on local cluster interaction [79].

b) Data Integrity

Data integrity ensures the integrity of the process of transmitting and receiving data inside the network, preserving the original formats and sequences and not allowing the data packets modifications, alteration, disruption and absorption by network attackers. In WSNs, Routing protocols ensure the routing maintenance by providing reliable multi-hop communications for different network configurations.

Data integrity is assured by effective routing and networking protocols which are characterised in WSNs by the migration of early flooding-based and hierarchical protocols over the last two decades to geographic and self-organizing coordinate-based routing solutions [80]. The networking protocols are needed to support the implementation of various network control and management functions such as synchronization, node localization, and network security. The first category of protocols is a blind technique which results in duplicated packets that might keep circulating in the network, causing an implosion or overlap problem [81]. These duplicated packets result from the same sensed values generated successively by the same sensor node or simultaneously by different ones located in the same proximity. Their elimination can be obtained by using the gossiping technique [82] which consists of selecting only one copy of each packet. The gossiping technique tackles the network implosion, and the delay required for the packet selection is reduced using in-network processing capabilities available with the active node of the sensor nodes cluster.

c) Service Availability

Service availability includes the proper working of all homogeneous and heterogeneous devices, non-interrupted communications and in-network processing, and services, data and network resources that legitimate users can access when requested. This availability is characterised by no delay or interference which are inherent to three major types of security threats observed mainly on multi-hop WSNs: passive, active and Denial-of-Service (DoS) attacks [83].

Passive attacks which result in simple stealing of information over the wireless medium and compromise data confidentiality, are unnoticeable and do not harm the network. Their detection is very difficult. Of further incidences on the network, active attacks which are permissive by non-elaborate routing protocols, modify, temper and alter the packets, affecting the integrity of data in the network. DoS attacks target availability of services to the users, by preventing a sensor node from sending traffic or by preventing the communication between the networks.

2.7 Hybrid Intelligent Decision Support Systems

Hybrid intelligent decision systems support the resolution of a wide range of complex decision problems involving imprecision, uncertainty, vagueness and high-dimensionality. They contain many different components or sub-tasks, each of which requires different types of processing [84]. They are developed to implement hybrid solutions for real life applications, using a combination of traditional hard computing techniques (decision support systems, executive support systems and expert systems) and soft computing (SC) techniques which include fuzzy logic, neural networks, and evolutionary algorithms [85] .They support different knowledge entities modelled into intelligent agents interacting in real time in open and dynamic environments. They support the management of several complex events involving different knowledge components at unpredictable times [86] . These entities are represented as agents defined to be encapsulated computer systems or computing elements capable of performing flexible, autonomous actions to meet design objectives in different situational and environmental contexts.

2.7.1 Intelligent Agents

Intelligent agents are defined as *"anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors*" [87] . Agent actions are controlled by actuators defined as anything that creates the agent outputs. They may cause changes in the environment, or move the agent to a new location in the environment. They can be used just to generate information or knowledge in the multi-agent decision support system.

Agents are grouped in a loosely coupled network, and work together to support decision making processes requiring problem solving capabilities and knowledge elaborated beyond the different entities themselves. This network configuration is called a multi-agent system (MAS) based on the use of intelligent techniques and models modelled in the form of different agents following an agent typology. The agent models are used in hybrid intelligent decision systems to define the building blocks of the system to be loosely integrated in a multi-agent distributed architecture. These are used to support cooperation, coordination, negotiation, and the like between them [88].

2.7.2 Multi-Agent Systems and Agent-Based Models

Multi-agent systems are computer programs composed of a homogeneous collection of interacting agents within a complex open environment. They aim at solving complex problems, and are a hierarchy of box components with a messaging interface. The design of MAS is based on four concepts: agent, environment, interaction and organisation [89]. Of great importance in the modelling, design and construction of hybrid intelligent decision systems is the use of the multi-agent system concept due to the flexible nature and large scope of intelligent agent interaction at run-time. Intelligent interaction may include methodical, functional and procedural approaches, algorithmic search and reinforcement learning. Of similar importance in the search for an explanation of the collective behaviour of agents is the use of the agent based model concept.

2.7.2.1 Agent Typology

An agent interacts with its environment to collect data via its sensors and acts via actuators. It might change its environment as it acts in it, and learn from it. It may operate autonomously, cooperate and learn. An autonomous agent operates without the help of human guidance, its behaviour is determined by its own precepts and experience, and has the ability to learn and adapt. Several different constructs can be used individually, or in combination, to determine different types of agents [15].

Agents can be static (static agents) or moving around the network (mobile agents). They can be proactive, initiating interaction with other agents or active, just reacting to solicitation from other agents. Deliberate agents can have a reasoning model and engage in planning and negotiation while coordinating with other agents, whereas reactive agents use a pre-set response when they operate and interact with each other. Agents which play more than one role in the multi-agent system are called hybrid agents.

Depending on their abilities, agents can be: collaborative agents (collaborative and autonomous), collaborative learning agents (collaborative and learning), interface agents (autonomous and learning) and truly smart agents (collaborative, learning and autonomous) [90] . Other agent constructs can be combined to determine specific agent types, such as static deliberative collaborative agents, mobile reactive collaborative agents, static deliberative interface agents, mobile reactive interface agents, etc. Agents can fall into one of the following categories: table driven agents, simple reflex agents, model-based reflex agents, goal-based agents, utility-based agents and learning agents.

In the present research work, the typology agent only is limited to the following types: collaborative agents, interface agents, mobile agents, information/internet agents, reactive agents, hybrid agents and smart agents.

2.7.2.2 Agent Environment

Agents operating in a multi-agent system can receive information from the environment through sensors and affect it via actuators, and the MAS design is particularly influenced by the agent-environment interaction interface [91]. Similarly to the agent typology, several different constructs are used to determine the different types of agent environment.

Depending on whether an agent can sense the complete state of the world or not, its environment is accessible or inaccessible. The states of changes of the environment are completely determined by the agent current state in a deterministic environment, whereas in a non-deterministic environment, it is irrelevant to the state of changes of the environment.

Depending on whether the agent's interactions with the environment are limited or not in terms of a limited number of distinct, clearly defined precepts and actions, its environment is discrete or continuous. It is dynamic by opposition to static, when the state of the environment can change while the agent deliberates.

The agent environment is episodic by opposition to non-episodic (sequential) when the agent's interaction sequences with its environment (or "episodes") are independent, and decisions do not depend on previous agent decisions/actions. A single agent operates by itself in an environment. Of great significance in the definition of an intelligent agent, is the definition of its task environment in terms of specifying its performance measure, environment, actuators and sensors. Agents must observe their environment in order to operate, even when the observable environment might be limited by the current spatial, social or communication context of the agent [92] .

2.7.2.3 Virtual Environment

Virtual environments are heterogeneous and open multi-agent systems dedicated to a collaborative, adaptive and realistic environment for learning and training to perform some collective tasks. In these environments, these tasks represent sets of actions, which define roles, allocated to agents modelling the organisational actors [93] . Of great interest in the design and implementation of MAS involving virtual environments is development of cognitive agents capable of interacting with humans in a hybrid decision making context. This interaction can be simulated involving user-created avatars in a 3D world that uses the metaphor of the real world for exploration and interaction to simulate real-life situations, generating similar degree of complexity and dynamics as the physical world [94].

2.7.2.4 The Agent Behaviour

The agent based modelling research has extended the agent integration of a wide variety of entities in a hybrid, self-configurable, multi-layered and evolutionary architecture for cooperative agents. The different layers of the system architecture support the various aspects of the problem solving, requiring the use of specific soft computing techniques to integrate several learning capabilities and emergent properties for a self-configuring internal agent's architecture and incorporating initial basic behaviours to create more complex behaviours from the continuous interaction of much basic behaviour [95] .

A basic behaviour results from an initial learning by an agent of its environment and is generated as an internal world-model reinforced by the different agent states occurring from its initial self-configuring.

2.7.2.5 The Agent Interaction

Of great importance in the agent based modelling is the integration of change of environmental conditions about other agents interacting together, the identification of desired behaviours associated with positive impact on the purpose and goal meeting, the integration or suppression of a specific behaviour without using pre-configured rules, and how a behaviour generates an internal world- model, and links to the environments via the agent's sensors and actuators to refine its internal model. The agent interactions analysis provides valuable information to determine successive agent behaviours.

The interaction between agents requires the specification of actor's interaction, the interaction context and nature, and the environmental resources needed for its support. This interaction between agents is a collaboration which consists of synchronizing tasks and managing conflicts when possible. It results in agent group formation and task coordination which are used as a means of adapting better to the dynamism of shared environments.

2.7.2.6 Agent Argumentation and Negotiation versus Arbitration

Negotiation has received a lot of research interest in agent-based modelling studies, and the current focus is on the use of arguments in negotiation. Several types of arguments have been proposed in [96] . Decision-making processes have been extensively examined to develop a variety of agreement management methods aimed at reducing disagreements and reaching satisfactory agreements, good enough with respect to the requirements of agents. Argumentation in negotiation has been introduced in agent-based modelling frameworks to supply the negotiating agents with additional behavioural information and help them convince each other by adequate arguments by exchanging arguments, and consequently changing their behaviour without affecting their properties [97, 98] .

Argumentation in negotiation is an iterative process resulting from exchanges between agents when persuading each other and bringing about behavioural changes in their planned actions. This process aims at identifying the interaction arguments which can be quantitative or qualitative. Arguments are associated to justifications used during the negotiation which consists of persuading in trading off the behavioural changes. These justifications are represented by proxy attributes values. Agents have a memory of the past negotiations using past examples as arguments. They assign a value to every physical object or action they are interacting with. The most common arguments of focus in this research are threats, examples of similar situations and appeals to self-interest.

In agent argumentation in negotiation, models refinement of other agents involved in the interaction is a solution advocated to reach better results in negotiation [99] . The model refinement process consists of using the agent models to adapt its negotiation with other agents by mapping their characteristics to identify their plausible reactions taking into account past negotiations to develop negotiation plans.

Although trust is a critical prerequisite of any agreement process, the lack of evidence in terms of difficulty to establish causality when conveyed in the agent arguments, accentuates the decision complexity. The argumentation in negotiation must be based on reliable and strong evidence to support the arguments acceptance which results in a valid arbitration of current behaviours.

2.7.2.7 The Behaviour Repertoire

Agent behaviours are classified in a behaviour repertoire according to their category. This classification is performed using a co-evolutionary mechanism which captures, analyses and stores agent emergent properties from the actual learning, enabling its selection by another agent in the next generation [100] . The agent self-configures in an automatic way its own behaviours structure, making internal knowledge representations and adapts to environmental changes.

The dynamics of the continuous complex interaction between agents can generate intelligence when agent emergent properties arise from the interaction of their different behaviours at both the individual (single agent) and group level (multi-agent system).

2.7.2.8 Behaviour Arbitration

The co-evolutionary mechanism which is an essential element of self-configurable architecture, supports the self-configuring agent's behaviour arbitration process which consists of defining the number of the system configuration layers, logging the agents behaviours, establishing connections and hierarchies between the different stored behaviours with a continuous monitoring of the submission process regarding the valid behaviour arbitration: inhibition, suppression and aggregation of behaviours. It supports also the agent's behaviour evolvement alone or in cooperation with other agents by learning a set of rules and generating its own knowledge base, validating some multi-agent system specifications and capturing causality among messages sent by agents. This causality which relates to a concrete event, is the cause associated to the event occurrence, and results in semantic information explaining what actions are performed by agents and how their behaviours are modified by these actions [101] .

2.7.2.9 Agent Coordination

Of great complexity in inter-agent coordination is the specificity of autonomous agents posing a major problem is the gradual design of the agent behaviour. Agent-based learning is advocated for implementing the agent behaviour by using agent-based simulation to contour the current lack of rigorous modelling and automation principles in agent-based modelling [102] . The agent-based simulation requires only specifying the general agent capabilities concerning perception, action, feedback, and the environmental model to support the agent learning mechanism and produce behaviour models that can be understood and interpreted by the agent modeller. An example of agent-based modelling for a small evacuation scenario in the domain of crowd simulation has proved that it's possible to produce plausible behaviour using an agent-based simulation based on agent strategies and specify very complicated collision-free movements with individual destinations, speeds, perception radius, etc. using a rule-based approach [103] .

The process of agent coordination, which aims at adapting to the environment, consists of two major tasks: dependencies detection, and selecting the appropriate coordination actions to apply [104] . The emergence in the coordination of new agents and/or the behaviour changes in existing agents require to accommodate additional individual plans to incorporate new dependencies, ensuring the validity of the behaviour arbitration process. These dependencies are between the agent's own prospective actions and potential actions of other agents, exploring the coordination synergy of extended emergent properties to ensure that all the agent goals are achieved, and this result in a global plan detailing decisions and actions [105, 106]. The type of this plan will differ, depending on the nature of the agreement/disagreement between the agents present in the coordination. This plan is called a joint plan if an agreement between agents has been reached and a multi-plan otherwise.

Of great significance in the evaluation of this plan is the agent joint goals as related to the multi-agent system functionality represented using the dependency model of coordination showing the agents dependency requirements, including the complexity of patterns of interactions among agents pursuing partially conflicting goals. These agents can choose to play or abandon certain roles within the coordination following the appropriate the sequence of plan actions that best achieve their goals ensuring the respect of the given regulations within the system [107].

Agent coordination is based on four tasks: the use of models of coalition formation to determine when and with whom to interact for the achievement of some common individual and global goals, the task re-distribution between agents, the integration of the results to measure the agent's performance, and the benefits distribution of synergies resulting from this cooperation [108] . It is used for coordinating open multi-agent systems, enabling the accommodation of heterogeneous agents ensuring a secure control of access rights to eliminate or reduce security risks [109]. The visual representation shows only the agents coordination [110].

2.7.2.10 Agent Simulation

Agent simulation is based on the use of rules to understand their actions and interaction, the evolution of their cooperation, and assess their impact on the functioning of the system representing the entities activity. Intelligence is not necessarily in the production of the explanation.

2.7.3 Multi-Agent Modelling

Multi-agent modelling starts with the specification of the agent functionality by defining their responsibility and capabilities in terms of operations, rules and planning; taking into account the organisation that describes the framework where agents, resources, tasks and goals coexist. The functionality of the organization is defined by its purpose and tasks decomposed into operations and distributed between the different agents. Operations are structured into tasks and plans, and associated to goals and consequences resulting from the performance of these tasks. Satisfaction and failure relationships are defined to represent the positive or negative influence of the goals by the execution of the tasks by the agents.

2.7.4 Agent Based Modelling

Agent-based modelling (ABM) is essentially a decentralised and individual centred approach to model design which is aimed at identifying active organisational entities structured into agents to represent and understand their behaviour. The global behaviour of these entities emerges as a result of interactions of the agent behaviours acting individually or interacting together.

ABM consists of using computational models to simulate both actions and interactions involving autonomous agents performing individually or collectively individual or group tasks with a view to identify the changes on the system and derive plausible explanations to their behaviour. In this research, only the agent-based modelling patterns considered are the model architecture, the agent synchronisation and the connection and communication between agents.

Of great importance in the agent-based modelling is the generalisation of the classic logical implication which has shown some limitations due to the complexity of the context-dependent functions. The suggested solution remains that the expert has to decide rules from his knowledge, and the operators are chosen that work well in every context invoking these context-dependent functions.

2.7.5 Knowledge Entities Agent-Based Model

Agent based models are computational models or devices (robots) used for the simulation of the behaviour of autonomous agents representing individual or collective organisational entities in open environments which are characterised by spaces in which these agents interact. These spaces can be continuous, discrete, or characterised by networks. ABM, which are built using mathematical and experimental approaches, are often used to analyze systems that are either not sufficiently understood, or functionally difficult to break down and analyse. Different types of ABM have been suggested, and the most popular are the scale model, the analogical model and the ideal-type model [111] .

2.7.5.1 Knowledge Entities Integration

The generalisation of agent-based modelling in the integration of all organisational knowledge entities aims at overcoming individual limitations of the different agents and achieve synergetic effects through hybridization or fusion of the various soft computing techniques, to integrate the different learning and decision styles, and agent adaptation techniques in a multi-agent system configuration [112] .

Social-reasoning mechanisms based on agents exchange values are incorporated for the integration of autonomous characters displaying social behaviours to represent intelligent virtual humans playing the social role in real life applications [113]. The interaction between virtual actors mostly involves facing the complexity of animating pure social behaviours to manifest all the cognitive agent properties and create fully automated services.

2.7.5.2 Knowledge Entities Interaction

Organisations are involved in some real life application social systems which consist of a collection of individuals that interact amongst them. These individuals are motivated by their own beliefs and follow their own personal goals, and the circumstances of their social environment are very specific to them. They can be unpredictable and evolve autonomously making their own decisions and producing a set of behaviours which might be complex and change depending on their interaction context and nature. These behaviours illustrate the complexity of social dynamics which is explored using agent-based simulation tools. Observations on agents have received a lot of research interest, for the design of frameworks to assist in the analysis of the collective behaviour and trends of system evolution called in social studies the sociological analysis [114, 115] .

Of great significance in these observations is the limited number of nuances simulated, limiting in fact the social agent interaction and the characterisation of its environment. The simulation of concrete social processes is proposed with a focus on specific concrete processes to study emergent behaviour that results from deterministic behaviour of agents without integrating the social beliefs and values [116] .

2.7.6 Knowledge Discovery and Extraction

Knowledge discovery and extraction is supported by knowledge representation, reasoning and learning, and involves establishing inter-agent coordination in multi-agent systems. This is a very complex and challenging task due to the difficulty of enabling autonomous agents to allocate tasks. In this research, the concept of knowledge presentation is based on how to support knowledge discovery and extraction within the domain knowledge, using a panoply of knowledge models aimed at making intelligent environments and their interactions, with a focus on their symbolic interaction and complexity visualisation. This will result in developing a new reasoning environment for interpreting intelligent agents roles and behaviours in the same context of the use of the cognitive social psychology to understand human reasoning and inferring actions.

2.7.6.1 Knowledge Representation

The difficulty of enabling autonomous agents to allocate tasks, is accentuated by computational agents participating in social and coordination processes without a clear definition and representation of their roles and behaviour, in addition to the presence in the interaction, of agents with limited modelling abilities affecting the coherence and consistency of collaborative problem solving system [117] . This poses the problem of their knowledge representation and reasoning in terms of social choice rules, complexity of reasoning with such representations, and the handling of preferences. The coordination between these agents is reflected by the agreement between them, and can be seen as “the management of dependencies between organisational activities” [118] , or the rules of governing the interaction between agents aimed at the agents convergence on interaction patterns which deal with solving the dependency detection and decision tasks.

2.7.6.2 Organisational Agent-Based Models

The specification of agent concepts and properties, and the structure of their governing mechanisms for coordination are supported by a wide range of organisational models (Agent-Group-Role, MOISE, EI, or RICA) playing the role of facilitator to support decision making tasks by suggesting ideal agent partnerships for common goal achievement, making available relevant interaction information including the access to the agent behaviours repertoire, structural information about agents roles and their hierarchy, log of agents past interactions and the usability of services available to the agents [119, 120]. Agent based models are more elaborate when they fully capture what can be observed and what can be influenced.

Of great significance in the agent modelling organisational model is the gulf existing between the use of the design-time coordination mechanism for mainly closed distributed problem-solving systems and the adaptive flexible run-time coordination mechanism for dynamic complex problem-solving systems deployed in open environments [104] .

2.7.7 Agent-Oriented Software Development Methodologies

Research into agent-based modelling has produced a choice of methodologies, design tools and platforms for deploying autonomous agents in open complex environments. Several agent-oriented software development methodologies have been elaborated in the last past decade, emphasizing more on the description of agent models and their usage during the development of multi-agent systems. The most used among these methodologies are Mulan, Gaia, MaSE and Prometheus, Tropos, PAOSE [121] .

These methodologies which are process centred and object oriented use the same common concepts in agent-based modelling. These are cases, system structure or organisations diagrams, role models, interaction diagrams and protocols, models of internal events, data structures and decision making capabilities. Their openness to deal with designing open complex multi-agent systems has required the development of more than hundred agent-based modelling software, addressing the specificity of different domain of system use, programming language and operating system [122]. Although there is a proliferation of modelling software, tools support is not sufficiently covering the agent modelling and cooperation requirements [123].

Several multi-agent architectures and frameworks aimed at defining agent-based structures to resolve distributed computational problems and facilitate user interactions have been proposed. A few examples are: Open Agent Architecture, RETSINA and JADE [124]. In this research, framework refers to all the multi-agent system design concepts, tools, principles and methods used to structure the different system components composing the system architecture that reflects its holistic view.

2.7.7.1 Individual Based Modelling

IBM has been introduced to improving the classical state-variable approach to study local interactions among individuals, describing the individuals as discrete and autonomous entities. It consists of interpreting the current status of a population of people, animals and objects, predicting future development or evolution, and identifying critical processes within the interaction between individuals and their environment [125]. In individual-based models, the characteristics of each individual are tracked through time and location. These models deal with many entities, spatial scales, heterogeneities, and stochastic events. They focus on how to represent individual-level behaviour in a way useful for explaining the different system level processes, like for example the deployment and configuration of every homogeneous or heterogeneous device connected to a WSN.

Of great significance in understanding how to control a system is the capture of the properties and behaviour of individuals that determine the properties of the systems they compose. The system control becomes a necessity due to the different and adaptive nature of individuals, and IBM enables the study of the relationship between their adaptive behaviour and emergent properties. They can provide an explicit basis for supporting the modelling of decisions and reducing the need for ad hoc decision modelling.

2.7.7.2 Cooperative Control Model

The study of cooperative control models has received a substantial and increasing interest in recent years from researchers and practitioners to enhance strategic decision-making in terms of determining, coordinating and executing a plan of intelligent agents deployment, collaboration and cooperation in multi-agent complex networks called swarms, in response to real-time data as events unfold [126].

Cooperative control models aim at structuring a collection of decision-making components of any nature in a distributed multi-agent architecture, with limited processing capabilities that include homogenous and heterogeneous devices, basic or smart or intelligent, locally sensed information, and limited inter-component communications, all interconnected and interacting in an open complex and dynamic environment. Cooperative control deals with the emergence of collective behaviour by designing the networks local interaction rules to exhibit a desired collective behaviour assigned to distributed multi-agent complex networks [127] .

The concept of cooperative control covers three essential structural elements of global optimised systems: multi-agent control, distributed systems and networked control. The access to the global information collected by all agents during their interaction in a distributed multi-agent system configuration poses the problem of information distribution and its control within the network between the different agents and outside between the different users. Any information gathered by a single agent does not reach other agents without explicit communication. The decision interdependency and aggregation within the system which require agent's collaboration and cooperation for a real-time adaptation when self-organising and deploying given their spatial distribution, outlines the system control complexity.

2.8 Decision Support Systems

Ample research work on decision support systems for incident management has been carried out over the last three decades [128]. The use of intelligent software agents has been advocated to enhance the decision making process facilitation using a hybrid-human agent to support the business processes of Crisis Response and Management real world applications, mainly those involving the mobile human surveillance in which the assignment of a route to alarms is a complex problem.

The importance of hybrid intelligent decision support systems as an essential element of the legacy system network, is emphasized by the need to support the networks tasking between the agent network, the logistics network and the communication network to improve the response time to incidents by reducing the communication bottlenecks [129]. The incorporation of agent technology in conceptual frameworks aims at examining the functional requirements for elaborating an effective and reliable self-organizing incident monitoring and communication support.

2.8.1 Intelligent Software Agents

Intelligent software agents undertake many of the operations performed by human users as well as a multitude of other tasks representing the MAS activity. Of greater complexity in the development of large scale MAS based on the use of intelligent software agents, is how to support the facilitation of the communication among agents of different types, in terms of modelling the different types of agents: interface agents, task agents, information agents and middle agents. This facilitation process poses the complex problem of heterogeneity which is derived from differences of communications, coordination, environmental, functional, security, semantic and system and hardware [130] . These differences which are expressed in terms of broad requirements translated into specific implementations are modelled into intelligent software agents composing the agent architecture of the MAS infrastructure.

2.8.2 Hybrid Human Agents

The study of behaviour of humans involved in group activities and situations has shown that humans behave differently in crowded scenarios. The computerised representative of human agents with no decision making autonomy form composite agents, and are used for generating multiple agents interactions and simulating crowd movement patterns, validating the human-like behaviours generated by these agents [131] . Each composite agent consists of a basic agent that is associated with one or more proxy agents.

Hybrid human agents are active hybrid agent-user systems forming multi-agents systems that can achieve a highly challenging and interactive cooperation, modelling a variety of emergent behaviours for agent-based crowd simulation as group models occurring in various domains like emergency escape or response, or real-time crowd systems for video games [132] . The decision making process is created automatically by executing computerized instructions.

2.8.3 Web-Based Support Systems

Web-based support systems (WBSS) are an emerging research multi-disciplinary domain aimed at studying the support of human activities with the Web as the common platform, medium and interface. The generalisation of the use of web services for any aspect of life has resulted in moving a wide range of support systems to extend the human physical limitation of information processing in the information age by creating a vast amount of data and process integration for different domains of application and groups of mobile users. Support systems are intelligent software-intensive systems that be must be flexible, fault-tolerant, robust, resilient, available, re-configurable, secure, and self-deploying. They are based on the use of advanced information and communication technologies (ICT) which include digital library services, computational and data grids, cloud computing (CC), service-oriented architecture (SOA) and provide organisations with a pervasive collaborative working environment enabling their members and entities to work together more efficiently in their real life activities in a collaborative virtual work environment (CVWE) composed of a network of several workplaces technologically connected [133-135] .

2.8.3.1 Web-Based Cloud Architectures

There is an increasing demand of high quality and productivity systems architectures integrating distributed and multi-agent systems in cloud computing integrated into service-oriented multi-agent architectures applicable to the development of intelligent highly dynamic environments. Such environments require to effectively supporting more individual complex tasks, to ensure full availability, accessibility and flexibility of tools to enhance the use of WBSS, and facilitate the distribution and management of functionalities through the distributed agent-based architecture. This management aimed at optimising usability and performance, consists of involving autonomous agents to cooperate in solving problems and generate knowledge and experience, and providing more flexible ways to move functions to where actions are needed [136] using reasoning mechanisms or learning techniques to handle these cloud services requirements. Such requirements include the access to services from a wide range of mobile devices such as tablets, smart phones and personal digital assistants (PDAs), the support of varied open complex context environments, high levels of human-system-environment interaction, ubiquitous communication, computing and adaptable interfaces, and advanced flexibility and customization to easily add, modify or remove services on request, with very limited impact from the programming environment.

Cloud computing architectures is the ultimate integration level providing simultaneously in one integrated novel design framework infrastructure (IaaS), platform (PaaS) and software (SaaS) as a service, adding composite services and applications as interaction blocks between users. All available services are stored in the Web Services Architecture Model (WSAM), a sort of model base supported by a Web Services Description Language (WSDL) establishing the logical link between applications and services.

Of great complexity in the implementation of these integrated service-oriented multi-agent architectures is the incompatibility between the agent's platforms. The advocated solution is either the distribution of services and applications in the agent infrastructure by modelling the functionalities of the agents and the systems as services and applications invoked by the agents, or the organisation of the communication between the different agent-based models of the platform [137] .

2.8.3.2 Web-Based Groupware Systems

The fast development of mobile technologies, such as Wi-Fi networks, PDA, and smart phones, has made it possible for users to instantaneously access any Web-based system from various kinds of devices, anytime and anywhere, extending further the scope of Ubiquitous Computing [138]. Extensive research and development have been carried out on applying context-based filtering technology for a Web-based group decision support system and its mobile users for the Context-Aware Adaptation in Web-based Groupware Systems [139] .

Web-based groupware systems integrate both the user’s physical and collaborative context, and are built using object-oriented models. These models aim at personalising information content which consists of enabling the filtering of context-aware profiles to match the users’ context and the use of progressive access models to organize the selected information corresponding to the available content matching the profile. Wiki systems such as XWiki and MediaWiki, can be considered as a new generation of Web-based groupware systems enabling the combination of mobile technologies together with some of the Web principles that allow mobile devices to share data and contextualized information.

2.8.3.3 Mobile Devices Adaptation

The use of mobile devices in Web-based groupware systems in the context of people access control system, poses the problem of the users' specificity in terms of personal criteria such as user's personal characteristics, background, culture, interests and preferences, and the context of their use that includes the location, specific situations and environmental conditions [140] . Of great significance in the research and development effort to enhance the access to Web-based collaborative systems, is the adaptation mechanisms and principles aimed at reducing the limitation of the mobile devices in terms of their battery lifetime, screen size, interoperability and intermittent network connections, to display or introduce the appropriate informational content. The improvement of the adaptation process consists of implementing a context-based filtering process that proposes to adapt the information delivered to mobile users by filtering it according to the current user's context and to the user's preferences for this context. Allowing a direct participation of the users into the adaptation process to express individual user profiles, a progressive refinement of the profiles description, and the simplification and reuse of profiles, results in additional requirements about the delivery of services, data and presentation [139]. Taking into account the interface requirements of mobile devices in use in the MAS, these additional requirements are translated into specifications incorporated in the design of interface agent's actions.

2.8.3.4 Dynamic Re-Configurable Web-Based Applications

The search for new ways to design and manage the deployment of systems and services has always been a constant engineering challenge for researchers and practitioners to deal with systems in a continuously changing environment and with emerging requirements that may be unknown at design-time. In recent years, web self-adaptation systems emerged, and considerable progress has been made in several software engineering domains to advance and improve the dynamic aspects of system reconfiguration aimed at providing web-based collaborative self-assembling and self-adaptive applications by proposing the feedback loops concept from the perspective of control engineering to control self-adaptation of systems [141]. These domains include requirements engineering, software architecture, middleware, and component-based development.

Self-adaptive systems are aimed to meet their higher-level objectives which are to be deployed on a large scale, able to function without any or very little human intervention, and regulating emerging requirements and orchestrating emergent properties.

2.8.4 Web-Based Learning Support Systems

A tremendous effort has been consented by researchers and practitioners in the domain of web-based support systems to enhance the design and increase the usability of personalized or collaborated learning support in dynamic and heterogeneous learning environments. Of great importance in the design of these support systems is the implementation of learning mechanisms to increase the learning intelligence by enhancing the interactive interrogation of learners and providing them with a cognitive support for enquiry-based learning (EBL) which includes problem based learning [142] and uses knowledge as a cognitive structure of a person, and learning as an active process of elaborating knowledge, stimulating learners to share the knowledge acquisition [143].

The new configuration of web-based learning support systems is based on the use of Adaptive Web technologies to integrate personalization and collaboration in a web-based learning management environment. These systems support learning as an interactive, dynamic, and active feedback process in which the learning facilitator replaces the direct interaction between the teacher and students. They are integrated adaptive and intelligent learning management systems (LMS) that support a wide range of learning facilitator's roles using different learning models [144] . They aim to distribute information and deliver knowledge to an increasingly wide and diverse audience, using personalized or group pre-designed learning paths which can be modified during the course of learning, depending on individual learning progression. Learning requirements and learning styles are integrated in the definition and support of personalized learning needs, taking into account the key characteristics of learning support: complexity, individuality and adaptability, interaction, and activity and assessment.

In recent years, intelligent technology-enhanced assistance has been introduced in the configuration of web-based learning support systems to search and locate suitable information, structure and refine the returned information [145].

2.8.5 Web-Based Service Management

The complex and dynamic nature of varied innovative and generic web-based services supporting web-based collaborative self-assembling and self-adaptive applications using advanced information technologies increases the complexity of service management that attracted various related research and development efforts offering e-solutions for globalization, automation, and self-service activity developments. More elaborate e-environments based on the use of network organisational models are continuously proposed to support the automation of the cooperation over the web of service providers and service consumers. This aims at providing a cost-effective, rapid and reliable new product and application services to instantly interchange documents and information, and share collaborative decision making processes with many different organisational entities [146] . The main services included in the service management are: desktop management (DASH), network management (NetMan), storage management (SMI), systems management (SMASH) and virtualization management (VMAN). The storage management includes services supporting the plug-ins of a wide range of domain knowledge sources, its related services and a context-aware capability to dynamically identify the relevant services according to the current focus of attention. The domain related services which can emerge or cease, are structured and deployed using a domain service bus (DSB) aimed at dealing with the service domain users requests.

The implementation of web-based service management software requires the service management to be based on service policy in conjunction with service registry for the registration of services.

2.8.6 Web-Based Knowledge Management

Web-based knowledge-based systems (WBKBS) are determinant in the use of prior information to improve the performance of deterministic and adaptive systems in general, and multi-agent systems in particular. Knowledge-based systems contain specific information to a problem domain, and the reasoning leading to making decisions is supported by an inference engine.

2.8.7 Self-Organizing Support Systems

The prominence gained in recent years by wireless communication applications with the growing technology of ad hoc networks and agent-based architectures has led to the design of innovative self-organising intelligent decision support systems to effectively support the deployment and control of integrated RFID – WSNs. These support systems which are based on self-organized agent based architectures supported by collaborative decision mechanisms, provide an efficient way of choosing the network configuration and control policies and scenarios to reduce both computational overhead and energy consumption. They need to be explicit as to what the underlying decision mechanisms are, and what the functional consequences of the decisions are.

The decision making support is based on decision mechanisms enabling individual decisions by individual members needing to be made jointly with other group members to reach a consensus and so avoiding conflict of interest between group members. These members can be people, smart devices and intelligent agents. Following their local (individual) behavioural rules, results in organized behaviour by the whole multi-agent system without the need for global control from outside the system involving external decision makers.

2.9 Decision Making

Decision making activities in complex environments are based on real time group decisions requiring a decision consensus needed to support the agent argumentation and negotiation.

2.9.1 Group Decision Making

Group decision making is a complex activity requiring computer technology solutions to support the different steps of the decision making process: intelligence, design and choice [147]. Collaborative decision support systems are proposed to help in solving structured, unstructured, and semi-structured problems.

The advent and generalisation of web-based services decision support has enabled inter-organizational collaborative decision support systems and integrated group processes supporting a wide variety of real-time complex decision making activities. Individuals, smart devices and elements of behaviours and system control modelled as agents, often make decisions in small groups or in large organizational networks interacting together.

2.9.2 Decision Consensus

The decision consensus is obtained taking into account the decision independence of some members with the group decisions which include combined decisions, aimed at tasks allocation that might require a new consensus depending on the tasks outcomes. These tasks result from the decomposition of the activity covered by WSNs in addition to those required by the deployment, configuration and control of the network.

Agents allocate to themselves and others tasks that might involve other agents, and if combined decisions involve significant conflicts of interest, agents can struggle for control

[148] . Consensus group decisions aimed at agreement between several agents, require different cohesion and aggregation mechanisms from individual-based combined decisions. They can be examined to the extent to which they involve conflicts of interest between group agents and whether they involve either local or global agent communications [149] .

Conflicts of interest can affect the fitness consequences of the decisions. Agent groups with local communication rely on self-organizing rules generated from their own behaviours, whereas more-complex negotiating behaviour can occur only in agent groups that are small enough to enable global communication. This second aspect applies only to human agents and their limited local communications.

Of great significance in reducing the conflicts of interest to reach a decision consensus is the full understanding of who makes the decisions, what the underlying decision mechanisms are, and what the decision functions are. This results in defining whether group decisions are shared or unshared.

2.9.3 Real time data capture, predictions and decision making support

Real time data capture, predictions and decision making within the surveillance domain for hazard identification and mitigation require the use of a variety of decision support systems for to support the domain fusion functions that include data processing and mining, knowledge discovery and extraction. The main aspects of decision making process used in fusion functions are detailed in Chapter 3.

2.10 Research Gaps

The proposed research aims at providing a novel integrated solution for the several problems identified in recent works, studies and developments.

– Ad hoc WSNs configuration

- The studies examined in this work have suggested a network typology based on the distinction of homogeneous and heterogeneous devices around the sensor node components that will confer an active or passive role to the node, depending on its configured components [59]. In the proposed research sensor node devices configured primarily to perform different functions of sensing, localizing and tracking, as listed in Table 2.1 are to be considered generic smart homogeneous devices. Their deployment and configuration can be enhanced by the use of heterogeneous devices such as RFID readers, sprinklers, people counters, etc...

- The examined literature has not covered the design of generic homogeneous sensor node devices which is considered in this work as an essential feature in the definition of flexible adaptive configurable WSN architectures.

– WSN-RFID integration:

  - Although a hardware solution has been proposed to adapt the integrated WSN-RFID in a context aware mode for new extended sensing capabilities by integrating RFID tags and readers WSN nodes [153], the study has not addressed the devices interoperability, not enabling to support the dynamic smart nodes with automatic reconfiguration information generated by dynamic control requirements imposed by self-turning distributed multi-agent systems. Of great interest in the study of the RFID-WSNs integration problems, is the needed validation of integrated configurations when integration by multi-sensor heterogeneous data fusion is allowed.

  - A taxonomy of the different ways to distribute the functions in the integration of RFID and WSNs has been proposed [47], the current study examines the requirements and specifications for supporting effectively in a hybrid intelligent control system, the facilitation process of the generic integration of the various functions associated to the different integration modes. This functional composition may result in newly elaborated functions, taking into account the standardisation requirements in terms of device interface, data acquisition and processing, problems, protocols and communication, security and performance. He news functions can be composed from information and knowledge fusion.

– Novel approach for data, information and knowledge fusion:

  - The recent development of different types of networks that include ad hoc networks and WSN has influenced the applications design and distribution [154]. The proposed research focuses on a novel approach for data, information and knowledge fusion. Multi-sensors heterogeneous data fusion that includes data cleaning, compression and aggregation based on the cluster based approach, and effectively supported by data warehousing, is an upstream step to the process of information and knowledge fusion that contributes to the increase of both the WSN and information fusion system performance.

- This novel approach supports the strategy of decoupling the data capture and processing from information and knowledge fusion.

– Multi-agent systems for intelligent information and knowledge fusion:

- The integration of traditional hard and soft computing techniques to be used in combination, are advocated for the design and development of hybrid intelligent systems [102]. Intelligent information and knowledge fusion requires complex interactions between the various knowledge components to be modelled by intelligent agents configured in distributed multi-agent systems supporting the deployment and configuration of ad hoc WSNs in the domain context of civil defence.

2.11 Summary

This research focuses on hybrid intelligent decision systems based on MAS architecture to support the configuration of integrated RFID and wireless sensor networks (WSNs). Its interests reside in examining severe constraints that are imposed on the sensing, storage, processing, and communication features of the sensor nodes, and designing a flexible and adaptive WSN configuration solution to enhance their deployment and increase their performance using hybrid intelligent web-based support systems. This network architecture is considered for the support of distributed detection in the domain context of civil defense.

The reconfiguration of WSNs is needed when the sensor nodes may become faulty due to improper hardware functioning and/or lack of energy supply (dead or low battery power). Their deployment covers a wide variety of environmental settings, ranging from harsh and remote environments to residential buildings and clinical units, supporting a large range of applications. These applications include, among others, military and civilian surveillance, tracking systems, environmental and structural monitoring of home and building automation, agriculture and industrial settings, and health care.

The literature review presented in this chapter is an overview of the different concepts involved in the research conceptual framework developed in this research. The influential elements and considerations of self-organized multi-agent based distributed architectures for the deployment and configuration of ad hoc WSNs have been exposed in the line of technological and organizational developments, underlining their importance.

Chapter 3: The Theory of Hybrid Intelligent Decision Systems

3.1 Introduction

The emergence of advanced internet and wireless technologies has resulted in real-time remote monitoring and system control becoming an essential need for organizations to timely capture real-time heterogeneous data. This requires accessing accurate information and making improved real-time decisions to meet strategic objectives and respond appropriately to changes in the environment. But increasingly, these organisations are facing tremendous challenges in their quest for up-to-date and accurate context-aware information. This requires real-time integration of reporting and analytics with the aim of developing intelligent capabilities for handling large amounts of complex and non-traditional data, making better decisions and taking meaningful control corrective actions at the right time.

These integrated technologies are pushing toward the full continuous web monitoring of environmental conditions and facilities through the increasing use of intelligent solutions and ubiquitous computer and internet. A smart design environment is needed to help build, deploy, operate, integrate, aggregate, and use a spectrum of services delivered over the web, processing data collected from wirelessly connected heterogeneous devices, in an effort to cope with increasing market changing requirements induced by globalisation, digitalisation and changes in safety and security legislation. This design environment is based on the use of an integrated conceptual framework for intelligent support systems.

3.2 Integrated Conceptual Framework for Intelligent Support Systems

This research focuses on how to design and compose smart, robust, adaptive and reliable service knowledge, service models, service data and service support capabilities using integrated advanced computing technologies and communication in a conceptual framework shown in Figure 3.1. This framework is based on the concept of web based intelligent agents processing real-time data captured and collected by ad hoc WSNs and integrated RFID, using data and knowledge driven support systems.

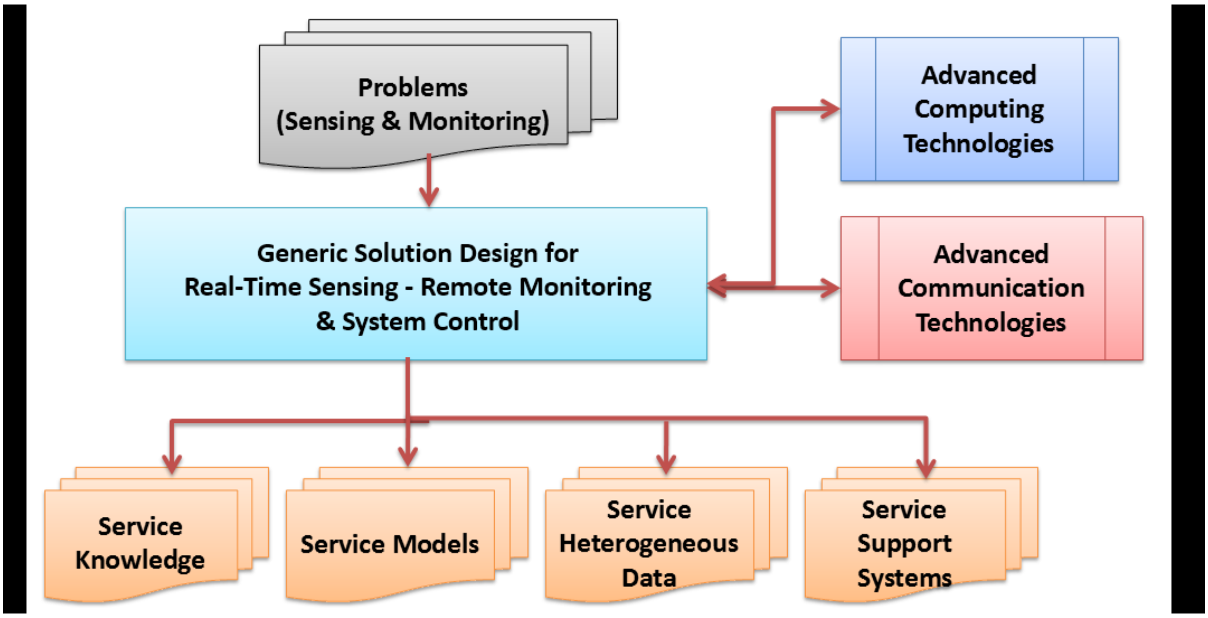

Figure 3.1: Integrated Conceptual Framework for Web-based Hybrid Intelligent Decision Support Systems 1

This integrated conceptual framework develops a specific interest on how to apply the most adapted optimisation model automatically and without the need for expert interference, and integrate generic real time collaborative decision making processes with the following particular characteristics illustrated in Figure 3.2:

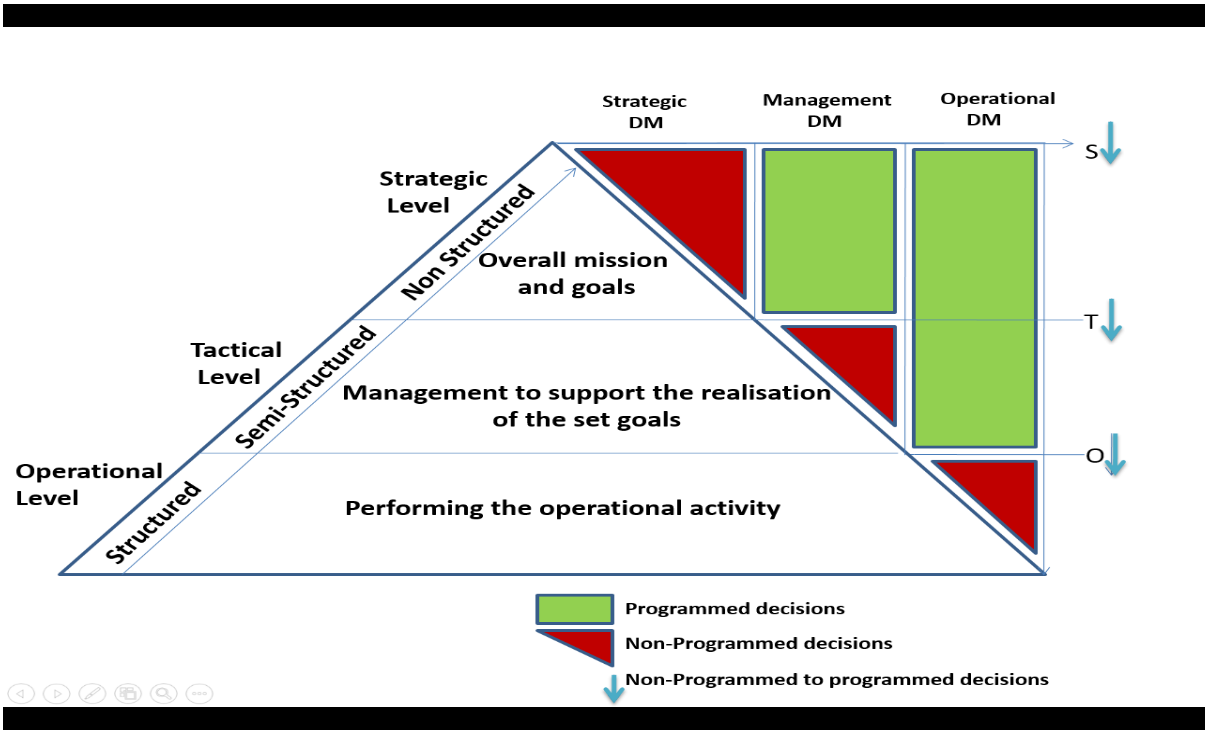

Figure 3.2: Activities vs Decisions Characteristics 1

- the kinds of unstructured or semi-structured data generated by heterogeneous entities and resulting in tangled clumps of messy data culled from multiple sources,
- the horizontal data integration between the network control and the decision making levels at the different management support levels, taking into account the four data dimensions which are volume, variety, velocity and relevance, and
- the kinds of unstructured or semi-structured decisions required for the adaptation of agents behaviours representing the organisational units and their associated patterns of deployment and control.

