Automatic Triangulation Positioning System for wide area coverage from a Fixed Sensors Network

A Thesis Submitted for the Degree of

Doctor of Philosophy by

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Abstract

In a wide area that many Transmitters (TRs) operate, systems of Fixed Sensors (FS) might be used in order to detect them and find TRs position. The detection and the accurate location of a new TR entering in the area frequently can be missed if the system fails to triangulate accurately the relative readings and analyze the changes in the received data. Additionally, there are cases that a Triangulation Station Network (TSN) can detect the heading as well as the transmitter's position wrong.

This thesis presents the design of a Sensors Network (FSN) system which is able to interact with a user, and exploit the relative data of the Sensors (SRs) in real time. The system performs localization with triangulation and the SRs are detect only TRs bearing data (range free). System design and algorithms are also explained. Efficient algorithms were elaborated and the outcomes of their implementation were calculated. The system design targets to reduce system errors and increase the accuracy and the speed of detection. Synchronously and through interaction with the user and changes of relative settings and parameters will be able to offer the user accurate results on localization of TRs in the area minimizing false readings and False Triangulations (FTRNs). The system also enables the user to apply optimization techniques in order to increase the system detection rate and performance and keep the surveillance in the Field of Interest (FoI) on a high level. The optimization methodology applied for the system proves that the FSN system is able to operate with a high performance even when saturation phenomena appear.

The unique outcome of the research conducted, is that this thesis paves the way to enhance the localization via Triangulation for a network of Fixed Sensors with known position. The value of this thesis is that the FSN system performs bearing only detection (Range free) with a certain accuracy and the Area of Interest (AOI) is covered efficiently.

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List of Abbreviations

Ao**I**	**A**rea of **I**nterest
Ao**A**	**A**ngle of **A**rrival
AoU	**A**rea **o**f **U**ncertainty
APIT	**A**pproximate **P**oint **I**n **T**riangulation
AuR	**Au**tonomously **R**epair
ARU	**A**utomated **R**eceiving **U**nit
BRNGs	Bearings
CoG	**C**enter of **G**ravity
EM	**E**xpectation **M**aximization
FAPIT	**F**uzzy logic system **APIT**
Fo**I**	**F**ield of **I**nterest
FSN	**Sensors Network**
FTRN	**F**alse **T**riangulation
GPS	**G**lobal **P**ositioning **S**ystem
IAPIT	**I**mproved **APIT**
PIT	**P**oint **I**n **T**riangulation
PTRs	**P**seudo **T**ransmitters
PTRNs	**P**seudo **T**riangulations
Qo**S**	**Q**uality of **S**ervice
k-**UC**	k-**U**nit-disk **C**overage
k-**NC**	k-**N**on-Unit-disk **C**overage
LAN	**L**ocal **A**rea **N**etwork
MR	**M**ulti **R**esolution
NTRs	**N**ew **TR**ansmitters
RSS	**R**eceived **Si**gnal **S**trength
RSSI	**R**eceived **S**ignal **S**trength **I**ndication
RF	**R**ange **F**ree
SN	**S**ensors **N**etwork
TC	**T**opology **C**ontrol
TRN	**T**riangulation area
TDo**A**	**T**ime **Di**fference of **A**rrival
To**A**	**T**ime of **A**rrival
TRs	Transmitters
VPIT	**V**oronoi **P**oint-**I**n-**T**riangulation
WANET	**W**ireless **A**d hoc **N**etwork
WSNs	**W**ireless **S**ensor **N**etworks

List of Symbols

C	*A Polygon centroid*
λ	*The ratio of the fraction dividing the two triangles*
D	*The centroid of a triangle*
SR_{BL}	*A value that presents the blindness of a SR*
SR_{ER}	*The detection error in degrees*
R_{SRs}	*The number transmitters detected for a Sensor*
N_{BL}	*The overall Network blindness of a FSN system with a number of n SRs*
n	*The number of SRs*
N_{AST}	*Network Sub-area Saturation Status*
TRN_i	*The area covered by triangulation*
A_S	*The area size*
N_{TAST}	*The Total Network Saturation Status*
A_{TS}	*The total Area size*
P	*The probability P of detection*
p	*The level of possible detection*
P_T	*The total probability P_T of TR detection in a FSN with n subareas*
R	*The SR radius*
ETRNs	*The number of existing triangulations*

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Declaration of Authorship

I MARIOS SFENDOURAKIS, declare that this thesis titled, "Automatic Triangulation Positioning System for wide area coverage from a Fixed Network of Sensors" and the work presented in it are my own. I confirm that:

•This work was done wholly or mainly while in candidature for a research degree at this University.

•Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.

•Where I have consulted the published work of others, this is always clearly attributed.

•Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.

•I have acknowledged all main sources of help.

•Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Signed: ___________________

Date: ____________________

Chapter 1 Introduction

1.1 Chapter overview

This introductory chapter delivers a brief report on the background to the rest of the thesis, including the motivation for research, basic concepts related with a Sensors Network - FSN system for localization with triangulation - TRN. The general methodology followed during the research and contributions to knowledge are described here. A list of publications arising from the Ph.D. is given and the thesis outline is provided to help guide the reader through the document.

1.2 Introduction

This study examines how a FSN which might work autonomously as a system can provide results of localization of transmitters - TRs with the method of triangulation. The FSN is processing the SRs data with a bearing only mode of detection and a certain detection error, a topic that is relatively unexplored in literature. This chapter provides an introduction to the study and sets the background for the research. Also, it provides an overview of the subsequent chapters of this thesis. The rest of this chapter is organized as follows. Section 1.2 provides the background of the study. Section 1.3 presents the motivation under which this research was undertaken analyzing the existing knowledge gap and the potential benefits of this research. In Section 1.4 there are presented the scientific contributions of this research. In Section 1.5 we have the overall Scope of the thesis demonstrating its aim and objectives. Section 1.6 presents the Organization of the thesis in the chapters.

1.3 General background

The Triangulation problem is still under examination and a lot of research is still being conducted as triangulation is used in many applications like GPS positioning, Areas of Mobile phone technology, Robotics position finding etc. Yet, the ability to detect the existence of a possible intersection among pairs of objects can be important in a variety of problematic domains such as geographic information systems, CAD/CAM geometric modeling, networking and wireless computing.[1] In many cases we have a number of transmitters and a number of sensors which have to acquire and interpret data. But relative positioning of the transmitters is strongly related to a right triangulation procedure in order to have correct data analysis and extract right information. Intersection detection is a complex problem and the algorithms used to speed up the process are still being explored to meet the needs of various applications. [2].

When we frequently have a lot of multi sensor network readings we miss valuable information and we cannot analyze readings properly and accurately. That way it is possible to lose important data containing special information and need further analysis and investigation. Another problem that we might face is that inaccurate results in combination with inappropriate tools of analysis could become confusing and even worst, lead us to false readings.

1.4 Motivation

In general the main challenge that this research is trying to answer is the question that in spite of the large number of algorithms and ways to increase a network performance that already exists, the issue of finding a way to optimize the network performance instantly and increase its Quality of Sensing (QoS) still remains an issue of extensive research. And for a sensor network that performs localization with triangulation and which operates in an environment with existing TRs that acting as obstacles affecting the sensor network performance, further research is required as many factors are to be investigated. So, there are four main factors that motivate the research undertaken in this PhD study.

First, there is a dearth of research on WSNs and Fixed Sensor Networks FSNs that deal with localization via Triangulation procedures with range free algorithms but for small distances and small areas. And in the most cases the localization procedure is focusing on the issue of finding the position of an unknown sensor.

Second, there is not adequate scientific research on a FSN system that deals with a large number of SRs and TRs able to perform detection with a certain error and within an area of already existing TRNs that affect the network performance.

Third, there is a need to examine this topic as new technologies and their applications on networks with large number of sensors - SRs demand detection ways with low energy consumption. In this research this system belongs to a low energy consumption category as it performs detection using a bearing only mode, activation of clusters of SRs and data processing with a central hub.

Finally, as new technologies appear to implement SRs networks and seek for localization via triangulation for the SRs position, a FSN system that performs automatically and continuously area target surveillance of new TRs which enter a Field of Interest - FoI with a bearing only mode is required. These issues are discussed in the following two subsections.

1.4.1 The knowledge gap

Prior research focuses mostly on localization via triangulation for sensors - SRs which are spread in an area of surveillance and their position is unknown contrary to this research that seeks for the position of unknown and new transmitters - TRs. There have been various attempts to deal with coverage and connectivity issues between SRs in WSNs in an area of surveillance. In [1.1] there is a survey on two major challenges in wireless sensors networks - WSNs which are coverage and connectivity. It is noted that the deployment of wireless sensor nodes to monitor a temporary worksite is a typical use case representative of industrial applications where full coverage and full connectivity are required. In [1.2], it is noted that coverage and connectivity are two of the most fundamental issues in WSNs, which have a great impact on the performance of WSNs. Coverage hole issues are commented together with coverage deployment strategy, sleep scheduling mechanisms and adjustable coverage radius as ways to increase the Quality of service - QoS.

In addition, a key challenge in sensor networks is how to improve and optimize coverage quality which is a fundamental metric to characterize how well a point, a region or a barrier can be sensed by the geographically deployed heterogeneous sensors and a great amount of research focusing on this issue [1.3]. But these types of research of QoS, are different from our perspective, as in this research, we are focusing mainly on how QoS and network detection performance are decreased as gradually many TRs enter the Area Of Interest AOI and on what is happening in the network from an initial state to a new state. In a similar vein, research in [1.4] focuses mostly on issues related with WSNs coverage and connectivity in the FoI and challenges the Area, Target and Barrier Coverage. But this research work is also estimating the sensing coverage in the FoI using the deployed sensor nodes in WSNs without taking into account how coverage quality deteriorates and how network sensing is decreased as many TRs enter the FoS. Therefore, there was an existing opportunity to look into a FSN system and understand how the network performance is decreased when many TRs enter an area causing network saturation or gradually sensor blindness. The QoS is a fundamental issue for research in WSNs but in an FSN system of the previously mentioned type, it still remains a challenge especially because the amount of research presently is very little.

Additionally, localization in WSNs has attracted a large number of researchers lately. As a result, several localization algorithms have been proposed in the field of literature. These algorithms can broadly be categorized into two categories, i.e., range-based and range-free localization algorithms [1.5]. But in this research also, localization is related to finding the positions of SRs which are spread in an area. That, along with other traditional approaches for localization, such as the Global Positioning System (GPS)-based methods manual measurement/calibration Sensors methods, etc., become infeasible due to a number of reasons including, prohibitively high monetary cost, unsuitability of technology [1.6], to name just a few, although there are many more.

Furthermore, most of the existing work for solving the target tracking problem considers only 1-target tracking [1.7]-[1.8].Moreover, it should be mentioned that the impact of k on the number of required nodes for k – target tracking in connected WSNs was studied in [1.9]. The *k*-target tracking problem using directional nodes in *m*-connected WSNs was solved. Authors present an analysis which can be used in the planning and design of large-scale WSNs with deterministic deployment of directional nodes for target tracking in the FoI. They determined the orientation of the tracking region, a pattern which required a minimum number of directional nodes, optimal side length of the pattern, and location of the nodes to solve target tracking problem. But this work is limited and lacks to explain how the network coverage is affected when many TRs appear synchronously in the FoI. In addition to the above studies, a novel framework for area localization using Wi-Fi Wireless access points (APs) APs' aiming to achieve both coverage and communication was proposed in [1.10]. It was formulated as an Optimal Loc-deployment problem aiming to deploy a minimum number of APs to achieve full coverage and area localization with any given accuracy parameters. Finally, in [1.11] the Sensing coverage metric for WSN performance has been examined. Authors proposed a percolation-based coverage & connectivity combined model (PCCC) to obtain the critical density at which the network abruptly becomes covered/connected. The PCCC was based on directional sensor network in which sensors were assigned a determined sense direction sector with a varying angular interval from 0 to 2π. It's worth mentioning here that in both previous two research projects [1.10] and [1.11], the issue of how SRs coverage and network performance differentiates when TRs enter the area hasn't been included. Closing these thoughts, it's worth stating that the knowledge gap related to finding the position of a TR with triangulation by using a FSN system, is an open research issue. To my perspective and according to literature reviewed above, this topic of research is an issue of high significance as it offers a new two 2D way of localization and positioning of new TRs with many applications.

1.4.2 Potential benefits

An investigation of a system that performs localization via triangulation in a large area is the main goal of the scientific inquiry in this Phd study. But there are various issues which are of vital importance and have been studied here offering potential benefits.

First, there have been examined cases of non real TRNs false triangulations - FTRNs, and how the network is affected when already many TRNs exist and new TRs enter the area. I looked into this issue in order to find out how the network coverage state is affected. And I did that taking into consideration that a new TR might be missed if the network does not apply to relative changes.

Second, it has been investigated how the FSN performance deteriorates as SRs blindness appears gradually resulting in network saturation. It is an issue of great importance as the FSN system has to analyze its data and locate the problematic areas of non-coverage. Target intrusion from an area of that type is a possibility that the FSN as a system has to face well in advance and from state to state. The benefit here is that the system’s user is able to acquire the system state in order to intervene.

Third, this study examines the fundamental issue of how QoS and coverage are affected when the number of TRs increases. A network optimization methodology from an initial state to a new state, that is, when QoS has to remain high and the network has to apply changes in its operation parameters is also presented. In other words, it is a system of continuous evaluation resulting in determining the level and type of user intervention. The FSN system is able to change the SRs sensitivity and increase or decrease the detection radius R. Otherwise, the system loses its credibility, performance is decreased, respectively, and a new TR might be lost.

1.5 Scope of the thesis

The aim of this thesis is to do some research on a Sensors Network - FSN system which will be able to detect TRs in a large area with a bearing only (range free) mode. That presupposes the design and implementation of some supervisory software which will be able to analyze the data acquired from the SRs, alert the user for inaccurate readings and also alert about an area with increased probability to have a transmitter-TR and need to be checked. The operator of the system will be able to define the sensors sensitivity while in operation, also able to determine the relative algorithms that will increase the triangulation correctness (bearing error), as well as, determine the SRs in use and their characteristics. Parameters like operational distance of the sensors, in combination with detection error are configured before the search as an initial state of the system. Then the user will be able to implement changes in relative parameters in order to have the best possible and most accurate readings. The programming of system parameters and characteristics can be done in advance and while in operation, from state to state. By this way the system - user interaction is high resulting in optimal results in detection of TRs.

1.6 Contributions to knowledge

The contributions of this thesis are the following:

- A software design which enables the user to perform localization in a vast area, with many transmitters and detect existing transmitters and new transmitters that might enter the area, with high accuracy.
- A new algorithm for triangulation for bearing only detection (Range free) for a FSN system is proposed.
- The Sensors Network (FSN) system, performs localization via triangulation with a certain beam error for all the system.
- The FSN system assess the data and after processing provide results in the FoI for many TRs synchronously and for the whole area.
- Optimization methods are proposed for the system to minimize the missing probability of new transmitter.
- It is proposed a coverage optimization methodology for the system with a fixed detection radius R for each Sensor of the Network.

- It is proposed a coverage optimization methodology for the system with varying detection radius R for each SR which is the system “radius R key combination” of the Network.

1.7 *Organization of thesis*

This thesis is organized into seven chapters:

- In chapter one it is presented the Introduction of the thesis.
- Chapter two gives the background related with a Triangulation for Localization Network System.
- Chapter three presents the Localization using triangulation Problem for a Fixed Sensor Network - FSN Range Free System.
- Chapter four presents a methodology for localization using triangulation for a Fixed Sensor Network Range Free System.
- Chapter five presents the Optimization of Area Coverage with existing transmitters during system operation and Optimization methods are proposed for the system to minimize the missing probability of new transmitter.
- Chapter six presents results and discussion together with issues for further work.
- Chapter 7 is the closing chapter with the review and conclusions of the thesis and its contributions.

1.8 Publications arising from the Ph.D.

Journal papers:

- Sfendourakis M., Nilavalan, R., & Antonidakis, E. (2017). Triangulation positioning system network. *MATEC Web of Conferences*, *125*, 2069–. https://doi.org/10.1051/matecconf/201712502069.

- Sfendourakis, M., Zakynthinaki, M., Vasilaki, E., Antonidakis, E., & Nilavalan, R. (2021). Coverage Area of a Localization Sensors Network System with the process of Triangulation. *Journal: WSEAS TRANSACTIONS ON INFORMATION SCIENCE AND APPLICATIONS*, 39-56.

Conference papers:

- Sfendourakis, M., Rajaponal, N., & Antonidakis, E. (2015). Automatic Triangulation Positioning System for wide area coverage from a Network of Stations in Fixed Positions. In *Proceedings of the Zakynthos ICCS*.

- Sfendourakis M., Nilavalan, R., & Antonidakis, E. (2016). Sensors Networks - Localization and Topology. *2016 Third International Conference on Mathematics and Computers in Sciences and in Industry (MCSI)*, 143–154. https://doi.org/10.1109/MCSI.2016.036.

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Chapter 2 Background

2.1 Introduction

The problem of localization has been under research lately and as the applications of Sensors Networks are still spreading in many fields, ways to find the position of a Sensor or a Transmitter with high accuracy are still being tested and are still thought very important. One of the localization techniques is the process of Triangulation which was analyzed in [2.1]. It was also shown that in a large network with a great number of Sensors - SRs there are cases of pseudo Transmitters - PTRNs which need to be examined on a case by case basis. For these reasons, we have to shed light on the various issues that should be put in consideration when a Sensors Network - SN has to work as an automated system. Various characteristics will be analyzed and it will be shown what makes a sensors network unique.

2.2. Sensor Networks

There are many types of Sensor Networks which have been used in a wide area of fields lately. For example, Networks are used in agriculture, environmental monitoring, scientific or military purposes etc. A sensor network could be described as a group of sensor nodes which co-ordinate to perform specific actions. Unlike traditional networks, sensor networks depend on dense deployment and co-ordination to carry out their tasks. But depending on the purpose a Network is designed its architecture, topology, scalability, sensors characteristics and many other properties might vary.

Network hole problems (non-coverage) are also presented as they are of vital importance when a network has to perform accurately and with a minor number of areas that are problematic or may degrade its performance. It is easily understood that a network's overall performance is affected by a combination of attributes that need to be examined on a case by case basis.

2.2.1 Sensor Networks types

There are various types of Networks depending on their state, if they are mobile or not, if they are wireless or not etc., and the analysis of all the various types of networks is beyond the scope of this paper. The networks also can be classified in accordance with the types of sensors, their topologies and their scale. When a network is spread in a large area, issues of scalability arise in combination with cases of coverage. Lately, and as sensors properties are increased, the dynamic of a network might be adapted to the demands of the purpose for which it is designed. For that reason, every network which is designed for a single purpose and working properly, could be completely unsuitable in another case. That means that every network is unique and has its own purpose and properties.

2.2.2 Fixed Sensor Network

In a fixed station network the sensors positions are fixed, meaning that their position is already known. Sensors positions have been acquired with GPS and the system is aware of their coordinates. In this case the network does not have/need to find the sensors position. The set of sensors are deployed within a predetermined geographical area to gather and aggregate data. The data are forwarded to a base station for processing or a remote database.

