Intelligent Networks Data Fusion Web-based Services for Ad-hoc Integrated WSNs-RFID

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Abstract

The use of variety of data fusion tools and techniques for big data processing poses the problem of the data and information integration called data fusion having objectives which can differ from one application to another. The design of network data fusion systems aimed at meeting these objectives; need to take into account of the necessary synergy that can result from distributed data processing within the data networks and data centres, involving increased computation and communication. This papers reports on how this processing distribution is functionally structured as configurable integrated web-based support services, in the context of an ad-hoc wireless sensor network used for sensing and tracking, in the context of distributed detection based on complete observations to support real rime decision making. The interrelated functional and hardware RFID-WSN integration is an essential aspect of the data fusion framework that focuses on multi-sensor collaboration as an innovative approach to extend the heterogeneity of the devices and sensor nodes of ad-hoc networks generating a huge amount of heterogeneous soft and hard raw data. The deployment and configuration of these networks require data fusion processing that includes network and service management and enhances the performance and reliability of networks data fusion support systems providing intelligent capabilities for real-time control access and fire detection.

Keywords: data fusion, RFID-WSN integration, intelligent agents, dynamic multi-agent systems.

1. Introduction

Advances in telecommunications and information technologies, and their integration have enabled distributed sensing and tracking to solve a wide range of context aware environment problems that have common characteristics. Innovative fusion solutions for distributed detection that includes sensing and tracking, and inferring decision making have been designed in the light of new hardware and software developments supported by distributed networks data fusion support systems. These developments are based on the integration of a panoply of technologies which includes WSN, RFID, smart detectors, intelligent agents, web-based services, multi-agents distributed architectures, and hybrid intelligent decision support systems to translate sensing and identification, and tracking activities into web-based services [1]. Their implementation requires the support of multi-sensor data fusion functions for the capture of real time context environment

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data. These functions use methods and techniques developed in different areas such as artificial intelligence, neural networks, pattern recognition and statistical estimation.

Problems inherent to the capture of real time context environment data have been addressed as sensor models and multi-sensor integration few decades ago [2]. The potential of sensor fusion has been examined in the context of innovative network architecture [3], and particularly in the context of data fusion in decentralized sensing networks [4], developing the concept of sensor collaboration [5] towards real-time information processing of sensor network data [6] that involves sensor node generic design and configuration [7], network configuration, deployment, planning, and management [8]. The configuration of these sensor networks has received a huge interest from researchers and practitioners to develop:

- integrated configurations of distributed sensing networks for cooperative sensing [8] and developing a flexibility that allows sensing devices to self-configure for a wide range of data fusion applications in dynamic environments [9], and
- frameworks for the modelling of data fusion establishing several fusion decision levels [10] and decentralised mobile sensor coordination based on adaptive sensor nodes clustering [11] required to appropriately support a wide range of data gathering tasks, and various data fusion functions.

Networks data fusion is presented in Section 2, defining data fusion and the problem, before presenting in Section 3, multi-sensor data fusion requiring a novel integrated fusion approach for big data, and examining data fusion requirements. Section 4 focuses on ad-hoc integrated RFID-WSNs data fusion support, defining generally an ad-hoc WSN architecture and presenting the three integration levels of RFID and WSNs, and a generic sensor node data fusion design implementation. Finally, a functional web-based service framework for data fusion solutions is proposed in Section 5 before presenting the conclusions and future work.

2. Networks data fusion

The main problem in networks data fusion is the shift from conventional detection relying on centralised incomplete observations processed at a central processor, to distributed detection based on complete observations processed by distributed processors created inside and outside the networks. These distributed processors form a distributed architecture that links several fusion centres in a detection network topology that supports in real time, a cooperative fusion processing and integrated decision making activities that extend data fusion to information fusion and knowledge discovery and extraction.

2.1 Data fusion

Data fusion translate raw sensor data into information required by domain context applications to discover the situation context and efficiently disseminate contextual information describing the situation, and support real-time decision making. It is an ongoing process that uses various methods, techniques and algorithms to combine different types of context aware data from distributed sources in networks and elsewhere, to perform inferences and drawing conclusions about the environment, in the same way humans develop their abilities to infer about what they observe and feel. The nature of the data combination depends greatly on:

- the type of application, situation and domain context,
- the different features generated from the analysis of the situation describing the interaction of objects identified by knowledge elements , and
- the level of fusion processing: object, situation and impact assessment, and process and cognitive refinement[12].

Data fusion support plays a key role when designing integrated solutions based on the use of ad-hoc WSNs supported by intelligent sensor-based systems. In these systems, data multi-sensor fusion integrates the collection of different types of data also called signatures, from different sources to observe a dynamic behaviour of a knowledge entity to identify fusion events in the context of distributed detection involving three main iterative functions: surveillance, intelligence and communications. A device may have different types of signature that reflect several situations analysed to determine the associated behaviour.

2.2 Problem definition

Solutions for secure real-time distributed detection, access control applications and real-time inferring decision making are supported by a generic hardware RFID-WSN integration that is enhanced by a flexible and adaptive functional integration extending a hardware integration and enabling new elaborated functionalities in the domain of application. This study examines the complexity of network data fusion in the domain of indoor sensing and tracking with a particular focus on the sensors and tags heterogeneity.

The sensors and tags heterogeneity is a major focus in this study and is concerned by the presence of heterogeneous nodes that have enhanced capabilities in terms of energy and communication capability, which both are 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” [13].

The context considered in this paper is the domain of sensing and tracking activities that are supported by real-time detection systems, based on the gathering from different sources of a huge amount of heterogeneous data made up of different types of soft and hard data provided by integrated devices containing sensors and RFID tags. These devices which may be of the same or different types, and have different strengths and weaknesses, are deployed simultaneously in distributed environments, and wirelessly connected in an ad-hoc network topology. Their concurrent operating enhances their combined performance. This study examines the data fusion support for the deployment and configuration of these devices integrated into an ad-hoc WSN.

2.3 Indoor sensing and tracking

Surveillance is an activity that includes outdoor and indoor sensing and tracking, and consists 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. Rapid advances in digital and communications technologies have made a wide range of theoretical capabilities practical with sensing, tracking and data processing, using hybrid communications based on network domains and mobile IP protocols.