The tasks resulting from decision activities are differently structured depending on the decision characteristics and the management level decision requirements in terms of uncertainty, aggregation, prediction and validity. Ranging from structured to ill structured, the decision tasks result in programmed to non-programmed decisions. The use of intelligent support systems aims at reducing the level of non-programmed decisions.

The analysis of decision tasks in the domain of real-time remote sensing, monitoring and tracking, and system control shows a growing need to detect and react to environmental events as they happen in real life. This reduces the length of the batch window to a few seconds, or even less, and requires the use of web-agent based enabled decision support systems as the fastest and easiest way to bring real-time data onto the World Wide Web, and use appropriate services to integrate data and decision making activities. The validation of detected events requires the tracking of all changes leading to these events for auditing and analysis purposes to trigger appropriate responses using real time decision mechanisms mainly in large network systems.

The keeping of data in synchronisation across the networks becomes an important increasing need to ensure that the most recent status of all system agents, associated to devices and people, are available within the distributed processed applications accessible to end-users in the form of web-services. Software frameworks are proposed to support these applications across relatively different network configurations that enable the access to real-time knowledge discovery and extraction, and enhance the quality and timeliness of decision making support due to the widespread use of the Internet and web-based platforms, the wider accessibility of smart devices, wireless sensor technology and mobile communications integrated in a dynamic ubiquitous environment [150].

3.3 Decision Support Systems

The integration of database and modelling capabilities have benefited from technological innovations enabling continuously far more powerful DSS functionality. DSS are computer technology solutions that can be used to support complex decision making and problem solving, improving the decision making process support and decision effectiveness and efficiency. They support some or several phases of a decision making process, at the individual, team, organisational or inter-organisational levels. They were initially developed to support individual decision-makers, but later DSS advanced technologies were developed to support workgroups or teams, especially collaborative support systems and virtual teams [151].

The advent of web-based services and the growing technological development of mobile tools, mobile e-services, and wireless internet protocols has extended the inter-organizational decision support systems used for evaluating strategies for device deployment, and agents and services composition. In these intelligent systems designed to support different decision activities in distributed collaborative environments in terms of time, spatial distribution and individual and group interaction, the integration of the different aspects of the decision problem and the varied group compositions requires the study of a set of characteristic requirements needed to organise the different phases and reduce the span of the decision-making process.

3.3.1 Decisions Characteristics

DSS aim at integrating the different categories of management activity with the different decision types [152]. The management categories include the strategic planning level setting overall mission and goals, the middle management control level leading the organisation to the set goals, and the operational control level performing the operational activity [153]. These activity levels face different decision problems as existing on a continuum from programmed to non-programmed decisions [154]. Programmed decision activities are characterised by routine, repetitive, well structured, easily solved problems, whereas non-programmed decision activities involve new, novel, ill-structured, difficult to solve decision problems. Decisions are structured when they are programmable, pre-planned and made routinely under established situations; they are unstructured when they are made under emergent and non-planned situations of one-of-a-kind, which are uncertain and unclear. They can also be semi-structured.

3.3.2 Decision Making Process Characteristics

Similarly, decision making processes can be ill-structured. Their support requirements have been specified in a generic design framework aimed at iteratively integrating the different steps of the solving process to reach a satisfying decision. These steps are intelligence for the search of problems, design for the development of alternatives and choice for the alternative analysis and implementation of the selected alternative [154], as illustrated in Figure 3.3.

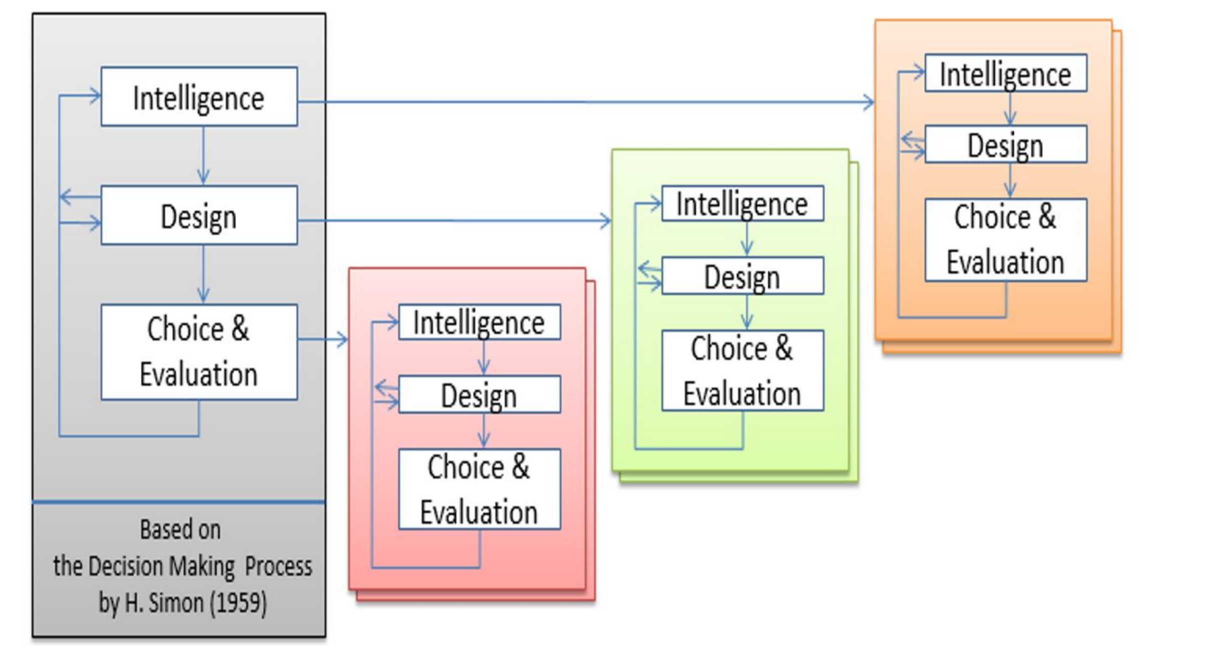

Figure 3.3: Decision making process steps overlapping 1

The decision making process is structured into three iterative steps (Design, Intelligence & Choice) which can be overlapping and requiring individually one or several global processes to serve their purpose.

The evaluation of implemented decisions based on intelligence support is used as an additional step in the generic decision making process design framework [155].

A decision making process can be based on unstructured data, and the lack of structure in data requires time and energy for its compilation using data analysis mechanisms. DSS aim at reducing this lack of structure, and to create a relational structure, a sort of data intelligence that enables its integration into the data model, and constitutes an important aspect in the problem solving formulation and the development of alternatives. Turning unstructured data into structured or semi-structured data enhances modelling capabilities needed to support the search and development of decision alternatives and their comparison using multi-criteria attributes to trade-off their possible outcomes.

Problem analysis and model development are two essential elements of problem solving and rational decision making. In this context, decision support requirements include the facilitation of the creation of decision models aimed at searching or generating alternatives, and comparing them. This facilitation is based on an iterative process that can be overlapping in the sense that the search or analysis of alternatives can induce a problem reformulation or different design actions. The steps of the decision making process overlap and blend together in the effort of searching satisfying alternatives, requiring often frequent looping back to earlier stages to incorporate what has been learned about the problem formulation and its solving, enhancing its perspectives for a much broader form of analysis and reasoning, relying more on intelligent data and modelling in an integrated framework.

3.3.3 DSS Functions

DSS combine sophisticated database, knowledge and model management capabilities to meet the above mentioned facilitation requirements. They enable access to internal or web-based external data and information, and knowledge. They rely on internal and external powerful modelling functions available locally or accessed via a web-based model management system. They are based on advanced powerful user interface supporting interactive group interactions, knowledge and model representation, decision maker's rapid information dissemination, queries, reporting, and graphing functions. They provide decision makers with smart support, enabling them timely access to a panoply of decision making tools via services through mobile and smart wireless devices as much as through their desktop computers. These services include internal and web-based services for data warehousing, on-line analytical processing, data mining, decision tools, collaborative decision support systems, virtual teams, knowledge management, model management and optimization-based DSS models, and active decision support for distributed multi-agent systems [156].

3.3.3.1 Data Management

The data management system is based on supporting integrated knowledge and model driven applications (OLTP), and data driven applications (OLAP) forming the dynamic data warehousing, organising the data migration to enable the extraction of data in independent and dependent data marts. These applications can be grouped by their nature to construct a panoply of DSSs based on processing patterns: data (data driven DSS), knowledge (knowledge driven DSS), model (model driven DSS), and document (document driven DSS) [157].

Data mart, on-line transactional processing (OLTP) and on-line analytical processing (OLAP) are three essential tools supporting dynamic data warehousing, a system used for data mining, analytics, visualisation decision making and reporting, information and knowledge fusion, as illustrated in the system data management architecture shown in Figure 3.4. Data systems can be transactional (OLTP) providing source data to data warehouses, or analytical (OLAP) helping to analyze it, or master data (MDM) linking all of the critical data to one file.

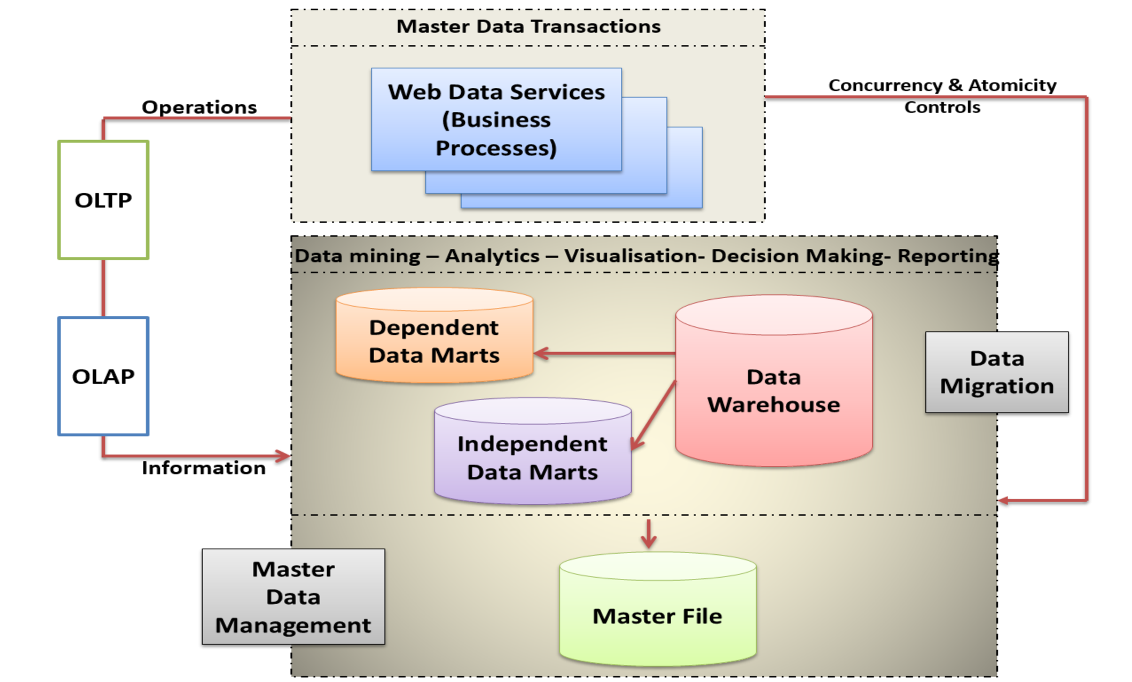

Figure 3.4: Data management architecture 1

a) Dynamic Data Warehousing

A data warehouse is a "subject oriented, integrated, non-volatile and time variant collection of data in support of management's decisions" [158], namely a database designed to support decision making in an organization. It aims at emphasizing operational processes by combining core organisational processes and fast and up to date data from external sources in a format to support decision making. Evolving from centralized data repositories to data marts, data warehouses are based on a logical dimensional model aimed at making data intuitively and rapidly available to end-users for routine and ad hoc analysis. Data warehouses are collections of integrated data from different sources, remotely distributed, made timely available to operational systems supported by different types of DSS [159, 160].

b) Data Migration

Data migration is a process aimed at extracting, transferring and loading data within a multi-distributed system architecture when replacing server or storage equipments or network devices, maintenance or upgrades, or data centre relocations. This process, which is performed automatically, is made up of five steps: design, extraction, cleansing, loading, verification and testing.

Of great complexity in this process is the data cleansing to improve data quality, eliminate redundant or obsolete information, and data synchronisation, harmonisation and verification to ensure data consistency between source and target storage, and also that all ordered and unordered data was accurately translated and complete, identifying data disparities and fixing data loss. The scope of data migration can be the storage, or the database, or the application, or the business process [161].

c) Data Mart

Data mart is a corporate data model, representing a sub-model of data warehouse or designed as a component of the master and distributed data warehouse, aimed at subject-oriented reporting and analysis, and containing data typically expressed in some combination of criteria covering a functional area such as geography, organisation and application, or business functions. The data is structured in a data model representing a database composed of several tables that support end-users analysis leading to more informed decisions for various functional segments of the organisation. Operational systems that handle the day-to-day transactional activities supporting the different management levels are the primary sources of data for data marts. However, the primary data may need to be processed to meet the format requirements of data marts. This intermediate processing consists of data translation and formatting using a variety of filters and formulas for data aggregation [162].

It is essential to define the business process requirements in terms of users varied information requirements, to better understand how decisions are made within each functional area of the organisation, taking into account the changing needs of end-users. These requirements include:

- Functional criteria such as specific data content, relationships within and between groups of data, the logical relationships among the objects, the data transformations required, frequency of update, priorities, and level of detail, and
- Technical criteria that specify where you get the data that feeds the data mart, and the most effective and efficient ways of storing and retrieving the data.

Data marts are based on the use of metadata containing information about the data, and providing a directory of technical and functional views of the data mart. Metadata includes a description of the data, its format and sources, and has two aspects:

- Technical supporting the data mart management by indicating the data acquisition rules, explaining the transformation of source data into the storage format in the target data mart and the data updating mechanisms, and specifying the schedule for backing up and refreshing data, and
- Functional indicating to end-users what information is contained in the data mart, and how to access them.

Among other requirements for the design of data marts, the problem of data creation, maintenance and security remains essential. Data can be created locally or in a central data warehouse. Data marts can be dependent and independent, depending on the data sources feeding the data mart and their frequency of use, and the communication resources required. Independent data marts are standalone components supporting the Extraction-Transformation-and Loading (ETL) process aimed at the moving of data from operational systems and external sources, and it's filtering and loading into the data mart. Dependant data marts rely on a master data warehouse from which data can be extracted and distributed to local data marts.

Consistent schemas and data formats are required to support rich varieties of distributed and corporate data views enhancing interoperability, achieving data consistency and increasing data usability. These schemas contain measurable or countable fact data.

d) On-Line Transactional Processing

On-Line Transactional Processing (OLTP) are computer data processing systems used by end-users in a multiple access environment to perform short and fast updates of OLTP databases using the original source of the operational data. They aim at optimising distributed databases by running and controlling web services tasks, and ensuring the data normalisation, consistency, integrity, back-up and security, and providing the OLAP data. They facilitate and manage transaction web service oriented applications aimed at data entry and responding instantly to end-users requests using different computer platforms in a network, and monitoring the transactions processing for a better coordination of data services. They ensure that data is not updated while in use by other users (concurrency controls) and all steps of the transaction are satisfactorily completed (atomicity controls) [163].

e) On-Line Analytical Processing

On-Line Analytical Processing (OLAP) is intelligent computer data processing aimed at answering a multi-dimensional analytical query using a transaction involving a database, reporting and data mining to enable end-users in a multiple user environment to analyse multidimensional data interactively from multiple perspectives to establish numeric facts [164], uncover useful information such as hidden patterns and unknown correlations, and support the discovery of influential relationships between data items. This processing is based on the use of a multidimensional data model, and consists of multi-dimensional aggregation of data, navigation in the aggregated detailed data, and selection and extraction of segments of data from different viewpoints. Established numeric facts called measures are exposed by dimensions [163].

OLAP uses dashboards aimed at facilitating ad hoc analysis, enabling quick, easy data access from point-and-click interfaces for rapid decision making.

f) Master Data Management

Master Data management (MDM) consists of linking all of the critical data to one file, called a master file that is used to provide a common point of reference to different end-users, applications, platforms and multi-system architectures sharing the same data in multiple access environments. This type of data management requires frequent coordinated updates to the master data file, and end-users are continuously informed.

g) Data Modelling

A data model is a diagram that illustrates the relationships between data representing the description and behaviour of the different organisational entities. Data is stored in multi-dimensional databases organised using multi-dimensional structures to configure hierarchical and functional relationships between the different entities. The data attributes are defined as dimensions used in terms of intersections to represent the data selection required in data extractions to populate data marts. Sub-attributes can be used when attributes refer to different categories or a period of time. The conceptual data model represents the highest-level relationships between different entities, whereas the enterprise data model being similar to the conceptual data model; represents the functional data requirements of a specific activity involving the entities. The logical data model which is used for the creation of the physical data model, illustrates the links between the specific entities, attributes and relationships involved in an activity [165], and used in data predictive analysis and visualisation.

h) Predictive Modelling

Predictive analysis is a technique used in data mining, predictive analytics and machine learning to extract information from data and use it to predict trends and behaviour patterns. Predictive modelling is a process used in predictive analytics to build a future behaviour model in terms of forecasting probabilities and trends by analysing current and historical facts to make predictions about future behaviour states and identify unknown events [166].

i) Data Visualisation

Data visualisation is an essential function of data management supported by intelligent software. It’s aimed at enhancing the understanding of data, illustrating its significance and interpreting its different patterns, trends and correlations by the use of interactive capabilities and indicators based on visual concepts which include infographics, dials and gauges, geographic maps, spark lines, heat maps, and detailed bar, pie and fever charts [167].

3.3.3.2 Model Management

Model management is concerned with the elaboration and management of models needed to support the use of association rules and descriptive, predictive and prescriptive analytics required by the data fusion functions.

a) Association Rules

Aggregation and analysis of data enables the identification of if/then patterns by using the concept of support and confidence, to establish on one hand, the support defined here as how frequently the items are identified, and on the other hand, the confidence defined here as the number of times the if/then statement has occurred in the data collection.

If/then statements are called association rules in the sense that they help establish relationships between seemingly unrelated data in a database or other information. If and then are the two parts of an association rule: the antecedent condition (if) is an item found in the data, and the consequent action (then) is an item that is found in relation with the antecedent. Association rules are useful for analysing and predicting the organisational and functional entities behaviour.

b) Descriptive, Predictive and Prescriptive Analytics

Decision making supported by business analytics consists of synthesising data based on the use of multiple disciplines to make predictions and suggest decision options. This process is made up of three steps. First, descriptive analytics deal with primary requirements concerned with studying the decision problem, answering the questions about what happened and what has caused it to happen by looking and understanding past performance. Then predictive analytics search for answers to the question what will happen, using rules, algorithms and models on past historical performance and structured, unstructured and external data to predict probable outcomes. Finally, prescriptive analytics suggest actions to be taken and outline the decision options implications [168, 169].

Of great significance in the analytics process is the continuous effort for increasing the prediction accuracy and prescribing better decision options by performing iteratively the last two steps of the process, considering new data to re-predict and re-prescribe.

3.3.3.3 Knowledge Management

Decision support systems are designed in light of knowledge management which consists of continuously eliciting, creating and disseminating new structural knowledge embodied in web based services, technologies and systems, to enhance complex problem solving performance. Decisions are consistently compared with Knowledge Management (KM) activities.

Different types of knowledge compose a domain, and differ from each other depending on the domain complexity. Knowledge includes structural and tacit knowledge, and it’s of great importance to understand where knowledge creation occurs, and how it can be represented, created, elicited, converted, integrated, shared, transferred and applied to enhance practice. Of great significance in KM is the knowledge codifiability and consciousness of its use [170] and knowledge can be classified accordingly to the level of management of its codification and use: operational, tactical and strategic.

Knowledge can be explicit/propositional, and its production can rely on prior acquired skill (procedural knowledge) and judgment (based on experiential knowledge). It is iteratively used to formulate new knowledge in the form of propositional knowledge in its explicit form. Tacit knowledge is converted into explicit knowledge using knowledge-based processes, and the continuous interaction between these two types of knowledge is essential to the creation of new knowledge [171]. However, some aspects of tacit knowledge remain ineffable and deal better with non-formal knowledge processes.

a) Structural knowledge

The elicitation of structural knowledge consists of the domain declarative knowledge, establishing knowledge links or relationships between the entities' attributes represented in a cluster graph. Structured knowledge is coded and represented as illustrated in Figure 3.5,

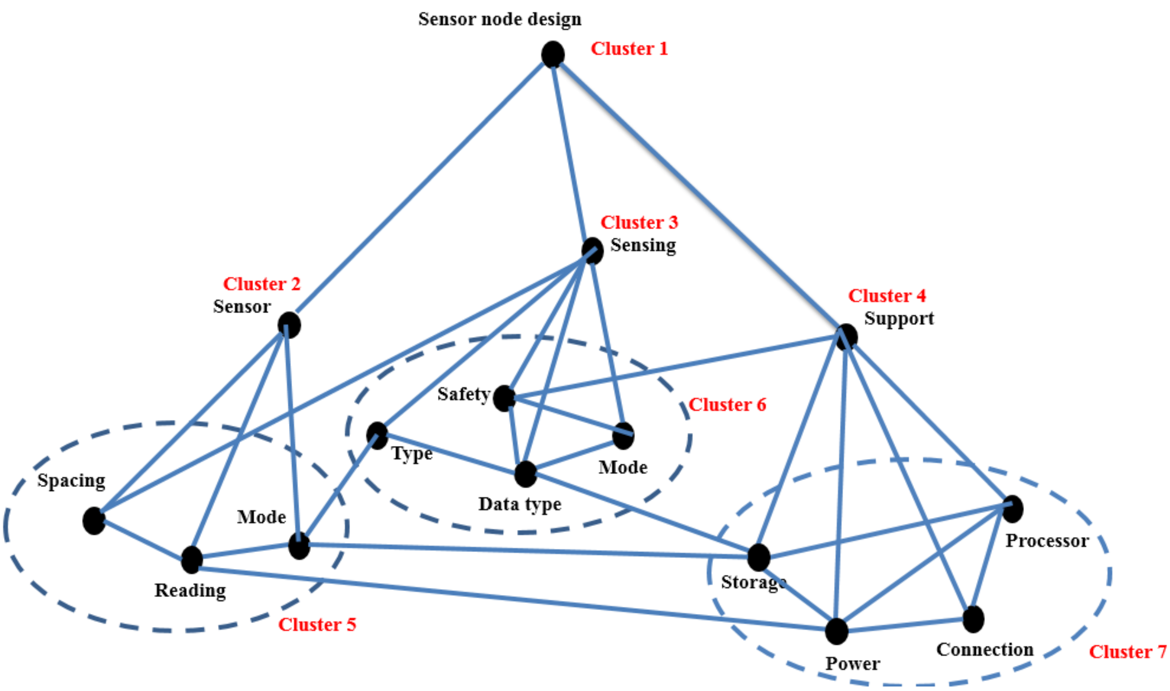

Figure 3.5: Example of knowledge elicitation graph

by a map of clusters called individual knowledge graphs, in which each graph shows inter and intra cluster links representing the cluster edges between nodes. Measurement of the graph size is used for the assessment of the reliability and validity of the knowledge elicitation process, and establishing the link with explicit knowledge [172]. It is based on the use the following concepts:

- Size: number of nodes,
- Degree: number of edges,
- Density: number of present edges in comparison with clusters and graph,
- Diameter: longest path in the network, and
- Number of clusters.

b) Tacit Knowledge

Complex real decision problems are associated concurrently to both explicit and tacit knowledge due to their difficult characteristics such as:

- Intransparency: lack of clarity of the situation described by the problem,
- Polytely: multiple goals which might conflict with each other,
- Complexity: involving large number of interactive heterogeneous entities, and
- Dynamism: time and latency.

In tacit knowledge, the comprehension about the domain is described in the propositional knowledge, whereas procedural knowledge explains the activity and how it can be performed, and experiential knowledge describes the meaning of experiences and how to interpret them using explicit knowledge [173]. The transfer of tacit knowledge can require its application depending on its level of formulation. The knowledge transfer requires experts to facilitate the learning process by mentoring or coaching. Non-propositional knowledge includes both procedural and experiential knowledge.

c) Knowledge Discovery and Detection

KM supports the elaboration of knowledge-based processes in organisations, including knowledge enhancement in its different roles at different stages of a domain. These processes create knowledge at the individual or micro-level, and organise its refinement interactively through different interactions at the collective or organisation level.

Different methods and practices can be used to make knowledge easier to detect, and use it for the search of patterns that might lead to new insights. These include asking individual team members to provide their understanding of the knowledge processes they are involved in, and also gathering all the domain knowledge embedded in the documents in use by these processes, and in use through external networks [169].

3.3.3.4 Group Support Systems

Group support systems (GSS) referred to, also, as group decision support systems (GDSS) support integrated collaborative computing, combining communication, hardware and software innovative technologies and including smart devices and intelligent agents to enhance team-based decision making and decision quality, and improve group performance and satisfaction in networked distributed physical and virtual environments. They are based on the use of a context-aware filtering process for adapting content delivered to individual and mobile users, identified by context-aware profiles, expressing the users' preferences for particular context situations involving them [139].

GDSS support and structure group interaction, and facilitate collaborative learning and training using virtual teams, computer-supported collaborative and distributed work including e-group meetings. Of great significance in the design of GDSS is the release of three moderators from consideration: group size, time and proximity, focussing mainly on task type, level of technology and the existence of facilitation through groupware and GSS tools to enhance the group adaptation process in a generic support perspective.

Of great importance in GDSS is the existence of automated group facilitation using in combination the knowledge and model management capabilities of DSS embedded in a wide range of web-based services composing collaborative support systems.

a) Web-Based Collaborative Support Systems

Web-based collaborative support systems are based on cooperative work using web-based multi-agent collaborative computing and internet technologies, to support collaborative decision making processes, involving information and knowledge produced and exchanged between different agents, forming workgroups or teams including virtual teams.

Collaborative decision making processes are supported by Knowledge-Intensive Intelligent Decision Support Systems (KIIDSS), enabling individual agents to carry out, in a distributed environment, collaborative tasks during the three steps of the collaborative system: decision making modelling, knowledge management, and decision problem solving support. They require rigorous evaluation, comparison and selection of solution and decision alternatives, and optimisation from a global perspective translated in terms of quantified and/or qualitative criteria expressing a policy setting scenario. Their development model and framework are generic, adaptive and flexible enough to be used differently in a variety of design decision problems, concurrently integrating multiple cooperative knowledge sources and models.

Collaborative support systems focus on decision knowledge modelling and the use of support schemes for their representational capabilities for non-explicit (tacit) knowledge involving learning and skills. They require a robust set of collaborative new web-based tools for use within a network based environment. These tools provide collaborative decision makers with rapid, accurate access to multiple sources of information, coordinating information and intelligence exchange directly between numerous organisational entities and agents. They include integrated smart devices involving intelligent devices and sensors enabling environmental data capture and obtain the synergy of their integrated use in terms of intelligence-gathering capabilities [174].

b) Collaboration Process Modelling and Visualisation Support

Collaboration process modelling and visualisation consists of sharing and applying expertise of domain experts in modelling and solving problems using a modular approach based on web semantic modelling tools. Complex knowledge systems and domains are broken down into modular components to create a collaborative structure of knowledge models, enabling a virtual communication among collaborating agents and computing models. This knowledge modelling process is based on an iterative knowledge visualisation and rework for managing knowledge processes workflows. This management includes supporting complicated scheduling, sequencing, and iteration of knowledge processes.

The development of web based knowledge services is required to invoke existing knowledge models for enhancement through adapting, expanding, customising and improving them by processing different context situations. This process aims at providing a generic model or system creator that can help in the sharing of knowledge amongst different domain experts, and the converting or translating of abstract ideas contained in tacit knowledge into models needed to build knowledge process models. These models are classified in the form of ontologies that are used as communication schemes tools in the web linked modelling environment, to ease and facilitate the interaction between network agents. This interaction is part of the ontologies management that enables the identification of acceptable agent behaviours that validate the effective use of embedded knowledge models to solve decision making problems in the knowledge domain, and also the different steps of the knowledge processes [174].

c) *Collaboration Environment Design Support*

Of great significance in the design of collaboration environment design support illustrated in Figure 3.6, is the inter-layer transformation sequence, containing the following three steps of transformation of:

- Information strategy planning to business area analysis layer
- Business area analysis to perform system design layer, and
- Collaborative system design to construction layer.

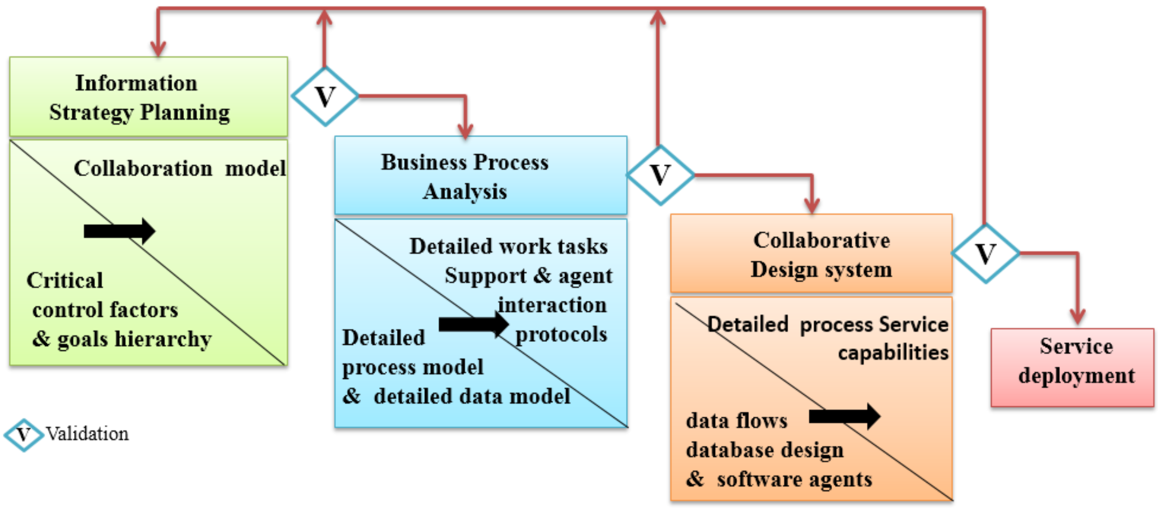

Figure 3-6: Collaboration environment design process

The collaboration environment design process is based on the continuous iteration of its different steps, subordinated to the validation of the different design levels. The collaboration model based on the context representation and context description is associated to the success control factors and the goals hierarchy. The business process model is associated to detailed work tasks support and agent interaction protocols to a detailed process model and data model. The system design layer structures the process service capabilities, and is associated to the different agent software, supported by the detailed data flows and the database design.

d) *Context Description and Representation Support*

Context description and representation of context situations is based on the use of object-oriented representation to describe and structure both the user's physical and collaborative contexts when designing and implementing distributed collaborative systems to support collaborative activities. The user's physical context includes the concepts of location, device, and application which can involve a web-based service containing intelligent agents interacting in a multi-distributed agent system, whereas the user's collaborative context includes the concepts of group, role, member, calendar, activity, shared object, and process, which are the collaborative elements.

A context description, which is defined as a composition of context elements, represents the concept of context. This composition group of both physical and collaborative elements is illustrated in Figure 3.7.

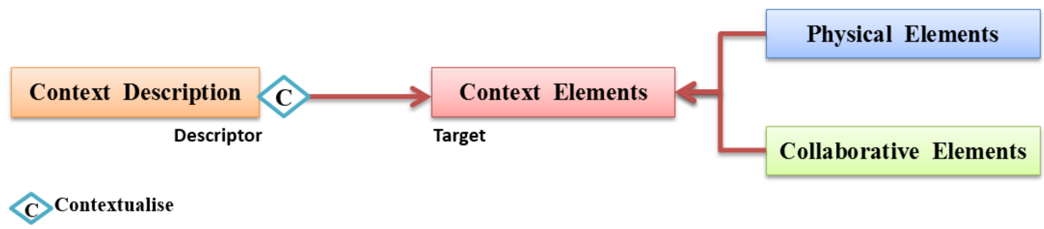

Figure 3.7: Context description representation

A context situation is represented in this model by an instance of the class Context Description, which is linked by composition to instances of the class Context Elements and its subclasses. A context element subclass is a concept of context as illustrated in the context model shown in Figure 3.8.

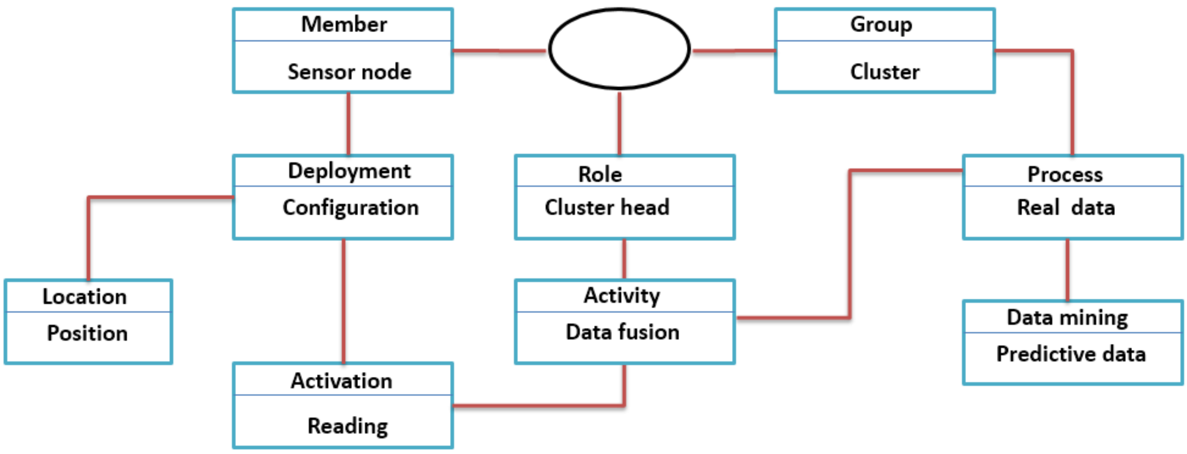

Figure 3.8: Context model representation

The number of physical and collaborative elements can vary depending on the organisational settings and the complexity of the collaborative activities. In the context model representing the elements functional association, the elements Member and Group can be associated to the

Agent and Web based service in an attempt to represent the service composition model, assuming an intelligent agent is an element of a service designed to describe a set of system functionalities, and a collaborative activity involves a set of services.

e) Group Awareness Information Support

Of great importance in organising collaborative activities are the elaboration, availability and representation of relevant information to supply to different agents during their cooperation when invoking their corresponding services, and enhancing the agents' interaction learning about each other's behaviour and influences. This information can be relevant to the modification of the service composition conditions that might alter the agent current context situations, preferences and actions. It contains common knowledge made up of individual agent contributions through the evolvement of their different behaviours when reacting to new context changes, or interacting in different contexts [175]

f) User Preferences Support

Profiles are used to represent the agent interests and preferences, and the interaction and cooperation constraints imposed by different collaboration context situations. These elements often vary during the agent's cooperation when sharing collaborative activities. A model representing these profiles is based on the use of profile-based filtering rules to support the service composition model in matching the agent current context with the service application context, describing for each agent the needed information for each service associated to a context situation and how it is organised.

The profile model is based on a set of profiles associated to a context description and element, depending whether the preferences are application context based or agent related. Each profile is linked to a set of preferences which might be shared simultaneously by different context applications and agents. An agent preference is described by a content containing an event and a result, and indicating a format and its different characteristics, as illustrated in Figure 3.9, whereas an application profile is a preference request. The preference matching is supported by the preference association process (PP) [176].

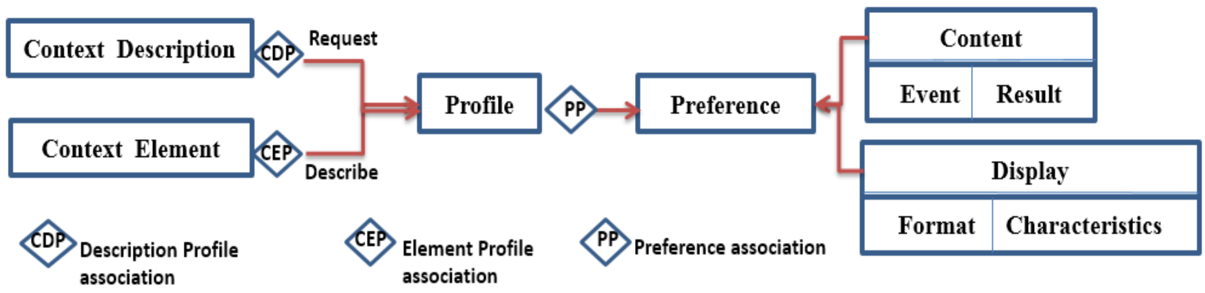

Figure 3.9: Context element profile and preference model.

Intelligent agents forming the multi-agent system composing knowledge-intensive intelligent decision support systems, are associated to different profiles, depending on their different roles during their cooperation constraints imposed by different collaboration context situations. These systems support the dynamic changes of their environment, in accordance with the context situations These changes are inherent to identified hazards in the domain of indoor surveillance and also to any malfunction of the surveillance network and support systems. They can be classified as follows:

- Implications of changes, changes side effects and upstream hidden changes,
- Identified system deviations, and task divergence, delays and conflicts,
- Changes to state variables, context description elements, agents profiles and preferences (content and display), and internal dependencies,
- Knowledge and decision rules,
- Static and dynamic uncertainty, and
- Specification changes and impact of different external conditions

g) Knowledge-Intensive Intelligent Decision Support Systems

Knowledge-Intensive Intelligent Decision Support Systems (KIIDSS) are automated tools in the configuration of distributed multi-agents systems that increase the speed in developing and modifying collaborative decision making processes, and coordinate and update a large amount of knowledge for different network web-enabled application domains. Elaborate decision-making techniques and tools, and design criteria are used to develop and evaluate various alternative decision making processes with a view to increasing design knowledge. This knowledge is iteratively used to effectively support decision making processes based on a variety of computer-based models, to make correct real-time intelligent decisions during process modelling, knowledge modelling and decision support [174].

3.3.3.5 Real-Time Collaboration Support

Real-time collaboration is an important support function of DSS, associated with intelligent thinking based on the use of cybernetic and system theory principles, and self-organisation to provide intelligent cognitive support systems and collaborative tools. It consists of enabling a group to actively collaborate using computer interaction, working simultaneously on the same data to derive conceptual understanding and generate new knowledge to integrate in an existing knowledge framework, to possess a high degree of domain related knowledge and resolve problems in real-time situations. The enhancement of cognitive processing at the individual and group levels, poses the problem of better understanding of how the generation of new knowledge may be supported during real-time collaboration in self-organisation with a high level of intelligent interaction required for deep learning called metacognition. Self-organisation is based on the identification of patterns of connection, an essential concept used in services systems detailed later in this chapter [177].

Real-time collaboration supports the process of knowledge processes refinement through the use of integrated advanced computer and information technologies, to enhance the discovery, learning, and knowledge acquisition process in general, and augment and empower the participant's cognitive processes in particular. Of great importance in this support is the need for processing real-time data with the aim of structuring, identifying, deriving potentially relevant knowledge, sharing the process of constructive knowledge refinement, involving complex levels of interactivity that guide agents to establish key influential relationships between decision variables and derive new decision options. During the real-time decision collaboration process, web-based support tools and information strategies are needed for the knowledge construction, enabling agents fully interconnected and iteratively interacting in a group decision system, establish new associations between concepts, actualise, refine and synthesise data and information to create new knowledge for effective incremental real-time decision making.

3.3.3.6 Virtual Teams Support

Virtual teams, which include geographically dispersed, distributed, remote teams, or virtual reality teams, are knowledge-based groups of agents working across space and time in a non-hierarchical multi-distributed environment. They support cross-functional collaboration within and between organisations [178]. Their organisational boundaries are extended by computing and communication technologies, overcoming the group teams' geographical restrictions for the share of systems, processes and use of devices.

The concept of a virtual team is based on the use of a model defined around three aspects: purpose, people and links. Of great importance in this model is the significance of the purpose of the team composition, which can be translated in terms of common goals, individual tasks and results [179]. These tasks can be synchronous or asynchronous requiring the use of coordination mechanisms.

a) Empowerment

Empowerment of virtual teams leads to better learning and process improvement when performing highly complex tasks in organisations with high levels of dynamic, complex change and environmental uncertainty. It is based on face-to-face to no-physical interaction, and related to virtual team performance. Defined as increased task motivation, team empowerment emerges from collective cognition [180]. This motivation results from the team member's collective assessments of their inter-independent organisational tasks, and the conditions under which they have been performed. This is reflected by the different behaviours of the team members with a particular emphasis on their individual level of motivation.

Individual and team empowerment requires the use of consensus models to enhance the performance of team processes in terms of improved communication between the different members, and conflict elimination. This involves interdependent actions to be taken by the team members to achieve team goals [181].

b) Virtualness

Virtual teams are a viable alternative to face-to-face work due to the importance of the information technology role in diminishing physical and temporal boundaries, and the dissemination of knowledge across organisations, enhancing the dynamics of knowledge development and transfer, and organisational learning [182].

Understanding and measuring virtualness involves effectively integrating coordination and communication between team members. This communication can be complex, depending on the member's location and their work cycle synchronicity. Other influencing aspects such as culture are not included in this framework. In this research, virtualness is associated with collaborative information technology.

c) Virtual Tools

Of great significance in the design and selection of virtual tools is:

- the full understanding of the extent to which the virtual team members use the support tools to coordinate and execute their organisational tasks and team processes,
- the amount and type of information provided by these tools and exchanged by the virtual team members, and
- the concurrency of events that may be connected by causality or just by meaning, not having a causal link [183].

The concept of synchronicity associated to meaningful coincidences, is of great importance in the view of the structure of reality which represents a causal connection of coincidently meaningful events.

3.3.3.7 Services Support Systems

Services support systems are computer systems that implement interoperability between different software applications, distributed across networks on a variety of platforms and/or frameworks. A Web service is a "software system designed to support interoperable machine-to-machine interaction over a network" [184].

Knowledge domains are fragmented, and the emergence of service systems has tremendously contributed to linking their collaborative activities and supporting the interaction among the various organisational agents which include all resources and shared information, all connected internally and externally across networks. This interaction takes place at the service interface between the service provider and service users.

Of great importance in the services system development and delivery, which includes service management and operations, is the complex multi-distributed architecture to support connecting the content of core and provided services, and their availability across the network, in the form of customised pluggable, reliable and robust integrated functional and operational services. The services availability supporting process, oriented to problem solving to integrate external evolving requirements, is supported by dynamic reconfigurable systems which are self-adaptive and based on constructing self-assembling and self-adaptive components, benefiting from the increasing usability of the panoply of adaptive advanced information, computing and communication technologies. The implementation of such systems requires a component model and a service registry to support a dynamic service management.

a) Dynamic Service Management

The service management infrastructure includes web service discovery supported by a collaborative framework shown in Figure 3.10. This framework supports the process for enabling web-based collaboration between service providers and service end-users in the context of aware services provision. This infrastructure is based on provided services to provide organisations with composed services resulting from the modelling of their own process oriented problem solving. Composed services are obtained by assembling components of internal and technical services and also registered services.

- **Web service discovery process**

This process focuses mainly on a collaborative task aimed at both parties to "become known" to each other and agree on the web service semantics and description required for the service requester and provider interaction. Semantics includes what is expected from the behaviour of the agents composing the service, whereas description represents the mechanics of the message exchange during the agent's interaction while executing the service [185, 186].

- **Web-based collaboration supported**

Information of provided services, including their semantics and description, are published online by service providers into the Service Registry and Repository through the Service Management module. Information about available composed services is accessible to service consumers/end-users using the service management to formulate their service requests, and requested composed services are made available to them through the service bus. This service can be global or specific; i-e grouping the main services of a knowledge domain, like for example the Health Service Base (HSB) supporting e-health applications and services for GP's [187].