2.2.3 Wireless Sensor Network

A wireless sensor network (WSN) is a special kind of ad hoc network that consists of a number of sensors spreading across a geographical area. Mobility has relegated the traditional wired network as similarly was happened with the mobile telephone in relation to its contemporary land-line phone. Easy and simple network set up procedures allow everyone to connect to any network which is available with adequate signal. There are three basic components of a wireless Local area network - LAN. The access point, which bridges the gap between the client and the Internet, the Wireless Medium and the Client/Station [2.2]. A typical client can be a laptop, a tablet, an I - Pad, or even a smart phone with Wi-Fi. Two important aspects of the communication in wireless sensor networks are the topologies and the internal architecture. The selection of best topology in accordance with the internal architecture of the wireless sensor node is a very critical job in producing communication among all the nodes according to the application [2.3]. In addition, to that and assuming that a base station is needed for collecting and processing the sensors network data, the positioning and placement of the base station is critical in order to optimize the total energy consumption of the network [2.4].A **wireless ad hoc network - WANET** is a decentralized type of wireless network. The network is ad hoc because it does not rely on a pre-existing infrastructure, such as routers in wired networks or access points in managed infrastructure wireless networks. Instead, each node participates in routing by forwarding data for other nodes, so the determination of which nodes forward data is made dynamically on the basis of network connectivity [2.5].

2.2.4 Mobile Sensors Network

In a mobile network the SRs does not have fixed positions and they are movable. The sensors might be moved in an area of interest, or distributed in a place to cover holes in one area that needs a high level coverage. In [2.6], it was shown that this approach has the advantage that it does not require centralized control, communication, and for that reason scale to very large networks. *Flocchini et al.* [2.7] studied a ring type self-deployment of mobile sensors in a purely decentralized and distributed fashion. In a finite time a state of static equilibrium is reached in which the sensors network uniformly cover the environment. For a mobile network the issues of coverage and energy consumption are of prime importance as the sensors move in a geographical area. *Teng et al.* [2.8] used a sensor relocation application and showed that after a sensor node failure, where a coverage hole is created, a mobile sensor node can be relocated to cover the hole in a timely and energy **-** efficient way.

2.2.5 Hybrid Sensors Network

In a Hybrid network there is a group of sensors that have fixed positions and a group of sensors that are movable. By moving the available mobile sensors, Wang et al. [2.9] shows the single coverage problem in contrast with (to) a hybrid network which is able to heal coverage holes by using the movable sensors. They used Voronoi diagrams to detect coverage holes and used one of three algorithms to calculate the target locations of sensors if holes exist. They showed the effectiveness of the protocols and calculation of algorithms under different application requirements and working conditions.

2.3 Sensors characteristics

A sensor node usually consists of four sub-systems. The **Sensing** the **Computing**, the **Communication**, and the **Power supply** subsystem. All these systems participate in order to fulfill the tasks of a single Sensor which will finally offer the Network its data for processing [2.10]. Also, the number of SRs which form a Network might vary. Another issue which has to be tackled with is the number of sensors nodes which are required in a given area. That is, determining the network density. In [2.11] network density is defined as in the following equation (2.1):

$$\mu(R) = (N \cdot \pi \cdot R^2) / A \qquad (2.1)$$

where N is the number of scattered nodes in a region A
R is the radio transmission range
μ(R) gives the number of nodes within the transmission radius of each node in region A.
Addition of extra nodes does not provide additional sensing nor coverage fidelity, beyond a critical value λ. Hence techniques would be required to decide optimized deployment for an area of interest.

2.3.1 Sensor Network states in WSNs

During cooperation between sensors and the base station of the network in WSNs the SRs can be in four different states as follows:

1) ***Sensing*:** SR is monitoring, digitizing, processing the information and then stores the data which will be eventually sent back to the base station.

2) ***Relaying*:** The SR receives data from other SRs and forwards them towards the

base station.

3) ***Sleeping*****:** A sleeping node does not participate in either sensing or relaying. Most of the device is either shut down or works in a low-power mode. However, from time to time it might change its state and “wake up” in order to listen to the communication channel and answer to requests from other nodes. Depending upon the type of the received request its state transition changes to “sensing” or “relaying”.

4) ***Dead*****:** A dead node has either used up its energy or has suffered a vital damage. Once a node is dead, it is no longer available to the sensor network and it cannot re-enter any other state [2.12].

2.3.2 Recovery from SRs failure in a Wireless Sensor Network-WSN

A SR failure or the simultaneous failure of a number of SRs in a WSN might create disjoint segments and miss critical information. There exists a significant amount of work related with connectivity recovery. In most of the work done already, a group of SRs or different groups contribute to the recovery process by using their movement.
In a WSN where SRs are movable [2.13] a novel distributed algorithm was presented, named Autonomously Repair AuR which enables a network to restore connectivity by only local coordination among SRs in the individual segments. AuR models electrostatic forces of attraction and repulsion. The neighbors of a failed node in order to overcome this problem, collaboratively decide on how to bridge the gap that a loss introduces by moving one or multiple healthy nodes. Self-spreading of nodes and movement toward the center of the deployment area offers recovering from a multi-node failure.

2.4 Localization in WSNs

The two main categories of localization in WSNs are the Target/source localization and the Node self localization.

2.4.1 Target/source localization

Target/source localization can be classified into two main categories depending on the area of interest. These two categories are the indoor and outdoor environment. In the indoor environment the target might be a human or a device which is located in a house, whilst outdoors the target might be a vehicle or an aircraft. There are also cases of underwater localization. In this case the target might vary depending upon the type of animal under research. The target might be a sea animal like a seal or a whale which are under research.

2.4.2 Single -Target/Source Localization in Wireless Sensor Network

There are several ways to estimate the source location:

Angle of arrival (AOA) [2.2] and
Time Difference of Arrival (TDOA) [2.3–2.6],

Energy-based. Energy-based method is an attractive method because it requires low hardware configuration which makes it an inexpensive approach. Single-source localization can be further divided into: energy decay model-based localization algorithm and model independent localization algorithms.

(1) Decay Model-Based Localization Algorithm.

Although this energy decay model appears quite simplistic, it is the one commonly used in literature. Since the objective function of single-source localization method has multiple local optima and saddle points [2.7], the authors formulated the problem as a convex feasibility problem and proposed a distributed version of the projection onto convex sets method. A weighted nonlinear least squares and weighted linear least squares methods [2.8] were proposed to estimate the location of the target. In [2.9], the authors proposed normalized incremental sub-gradient algorithm to solve the energy-based sensor network source localization problem where the decay factor of the energy decay method is unknown. Unlike the signal models in [2.7–2.9], the authors derived a more generalized statistical model for energy observation [2.14], and a weighted direct/one-step least-squares-based algorithm was investigated to reduce the computational complexity. And in comparison with quadratic elimination method, these methods were amenable to a correction technique which incorporates the dependence of unknown parameters leading to further performance gains. This method offered a good balance between the localization performance and computational complexity. Energy ratio formulation [2.11] was an alternative approach that is independent of the source energy. This was accomplished by taking ratios of the energy reading of a pair of sensors in the noise-free case. In [2.12], the authors proposed an energy aware source localization method to reduce the energy consumption in localization.

(2) *Model-Independent Methods.* In [2.16] cited by Cheng, et al.[2.17] a novel model-independent localization method was proposed. Since the nodes with higher received signal strength measurement were closer to the source, a distributed sorting algorithm is employed. If the sensor nodes know their rank, the required distance estimates are obtained as the expected value of the respective probability density functions. Finally, the projection onto convex sets (POCS) method was used to estimate the location of the source.

2.4.3 Multiple-Target Localization in Wireless Sensor Network

Many works examine the single-target localization. However, very limited papers look into the multiple-target localization. Most of the works are based on the maximum likelihood estimator. A multi resolution (MR) search and the expectation maximization (EM) method were also proposed [2.17].

2.4.4 Range-Based Localization

The classic methods to estimate the indoor location are time of arrival (TOA), Time Difference of Arrival (TDOA), Angle of Arrival (AOA), and Received Signal Strength (RSS). TOA method measures travel times of signals between nodes. TDOA method locates the signals arrival time by measuring the difference between anchor nodes and unknown node. That way it is able to achieve high ranging accuracy. The disadvantage of this method is that it requires extra hardware and consumes more energy. It could be mentioned that a large network consumes a lot of energy, which needs to be dealt with well in advance.RSS has established the mathematical model on the basis of path loss attenuation with distance. It requires relatively low configuration and energy and it is an inexpensive approach. AOA, is a method in which the angles between unknown node and a number of anchor nodes are used to estimate the location. This method needs the antenna array which is an expensive solution for low-cost sensor node.

2.4.5 Range-Free Localization

Range free - RF techniques prove to be the best option in WSNs networks as only a fraction of sensor nodes (called anchor nodes or beacon nodes) are employed with GPS.SRs that do not know their location, (unknown nodes) calculate their position using anchor nodes by a process called *node self localization* or *cooperative localization.* The high cost of hardware for range based approaches in WSNs lead to range-free localization solutions as a cost-effective alternative. In this case absolute point-to-point distance estimates are of less importance. In [2.19], four Range-Free algorithms are presented (*Centroid Algorithm, CPE Algorithm ,APIT Algorithm ,DV-hop algorithm)*. In comparison to various attributes, Table 2.1 *showed that* DV Hop algorithm is efficient in larger sensor network with greatest accuracy whilst the Centroid algorithm is very cost effective [2.18],[2.21].

S No	*Type of localization algorithm*	*Accuracy*	*GPS Error*	*Number of Neighbor Anchors*	*Overhead*
1	*Centroid Algorithm*	*Fair*	*Good*	≥3	*Smallest*
2	*CPE algorithm*	*Fair*	*Fair*	≥3	*Small*
3	*APIT Algorithm*	*Good*	*Good*	≥3	*Large*
4	*DV-hop algorithm*	*Good*	*Good*	*No restriction*	*Largest*

Table 2.1 Range Free algorithms comparison [2.19]

2.4.5.1 Hop-Count-Based Localization.

DV-Hop is the typical range-free positioning system. It does not need to measure the absolute distance between the beacon node and unknown node. It uses the average hop distance to approximate the actual distances and that way reducing the hardware requirements. Its implementation is easy and can be applied to a large network. The problem is that the positioning error is correspondingly increased. The positioning process of DV-Hop is divided into three stages:

-Information broadcast

-Distance calculation

-Position estimation

In **information broadcast stage**, the beacon nodes broadcast their location information package, which includes hop count and is initialized to zero for their neighbors. The receiver records the minimal hop of each beacon nodes and ignores the larger hop for the same beacon nodes. Then the receiver increases the hop count by 1 and transmits it to neighbor nodes. All the nodes in a network can record the minimal hop counts of each beacon nodes. In **distance calculation stage**, according to the position of the beacon node and hop count, each beacon node uses the following equation to estimate the actual distance of every hop: where (*xi*, *yi*) and (*xj* , *yj*) are the coordinates of beacon nodes *i* and *j*, respectively. *hj* is the hop count between the beacon nodes. Then, beacon nodes will calculate the average distance and broadcast the information to network. The unknown nodes only record the first average distance and then transmit it to the neighboring nodes. In **position estimation stage** the unknown node calculates its location.

2.4.5.2 Pattern Matching Localization

One of the most viable solutions for Range-Free localization methods recently is the Pattern matching localization, also called Fingerprint or Map-based algorithm. The fingerprint localization has two phases. In the first phase, the received signals at selected locations are recorded in an offline database called radio map with RSSI In the second phase, it works at the online state and match online measurements with the closest a priori location fingerprints. But when using the fingerprint-based method, a commonly used method of estimating user location is to find the nearest reference point, using the Euclidean distance in signal space. Euclidean distance method is prone to error, especially when Wi-fi access points are unstable: a problem that frequently might occur. Another issue is that some access points may be active when generating a radio map and not active when their location is estimated. In addition, even if an access point is active, the user may not receive signal due to problems such as collisions. When the signal strengths from unstable access points are fed into the standard estimation algorithm, they can lead to serious estimation errors. Also, observations made show that RSSIs can be shifted from access points due to various reasons, such as height difference of users [2.17],[2.20].

2.4.5.3 Range Free -RF Localization Algorithms

During the last decade a number of algorithms has been proposed in order to tackle the localization problem with a Range Free (RF) method in WSNs. In the Point-In-Triangulation Test (PIT) Fig.2.1, a node chooses three anchors from all audible anchors (the anchors which had received a beacon) and tests whether it is inside the triangle formed by connecting these three anchors. This test is used as a basis for many algorithms to find the possible area in which a target node resides.

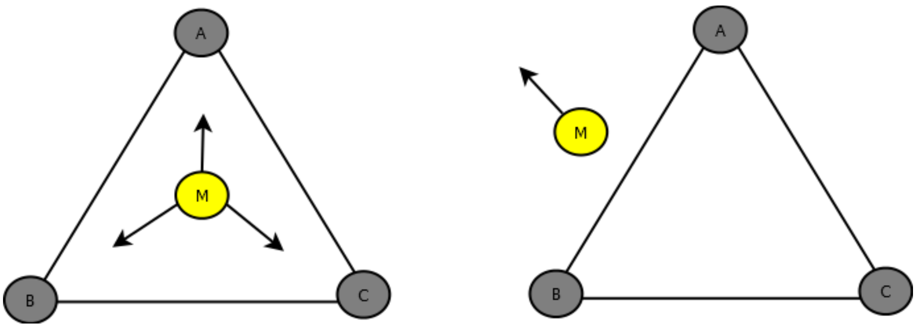

Figure 2.1 PIT location Test [2.19]

He et al. proposed APIT [2.21], where an unknown node position is estimated as the center of gravity of the triangles overlapping region Fig.2.2. The triangles are formed, by connecting all three anchor nodes heard by unknown node and PIT test is applied for each triangle. This algorithm requires low hardware, however, the accuracy of localization in this method is affected by a node's presence whether it is within the triangular regions or not [2.22]. The Approximate Point in Triangulation - APIT is one of the typical PIT algorithms based-on regional determination. However, APIT algorithm requires anchors in a single hop, high nodes' density and anchors' uniform distribution. Yet, nodes' density is seldom high and nodes' distribution is uneven in actual WSN networks, in which the accuracy of APIT only reaches to about 35%. Thus, APIT algorithm requires harsh conditions and its accuracy is not high.

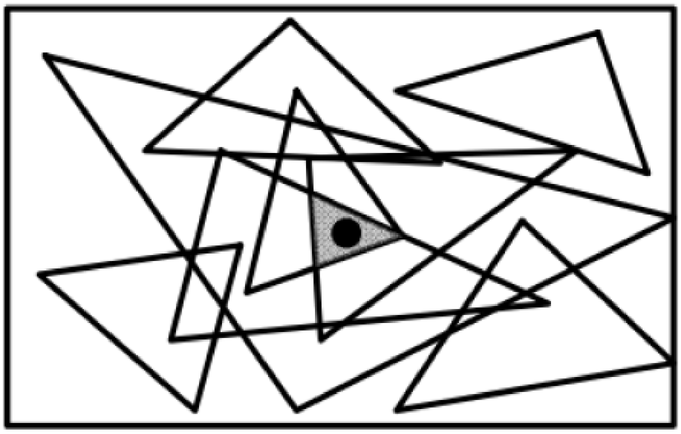

Figure 2.1 APIT location Algorithm [2.21]

Xu et al.,[2.23] introduced a Novel PIT Localization Algorithm based on Coverage of Anchors. The novel algorithm improves the accuracy about 20%. by determining whether the test point is inside the triangle formed by three anchor nodes through judging whether the center of gravity of the intersection of the anchors' coverage area is inside the triangle Fig. 2.3.

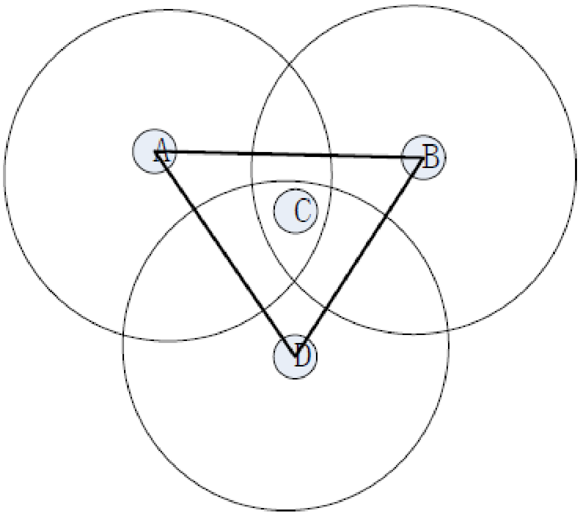

Figure 2.2 Schematic diagram of the Novel PIT Algorithm [2.23]

Wu et al., [2.24] combined the RSSI (Received Signal Strength Indication) and APIT (Approximate Point in Triangulation) algorithm to improve APIT algorithm. They showed that APIT has some errors in the localization procedure and proposed the improved APIT algorithm, IAPIT. To solve the problem of location precision that exists in the APIT location algorithm, RSSI was introduced to revise the location precision. For the anchor nodes within one unit of the unknown node, they used RSSI to measure the distances between the unknown nodes and the anchor nodes and then selected three anchor nodes with smaller distances, and calculated the estimated position by using trilateration measurement. Then they calculated the center of mass of the overlapping region as the estimated position, according to APIT algorithm. Finally they calculated the average value of these two positions as the final position coordinates. For the unknown nodes that were unable to be located by APIT algorithm, they used RSSI ranging quantitative model to assist location and find the estimated coordinates of the unknown node. As the APIT algorithm suffers from significant position errors due to theoretical defects and (and) RSSI inaccuracy, Xiaofeng Li et al. [2.25] presented the FAPIT, which is a combination of IAPIT and a Fuzzy logic system, where the SRs coordinates are estimated by using the Centers of Gravity - CoGs of the triangles intersection areas. By presenting the defects of the APIT and the IAPIT the proved that the FIAPIT works better as the fuzzy logic inference based on IAPIT helps to manage relative uncertainties which are associated with irregular RSSI. They also showed that IAPIT works better than APIT when the Node Density is large enough. High level of FAPIT is depicted in Fig.2.4.

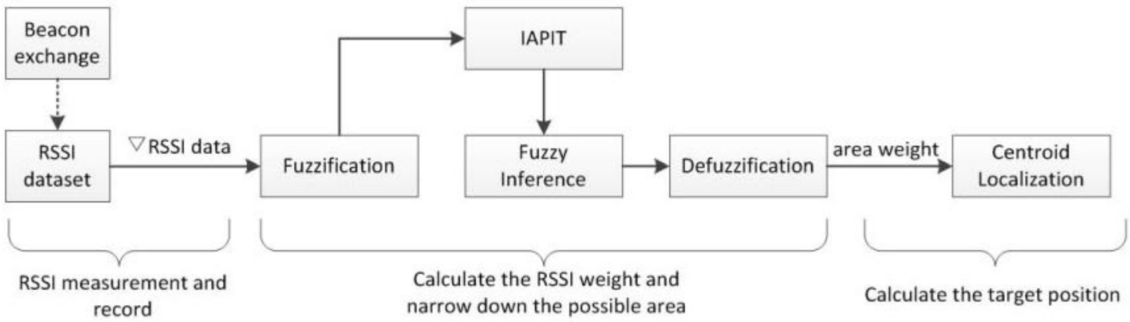

Figure 2.3 High level of FAPIT [2.25]

X.Sun et al. [2.26], tried to improve the accuracy of the node localization in WSNs and proposed a new range-free localization using Voronoi diagrams based on the Approximate Point-In-Triangulation test (APIT) algorithm. Their design of Voronoi Point-In-Triangulation VPIT mainly consists of P.I.T test and Voronoi diagrams, then is following the stage of calculation of the overlapping region center of gravity. The work-flow diagram of VPIT is depicted in Fig.2.5.