The surveillance knowledge domain supports the sensing and tracking design in smart, safe, sustainable, and energy efficient buildings attended by people, where the determination of environmental conditions and presence in physical locations is a central problem in location-aware computing. This knowledge domain is analysed in the light of advanced technological hardware and software developments integrating WSNs and RFID, and their configuration and deployment. The case study developed in this research 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 coordinating system for locating, meeting the precision and accuracy of localisation requirements.

3. Multi-sensor data fusion

Multi-sensor systems generate data fusion that requires a novel integrated fusion approach for big data to solve multi-sensor data fusion problems that include raw data sensitivity, data fusion modelling, and fusion requirements.

3.1 Novel integrated fusion approach for big data

The data fusion approach takes into account the necessary decoupling of the service-based data applications processing from the raw data collection. The generic nature of data processing in the domain context applications consists of inferring decision making. This requires the elaboration of predictive distributions on data marts extracted in the context of data warehousing by selecting and estimating distinct collections of multidimensional discrete or continuous variables of interest in the domain context. This approach is also based on the integration of the real-time context aware data collected, in a forward modelling approach to evaluate, simulate and validate a wide range of plausible models related to the representation of the domain context entities, their behaviour and interactions.

3.2 Multi-sensor data fusion problems

The domain context examined in this research includes sensors and tags status and measurement accuracy, sensor nodes connectivity, location model, fire model, evacuation model, and other models. Data integration from multiple sources by the means of sensors and tags requires integrating new data expressed in different forms into historical, temporal and spatial contexts. The technical design of sensors, tags and sensor nodes, and the enhancement of their capabilities have a huge data impact on the specifications for their accuracy and the quality of their metrics.

3.2.1 Raw data sensitivity

The multi-sensor data fusion approach above detailed, includes the evaluation of the raw data sensitivity required to:

- Constraint the several models above mentioned,
- Reduce the data measurement errors,
- Increase the location accuracy, and
- Solve multi-sensor data fusion inherent problems.

3.2.2 Data fusion models

Multi-sensor data fusion problems are solved by context-aware computing large scale systems which rely on the use of location (symbolic or geometric) and logic-based models to:

- Discover and take advantage of contextual information and sensing context changes,
- Support both passive and active context awareness, and context triggered actions, and
- Enable an automatic contextual reconfiguration.

The nature of these large scale systems is hybrid in the sense that the fusion decision levels involve for the elaboration of intelligence information, different types of fusion, varying from a smart device to a software agent, all based on one or several models, interacting within a distributed framework.

3.2.3 Multi-sensor data fusion requirements:

The main multi-sensor data fusion requirements of for the design of these systems are:

- Group shared multi-level fusion activity by different fusion centres, considering the limited communication between sensor nodes, and the difficult balance ensuring a rational power supply and consumption while maintaining both an adequate desired coverage and connectivity in distributed ad-hoc wireless sensor networks.
- Different sensors and tags observing one or several common problems considering the context sensed in which the results of the different sensing and tracking tasks can conflict with each other, creating ambiguity in the data aggregation processes to perform and the data to store.

- Ad-hoc integrated WSN-RFID networks integrate three levels of sensor intelligence (fixed actions, actions adapted and data integration with work adjustment) which may be used in three different environments (designed world, real world and hostile world), facing variations of the detection network (depending of the different dynamic sensor node configurations that might impose new fusion processing constraints) requiring the integration of the generated heterogeneous raw data representing different levels of data fusion.
- Distributed fusion poses the complexity of supporting a detection network topology due to the variations of the parallel fusion network when global inference in the form of feedback from distributed fusion centres is needed, and combined decision making involving individual sensor nodes that can use specific decision criteria depending on the tasks they perform, is needed.

Multi-sensor data fusion processing is very domain context dependant, and its design is constructed around the data network technical spectrum that includes in the context of real-time detection, false alarms from sensor nodes, dead sensors or tags, disconnected nodes, and also hostile actions resulting from intrusion events and other network treats. These events can be problematic for the network, persistent, and preponderant in nature and importance.

4. Ad-Hoc Integrated RFID-WSNs data fusion support

The research work presented in this paper takes into account the fact that integrating WSN and RFID technologies can be a complex design process, mainly when supporting real-time applications, which involves both hardware and software integration. The study has examined severe constraints imposed on the sensing, storage, processing, and communication features of the sensor nodes, in the context of designing a flexible and adaptive ad-hoc WSNs configuration solution based on the use of hybrid intelligent web-based support systems. The reconfiguration of WSNs which aims at enhance the network deployment and increase its performance, is needed when the sensor nodes may become faulty due to improper hardware functioning and/or lack energy supply (dead or low battery power).

4.1 Ad-hoc WSN architecture

The proposed Ad-hoc WSN architecture includes homogeneous and heterogeneous devices wirelessly connected. Due to the devices differences, their integration requires a high-level of data modularity and adaptability in the distributed multi-agent system architecture. Homogeneous devices are smart fire detectors composed of a several sensor and nodes as developed in the hardware integration description of the next section. Heterogeneous devices are IP smart devices which are deployed to enhance the deployment of homogeneous devices. They include RFID reader, IP Camera, Sprinkler, Message and Sign Displayer, Opening and Closing controller, People Counter, RFID reader, and other smart devices.

4.2 RFID-WSN integration

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

- the mode of functional and hardware integrations and the resulting data fusion[14],
- the allocation of specific tasks to RFID and WSN devices [15],
- the classification of both RFID and WSN devices to create similarity classes of their deployment attributes[16], and
- the use of low-level programming knowledge to adapt successfully RFID devices to ad-hoc WSN.

4.2.1 Functional integration

The functional RFID-WSN integration adopted in the proposed study, can be configured in six different ways [17], as summarized in Table 1. Although a hardware solution have been proposed in the next section, to show the adaptation of the integrated WSN-RFID in a context aware mode for new extended sensing capabilities by integrating RFID tags and readers in WSN sensor nodes, the conceptual design framework developed in this study has addressed the devices interoperability.

Table 1 Functional RFID-WSN integration

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

Data fusion processing integrates the enabling of 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 knowledge-based validation of integrated configurations when supporting multi-sensor heterogeneous data fusion. Heterogeneous data includes soft and hard data processed by data fusion techniques, prior to information and knowledge fusion.