Services include third parties services (provided services) and internal services, which are called core services, and are those managing knowledge, data, tasks, and communications.

Their invocation poses the problem of all-the-time service availability, taking into consideration some key factors, such as, services failures, server failures, services maintenance and application program control problems.

Available services are identified through services discovery, prior to their composition and execution. During the composition process, they can be orchestrated, i-e grouped together or packaged to automate a process, or synchronize data in real-time. The size of the package in terms of level and types of services, and their required resources, are key performance factors of the orchestration process which requires dynamic and intelligent allocation of resources.

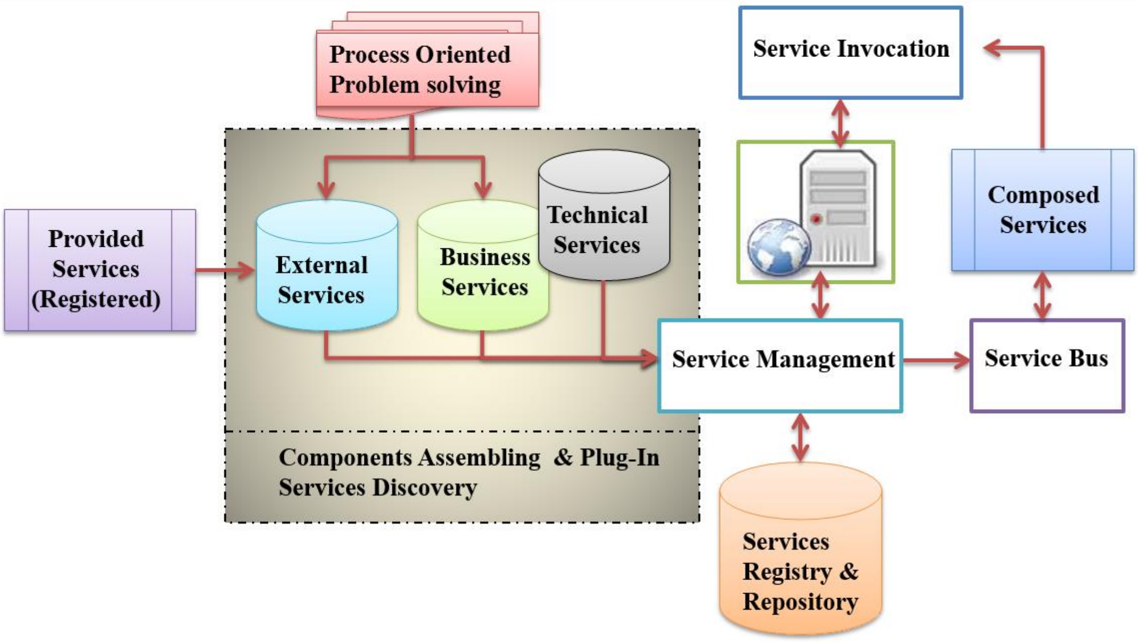

Figure 3.10: Web-based collaboration supported by service framework

Of great importance in the service management process is the process workflow supporting the appropriate selection of the business logic modules linking the service providers to assist services discovery, composition, and execution before elaborating and delivering results to end-users [188]. Of great significance in the services invocation is the service knowledge and information available to end-users prior to, in terms of what is the service for, the information requirements before the service execution, the pre-defined processes and procedures, and whether the service will fulfil the users' needs.

b) *Architectural Models*

The services system architecture is based on the use of the concept map defined as a graphical way of representing key concepts and relationships [184]. This architecture is built around several component models focusing on the creation and use of services by agents. These architectural models are:

– Message oriented model: focuses mainly on messages, message structure and message transport,
– Service oriented model: focuses on aspects of service and actions,
– Resource oriented model: focuses on resources used by services, associated with their owners and users, and
– Policy model: focuses on constraints on the behaviour of agents and services.

c) *Service Composition*

Existing independently developed software agents and hardware smart components, called capabilities, can be grouped in different web services that can be used to support the automation of a business or knowledge process. These services can be composed or recomposed to build a wide variety of solutions with different types of design principles. Once a service has been composed or recomposed, it can be reused, and doesn't require any design change. A web service has functionality, and is implemented by a concrete agent associated with one or several capabilities.

The service composition process consists of creating:

– A controller service which is a service that controls other services, or
– A composition member which is a service that provides functionality to other services in the composition without further composing other services [186].

There are several variations of service composition. A service is standardized when it does not require a runtime data model transformation during its invocation, avoiding a negative coupling with another service within the composition process.

d) *Service Registry*

Services end-users and providers work together through a service registry along the service bus. Depending on the importance and complexity of the knowledge domain, the service framework supporting a web-based collaboration might structure separately services per domain using parallel services buses. The service registration requires the implementation of a service policy development aimed at facilitating the collaboration across the Web of service consumers and service providers [186].

e) Services Learning Support

The services learning support aims at enhanced gradual individual and group learning in terms of an accumulation procedure of experience and knowledge for the use of services. This learning process support is based on implementing different learning styles that effectively accommodate a wide variety of learning capabilities to ensure an active service usability based on service users with different skills, background, and cognitive learning styles [189].

The information distribution and knowledge delivery through services within a collaboration process poses the problem of services learning support in terms of registered services and how to use them in relation with identified collaborative activities, relying less on human assistance or guidance. This problem shows the design complexity of personalised learning support in dynamic and heterogeneous services learning environments, creating adaptive learning environments for the Web towards the creation and customisation of web personal services. This complexity is reflected in the key learning requirements for the support of collaborative activities to enhance human limitations of information processing with web service-based technologies [190]. These requirements are:

- Learning support complexity requiring the support of different learning cognitive styles.
- Individuality and adaptability support consisting of adapting to the ability and skill level of individual users.
- Interaction support enabling users to be integrated in the interaction process.

Activity and assessment support reflecting the users' participation in the service understanding, execution and improvement.

A framework of service structure can be used to support services knowledge structure visualisation for representing a dynamic and personalized services learning process for end-users. This knowledge structure map is derived from the context element profile and preference model used to represent the users' preferences.

3.4 Reasoning Support for Specific Domains

The reasoning required to support specific domains is twofold: knowledge and model based reasoning.

3.4.1 Knowledge Base Reasoning

A real-time web-based agent tool and wireless sensor network process monitoring system supports the implementation of e-surveillance systems in which a model-based component is included in order to decide the rules embedded in the planning and surveillance processes. This component integrates a hybrid knowledge/case based system (KBS/CBR) using a combined ruled and case based approach to select appropriate decision making support models [191].

3.4.1.1 Rule-Based Reasoning

Of great importance in the design of a web-based knowledge support system (WBKBSS) is the configuration of the knowledge representation which is generally based on a ruled-based system. The knowledge of a domain is represented by facts describing the domain and the rules for manipulating the facts. These rules composing the WSKBSS are defined as logical implications and used as inference bases, support ruled-based reasoning (RBR). They are acquired initially from experts' knowledge, and later after the system deployment from knowledge production resulting from agents learning [192].

3.4.1.2 Case-Based Reasoning

The use of case based system is an alternate solution to contour the absence of satisfying rule when using RBR to select the appropriate decision model.

Emerging intelligent hybrid decision support systems supporting ad hoc WSNs are based on a flexible, adaptive and hybrid multi-agent distributed architecture composed of a number of heterogeneous components originating from a variety of integrated innovative technologies. This architecture allows support systems to embody deep up-to-date knowledge elaborated iteratively from causal loop modelling and reasoning under certain uncertainty, using systems dynamics and simulation modelling for predicting agent behaviour under different policy strategies, and increasing efficiency and accuracy in agent management. Additionally, it employs local data pre-processing and statistical techniques for intelligent data analysis and reduction which are based on the use of database techniques for data storage, analysis and representation [192].

3.4.1.3 Decision Making Representation Models of Reality

Decision making representation models of reality are needed in all aspects of decision making to represent the decisions feedback characteristics which might include circular interconnections among elements for the activities of supported activities. These models show how organisational structure, amplifications (in policies) and time delays (in decisions and actions) interact to influence the decision inference mechanisms, and understand the causal relationships among the elements composing the system [193].

Different decision making tools such as Cognitive Maps (CM) and Causal Loop Diagrams (CLDs) are extensively used to understand the feedback structure of the system, in terms of inference on the system behaviour.

3.4.2 Model Based Reasoning

Model based reasoning is required when using explicit models for emerging issue tracking. Such implementation in the real world is based on the use of an engine to associate the model knowledge with observed data to infer conclusions at run time. These models are stored in a model base, and can vary in their nature (qualitative or quantitative), represent normal or unusual situations, and differ in other characteristics (static or dynamic, deterministic or probabilistic, causal or non-causal, compiled or first principles).

3.5 Summary

DSS have extensively evolved through the continuous integration of advanced communication and information technologies, procuring self-organisation and real-time collaboration. The full automation of real-time decision making activities using services systems is an important development based on substantial improvements made at different levels of decision managements: data, knowledge, models and virtuality.

The acquisition and creation of valid and updated knowledge extends far beyond the transmission of knowledge and the development of advanced information-processing skills. The knowledge procurement is the base for the creation of intelligence distributed among the organisational entities which include people, devices, processes fully interconnected via a panoply of networks.

Chapter 4: The Generic Design

4.1 Introduction

The design under consideration in this research concerns the elaboration of generic solutions for indoor distributed detection applications requiring the use of HIDSS to support the design, configuration and deployment of ad hoc integrated WSN RFID used for real time detection data capture. Indoor detection requirements result in detection specifications that need to be met by detection equipment installed in the covered indoor premises.

The HIDSS aims at data, information and knowledge fusion which consist of supporting information scanning and emerging issue tracking, using an open loop control process to synthesize and generate vigilant information processing tasks in knowledge-based reasoning. This is based on applying both data and model driven approaches to elaborate and structure knowledge and group decision making processes. This study is in the context of strategic planning and relates to making real time decisions based on how best to utilise limited intelligence, surveillance and reconnaissance (ISR).

Strategic real-time decision making supports the organisational need to remain at all time, alertly monitoring for weak signals and discontinuities in the organisational environment in terms of data sensing, storage and communication across networks, identifying emerging or established threats upon issue, goal seeking and sensitivity analysis.

This chapter describes succinctly the main elements of the generic design conceptual framework for the development of HIDSS, with a particular focus on the domain analysis method and the knowledge domain analysis. The domain analysis method is essential to create the use and re-use of the design for different domains, and the knowledge domain analysis is a necessary step to elaborate generic knowledge tasks of the domain of interest, and reduce and solve their complexity. A specific knowledge domain has been suggested for a case study in the area of indoor distributed detection that includes sensing, localizing, tracking and monitoring, for a wide range of applications, including emergency planning for fire detection, control access and other related issues.

4.2 Motivations

The motivation behind the use of generic design framework is the need to identify re-usable modules of processes, hardware and software to:

- Reduce the domain and system analysis complexity by applying the separation of concerns principle,
- Analyse the individual knowledge domain models during the domain analysis to better understand their mutual influence and dependency during their implementation,
- Analyse the system modules behaviour working solely before their integration in the system, checking properly the data structures appropriateness and the effectiveness of the algorithms and models,
- Better understand the system modules mutual interaction for a structured agent design and service composition for a flexible and adaptive distributed implementation,
- Facilitate the incremental design and implementation of the system architecture decoupling the fusion functions, and
- Reduce the system design and implementation costs.

4.3 The Generic Conceptual Design Framework

The generic conceptual design framework developed in this research is a methodological support that enables the mapping of a knowledge domain model and architecture to a generic design for building monitoring control applications in a domain of interest. These applications are required to be deployed in the form of web services for fast and flexible access to real-time data captured by ad hoc integrated WSN-RFID networks and processed locally and/or at the server to support real-time decision making in the context of data, information and knowledge fusion.

4.3.1 The Distributed Service System Generic Design

These distributed services integrate concurrently third party data and models, and share tools and processes jointly supported by web-based GDSS linking end-users. They support generic solutions in the domain of interest in which their various distributed application are structured in the form of services supporting fusion functions for the elaboration of knowledge processes, models and data, and support system capabilities as illustrated in Figure 4.1. The proposed generic design conceptual framework focuses on service interoperability which is based on generic and recursive design in problem solving using the different management components (knowledge, model, data and support capabilities) to deploy, operate, integrate and aggregate end-user services.

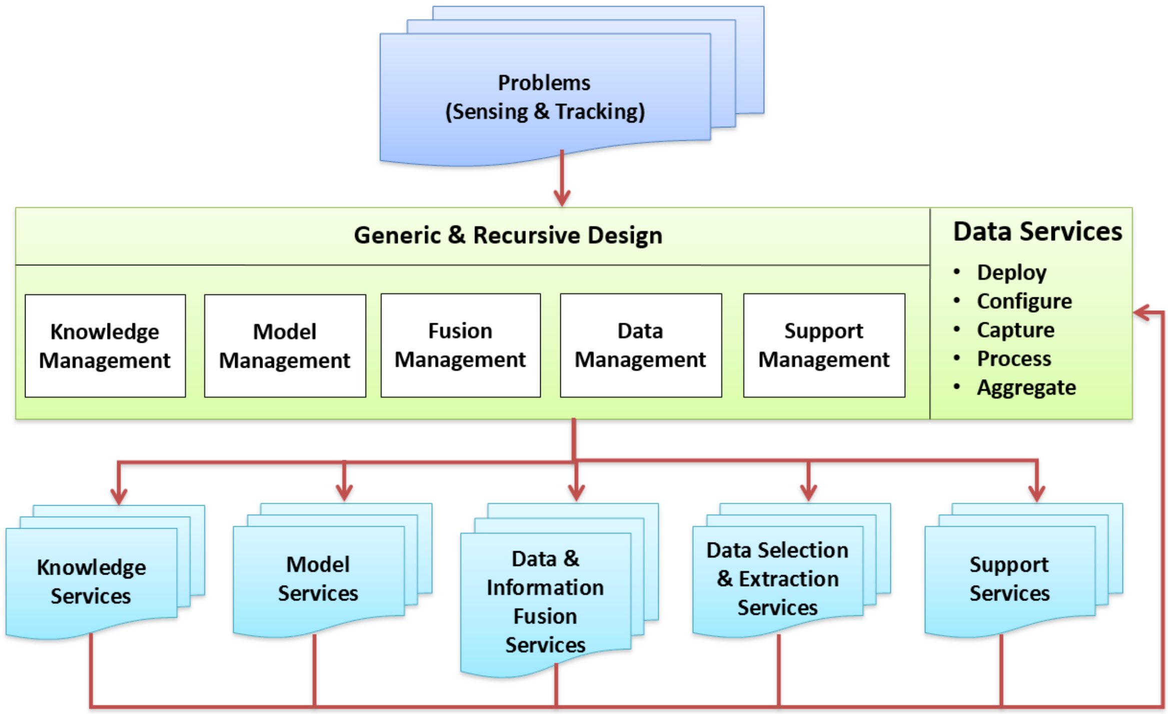

Figure 4.1: Service Interoperability based on Generic and Recursive Design

Of great importance in the different management components, the architecture of data management shown in Figure 3.4, is the essence of the service interoperability due to its importance in linking on-line transactional and analytical processing to translate the end-users operations into the knowledge domain information.

4.3.2 Hybrid Intelligent Web-Based Decision Support System for Specific Domains

In dynamic environments, only real-time data for specific domains can provide decision makers with relevant knowledge using a panoply of models structured in a model base, to provide users with predictions and explanations as shown in Figure 4.2. Up-to-date and trusted real-time information remotely available, is imperative to making actionable decisions that enable heterogeneous organisational units to adapt their behaviour to environmental changes. These organisational units interact with each other, and their interaction can result in some influence between them, requiring a comprehensive approach to their coordination and control. Such an approach is illustrated in the dynamic collaborative framework shown

Figure 4.3. This framework is generic to different domains, and depends on the sources of the domain knowledge as plug-ins, depending on the domain knowledge sources and the tasks under consideration. It is based on defining a strategy for the entities deployment and configuration, and a control policy effectively and efficiently supported by hybrid intelligent decision support systems providing a logical support process for agent group composition and negotiation, assessment of strategic architecture configuration factors, and performance measurement.

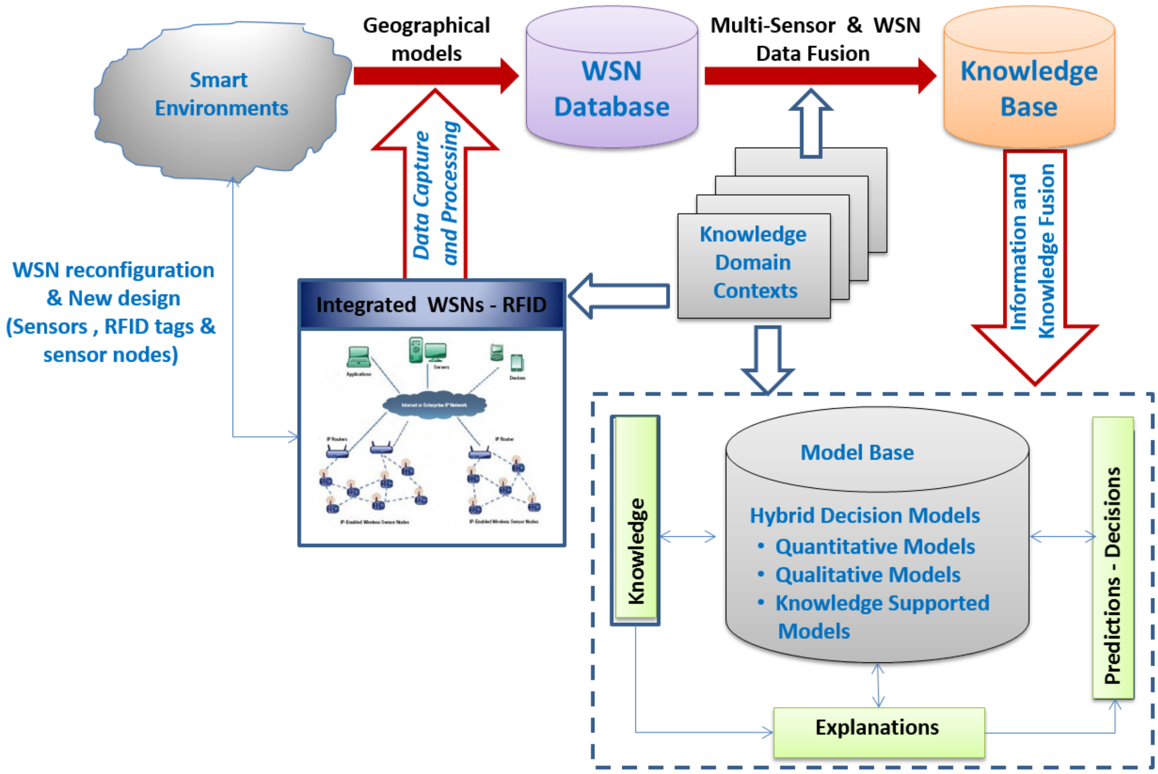

Figure 4.2: Conceptual solution 1

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The generic design advocated in this research to support the development of support systems, which is based on the use of a generic data support illustrated in Figure 3.4, and represented by the WSN database in Figure 4.2, increases the reusability of software agents implemented to meet the requirements and fit within that the physical system design by creating a wide range of agent behaviour patterns and identifying those required for the control system aimed at enhancing both strategic and operational real-time decision-making effectiveness and efficiency. Their generic terms, which are used to represent the diagnostic knowledge in a domain, are smart devices and agents composing hierarchies, goals, rules of association, behaviours, generic process tasks and subtasks and performance.

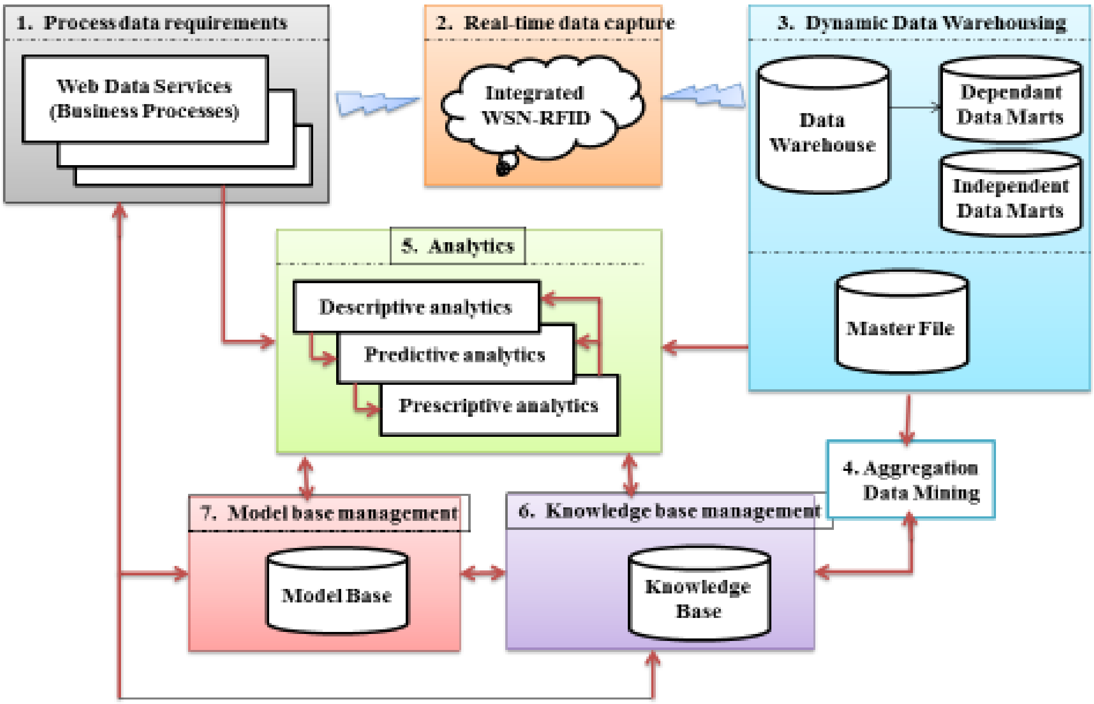


Figure 4.3: Hybrid intelligent web-based service decision support system architecture

The major challenge in the definition of requirements for this support of changes adaptation process is the integration in a hybrid decision making model, of the user context conditions, i-e regardless of what applications created and updated the data, what platform they're running on, or where they are accessible from, i-e stored in databases or locally stored in the network in smart devices or smart sensor devices, and in backend systems.

The above system architecture shown in Figure 4.3, integrates the following functional components:

1. Web data services defined as business processes describing the different context situations (processes and events) of the application domain, result in support data requiring the specification of the data sources identified and wirelessly connected to

an ad hoc network that integrates both RFID and WSN, and homogeneous and heterogeneous devices.

2. Real-time data capture occurs following the configuration and deployment of the ad hoc network, and results in networking processed data and/or real time data stored in the server, outside the network.

3. Dynamic data warehousing integrates data warehouses and on-line analytical processing tools which are essential elements of decision support systems aimed at processing big data captured from heterogeneous sources. This processing includes checking, validating extracting, transforming, cleaning and consolidating data.

4. Aggregation data mining provides the required support for data fusion which consists of discovering patterns in large data sets and extracting information presented in a readable or understandable structure that enables its association to other information.

5. Analytics are necessary support systems elements dealing with data analysis using concurrently descriptive, predictive and prescriptive modes to provide a holistic view of the context situation, anticipating on what has happened, what could have happened and what needs to be done. This is supported by exiting models and knowledge rules, and can result in the elaboration of new models and knowledge rules.

6. Model base management consists of model validation supporting reasoning to combine the model knowledge and available data to elaborate predictions.

7. Knowledge base management consists of knowledge rules validation supporting the storage of complex structured and unstructured information to support automated inference.

The last three components support information and knowledge fusion functions.

4.3.2.1 Hybrid Intelligent Decision Support Systems

Hybrid intelligent decision support systems form the group systems that are the result of integrating the different types of DSS with other tools and technologies for decision support, maximizing the efficiency and efficacy of an organisational and group decision-making process [194]. These DSS embodying panoply of decision model structures illustrated in Figure 4.4, are of the third system generation characterised by process intelligence.

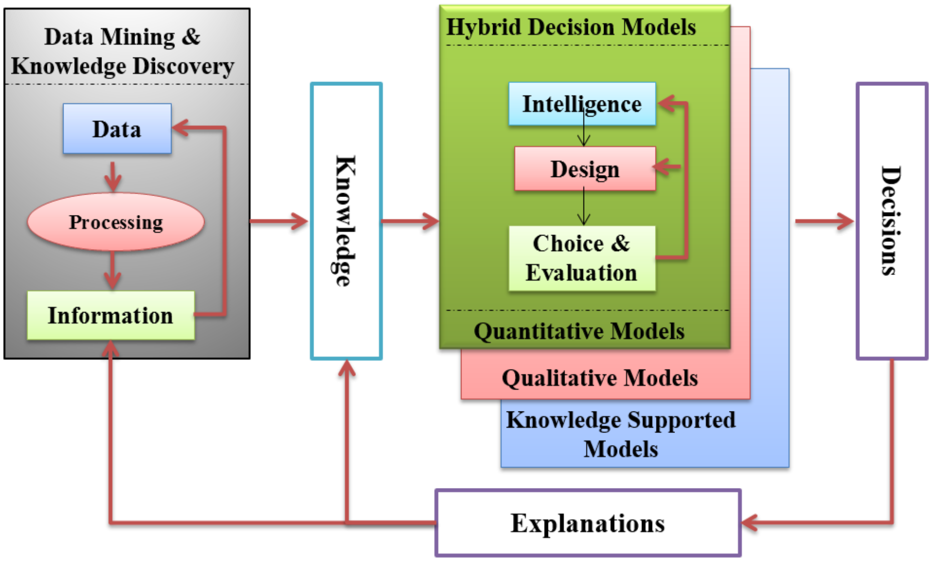


Figure 4.4: Hybrid intelligent decision support systems architecture

Of great significance in the design of hybrid intelligent agent-based systems for specific domains in heterogeneous environments, is the data lifetime that poses the need for its storage and accessibility requiring intelligent mechanisms that lower CPU and storage capabilities, for both mainframe and distributed environments, to ensure the data replication and availability supporting processing continuity in the case of partial or total network failures. The real-time replication of data and its changes poses the problem of robust and scalable performance with acceptable transactional integrity and consistency, and full recoverability. This problem is even more challenging when replicating large data volumes requiring comprehensive monitoring and diagnostic capabilities to effectively support the data acquisition, aggregation, consolidation and migration, and ensure its full visibility [195].

Existing decision support systems are lacking capabilities in several areas such as:

- The incapability of supporting various individual and group different roles during the decision making interaction,
- The difficulty of collecting in real time the required big data from heterogeneous sources,

- The processing model limitations and assumptions imposed by context aware uncontrolled factors and environments,
- The difficulty of defining and quantifying decision variables, and discovering and extracting knowledge, and
- The handling of technological knowledge resulting from the use of existing and new technologies involved in their design.

The novelty in this research is the generic recursive design framework and the hybrid system architecture built around:

- The use of hybrid integrated elements in the same recursive design framework for the development of a large enterprise-scale data warehouse with various distributed intelligence applications that covers the different domain contexts of a knowledge domain,
- The real time processing of most of the big data at the source using in-networking as part of the data fusion, and the communication of other and aggregated data outside the network to support information and knowledge fusion that focuses on knowledge discovery and extraction, and
- The decoupling of data fusion from information and knowledge fusion functions.

The essential aspect in this novelty is the focus on real time processing of big real time data from remote heterogeneous sources for real time predictions and instantaneous decision making. This has requested from the system architecture to incorporate hybrid elements, and the contribution of this research lies in the extension of the hybridity concept which is threefold: conceptual, hardware and software integration.

a) The conceptual integration deals with the creation of recursive generic design frameworks based on the concept of distributed multi-agent systems and hybrid self-tuned intelligent decision systems to support:

- Agent interaction and integration in web-based services,
- Fusion functions, and
- Pro-active decision making.

b) The hardware dimension is related to the possibility of using:

- A variety of homogeneous and heterogeneous devices, wirelessly connected via different configurations of network architecture, and integrating different types of technologies which include WSN, RFID, communication and computing,
- Smart devices containing different types of hard programmed controls, and
- In-networking along data processing outside the network.

c) The software dimension deals with the following:

- Use of human and software agents in the same cooperative decision making process,
- Integration of different types of decision support systems, as listed in Section 2.8, and
- Integration of different middle layer software required by the technologies integration above mentioned.

Although domain experts is required at the launch of the hybrid intelligent decision support system, they will be replaced by intelligent software agents for real time knowledge discovery and extraction.

4.3.2.2 System architecture components

The system architecture components are:

- Data mining and knowledge discovery support big data processing and management, and the provision of a link between transactional and analytical data by identifying and analysing patterns that enable information to be structured as the basis for knowledge discovery.
- Hybrid decision models which include qualitative, quantitative and knowledge supported models, support decision making under uncertainty characterised by several contributing factors and plausible occurring events, and individual and group agent(s) with different dynamic roles and goals interacting (co-operating and collaborating) in a multi-agent decision process.

- Knowledge which include all what agents perceive, discover and learn, provide the knowledge domain contexts understanding and support the elaboration of hybrid decision models that provide the decisions.

- Decisions which are influenced by the knowledge discovery and extraction process that provide the decisions explanations, support the meeting of agents goals and confer the agents existence, roles and goals to support the dynamic changes occurring within the multi-agent system. Decisions outcomes which result from the decision making, contribute to the provision of the decision understanding and plausible explanations, taking into account the impact of latency and/or absence of causality.

- Explanations are based on the decision outcomes which take into account the decision context and conditions.

The decision making process is based on three iterative stages: intelligence aimed at understanding the problem, design concerned with elaborating the different decision alternatives and their plausible outcomes, and choice concerned with ranking the decision alternatives based on elicited preferences.

4.3.2.3 Intelligent agents and Multi-agent system

Agents are concerned in this research with reasoning about actions to be taken in reaction to surveillance and mitigation events, and also with changes to implement in the context of the control system.

Agents can be smart and intelligent devices, and software components aimed at performing individually or in a group, one or several reasoning tasks which differ in their nature. Smart and intelligent devices reside in the sensor nodes which are wirelessly connected to the sensor nodes of the ad hoc network, whereas software agents are generated and implemented in the hybrid intelligent decision support system to compose web-based services that support the knowledge domain processes.

In the context of multi-agent systems, these tasks include goal reasoning, plan coordination, failure recovery, goal-plan conflict and resolution, and other specific tasks like computational logic and linguistics, agent collaboration, cooperation and arbitration, simulation, agent dialogue and communication, agent replication or destruction, automatic code generation, agent learning, etc...They are performed under the control of agents structured in a hierarchy that confers the different roles for filtering information, identifying individual or group tasks with similar interests, and automating repetitive tasks.

Intelligent agents work continuously and independently in a specific environment interacting with other agents (collaboration or cooperation) to support in real time the knowledge domain of context events and processes. Conflicts between agents in multi agent systems, can be single or multiple, result from coordinating activities and are supported by conflict resolution in the agent control component of the hybrid intelligent decision support system. This component aims at supporting a generic conflict resolution process which includes conflict detection, search for solutions, and communication among agents.

Conflict resolution is based on using three different strategies: negotiation, arbitration and mediation, which are supported by a diversity of intelligent techniques for resolving conflicts of knowledge. Among the main techniques, Bayesian Network, Case Based Reasoning, Expert Systems, Fuzzy Systems, Genetic Algorithms, Ontological, and Searching based techniques, can be used in combination to reduce knowledge conflicts between intelligent agents.

4.3.2.4 Web-Enabled Decision Support Systems

The web-enabled approach advocated for use in this work, is based upon client–server architecture that enables the sharing and delivery of computerised models for agent interaction and negotiation, service composition, and knowledge via the internet, intranets or extranets, which allows instantaneous widespread access to authorised users throughout the system environment. This approach structures the system support by function, separating the data support from the knowledge and decision making support, and substituting the human judgement to agent model-based coupling analysis to know and explain agent behaviour patterns in an increasingly efficient way, increase levels of knowledge, increase the number of observed variables, improve decision variables visibility, save time and improve decision-making quality, and elucidate the knowledge base using real-time prediction tools [196] and decision trees [197].

Of great importance in the web-based data support aimed at knowledge discovery, is the availability and accessibility of log-based up-to-date critical information through a multi-media comprehensive support set to efficiently and effectively perform remote monitoring using services web-enabled platforms. Web-enabled intelligent data support services aim at achieving near-zero downtime performance and can effectively minimize the massive information bottleneck that exists between sensor nodes and backend network support systems.

The demand to connect with backend decision systems supporting distributed ad hoc network configurations is increasing. This connection aims at synchronizing remote monitoring systems and distributed applications services, and supporting horizontal integration to provide information integration between a lower network level and an upper decision making level.

The trend of the future e-network for the management of data support is to bridge the gap between front-end and backend data support processes. There are various issues related to design and deployment of a web-enabled distributed control application platform for automated activity surveillance where the built-in web composite services enable the execution of distributed multi-agent control applications through a web browser [198].

4.3.3 The System Generic Design Architecture

The system generic design architecture supported by the generic design framework which aims at providing the support for the ad hoc integrated WSN-RFID design, configuration and deployment capabilities, is based on the integration of existing and new web services, and a rule-based framework with procedural attachments for domain analysis, to support the hybrid intelligent web-based service decision support system architecture shown in Figure 4.3, and the service management involving connections with the system control issues and requiring a panoply of support capabilities categorized and illustrated in Figure 4.5.

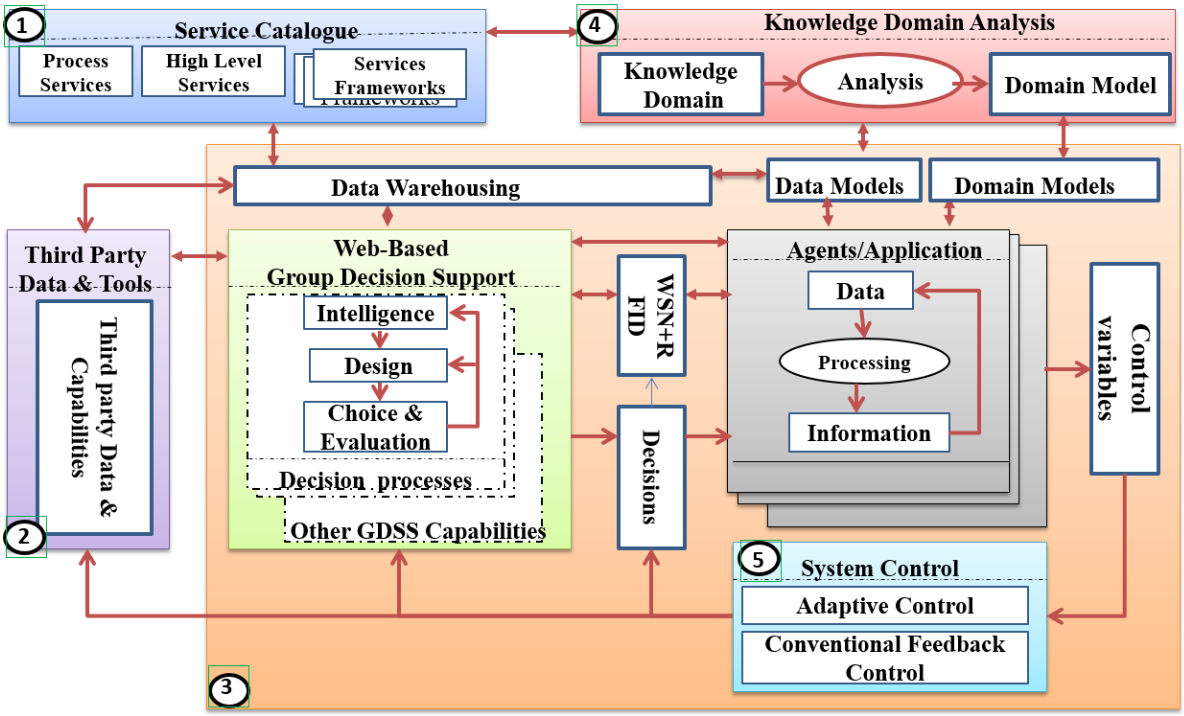


Figure 4.5: System generic design framework

4.3.3.1. The Service Catalogue

The service catalogue is an open centralised support containing all the core services elaborated by the service process which is a key step in the system generic design, and identifies internal processes necessary to provide and support the core services. This process integrates new services to existing ones, and is made up of the following four steps:

- Service description,
- Service help,
- Service support and
- Service delivery.

Service cost and pricing is an additional step that is carried out to show how the service can be supported and delivered.

4.3.3.2. The Third Party Capabilities

Third party tools include:

- Additional attachment procedures about the knowledge domain,
- Mathematical models and tools for interactive multi-attribute decision making with incompletely identified information, where the incomplete information becomes the set of

constraints in the models, and examining the dominance structure of all alternatives to apply the weak dominance technique for alternative selection at the choice step of the decision making process.

- Core services layer, containing high level features and generic core services frameworks which are necessary to enhance the service framework effectiveness and efficiency. High level features include:
  - Peer-to-Peer Services to support multi-peer connectivity to initiate communications sessions with nearby devices.
  - Block Objects Services to incorporate additional functions to be executed with associated data for facilitating performing knowledge tasks.
  - Core Data services aimed at supporting the management of the data model, using a data model view controller service application. This role of control is essential for the support of the data warehousing in terms of:
    - validation of data values,
    - propagating the data changes and ensuring the data integrity and the consistency of the relationships between objects, and
    - aggregating by grouping, filtering, and organizing data in multi-distributed configurations.

4.3.3.3. The Web-Based Group Decision Support System Capabilities

A web-based group decision support system is the heart of this conceptual framework, providing data marts illustrated in Figure 3.4, needed by mechanisms aimed at supporting knowledge processes, reducing disagreement and facilitating consensus on interpretations by decision-making groups of agents including people, smart devices and software agents [199]. Many of them are embodied in the generic information and communication technology core services listed in the section below, involving fast and flexible access to knowledge, model and databases.

4.3.3.4. The knowledge Domain Analysis

In knowledge engineering, domain analysis consists of analysing related knowledge processes in a domain to find their common and variable parts, defining the different domain models and establishing the different knowledge contexts, situations and events for process re-use. This analysis principle is advocated for use in the proposed system generic design framework to identify and model the knowledge functions in software agents, eliciting the support system requirements and system architecture. The proposed research framework aims at supporting a wide range of goals, domains, and involved processes in information scanning and emerging issue tracking and monitoring. A combination of domain analysis techniques are proposed for use, depending on the different particularity and characteristics of the knowledge domains of interest. The representation of the knowledge domain models is based on the use of object-oriented models or data models, depending on the analysis approach considered (model or data driven).

A domain model is a goal oriented functional representation of the knowledge and activities related to a particular domain application. It aims at simplifying the design process by identifying recurring behavioural patterns in the application domain, and promoting positive interaction between the system agents. It enables the development and standardisation of software agents.

The development of services composed of software agents is fully based on understanding the interaction between the domain model entities of the core services supporting the application domain. The domain model requires an extensive compatibility between the logical models representing the different views of core service managers, service designers and developers, and users of the application domain. These models reflect the representation differences between the three service architectural levels: external, conceptual, and internal.

4.3.3.5. The System Control

The system control aims at reducing the disturbances within the monitoring alert process. It requires a continuous assessment of the system, prior to deciding which type of control is more appropriate to apply to eliminate disturbances. There are two types of control:

- Conventional feedback control, based on acting by measuring controlled variables to eliminate the effect of disturbances, and
- Adaptive control consisting of acting upon the data context aware environment model parameters, using an index of performance to eliminate the effect of parameter disturbances called variations.

The system assessment focuses on identifying different types of agent's behaviour changes that help determine key parameters or influencing factors affecting their individual behaviour and the global result of their interaction.

4.4. The knowledge Domain Analysis Method

The knowledge domain analysis method suggests the use and re-use of the knowledge domain design for the support of different knowledge domains contexts. It is based on successive decomposition of the domain into elementary knowledge tasks associated to knowledge objects or entities represented in a domain model. This method allows the grouping of knowledge tasks into knowledge functions requiring the mapping of capabilities to software agents composed into services, using a rule based approach. These services are logically defined as subsystems, which are:

– Independent of implementation options to enable the support of the service distribution model including centralized versus distributed processing, individual versus grouped uses of services across networks, and

– Usable for all domain applications.

4.4.1. Knowledge Requirements Elicitation

In the knowledge domain analysis method, the focus is on understanding and describing the environment where the knowledge functions or modules are to be implemented and performed to meet the knowledge requirements. This description will result in separating the system requirements into two classes: functional and non-functional requirements.

Functional requirements are the description formalisation of the activities performed by the system when fully implemented and operated. These activities contain both:

- Specific business tasks dealing with the context applications and putting the emphasize on all that might change within the system environment anticipating the modelling and the integration of these changes without affecting the system integrity , and
- Technical tasks needed to support the technical requirements of the system, covering from the deployment of the network to the control of the network activity.

Non-functional requirements are of important consideration in the system life time, as they concern the key success factors related to the system security, efficiency, effectiveness, operability, reliability and performance.

4.4.2. Syntactic Conflict Resolution

The rule-based approach if-then is selected to support system generic design for generating syntactic conflict resolution strategies when eliciting knowledge requirements using software agents, mainly when knowledge is viewed at the appropriate level of service composition. The consistently use of meta-rules enables the production of a highly relevant body of knowledge without any need for conflict resolution. These meta-rules are basic agent decision rules for making service composition rules, supporting more a pro-active adaptation of rules to a changing data context aware environment than a re-active adaption through approximate adaptation through evolution, incorporating consideration of how to adapt the service composition policy through time. This process is supported by a continuous analysis of cumulative changes in agent's interaction and behaviour for an adaptive control, using a set of techniques for automatic adjustment of the controllers in real time.

The adaptive control aims at achieving or maintaining a desired level of performance of the control system in terms of real-time alert monitoring, mainly when integrating the parameters of the dynamic model supporting unknown parameters, events, and/or device deployment and agent's behaviour change in time.

4.5. The Knowledge Domain Analysis

A knowledge domain is a large collection of unorganized associative patterns that require the use of a problem solver based on rule representations and forward-chaining (reasoning from facts to conclusions) or backward (reasoning from goals to facts) controls for establishing data-directed or goal-directed associations embodied in the different system agents structured in different domain models.

Conceptually, the problem domain is composed of declarative knowledge which provides the knowledge base, and the problem solving method constituting the inference engine. This is done by using the notion of reasoning by mental modelling based on internal individual and group models to make generalisations true. These models embody both spatial and temporal relations and causal structures linking the events and entities of the domain components. They are based on merging different internal models of the situations, events and processes representing the domain expertise.

Available expertise in the domain incorporates much better organized collections of knowledge, with agent control behaviour represented in the different forms of knowledge they contain. The resulting embodied structured knowledge is organised in building blocks to form the elementary generic knowledge tasks, observing a hierarchical classification and concluding matching hypothesis testing to establish context situations knowledge-directed information. This organisation is based on a top-down approach decomposing iteratively the domain into components associated to entities, still obtaining non-decomposable components.

4.5.1. Generic Knowledge Tasks

Each of the elementary generic knowledge tasks is characterised and described in terms of specifications of its knowledge structure containing:

- The generic types of input and output information,
- The various formats used to represent the basic pieces of domain knowledge needed for the task,
- Specific construct mechanisms and organizations of this knowledge particular to the task, and
- The set of homogeneous or heterogeneous control regimes appropriate for the task, .

The generic knowledge task specification provides a description of its direct and indirect contribution to the change of the object functionality, specifying its knowledge requirements and the knowledge process of the different functionality changes. Figure 4.6 illustrates the generic support knowledge tasks decomposition for operating a knowledge object such as a smart sensor node. Action and control tasks perform the interactive functionality change during the sensor node deployment and configuration. The individual control regimes explicitly indicate the real control structure of the knowledge object at the task level.

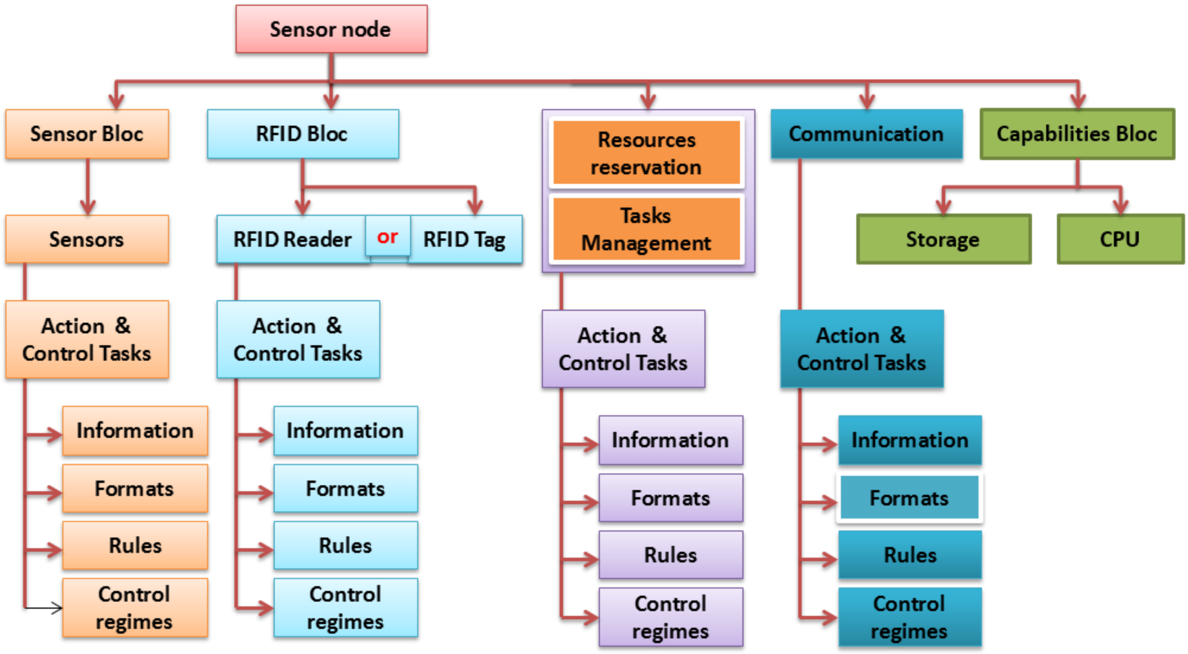


Figure 4.6: Generic knowledge task specification

The generic design of core processes describing the domain knowledge is a classificatory problem-solving process based on a matching process, aimed at structuring the nature and organization of knowledge and supporting the control processes required for hierarchical classification.