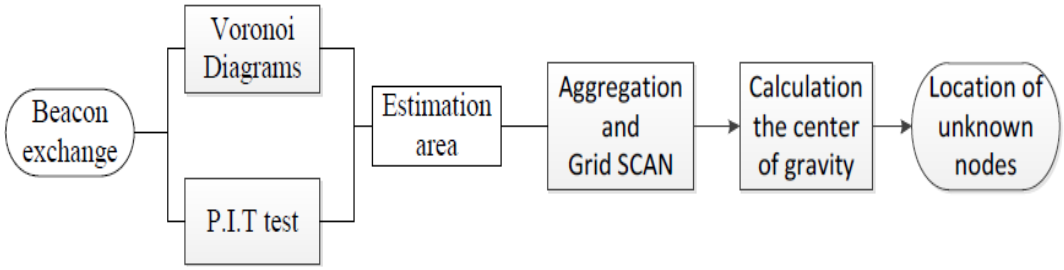

Figure 2.4 VPIT Work - flow diagram [2.26]

They compared their algorithm to APIT. Their simulation results showed that their VPIT algorithm improved the precision of localization by narrowing the node's geometry region. Compared with APIT, the estimation error of VPIT algorithm was lesser and better performed.

2.5 Localization in Telemetry

Another type of localization is the localization in telemetry where researchers use bearings to locate species of animals. Telemetry for the observation and research of wildlife was introduced more than 50 years ago, by Adams 1965, and Cochran et al., 1965 [2.27], [2.28]. It is applied localization through triangulation by radio tracking in areas of surveillance, mostly where species of animal behavior and movements are under investigation. One of the common known method is the “ad hoc” method, in which the location is estimated to be somewhere in the middle of the intersections of several bearings. The ad hoc method is easy to use, but neither the location nor the error estimates are objective. Another technique is the “error polygon method” which was introduced by Heezen et al. cited by Nams et al in which an error polygon is represented as the intersection of the arcs formed by the confidence intervals of 2 bearings. This method is restrictive in that it only measures precision of individual locations for 2 bearings [2.29]. Heezen et al. in their research of three deer movements [2.30], showed that as the distance from the base line of detection increases there is an increase in the size of the error polygon, d1 > d2, Fig.2.6.

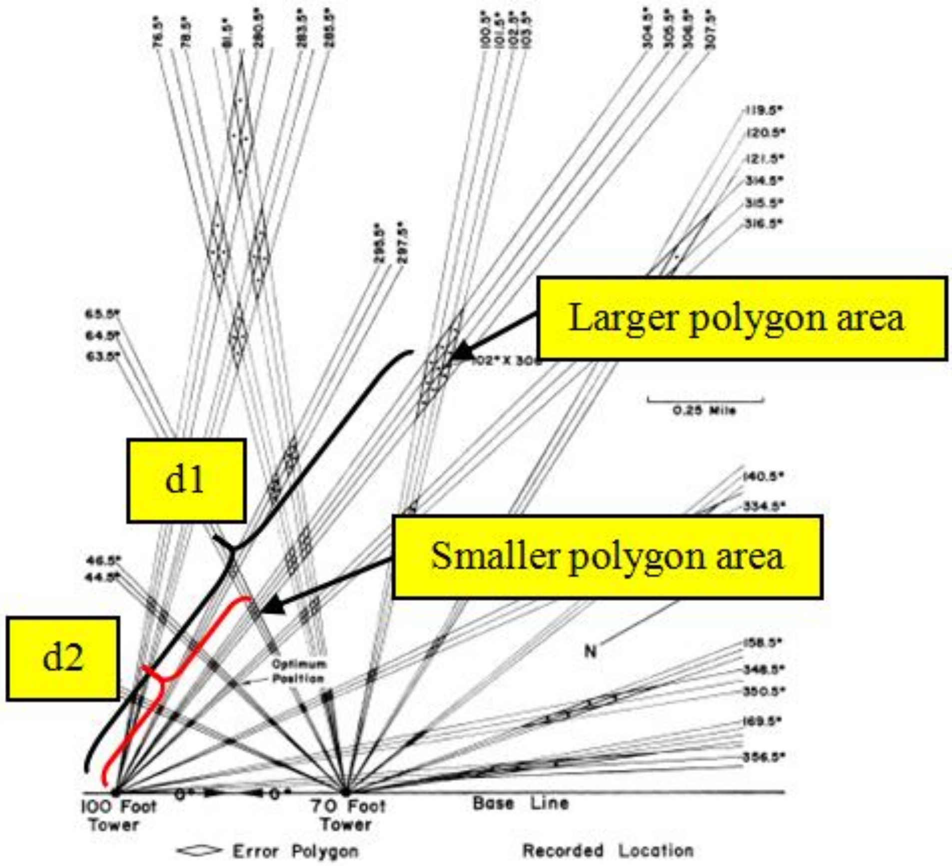

Figure 2.5 Relative sizes and shapes of error polygons at selected locations in relation to the two tracking towers. Any true location within an error polygon would be recorded at the center of that polygon [2.30]

The third method, which is “the error triangle technique” uses 3 bearings and defines the error polygon by the points at which the bearings from the receiving antennas cross rather than the intersection of the error arcs. The problem with this technique is that although one can measure the area of the triangle, there is no suggested way to estimate the probability of the true location being within the Triangle, and there is no probability value given to the size of error triangles. The fourth method developed by Lenth cited by Nams et al. uses maximum likelihood estimators to estimate both location and precision. The Lenth maximum likelihood estimators objectively estimate both location and precision of the location for any number of bearings. In relevance with (to) the telemetry error in localization , Montgomery et all, [2.31] pointed out that telemetry error, patch size and categorical raster resolution interact with each other and influence the accuracy of assigning co-variant values to estimated wildlife telemetry locations. They quantified the analogy of Telemetry errors as it is described below:

-The probability of being correct for all patch sizes, will generally have > 50% for telemetry errors up to 60 m.

-Accuracies > 90% tend to be restricted to intermediate telemetry errors (10 m < telemetry error < 36 m) at larger patch sizes (20-200 ha) or small telemetry errors (telemetry error < 10 m).

They also provided metrics and a replicable methodology by which researchers and managers are able to identify the relative accuracy of wildlife models given the mean error of their telemetry system and the patch size characteristics of their study. Ward et al. [2.32] in their research with an automated telemetry system and by using arrays of single Automated Receiving Units (ARUs) managed to detect snakes' positions as well as their movements. A snake's position by using an ARU array was determined with bearings from each of the ARUs and estimation of the location based on the intersection of those bearings. The spatial accuracy of the system was affected by a number of factors, like the strength of the transmitter, the height of the transmitter above the ground, its orientation to the ARU antennas, the density of vegetation or other structures between the transmitter and the ARU. They concluded that the most obvious advantage of tracking snakes using ARUs was that automation greatly increased the amount of data that could be collected per individual and potentially the number of individuals that can be tracked simultaneously, with much less human involvement. Also, and as data were collected around the clock and potentially for as long as transmitters were operating, the activity and movement profiles generated were far more complete than would be possible with conventional tracking, meaning the hand tracking.

Some shortcomings of using the ARUs were that the targets had to remain within their detection range, and unlike hand tracking, where a snake's position could be determined within a few meters locations determined by ARUs had errors of tens of meters at best. They commented that due to limitations of that technology and in order to become most effective it should be coupled with both appropriate species and appropriate questions and future research seems likely to benefit from using a combination of the two technologies (Conventional and automated).

2.6 Network Topology

Every Sensors network has a different topology depending on its type and purpose. Over the past few years there has been extensive ongoing research related to network topologies which might offer a great amount of coverage, energy efficiency and internal network communication. Topology should be carefully designed so as the base station to receive and not miss the sensors data. As it is depicted in Fig.2.7 there are a lot of topology issues that should be examined carefully when a WSN will be designed [2.65].

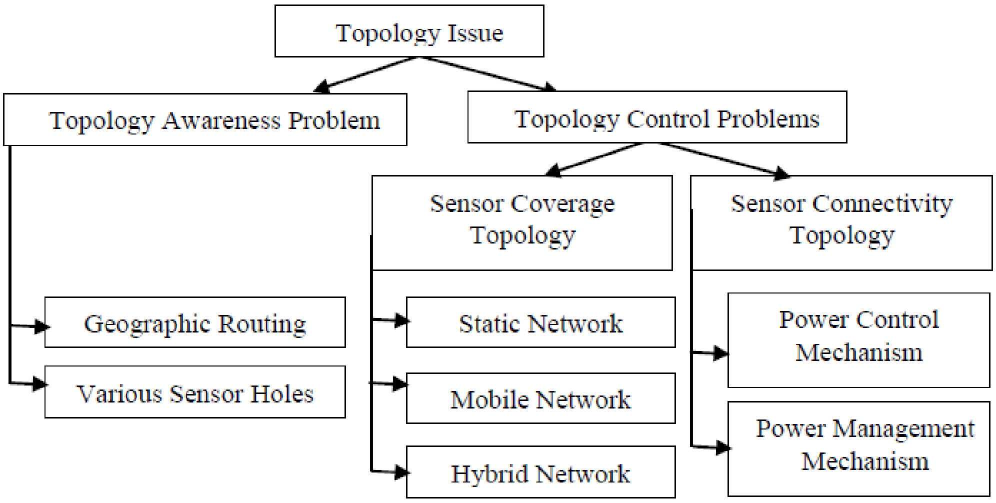

Figure 2.6 Taxonomy of topology issues in WSNs [2.65]

2.6.1 Wireless sensor networks topologies

In the Wireless sensor networks the topologies are the **Bus, Tree, Star, Ring, Mesh, Star-Mesh, Circular and Grid.** Each one of them has its own performance and contributes in the energy conservation of the system, whilst the Grid topology appears to be the most energy efficient [2.33]. Nivedita et al. [2.34] presents different basic network topologies and as every topology has its own advantages and disadvantages they suggest that a combined topology known as Hybrid topology, which is reliable, scalable, flexible and effective, can be used. The only disadvantage is the complexity of its design and a costly infrastructure due to the combination of two or more different topologies.

2.6.1.1 Mesh Topology

Wireless mesh networks Fig.2.8 were originally developed for military applications. Mesh networks are typically wireless. As over the past decade, the size, cost, and power requirements of radios have declined, enabling multiple radios to be contained within a single mesh node, thus allowing for greater modularity. Each node can handle multiple frequency bands and support a variety of functions as needed [2.35]. One of the main advantages of this topology is that there is no single point of failure. The chances of data loss are highly unlikely as an alternate path can be found in this type of topology for the nodes. That makes it the most reliable communication network structure whilst synchronously it is a scalable network. The disadvantage with this type of network is that there are too many redundant paths and that for a wireless sensor network all the point-to-point links must be tuned. Overall this results in high power consumption.

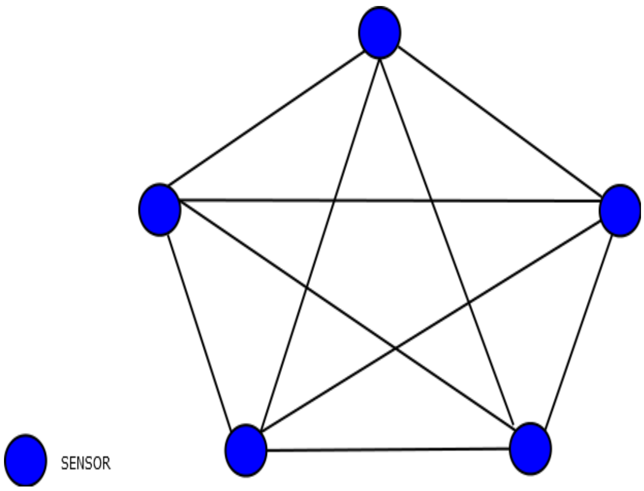

Figure 2.7 Mesh Topology [2.35]

2.6.1.2 Tree Topology

All the sensors construct a logical tree and for that reason we call it a Tree Topology Fig.2.9. In this topology we have two types of nodes; one is a parent node and the other is a leaf node. Data packets are passed from a leaf node to its parent nodes. The advantage of this topology is that it consumes less power than other topologies, whilst one of its main advantages is that if a node fails then the entire sub-tree is cutoff from the base station. Additionally, except for being time consuming and costly as the data have to be transmitted from the leaf nodes to the root node we would say that this topology is not either promising or trustworthy [2.35].

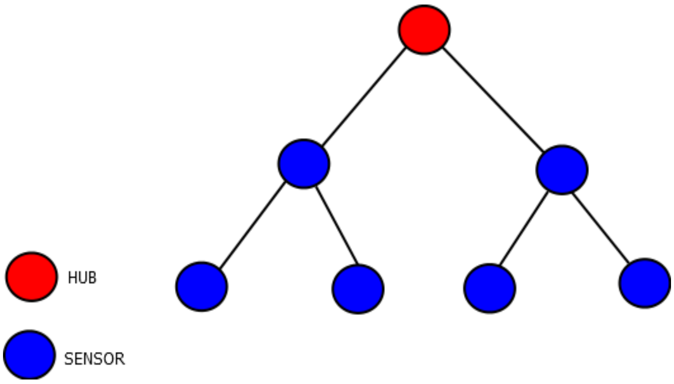

Figure 2.8 Tree Topology [2.35]

2.6.1.3 Star Topology

In this topology Fig.2.10**,** compared with the Mesh topology we have lower power consumption and it is easy to enlarge which makes its structure scalable. The main disadvantages of this topology when used in a wireless sensor Network are that there is no reliable communication due to a single point failure and there is no alternate path in this structure of any node [2.36].

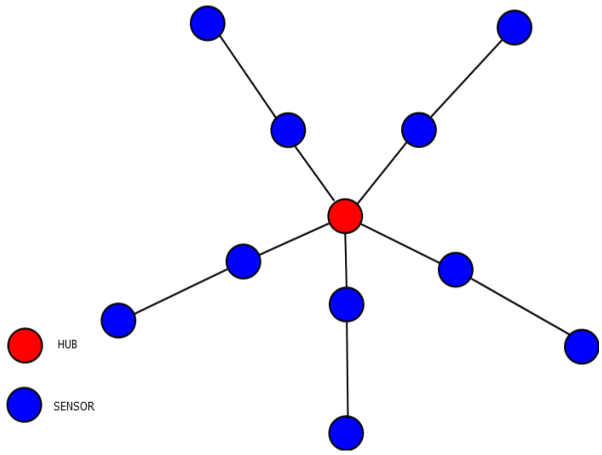

Figure 2.9 Star Topology [2.35]

2.6.1.4 Star - Mesh Topology

Star-Mesh topology, Fig.2.11 is a hybrid topology that combines the advantages of star topology and mesh topology. Among all nodes, one node is specified as the PAN coordinator and with it the network can be identified. This hybrid topology organizes the nodes in star topology around mesh nodes, which finally turn into a mesh network. The hybridization of Star-Mesh network offers the highest degree of sensor node mobility and flexibility for fast changes in the network population and the overall low power consumption. For this reason, the star - mesh hybrid has proved to be a logical choice for many implementations of wireless sensor networks [2.37].

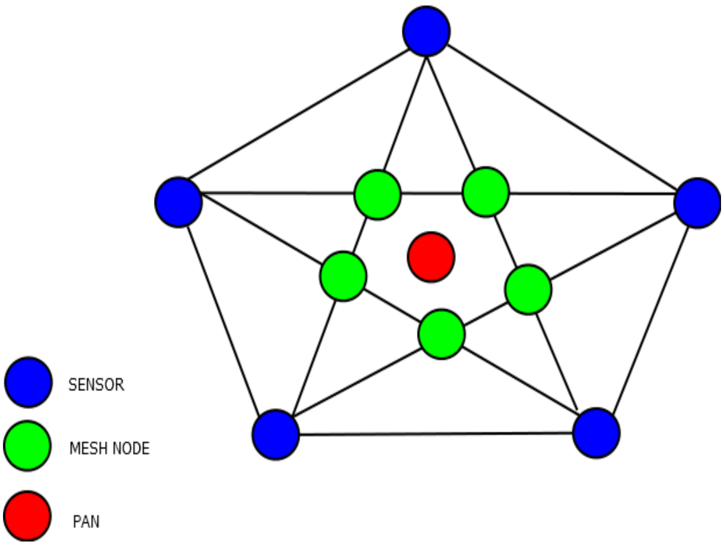

Figure 2.10 Star - Mesh Topology [2.37]

2.6.1.5 Ring Topology

In this topology Fig.2.12 only neighboring nodes are able to communicate with each other. One advantage of this sensor network topology is that it does not have any leader (central node), but if any node or link is broken during the communication, then it will affect the whole sensor network. The main disadvantage is that data packets must pass through every node between the sender and the recipient and that makes the network slower. Additionally, if any of the nodes fail then the ring is broken and data cannot be transmitted successfully. For that reason nowadays, ring topology is not much preferred in applications.

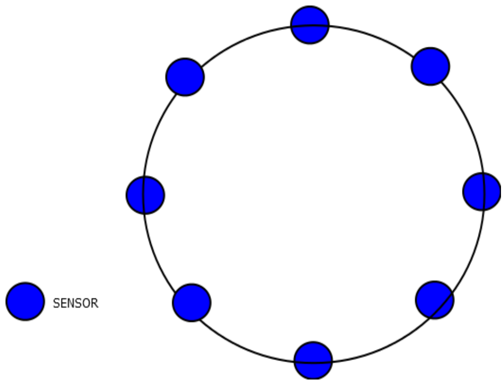

Figure 2.11 Ring Topology [2.37]

2.6.1.6 Circular Topology

In this topology, Fig.2.13 there is a sensing area which has a sink at the center. SR nodes sense the area and when they sense an event they transmit data to the sink. Nodes are randomly deployed with uniform density all around the sink as shown in Fig.12. Circular web topology is more efficient, easier to establish and easier to maintain [2.38], [2.39].