4.2.2 Hardware integration:

The Hardware configuration of the integrated RFID-WSN sensor node is based on the functional integration resulting from the tasks requirements of the domain applications, as illustrated in Fig. 1.

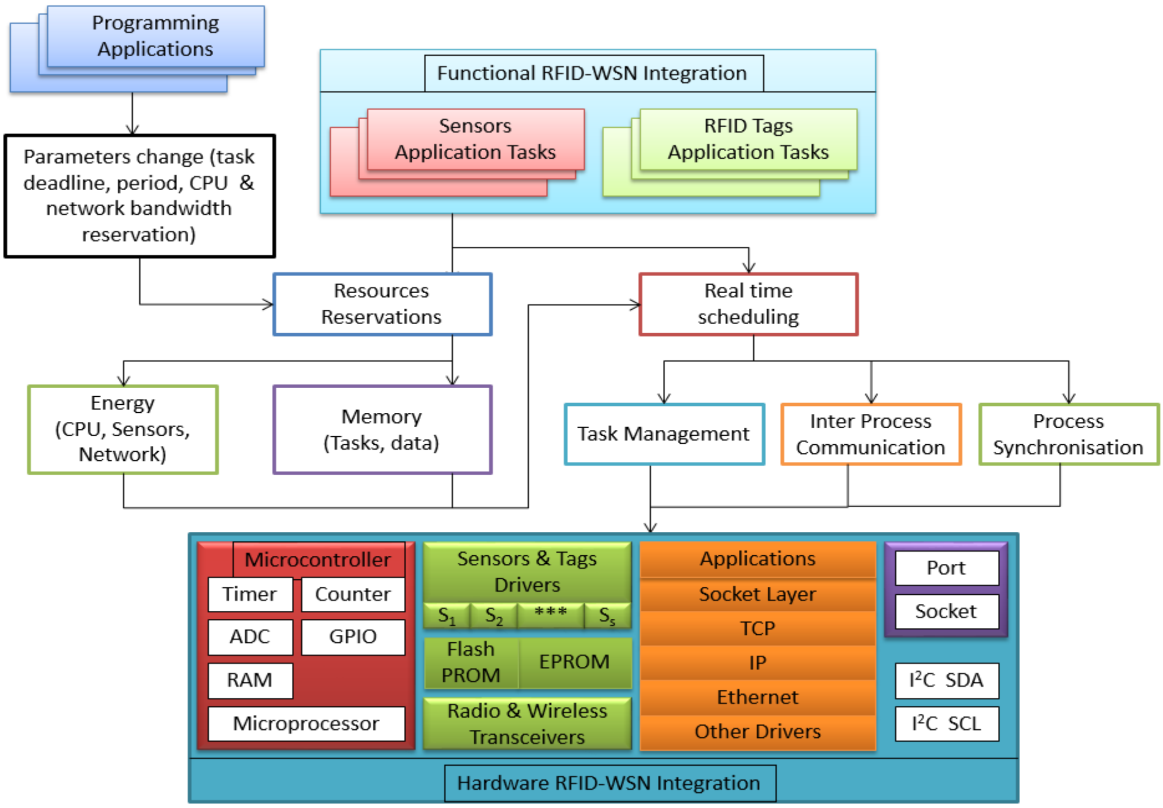

Fig. 1 Hardware RFID-WSN integration

The hardware development of the generic sensor node is not the focus of the paper. However, the proposed principles are to be considered in real world implementation:

– An RFID node is integrated in the sensor node that reads data from tags attached to people or goods.
– RFID readers placed in the read data from tags contained in fix sensors nodes.
– RFID nodes and readers contain the required components and functions to support a communication interface (I^2C interface for example) to send and receive parallel data through a serial data line (SDA) and another bus line for the serial clock line (SCL). These functions which include elementary commands (Initialisation, Read and Write) are pre-programmed, can be re-programmed in the context of their configuration and deployment.

4.2.3 Software integration

The communication interface I^2C assists the embedded software supporting the generic sensor node, or the intelligent fusion system supporting the network to detect in real-time tag IDs, and verify their existence and status in the network database. The proposed integration configuration is supported by distributed generic sensor node control and database control functions which are performed simultaneously and integrated in the network data fusion processing. The data fusion process includes the monitoring and reduction of RFID reading and/or identification errors, to provide a robust way to effectively enhance the RFID and WSN integration. Although it has been suggested that the hardware integration needs to be completed before configuring and programming the generic sensor node, the network data fusion process explores at the maximum the sensor node hardware configurability that procures a multitude of different hardware configurations needed by a wide variety of distributed detection and tracking applications. Based on distributed services composing the service layout which is decoupled from the network data fusion processing supported by Intelligent Fusion Support Systems (IFSS), the system architecture shown in Fig. 2, integrates the exchange support to the middleware, coordination and communication software layers in the data fusion system.