The classification hierarchy is based on searching and identifying knowledge concepts by using the question "how to" to enable the most plausible knowledge association on how well the concept matches the data. The same concept knowledge can be associated differently to the matching of different data, requiring a continuous knowledge association refinement to eliminate uncertainties and enhance appropriateness, using forward or backward chaining, and establishing association rules for knowledge elaboration. This matching process is independent from the design of the domain applications, in the sense that the execution of the tasks at the application level might not reflect its outcomes as described at the generic design level.

4.5.2. Complex Generic Knowledge Tasks

Complex generic knowledge tasks characterise complex knowledge domains with complex data and/or a large number of objects with high interaction level, covering different real world knowledge situations. They require further decomposition into components that are more elementary in terms of knowledge structure homogeneous and control regime for behaviour changes, effectively establishing paths and conditions for information exchange between agents associated with the generic tasks. These are described in action and control tasks as illustrated in Figure 4.7, showing the example of complex generic task knowledge aimed at interpreting a sensor data reading.

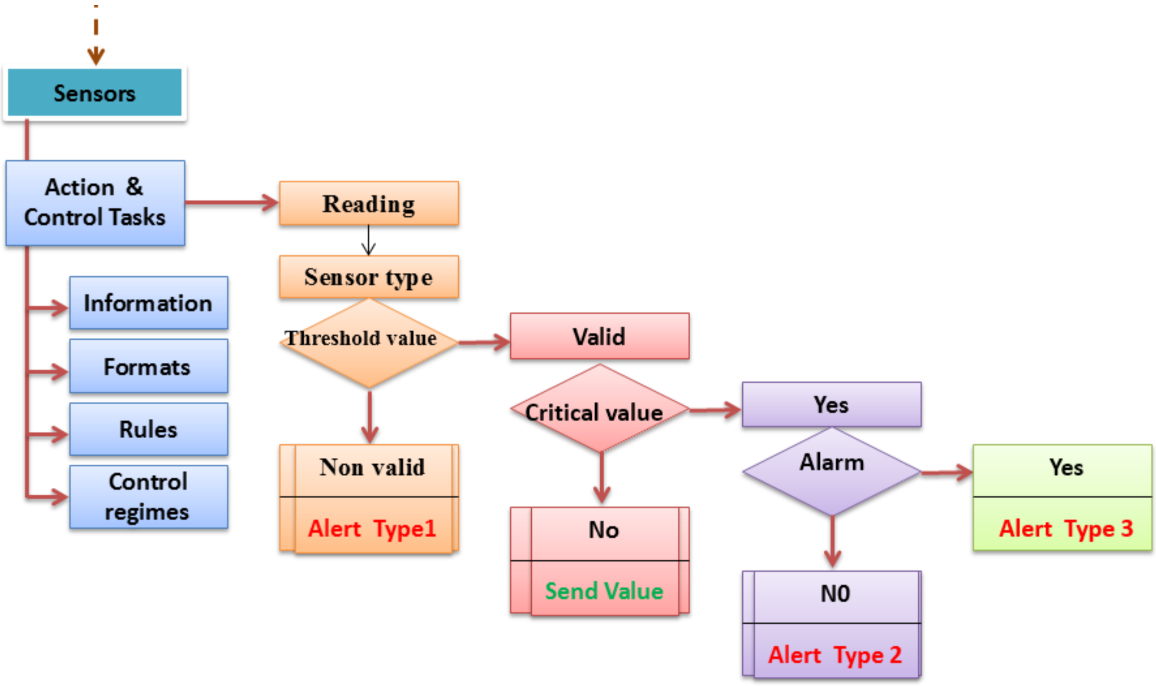


Figure 4.7: Sensor data reading

The generic knowledge tasks decomposition process is an iterative process which requires the use of different tools that include procedural reasoning, logical network-based inference mechanisms supported by description and predicate logic, and conflict resolution strategies. This decomposition process results in more elementary problem-solving tasks for greater clarity. These tasks generate a body of knowledge that is used to reason and draw conclusions, to determine the truth or falsity of rules.

The ability to decompose complex generic knowledge tasks is based on using an incremental flexible knowledge architecture of generic tasks containing a data abstraction aimed at fully supporting the functionality of the knowledge-directed data inference component explained in the following section.

4.5.3. Knowledge-Directed Information Passing

The principle of knowledge association is covered by combining hierarchical classification, hypothesis matching and knowledge directed information passing applying three states:

definite, very likely and definitely not. The definite state covers a task knowledge association based on knowledge-directed information passing, elaborating generic knowledge association rules and establishing default values for attributes that can be used to build up inferring strategies. This type of reasoning supports the various rules about how the datum might be obtained, including setting the instances default values. Knowledge-direct passing values is supported in its reasoning by a model that is used to executes the task by considering attributes of some knowledge entities initialised without detailed knowledge of the environment to determine the attributes of other data by inferring from available data.

4.5.4. Building Blocks

The knowledge generic tasks elaborated from the domain analysis and structured as building blocks are used for other types of problem solvers in the same or other knowledge domains, using the principle of routine design to build the object structure. The object knowledge is organized as a hierarchy of generic tasks, using the entity-component hierarchy of the object structure. Each task is associated to a form of knowledge, an organization, and a control regime which define the domain objects specifications.

The design of the object specifications is associated to the definition of functionality of its components and how they relate individually and globally to the functionality of the system in terms of how associated knowledge affect components functionality, establishing their state changes which illustrate the agents behavioural changes.

4.5.5. Knowledge Representation and Description Language

Building blocks are used to structure and represent the various knowledge-based systems involved in the generic design framework proposed in this research. The advocated hybrid intelligent decision support system required for the implementation of this framework, supports the language needed to represent domain knowledge, the knowledge generic tasks description, the knowledge object description and manipulation.

The knowledge generic description language includes:

- Capabilities for :
    - hierarchical decomposition and description of knowledge tasks and objects, and software agents,

    - manipulation of knowledge objects and software agents,
- Real time scheduling that includes:
    - Knowledge task and software management: sequencing and synchronization,
    - Resource reservation and management,
    - Inter-process communications,
    - Process synchronisation, and
- Execution monitoring and exception handling.

These different knowledge generic tasks elaborate the various knowledge procedures aimed at making inferences to produce solutions to problems. They are integrated using a knowledge task description language, enabling the communication between the different building blocks, and organising the system agents' interaction supporting the domain knowledge processes implemented as workflows composed of individual tasks and execution conditions.

The proposed hybrid intelligent decision support system is a distributed multi-agent system supporting different concurrent activities involving different classes of agents that must achieve high level goals while remaining reactive to contingencies and new opportunities. These activities concern principally the environment monitoring and the reaction to dynamic behavioural changes and exceptions.

The knowledge generic tasks description language, as any task language description used for robot control (TLD), provides syntactic support for task decomposition, synchronization, execution monitoring, and exception handling. This language supports the elaboration of design plans for the management of the domain knowledge resources. Their real-time control is supported by the system agent's interaction when scheduling and synchronising concurrent activities, recording their behavioural changes while controlling actuators and collecting sensor data, and reacting to exceptions.

4.5.6. Procedural Reasoning and Task Control Management

In complex knowledge domains, procedural reasoning (PR) can be used to facilitate the identification of tasks, their time and order to be allocated to agents for execution, resulting in structuring the agent task tree or the execution flowchart containing the synchronisation constructs. The agent task tree has leafs that are called the task execution commands executed by the task control management process.

Of great importance in systems supporting the task allocation to agents for execution, is the use of a task-role-based access control model enabling the control user's access in order that only authorized agents can access information objects [200]. The agent roles represent different specific task competencies. The authorisation process is based on grant permissions also called access authorisations depending on the agents status that confer them a new different role at each interaction level, and equally the importance of resources requiring access privileges. This process takes into account the necessary discretionary and mandatory task access control essential for the system security and the support of multiple applications and serving multiple users.

4.5.7. Mapping Process

The effective system support of knowledge domain analysis requires the full understanding of the mapping process for moving from domain models to generic designs of distributed hybrid multi-agents systems. The mapping process associates to the knowledge domain objects all related features that describe the software agents which model the objects behaviour during their interaction. Applicable information from the domain model structures and the knowledge object specifications are logically organised in the domain data model used to design the data forms required for the software agents invocation during the services composition.

The knowledge domain mapping process results in three models which are essential in implementing various applications in a domain. These models, which are derived from the Feature Oriented Domain Analysis (FODA) method [201] are:

- The information model analyses and structures of the domain knowledge, and elicits data requirements.
- The specification model details both the general and specific capabilities of applications in a domain presented in the form of web-based services.
- The functional model shows the functionality and behaviour of the agents invoked by different applications in a domain, explicating how to make use of the data entities.

The FODA method consists of an iterative process of the following steps:

- Select features from the domain model.
- Create object specifications, by:
  - identifying the domain objects, including their name and description, and
  - deriving objects operations, detailing input data and output information.
- Create agent specifications by identifying the domain objects invoked in the gent interaction, including and the required inputs and outputs from the Object Specification.
- Create device specifications by selecting the appropriate control characteristics including the software and hardware elements.

4.6. Distributed Detection Knowledge Domain

This knowledge domain supports the indoor detection design of smart, safe, sustainable and energy efficient buildings attended by the public, where the determination of physical location is a central problem in location-aware computing. This knowledge domain is analysed in the light of the advanced technological developments integrating WSN and RFID to provide elaborate smart detectors. This generic design framework proposed in this research is based on the use of sensor-purpose matching, requiring the invocation of existing sensors knowledge-base systems to import elements for sensing, localising and tracking assignments. This knowledge-based system is built upon a set of semantic sensor network ontology's [202] that can be extended by the incorporation of RFID tags and readers.

The case study developed to support the research study uses a symbolic location related to the virtual layout chosen to represent the indoor sensing premises. The symbolic location is based on absolute location systems which use a coordinating system for locating, meeting the precision and accuracy of localisation requirements.

4.6.1. Indoor Distributed Detection Using Knowledge Based Design and Ad hoc Integrated WSN-RFID

The indoor detection activities examined in this research is based on matching sensors using a knowledge-based system to identify the most appropriate sensors that enable meeting the different missions covering this domain. Existing sensor data elaborated using a Sensor Semantic Network Ontology is available in a database, and the selected sensors are integrated in a sensor node platform wirelessly connected to form a WSN supported by a server storing the WSN database. This integration is supported by an intelligent support system that determines the sensor platform specifications using the individual requirements of sensors to be grouped in a sensor node. This sensor platform is designed to be a homogeneous device representing, for example, a smart fire detector.

In this framework, the proposed ad hoc WSN also includes heterogeneous devices connected wirelessly. This heterogeneity results from the use in combination in the integrated WSN-RFID of a variety of devices and RFID tags that includes fire detectors, cameras, attendance and motion sensors or microphones, to enhance the role and use of homogeneous devices. This enhancement is supported by the integration of different device functions modelled in intelligent agents composing the different services. Due to the devices differences, their integration requires a high-level of data modularity and adaptability in the distributed multi-agent system architecture.

4.6.2. Matching Sensors Using a Knowledge-Based System

Data integration from multiple sources by the means of sensors requires integrating new data expressed in different forms into historical, temporal and spatial contexts. The technical design of sensors and sensor nodes, and the enhancement of their capabilities are of great interest in terms of specifications for their accuracy and the quality of their metrics.

4.6.2.1. Sensors

Sensors are defined as devices that measure physical (e.g. temperature, force,) or abstract quantities (e.g. the number of people in a room). They measure simple physics and the environment, and can be used for sensing and monitoring various activities, from simple phenomena to complex events and situations. They are integrated and/or connected with a multi-purpose device, depending of their use. When incorporated in smart homogeneous and heterogeneous devices connected to networks, the device is considered as a sensor node using a micro-controller that requires CPU, memory and power.

The modelling and publication of sensor data and their contexts of use consist of using a data representation which is based on the sensor data being annotated with semantic metadata, with the aim of increasing interoperability for sensors and sensing systems, and providing contextual information essential for situational knowledge [203]. This representation is supported by the sensor semantic network ontology (SSN), defining data encodings and web services to store and access sensor-related data [204].

4.6.2.2. Sensor Semantic Network Ontology

The SSN ontology is a solution elaborated to describe the WSN sensors, their data and their contexts of use. This description allows autonomous or semi-autonomous knowledge agents associated to the deployment of these sensors to assist in deploying, configuring, collecting, processing, reasoning about, and acting on sensors and their observations. It describes sensors in their main characteristics, which include their capabilities, measurement processes, observations and deployments. It provides sensors metadata vocabularies supporting the sensors semantics and the main WSN issues, including the sensor nodes interoperability, data communication policy in terms of sensor nodes parameterisation, use of sensors for their enhanced context adaptation, and data communication limitation for less power consumption [205].

The SSN ontology is of great importance given the wide variety of sensors and sensor nodes, and also the huge volume of sensor real time data requiring its full integration by associating to the data a description of its acquisition and communication policy. It is a support tool for the development of intelligent agents able to modify the sensor nodes' behaviour to enhance their configuration and optimize their performance in terms of lifetime.

4.6.2.3. The Sensor Mission Matching

The main knowledge domain feature considered in this research to demonstrate the conceptual framework feasibility is the sensor-task matching. This mission assignment consists of allocating a collection of sensors and sensor platforms (sensor node) to one or several monitoring missions with the aim of meeting the missions monitoring requirements.

The monitoring planning process aims at assigning monitoring missions that require sensor mission matching which deals with first identifying potential hazards that might occur in a defined space, and then examine available capabilities that will eliminate these hazards. This can be extended later to include their use for continuous sensing, event detection, pattern identification, location sensing, access control and local control of actuators.

The sensing mission matching is a sensor domain feature which consists of breaking a monitoring mission down into a collection of sensing and monitoring operations**,** each of which is broken down further into a collection of distinct elementary measurement, control and coordination tasks. Each task has specific capability requirements that enable the accurate measurement of the feature of interest associated to the task.

On the other hand, the sensor mission matching is a requirement engineering process that supports the measurement requirements and capabilities association, validating in a second step the selection of existing sensor nodes during the individual tasks composition, or suggesting the design of specific sensor nodes. This process is illustrated in Figure 4.8 shown below. The individual tasks composition results in the identification of a group of capabilities already present in existing sensor nodes, or these grouped capabilities are a candidate for the design of new sensor nodes.

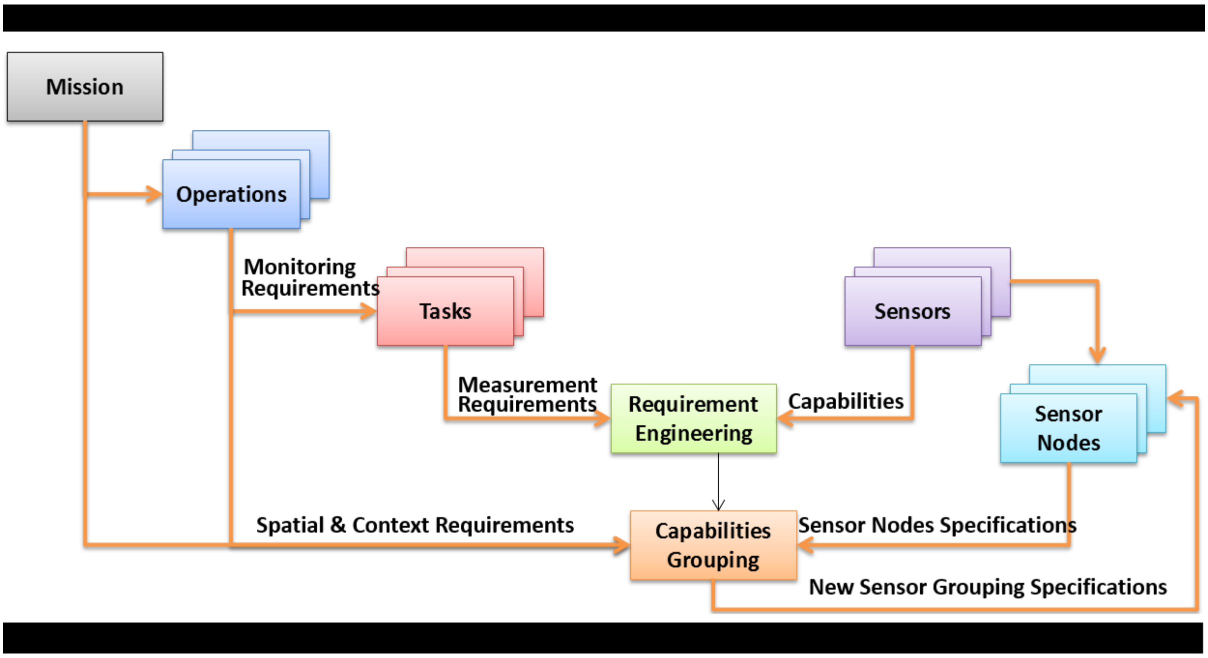


Figure 4.8: Sensor capability task matching

4.6.2.4. Sensors Capabilities Grouping

The proposed conceptual framework developed in this research, details the knowledge-based system supported by the sensor knowledge domain shown in Figure 4.9. It provides a structured way to analyse monitoring in terms of individual and group sensing tasks, and assess the effectiveness of various means required for accomplishing those tasks. This analysis is based on matching the knowledge domain requirements to the domain-providing capabilities of available sensors using a requirement engineering process associating capabilities to measurement requirements.

Available sensors data stored in the sensor database [205] can be used to make decisions about which sensors are more or less appropriate for a specific mission requiring the performance of intelligence, surveillance and reconnaissance tasks in a monitoring activity.

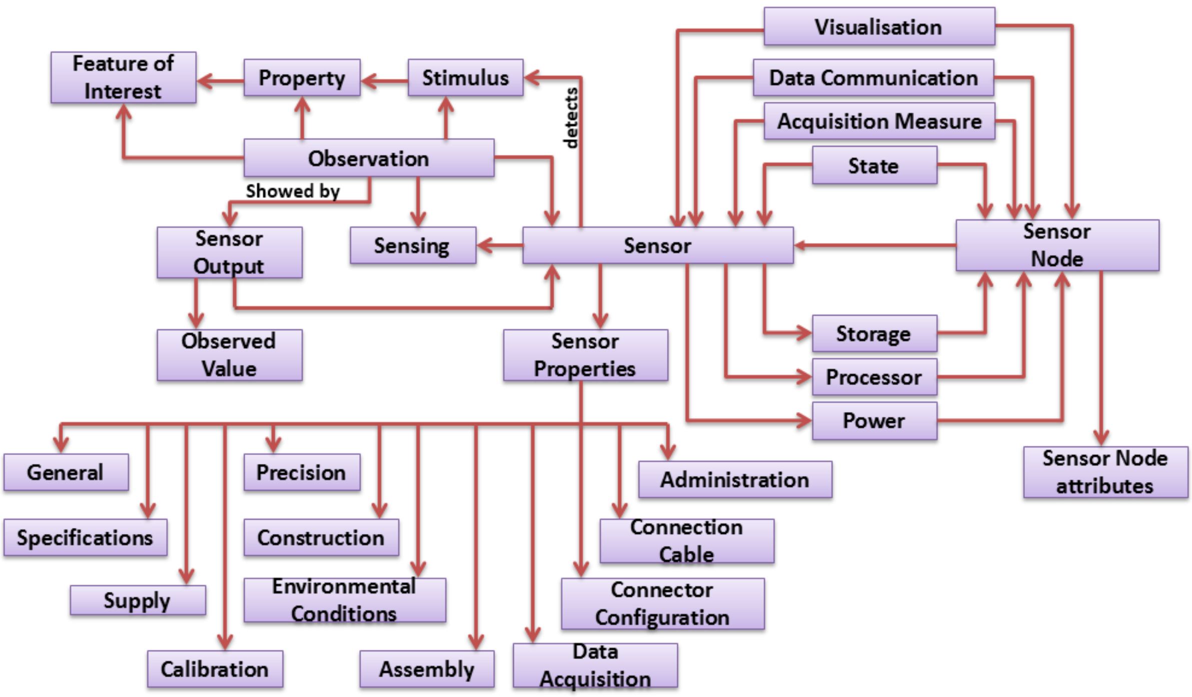


Figure 4.9: Sensor domain model

The selection of the support for the grouping of sensor capabilities depends on the mobility of the domain entities to be sensed and/or monitored. Fixed entities require the use of smart detectors and or monitors whereas the mobile entities can be connected to smart active tags attached to objects or people, using the RFID technology. These tags are sensing and radio-equipped devices and the generic sensor node resulting from the integration of RFID and WSN is a hybrid embedded system wirelessly connected to the WSN.

4.6.2.5. The Sensor nodes Heterogeneity

The sensor nodes heterogeneity is concerned by the presence of heterogeneous nodes that have enhanced capabilities in terms of energy capacity, storage, calculation and communication capability [206], which are both required in a sensor network to increase the network reliability and lifetime. Heterogeneous nodes when adequately defined in the ad hoc WSN can “triple the average delivery rate and provide a 5-fold increase in the lifetime (respectively) of a large battery-powered network of simple sensors” [207].

Heterogeneous nodes are considered in this work to be additional nodes to the existing nodes of the ad hoc WSN. They have homogeneous software architecture, and are different in the sense that they have a different software architecture based on the integration of high-speed microprocessors and high-bandwidth, and long-distance network transceivers. They enable the ad hoc WSN to acquire in-network functional and data capabilities, to process and store long term range data, and also exchange data with the main system.

4.6.3. Integrated WSN-RFID

Pervasive context-aware applications, which cover extensively the domain of environmental sensing, tracking and monitoring, are based on the joint utilisation of WSN and RFID technologies, taking advantage of the confluence of the use of a unique digital identifier associated with each physical item and the non-use of a battery in the sensor node device. These two technologies are also used substantively when required, depending on the sensing, monitoring and tracking domain requirements, mainly when involving mobile smart devices required in emergency response actions for mobile communication and/or GSM positioning or localisation used in indoor positioning systems based on real-time localisation.

4.6.3.1. WSN-RFID Integration

The resulting WSN-RFID integrated device is based on a hybrid architecture integrating the WSN good radio coverage but with a low positioning accuracy, with the RFID very precise localisation information with possible coverage discontinuity, ensuring increased positioning accuracy and extended coverage availability.

4.6.3.2. WSN-RFID Hybrid Architecture

The hybrid device is composed of two segments: the WSN sensor node as designed below, and the frequency RFID segments composed of the UHF-RFID and HF RFID components [208]. Data is collected by these two components which provide different detection ranges, using UHF RFID readers composed of UHF readers antenna fixed to the building ceiling, and a contactless UHF card/badge/tag reader fixed at different wall locations between configured spaces (rooms, zones, etc.).

4.6.3.3. The Hybrid Location Engine

The hybrid location engine is the intelligent system supporting the positioning and tracking of objects, and using a positioning algorithm to localise the network mobile sensor nodes by estimating their positions. This system’s capabilities are integrated in the HIDSS.

The collected data, as part of the measurement information, is composed of RSSI measurements provided by the WSN and a detection of UHF tag or HF badge procured by

RFID. This data is associated to the location of all mobile devices identified by attached tags. RSSI is the measurement of the power present in a received radio signal.

4.6.4. Sensor Node Design

The characteristics of the sensor node functional components depend on the specifications that meet the sensing-monitoring-tracking requirements in terms of power supply, and data communication, processing and storage, as expressed individually for each sensor and possibly their attached RFID tags. Sensor nodes are designed as smart devices procured at low cost and built with optimal capabilities for energy efficiency, wireless communication, programmability, expansibility, intelligence and size reduction.

There is a clear separation between programming applications aimed at modifying the device parameters (task deadline, period, and CPU and network bandwidth reservation) and the sensors application tasks representing the different sensing tasks and the sensor node configuration. Of great importance for the sensor node performance and life time, is the incorporation in the node deployment process of two essential tasks: the resources reservation (energy and memory) needed for the support of both programming and sensor tasks applications, and real time scheduling for the support of task management, inter process communication (data exchange between processes), and process synchronisation, as illustrated in Figure 4.10 which shows also a generic active sensor node architecture.

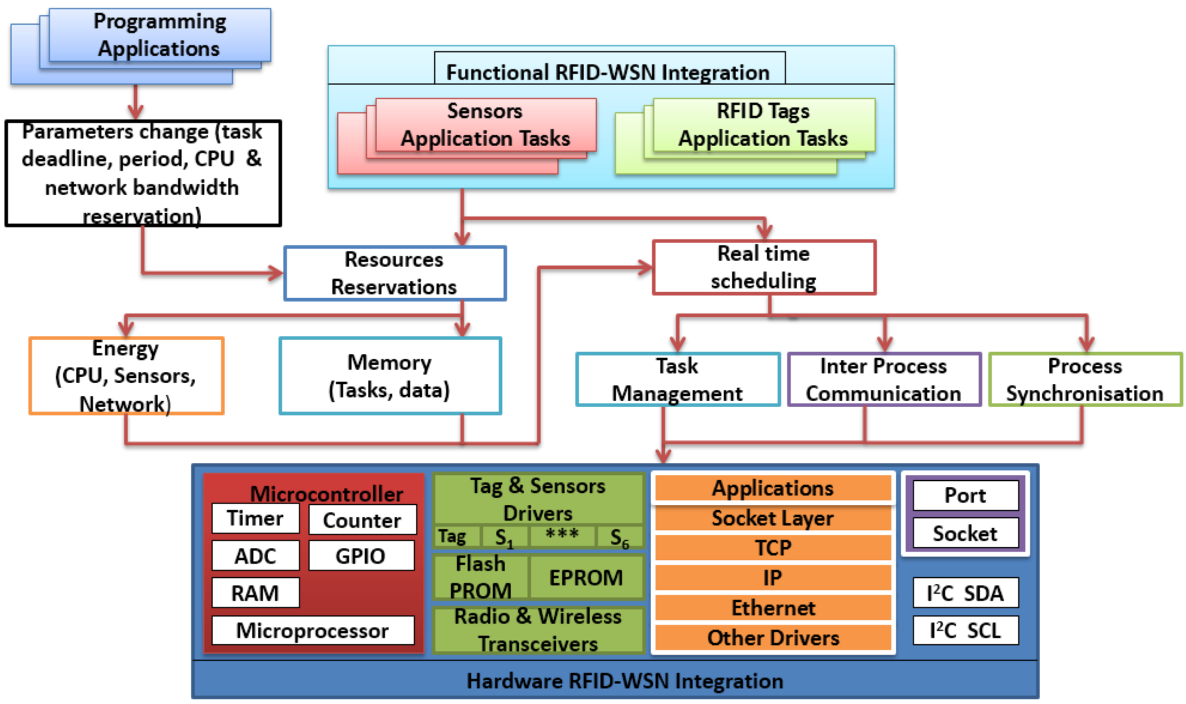


Figure 4.10: Generic active sensor node functional and system architecture

4.6.4.1. The Power Management

The power management consists of supplying the sensor node with a dual source composed of a DC-DC converter, a voltage regulator and a battery composed of a primary and secondary battery. The converter is used to boost the battery voltage, whereas the regulator is needed to maintain the output voltage at a fixed value.

Dynamic power management (DPM) is used at runtime as a major power saving technique based on the variations in workloads, shutting down the devices when not needed and getting them back when needed. This is based on using during the WSN configuration of three different device states: active, sleep and idle. More importantly, the energy consumption is monitored with a focus on selecting the processes to run depending on available power in the device.

The DPM technique requires the use of an appropriate embedded operating system to support the execution of internal commands implemented in the device and external users' commands. More importantly, the use of active sensor nodes to reduce the quantity of data transmitted across the network by organising the local processing and storage of data, reduces the energy consumption considerably.

A variety of decision making support tools can be used for calculating energy consumption in sensor nodes [209]. This evaluation is based on both the characteristics of the sensor nodes functional components, and on a number of user-defined initialization parameters used in organising the deployment and configuration of the device. The monitoring of the WSN power management is an essential component of the HIDSS supporting the proposed research conceptual framework.

The energy reservation in the sensor node concerns the CPU, the sensors and the network.

4.6.4.2. The Processing Unit

Of great importance in the sensor node design is the configuration of the processing unit needed to meet the storage and processing requirements when considering the use of the device in a wide variety of domain applications. These applications involve different needs for communicating, processing and gathering sensor data, requiring large computational capabilities and power supply.

Of great flexibility for processing devices implementations is the use of microcontrollers which are composed of microprocessors, non-volatile memory and interfaces such as UART, USB, SPI and I2C, and peripherals such as A/D Converters (ADCs), radio and wireless transceivers, counters and timers [210]. The Universal Asynchronous Receiver/Transmitter (UART) device performs serial-to-parallel conversions on data received from a peripheral device and parallel-to-serial conversion on data received from the CPU. The Serial Peripheral Interface (SPI) bus is a synchronous serial communication interface specification used for short distance communication in embedded systems. The Inter-Integrated Circuit (I2C) is used for attaching lower-speed peripherals to processors on computer motherboards and embedded systems.

The integration of surveillance functions in heterogeneous devices requires camera interface, and VGA display units which will be incorporated with the soft core unit using a multi-cycle architecture providing enhanced capabilities to perform a wide variety of operations, including basic image capturing and processing [211]. The device memory is twofold: user memory used for storing related applications and data, and program memory used for programming the deployment of the device and its self-organising.

4.6.4.3. The Sensing and/or Actuating Unit

In homogeneous sensor nodes, the sensing unit is composed of a collection of sensors which produce the electric signal by sensing physical environment. The signal is transformed by the Analog to Digital Converter (ADC) which is integrated in the microcontroller. In these devices, the incorporation of several sensors in the same sensor node poses the problem of their individual sensing limitations in terms of distance that restricts the device coverage to the minimal of the different sensing distances.

In heterogeneous sensor nodes, other heterogeneous monitoring devices such as IP cameras, people counter, and other intelligent instruments will be incorporated in the actuating unit and wirelessly connected to ad hoc WSN to cooperatively monitor physical or environmental conditions. These devices require an interface for plugging-in an actuator to perform mechanical actions on a domain application-specific basis.

4.6.4.4. The Sensor Node Design Knowledge Base

The proposed framework integrates a knowledge based system for the design of sensor nodes, eliciting the requirements of the sensing and/or monitoring unit and deriving the specifications of the device's functional components: processing unit, microcontroller and onboard memory, and power unit based on one or more batteries.

The sensor node design quality can be improved during the WSN deployment and configuration using a knowledge-based approach for enhancing the collaboration among sensors nodes within clusters to better share resources and reduce sensor nodes workloads, and support neighbourhood sensor nodes failures [212]. In this context, the configuration of sensor nodes may be influenced and modified by inferences and knowledge of neighbourhood sensor nodes in order to obtain a more accurate and reliable behaviour. The sensors nodes are supported by a ruled based system sharing between them variables, data and knowledge when collaborating in achieving a global objective by fusing local and remote information.

4.7. The WSN Design

The WSN design is a planning process based on identifying the domain contexts and situations for which appropriate sensor nodes are selected to form the ad hoc network. This process includes the WSN configuration and the data management as illustrated in Figure 4.6.

4.7.1. Domain Context and situations Analysis

The sensor nodes selection is based on the sensing and monitoring specifications of the domain contexts and situations which are derived from the different requirements linked to the location and use of sensors in the domain context.

The domain context considered as a case study in this work to support the conceptual framework implementation is sensing and monitoring in public attended places for detecting a list of events. These places have the buildings configuration, composed of rooms and halls, where people gather for different purposes.

4.7.1.1. Indoor Detection Monitoring Requirements

These requirements represent design goals on which to base future sensing subsystem designs of emergency systems in domestic applications. The requirements integration ensures the identification of conflict situations, and takes real-time action to solve them. They support the elaboration, iteration, and finalization of sensing system performance for the broad range of daily sensing and monitoring missions, taking into account the future developments affecting all the organisational entities. The main requirements are:

- Full sensing and/or monitoring of these places in terms of devices working or not, people and object locations, adequate signal coverage of sensed areas, and full time connectivity.
- Wall sensing obstruction.
- Integrated sensing and/or monitoring.
- Event alerting.
- Fault finding.
- Coordinated effort in emergency response.

4.7.1.2. Indoor Detection Monitoring Specifications

The solution developed in this research aims at monitoring the real time sensing data changes about the environment and the ad hoc WSN that controls it. These changes are related to indications of network configuration, and fire flames or temperatures rises interpreted by sensors wirelessly connected via nodes to the WSN gateway. The localisation of sensor nodes is a key criterion in the system setting, considering that full scale detection coverage is required to reduce the fire detection time. The concept of spacing model is used in this study to search the optimisation of the detection coverage using different methods of locating the fire detectors and also the required dispensers. The resulting specifications are:

- Integrated sensing and/or monitoring devices.
- WSN & RFID integrated for sensing the presence of people and objects places where hazards are identified to ensure safety at the same level as safety policies statement.
- Sensor nodes clustering.
- Sensor node cluster management.
- Cluster head sensor node.
- Device distribution models.
- WSN data management.

4.7.1.3. Sensors Functionalities

The main specifications are:

- Local and remote sensing with single and multiple alarms.
- Accuracy range from ±0.8% to ±2.0%.
- Operating temperature range.
- Multiplexed sensors on a single programmable pin.
- Sensor with integrated voltage reference and frequency output.
- Multifunction sensors.

An example of sensor specifications detailed for a multifunction sensor used in this work is:

- This multifunction sensor is a measurement device for control systems with LED indications. It is ideal for applications that require ventilation on demand for public attended places such as Schools, Libraries, Universities, Offices, Sport Halls, Theatre and Leisure centres.
- The sensor should be located:
  - Away from any windows, doors or any sources of direct air flow in the measured space.
  - Away from any heat sources.
  - Away from any areas with poor air circulation such as dead spots behind doors, for example.
- Sensor Outputs:
  - CO_2: 0-10 V for 0-2000 ppm

    - Temperature: 0-10 V for 0-50° C
    - Humidity: 0-10 V for 0-100%
    - Sensing range: 0-5 m
- Sensing range: 0-5 m
- Accuracy @ 25' C and 50% RH:
    - CO2 +/- 40 ppm +2% of reading
    - Temperature (voltage) +/- 0.5° C
    - Temperature (resistive) +/- 0.5° C
    - Humidity (option) +/- 3% RH
- Power Supply: 24 V AC/DC (+/- 15%)
- Power Consumption: 100 mA
- Operating Conditions: 0-50° C 10 to 80% RH non-condensing
- Warm up time: 2 Minutes (operational) 10 Minutes (peak accuracy)
- 3 x LED indication (optional)
    - Green – on below 1000 ppm
    - Yellow – on at 1000 to 1500 ppm
    - Red – on above 1500 ppm
- Terminals: Max cable size 1.0 mm
- Dimensions: 80 mm x 80 mm x 29 mm

4.7.2. Sensor Nodes Selection

Sensor nodes which are available on the market, in addition to the prototypes resulting from the sensing grouping process, are stored in a database. The sensor nodes database is an essential tool for selecting the appropriate sensor node meeting the declared specifications. This selection is based on a search iterative process based on the use of query procedures to match the search elements.

The selection process can be refined to review the domain contexts specifications when the search returns a NULL value. This process is supported by a decision making process involving different techniques needed to compare and rank plausible alternatives returned by the query.

4.7.3. The WSN Deployment

The WSN deployment consists of connecting and deploying the different sensor nodes identified the best to meet the sensing and monitoring mission requirements within the space configuration to be considered. This operation is preceded by the device planning which consists of finding the number of devices needed for the full coverage of the sensing and monitoring area. Location algorithms based on centrality, and rules of thumb are used to locate the different homogenous and heterogeneous devices.

4.7.3.1. Prior Devices Planning

In the study of the WSN requirements developed in this research, the node discovery location is very specific in the sense that the node field is well defined and corresponds to a building represented by its layout. It requires prior planning to ensure an optimal spatial observation and detection coverage.

In this prior planning, the node location is a unique point calculated with a localized algorithm based on the use of a specific knowledge procedure depending on the type of sensor node needed to perform the required task, such as, for example:

- Sensing for fire detection,
- Human presence and tracking,
- Recording a scene, and
- Sprinkling.

The exact node location, as accurately determined by the appropriate node localization algorithm detailed in the following sections, enables the improvement of the data fusion performance [213]. Data fusion plays a key role when designing an integrated solution based on the use of ad hoc WSN due to the data multi-sensor fusion integrating the collection of different types of data from different sources.

4.7.3.2. Homogeneous Devices Location

In the case study used in this research, the homogeneous devices are smart detectors grouping multi-function sensors aimed at sensing CO2, heat, smoke and humidity which are four essential elements used to detect the presence of smoke and fire. The exact node location for a fire detector device is determined by the spacing distance between two nodes distributed following a geometric pattern that satisfies the following two conditions:

- Optimal equal distance between all the detectors
- Optimal coverage of the environmental sensing area

This geometric distribution which is based on the use of the square or hexagonal pattern, associates real world point coordinates. These point coordinates are adjusted when the point falls outside the room walls and, therefore, relocated in the nearest horizontal and or vertical neighbourhood. Of major importance in using intelligent detectors is the increase of the speed detection, the identification of the fire location and also the maintenance cost to the detector. The grouping of a variety of sensors in one sensor node poses the problem of adequate sensing coverage when the sensing spacing distance differs from one sensor to another. The required flexibility in the selection of sensors and the constant effort for a cost effective solution imposes the need to define a sensor grouping policy that will enhance the devices configuration. This policy is a key knowledge component of the indoor sensing knowledge domain. The knowledge consistency with this domain requires the checking of the fire detection model against the local node model to reduce the number of false alarms, but also to enhance the fire prediction and increase the detection reliability.

4.7.3.3. Heterogeneous Devices

Heterogeneous devices are a variety of devices used to perform additional tasks, such as dispensing, recording, sensing attendance and tracking presence, opening and closing doors and windows. They include:

- RFID Tags Human attendance and tracking sensors,
- IP Cameras,
- Sprinkler sensors, and
- Door and window control sensors.

These devices are wirelessly connected to a node base station.

The generic nature of this conceptual framework would suggest unifying the concept of sensor node under the appellation of device sensor node that will regroup both homogeneous and heterogeneous devices.

4.7.4. Ad hoc WSN Configuration

The WSN configuration consists of supporting:

- The modular segmentation of the network by clearly:
  - separating the homogenous sensor nodes from the heterogeneous devices
  - defining viable clusters of nodes, and
  - allocating an active role to sensor nodes within a cluster of nodes to perform the nodes configuration, re-configuration and operational tasks.
- The automatic control of:
  - the network using the concept of intelligent agents based on the deployment of existing individual services to compose new services federating several agents to perform network control (configuration, re-configuration and activation) and data processing and communication tasks, and
  - the emergency response, integrating the different levels of decisions in elaborated single decisions designed to support the several events identified from the context applications and also to coordinate the emergency response actions.

4.8. Sensing and WSN Data Management

The deployment of ad hoc WSNs for sensing purposes generates a tremendous volume of heterogeneous data that can be stored in three different categories: sensor data, sensor node data and WSN data as illustrated in Figure 4.11.

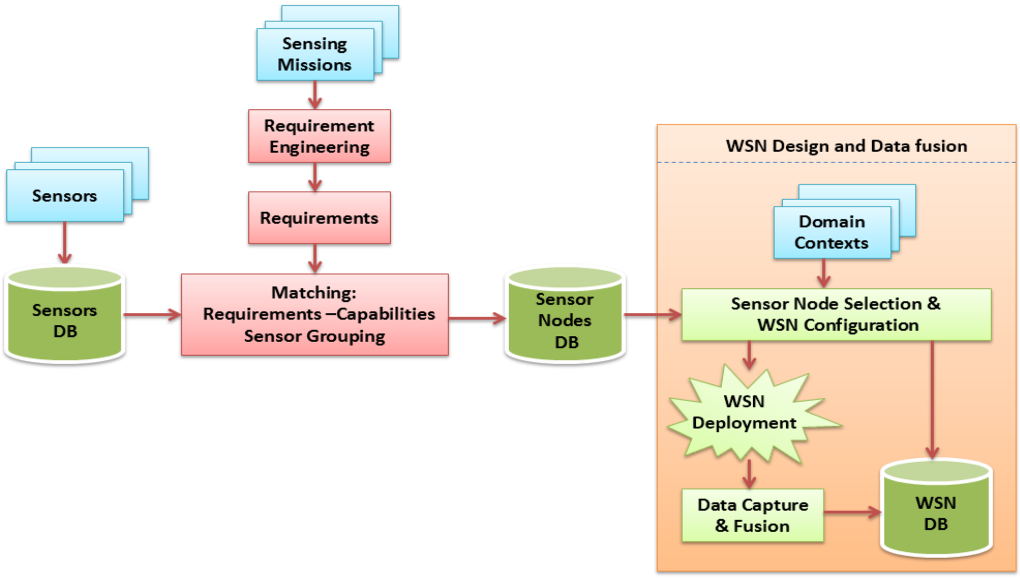


Figure 4.11: Integrated model for WSN design

The first two categories relate to descriptive data illustrating the sensor semantic network ontology's for sensors and sensor nodes, the third category is composed of the network configuration data and the sensing data. Each category of data is supported by a specific domain data model resulting from the sensing knowledge domain analysis.

4.9. Summary

The generic conceptual design framework is a methodological support that guides novice users to sensors and sensor nodes knowledge discovery by providing them with generic knowledge processes decomposed into elementary knowledge tasks. These tasks provide a flexible composition structure to build re-usable blocks, or agents software, using the task description and manipulation language of integrated knowledge domain of sensing and WSN-RFID domains. The case study used in this research and presented in the research evaluation, is an example of complex problem solving involving real time decisions based on real time heterogeneous data, with a high level of individual and group continuous interaction of every heterogeneous entity composing the organisation environment and collaborating to preserve the system control.

Chapter 5: System Developments

5.1. Introduction

The definition of system development as presented in this chapter does not refer to the tradition of six phases of system analysis and design process [199]. It corresponds only to its fourth step "Develop the System" that includes the three following stages: develop, test and evaluate the software. This step is preceded by the requirement analysis and the architecture design, and described in the previous chapter. The system is defined in this work as the system prototype.

Of great importance in the requirements analysis, is the customisation of the intelligent decision support system management functions to support a large number of distributed applications deployed via the web in the form of services based on distributed multi-agent systems.

Hybrid Intelligent Decision Support System (HIDSS) is the software proposed in this research to support sensing-monitoring knowledge domain analysis, sensor node design, integrated WSN-RFID configuration and deployment, and context aware real-time data capture and sensor and WSN data fusion.

An indoor sensing and monitoring case study has been proposed in this research to apply the generic system conceptual design framework presented in the previous chapter, to support information scanning and emerging issues for a wide range of applications including emergency planning for fire detection, control access and other related issues.

5.2. System Development

A prototype system has been developed in this research to demonstrate the practicality of the generic design conceptual framework, using a case study.

5.2.1. Development Methodology

The system development methodology used in this research is a combination of both an iterative design method and an incremental build model approach. This choice is based on the need to sustain the large development effort required because of the multiple design concepts integration, justifying the relationship between iterations and increments. This effort emphasizes the importance of what has been learned from integrating different design concepts, discovering new functional requirements and understanding the impact of non-functional requirements, and testing the different system functions segmented into partitions. This approach enables the modifications easier to make as the iterations progress, and the different modules are logically segmented.

The discovery of new functional requirements results from the sensor and WSN data fusion process which describes the different steps of integration of sensors and WSN data and knowledge from several sources.

These steps are:

– Data Input,
– Data processing,
– Data level fusion,
– Signal classification and
– State classification.

The sensor and WSN data fusion functional diagram is shown below in figure 5.1.