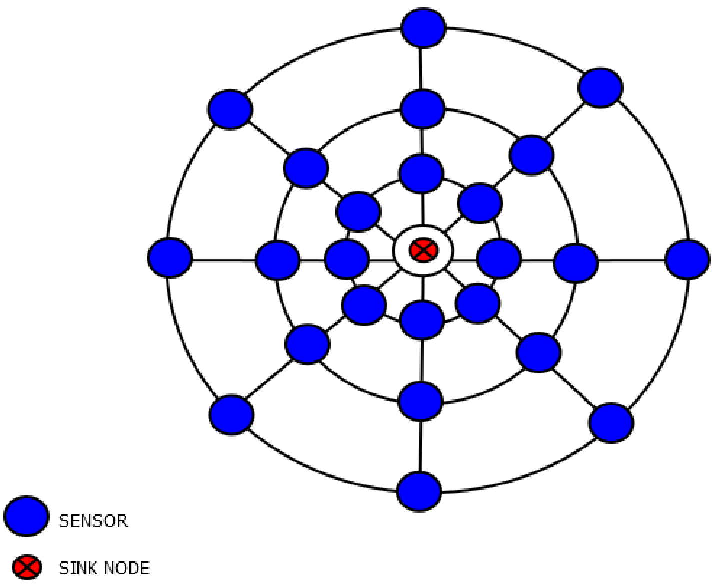

Figure 2.12 Circular Topology [2.38]

2.6.1.7 Grid Topology

In this topology the sensor network field is divided into grids as it is depicted in Fig.2.14. The network area is partitioned into non-overlapping square grids of the same size. In each grid there should be at least one and only one node in working state at any time. The nodes in a grid should work in turn in order to extend the network life time. In each grid, there is one node which is selected as a grid head and which is responsible for forwarding routing information and transmitting data packets. Routing is performed in a grid-by- grid manner. A Grid-based multi-path routing protocol intended to route packets fast, utilize and extend sensor nodes energy in addition to avoiding and handling network congestion when it happens in the network [2.38].

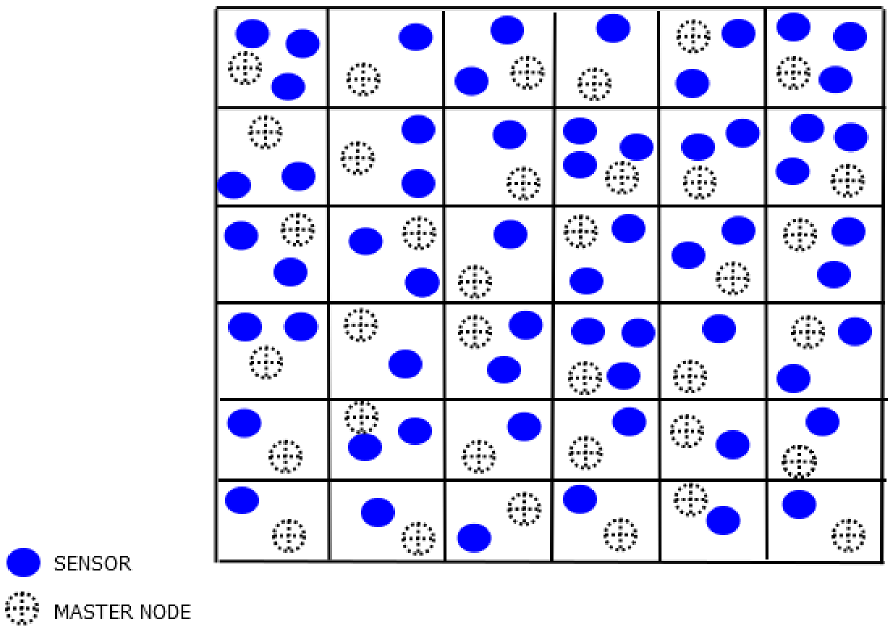

Figure 2.13 Grid Topology [2.38]

2.6.1.8 Bus Topology

Bus topology Fig.2.15, is easy to install and in this topology, each node sends a message to another node on the network. In this topology a node broadcasts a message if it wants to send any information to any other node in network. All nodes see or receive the message but only the recipient actually processes the message and the rest of the nodes discard it. As it has a single path communication traffic congestion may easily make the network unavailable. Bus networks work best with a limited number of nodes. If more than a few dozen of nodes are added to a network bus, performance problems will likely result. It cannot be counted as scalable as it has limited length and range and it is relatively slower [2.38],[2.40].

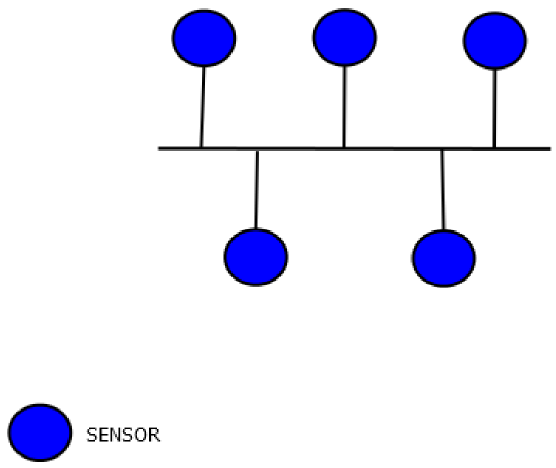

Figure 2.14 Bus Topology [2.38]

2.7 Topology Control

Topology Control-TC allows the maintenance of the communication links between network nodes and their connectivity. Also, it characterizes the group of network nodes, adding or deleting nodes in the group. Transmission range and scheduling of nodes alter the topology of sensor network. By controlling the topology more energy can be saved for the network. For that reason TC plays an important role in energy conservation and might increase the life expectancy of the overall network. But a network in order to achieve its purpose and remain reliable has to deal with a various TC problems. The TC problems can be divided into two categories: Sensor Coverage Topology and Sensor Connectivity Topology [2.13].

2.7.1 Sensor Coverage Topology

The coverage topology describes the topology of sensor coverage and is concerned about how to maximize a reliable sensing area while consuming less power. The SRs locations can be predefined in the sensor field or might be positioned at places which are more weighed and suitable for monitoring [2.41]. There are three categories into Sensor Coverage Topology: Static, Mobile and Hybrid

2.7.1.1 K-coverage

In many applications where a strong coverage capability is needed every point in the area (monitored or tracked by sensors) should be covered by at least a fixed parameter of k sensors, where k is a predefined value. In a case that k = 3 every point should be covered ***by a minimum of three SRs*** **or more**. Huang and Tseng (2005) [2.42], proposed a novel solution to determine whether a sensor network is *k*-covered. They checked if the sensing range of each sensor can be a unit disk *k-Unit-disk Coverage (k-UC) or a k-Non-unit-disk Coverage (k-NC) Problem.* Their approach looked at how the perimeter of each sensor's sensing range is covered or not, and proved that the whole area is sufficiently covered as long as the perimeters of sensors are sufficiently covered. The k coverage problem has been extensively studied over the last years [2.42] - [2.45], and specifically especially for the positioning with triangulation problem triangulation-based positioning protocols [2.45] - [2.47] which require at least three sensors (i.e., $k \geq 3$) to monitor a moving object in the sensing area of interest [2.48],[2.49].

2.7.1.2 Static Coverage

The *Partial Coverage* where only a necessary set of sensors is working and the second is the *Single Coverage.* A static network must be deployed according to a predefined shape. The predefined locations of the sensors can be uniformed in different areas of the sensor field or can be weighted weighed to compensate for the more critically monitored areas [2.44].

2.7.1.3 Mobile Coverage

Different from static coverage, the nodes here use dynamic coverage and a group of nodes or all of them have the ability of moving. In this case, when an area is given to monitoring, the proposed distributed self-deployment protocols first discover the existence of coverage holes in the target area then calculate the target positions. Then they move sensors in order to diminish the coverage holes [2.44].

2.7.1.4 Hybrid Coverage

In this type of Coverage, there exist SRs that are capable of movement. Those SRs can help in deployment and network repair by moving into appropriate locations within the field to achieve desired level of coverage. It is a combined solution for the exploration and coverage of a given target area. A coverage problem can be solved with the help of a constantly moving SR or a set of SRs in a given target area of interest. The available mobile sensors in a hybrid network might be moved to heal coverage holes. All decisions are made by the moving SR by directly communicating with a neighboring SR [2.44].

2.7.2 Sensor Connectivity Topology

The connectivity topology on the other hand is more concerned about network connectivity and emphasizes the message retrieve and delivery in the network. Two kinds of mechanisms have been utilized to maintain an efficient sensor connectivity topology:

2.7.2.1 Power Control Mechanisms

Parameters which are used to evaluate the TC of a network are: Connectivity, Energy efficiency, Throughput and the Network lifetime [2.50].

2.7.2.2 Connectivity

The multiple path between nodes should be maintained and the connectivity between nodes to share messages should be on the right percentage which will allow all the messages to reach the base station.

2.7.2.3 Energy efficiency

The two factors that determine the energy efficiency of the network are the "Energy stretch factor" and the "Hop Stretch factor. Also, the distance between nodes influences proportionally the energy consumption for transmission and reception between nodes.

2.7.2.4 Network lifetime

The overall network's life expectancy is required to remain high in order to maintain the connectivity and coverage of the network. Nodes failure to balance energy consumption might decrease the network's life expectancy or even worse lead to a network failure.

2.8 Topology awareness

Topology Awareness is another issue of topology and includes the *geographic routing problem* and the *sensor holes problem.* Failure to use adequate geographical and topological information will result in low routing efficiency and high power consumption. This eventually, might easily lead to network degradation and subsequent inefficiency.

2.8.1 Geographic Routing

Geographic routing uses geographic and topological information of the network to achieve optimal routing schemes with high routing efficiency and low power consumption. SR holes, such as Jamming holes, sink/black holes and worm holes, may form in a WSN and create network topology variations which trouble the upper layer applications. In a network with a great number of nodes in which intense communication is taking place this may result in the creation of jamming holes and failure message delivery to the exterior nodes. Another type of holes is the Sink/Black holes and Worm holes which are caused by exhausted nodes) around sink node or pretended sinks or by malicious nodes. SR holes issues should be treated carefully, as they will create a costly routing table and will exhaust the intermediate nodes rapidly.

2.8.2 Network Holes

Whenever in an area of the network either nodes are not available or the available nodes cannot participate in the actual routing of the data due to various reasons, a routing hole is created. **Sink/Black holes** and **Worm holes** are related to the power consumption in the network and are gradually formed due to sensor node power exhaustion and possible denial of service attacks in the network. Prevention of data loss and reliability of the network is ensured with Hole detection and the various types of holes are the following:

2.8.2.1 Coverage holes

Coverage holes are formed due to bad design or unsystematically area arrangement. Also, poor installment, weak power of nodes or topology failure due to the presence of obstacles, might lead to the appearance of a coverage hole, [2.51]. In [2.52], what was discussed and analyzed was a system, Fig.2.16, to deal with the holes problem and the ways to heal the network. Hole healing is done by moving the nearby nodes with high energy. Neighboring nodes are selected in such a way that network connectivity is not disturbed. During the healing process, the originator finds the nodes with minimum distance and moves them to a particular distance. And the process of healing the hole is completed.

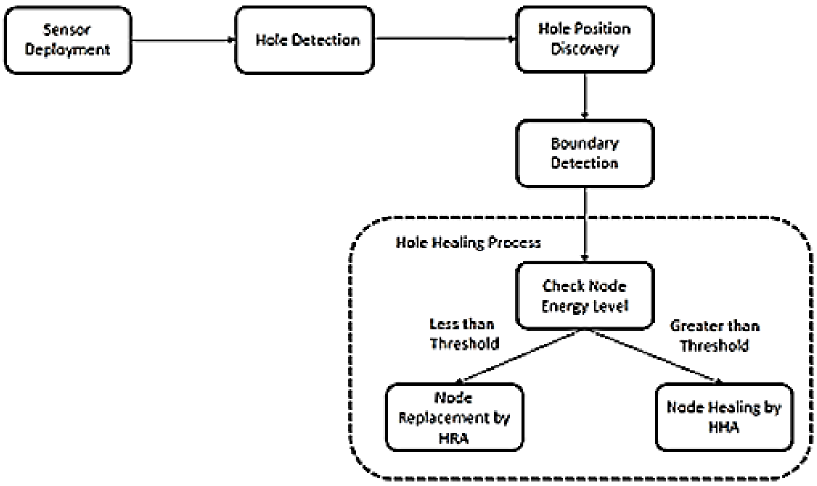

Figure 2.15 System diagram for hole detection and network healing [2.52]

2.8.2.2 Jamming holes

Jamming holes are the type of holes which circumvents the ability of nodes in a specific area to communicate and sense and by that way a virtual hole emerges. Jamming can be deliberate or unintentional. The zone of influence centered at a jammer is referred as a jamming hole. Unintentional jamming results when one or more of the deployed nodes malfunction and continuously transmit and occupy the wireless channel denying the facility to other neighboring nodes. Though in deliberate jamming an adversary is trying to impair the functionality of the sensor network by interfering with the communication ability of the sensor nodes [2.53].

2.8.2.3 Sink/Black holes

Sinkhole/Black holes is a type of attack where compromised node tries to attract network traffic by advertising a fake routing update. The attacker listens to request for routes and then replies that it contains the shortest path to the base station. Once the malicious device inserts itself between the sink and the sensor node it can do anything it likes with the data packets passing between them, Fig.2.17. One of the impacts of sinkhole attack is that, it can be used to launch other attacks like selective forwarding, acknowledge spoofing and drops or altered routing information. It can also be used to send bogus information to base station [2.54].

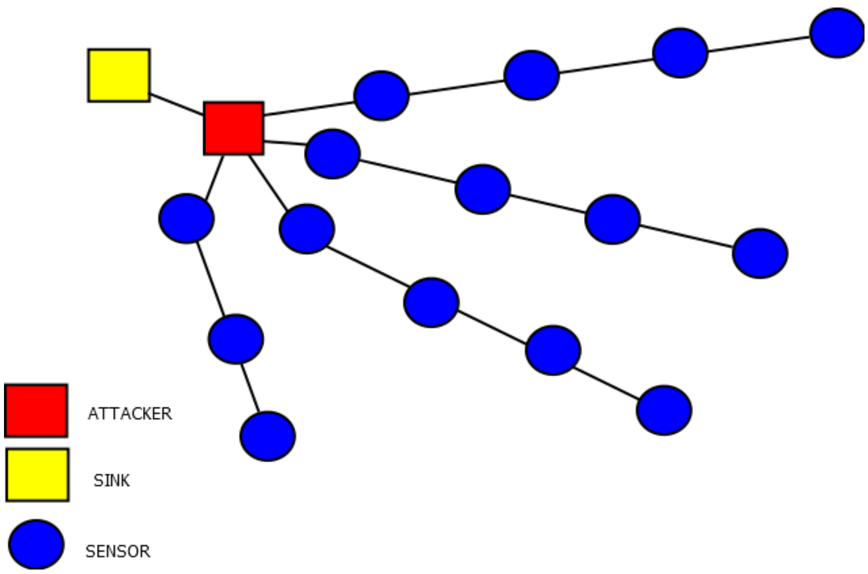

Figure 2.16 Sink hole attack topology diagram [2.54]

N. Gandhewar et al. in [2.55], suggests a mechanism to identify sinkhole attacks by checking for very large variations in the sequence numbers for the Request packet. They discussed the AODV protocol and they showed its performance with no sinkhole attack, under attack & after applying a mechanism.

2.8.2.4 Worm holes

Worm holes are formed when a malicious node causes nodes located in different parts of networks to believe that they are neighbors. This results in incorrect routing convergence and communication overhead [2.56]. Wang et al. in [2.57] proposed MDS-VOW, a mechanism, to detect wormholes in a sensor network. MDS-VOW does not require the sensors to be equipped with special hardware, and adopts and combines techniques from social science, computer graphics, and scientific visualization to attack the problem in network security. Results showed that MDS-VOW has a low false alarm ratio when the distance measurement errors are not large.

2.9 Fuzzy logic theory

Fuzzy logic is an extension of Boolean logic by Lot Zadeh in 1965 based on the mathematical theory of fuzzy sets, which is a generalization of the classical set theory. The phrase "fuzzy" refers to something that is unclear or ambiguous. In the actual world, we frequently encounter situations in which we are unable to discern whether a condition is true or false; their fuzzy logic gives a solution. In the real world many times we encounter a situation when we can't determine whether a state is true or false, their fuzzy logic provides a quite valuable flexibility for reasoning. In this approach, we can account for the inaccuracies and uncertainties of any situation. The absolute truth value in the Boolean system is 1.0, while the absolute false value is 0.0. However, there is no logic for absolute truth and absolute false value in the fuzzy system. There is also an intermediate value in fuzzy logic, which is present and is partially true and partially false [2.61]. In Fig.2.18 we have a depiction of fussy logic compared to the Boolean system of truth related with temperature.

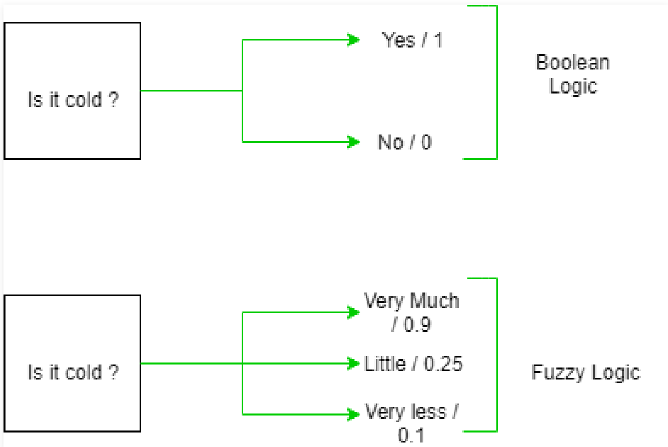

Figure 2.17 Depiction of Boolean truth compared with Fuzzy logic related with cold temperature [2.61]

By introducing the notion of degree in the verification of a condition, thus enabling a condition to be in a state other than true or false, fuzzy logic provides a very valuable flexibility for reasoning, which makes it possible to take into account inaccuracies and uncertainties. One advantage of fuzzy logic in order to formalize human reasoning is that the rules are set in natural language [2.59].Fuzzy logic is based on the theory of fuzzy sets, which is a generalization of the classical set theory. Saying that the theory of fuzzy sets is a generalization of the classical set theory means that the latter is a special case of fuzzy sets theory. To make a metaphor in set theory speaking, the classical set theory is a subset of the theory of fuzzy sets, as illustrated in Fig.2.19.

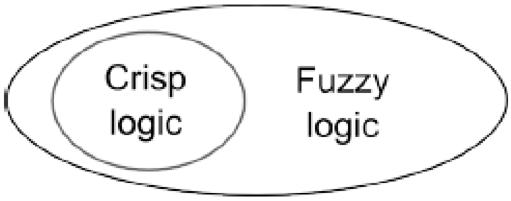

Figure 2. 18 "The classical set theory is a subset of the theory of fuzzy sets" [2.59]

classical set theory is a subset of the theory of fuzzy sets, as illustrated in above Fig.2.19. A fuzzy system designer, as with all fuzzy operators must choose among several possible definitions of defuzzification. A detailed list can be found in the research article [2.60]. The two main methods of defuzzification are: the method of the Mean of Maxima (MeOM) Fig.2.20 and the method of Center of Gravity (COG), Fig.2.21.