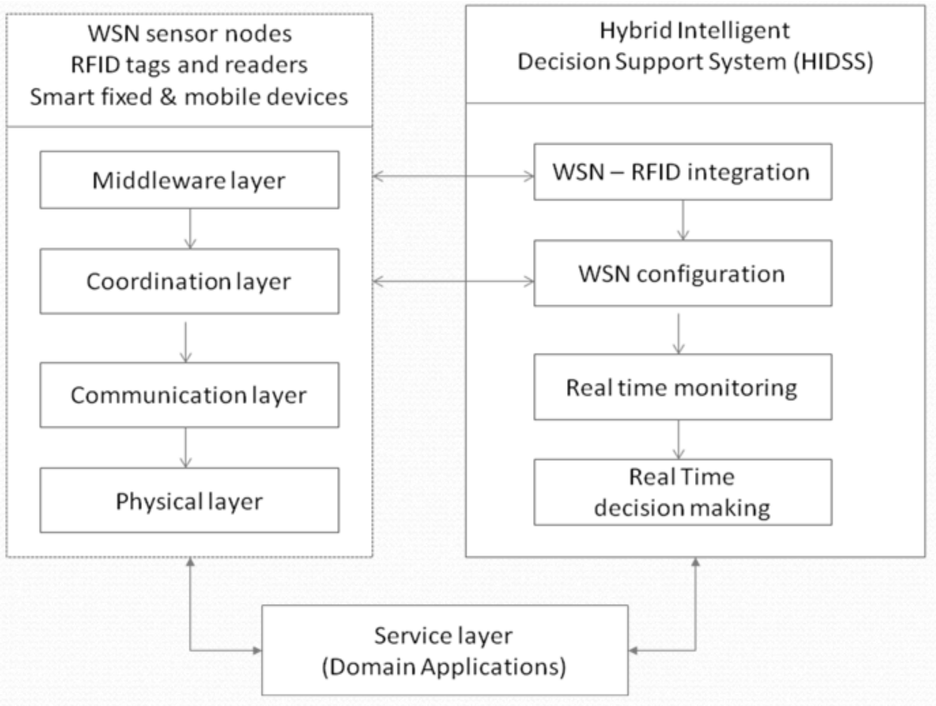

Fig. 2 Software integration for intelligent fusion support systems

4.3 Generic sensor node design implementation

Homogeneous devices which are generically designed using a knowledge-based design support are smart sensor nodes that are formed by grouping a variety of sensors and RFID tags, wirelessly connected in an ad-hoc network topology. An example of implementation is illustrated in Fig. 3. The modelling and publication of sensor data and their contexts of use consist of using of 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[18] . This representation is supported by the sensor semantic network ontology (SSN), defining data encodings and web services to store and access sensor-related data [19].

4.3.1 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. 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 in the task.

4.3.2 Sensor and RFID tags mission matching

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. 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, as illustrated in Fig. 3 and implemented in Fig. 4.

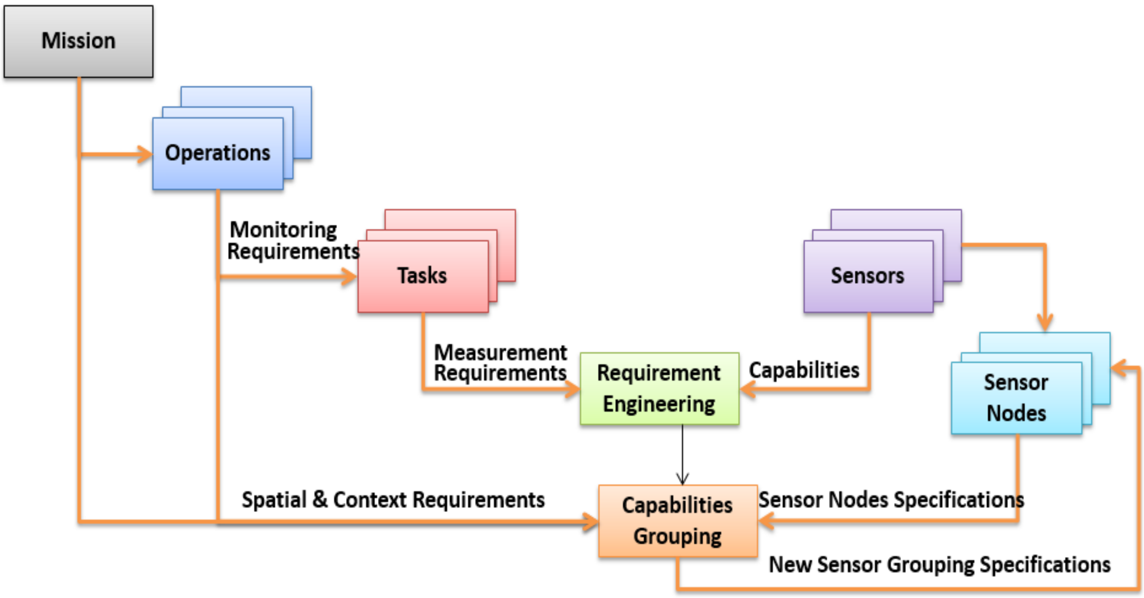

Fig. 3 Sensor capability task matching

Sensor nodes can be fixed or mobile. They are self deployed, and their sensors can be:

- Duplicated to enable the inclusion of a safety factor,
- Of different:
  - types, depending of the tasks they perform
  - configurations & sensing distances depending of the sensing requirements and their conditions of use, and
- Active or Passive.

Sensor nodes act independently, processing and/or transmitting the sensed data to a base station or another sensor node (multi-hop communication), for further processing and aggregation. Multi-hop communication is of great advantage for in-network distributed processing. At the implementation level, a software consisted of a program module controls the microprocessors of the nodes, and a RFID table is created in the WSN database to record the tag IDs of devices attached to, or of people wearing them.