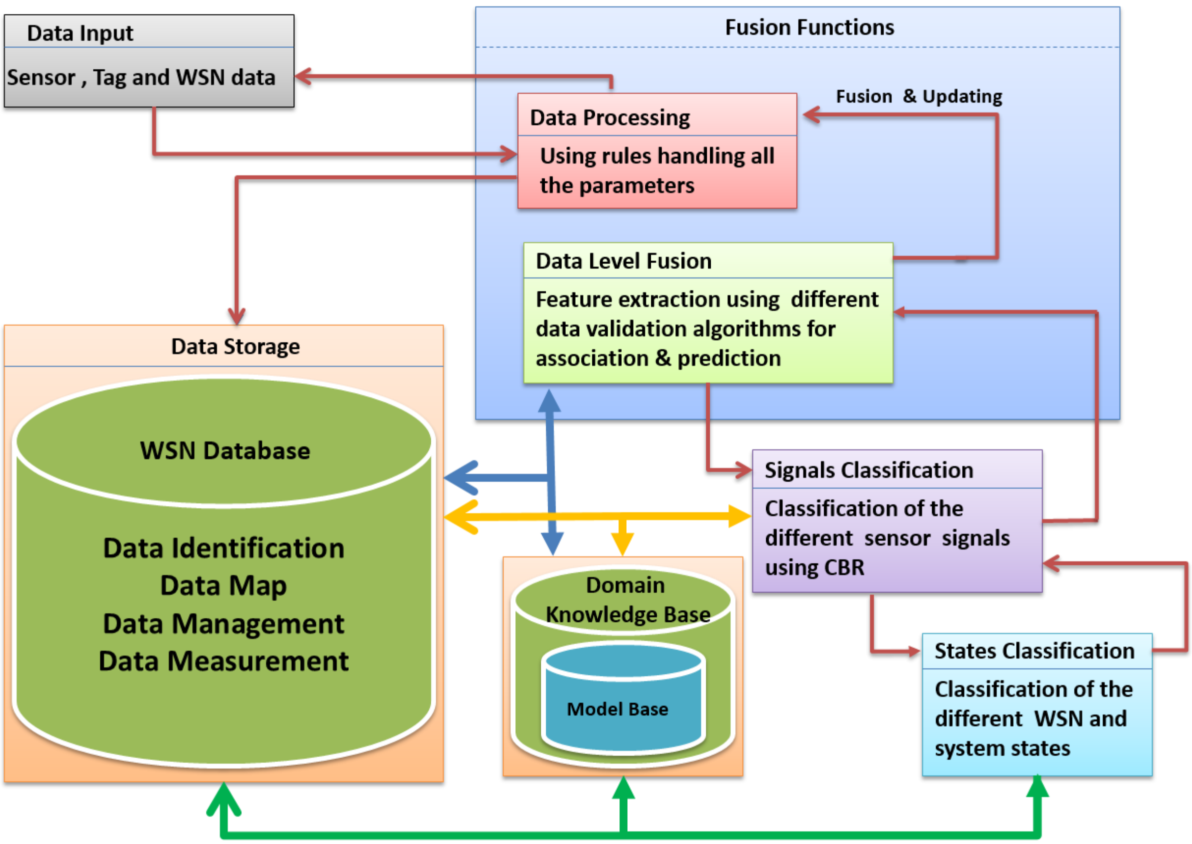


Figure 5.1: Sensor and data fusion integration process

This data fusion process which is illustrated in the data management architecture shown in Figure 3.4, is part of a context aware information fusion that includes support capabilities for on-line transactional and analytical processing, based on a panoply of theory, techniques and tools for exploiting the synergy in the information acquired from multiple sources and produce knowledge supported by fusion functions. The integrated WSN-RFID plays a preponderant role in enhancing sensing, monitoring and tracking, observing and analysing the environment to instantly identify situations that require taking immediate actions. This results in updating knowledge and models stored in databases, about previous behaviour, simulations predicting future behaviour.

5.2.2. Case Study

The case study presented in this work consists of the design of an integrated WSN-RFID based on the use of a virtual building layout to support:

- Emergency preparedness and fire simulation,
- Sensor data collection and communication of this data to a centralized data repository, and
- Building control access and evacuation simulation.

In this case study, we have considered a building made of three rooms attended by people, and containing some objects that can be used to support people-object proximity and collision detection while people will be evacuating the building. This support is based on the development of the software HIDSS which fully integrates the different steps of the decision making process when designing, configuring and deploying the integrated WSN-RFID. The following sensitive issues are considered:

- Organising the scheduling for
    - the in-networking,
    - the sleep sensor and
    - the passive sensor node,
- Data compression,
- Energy-efficient monitoring of sensor nodes extreme values
- Selective reporting and collision search,
- Performance analysis of devices and routers,
- Extreme value finding in a sensor node cluster,

- Eliminating or reducing a data bottleneck when sending and receiving in the network,
- Implementing an effective sensor node reconfiguration policy to reduce the limitation of communication bandwidth,
- Eliminating redundancy among data values from neighbouring sensors, and
- Reducing energy consumption by implementing in-networking and reducing the large amount of data communicated within the network.

5.2.3. Physical Entities

The data description of the physical entities is essential to the implementation of the different system functional units. This description is illustrated in the entity relation model shown in Figure 5.2, representing the different devices performing a wide range of sensing, monitoring, tracking and communication. These devices are:

- Sensors,
- RFID Tags,
- Homogeneous devices (Sensing, monitoring and tracking devices),
- Heterogeneous devices that enhance the deployment of the homogeneous devices, and
- Gateways and routers.

5.2.4. Devices Support

Of great importance in the support of the data and information fusion is the device assessment functionality supported by the data fusion model which includes several fusion levels, illustrating the sensor network signal processing tasks, and corresponding to the following functions:

- Signal or feature assessment involving data extraction, analysis and event detection,
- Entity assessment that includes the parametric and attributive states of devices during their configuration and deployment,
- Situation assessment regarding the nature of influence of between the different devices,
- Impact assessment concerning predicted impacts on other devices, and
- Performance assessment in terms of measures of effectiveness.

This device support, which is organised in a distributive architecture system, integrates data fusion and mining to produce optimal decision fusion by considering a set of finite of decision alternatives at each data fusion level. This process integrates low level decisions, and can be decomposed into two functional components:

- Real time detection of known or expected patterns as the heart of the information fusion process to filter known patterns, and
- Off-line discovery of new patterns supported by data analytics and aggregation as the data mining process.

5.2.5. WSN Database

The design of the WSN database which takes into account of the need of supporting online transactional and analytical processing illustrated in Figure 3.4, and data storage (data identification, mapping, management and measurement) shown in Figure 5.1, is based on the use of the sensor domain model shown in Figure 4.8, insisting on the importance of the selection of the support for the grouping of sensor capabilities which depends greatly on the mobility of the domain entities to be sensed and/or monitored and tracked. Fixed and mobile sensing, or detecting devices, and attached RFID tags to people, sensor nodes and objects are used in the design of the generic or universal sensor node supporting the integration of RFID and WSN as a hybrid embedded system wirelessly connected to the WSN.

5.2.6. Link between the HIDSS architecture and the case study

The framework proposed in this research illustrated in the HIDSS system architecture shown in Section 4.3.2.1, establishes the conceptual link between:

a) Data, Information and knowledge using the Data Mining, and the Knowledge Discovery and Extraction, and

b) Knowledge, decisions and Explanations using Hybrid Decision Models.

These two conceptual links are reflected in the case study proposed in this research, at the following functional levels:

- Sensors and sensing knowledge discovery (b),
- Creation of the building layout (a,b),
- Design and configuration of detection and tracking devices (b),
- Allocate detection devices for optimal sensing coverage (b),

- Allocate heterogeneous to enhance the detection devices functionality (a),
- Deployment and configuration of the integrated RFID-WSN (a,b),
- Adjustment of the sensing context and devices selection (b),
- WSN generation (a,b),
- Data capture and processing (a,b), and
- Event simulation (a,b).

5.3. The Functional Processes

Of great importance in the implementation of the tasks composing the sensor and WSN information fusion process, is the structuration of the functional units listed in Table 5.1, and

Step	Functional process (Component)
1	Sensing & Monitoring Knowledge acquisition resulting in elaborating Sensor, RFID tags and Heterogeneous devices databases. Data communication Knowledge acquisition resulting in elaborating Gateway and Router database
2	Elaborate sensor nodes design and Update the sensor nodes and heterogeneous databases
3	Elaborate the virtual building layout using 8-Directional encoding model
4	Homogeneous and heterogeneous devices allocation using geometric model & rules of thumb
5	Adjust the sensing context and devices selection
6	Devices configuration
*	Energy plan elaboration (Not implemented)
7	Devices clustering
8	Clusters aggregation
9	WSN generation

Table 5.1: Implemented functional units.

describing the data interaction between the different entities shown in Figure 5.2. This task includes the preparation of the data support needed for the real time data input for the sensor and WSN data fusion, as the first phase of the sensor and WSN information fusion process; the second phase being the information discovery supported by analytics of data mining.

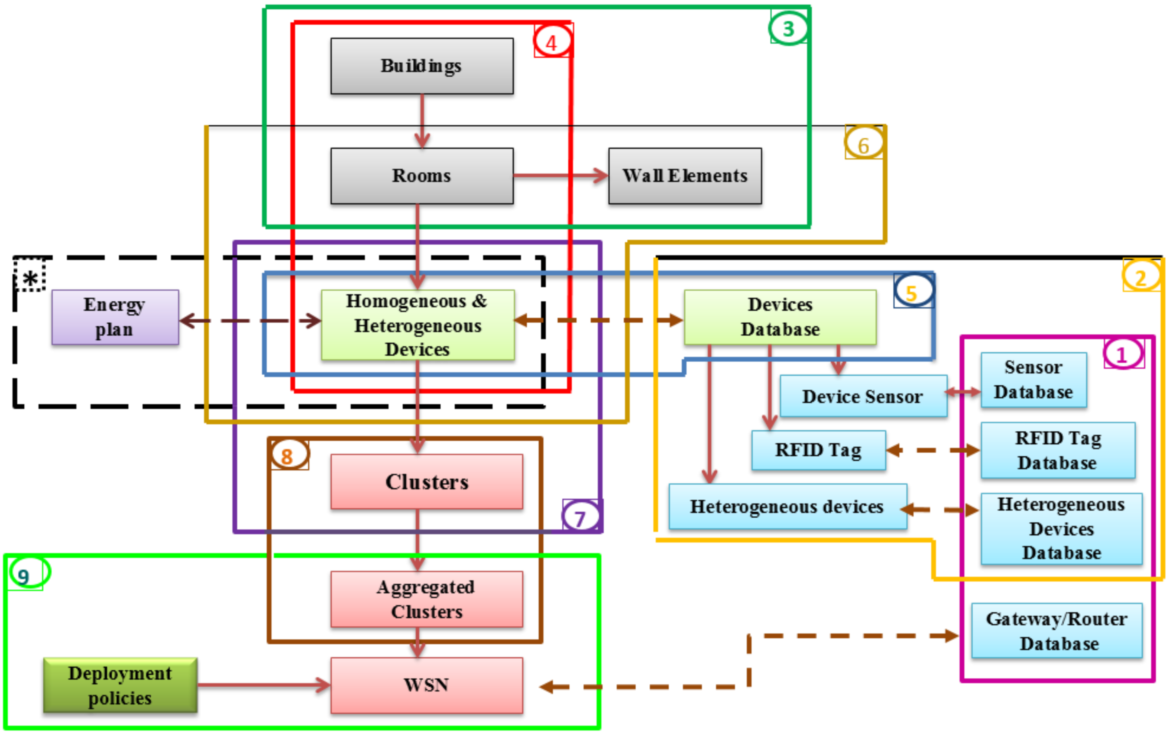


Figure 5.2: Functional processes based on the entity model

The structuration of the functional units is based on the analysis of data and knowledge structures, and agents that will be used to organise the next steps of the sensor and WSN data fusion process, especially when supporting sensor network signal processing tasks as a part of the devices support.

The implementation of the functional units listed above, is preceded by the design of the WSN and its deployment using the functional data model showing the different data entities. This model is essential to support the sensor and WSN data input, a necessary step performed prior to the data fusion process.

(*) This module corresponding to the WSN energy plan management is a planning process aimed at maximizing WSNs lifetime, and ensuring its continuous working has not been implemented.

5.3.1. The Sensor, RFID tag, Heterogeneous Devices and Gateway-Router Databases

The sensors and RFID tags databases provide the general characteristics description and functional specifications of every sensor or RFID tag which might be inserted/incorporated in device sensor nodes. These form the homogeneous devices of the ad hoc WSN.

Heterogeneous devices are described by a data collection of a list of devices used to enhance the deployment and actions of homogeneous devices, and the sensing, monitoring and tracking inside and outside a building. These devices include:

- People counters,
- IP cameras,
- Sign displayers,
- Window and door opening-closing control systems,
- RFID readers, sprinklers and
- Warning signs.

The gateway-router database provides the general characteristics and functional specifications of both gateways and routers used to wirelessly connect homogeneous and heterogeneous devices to WSNs. This database may include a table of the available routes and their conditions, updated from the network latest state information available. This information, used along with distance, signal strength and prevailing traffic, is essential to determine the fastest route for data communication.

The support databases are centralized and located on a unique front-end server. They are updated when incorporating new technical information resulting from their development improvement or performance assessment or new elaborated devices. A database update component is provided in the developed system to support these operations, enabling the basic manipulations of a database management system. The database data models and interface are shown in Figure 5.3.

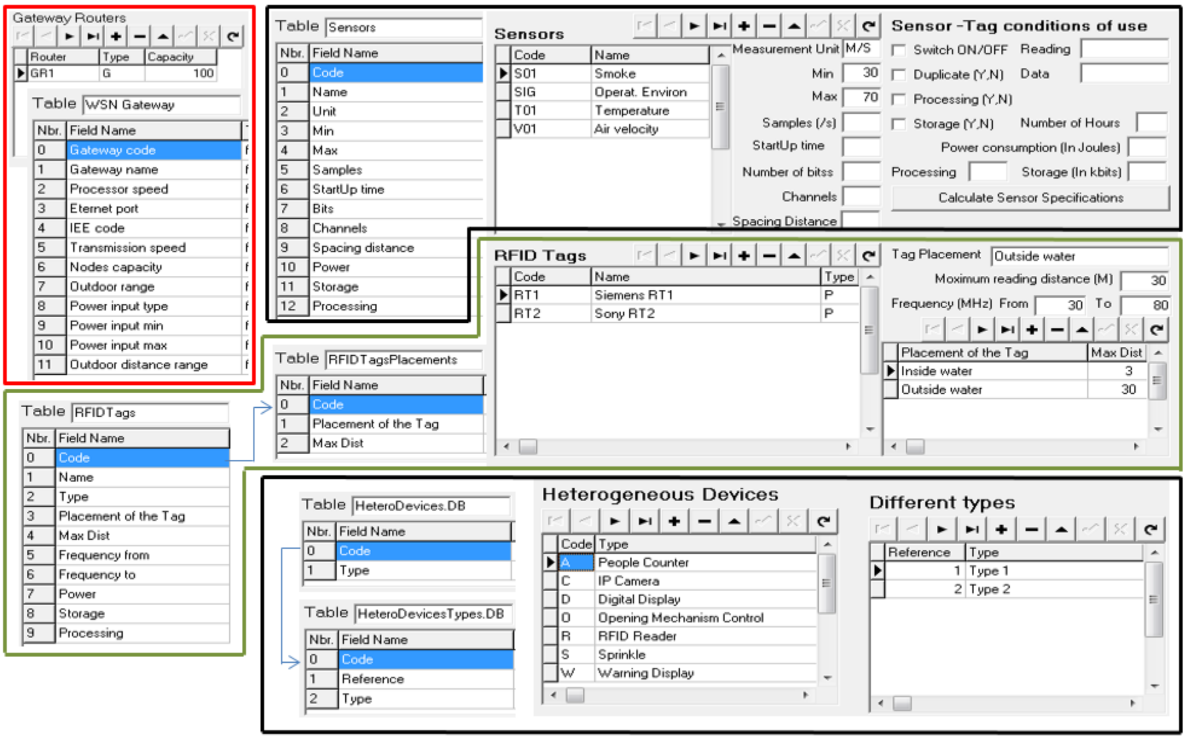


Figure 5.3: Databases data models and in interfaces

5.3.2. The Sensor Node Design and Database

The sensor node design is a key component of the generic design conceptual framework. It aims at ensuring that the sensing, monitoring and tracking requirements are thoroughly examined and the specifications of a device sensor node that fully meet these requirements are dynamically elaborated, performing an automatic update when these requirements have changed.

5.3.2.1. The Sensor Node Composition

The sensor node is defined in this implementation in its generic meaning, referring to a universal fixed device that can be repeatedly used in a configuration as a homogeneous device in the WSN. It includes, basically, all devices (sensors, RFID tags and other data, support and control components) that be used for sensing, monitoring and tracking, grouping different capabilities inherent to the integrated use of different technologies such as WSN, RFID and other technologies supporting the development of smart devices.

In this work, the sensor node design consists of grouping a set of sensors, the number being limited in this case study to six sensors per sensor node with the option of incorporating a RFID tag or reader, depending on the sensing, monitoring and tracking requirements.

Of great importance in the sensor node design, is the calculation of the device specifications (power consumption, storage and processing) elaborated should this device become fully active to perform local operations required in network processing and data storage. This calculation can be performed with different scenarios of sensor and sensor node configuration, depending on the setting of each sensor and device sensor node in the ad hoc WSN.

5.3.2.2. The Sensor Node Specifications and Resources Calculation Models

The rules for the calculation of the fixed device specifications are the result of the domain knowledge elicitation which focuses on various aspects of device deployment and utilisation in the WSN, ensuring that reliable procedures for fast activation and verification are elaborated, and re-tasking procedures are considered when reprogramming the sensor node devices. They are stored in the system model base as the resources calculation models. They support a decision tool for the sensing area for each device, ensuring that the sensing spacing distance is the sensors minimal distance (SSD) of each sensor composing the sensor node device, as shown in Equation 5.1.

$$SSD_{device} = \min (SSD_{sensor\ i}) \qquad _{for\ i=1,\ldots,6} \qquad [5.1]$$

There are a wide variety of calculation models for evaluating the power consumption of wireless sensor network applications [214]. These models are based on the use of different strategies to help predicting the WSN lifetime depending on the applications specifications for the use of the WSN, and optimize the required energy consumed using an effective energy plan.

The integrated functional unit aimed at the design of the generic sensor node is illustrated by the interface screenshot shown in Figure 5.4.

It is essential that the designed sensor node device meets the following quality requirements:

- High detection or identification rate
- Low false alarm rate,
- Low reporting latency, and
- Sufficient energy for continuous operating even when duty cycling is used.

5.3.2.3. The Sensor Node Design Implementation

The generic sensor node design process is based on the use of data described in the device sensor design data model illustrated in Figure 5.4.

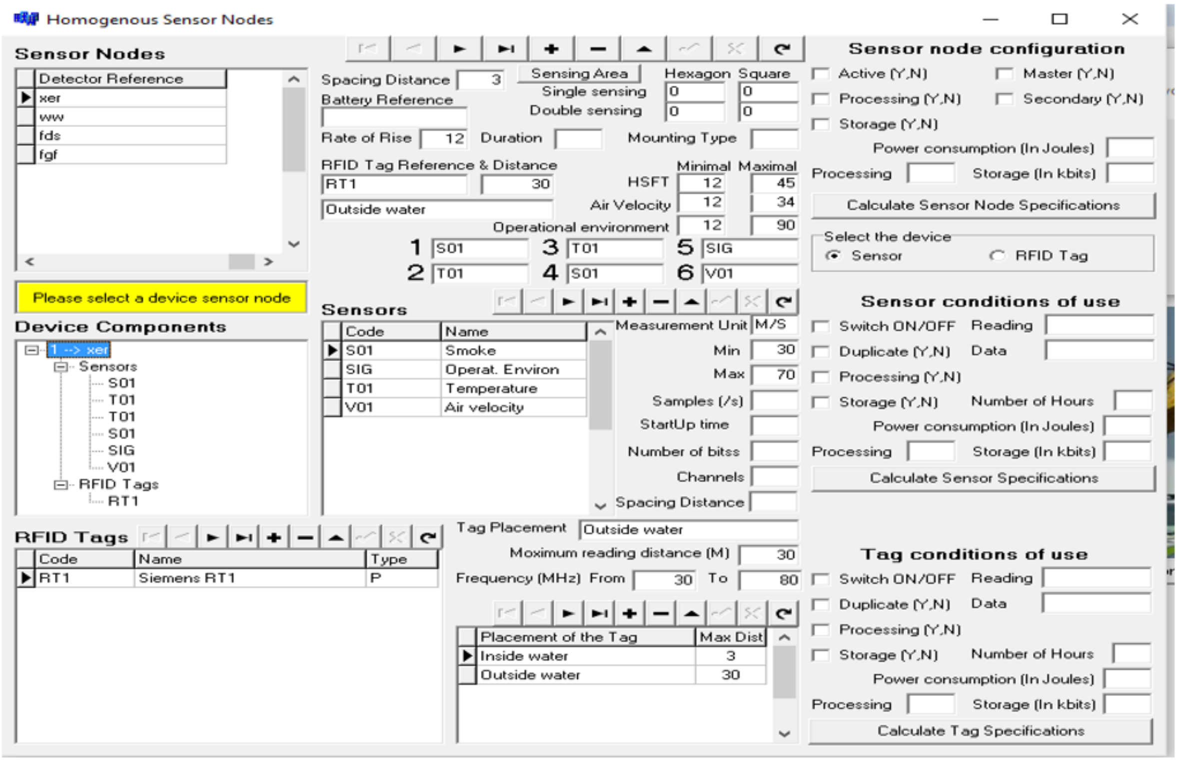


Figure 5.4: Device sensor node design interface

The content of this model can be context application specific in the sense that it can be updated depending on the general characteristics description and functional specifications of the needed sensors or RFID tags composing the desired device sensor node. This updating is supported by the system database management component which provides the flexibility to support both the definition and manipulation of data operations. Additional data functions need to be developed to support the data warehousing. An exhaustive list of sensor properties is published in technical documents.

5.3.2.4. The Mobile Sensor Node Device

Of great interest in the definition of the sensor nodes architecture is the composition and representation of people and objects interacting in the premises covered by the WSN. The solution suggested in this work is the attachment of RFID tags to people and objects. The architecture of these tags enables the incorporation of different types of sensors, and also a set of data pre-coded and modifiable depending on the WSN applications invoking these mobile devices. This data is structured using a language task description of the activity involving the tags correspondents. This language is required to implement the sensor node architecture: composition plans are converted into assembly commands which when performed result in perceptual data reflecting the status of each component of the node.

The composed devices are wirelessly connected to the WSN, interacting with the RFID readers installed in each room of the building, as explained later, in the section about the heterogeneous devices allocation.

5.3.2.5. The Sensor Node Data Model

The data model shown in Figure 5.5 is specific to the description of the fixed sensor node device represented by "Detector.db".

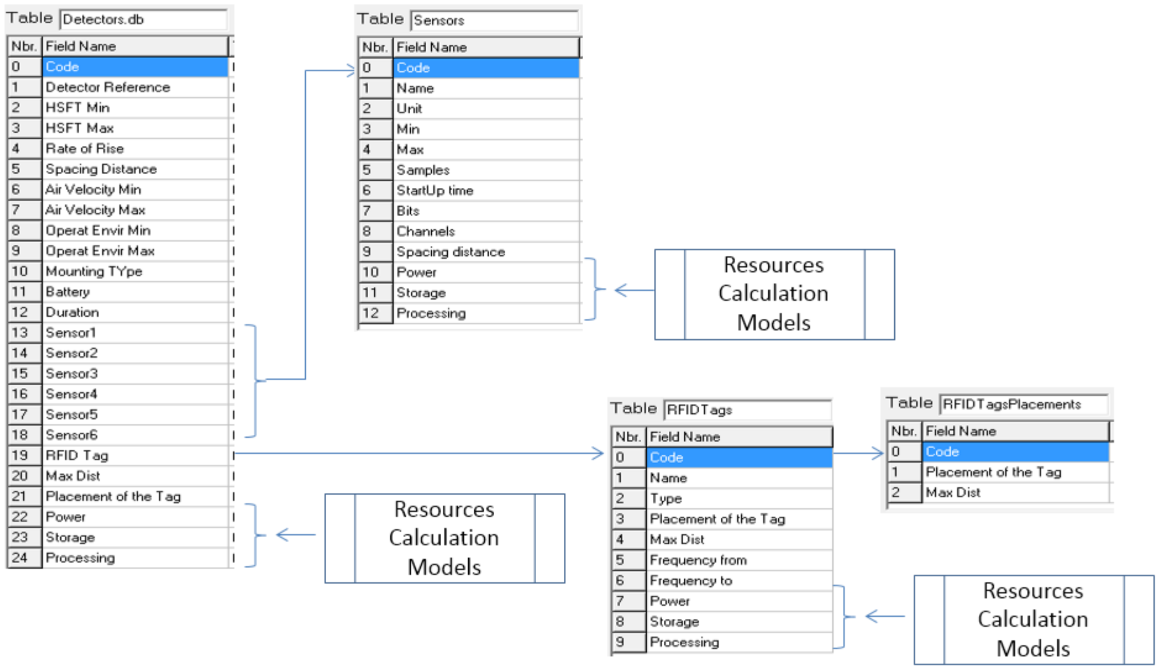


Figure 5.5: Device sensor design data model

Mobile sensor node devices will be linked to a table of people or goods to highlight the concept of device attachment to these two entities which can be grouped in the same database using an entity code to dissociate the two different types.

5.3.3. The Virtual Building Layout

The virtual building layout is an essential requirement for the support of:

– the localisation of the device sensor nodes and their spatial coverage,

– the localisation and tracking of people,

– the spatial measurements required by the different models used by the WSN applications, and

– the representation of the building features such as doors and windows, and energy supply points for the electric sockets and gas supply, needed for the determination of the sensing and control requirements.

The elaboration of the virtual building layout is based on the use of an encoding system to draw a 2D representation of the building walls in the form of lines represented in the data model shown in Figure 5.6. The layout is generated from a building wall segments using the 8 direction encoding system. An example of virtual drawing layout is shown in Figure 5.7.

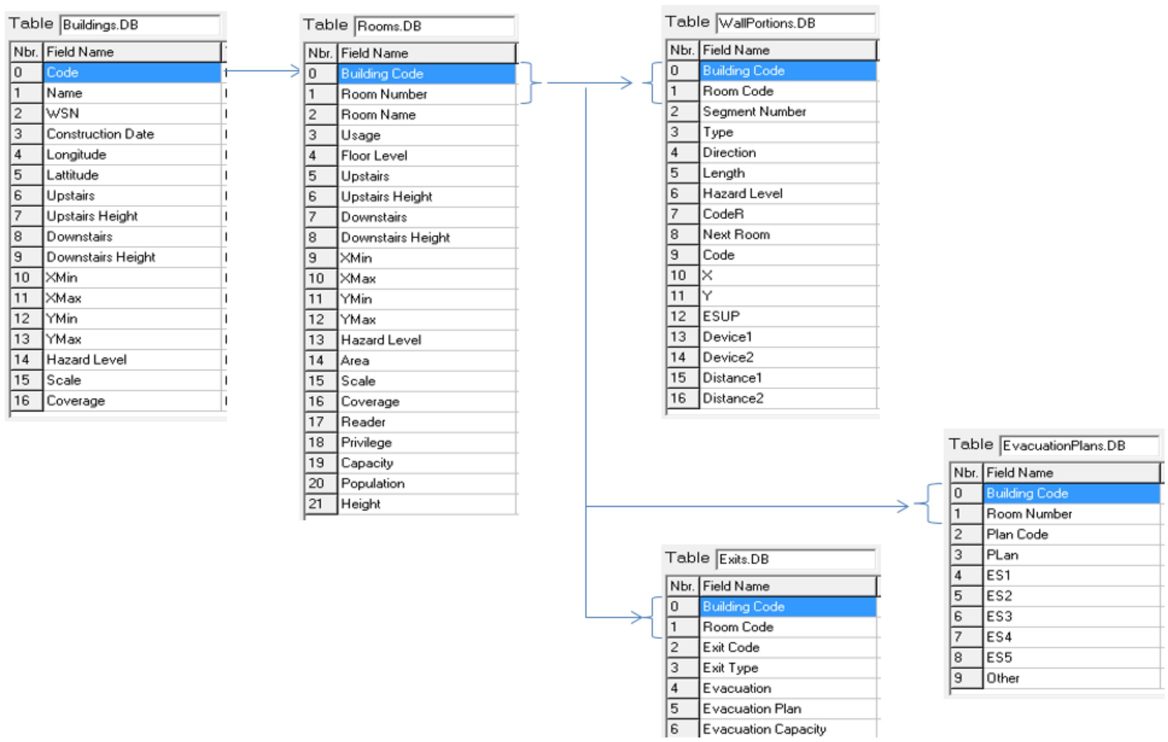


Figure 5.6: Virtual building layout data model

The encoding system used to draw this virtual drawing layout is an 8 or 16 directional coding procedure depending on the layout shape accuracy required. Both systems use the same principle illustrated in Figure 5.7. This principle is based on the use of a layout starting point (main external door for example) and use a set of segments of walls to compose the external and internal walls of the building, operating room per room. Each wall segment is composed of:

- a directional code called "Direction" in the data model, and represented by a decimal (0-7) character for the 8 directional coding or an hexadecimal character (0-9,A-H) for the 16 directional coding[155], indicating the drawing direction:
  - 0 : North-West,
  - 1 : North,
  - 2 : North-East,
  - 3 : East,
  - 4 : South East,
  - 5 : South,
  - 6 : South West, and
  - 7 : West)
- The length of the wall partition measured in metres, and
- Optionally:
  - A energy supply point, and
  - A room adjacent.

The building layout configuration consists of encoding the wall portions and openings, starting from the main door entrance as illustrated by a dot and the sign <. The encoding principles is based on a starting point $SP(x_{sp},y_{sp})$ corresponding to one extremity of the wall portion listed above. The coordinates of the wall partition (or wall segment) ending point $EP(x_{ep},y_{ep})$ are calculated using the segment length S_l and the direction code to indicate the angle value to use in equations 5.2.

$$x_{ep} = x_{sp} + S_l \times Cos(\alpha)$$

$$y_{ep} = y_{sp} + S_l \times Sin(\alpha) \quad [5.2]$$

where:

α is the angle,

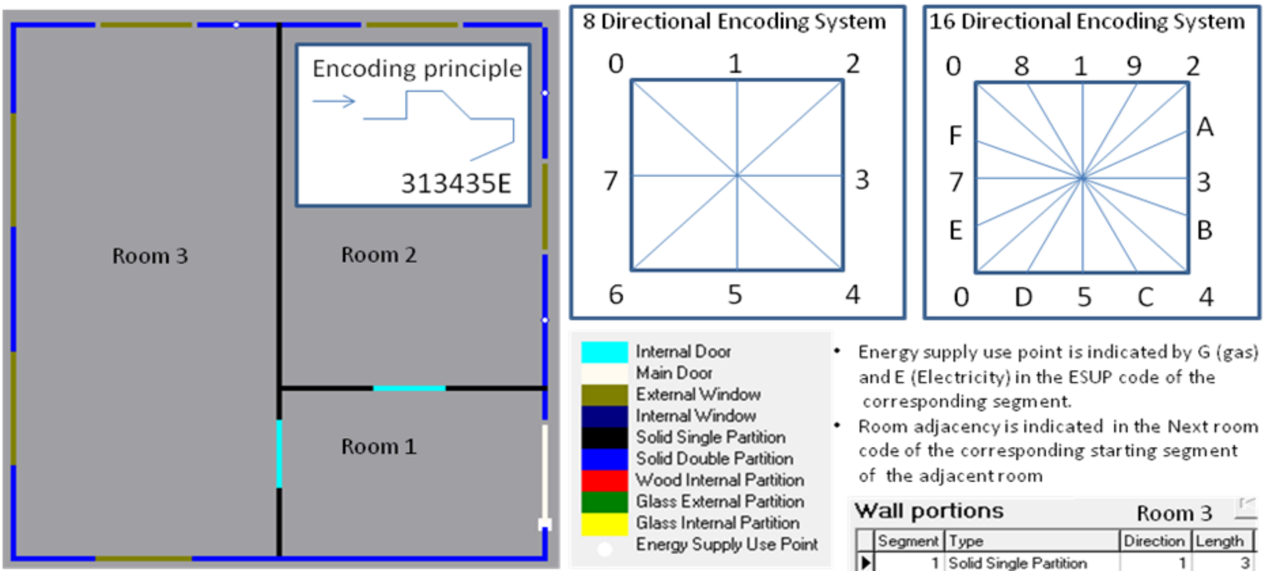
x_{sp},y_{sp} are the starting point coordinates,

x_{ep},y_{ep} are the ending point coordinates, and

S_l is the segment length.

The wall segments are generated, sequentially, clockwise. The first instance represents the starting segment of the first room layout. Adjacent rooms are linked by the indication of the first shared segment that is used to produce the layout of other rooms in the building. Energy supply use points are indicated by G (Gas) and E (Electricity) in the "ESUP" code of the corresponding segment.

Room adjacency is indicated in the "Next room" code of the corresponding starting segment of the adjacent room.



Wall portions — Room 1

Segment	Type	Direction	Length
1	Main Door	1	4.5
2	Solid Double Partition	1	1.5
3	Solid Single Partition	7	4
4	Internal Door	7	3
5	Solid Single Partition	7	4
6	Solid Single Partition	5	1.5
7	Internal Door	5	3
8	Solid Single Partition	5	3
9	Solid Double Partition	3	11
10	Solid Double Partition	1	1.5

Wall portions — Room 2

Segment	Type	Direction	Length
1	Solid Double Partition	1	6
2	External Window	1	4
3	Solid Double Partition	1	6
4	Solid Double Partition	7	3.5
5	External Window	7	4
6	Solid Double Partition	7	3.5
7	Solid Single Partition	5	16
8	Solid Single Partition	3	4
9	Internal Door	3	3
10	Solid Single Partition	3	4

Wall portions — Room 3

Segment	Type	Direction	Length
1	Solid Single Partition	1	3
2	Internal Door	1	3
3	Solid Single Partition	1	1.5
4	Solid Single Partition	1	16
5	Solid Double Partition	7	3.5
6	External Window	7	4
7	Solid Double Partition	7	3.5
8	Solid Double Partition	5	4
9	External Window	5	5
10	Solid Double Partition	5	5.5
11	External Window	5	5
12	Solid Double Partition	5	4
13	Solid Double Partition	3	3.5
14	External Window	3	4
15	Solid Double Partition	3	3.5

Figure 5.7: Example of virtual building layout, encoding systems and data

Of great importance in the virtual building layout data is the identification and localisation of building patterns that are required to help deciding the allocation of heterogeneous devices needed to enhance the role of the homogeneous devices in real time alerting and prompt emergency response. These patterns are essential for the configuration of both homogeneous and heterogeneous devices, and their effective wireless connection to the WSN.

Of similar importance is the signal coverage of routers and gateways wirelessly connecting these homogeneous and heterogeneous devices to communicate their data to the server and front-end system. These two major requirements are examined in the next two sections: homogeneous and heterogeneous devices allocation, and WSN configuration and generation.

5.3.4. Devices Allocation

The full optimal coverage is a prime requirement to ensure that working devices, properly monitored and tested, fully support sensing and monitoring effectively everywhere and at all times within the premises.

The device sensor node allocation and configuration is an incremental iterative requirement engineering process composed of the following steps performed independently for the first two steps:

- Select the most used sensing and monitoring device,
- Determine optimal device location,
- Determine specific sensing and monitoring requirements,
- Adjust the sensing and monitoring device selection, and
- Devices configuration.

5.3.4.1. Heterogeneous Devices Allocation

The role of heterogeneous devices is to enhance the role of homogeneous devices in a way to support control actions to respond to plausible events resulting from the analysis of their data. These actions are examined in the section about the WSN control. Their allocation which is based on using rules of thumb, results in the device location plan shown in Figure 5.8.

These rules based on the following location principles:

- Centre of the room:
    - IP Camera,
    - Sprinkler,
    - Warning.
- north-west corner or centre of the room:
    - RFID reader.
- Above or to the side of the door and window:
    - People counter,
    - Mechanism control (Open or Close),
    - Sign Display.

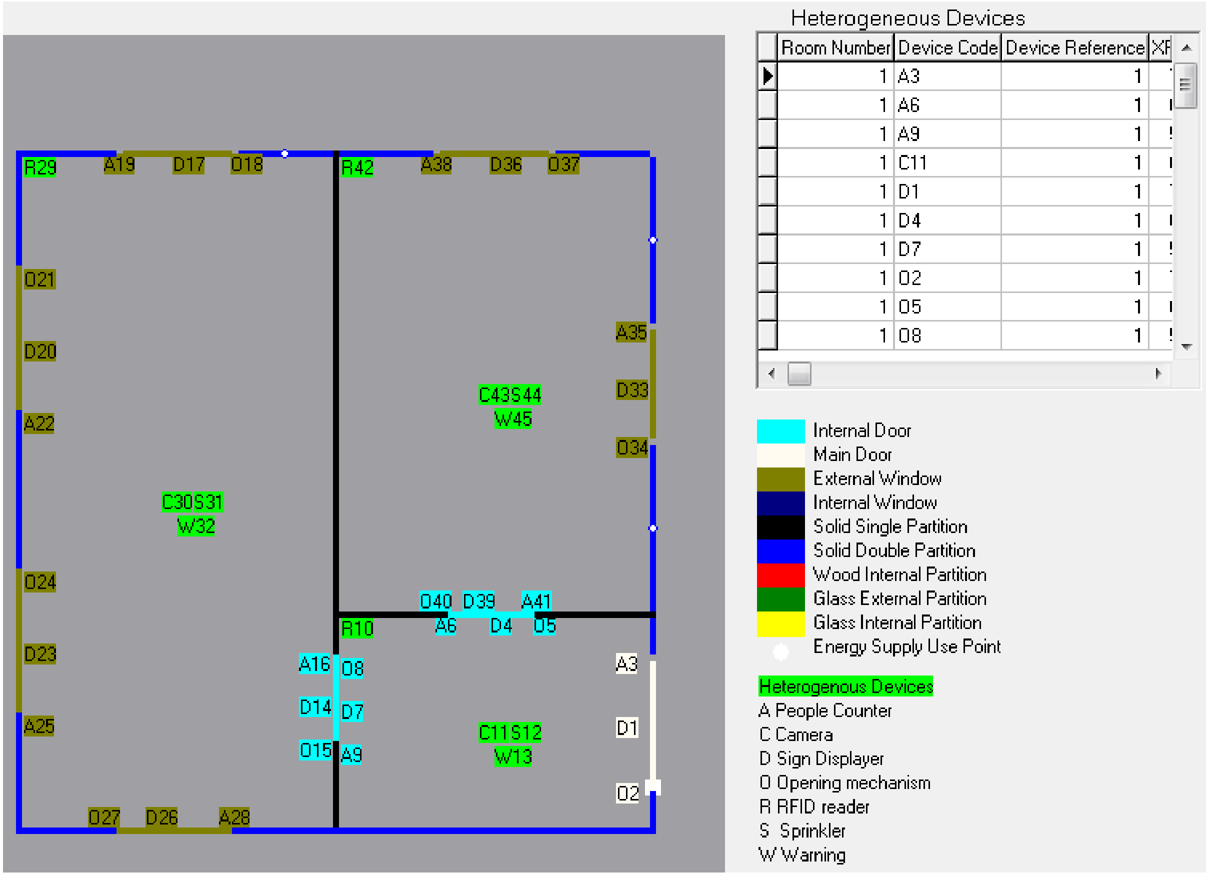


Figure 5.8: Heterogeneous devices allocation plan

The heterogeneous devices allocation process is based on analysing consecutively the different room construction patterns, and allocate sequentially the required devices, observing the following hierarchy order: sign displayer, opening mechanism, people counter (doors and windows), RFID reader, IP camera, sprinkler and warning display.

During the allocation process, the first type of each device is arbitrarily selected to generate the required heterogeneous devices. The device type selection will be refined taking into account the different rooms specific requirements and the homogeneous devices configuration.

Refinement of the selection process can be performed after the identification of the required heterogeneous devices, and integrate additional device configuration requirements. The data model is shown in Figure 5.9.

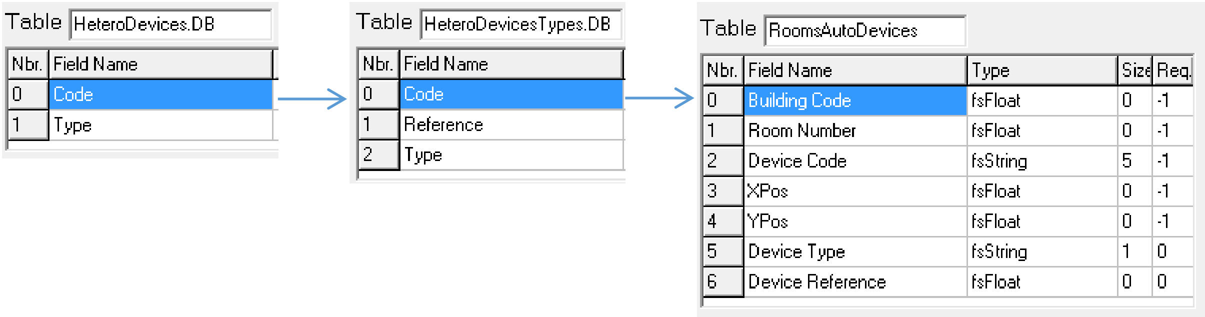


Figure 5.9: Heterogeneous devices data model

5.3.4.2. Homogeneous Devices Allocation

The role of these devices is to perform the activity of indoor sensing, monitoring and tracking. Their allocation is based on using geometric models based on the concept of centrality for a full spatial coverage [215].

a) The Allocation Model

Two geometric models have been suggested in this work to allocate the sensor node devices. These are the hexagonal and square models which are based on the use of the concept of centrality. These models are illustrated in their different support grids shown in Figure 5.10.

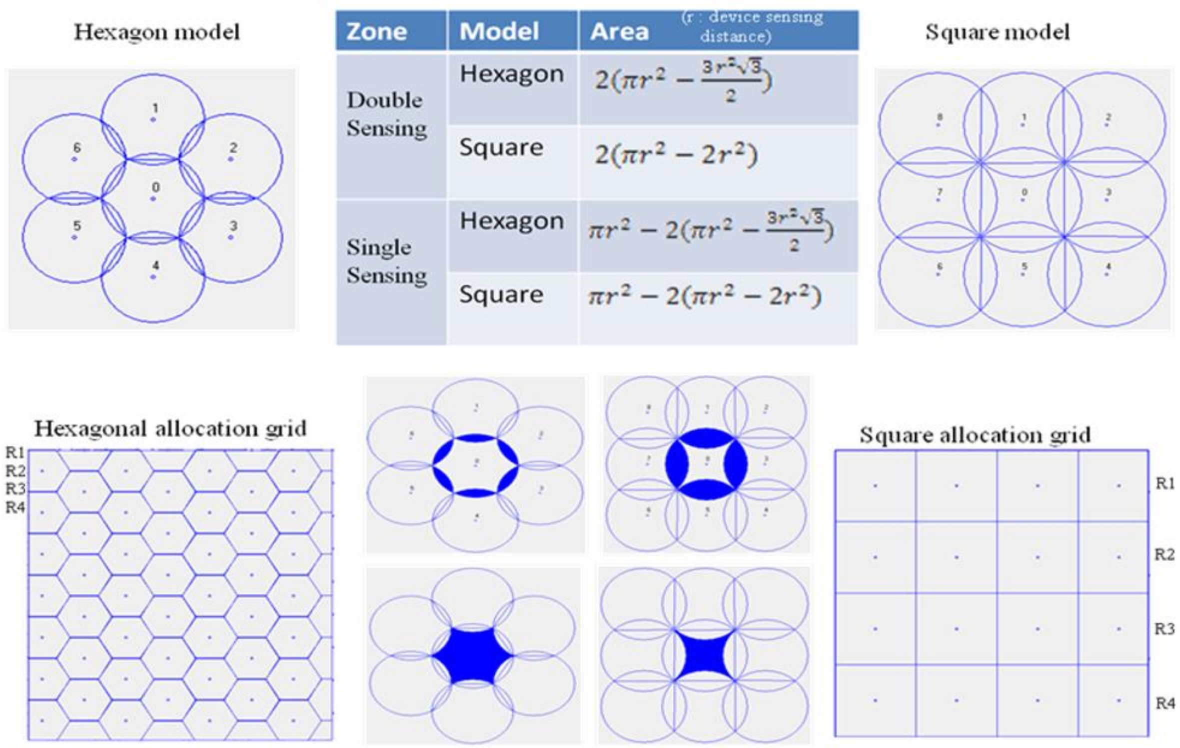


Figure 5.10: Geometric models for homogeneous devices allocation

b) *The Model Implementation*

The sensor node allocation model can be performed with and without taking into account the presence of the internal walls inside the building. The homogeneous device allocation process starts from left to right and from top to bottom. The automatic generated location of the sensor node devices can be altered manually to accommodate any device placement constraint and/or other requirements, such as, security, visibility and others.