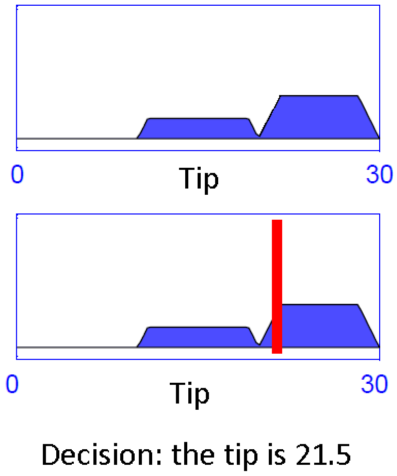

Figure 2.19 Defuzzification with the method of center of gravity (COG) [2.60]

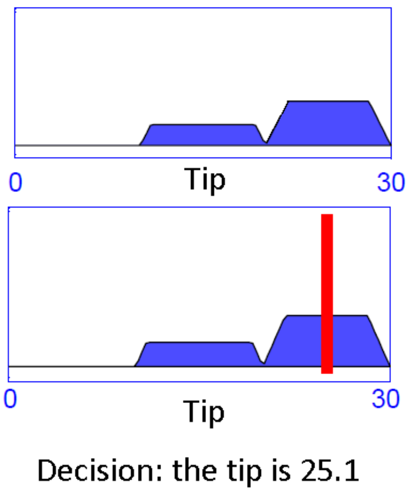

Figure 2.20 Defuzzification with the method of mean of center maxima(MeOM) [2.60]

The architecture of the Fuzzy logic is depicted in Fig.2.22 and contains the four parts of Rule base, Fuzzification Inference engine and Defuzzification [2.61]:

- RULE BASE: It contains the set of rules and the IF-THEN conditions for governing the decision-making system based on linguistic data. All these sets are provided by the experts and form the initial stage of the Fuzzy logic system. Recent advances in fuzzy theory have resulted in a number of useful strategies for designing and tuning fuzzy controllers. The majority of these advancements lessen the quantity of ambiguous regulations.
- FUZZIFICATION: This is a technique for transforming inputs, such as crisp numbers, into fuzzy sets. Crisp inputs are the precise data inputs measured by sensors and delivered to the control system to be processed, such as temperature, pressure, rpm's, etc.
- INFERENCE ENGINE: It specifies the degree of matching between the current fuzzy input and each rule, as well as which rules should be activated based on the input field. Then a combination of fired rules is taking place to form the control actions.
- DEFUZZIFICATION: It is utilized to change over the fuzzy sets obtained by the inference engine into crisp value. There are several defuzzification strategies accessible and the best suited one is utilized with a particular expert system to reduce the error [2.61].

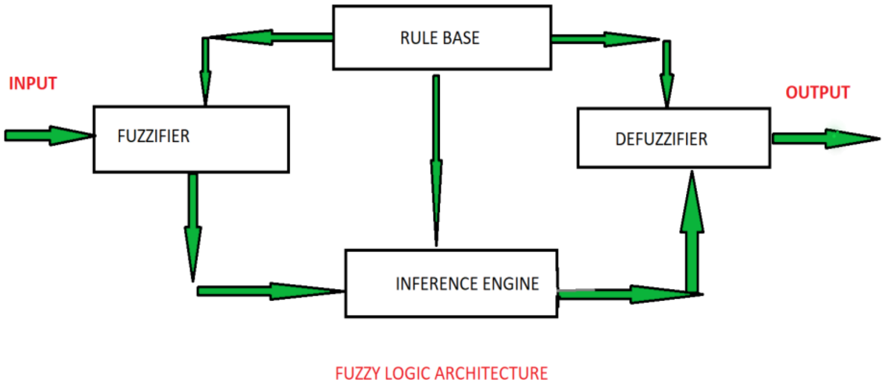

Figure 2.21 Overview of fuzzy logic architecture [2.61]

2.9.1 Fussy logic in Sensor systems

In Fuzzy systems the use of fuzzy sets allow for drawing conclusions and decision making. Fuzzy sets differ from classical sets in that they allow an object to be a partial member of a set. Event detection is a central component in numerous wireless sensor network (WSN) applications. In [2.62] it is demonstrated that using fuzzy values instead of crisp ones significantly improves the accuracy of event detection. It is also showed shown that fuzzy logic approach provides higher event detection accuracy than two well-established classification algorithms and a number of techniques have been developed that help reduce the size of the rule-base by more than 70%, while preserving the event detection accuracy. Several computational intelligence techniques like fuzzy logic, neural networks, reinforcement learning, swarm intelligence, evolutionary algorithms, artificial immune systems and reinforce learning have been proposed for cluster head selection in WSNs [2.63]. Cluster Head selection protocol using Fuzzy Logic (CHUFL) is presented in [2.64]. Protocols for WSNs require to be reliable and energy efficient. These features led to design the CHUFL, a clustering protocol which minimizes energy consumption of cluster head by choosing cluster heads nearer to Base Station - BS, having more residual energy and neighbors. Reliability of the protocol is increased by choosing cluster heads with a high value of LQI.

2.9.2 Fussy logic in WSNs

In WSNs fussy logic implementation plays an important role in the clustering in order to prolong the network lifetime. The cluster head controls the operation of sensor nodes present in its cluster like, making the sensor node go to sleep when its functioning is not required, it wakes the sensor node when an event occurs, it controls the sampling rate at which the sensor node has to sense the phenomenon, etc. Thus cluster head plays important role in increasing network life time, data delivery and data aggregation. Additionally, knowing the nodes positions is a key issue in order to locate precisely the sensor node thus localization is very important information about sensor nodes in wireless sensor network (WSNs). In [2.65] a new mechanism for geographic routing was proposed and finally implemented. The mechanism proposed relied on a weighed centroid localization technique, where the positions of unknown nodes were calculated using fuzzy logic method. The fuzzy localization algorithm uses flow measurement through wireless channel to compute the distance separating the anchor and the sensor nodes. A centroid algorithm calculates the position of unknown nodes using fuzzy Mamdani and Sugeno inference system for increasing the accuracy of estimated positions. The proposed mechanism has three main advantages: First it minimizes the position error of nodes and reduces the error localization average. Second, it increases the number of packets transmitted to the next hop cluster head (CH) based on the localization algorithm. The third is that it reduces the energy consumption of nodes and then extends the network life expectancy using an efficient selection of next hop CH [2.65]. Thus we can conclude that Fuzzy logic plays a crucial role in localization in WSNs whilst synchronously might increase the capabilities of a network system in an event detection. This issue needs further attention and it is implemented in our research and the FSN system for localization via triangulation.

2.10 Conclusion

As a conclusion we can mention that for a Sensors Network which has to perform in an autonomous way a lot of parameters should be examined carefully. This research shows that not only SR types, or their topology affect a network performance but also special attention should be paid to the network purpose. If it is a network for monitoring or a network for military surveillance its parameters might differentiate in order to reach a high rate of appropriateness. Also, hole types might decrease its performance and this is a network issue that ought to be examined carefully. Furthermore, a certain pattern of arrangement of nodes is also related with the efficiency of a SR, and a proper arrangement is required. A better arrangement results in a more efficient network. Additionally, a more accurate system able to calculate the data of many SRs is needed, which will also enable the researcher to process TRNs of SRs that use technology of telemetry for localization. Moreover, as the FSN has to operate as a system it is necessary to acquire and examine values of uncertainty in order to make the system more flexible and accurate.

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Chapter 3 Localization using triangulation Problem for a FSN - Range Free System

3.1 Introduction

The triangulation problem is not new in the computing technology as it is used in many applications. Relative bearings between sensors will intersect at certain points. A Network of SRs and TRs is depicted in Fig.3.1 where this status precedes the application of the triangulation procedure. By depicting the relative set of bearings for each sensor we see a complex web like the one that appears in the following Fig. 3.2 where the depicted sensors are omnidirectional able to detect in 360^0 degrees a transmitter.

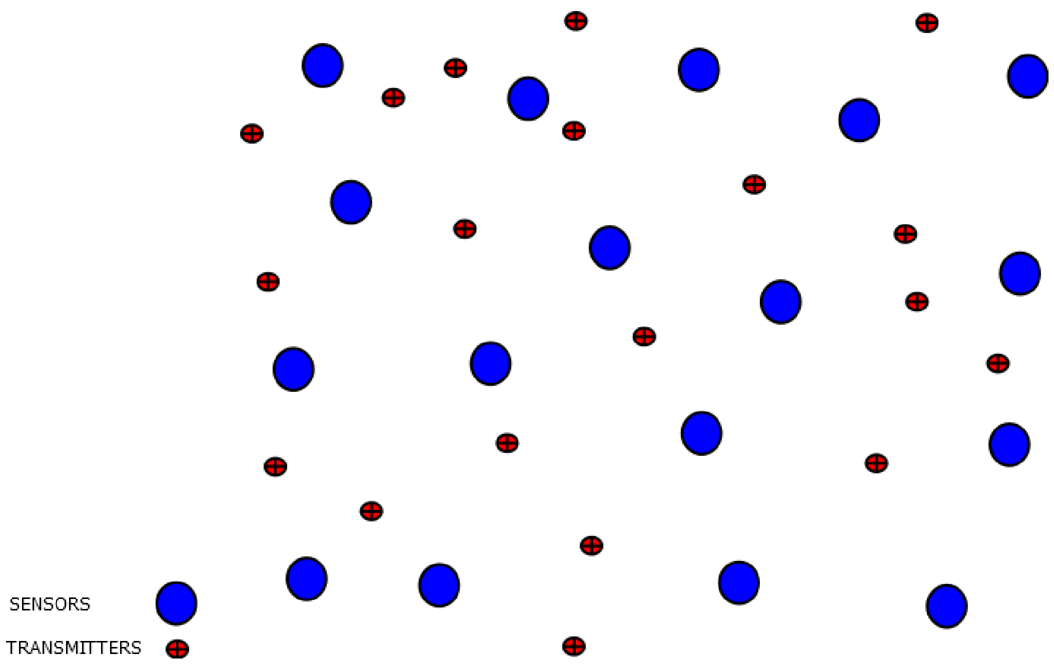

Figure 3.1 A Network of omnidirectional SRs and TRs

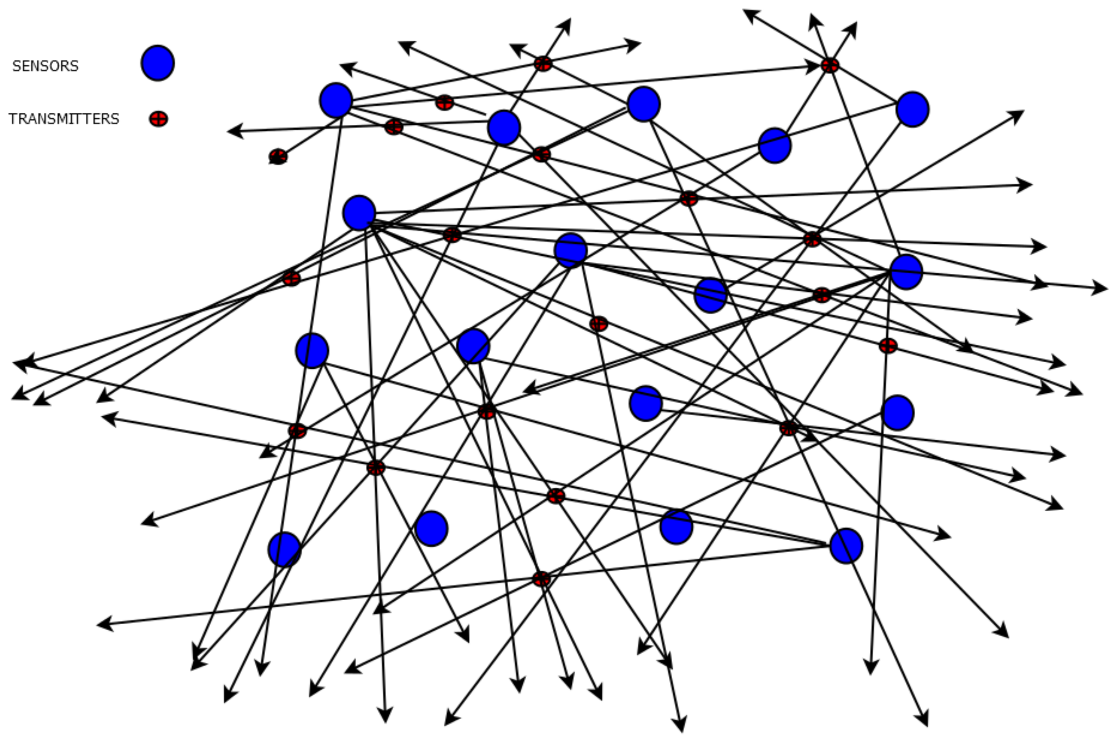

Figure 3.2 Visualization of omnidirectional SRs sets of bearings

SRs detect the bearing of a transmitter with certain accuracy. Assume that there is an amount of accuracy in the bearings, usually of a few degrees. This accuracy might vary from 2^0 to 5^0 degrees maximum. Then, the bearings are not considered as lines but as sectors of a circle, usually a few degrees wide. With this basic assumption that there will be a plus-minus amount of accuracy in the bearings, Fig.3.3, at long distances the segments of intersection have large areas of uncertainty since the sector opens up, see Fig.3.4. After applying the triangulation procedure there will be many correct triangulations (TRNs) and many pseudo triangulations (PTRNs). For that reason and as the number of SRs BRNGs is increased this might eventually lead to a high complicated case for distinguishing a real from a false TRN. This issue will be analyzed further in the next sections.

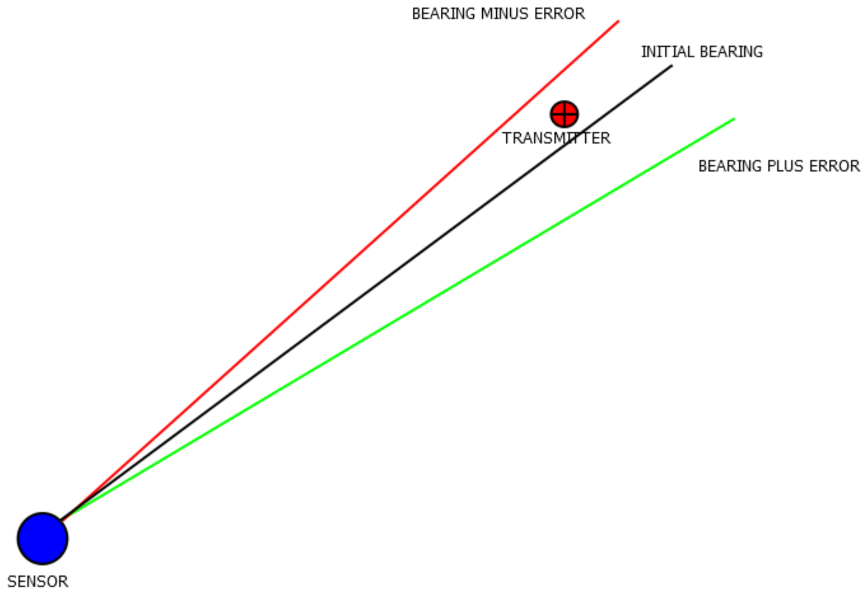

Figure 3.3 Plus-minus amount of accuracy of Sensors bearings

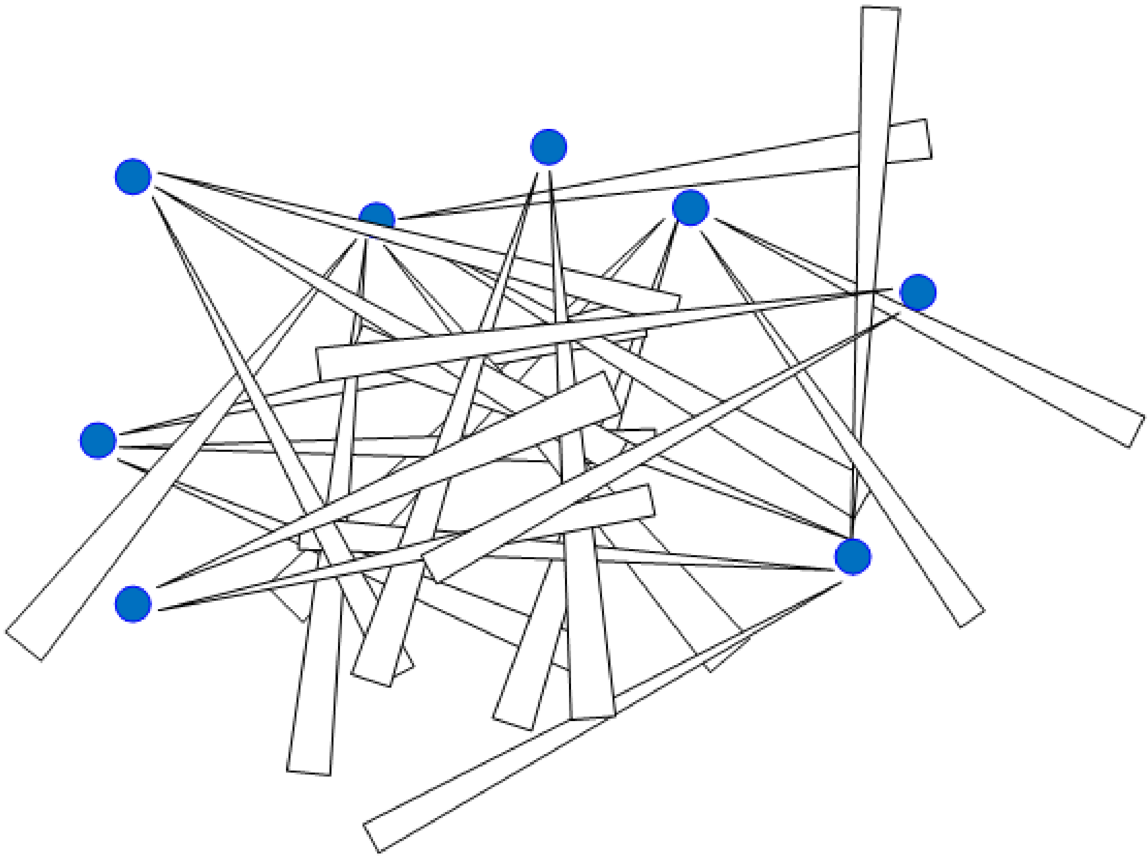

Figure 3. 4 Visualization of SRs sets of bearings

3.2. Triangulation Area

Triangulation area - TRN is the result of three or more bearings intersection. The common area of intersection of sensors - SRs beams is the area of triangulation. As it is depicted in Fig.3.5 and Fig.3.6 triangulation - TRN area size is analogous to distance of the SRs and the intersection point. It can be seen that the TRN area in Fig.3.5 is much smaller compared with to Fig.3.6,where the distance from the SRs is less compared with to the distance between the TRN area and the SRs in Fig.3.6. For that reason the distance parameter should be taken into consideration with relative cautiousness as a large area of TRN can cause undesirable effects in the network. The TRN area is defined as a polygon formed by the intersections of the SRs bearings - BRNGs in an area that exist a TR, Fig.3.8(a)and (b).