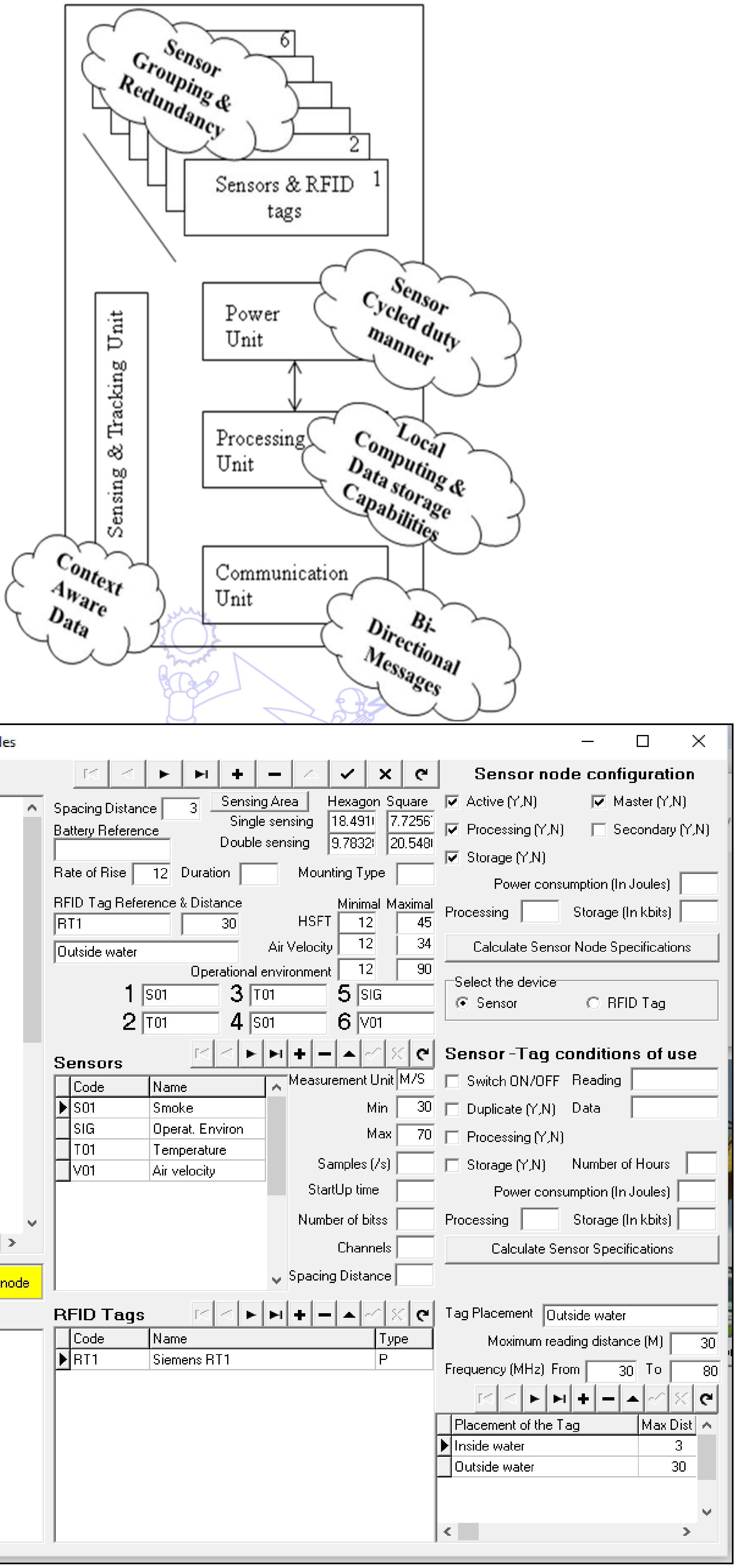

Fig. 4 Knowledge based support for generic sensor node design

4.4 Homogeneous & Heterogeneous devices location

Homogeneous and heterogeneous devices location requires a priori planning to ensure an optimal spatial observation and detection coverage. In this priori planning, the node location is a unique point calculated using 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 [20]. Fig. 5 illustrates for a "fire detection and people and goods tracking" application, the location of the physical network devices composed of homogeneous & heterogeneous sensor nodes wirelessly connected. Homogeneous devices have been distributed using a hexagon geometric patterns, whereas heterogeneous are placed using rules of thumbs.

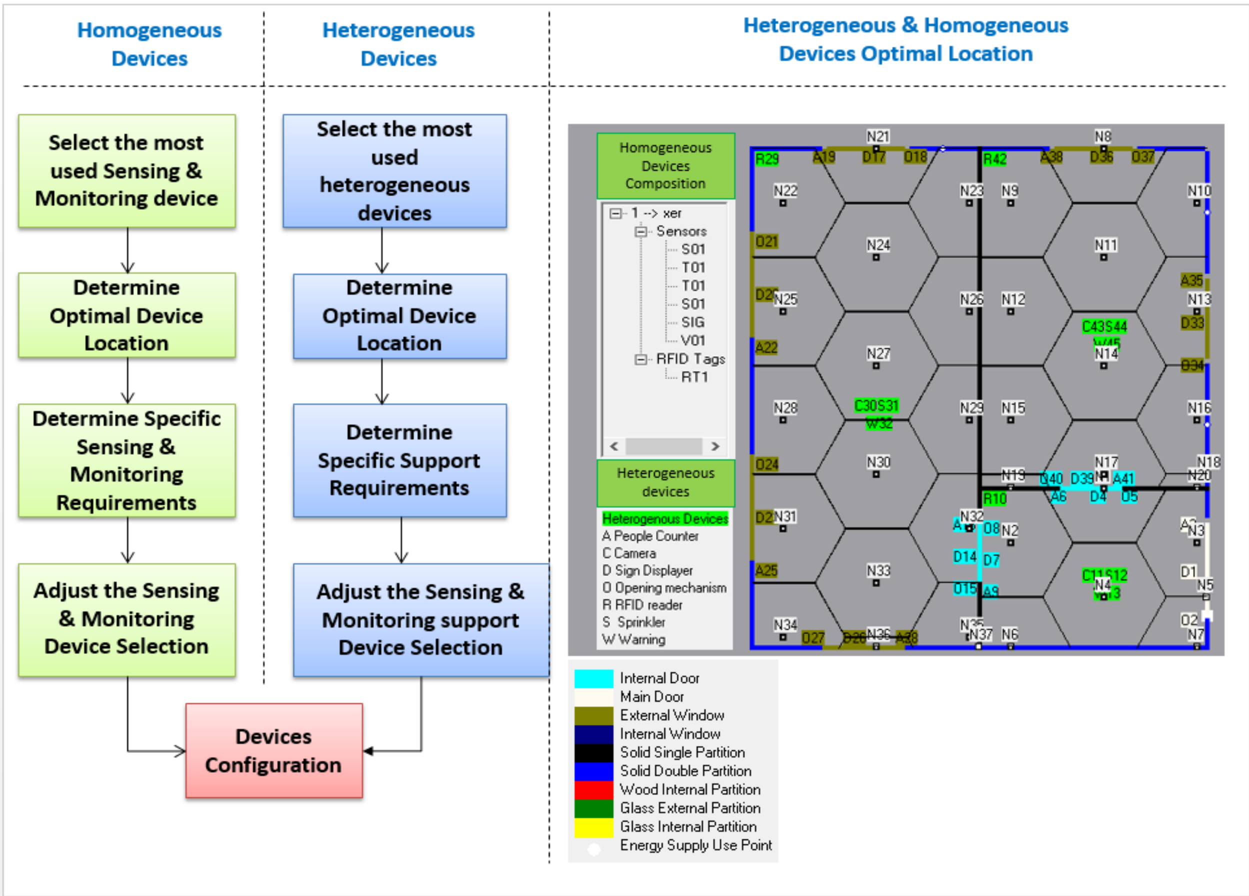

Fig. 5 Location model for homogeneous and heterogeneous devices allocation

4.5 Ad-hoc WSN configuration and clusterisation

Distributed topology control is a mechanism that enables adjustment at the 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, its in-networking and transmission to the front-end server, in the context of creating sensor nodes clusters. Virtual clusters defined as a logical level of grouping sensor nodes into clusters shown in Fig. 6, enable flexibility in the WSN deployment to support more effectively a variety of context applications.