The sensor node device location principle is similar for both geometric pattern shapes. It consists of locating the first device in the first top-left position on the room ceiling (90^0 vertical translation to produce the 2D building layout shown in Figure 5.7) using the spacing distance of the selected device. The accurate spacing distance between 2 sensor node devices changes from 2D to 3D by incorporating the height of the room to ensure a full coverage of the 3D space as illustrated in Figure 5.11. The real spacing distance is given by the formula [5.3].

$$SD_{3d} = SD_{2d} + \text{Room Height} \qquad [5.3]$$

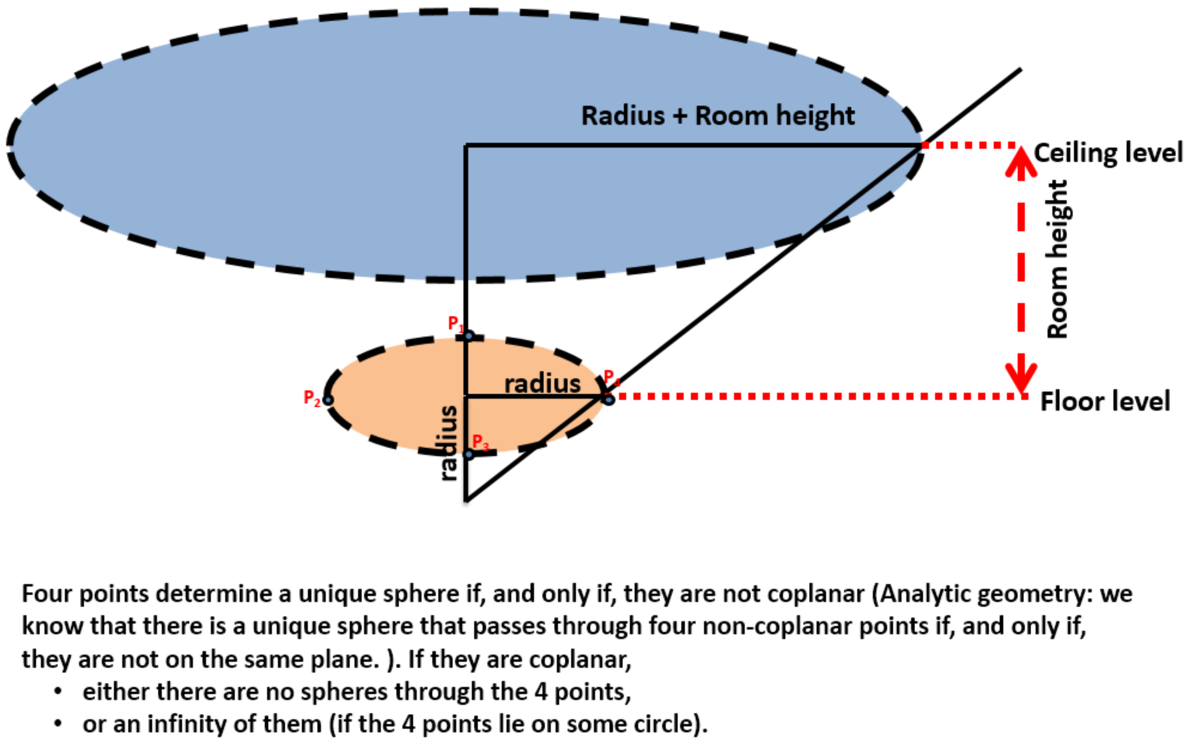


Figure 5.11: Spacing distance correction from 2D to 3D calculation.

The device location is the circle centre which is fully contained inside in the top left of the ceiling room layout. Then the neighbouring devices location is determined by coordinates increments as illustrated in the coordinates calculation formulas listed below where:

- SD = Spacing Distance between 2 sensor node devices
- X_{ltrc} = X coordinate of the left top room corner
- Y_{ltrc} = Y coordinate of the left top room corner
- X_{fd} = X Coordinate of the device
- Y_{fd} = Y Coordinate of the device
- i = i^{th} fire detector row iteration
- j = j^{th} fire detector in the row

In the location generation model, sensor node devices are deployed following an iterative row configuration deploying firstly, a first device, followed by other devices locally which are at the same distance from each other. The first fire device is deployed at different locations, depending on the geometric shape pattern, and also the iteration row aspect (even or odd). The devices location is given by the following formulas from [5.4] to [5.13]:

– **Hexagon geometric shape pattern**

- First device location:

$X_{fd} = X_{ltrc} + 4 \times SD \times Cos(60^o)$ in even device iteration row, [5.4]

Or $X_{fd} = X_{ltrc} + SD \times Cos(60^o)$ in odd device iteration row [5.5]

$Y_{fd} = Y_{ltrc} + I \times SD \times Sin(60^o)$ [5.6]

- Neighbouring sensor node device location

$X_{fd} = X_{ltrc} + (j \times 6+1) \times SD \times Cos(60^o)$ [5.7]

$Y_{fd} = Y_{ltrc} + i \times SD \times Sin(60^o)$ [5.8]

– **Square geometric shape pattern**

- First sensor node device location:

$X_{fd} = X_{ltrc} + SD \times Cos(45^o)$ [5.9]

$$Y_{fd} = Y_{ltrc} + SD \times Sin\,(45^{o}) \qquad \text{for first row} \qquad [5.10]$$

$$\text{Or } Y_{fd} = Y_{ltrc} + (2 \times i + 1) \times SD \times Sin\,(45^{o}) \quad \text{for next rows} \qquad [5.11]$$

- Neighbouring sensor node device location

$$X_{fd} = X_{ltcr} + (2 \times j + 1) \times SD \times Cos\,(45^{o}) \qquad [5.12]$$

$$Y_{fd} = Y_{ltrc} + SD \times Sin\,(45^{o}) \qquad \text{for first row,} \qquad [5.13]$$

$$\text{Or } Y_{fd} = Y_{ltcr} + (2 \times i + 1) \times SD \times Sin\,(45^{o}) \quad \text{for next rows} \qquad [5.14]$$

c) The Devices Location Generation

During the allocation device process, the first sensor node device from the database is arbitrarily selected to generate the required homogeneous devices using the data model is shown in Figure 5.12.

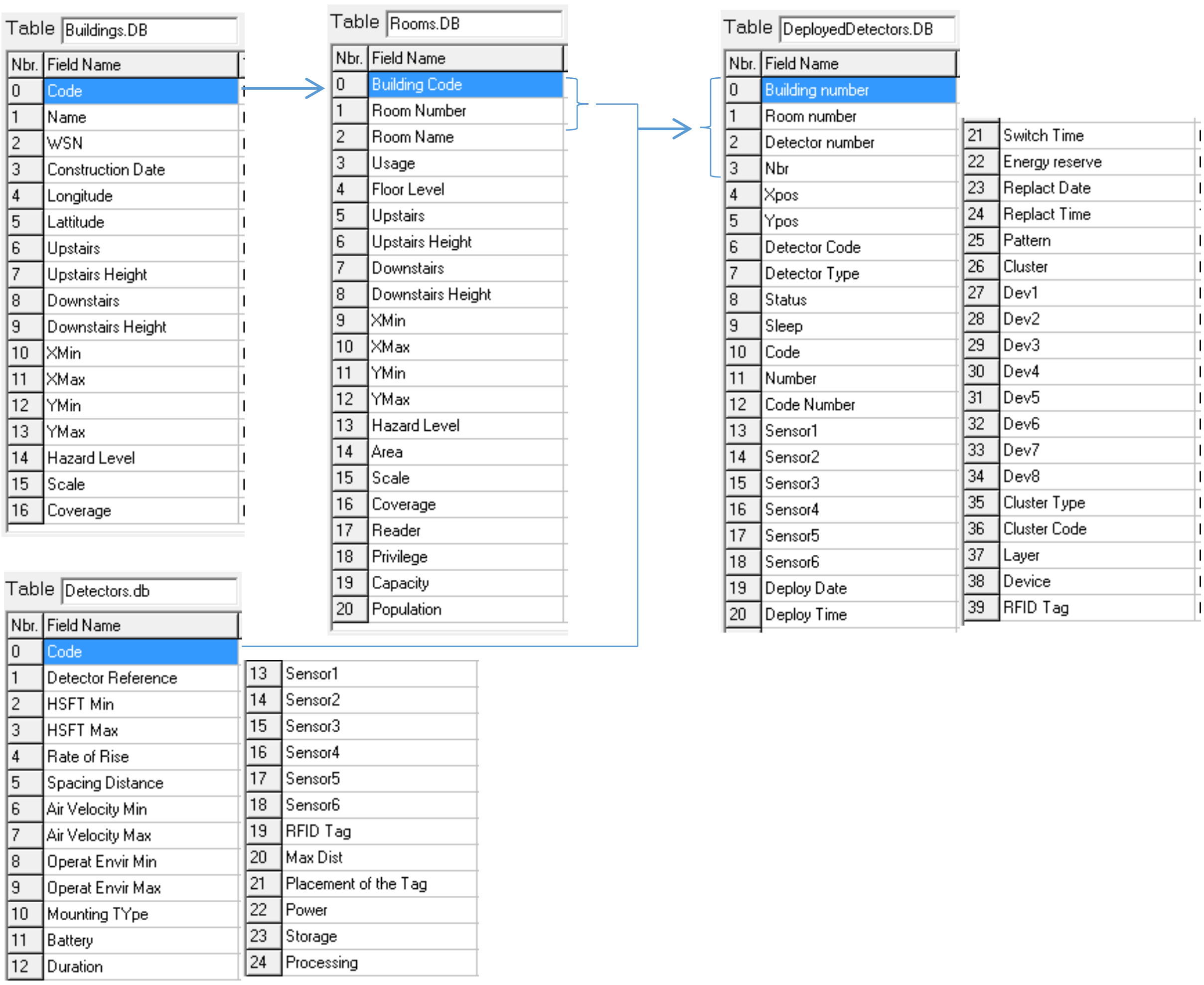


Figure 5.12: Sensor nodes devices data model

The device type selection will be refined after the devices location generation, taking into account the different rooms specific requirements associated with their usage. This refinement process can be performed after the identification of the required homogeneous devices.

The sensor node allocation model can be performed with or without taking into account the presence of internal walls in the building. The allocation process starts from left to right and from top to bottom. The automatic generated location of the sensor node devices can be altered manually to accommodate any device placement constraint. The generated sensor node locations for both models are illustrated in Figure 5.13.

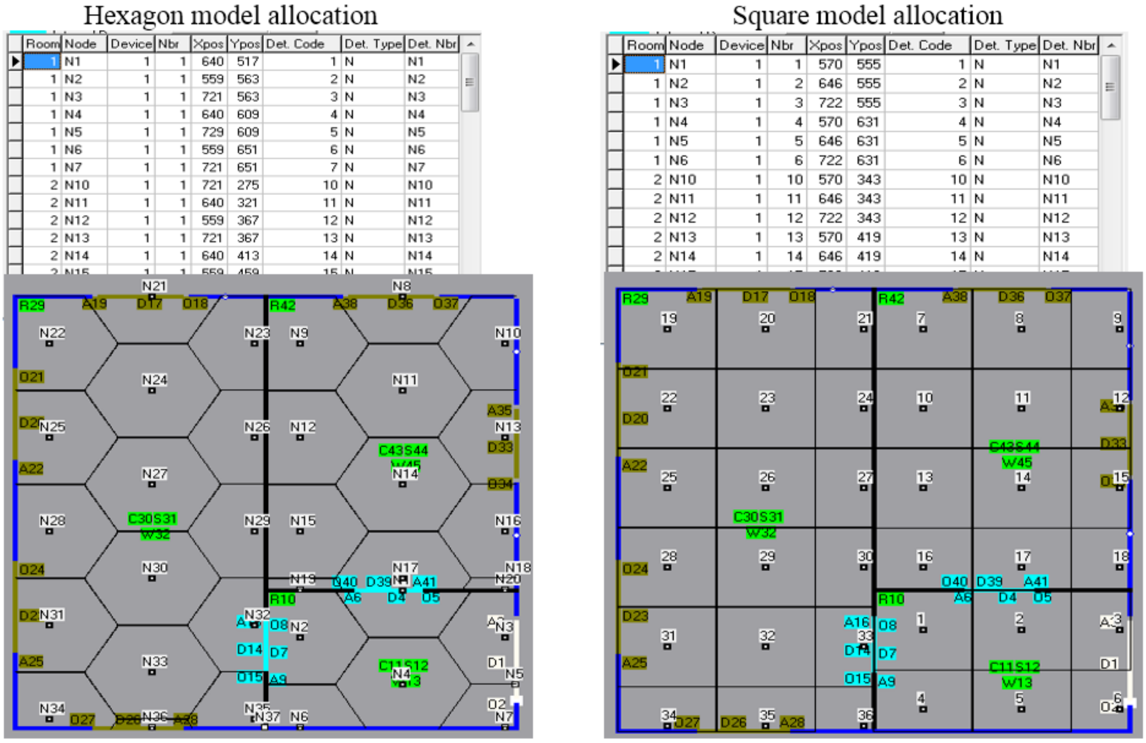


Figure 5.13: Sensor nodes devices allocation

The geometrical location distribution pattern is considered in this case study as the basis for the sensor nodes location generation. The consideration of both patterns, hexagonal and square, with different settings (localization per room or building, spacing distances, different clusters, etc) procures an extensive support for a multi-criteria sensor node localization decision making approach. The concept of single and double sensing zones for homogenous sensor nodes is used to evaluate the sensing overlapping shown shaded in Figure 5.10. This concept is an aspect important for the implementation of the safety factor used to increase the sensing and detection reliability.

5.3.5. Device Selection Refinement

The device selection refinement is an enhancement of the requirement engineering process to ensure that all indoor sensing or monitoring or tracking requirements are met by the selected homogeneous and heterogeneous devices. This engineering process integrates situational and technological changes in respect to:

- The device properties: accuracy, coverage, energy supply, and safety factor,
- The frequency of environmental updates, and
- The devices and WSN testing and maintenance.

Additional device and WSN requirements inherent to several policies for their configuration and deployment are integrated at a later phase. This refinement shown in Figure 5.14, is a manual process which will be fully automated in a second phase when the sensor and WSN information fusion is fully implemented, enabling to automatically select the appropriate device selection for a specific sensing or monitoring or tracking context situation.

The manual selection refinement procedure is based on selecting a device from the database (sensor node devices or heterogeneous devices) and change it as the desired device selected from the list of allocated devices..

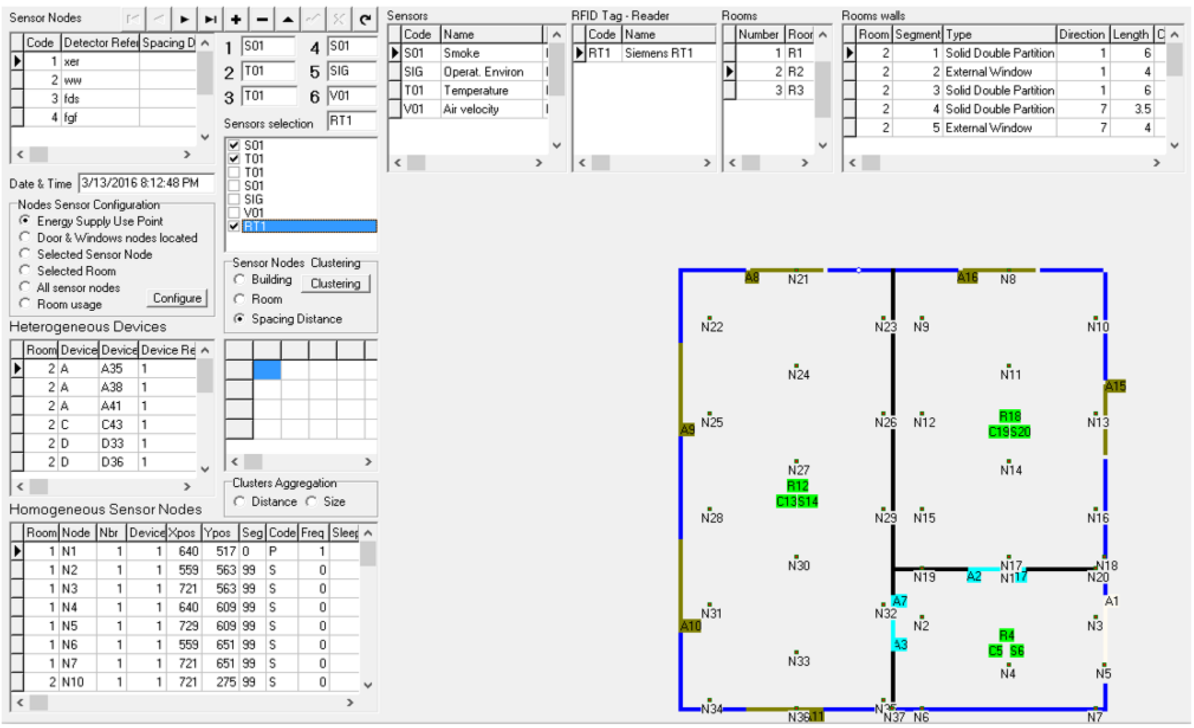


Figure 5.14: Devices selection refinement

This procedure results in heterogeneous data capture when selecting different sensor node devices composed of different sensors architecture and configurations.

5.3.6. Sensor Node Devices Configuration

The sensor node devices configuration includes their programming to enable them to perform a variety of operations described below and which include the definition and control of clusters of nodes. This programming, which is not included in this case study, aims at implementing high level operations using the concept of protothread corresponding to external macros written in the same development language and integrated in the main support system. However, their configuration and deployment in the WSN is fully functional.

Of great importance in the implementation of these operations, is the emphasis put on differences that might exist between sensors, mainly when multi-modal nodes and also different sensor nodes are used in the network. The calculation of the reading scale threshold must take into account some characteristics of the application context as some sensor nodes must remain switched on at all times. Examples of such devices are:

- Heterogeneous devices that perform data reading,
- Sensor nodes located to the proximity of sensible fire zones, such as any energy supply point, or any access from outside in the case of manmade fires, and
- Active sensor nodes controlling and coordinating a set of passive nodes.

5.3.6.1. Sensor Node Operations

The sensor node device, when active, i-e configured to operate continuously, works in full active mode in wireless sensor networks in general and networks of unattended wireless sensors nodes in particular. This poses the problem of node energy limitations due to the batteries lifetime. If much longer lifetimes are desired, the tracking of the sensor nodes energy failure and their batteries replacement becomes essential. However, more reliable solutions based on using ultra long life batteries and also new techniques, like nodes powered by radio waves to virtually eliminate or reduce the need of battery replacement in unattended wireless sensors. Replacement frequency is being considerably improved reaching two decades or more. These networks must remain fully operational.

5.3.6.2. Sensor Node Battery Replacement Schedule

Depending on the sensors battery life time, which can be in the time range of few hours to two decades, it is important to consider the monitoring of the sensor batteries energy consumption and plan their replacement when their threshold is reached, or battery failures are detected. The network specifications require the definition of the following battery characteristics which might differ from one battery to another, mainly when different life time batteries are used in the network nodes:

- Date of installation/replacement,
- Power consumption,
- Time of use, and
- Expected date of replacement.

5.3.6.3. Sensor Node Sleeping Schedule

Of great importance in extending the sensor nodes batteries is the energy saving feature integrated in the design of new sensor nodes which consists of a periodic switching between sleep and wake-up modes. This functionality is also used to reduce network congestion, enabling them to wake-up at a required data reading and pre-configured interval to take a reading and transmit data. Only non-redundant sensor nodes are concerned by the duty cycled manner, whereas redundant nodes will be operated in a sleeping mode till the need for sensor node replacement is expressed.

5.3.6.4. Sensor Node Reading Frequency

There is a substantial difference between the sensor node and the computer reading frequencies which is more accentuated when fast computers are used for reading sensing data when running a network simulation. More importantly, if the sensor node reading frequency cannot be adjusted accordingly to meet the application context requirements in terms of sensing data reading frequency, then using the network sensor nodes in a duty cycled manner becomes necessary when the reading scale threshold is reached. This action aims at reducing redundant data being transmitted over the network, reducing therefore the activity of both active and passive sensor nodes and their consumption power. Figure 5.15 illustrates the link between the application context requirements to be implemented according to the sensor node specifications which requires taking into account the time needed to deactivate the device when switching it off, and also the activation time after switching it on.

The sensor node pre-configured reading interval specification requires the definition of the following sensors characteristics:

- Pre-configured reading frequency,
- Deactivation time,
- Activation time,
- Reading date and time, format, and
- Data and format.

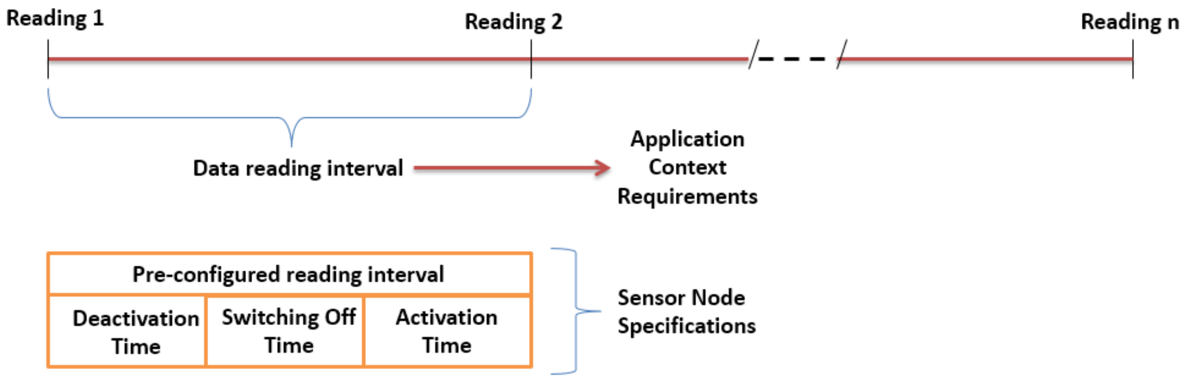


Figure 5.15: Sensor node pre-configured reading interval specification

The reading time is an important event processing specification as the data processing time might differ should delays occur during the data communication due to the differences in network link distribution [216]. Such differences can alter the real sequence of application context events as they have been expressed by the sensing data.

5.3.6.5. Sensor Sensing Distance

The increase of the number of sensor nodes when the spacing distance is reduced poses the problem of how optimal can the grouping of sensors in the sensor node be organized. It's thus of interest to consider the segmentation of the spacing distance range to enable the grouping of the sensors to characterize the sensor node spacing distance. Each segment of this range will correspond to a layer of sensor nodes as illustrated in Figure 5.16 where 3 and 6m are just examples of a segment threshold which can be elaborated when considering the variety of sensors required for use in the domain of the context applications.

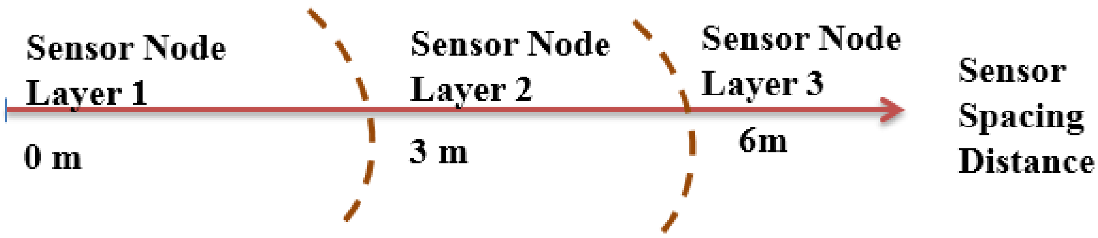


Figure 5.16: Sensing spacing distance segmentation to form sensor nodes layers

5.3.6.6. Sensor Node Spacing Distance Substitution

The allocation method of redundant sensor nodes is based on the fact that the sensor node location can be adjusted to enable the identification of nodes located in the overlapping neighbourhood. The identified nodes are considered to be redundant, therefore can be switched off until dead sensing is detected in the overlapping sensing zones. The nodes location coordinates are automatically generated during the device allocation process for the different spacing distances, as illustrated in Figure 5.17, showing two sensor node configurations generated with different spacing distances (3m and 4m). This figure illustrates the substitution principle (left), and shows an example of sensor nodes selection SN21, SN22 and SN23 illustrating the redundancy of SN14 which will be operated in a sleeping mode. Their coordinates will be adjusted respectively to those of SN11, SN12 and SN13. The problem of redundant sensor node location can be expanded to include the search for optimal sleeping nodes candidates and node location adjustment.

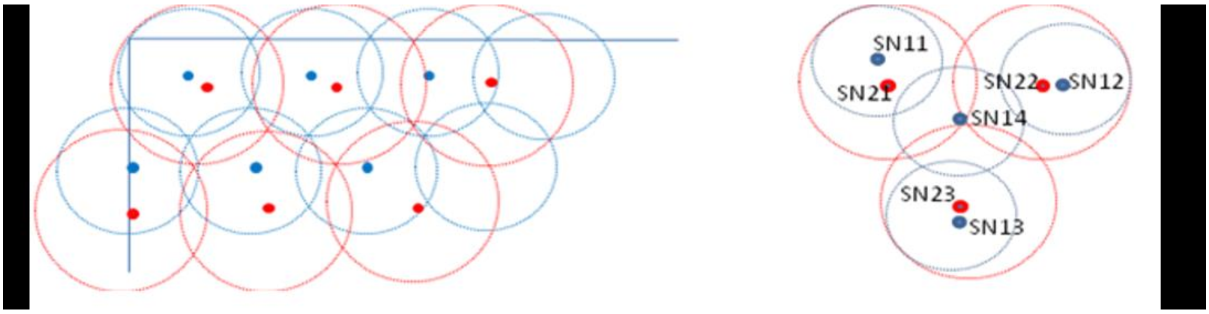


Figure 5.17: Spacing distance and sensor node substitution

5.3.6.7. Sensor Node and Sensor Status

Of great importance in the deployment of sensor nodes is the understanding of the mutual impact of sensor nodes and their sensors on each other in terms of status inheritance. Their deployment and configuration is a functional process requiring a real time monitoring of their working conditions depending on their individual status and settings, and the position and role of sensor nodes in their corresponding clusters. The device status for sensor nodes and sensors is specified depending on their corresponding sensing requirements and safety factor. Their configuration is supported by the process model shown in Figure 5.18 which includes the following main rules:

- All time active sensors nodes are those localised, either at the centre of a cluster of sensor nodes or nearest to the energy supply use points, doors and windows, whereas duty cycled manner sensors nodes concern the remaining ones.
- Active sensors nodes are those localised at the centre of a cluster of sensor nodes with additional functionality to perform the network functions at the sensor node and also data processing and storage.

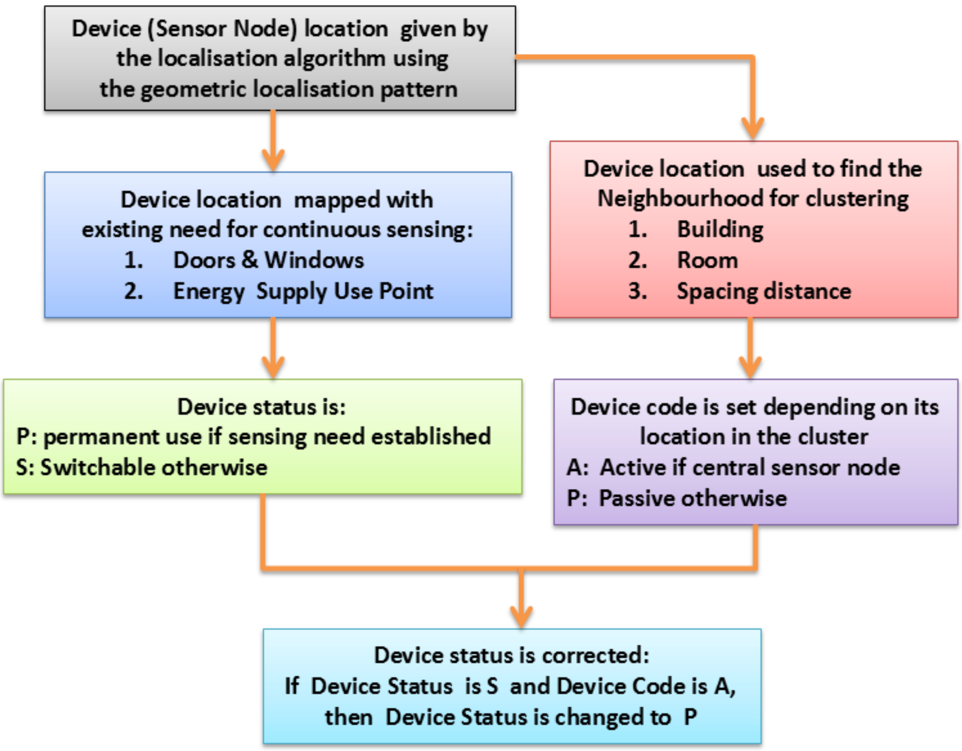


Figure 5.18: Senor Node and sensor status process model setting

The sensor node configuration is a continuous and iterative process as its relative position in the WSN could require its re-configuration, depending on several conditions:

- WSN performance,
- Sensor node performance and status, and

Event detected in the neighbourhood

This process model supports the implementation of sensor node status configuration policy which is based on a selective setting, sort of a configuration filter. The main options are:

- Energy supply use point,
- Door and Window located,
- Selected room,
- All rooms,
- Selected sensor node, and
- Room usage.

5.3.7. Device Sensor Nodes Clustering

Sensor nodes clusters (SNC) are required to connect sensor nodes to router nodes and to distribute the network functions for sensor deployment, configuration, activation and data processing. A SNC is a group of sensor nodes surrounding a central sensor node. The process of definition of these SNCs is based on searching all plausible clusters, ranking them on the descending order of their population, and browsing the building layout from the left to the right, and from the top to the bottom to select the SNCs ideal candidates using the Cartesian coordinates of the central sensor node location of the cluster. All the sensor nodes forming the selected SNC are removed from the remaining SNCs waiting to be selected. A process of cluster aggregation is proposed to add the selected, less populated, SNCs to the most populated SNCs of their proximity. The sensor nodes clustering is a dynamic process which is required when deploying and (re)configuring partly or entirely the WSN. The reconfiguring conditions are automatically determined by the configuring agents.

A SNC is required to have a sensor node cluster head (snCH) that must be supplemented by a sensor node cluster head substitute (snCHS) in case of the snCH malfunctioning.

The structural uniformity of the network can be extended to integrate:

- The network needs to preserve energy by assigning, taking into account the sensing requirements at each sensor node location, the sleeping mode to sensor nodes enabling them to switch between active and sleep modes depending on the network activity to conserve energy.
- The gulf existing between sensing spacing distances (SSD) of sensors that are needed at the same sensing location, which might result in grouping sensors of the same SSD in different types of sensor nodes.
- The prevailing conditions while using the network and the probable detected events require migration, which might suggest the network reconfiguration.

These three structural characteristics can be modelled around the concept of a virtual cluster defined at a logical level whereas the initial clustering made of the aggregated SNCs corresponds to the physical level, which is associated to one, or several logical levels, as illustrated in Figure 5.19.

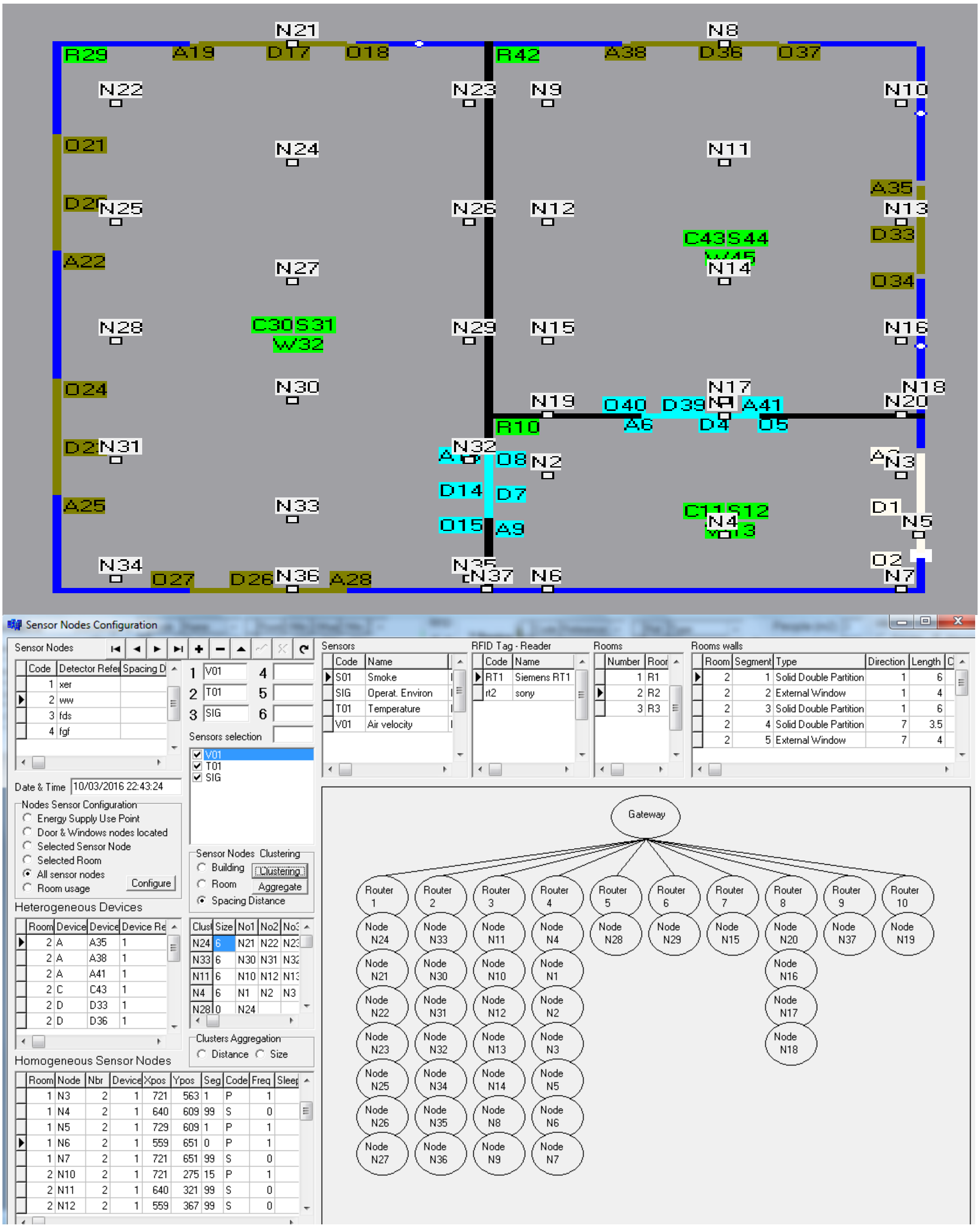


Figure 5.19: Sensor nodes configuration and clustering

The virtual cluster defined as a logical level, enables flexibility in the WSN deployment to support more effectively in a variety of context applications. Examples of cluster logical levels are:

- All the sensor nodes involved in an emergency response configured as one sensor node cluster with more reliable connection specifications (active connection, high performance routers, high band signal) whereas the other sensor nodes of the WSN will be configured separately in other clusters.
- All the non switchable sensor nodes are configured as one sensor node cluster whereas the other sensor nodes of the WSN will be configured separately in other clusters.

Sensor nodes clustering policies are an essential tool for the WSN configuration. This tool is supported in the HIDSS by a process model elaborated from the information fusion resulting from the configuration context knowledge domain.

5.3.8. Device Sensor Nodes Cluster Aggregation

Of great importance in the deployment of ad hoc WSNs is the need to balance the load on sensor nodes using a topology control in the sensor network. This topology control approach which is needed to increase the network scalability and lifetime is based on creating sensor node clusters of a homogeneous size.

5.3.8.1. Distributed Topology Control

The distributed topology control enables adjustment at a different level of the network in terms of prolonging network lifetime via power conservation and increasing network capacity using spatial bandwidth monitoring and reuse, ensuring reach ability between two sensor nodes within the same or different sensor node clusters.

The incorporation of different sensors in sensor nodes forms a network of heterogeneous wireless devices and generates a data heterogenisation with different maximum transmission ranges subject to asymmetric wireless links. A distributed topology control algorithm is required to calculate the nodal reading and transmission power required for the data reading, it’s in-networking and transmission to the front-end server.

5.3.8.2. Cluster Aggregation Level

In this research, this homogenisation is performed by reducing the size difference between the most and less populated sensor node clusters of the network. This size difference called here an aggregate level is comprised between 0 and 3. The aggregation of the sensor node clusters is shown in Figure 5.20.

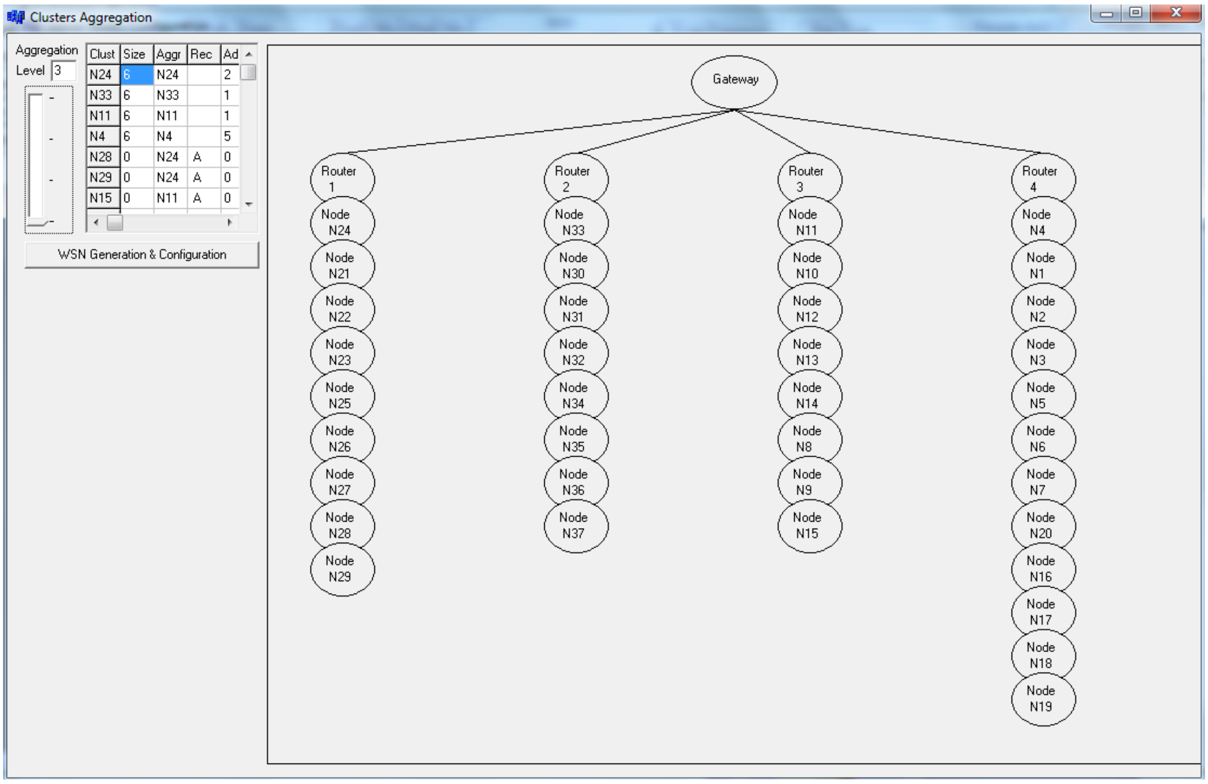


Figure 5.20: Sensor node clusters aggregation

5.3.9. WSN Generation

One main characteristic of WSNs is the heterogeneity of its device capabilities to perform a variety of configuration, sensing, computation and communication tasks by active sensor nodes which can also be allocated to control and assist a group of passive sensor nodes. Higher capabilities when required depending on the requirements of the application can result in the creation of a base node to integrate a variety of devices other than the sensor nodes to provide the needed capabilities. This can have an impact on the WSN architecture requiring the use of a multitier cluster based architecture. An example of a network topology advocated for use in this study is illustrated in Figure 5.21.

5.3.9.1. Node Type

The WSN generation requires the definition of its different elements, and their network architecture. These elements are:

- Coordinator node (CN or Gateway: G): one per WSN, its main function is to initiate the network formation by configuring the Channels, nodes ID and Profile).
- Router node (RN or Router: R): is an optional network component involved in routing network messages by maintaining a routing table and managing local address allocation and de-allocation for its assigned end device nodes.
- End device node (EDN): is also an optional network component used in low power operation optimization by taking advantage of sniff and sleep techniques.

5.3.9.2. Nodes Connection Types

The different connection types used in the ad hoc WSN deployment in the case study are:

- EDN →CN
- EDN →RN →CN
- EDN →RN →RN→CN
- RN →CN

5.3.9.3. Network Typology

The network topology, shown in Figure 5.21, is the multi-tier cluster based architecture used in this case study to generate the WSN.

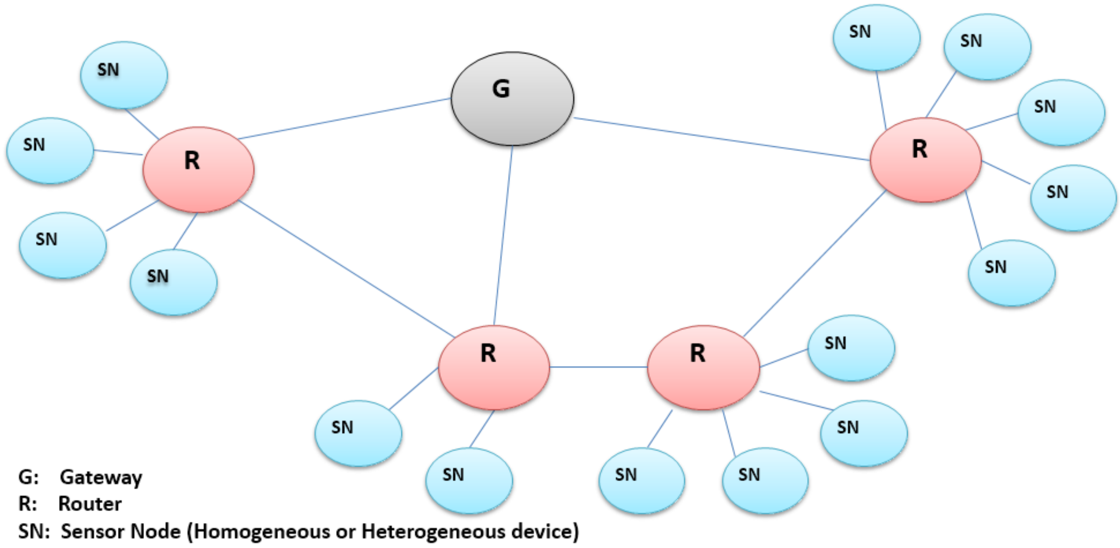


Figure 5.21: WSN multitier cluster based architecture

5.3.9.4. The WSN Mesh Generation

The WSN generation consists of wirelessly connecting all homogeneous and heterogeneous devices required to support the context applications. These connections require the choice of:

- Network characteristics: Node type, Node connection type, and Network typology.
- Device connection policy based on a strategy to attach a sensor node to a node type using the following options:
  - Sequential or alternative sequential attachment of devices to node type,
  - Sensor nodes of a room per node type or alternative room sequential,
  - Spacing distance per node type,
  - Separating sensor nodes from heterogeneous devices,
  - Cluster of sensor nodes per node type,

The device connection policy procures device attachment flexibility, enabling the composition of options mentioned above. For example, sequential device attachment can be composed with a separation between homogeneous and heterogeneous devices, as illustrated in the following WSN generation shown in Figure 5.22.

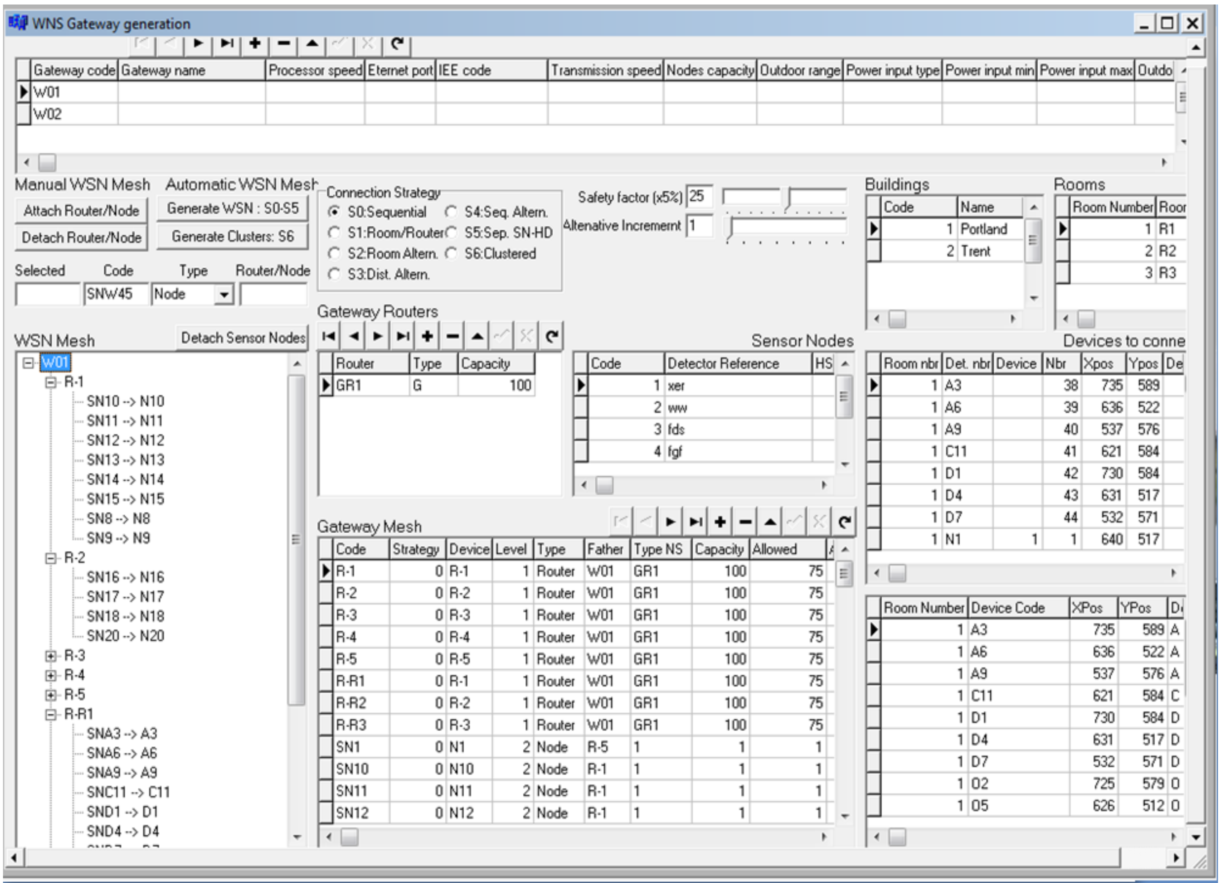


Figure 5.22: WSN generation

Of great importance in the WSN generation process is the safety factor required to reserve empty slots in the different node types that will be needed to accommodate clusters of sensor nodes that require reconfiguration due to a low bandwidth signal.