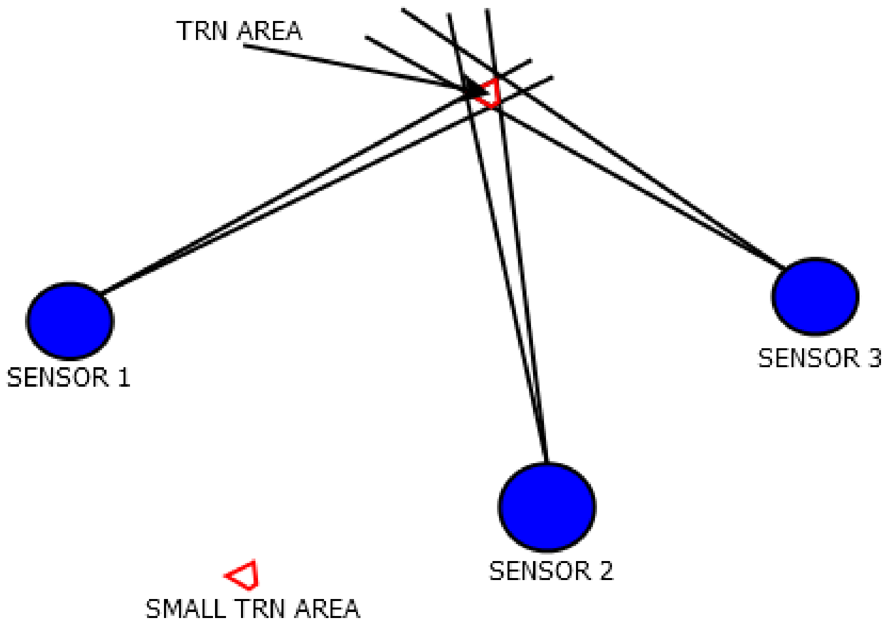

Figure 3.5 Triangulation area - SRs close to the TRN area

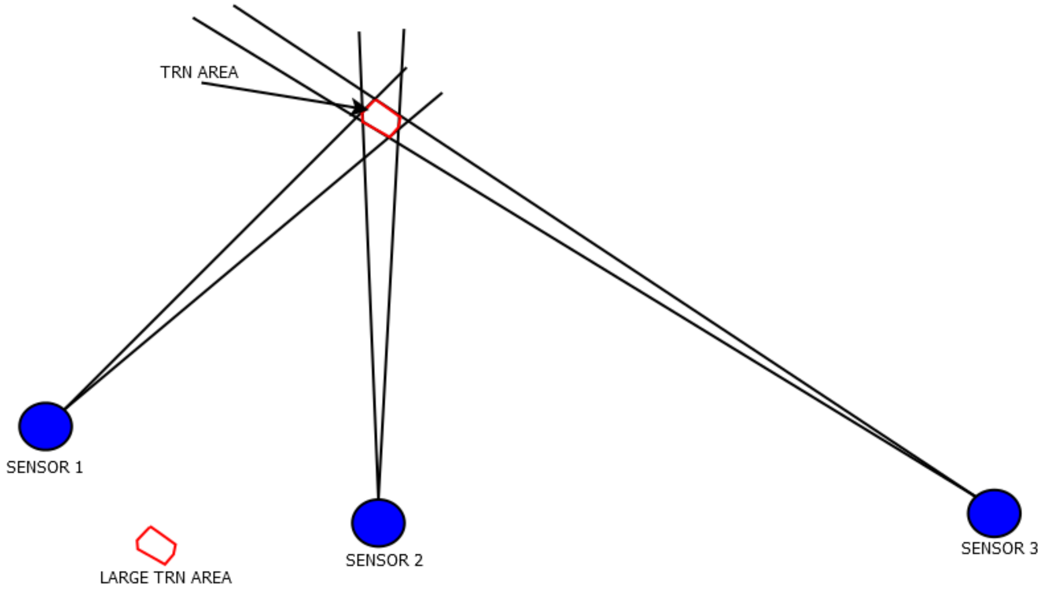

Figure 3.6 Triangulation area - SRs far from the TRN area

3.3 Intersection Area of Uncertainty

When we have many bearings that result in many intersection areas and cases do not exist and there is not a real triangulation of three SRs we have an Intersection Area of Uncertainty - AOU. Such a case was presented in [3.1] and it is depicted in Fig 3.7. In addition, minimum errors at long distances can create many AoU where we can't have accurate triangulation results and positioning. This assumption is applied in the software designed, which allow us to exact correct data. The system has to define a real triangulation from an area of uncertainty and under processing the present and the overall number of the existing real TRNs. The FSN system is processing all the intersection area's and when the three polygons A,B,C haven't got common points of intersection then there is no TRN. In the next paragraphs the conditions with which the system confirms a real TRN., are presented.

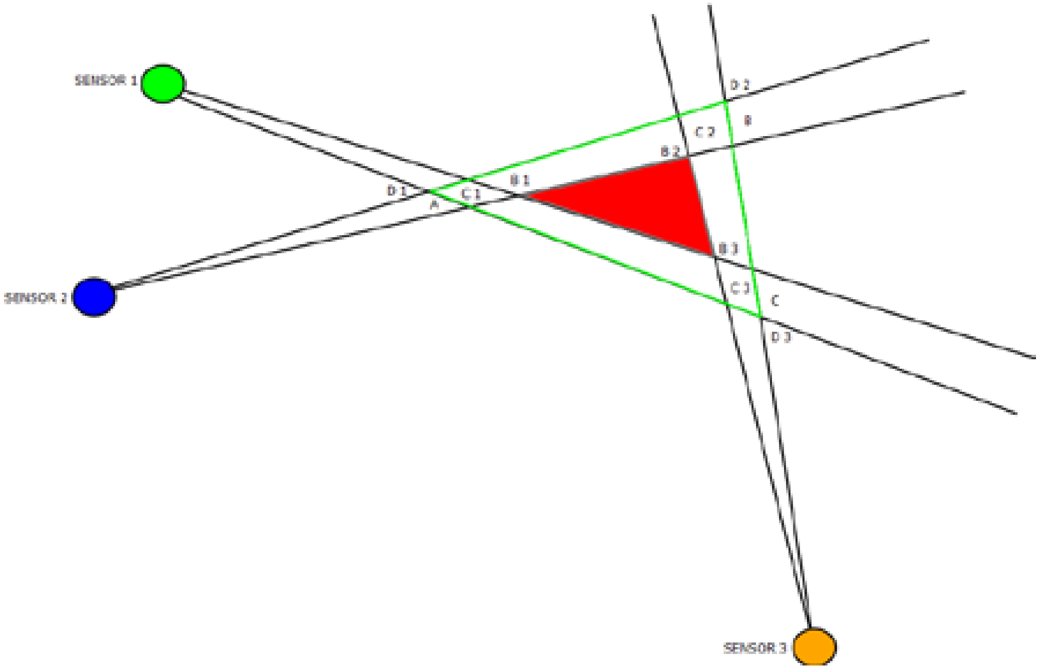

Figure 3.7 Intersection Area of Uncertainty

3.4 Real triangulation

In this case all three polygons A,B,C intersect and they have common area which is shown in the following Fig.3.8.This case is considered as a real triangulation. The smaller the triangle area Fig. 3.8 is, red triangle, the smaller the TRN area gets. The bigger the triangle area Fig.3.9 green triangle, is, the larger the TRN area gets.

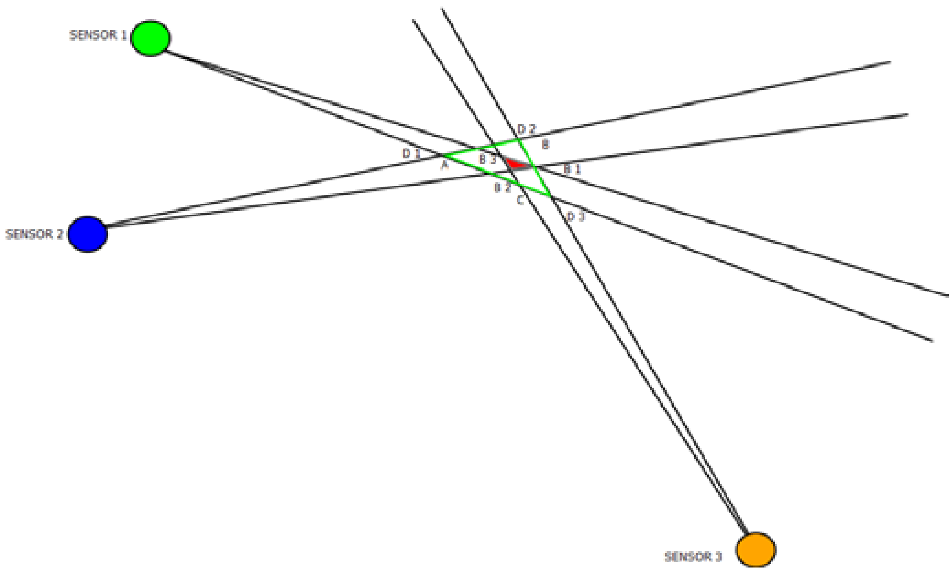

Figure 3.8 Real Triangulation - Small area

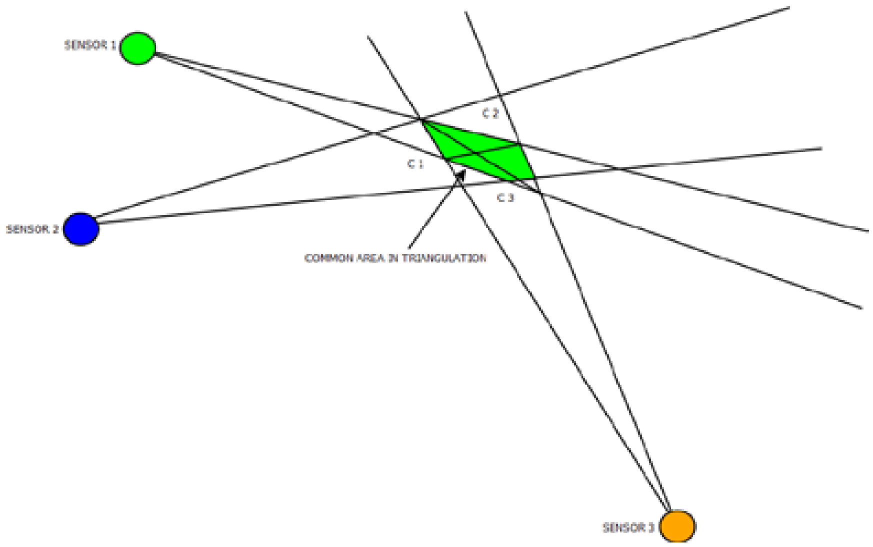

Figure 3.9 Real Triangulation - Large Area

3.5 Triangulation rejection Code

For the rejection of a triangulation we use the following hypothesis which was present ed in (www.movable-type.co.uk, n.d.) [3.3] and combines centroids of Polygons in co mbination with centroids of Triangles.

Hypothesis.

C1 C2 C3 are the Centroids of the three Polygons A,B,C respectively Fig 3.10.

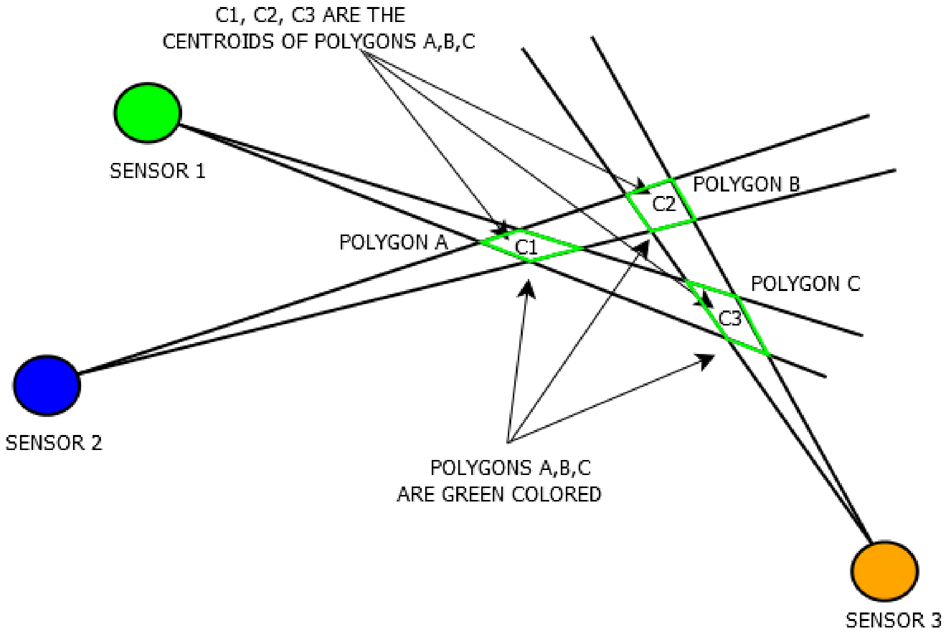

Figure 3.10 Triangulation area for processing

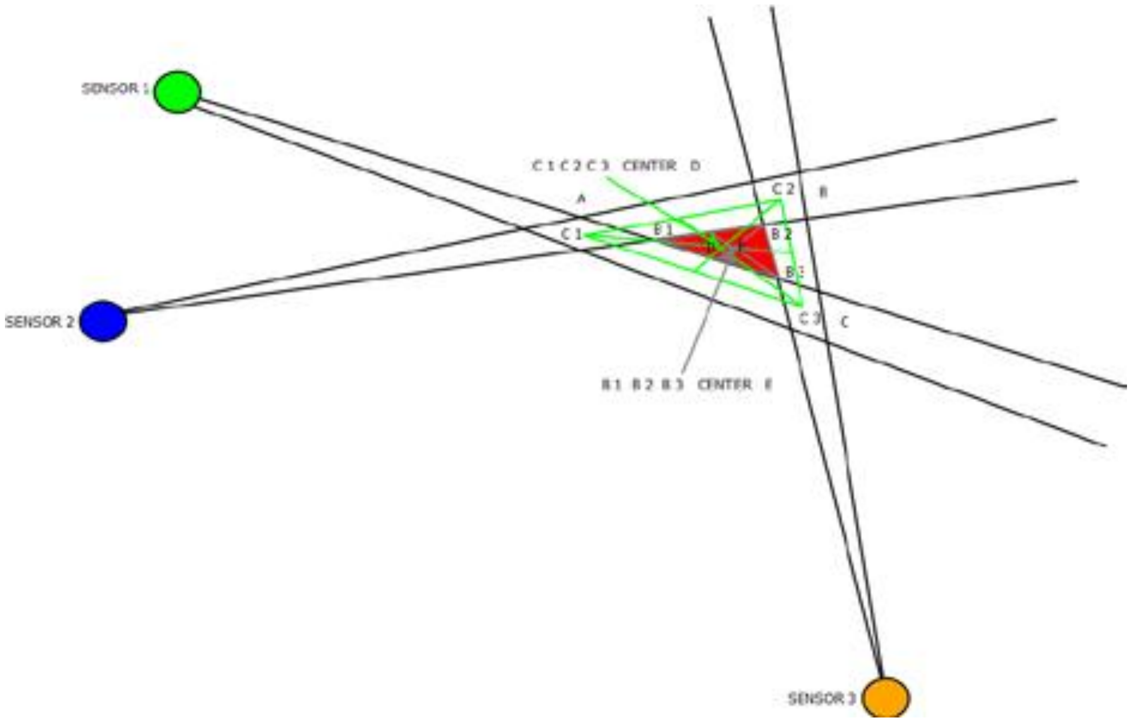

Figure 3.11 Triangulation area with triangles and polygons centroids

D is the centroid of a triangle which is formed with the Centroids C1 C2 C3 of Polygons A,B,C respectively, Fig.3.11.

B1 B2 B3 are the closest points of polygons A, B and C to the centroid D and they form the triangle B1 B2 B3.

The centroid of Triangle B1 B2 B3, is E, Fig.3.11.

Condition 1
POLYGONS A, B, C - "HAVE NO COMMON POINTS", Fig.3.10.

Condition 2
D AND E - "ARE BOTH INSIDE" Triangle B1 B2 B3.

Condition 3
D AND E ARE NOT within POLYGONS A, B AND C.
We define the triangle D1 D2 D3, Fig 3.13 which is formed by the following rule:

-D1 is the maximum diagonal distance point in Polygon A and point B1, Fig. 3.12 and Fig.3.13.

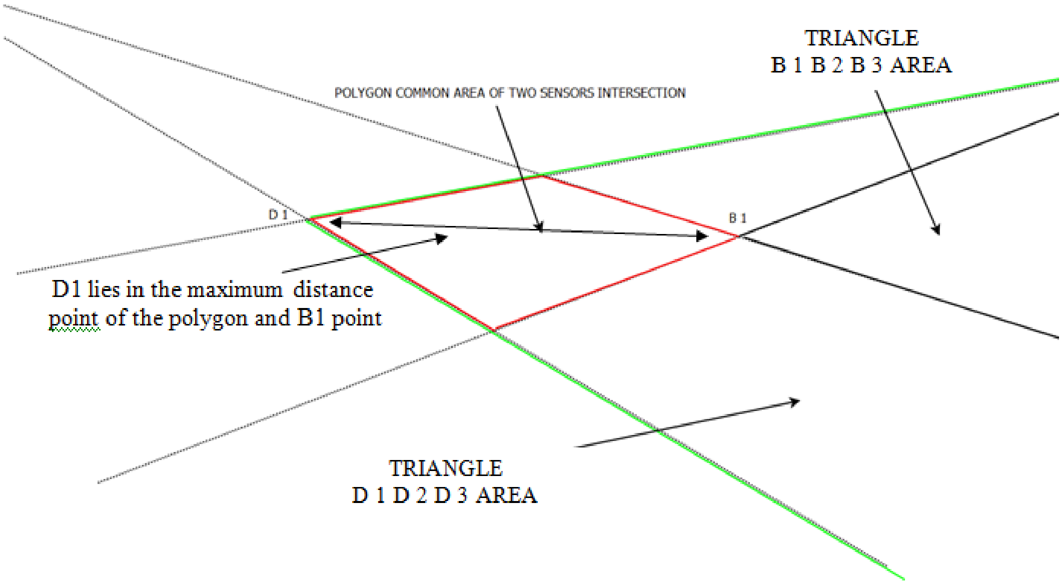

Figure 3.12 Two Sensors common polygon area of intersection

-D2 is the maximum diagonal distance point in Polygon B and point B2, Fig.3.12.

-D3 is the maximum diagonal distance point in Polygon C and point B3, Fig.3.12.