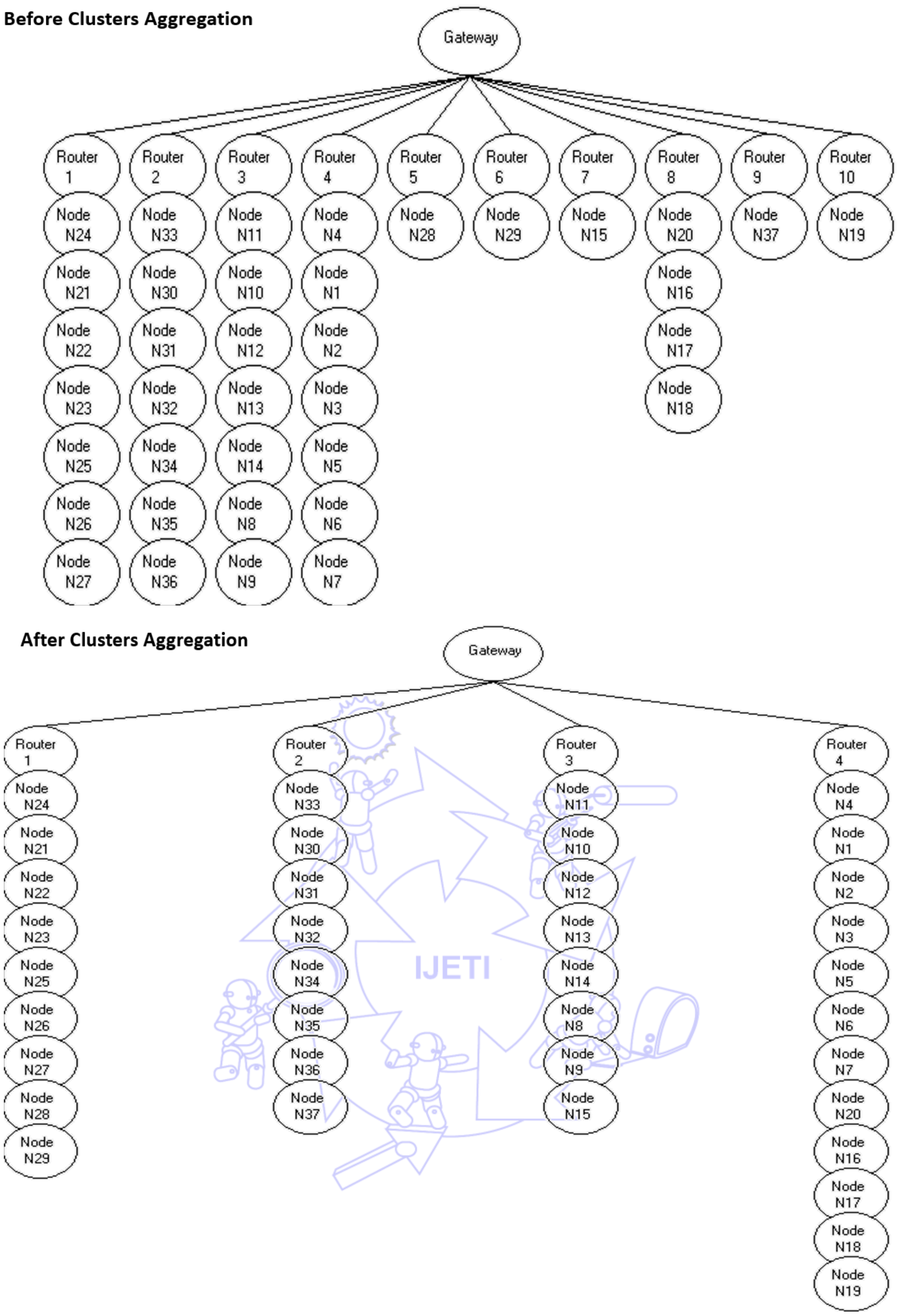

Fig. 6 Sensor nodes configuration and clustering

Examples of cluster logical levels above illustrated are:

- All the sensor nodes involved in detection event response are 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, elaborated from process model supporting the information fusion resulting from the context knowledge domain configuration.

4.6 Predictive data for building navigation

The predictive data for building navigation shown in Fig. 7 is based on calculating the rooms capacity and using average evacuation times to determine the minimal evacuation time required.

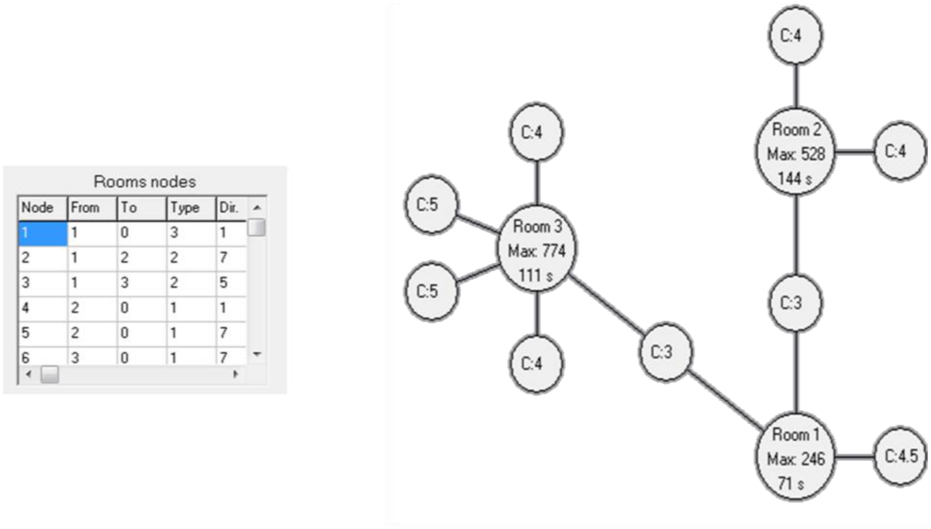

Fig. 7 Predictive data for building navigation

4.7 Predictive data for building evacuation

The predictive data for building evacuation shown in Fig. 8 is based on identifying the evacuation path set to be the direct line between the initial localisation of every person attending the building and the middle of the room door, and using average an algorithm for collision detection.