5.4. Tracking and Localising

The integration of WSN and RFID, which is an important aspect in this work, is shown in the case study through a context application for the indoor location and tracking of people and objects.

A population of people wearing a wrist band, and a collection of objects with attached tags, are identified and localised in this application by a sensor node composed with a RFID identifier and sensors needed to control the environment context of these people and objects. The corresponding data model is shown in Figure 5.23.

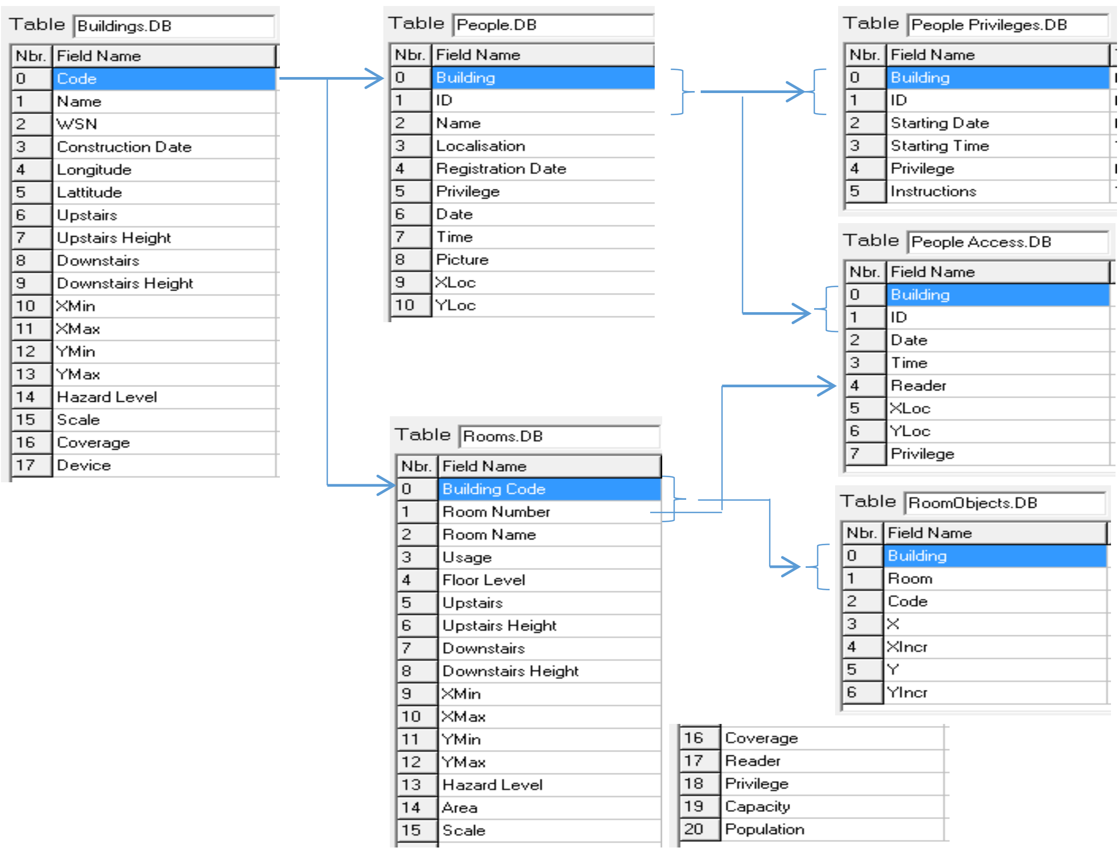


Figure 5.23: Tracking and localisation data model

In this application, every person is allocated with a set of access privileges to allow/restrict room access in accordance with the room capacity based on an occupancy model defining the number of people allowed in each room. Objects can be incorporated in any room, and collision detection between people and objects is implemented for the definition of evacuation paths, suggesting contouring them. The case study includes an application that enables the tracking of people in the building, the storing of the different rooms accesses, and the identification of people located in each room. This implementation is illustrated in the interface screen shown in Figure 5.24.

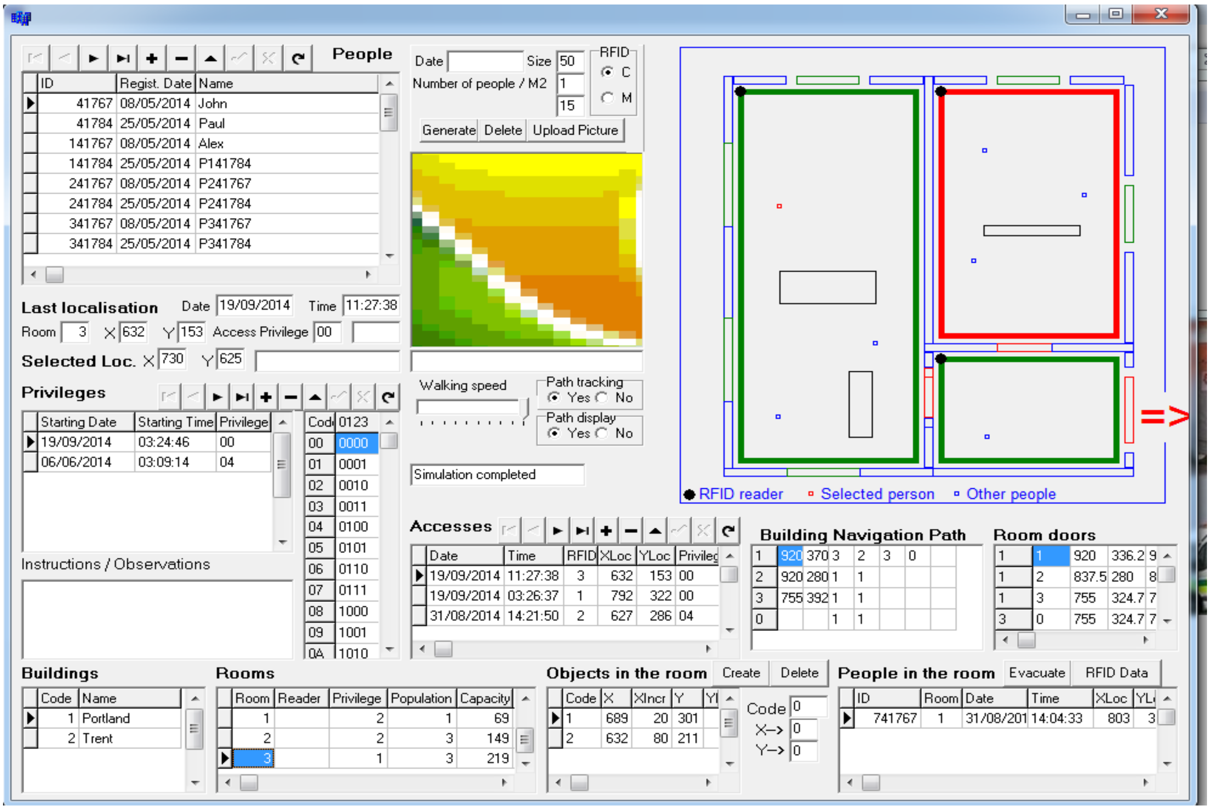


Figure 5.24: Control access and tracking of people and objects

The use of colours in the above screenshot enhances the system user interaction indicating the movement choices for the selected person: moving in the same room or to room 1 as indicated in the rooms frame in green.

5.5. System Simulation

The simulation of the WSN is an essential step in its design, prior to its deployment, and enables the isolation of several aspects inherent to its continuous and optimal working. Of great complexity in this simulation, is the isolation of single aspects based on configurable parameters that will enable the identification of the problems in need of fixing and to take appropriate corrective actions. Although the simulation of the WSN is not within the focus of this research, the system developed includes the concept of a virtual control room to visualize the different WSN entities and their configuration and behaviour. This system in relation with the proposed case study provides some simulation tools enabling:

- Visualisation of the WSN entities,
- A navigation path of the building with decision information control,
- The homogenous data capture,
- A sensor node cluster alarm reaction model, and
- The display of evacuation paths.

5.5.1. Virtual Control Room

The visualisation of the WSN entities and their status are displayed as the result of the data information fusion process, involving the activation of intelligent agents interacting with each other, when their corresponding services are automatically invoked during the deployment of the WSN and the execution of context applications. Supporting the monitoring of the domain activity, intelligent agents composing the invoked services are activated automatically when event conditions are identified and an automated instantaneous reaction is performed. An example of monitoring of the WSN architecture in the virtual control room is illustrated in Figure 5.25.

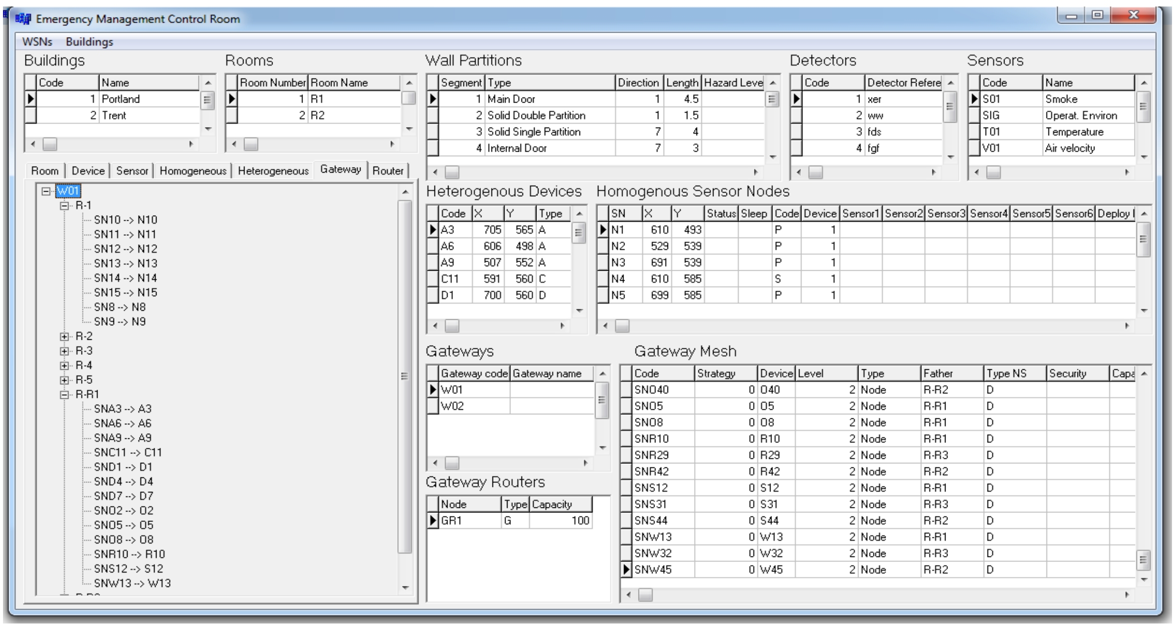


Figure 5.25: Example of screen from the virtual control room

The monitoring of the activity domain is based on a multiple screen-capable web-based service application aimed at providing an overview of the system working, highlighting possible defects in different areas of WSN control with a detailed mapping of the network entities, events, and corresponding domain applications to enable, when possible, rapid fault analysis.

5.5.2. Building Navigation Path

Building a navigation path, which is a path finding a way between the different rooms of a building, can be used to support:

- The access control of people in a building
- The definition of evacuation decision variables for:
    - The identification of evacuation exits inside and outside the building, and
    - The calculation of the theoretical time required to evacuate people from a room.
- The risk assessment required for emergency preparedness to ensure that the number of exits and their dimensions are ample to evacuate the population limit of a building.

This information is elaborated from:

- The wall segment of the rooms, particularly the door and windows segments for the identification of exits inside and outside the building, and
- The evacuation model for the calculation of the theoretical time, using in combination the room occupancy model and the evacuation rate.

The evacuation theoretical time can be improved by incorporating the position of each person in the building and the simulated time required for them to leave the building. This is illustrated in the decision tool shown in the next section.

5.5.3. Evacuation Simulation

The RFID technology used in this research work to support the localisation and tracking of people and objects can be used to assist people in their movements inside the building by identifying their physical conditions and associated actions which are essential, for example, in the case of emergency evacuation.

Enhanced messaging devices can be incorporated in their tags along with sensors, and elaborated information also stored to personalise the emergency evacuation.

The evacuation path is defined as the linear distance from:

- The person localisation to the exit of the attended room, and
- The door to door of the next rooms as suggested in the building navigation path shown in Figure 5.26.

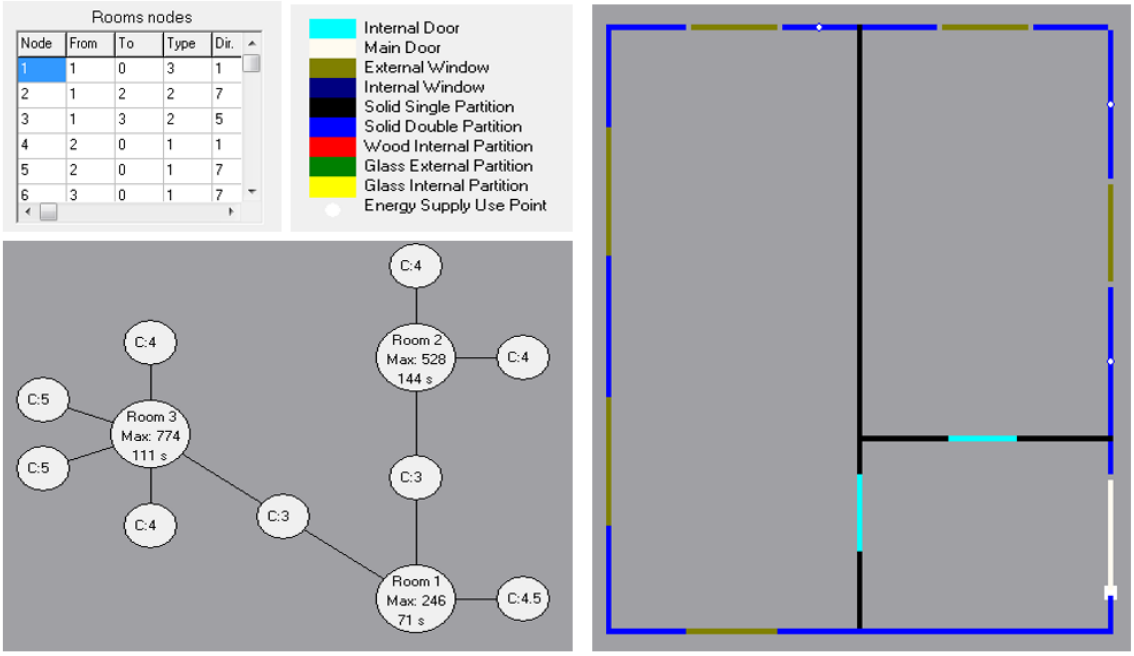


Figure 5.26: Building navigation path

The evacuation path finding takes into account the presence of objects in the path, and collision detection and path re-planning is performed when required. However, the evacuation time has not integrated the waiting time at the collision nodes which are the evacuation points (doors or windows) between the different rooms. In the evacuation data displayed in Figure 5.27, outside the building is referred as Room 0.

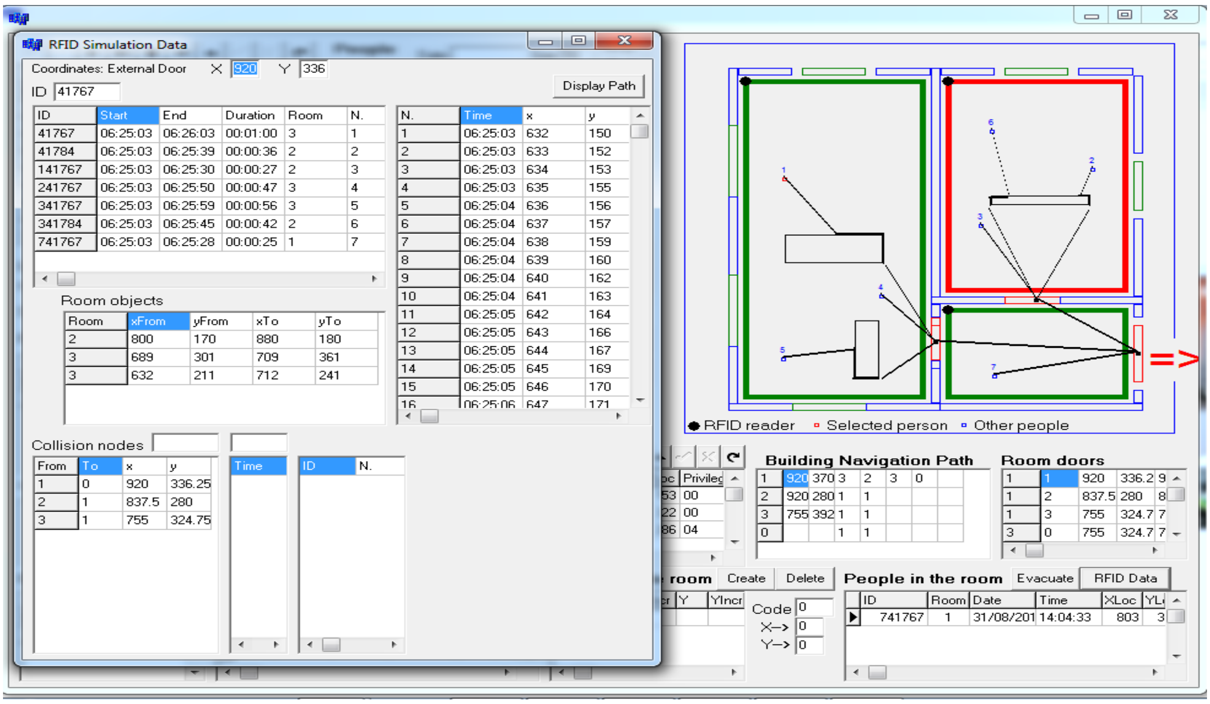


Figure 5.27: Building evacuation simulation data

5.5.4 Sensor Node Cluster Alarm Reaction Model

A sensor node cluster alarm reaction model has been developed to demonstrate the coordination of the different detectors forming the cluster in showing the progression of the alarm along the fire propagation.

This model is based on calculating the fire proximity to the detector location which sets its alarm on when this distance becomes equal or smaller than the sensing distance. As the fire propagates, the individual distance to each detector in the cluster and to other surrounding detectors increases by integrating the effect of the two following parameters:

- Fire expansion or propagation, and
- Temperature rise.

The data resulting from this alarm simulation is twofold:

- The predictive data given by the fire simulation model, and
- The data captured by the WSN from the different detectors.

The predictive data shown in Figure 5.28 is composed of:

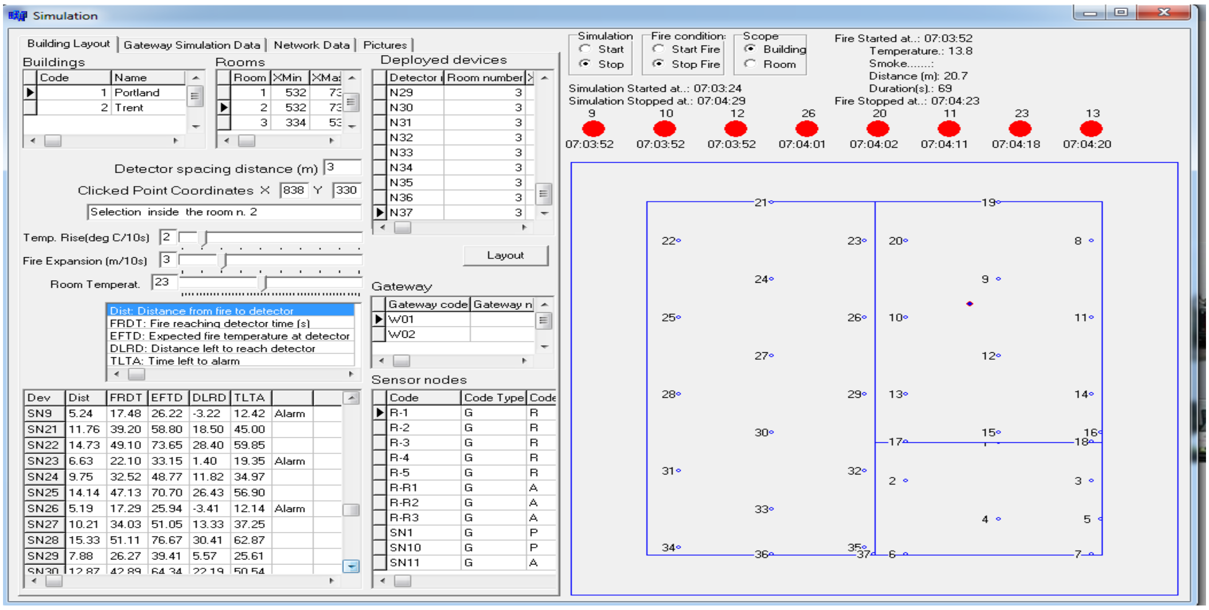


Figure 5.28: Predictive data for fire alarm simulation

- DIST: Distance from fire to detector,
- FRDT: Fire reaching detector time,
- EFTD: Expected fire temperature at detector,
- DLRD: Distance left to reach detector and

– TLTA: Time left to alarm.

The data captured by the WSN from the detectors is detailed in the next section.

5.5.5 WSN Data Capture Simulation

The data captured by the WSN, which is heterogeneous as it corresponds to the output of different homogeneous and heterogeneous devices which may have different configurations, is shown in Figure 5.29. In the case study supporting the implementation of the system prototype developed in this research, a data reading from a device is composed of nine values composed of:

– Device identification
– Six values allocated to sensors data
– Two values allocated to RFID data (x and y coordinates).

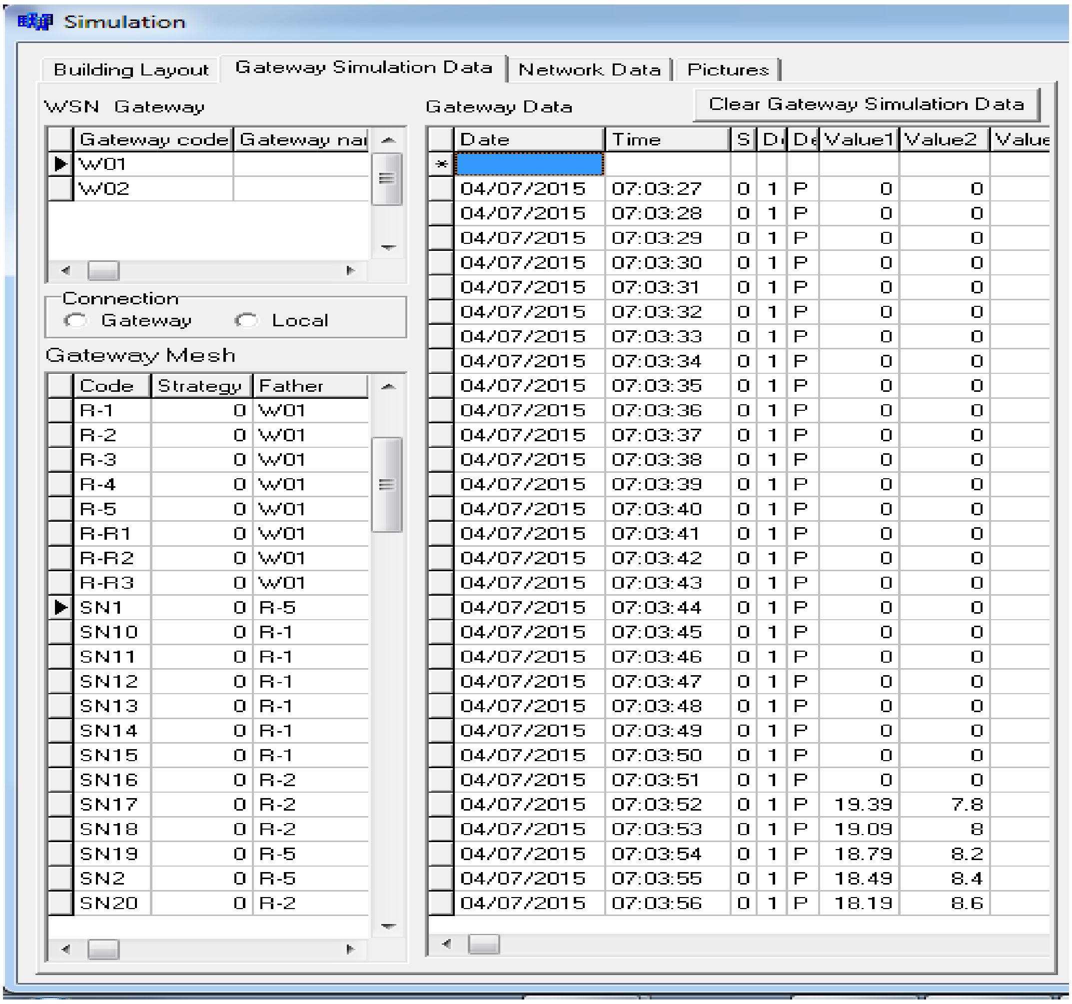


Figure 5.29: WSN generated simulation data

5.6 Summary

The implementation of the system prototype has been limited to the first two steps of the sensors and WSN data fusion involving data capture and processing. Although subsequent steps concerned by the support design for active nodes performing in-networking activities, and information fusion involving intelligent agents can take place only after the configuration and deployment WSN in real world, the case study has demonstrated the practicality of the conceptual generic design framework for hybrid intelligent decision support systems, illustrating the integration of the three major management components for data, knowledge and models. The integration of WSN and RFID is also illustrated in the design support and use of hybrid smart devices grouping WSN and RFID capabilities that enable functional integration of knowledge processes.

Chapter 6: System Evaluation

6.1 Introduction

This chapter is firstly a theoretical complement to the phase system design and development phase, made necessary by the specific complex implementation of hybrid intelligent decision systems which support distinctively in the study of knowledge domains the processes of data capture and the generic development of domain context applications.

The second part of this chapter is devoted to the discussion of the models used in the case study processed by the prototype system. The evaluation objective is to insure that the system meets its requirements from the end-users point of view, and the focus will not be only on the implementation, but also on the system prototype which can be evaluated. The system integration and testing aim at verifying the practicability of the design conceptual framework and the solution functionality.

6.2 System Evaluation

The evaluation of the system supporting the case study proposed in the work to demonstrate the concepts applicability, aims at testing its effectiveness, expanding its development and increasing its performance. This evaluation is an ongoing process offering great value when started at the early stages of implementation. Although the evaluation objective is the collection of information about the knowledge functions and processes, performing the system prototype testing earlier can demonstrate the validity and coherence of the main specific requirements of the knowledge domain.

6.2.1 Elaboration of Performance Goals

Of great importance in this collection of information is the elaboration of performance goals in meeting the system requirements. This can be done only in the context of sensors and WSN information fusion, extending the process of data fusion to the knowledge discovery and extraction as explained in the previous chapter.

Knowledge discovery is based on the use of a combination of sequential pattern mining and associated rules discovery techniques supported by knowledge functions and processes to elaborate new meta-knowledge and rules.

6.2.2 Meta-Knowledge

The meta-knowledge is required to guide future planning or execution or subsequent phases of the system in the real world, using a preference framework for situations in which the realisation of goals associated to the intelligent agents of the distributed multi-agent system is essential.

This framework is based primarily on behavioural types that describe the system agents' observable characteristics to be used for the evaluation of their different interactions with the help of interdependence models. These models are proposed in this work to support the system evaluation by end-users, by describing the system agents' intentions and ranking their influences.

Of great importance in the description of agents characteristics or attributes is the fact that an intelligent agent has only partial information for its own influence valuation, depending on others for their influences. The agent influences are also marginally dependent but conditionally independent. These differences in agent influence dependence structure have significant implications for the effective understanding of end users on how agents should behave for meeting their performance goals when using their own given properties and reflecting the other agents' properties.

6.2.3 Customisation of HIDSS

The evaluation of the system prototype developed in this research supports, furthermore, the customisation of the intelligent decision support system management functions to identify and structure the knowledge support functions and processes which are organised in the form of service based knowledge discovery distributed applications. This can be seen as a priority to the implementation of the sensor and WSN information fusion processes, which include the development of a knowledge based system for a sensor and WSN configuration tasks that identify boundary constraint violations and re-configure instantly.

These knowledge-based distributed applications aim at supporting sensing-monitoring knowledge domain analysis, sensor node design, integrated WSN-RFID configuration and deployment, sensor and WSN data and information fusion and context aware real-time decision making. They are to be deployed via the web in the form of services using a Three-Tier or Multi-tier logical architecture, depending on the complexity of grouping of the related knowledge functions.

6.3 The Evaluation Methodology

Of great importance in evaluating the implemented system, is the relevance of domain knowledge provided by domain experts, mainly when this knowledge is not predetermined. The objects of a domain knowledge are described by ontologies contained in a knowledge base system. Problem solving methods specify how knowledge tasks are decomposed and structured in terms of goal hierarchies composed of collections of smaller goals associated to basic knowledge tasks composing the knowledge domain processes. It is thus of interest to ensure the coherence between domain knowledge description and the primitive knowledge tasks, in an effort to acquire knowledge from end-users, and also to clearly specify for each problem solving method both available and missing knowledge and what can be achieved by the knowledge domain processes invoked method capabilities.

6.3.1 The Evaluation Approach

The evaluation approach used in this work is based around the capture of the following elements:

- The knowledge domain functions,
- The users' problem solving knowledge and
- The logical and physical architectures.

These elements aim at ensuring that end-users using the knowledge acquisition tools are able to modify the problem solving knowledge of a knowledge domain system. More importantly, the required meta-knowledge is composed of information about the system prototype, mainly the efficiency and reliability of its components.

6.3.1.1 The Knowledge Domain Functions

Of great importance in evaluating the system prototype is the identification of the knowledge domain core functions and processes which are the basis for the building and validation of the knowledge system performance criteria. The system testing is user inclusive, based on validating individual and corporate user models which aim at associating their expectations to the system functionality, using their specific requirements and use cases to acquire knowledge from them. This testing covers different aspects of system functionality and usability, integrating the different categories of users to identify missing or error case knowledge activities.

6.3.1.2 The Users' Problem Solving Knowledge

This step is essential in the implementation process of a system for the support and use of interdependency tests to acquire problem solving knowledge from the system end-users. It allows the system end-users to practice the knowledge and model capabilities of the hybrid integrated decision system. This practice is based on the use of a variety of examples and interdependency models to enter knowledge by relating to each other individual components of the knowledge base in order to incorporate and support their additional expectations. Direct authoring of the knowledge domain components interaction, used as trial-and-error testing when using knowledge acquisition tools, is becoming increasingly needed when examples are not readily available, to use demonstrated examples to create interaction rules.

This step constitutes a major challenge in the study and analysis of a knowledge domain, as an important part of the knowledge ongoing acquisition process, to enable the interaction increase between end users and knowledge engineers. This interaction procures a necessary and valuable end users feedback, enhancing the understanding by users of the knowledge base elements and the knowledge acquisition process, and extending the development of knowledge tools.

In this step, end users interdependency models are built around a varied number of user cases to examine knowledge interaction rules, are related to individual system components of both the knowledge and model base. This enables end users to be guided in specifying first their problem-solving knowledge, then addressing several questions and hypotheses for the acquisition of problem-solving knowledge. The required knowledge consensus, for example, in the sensor and WSN configuration task resides in the fact that there is an interdependency between the problem solving knowledge for finding fixes for violated configuration constraints and the definition of constraints and their possible fixes.

Of great interest in the use of interdependency models is the support provided to end-users to model the system agents' intentions represented by goals, by assessing how they affect other agent behaviours in terms of direct goals or reciprocal influence. These causal models are proposed for the illustration of the agents distinguishing influence to support:

- Knowledge inferences and
- Generic pattern identification.

6.3.1.3 The Logical and Physical Architectures

The system's logical and physical architectures are additional sources for the identification of specific areas of system implementation and network deployment concerns, mainly when considering acquiring the full understanding and control of the system architecture and trying to locate any performance bottleneck. These concerns can be accentuated by the typology of the network supporting the real time data capture and processing as a multi-sensor data fusion, supporting both soft and hard data, resulting from the design and composition of homogeneous and heterogeneous sensor nodes, their configuration and deployment, and the data communication.

The importance of the system architecture during the ongoing evaluation process resides in knowing, for each knowledge function, which components of the Three-tier or Multi-Tier architecture communicate with one another and how the different involved devices support this communication, and also which third party services are invoked and the capabilities provided.

The logical architecture is structured around distributed applications implemented in the form of web services, and supported by the physical architecture which can impede the effective support of knowledge functions and processes. It is composed of the database, the web server and the browser. However, it can be based on a single machine playing the role of host for several applications, or include clusters of machines using the same applications. Its internal architecture is based on a multi-level interaction between the different intelligent agents of the distributed multi-agent system. The evaluation of this interaction is complex and requires the use of interdependency models.

6.3.2 The Interdependency Models

The interaction between knowledge functions and processes poses the problem of synchronisation that makes them interdependent from each other. There are three types of interdependency that can characterise the models required to perform the system prototype testing. These are:

- Pooled interdependence consists of no-direct interaction during the testing between the knowledge functions and processes,
- Sequential interdependence links a testing sequence link between two or more knowledge functions and processes,

- Cyclical interdependence establishes a testing dependency between two or more knowledge functions and processes, and can be reciprocal or mutual, conveying a complex testing sequence.

The different characteristics of these models result in different testing requirements depending on the interdependence intensity which can vary from one knowledge domain to another. This dependency requires the use of:

- Standardization in rules and operating procedures for pooled interdependence,
- Flexible adaptive planning and scheduling for sequential interdependence, and
- Shared information and coordinated generic rules for cyclical interdependence.

6.3.3 Generated Versus Interpreted Behaviour

Of great importance in the use of these models is the support of the internal level of the system logical architecture and the dissociation between generated and interpreted intelligent agent behaviours. Generated behaviour is associated to a goal performance measurement, and can be the subject of imprecise performance goal measurement, whereas interpreted behaviour is based on interpretations of partial observations of a subset of agent properties. It is thus of interest to establish the influence dependence-independence of the agent property attributes to provide end users with an acceptable influence independence reasoning for increasing their correctness for behaviour prediction.

6.4 The Case Study Testing

The implementation of the case study has shown two levels of integration of four management functions: data, model, network and knowledge.

The integrated ad hoc WSN-RFID is aimed at hosting several context applications with different characteristics supported by HIDSS that integrates the different management support functions.

6.4.1 Data Management

The main data management functions, which include the collection, storage, processing, dissemination and efficient use of information in the context of sensing, monitoring and tracking, have been accurately simulated. The evaluation has consisted of tracking inputs and outputs. The outputs appear as planned in a one off operation, ensuring that the data input and update programme is on track and effective towards achieving its goals.

The data management evaluation has focussed on checking the following:

- The hierarchy of data via the use of a master source database mechanism and data indexes,
- The logical link between the different tables of the database using data indexes, and
- The data update supported by the use of the database grid to enter the data and modifications, depending on the different operations of the database navigator.

On-line transactional and analytical processing illustrated in Figure 3.4 and Figure 5.1 has been evaluated as follows:

- Transactional processing in devices allocation, and
- Analytical processing in analysing devices states of change to establish their proper functioning.

6.4.2 Data Exchange

Data exchange occurs with emergency operators when planning an emergency response. A Multi-Tier database application has been implemented to support these data exchanges. This application has been created following the three steps listed below:

- Create the application server,
- Register or install the application server, and
- Create a client application.

Of great interest in the data exchange is the choice of communication protocol used to connect client applications to the application server. Each protocol has different advantages, and its choice depends on:

- How many client applications will be connected to the WSN,
- How these applications will be deployed, and
- Considering future development plans.

The communication protocols which have different specifications for exchanging structured information in the implementation of service web-based applications are:

- Distributed component object module (DCOM) connection,
- Socket connection,
- Simple object access protocol (SOAP), and

- Web connection.

The client application is created after the database server application has been created and run. By specifying the client at design time, it has been possible to connect to the application server for the client connection testing. However, it would have been possible to create a client without specifying the application server at the design time, and only supply the server name at runtime. The drawback for doing so prevents it being possible to see if the client database server application works as expected when coded at the design time.

Alternatively, the data exchange instead of using a web connection, can use a SOAP connection or a socket connection. However, it has not been possible to use the same connection for multiple remote data modules. A separate connection component for every remote data module on the application server is required, and each connection component represents the connection to a single remote data module. This connection component cannot be a SOAP connection.

The data exchange is supported by a connection component involving the implementation of the following three components of a web module:

- A dispatcher component, which responds to incoming hyper text transfer protocol (HTTP) messages that include SOAP requests,
- An invoker component, which interprets and executes SOAP requests, and
- A publisher component, which publishes a list of web service description language (WSDL) documents describing the Web Services for client applications.

After creating the Web Module with the dispatcher, invoker, and publisher, the Server Application dialog displays a message box that asks if they want to define a new interface for the client SOAP module. The client application must know the application server's interface declaration at compilation time, WSDL documents describe the interfaces called by the database server application. These interfaces are different from the SOAP data module interface. The implementation of the web module deployment is supported by a connection to the WSN server using a client socket for the connection of the emergency operator via their web address. The client receives a buffer of data made available to the client.

Although the data exchanged with emergency operators is not yet structured and formatted, data contained in a database memo-field representing a data field chosen randomly from a table of the database, has been exchanged using a client connection.

6.4.3 Model Base Management

The model base implementation provides a flexible support for the evaluation of several policies related to the design, allocation, configuration and deployment of sensor nodes and WSN, and other models governing the interaction and safety of people and objects in attended places. This is done by system testing, based on the use of models, testing to represent the desired system behaviour when reacting to dynamic change of behaviour patterns or detected system control events.

Of great importance in the model testing is the system validation which is concerned with building the right system whereas the model verification is an implementation process that helps with building models and a fully functional system. Therefore, the requirements themselves are scrutinised for consistency and completeness, making the model validation and testing a reciprocal activity.

6.4.3.1 Model Testing

Testing models are used in many ways throughout the system life-cycle which include the following steps:

- Improved quality of specifications,
- Code generation,
- Reliability analysis, and
- Test generation.

They are used to understand, specify and elaborate policies in several domains of use and control systems. Their testing aims at measuring the overall functional compliance of the system to the specification by building the generation of:

- Model traces which are comprised of input and expected output, and
- Test cases which contain the various options for an implementation.

These are derived from the solution and system requirements, and must be sufficiently precise to be used as a basis for the generation of significant and meaningful test cases.

Although it is possible to automatically generate these model-based test suites, this evaluation is based only on manual test suites for the detection of:

- Failure detection,
- Programming errors, and
- Observable differences between the intended and actual behaviours of the system.

6.4.3.2 Selected Models

a) The Device Allocation Model

Accurate sensor node localisation is a critical requirement for the deployment of WSNs in a wide variety of applications. Based on a cooperative localisation, sensor nodes which are equidistant from each other, work together in a peer-to-peer configuration to make measurements and localise, and then form a map of the network composed of a mesh structured in a number of homogeneous clusters of sensor nodes.

The device allocation model, which consists of equally spacing sensor node devices from each other, is based on a dynamic sensor node allocation algorithm for full sensing and tracking coverage. Two types of algorithms have been implemented. These are:

- The hexagon model based on the central place theory, i-e each sensor node corresponds to the centre or vertex of an hexagon, and
- The square model.

These two models are based on the most effective geometric patterns to cover areas with a minimum sensing overlap. The geometrical location distribution pattern is considered in this framework as the basis for the sensor nodes localization. The consideration of both patterns, hexagonal and square, with different settings (localization per room or building, spacing distances, different clusters) procures an extensive support for a multi-criteria sensor nodes localization decision making approach.

The increase of the number of sensor nodes when the spacing distance is reduced poses the problem of how optimal can the grouping of sensors in the sensor node be organized. Table 6.1 shows for example, for the building layout shown in Figure 5.12 that 7 extra nodes (23.33%) will be required, when 3m spacing is used instead of 4m for the Hexagon pattern.

NLDP	Hexagon			Square		
Spacing distance (m)	3	4	5	3	4	5
Number of sensor nodes	37	30	18	36	20	18
Difference	7	12	---	16	2	---
Ratio (%)	23.33	66.67	---	80.00	11.11	---

Table 6.1: Relation between spacing distance and number of sensor nodes

The concept of sensing overlapping, composed of single and double sensing zones, for homogenous sensor nodes is used to evaluate the sensing overlapping shown shaded in Figure 5.10 and in Table 6.2.

	Localisation Distribution Pattern					
	Hexagon			Square		
Spacing Distance	3	4	5	3	4	5
Nbr of sensors (Room model)	37	30	18	36	20	18
Nbr of sensors (Building model)	33	17	14	36	20	16
Sensing Area	28.26	50.24	78.5	28.26	50.24	78.5
Double Sensing	9.76	17.34	27.09	20.52	36.48	57.00
Single sensing	18.5	32.89	51.40	7.74	13.76	21.50
Ratio Double/S	52.71	52.71	52.71	265.1	265.11	265.11
Ratio SSz	34.52	34.52	34.52	72.61	72.61	72.61
Ratio SSz	65.48	65.48	65.48	27.39	27.39	27.39

Table 6.2: Double and single coverage rations

Relevant information can be extracted from Table 6.2 the ratio (Double/Single) sensing zone is 2.65 times more important when using the Square geometric and only 0.52 time more important when using the Hexagon geometric sensor node allocation pattern. This suggests the preference for the square model, which results in sensing overlap simultaneously between two operating sensor nodes. This sensing overlapping could result in some activity redundancy (example of alarm stripping) which if detected can be processed at the node level should one at least of the sensor nodes involved be active.

b) The Fire Simulation Model

The fire simulation model has been evaluated on the basis that a fire location is selected inside the area sensed by a sensor node device. The fire location can be within the sensed zone of one or several sensor node devices, depending on the geometric pattern used to allocate them:

- Hexagon allocation model: 1 to 3 devices.
- Square allocation model: 1 to 4 devices.

When the temperature of the sensed region read by one sensor node exceeds a number of degrees of a pre-determined setting, taking into account the sensing tolerance value, the following three actions are taken:

- Invoke the emergency planning model,
- Check the validity of the temperature data and
- Prepare the emergency response.

• *The Emergency Planning Model*

The emergency planning model consists of a simulation aimed at predicting the fire propagation for a selected fire location, as illustrated in Figure 6.1. Although there are several fire propagation models in the literature, the one presented in the case study is just an illustration used to:

- Show the behaviour of the different sensor nodes in terms of activation when a fire is detected, and
- Evaluate the integration in HIDSS of different models.

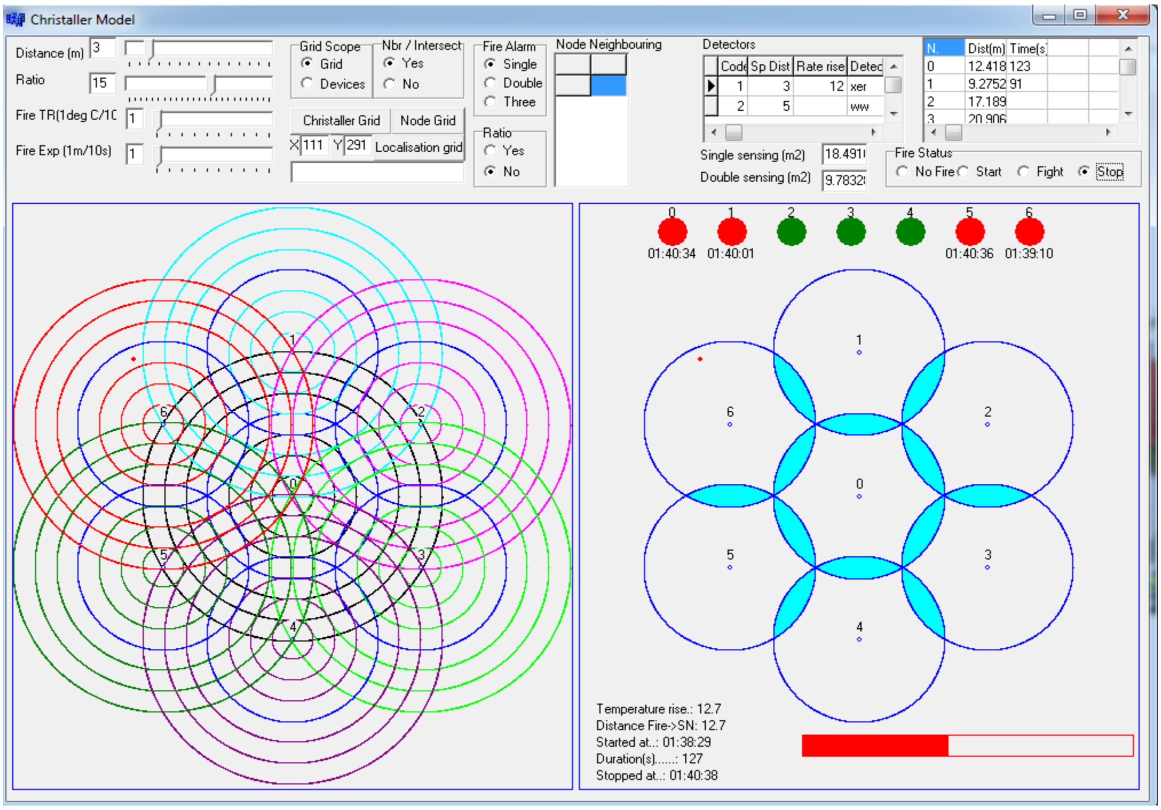


Figure 6.1: Fire emergency planning mode

The fire propagation knowledge domain is composed of several classes of algorithms used to simulate the spread of fire modelled as a complex dynamic-system. This complexity is characterised by a composition of combined and integrated sub-problems solved by using analytical and computational behaviour models integrated in a simulation support tool based on fire propagation behaviour prediction. Examples of sub-problems are:

- Heat capacity, production and evolution,
- Heat and moisture fluxes from the fire,
- Local wind predictions.