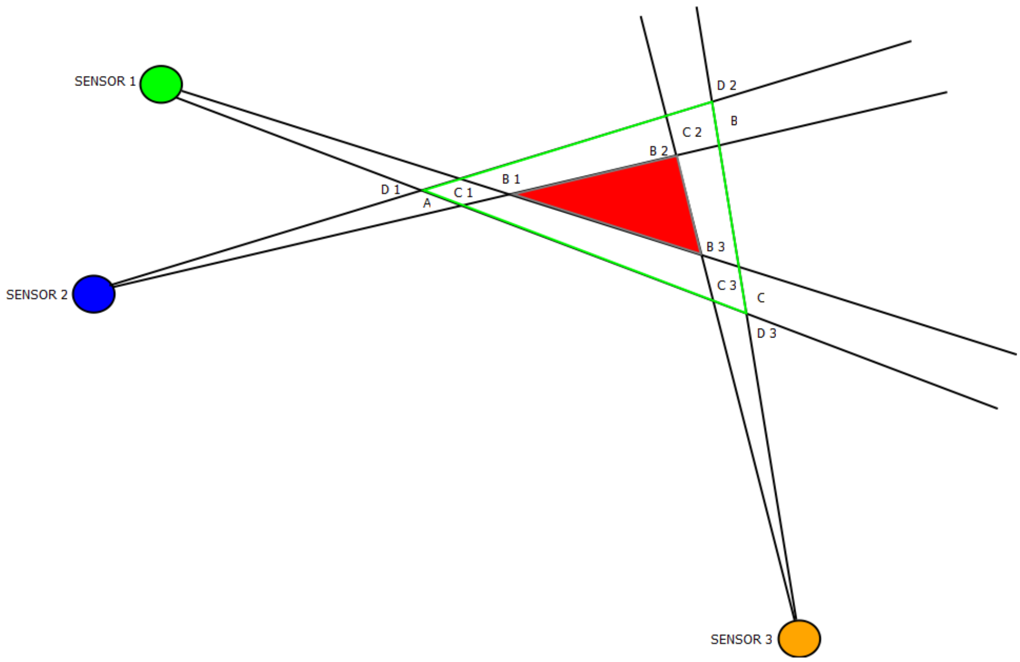

Figure 3.13 Three Sensors polygon area of intersection

We divide the area of the two triangles B1 B2 B3 and D1 D2 D3, Fig.3.12, and we have the Formula 1.

$$\lambda = \frac{Triangle B1B2B3}{Triangle D1D2D3} \qquad (1)$$

where λ is the ratio of the fraction dividing the two triangles

If **0<λ<1** and **λ close to 1**, then the triangle B1 B2 B3 lies within the triangle D1 D2 D3 and we don't have triangulation Fig 3.7.If **λ is close to 0,** then the triangle B1 B2 B3 lies within the triangle D1 D2 D3 and the Centroid point E lies within the common area of triangulation and we have a triangulation Fig 3.9. We also see that the area of triangle B1 B2 B3 is much lower than the area of the triangle D1 D2 D3.

CONDITION 4

As the triangulation area size is reduced the distance between the three Polygons A,B,C Centroids is reduced. This is an additional condition for the confirmation of a TRN. In the following figures Fig. 3.14 and Fig.3.15 we have the depiction of the Area of Uncertainty - AOU and it can be seen how the TRN is formed in Fig.3.14 when C1,C2,C3 are converging.

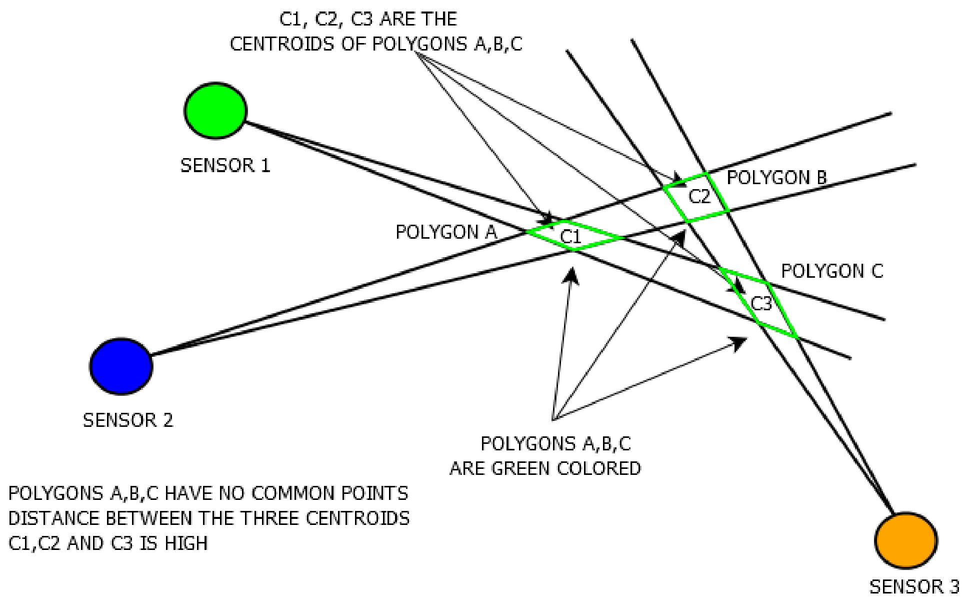

Figure 3.14 Three SRs polygon Area of Uncertainty - Polygons have great distance between them

Comparing the distances between the three polygons A,B,C of Fig.3.14, with the distances in Fig.3.15, we see that the distance in Fig.3.15 is reduced significantly.

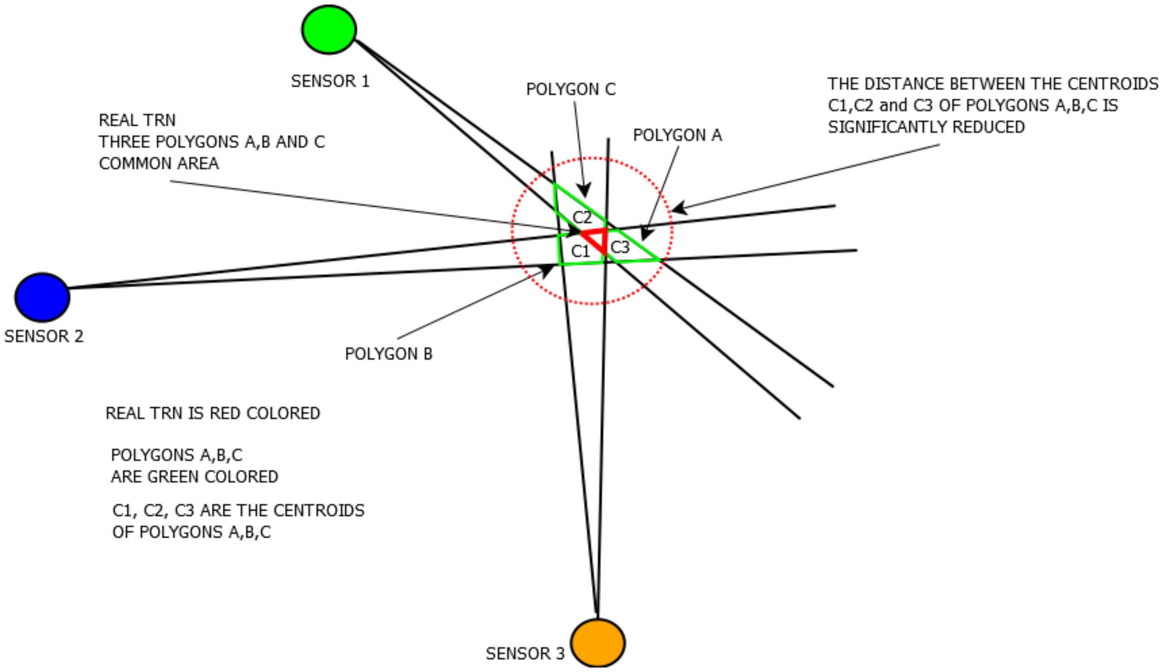

Figure 3.15 Three SRs polygon Area of Uncertainty
- Polygons have minor distance between them

3.6 Triangulation Software Architecture

The Software starts with the acquirement and storage of the data in a set of arrays. This is achieved by prompting the user to enter the number of sensors and their coordinates and then the data for each transmitter that has been detected in the area. For example, a SR might have detected a set of 8 BRNGs (30,45,70,220,235,255,280,320^0) degrees. The user will enter those data in the system and the relative TRs. These data are stored for each SR of the network. The language used is JAVA and the arrays are two dimensional and dynamic. By that way the user can create a Network of the scale that he wants. At this point for each SR the maximum number of allowed bearings detected is defined by the programmer. This parameter can change if more data are required for analysis. Software architecture is shown in Fig 3.16.

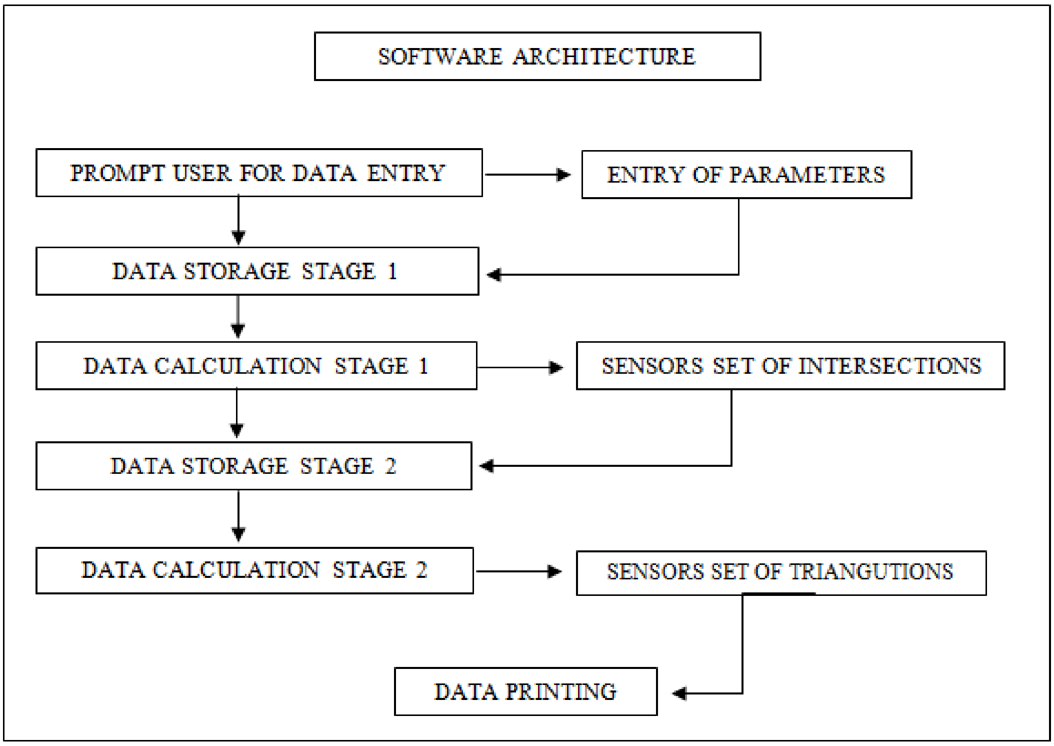

Figure 3.16 Software architecture for Triangulations processing

3.6.1 Software functions

The Software uses Veness [3.3] formulas in order to calculate and find the intersection points of relative SRs bearings(Given the latitude and longitude of two points and their bearings the software calculates and finds the intersection point of two lines). Also, as the intersection point coordinates are found the software calculates and finds the distance between the initial point (the SR) and the final point (the TR). Coordinates of intersection points are calculated as pairs between SRs and then the software search for TRNs (were three,) or more than three lines converge from different SRs forming a TRN area. Then the system stores each intersection point and provides the triangulations TRNs. Some tests executed appear in Appendix A.

3.6.2 JavaScript Code for calculations

Veness [3.3] provides code for implementation and calculations between geographical points. During this research and for the software which was developed the following code has been used:

Formula:	$\delta_{12} = 2 \cdot \mathrm{asin}(\ \sqrt{(\sin^2(\Delta\varphi/2) + \cos\varphi_1 \cdot \cos\varphi_2 \cdot \sin^2(\Delta\lambda/2))}\ )$	angular dist. p1–p2
	$\theta_a = \mathrm{acos}(\ (\ \sin\varphi_2 - \sin\varphi_1 \cdot \cos\delta_{12}\ ) / (\ \sin\delta_{12} \cdot \cos\varphi_1\ )\ )$ $\theta_b = \mathrm{acos}(\ (\ \sin\varphi_1 - \sin\varphi_2 \cdot \cos\delta_{12}\ ) / (\ \sin\delta_{12} \cdot \cos\varphi_2\ )\ )$	initial / final bearings between points 1 & 2
	if $\sin(\lambda_2-\lambda_1) > 0$ $\theta_{12} = \theta_a$ $\theta_{21} = 2\pi - \theta_b$ else $\theta_{12} = 2\pi - \theta_a$ $\theta_{21} = \theta_b$	
	$\alpha_1 = \theta_{13} - \theta_{12}$	angle p2–p1–p3
	$\alpha_2 = \theta_{21} - \theta_{23}$	angle p1–p2–p3
	$\alpha_3 = \mathrm{acos}(\ -\cos\alpha_1 \cdot \cos\alpha_2 + \sin\alpha_1 \cdot \sin\alpha_2 \cdot \cos\delta_{12}\ )$	angle p1–p2–p3
	$\delta_{13} = \mathrm{atan2}(\ \sin\delta_{12} \cdot \sin\alpha_1 \cdot \sin\alpha_2\ ,\ \cos\alpha_2 + \cos\alpha_1 \cdot \cos\alpha_3\ )$	angular dist. p1–p3
	$\varphi_3 = \mathrm{asin}(\ \sin\varphi_1 \cdot \cos\delta_{13} + \cos\varphi_1 \cdot \sin\delta_{13} \cdot \cos\theta_{13}\ )$	p3 lat
	$\Delta\lambda_{13} = \mathrm{atan2}(\ \sin\theta_{13} \cdot \sin\delta_{13} \cdot \cos\varphi_1\ ,\ \cos\delta_{13} - \sin\varphi_1 \cdot \sin\varphi_3\ )$	long p1–p3
	$\lambda_3 = \lambda_1 + \Delta\lambda_{13}$	p3 long
where	*φ_1, λ_1, θ_{13} : 1st start point & (initial) bearing from 1st point towards intersection point* *φ_2, λ_2, θ_{23} : 2nd start point & (initial) bearing from 2nd point towards intersection point* *φ_3, λ_3 : intersection point* *% = (floating point) modulo*	
note –	if $\sin\alpha_1 = 0$ and $\sin\alpha_2 = 0$: infinite solutions if $\sin\alpha_1 \cdot \sin\alpha_2 < 0$: ambiguous solution this formulation is not always well-conditioned for meridional or equatorial lines	
	The above code gives the intersection point of two paths given start points and bearings of two sensors[1]	

Actually by knowing two SR position points the software checks and finds the bearing from the Initial point SR, to the end point Bearing(s) lines and provides the intersection point.

3.6.3 Intersection between Sensors Pseudo-Code for Polygon Intersections

The routine pseudo code which was used in order to find a TRN is the following:

```
IF  ((CHECKBEARING1 IS EQUAL TO BEARINGθ13  MINUS ERROR
OR
CHECKBEARING1  IS EQUAL TO BEARINGθ13  PLUS ERROR
OR
IF  CHECKBEARING1 IS  EQUAL TO  BEARINGθ13 MINUS ERROR
AND
IF  (CHECKBEARING1  IS EQUAL TO  BEARINGθ13 MINUS ERROR
OR
CHECKBEARING1 IS EQUAL TO BEARINGθ13 PLUS ERROR
OR
IF  CHECKBEARING1 IS LESS THAN BEARINGθ13
AND
IS EQUAL TO CHECKBEARING1 MINUS ERROR
AND
(CHECKBEARING2 IS EQUAL TO BEARINGθ23 MINUS ERROR
OR
BEARING3 IS EQUAL TO BEARINGθ23 PLUS ERROR
OR
IF SR CHECKBEARING2 IS LESS THAN CHECKBEARING2
AND
IS EQUAL TO BEARINGθ23 MINUS ERROR ))
```

The real code used is depicted in **Appendix A** page 200. In the following Fig.3.17 we have the depiction of the two SRs sectors with plus and minus bearing.

[1]https://www.movable-type.co.uk/scripts/latlong.html)

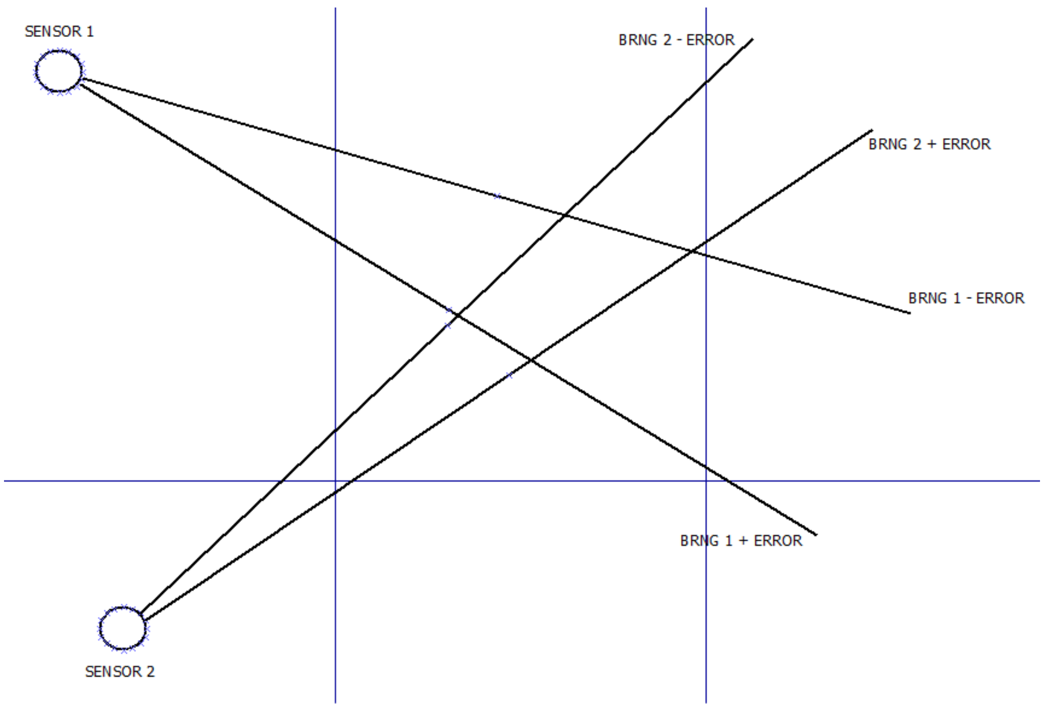

Figure 3.17 Lines of two SRs bearings with error

Point 3 is defined as an intersection between a bearing of Sensor 1 or a bearing from Sensor 2 and a another Sensor's bearing, in our case Sensor 3, Fig.3.18. The system finds all the intersection points between all sensors bearings and then by processing other sensors bearings one by one (from the set of bearings of each sensor), finds the real triangulations. That point is on the boundaries defined by the green colored polygon Fig.3.19. That polygon is the common area of intersection between the two Sensors, Sensor 1 and Sensor 2.