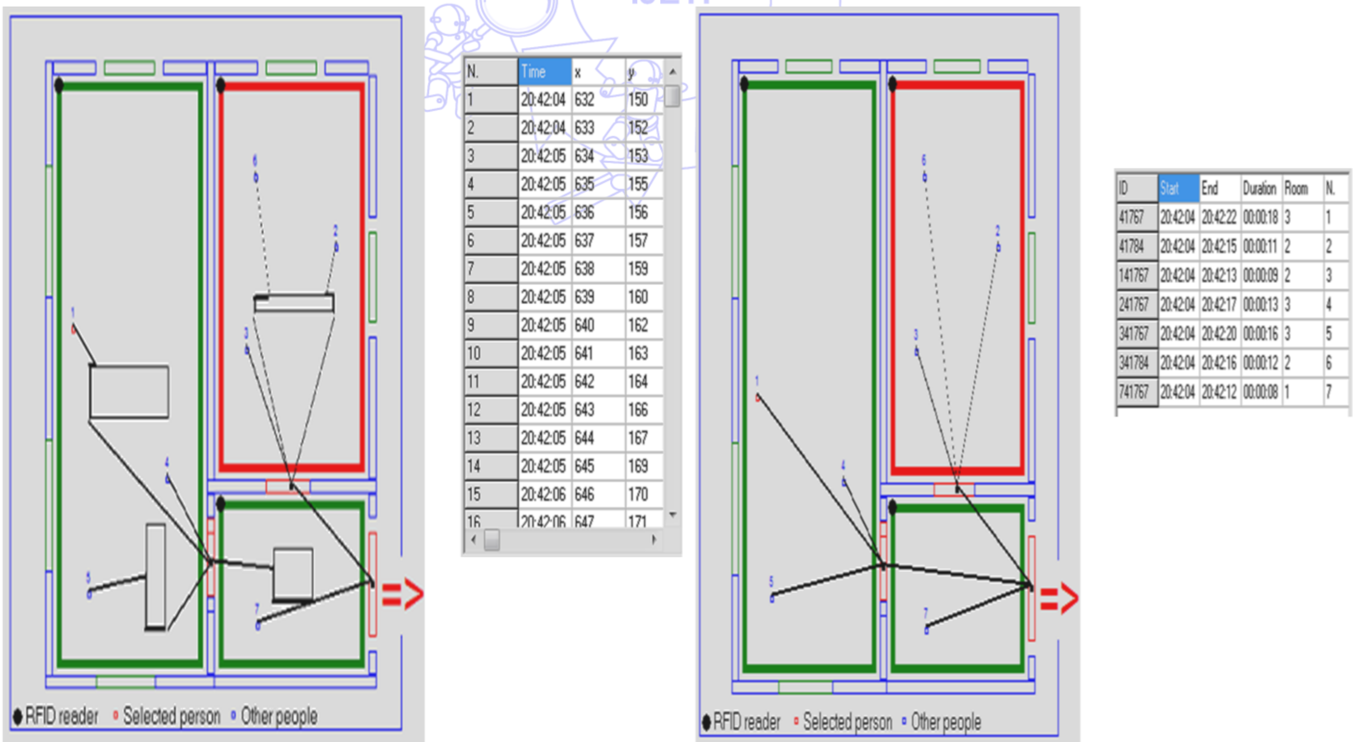

Fig. 8 Predictive data for building evacuation

4.8 Predictive data for fire alarm simulation

The predictive data for fire alarm simulation model shown in Fig. 9 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.