The model implemented in the case study is just a simple prediction based on the use of the fire temperature rise and expansion, without taking into account the different fire influencing factors which include:

- The wind characteristics,
- The materials used in the building, and
- The proximity of the fire to energy use points (gas and electricity).

- ***Checking the Data Validity and Accuracy***

Of great importance is the checking of the data validity and accuracy and the understanding of the distinction between 'primary' and 'secondary sources' of information; the primary source being the WSN and the secondary being the fire propagation model. This data validity checking aims at:

- Establishing the data consistency as the main measure of reliability,
- Eliminating or reducing the data errors during the network exchanges, and
- Eventually establishing and identifying the data losses within the network.

The predicted values provided by the fire propagation model are used by HIDSS to take the following control actions:

- Check that the sensor node is working properly.
- Re-examine the configuration status of the sensor nodes involved: their status is set to:
  - Off: when sensor nodes are not in use,
  - On: when sensor nodes are in sleeping mode, and
  - Active: when sensor nodes work.
- Attaching the sensor cluster to an emergency router connected with the highest width band of the WSN.
- Activate the heterogeneous devices aimed at enhancing the role of homogeneous devices and supporting emergency response.

c) Preparing the Emergency Response

The emergency response can be effective only after the following information is elaborated in real time:

- ***Fire Progression***

Real time fire progression data is available from the fire emergency planning model as discussed above.

- ***People Localisation and Tracking***

HIDSS provides real time people localisation and tracking as illustrated in Figure 6.2

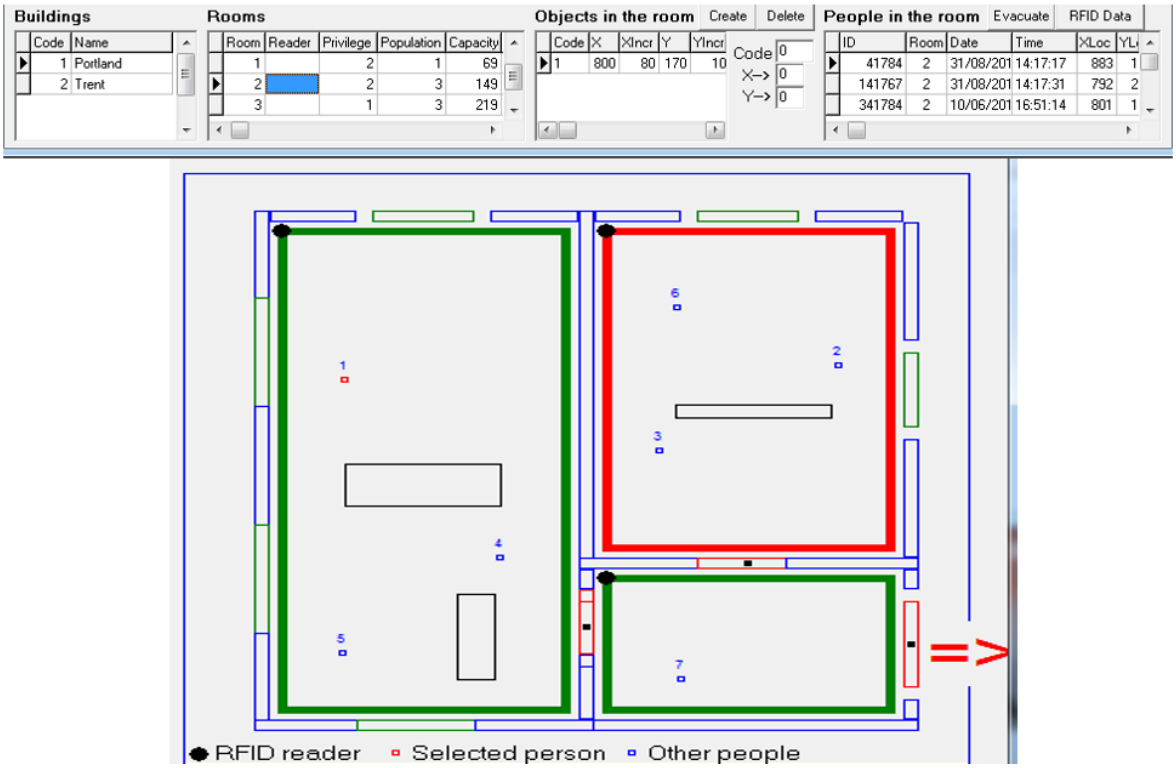


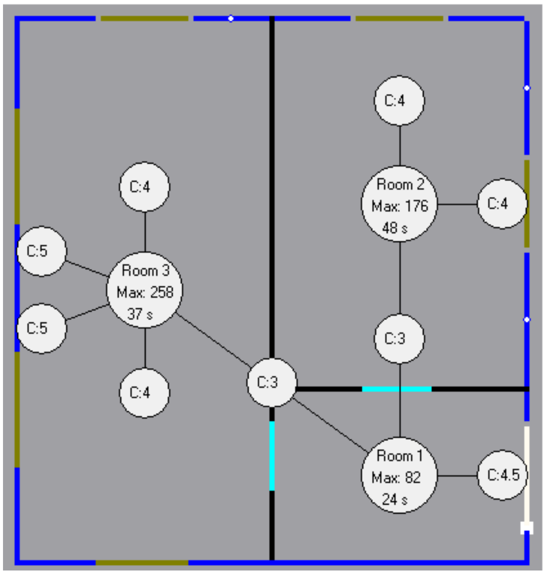
Figure 6.2: Real-time people localisation

. There is a read error rate associated to the use of RFID when supporting the functions of localisation and tracking people and objects. These errors are due to the fact that the integrated RFID-WSN are complex hybrid systems, consisting of analogue and digital hardware, and software components with some security issues that include:

– Tags not positioned appropriately,
– Positive readings when the tag is visible to the RFID reader, but cannot communicate with it, and
– Negative readings when the RFID reader cannot retrieve the tag identifier.

- ***Evacuation Flows Analysis***

HIDSS provides decision support for the analysis of the evacuation requirements expressed in terms of the number of people in each room, taking into account the evacuation capacity allowed by the doors dimensions and the evacuation speed which might be different for the various categories of people. This decision model, shown in Figure 6.3, indicates the theoretical capacities for occupancy and evacuation for each room in the building.



Code	Identification	Calculation
Cn	C: Door or Window n: Width	
Max(p)	Occupancy maximal per room	Room area/Number of people per m^2
N(s)	Theoretical evacuation time at the door	Room population*Evacuation rate/Exits length
The walking time needs to be added to N		

Node	From	To	Type	Dir.
1	1	0	3	1
2	1	2	2	7
3	1	3	2	5
4	2	0	1	1
5	2	0	1	7
6	3	0	1	7

Figure 6.3: Evacuation requirements mode

This model can be used in the emergency preparedness to support the evaluation risk assessment. As it can be seen from room flow diagram, the theoretical evacuation time at the room safety exits is an indication of the evacuation bottleneck that would require appropriate support actions.

- ***Evacuation Route Modelling***

Of great importance in the emergency planning is the evacuation or escape route determination which takes into account several factors that include:

- The configuration of the affected area,
- The absence of safety exits within the non-affected area,
- Validated safety exits within the non-affected area,
- The evacuation scale expressed by requirements in terms of population and time,
- The evacuation flows confluence between rooms, and their impact on the evacuation time,
- The evacuation or exit strategy, and
- The collision and deteriorated evacuation conditions, and individual people situations.

The problem of modelling evacuation routes from a building and out of an affected area is complex in the sense that the pre-defined set of exit points, illustrated in Figure 6.4, can be affected by the declared hazard and be a restricted area. The route finding process is the interpretation of the conditions contained in the evacuation risk assessment plan and their evaluation in the context of the hazard occurring. Hazards include fire, building structures, utilities and equipment failures and accidents.

The conditions-hazard context mapping aims at eliminating unsafe evacuation exits, and identifying validated safety exits within the non-affected area which can be composed, for example, by determining plausible exits using an efficient heuristic algorithm as a reference for comparative analysis and optimal time and safety calculation. Optimal safety calculation can include the potential hazard risks and the evaluation of their impact on people's health.

- ***Pre-Defined Exit Points***

The evacuation plans contain evacuation time and routes for different hazards as established in the escape risk assessment. These plans aimed at supporting an effective, timely and orderly planned group evacuation, contain instructions, guidance on exit usage, and information on how and when exits should be operated.

Pre-defined exits include: External doors and windows, Internal doors, and Additional specific exit points that include roofs, ground floors, and others.

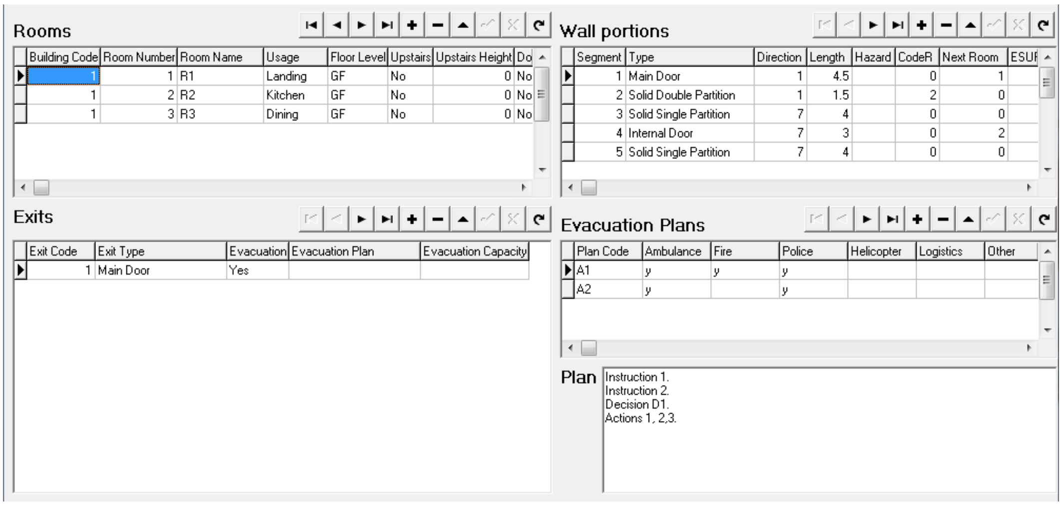
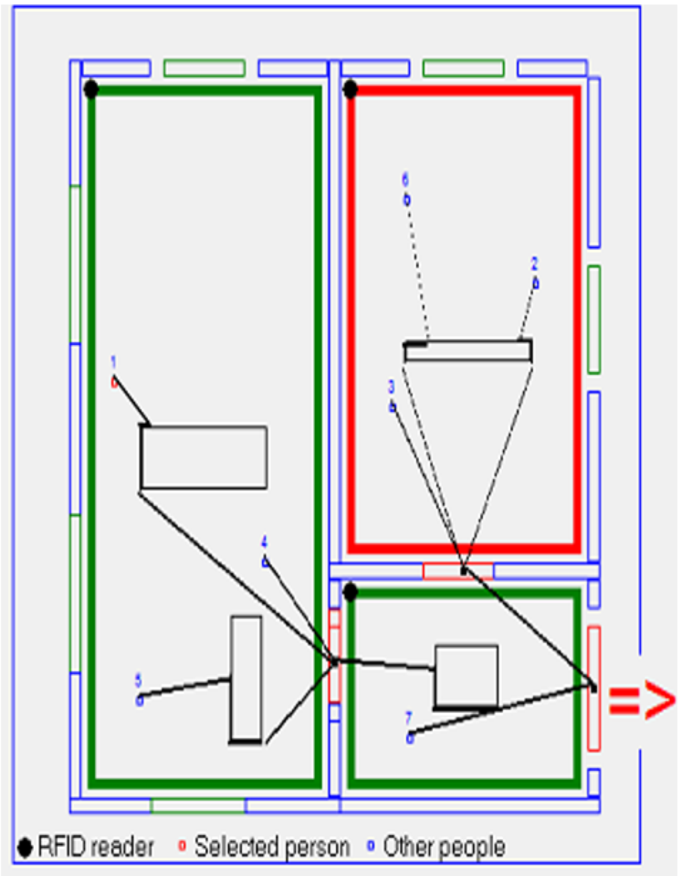


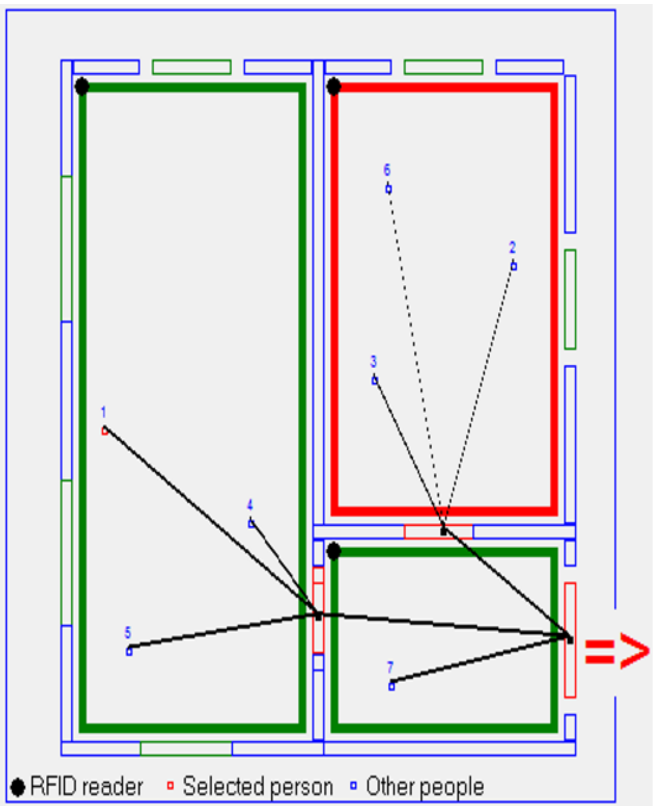
Figure 6.4: Pre-defined exits points for each room

- ***Route Planning Model***

The illustration of the route planning model developed in the research case study is shown in Figure 6.5. The route planning was elaborated by simulating a potential hazard by one or several objects stored anywhere in the room and is based on the following rules:



N.	Time	x	y
1	20:42:04	632	150
2	20:42:04	633	152
3	20:42:05	634	153
4	20:42:05	635	155
5	20:42:05	636	156
6	20:42:05	637	157
7	20:42:05	638	159
8	20:42:05	639	160
9	20:42:05	640	162
10	20:42:05	641	163
11	20:42:05	642	164
12	20:42:05	643	166
13	20:42:05	644	167
14	20:42:05	645	169
15	20:42:06	646	170
16	20:42:06	647	171



ID	Start	End	Duration	Room	N.
41767	20:42:04	20:42:22	00:00:18	3	1
41784	20:42:04	20:42:15	00:00:11	2	2
141767	20:42:04	20:42:13	00:00:09	2	3
241767	20:42:04	20:42:17	00:00:13	3	4
341767	20:42:04	20:42:20	00:00:16	3	5
341784	20:42:04	20:42:16	00:00:12	2	6
741767	20:42:04	20:42:12	00:00:08	1	7

Figure 6.5: Example of evacuation route and time

- Walk from point of localisation to the room door, and then from door to door till reaching the external door,
- Collision detection requires object avoidance and re-routing observing rules mentioned above, and

Queues at nodes or evacuation pre-defined points resulting in evacuation congestion and delays.

Although the walking path during escape can be random and disordered, straight movement has been used in this implementation to simplify the random successive steps and reduce the walk disorder. The navigation of people during the building evacuation is based on the division of the evacuated area in evacuation zones (rooms), defining instructions to follow using a pre-defined route.

- ***Evacuation Strategy***

The full implementation in the real world of the evacuation model will include giving escape instructions via individual RFID tags or heterogeneous devices. In the case study proposed in this research, its implementation is based on the generation of evacuation routes for each evacuation zone or room.

The model supports the evacuation strategy that maximizes the number of people reaching safety exits and also minimizes the total evacuation time. It aggregates the different zone evacuation paths, and this composition is an interactive and iterative real time process that takes into account the changing evacuation requirements which are affected by the hazard development and the dynamic conditions evacuation taking place.

d) WSN Configuration

The WSN configuration is an iterative process composed of the following four steps:

- Sensor node selection,
- Sensor node configuration and adjustment,
- Sensor node clustering, and
- Cluster aggregation.

This process is supported by a configuration strategy that provides several configuration options as illustrated in Table 6.3.

Configuration operation	Options
Sensor node configuration	○ Energy supply use point ○ Doors & windows sensor nodes located ○ Sensor node ○ Room usage ○ Room ○ Building
Sensor node clustering	○ Building ○ Room ○ Spacing distance
Clusters aggregation	○ Distance ○ Size
WSN generation	○ Sequential ○ Sequential alternate ○ Router per room ○ Router per room alternate ○ Router per sensor node cluster ○ Router per sensor node cluster alternate ○ Homogeneous vs heterogeneous ○ Homogeneous vs heterogeneous alternate

Table 6.3: WSN configuration options

These options enable a thorough evaluation of configuration policy shown in Figure 6.6, that

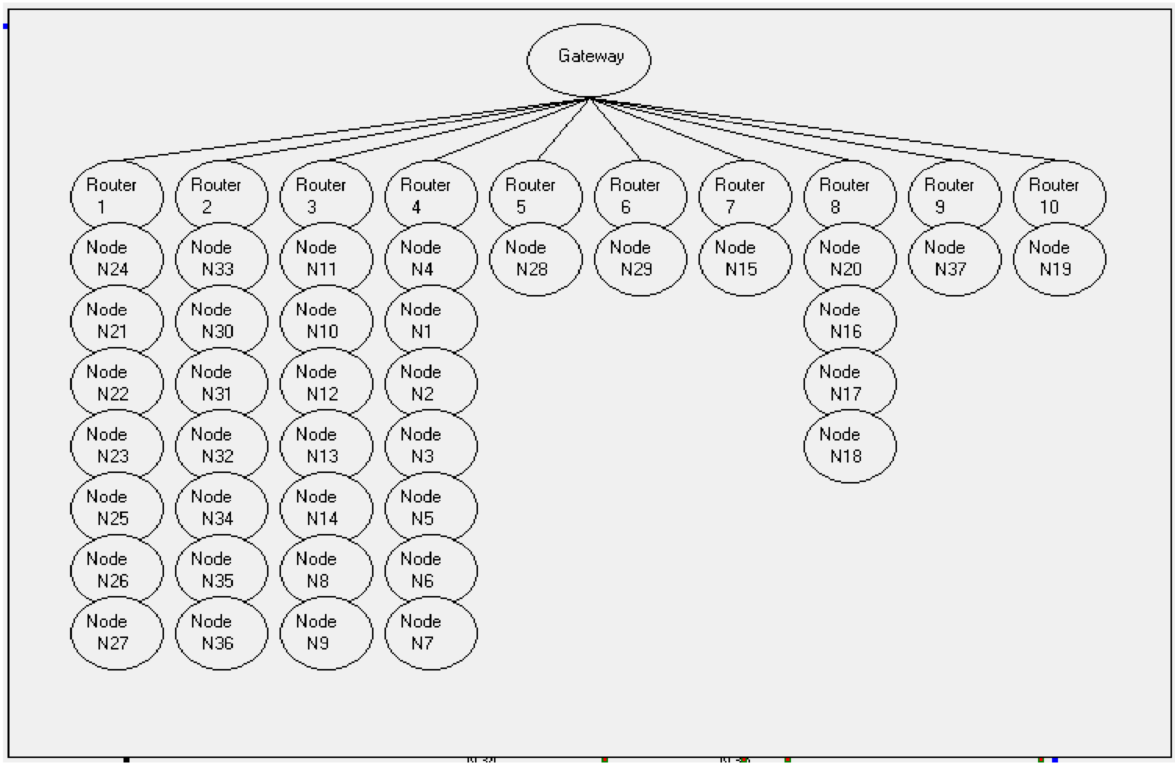


Figure 6.6: Sensor nodes clustering

is implemented to support a real-time sensor node and ad hoc WSN configuration and re-configuration when performance and security issues are identified. The implementation of the WSN configuration strategy has resulted in the following two WSN configurations. Different cluster aggregation configurations can be generated by varying the aggregation index expressing the cluster size difference to increase the network homogeneity.

The diagram in Figure 6.6 shows a sensor node distribution into clusters with a maximal size difference of 6 sensor nodes. Cluster aggregation consists of reducing the node size difference between clusters to make them less or more homogeneous.

The diagram in Figure 6.7 shows the result of the cluster aggregation reducing the number of clusters to four, and a maximal size difference between clusters of four clusters.

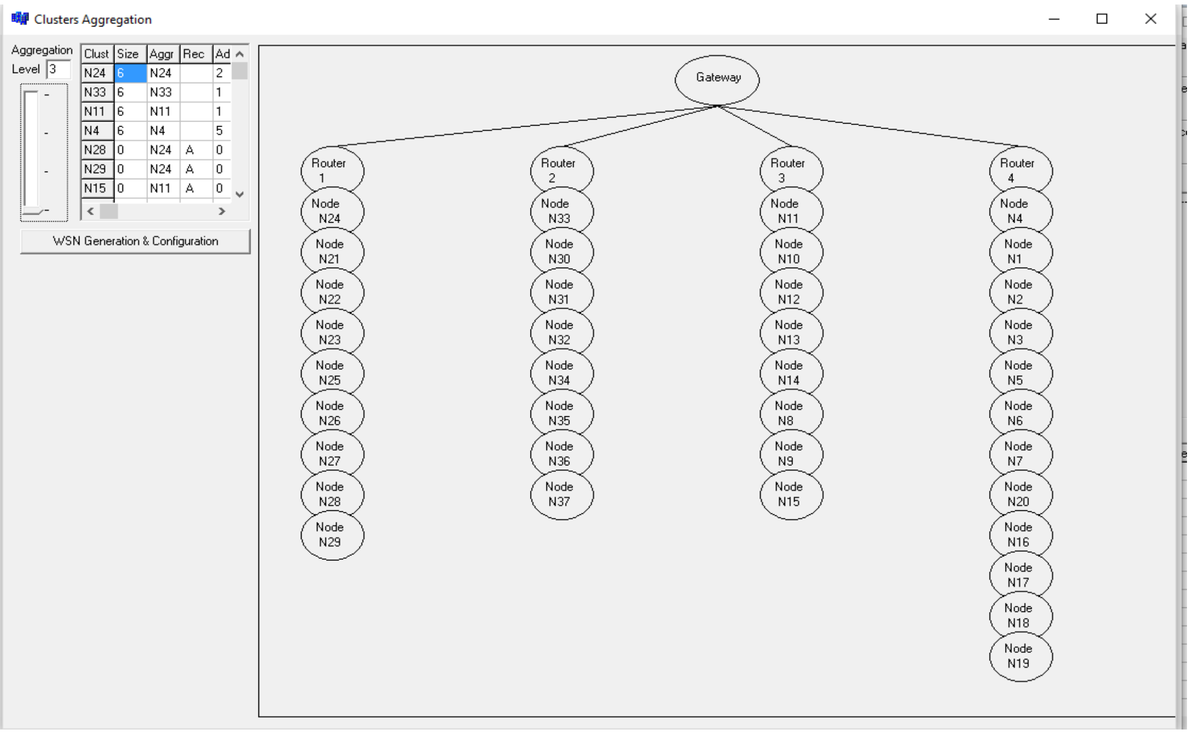


Figure 6.7: Sensor nodes cluster aggregation

e) `WSN Generation

The WSN generation is the second level of WSN configuration which requires the use of a generation policy to support the network variance homogeneity versus heterogeneity, as illustrated in Figure 6.8. This process is performed using the allocation options described in WSN generation in Table 6.3, to distribute the sensor nodes between the different WSN routers. The lifespan of the WSN is increased by ensuring a homogeneous distribution of:

– Nodes in the clusters, and
– Clusters in the network.

The concept of alternate distribution or allocation relates to:

– Sensor nodes allocated sequentially to different routers, or
– Sensor nodes allocated sequentially to the same router observing an increment to reserve empty connection slots for the purpose of:
  - Safety factor, and
  - Reconfiguration.

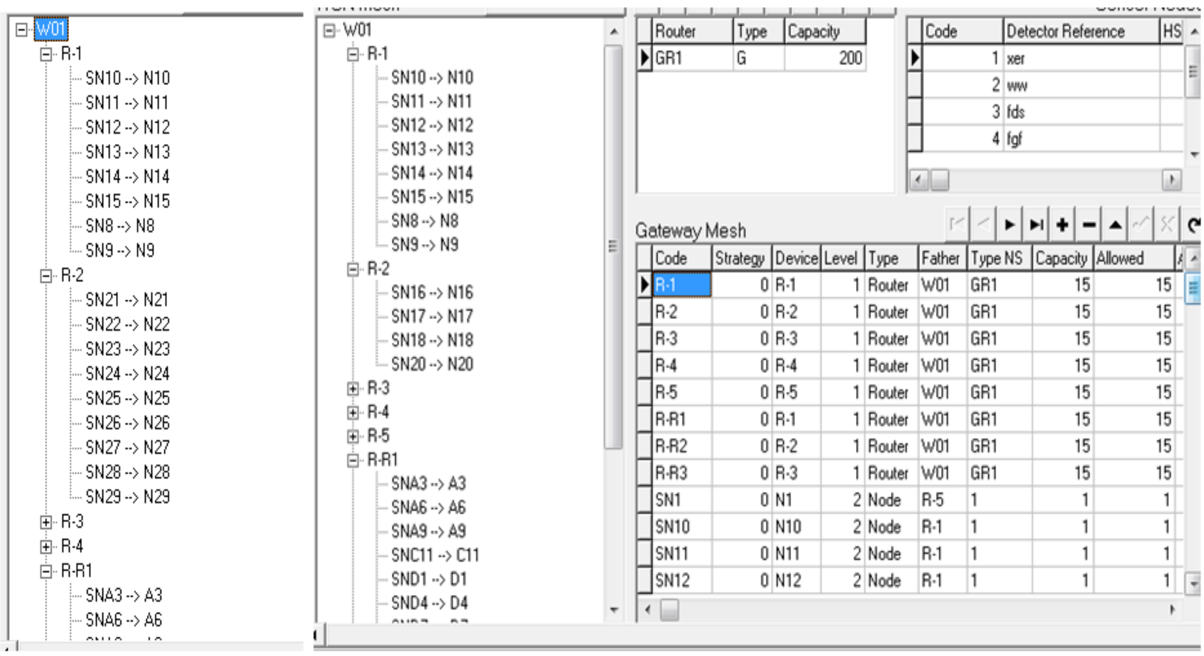


Figure 6.8: WSN variance homogeneity-heterogeneity

6.4.4 Network Evaluation

The continuing growth in traffic types and volumes is presented as the main problem in network management, in addition to detecting faults and intrusions, bandwidth management, checking and verifying performance, and maintaining and upgrading the sensor nodes and network. HIDSS has been designed to integrate support resolving and showing these problems and the use of virtual monitoring for the network management that includes inventory control, performance bottlenecks, applications intermittent crashing while operating multi-service switching, and resources reservation for routing protocols as part of traffic engineering.

6.4.4.1 Data Volumes, Visualisation and Backup

Although there are many third party WSN tools for visualisation, the heterogeneous data emitted by individual homogeneous and heterogeneous sensor nodes and collected by a gateway and forwarded to a base station connected to a server, is verified and stored by HIDSS in the WSN database from where it can be compiled and visualised. The implementation in the real world of HIDSS will result in large data volumes being needed for the deployment of context service web-based applications.

The testing operated in the case study has shown a low volume of data. The visualisation and backup were supported by the different knowledge functions and the database management functions of HIDSS as explained and shown in the previous chapter. The sensor nodes and WSN architecture is visualised to show the configuration status of the network, and also wherever it was required when invoked in the processing of the different implemented knowledge functions.

6.4.4.2 In-Networking

In networking is concerned with deploying active sensor nodes with storage and computing capabilities with the aim of real-time sensing and tracking control and the reduction of data communication volumes in the network. The configuration of the network evaluation kit, composed only of a few sensor nodes, has not allowed the testing and evaluation of in-networking.

6.4.4.3 Network Inventory Management

Hardware and software inventory control is an essential tool that supports the other network management functions. The network components, their identities and locations, and the services involved for their control are visible through the virtual control room monitoring. The testing of this monitoring has shown the sensor nodes and WSN identities and locations without linking them to the services invoked by their control. The software inventory control has not been implemented due to the absence of the service agent’s composition.

6.4.4.4 Network Fault Management

Of great importance in network fault management, is the generation of detection and exception alarms, in addition to fault analysis and correction. Fault analysis involves:

- Configuration audit to ensure that the sensor node device and their individual components meet the sensing or tracking requirements, and

– Tracking configuration changes requiring reverting or undoing the operated changes.

HIDSS supports the tracking of the sensor nodes and WSN control configuration and re-configuration, during the network first deployment, repair and upgrade.

6.4.4.5 Network Intrusion Detection

The flexible and adaptive security oriented policy specified for implementation in HIDSS is a part of the filtering system aimed at reducing network data volumes, and keeping a track of significant data. This policy is based on the fact that the network cluster configuration has allowed the selection and storage of two sets of sensing and tracking data emitted by both the cluster sensor node head and its substitute head. This context aware data is used to:

– Ensure the compatibility and validity of sensing and tracking data;
– Tracking the existence of any suspicious data fraudulently injected in the network.

Although there are several security tools incorporating anomaly detection functionalities that can be integrated as third party tools, HIDSS can interact with them to enhance intrusion detection and assess impact. On the other hand, software inventory management is a full scale HIDSS specification for the logging and monitoring of knowledge functions processing.

6.4.5 Knowledge Management

The evaluation of knowledge functions is concerned by the modelling and testing of the knowledge processes implemented in the knowledge management component. These functions include:

– The configuration of the network, and
– The simulation of models used for the implementation of the building structure and virtual layout and also data capture and processing.

The network routing knowledge functions have not been modelled, and the network management software testing for an ad hoc WSN is not included in the case study evaluation.

6.5 The system performance

The performance of the system developed in this research is related to its customisation as underlined in Section 6.2.3. This customisation depends on the hybrid decision models that are available from either the system knowledge elaboration and/or the public domain, and also on the technical aspects of the integrated RFID/WSN used for the real time data capture and in-network processing, particularly the network architecture and the communication support.

The system performance is concerned with the measured system performance, the interactive system performance, and the determination of causes of the system malfunctioning.

6.5.1 The measured system performance

The system prototype implementation has not gained from the measured system performance due to the nature of the simulated WSN used to capture the data. We have assumed that the network used in this research can be seen as a third party support, and its performance is independent of this work.

However, of great importance in the measured system performance is the quality of service associated with:

- The sensing data reading, requiring of the reading frequency adjustment when required,
- The sensing coverage that integrates both faulty sensing devices or low signal, requiring the network re-configuration, and
- The data communication and processing within and outside the network, requiring associating the quality of service to both each sensor node and its corresponding router.

This quality of service can be used to predict the system performance and error rates regarding the above aspects mentioned.

6.5.2 The interactive system performance

The interactive system performance so called the user-perceived performance, reflects the system responsiveness as perceived by its potential users, in terms of does the system do what it's aimed at, and identifying potential performance problems reflected in the system behaviour. This has been properly covered the case study testing, detailed in Section 4.4.

6.5.3 The system malfunctioning causes

Situations that may cause the system to malfunction are threefold:

- Situations that plague users when the system doesn't respond appropriately to the users expectations, occur when knowledge processes are badly modelled or coded, or result from latency, showing unexpected and/or non aggregated results,
- Normal situations which can convey uncertainty or imprecision, and that can lead to inappropriate system reactions, and
- Missing elements which characterise situations that require the incorporation of additional intelligence to fully integrate the tasks of a knowledge domain context.

The first group of situations have been handled over the repeated system testing, whereas the last two groups of situations are complementary in the sense that situations which convey uncertainty or imprecision, would require the incorporation of additional processes to reduce the uncertainty and/or imprecision. This can be illustrated by the following examples:

- A sensor data reading can be missing in the following cases:
    - The sensor can't read (faulty or non-configured),
    - The sensor has read, but not connected to the WSN (not configured or low signal), and
    - Data lost within the communication process.
- A sensor data can be interpreted in the different following ways, mainly in the case of detectors emitting sounds or lights to indicate the critical values reach. This situation requires additional checks to reduce false alarms which might result in inappropriate actions. An example of false alarm conflict resolution is presented in Section 4.5.2 (Complex Generic Knowledge Tasks).

6.6 Example of comparative evaluation of Evacuation systems

There is a variety of evacuation systems available in the trade. These include voice alarm systems such as E100 by Siemens.

6.6.1 Siemens E100 evaluation

The evacuation systems E100, as many other similar systems, are aimed at informing people of their immediate evacuation within minutes, from the building where a fire breaks out, using a voice alarm for clear announcements and following an orderly and safe evacuation.

These systems are connected to fire detection and alarm systems, contrary to HIDSS that integrates both functions planning evacuation, fire detection and evacuation. They rely on autonomous fire detectors that convey the risks of malfunctioning that include both false alarms or not breaking out in the case of fire occurrence. However, they automatically trigger a voice alarm using class D amplifiers, and focus on the quality of messages, ensuring that evacuation messages are not misinterpreted or disregarded, containing clear instructions that can be immediately understood. In addition to using optical orientation aids in the form of escape route lights and display panels to enhance the route guidance escape, they incorporate pre-programmed evacuation processes that will be activated according to the evacuation plan selected by the rescue team as agreed upon. The combined use of optimal orientation aids and voice messages aims at reducing the impact of visual and hearing impairment, and excessive noise and lack of visibility.

These systems support automatic phase driven evacuation, and are based on programmable control logic and digital signal processing. They can deliver simultaneously a variety of personalised messages corresponding to different hazards and scenarios requiring people evacuation from different zones at a time. They are based on the use of multiple audio communication channels with loop redundant network for uninterrupted information exchange to deliver both pre-recorded and live announcement messages, by the means of speakers and paging. These systems are operated manually by authorised people that support re-routing the evacuation when fire spreads and escape routes are no longer passable. They are based on LCD display with touch-screen, and automated procedures synchronised with fire detection and alarm systems. They can be connected to a computer to import a ready-made configuration, and connect to similar systems and also to fire-fighters phones, in a network configuration, managed by networked control units.

6.6.2 HIDSS evacuation

The software proposed to support the generic integrated design conceptual framework is based on essential capabilities inexistent in E100. These capabilities are:

- Identifying room exits, and associating one or more evacuation plans per room in the monitored premises as illustrated in Figure 6.9:

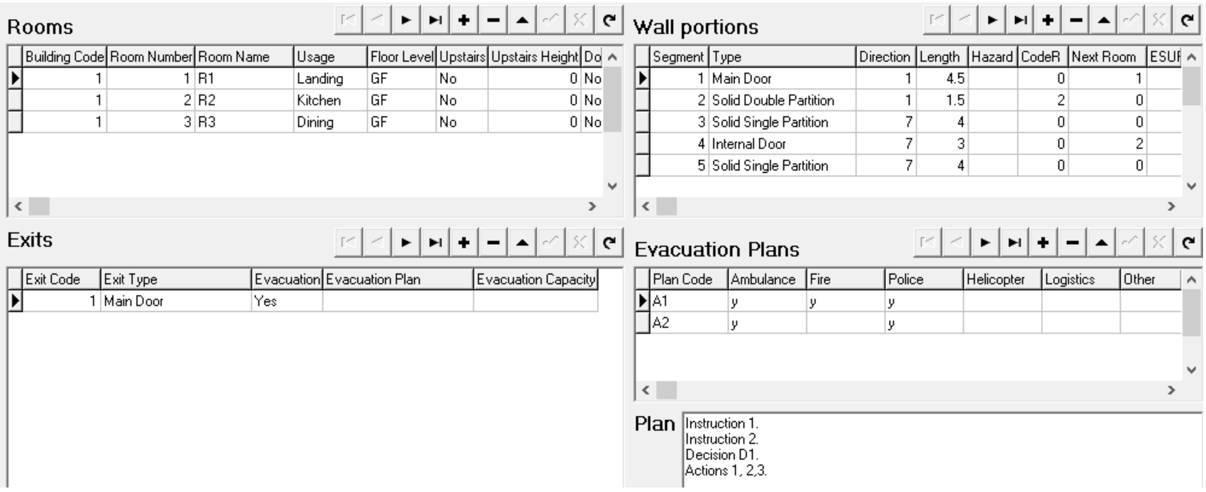


Figure 6.9: Exits and evacuation plans specifications.

– Specifying the nature and type of wall portion to enable the identification of exits and potential hazards associated to the building elements,

– Specifying the building navigation routes and flows in accordance with the room attendance capacity as shown in Figure 6.10.

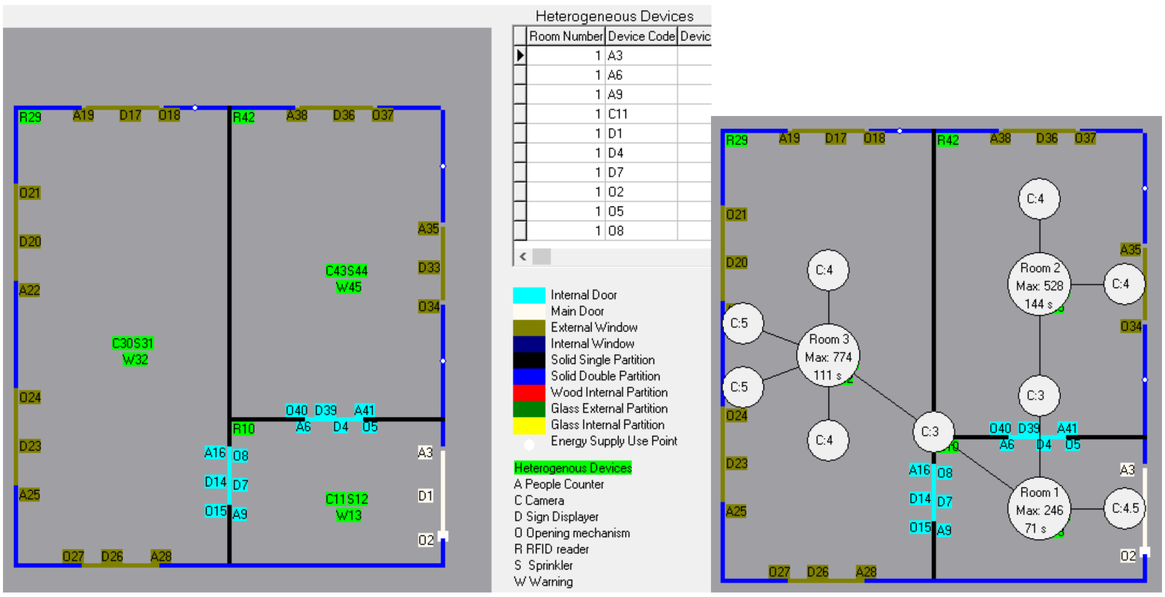


Figure 6.10: Heterogeneous devices specifications, and navigation and flow model.

– Enabling the deployment of control mechanisms supported by a variety of heterogeneous devices in each room following hazard occurrence and detection as shown in Figure 6.10, to automatically:

  ○ Record the situation prevailing in each room,

  - Deploy the room sprinklers,
  - Close or open doors as needed,
  - Switch on the lights, and
  - Display escape route lights,
- Identifying and tracking individually people equipped with wrist bands that integrate RFID and WSN technologies and linked to a database containing impairment data (hearing, sight and mobility) to:
  - Indicate specific evacuation needs,
  - Provide individual evacuation support emitting personal and adapted evacuation messages,
  - Provide predictive real-time evacuation data used as an evacuation guide as illustrated in Figure 6.5, and
  - Re-route evacuation paths taking into account the location of occurring hazards and their progression illustrated in the evacuation simulation by different objects that can be located anywhere within the monitored premises.

This comparative evaluation is based on showing the differences about the support capabilities required at the different stages of emergency systems: planning, surveillance and hazard mitigation. These capabilities are inherent to the systems performance and timing, mainly the time saving when using evacuations data models that include predictive data.

6.7 Summary

The evaluation of the system prototype has been limited to the testing of implemented functional components leading to the data capture and processing that compose the first step of the WSN data fusion process. The testing has revealed additional requirements that extend the design and development of HIDSS to derive new specifications for the support of other knowledge processes of the sensing - tracking domain, and knowledge rules elaboration for problem solving modelling (models) required for the generic iterative development and implementation of domain context applications.

This evaluation has not allowed the testing of all the problems inherent to the configuration and deployment of WSN in the real world. However, the case study has produced conclusive results that demonstrate the effective implementation of the knowledge entity model and confirm the practicality of the conceptual generic design framework for hybrid intelligent decision support systems. This framework illustrates the integration of WSN and RFID that extends the combined use of smart devices and contributes to the enhancement of the process integration of data, knowledge, and model functions in a multi-agent web based service architecture system.

Chapter 7: Conclusions and Future Work

7.1 Conclusions

The work presented in this research started with the idea of how best to design integrated web-services composed of intelligent agents interacting with each other to control dynamic data-context aware environments. The study of the research domain has exposed the importance of the specific characteristics of data context aware environments, which include real time heterogeneous data capture and dynamic collaborative decision making that enable intelligent analysis and effective real time response, mainly in emergency response situations.

The real time heterogeneous data capture results from the deployment of smart homogeneous and heterogeneous devices designed and built around an integrated WSN-RFID technology, and wirelessly connected to an ad hoc WSN forming a network mesh. This network, which requires configuration prior to deployment, became an essential element of the generic design conceptual framework supported by a hybrid intelligent decision support system.

The need for such a support system is justified by the complexity of the analytical modelling of dynamic and collaborative knowledge and decision making processes that are supported by the integration of data, knowledge and models. These three elements are essential for the study of knowledge domains and their structure into knowledge processes aimed at data and knowledge acquisition, in the context of data and information fusion.

The different functional components supporting the sensor nodes and WSN data fusion, and also information and knowledge fusion, have been articulated in a distributed web-based multi-agent system that aims at supporting several context applications. This system architecture has taken into account the necessary decoupling of the data capture and processing from the process of knowledge discovery and refinement, imposed by the hierarchy of the functional links of the knowledge domain study and the methodological approach used for its decomposition and analysis.

This research has covered several hybrid domains: integrated technology sensor node devices, homogeneous versus heterogeneous networks, processes, automated versus manual decisions, different classes and types of agents and services. These different domains integrated in the proposed conceptual framework demonstrates that integrated RFID-WSNs, coupled with the use of homogenous and heterogeneous smart devices integrating readers, can increase the robustness, accuracy and reliability of data in the intelligent monitoring of smart buildings.

The proposed hybrid intelligent decision support system is an integrated prototype system aimed at supporting the different steps of the knowledge domain study to derive collaborative domain knowledge for problem solving and decision making. This prototype system has been implemented on a case study covering an important aspect of the indoor sensing and tracking knowledge domain which has several application interests: hospitals, museums, nurseries, schools, hotels, prisons, and others. These applications share a common knowledge domain that is concerned with the indoor sensing of the environment and the localisation and tracking of people and goods within closed premises.

The system prototype has been evaluated firstly from the perspective of validating and enriching the system requirements and the specifications for the definition of the information and knowledge fusion support functions or services, and then assessing the results of the implemented functional components.

7.2 Future Work

This research's future work is in the domain of extracting and fusing information and knowledge from ad hoc wireless sensor networks (WSNs) and networking data base systems, as the next stage of the Sensor and data fusion integration process illustrated in Figure 5.1. This future work can be organised as follows.

- Fusion processes need to be fully automated, benefiting from intelligent fusion systems supported by dynamic distributed multi-agent systems processing a variety of soft and hard data collected from very diverse sources.

- The extraction and fusing of information and knowledge need the investigation of real-time support for decision level fusion performance improvement in several domains, such as multi-source soft and hard data fusion, computational complexity and multi-level inference or evidence fusion.

- The development of integrated and/or combined fusion models needed to automatically support intelligent fusion processes that enable consistent and accurate representation of knowledge objects and their multiple interactions in a variety of different domain context situations.

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