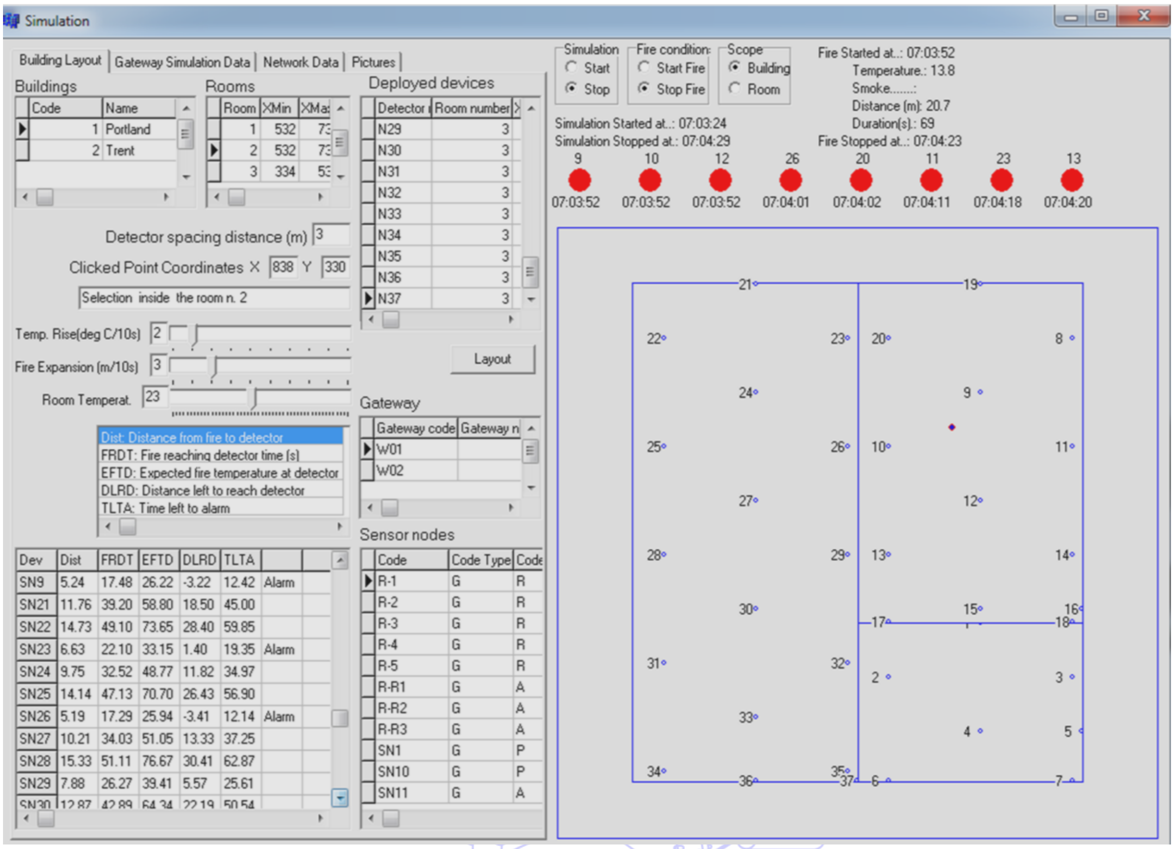

Fig. 9 Predictive data for fire alarm simulation

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 fore simulation model, and the data captured by the WSN from the different detectors. The predictive data shown in Fig. 9 is composed of: Distance from fire to detector (DIST), Fire reaching detector time (FRDT), Expected fire temperature at detector (EFTD), Distance left to reach detector (DLRD), and Time left to alarm (TLTA).

5. Functional framework for data fusion solutions

The generic fusion system design framework developed in this work is a methodological support that enables the mapping of a knowledge domain model and architecture to a generic design for distributed detection applications, covering several domain contexts that include sensing and tracking. These applications are designed in the form of web-based services for fast and flexible access to real-time data captured by sensor networks and processed to support real-time inferring decision making in the context of data, information and knowledge fusion. They integrate concurrently third party fusion data, models and knowledge, and share fusion tools and processes jointly supported by web-based GDSS linking end-users. They support generic data fusion solutions based on data and information fusion management to procure fusion capabilities structured in fusion process models services decoupled from other services representing knowledge processes, models, data & support system capabilities as illustrated in Fig. 10. The proposed generic design conceptual fusion framework focuses on service interoperability which is based on generic and recursive fusion in inferring decision making using the different management components (Knowledge, model, data and support capabilities) to deploy configure, and operate the network homogeneous and heterogeneous devices, capture, integrate, process, and aggregate their data.

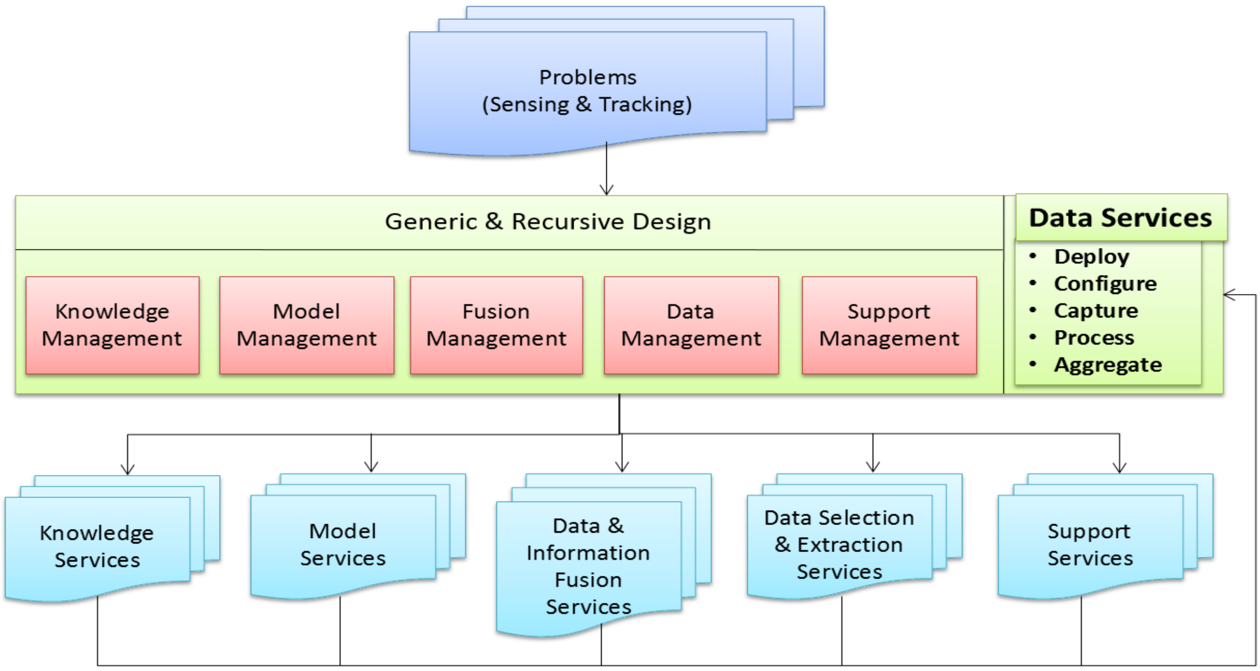

Fig. 10 Distributed Web-based service support for networks data fusion

6. Conclusions

A novel data fusion approach for big data has been proposed in this paper to solve problems inherent to networks multi-source data fusion for distributed detection based on the use of ad-hoc integrated WSNs-RFID combining generic homogeneity and heterogeneity. Although this approach suggests the decoupling of data fusion from information fusion, the case study used in this work has shown the inevitable interaction between these two hierarchical processes that enable the synergy of knowledge discovery and extraction. This interaction has been shown in the generic sensor node data fusion design implementation through the different techniques and models used in the proposed fusion framework to generate predictive data for fire alarm simulation, and also in the knowledge-based sensor node design and its integration of sensors and RFID tags to procure adaptive configurable smart devices for distributed detection.

7. Future work

The multi-level interaction between data, information and knowledge is under explored due to the importance of data uncertainty and complexity associated with both the knowledge domain context and the use of non-interoperable heterogeneous devices. The improvement of the elicitation methods, tools and models of fusion requirements in the context of requirement engineering to define elaborate fusion functions, and the development of more interoperable generic smart devices are new directions for future research and applications.

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