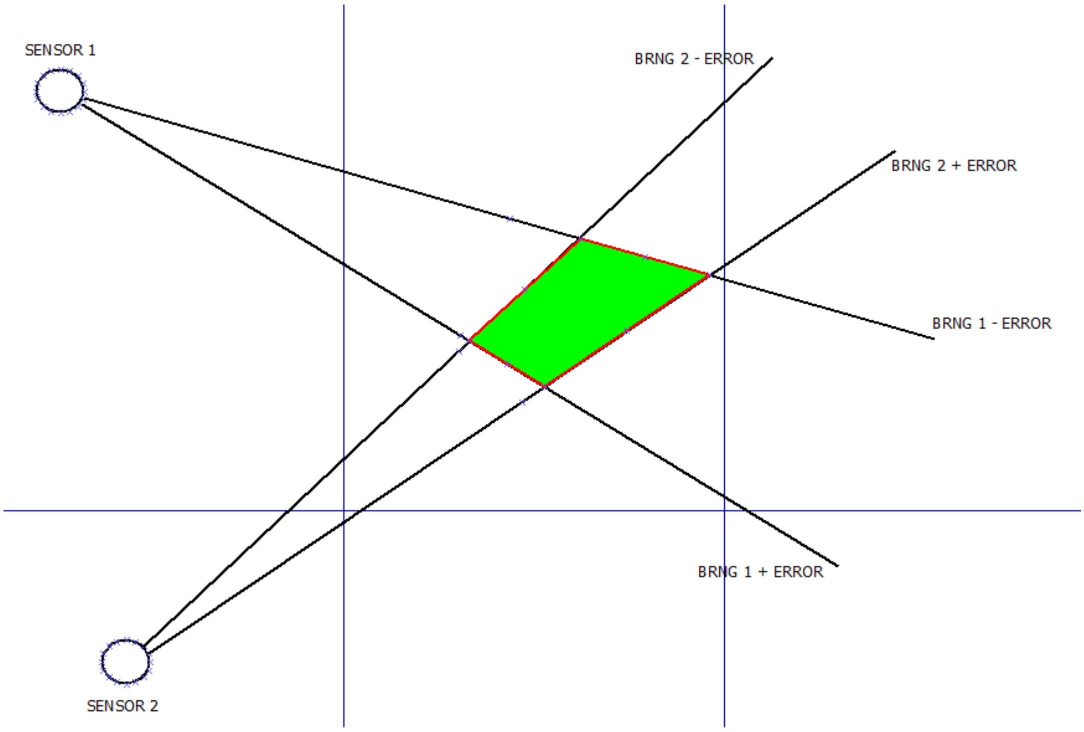

Figure 3.18 Intersection area of two SRs bearings with error

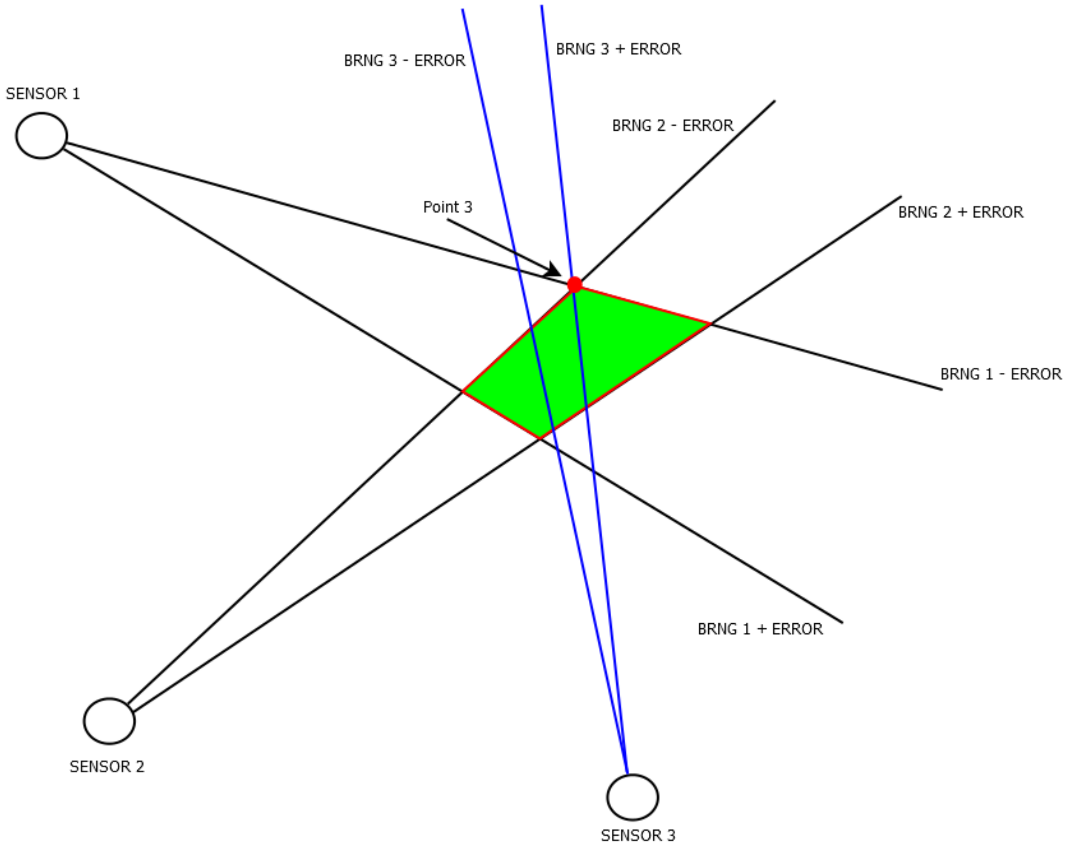

Figure 3.19 Intersection area of three SRs bearings with error

In the following Fig.3.20 we have the depiction of two Sensors intersection polygon area and two TRs within the intersection polygon.

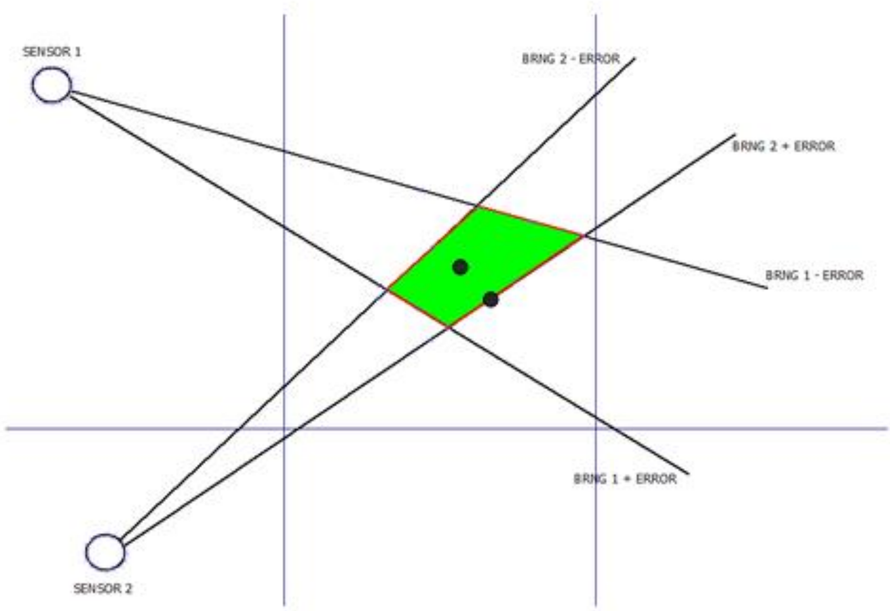

Figure 3.20 Intersection polygon area of two Sensors bearings with error and two transmitters within the polygon area

3.7 FSN TRNs Storing

In the following Table 3.1, we have the depiction of how the system is storing the data of intersections. The table has size (N x M) x (N x M). The diagonal of the table isn't used as it depicts the intersection of a SR with itself. The system is using the following loop in order to find all the intersections points between SRs (SR to SR) and then it is storing them in the previous table.

M = the number of SRs (max),

N = the number of BRNGs of SRs (max).

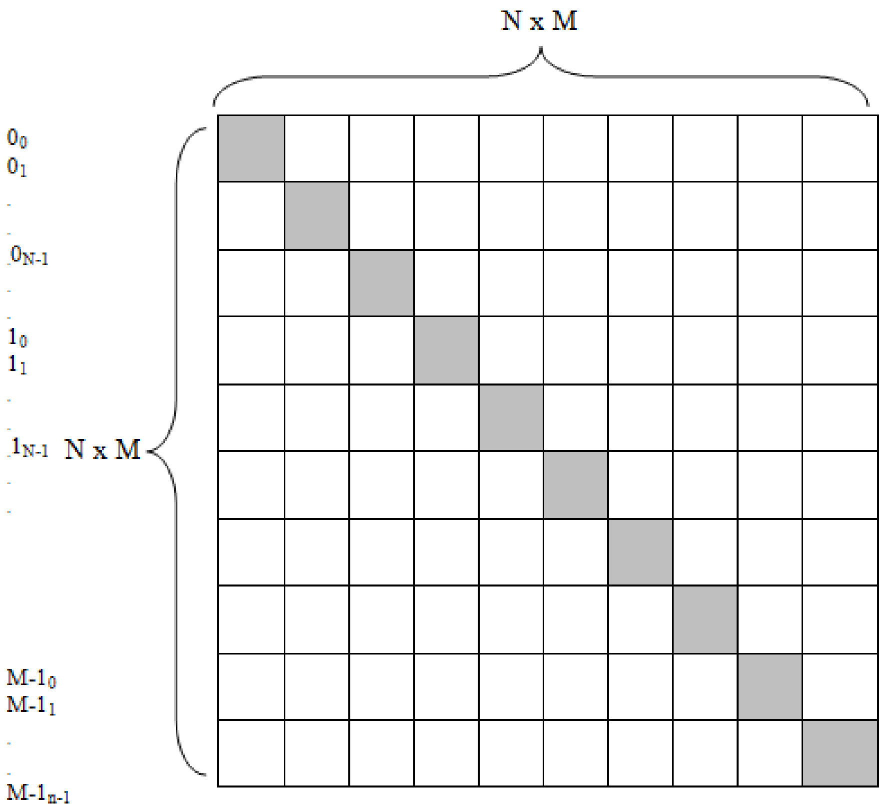

Table 3.1 System storing of data intersections

and the memory needed for storing is provided by the equation (3.1):

$$\frac{(NxM)x(NxM)-(NxN)xM}{2}x4(x,y) \qquad (3.1)$$

The pseudo code for SRs bearing lines intersections is the following:

```
for  K-= 0 to M-1
  {
    for   p = 0  to N
        {
        for   i=0 to N
            {
            for   L=K+2  to M
                  {
                for     j =0 to N
```

{

$K_p\ (k+1)_i\ x\ K_p\ L_j$

}

}

}

}

}

In the following Table 3.2, we have the depiction of 10 SRs (SR_0 to SR_9) intersection points SR to SR, and BRNG line by BRNG line ($Line_0$ to $Line_{10}$. It is assumed that every SR has 10 BRNGs maximum. In each intersection between SRs BRNGs the FSN system is storing four coordinates (x,y).

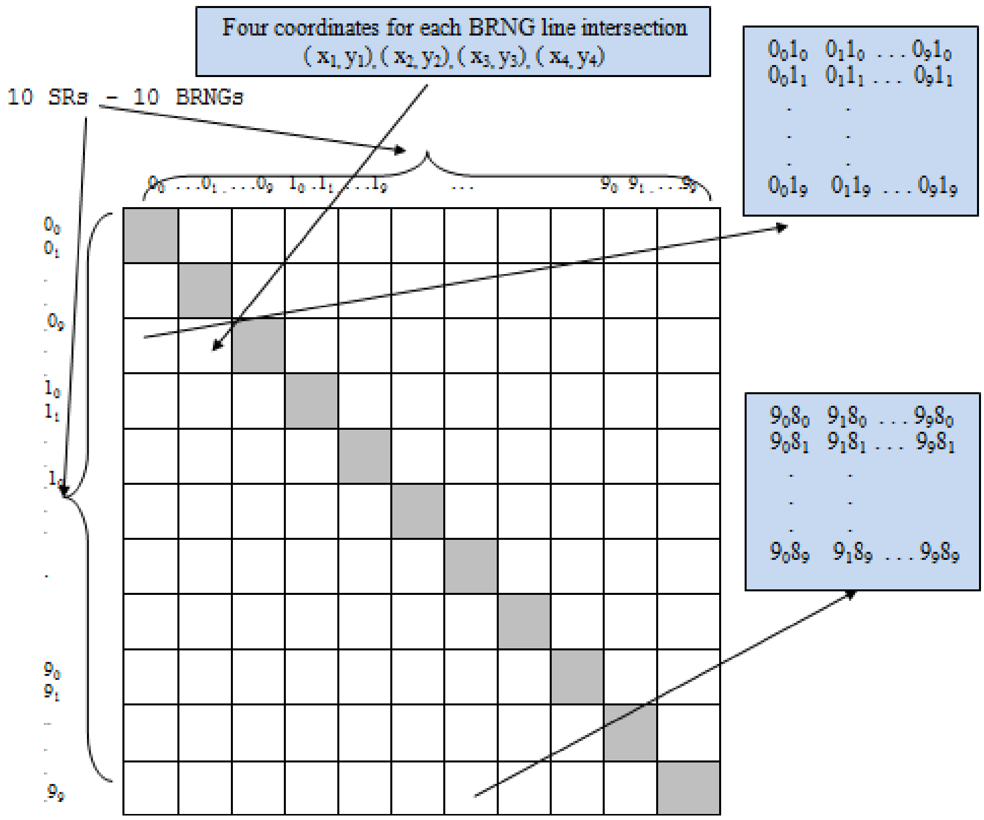

Table 3.2 Sensors bearings and intersections data storage - Each sensor has a set of ten bearings

In the following Fig.3.21 we have the depiction of SRs lines intersections points which the system uses for processing in order to get the results of triangulations.

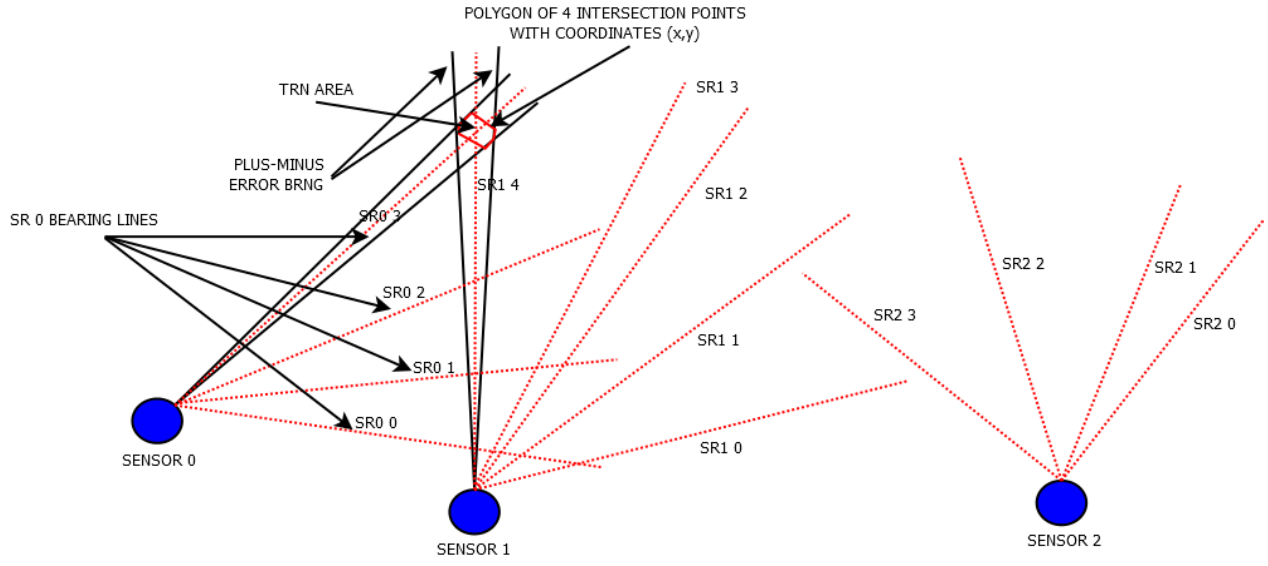

Figure 3.21 SRs bearing lines with intersection analysis

The system, after storing all the intersections points and all the polygons data, checks the polygons intersections one by one in order to find which polygon intersections have common areas with other polygons Fig.3.14. The pseudo-code routine used is the one in 3.6.3 page 81.

3.8 Triangulation Irregular Cases

Finding a TR position with the process of triangulation - TR is a complicated procedure. There are a lot of irregular cases that might decrease the network's performance and provide false results. In Fig.3.22 we can see that even if one SR is close to a triangulation area that resulted from other sensors bearings to an existing TR , if another transmitter - TR lies on the extension line (TR alignment) that intersects the TRN area then its bearing is irrelevant with (to) that area. If more than one TRNs are in such a condition then the issue of TRN becomes more and more complicated and the network should be able to reject a large number of false triangulations - FTRNs.

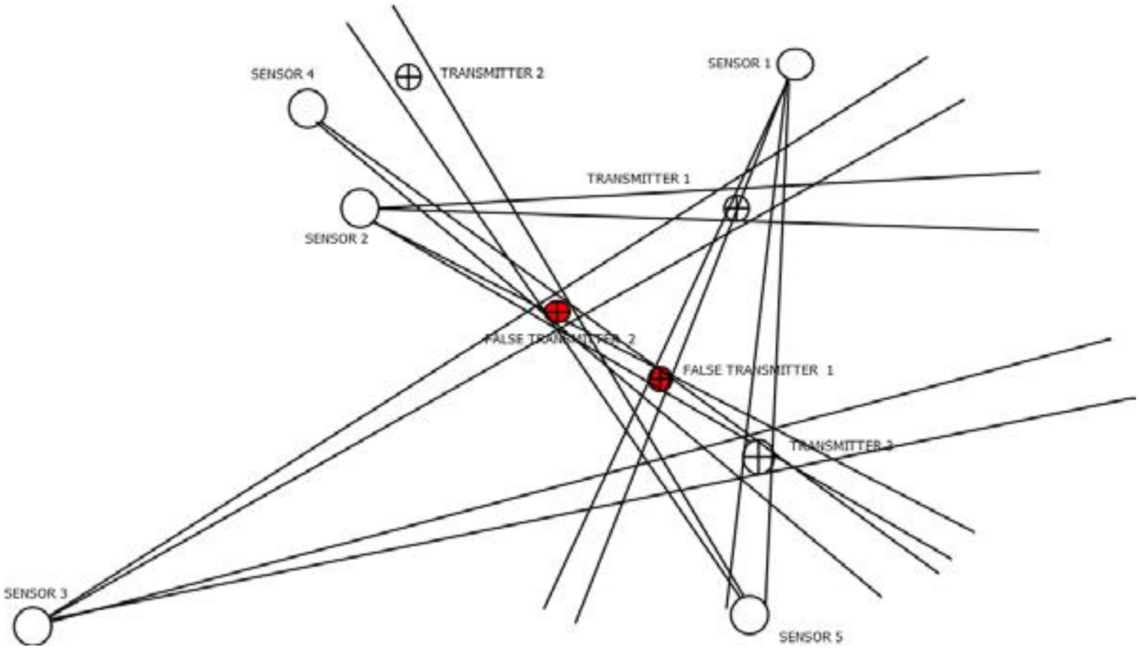

Figure 3.22 Many SRs with many TRs leads to TRN irregular cases due to TRs alignment

Also, as it is clear in Fig.3.16 the three SRs doesn't triangulate. Their bearing intersects in pairs and doesn't have a common area for all of them. Here the system has to define with other SRs in the area if there exists a TR, or those polygons are the result of other TRs in the area. We can name this case *"Close Polygon Areas irregular case".* Another irregular case is the *"Great SR distance irregular case"*. This happens when a SR is at a great distance from the TRN area and its beam covers a large area, as we can see in Fig.3.24, and doesn't give clear results. It is a condition in which a SRs beam covers the three intersection areas C1,C2,C3 of Fig.3.23 which happen to be close to each other, and the system might assume that there are three different TRN areas. It is a complicated case which ought to be implemented with adequate programming.

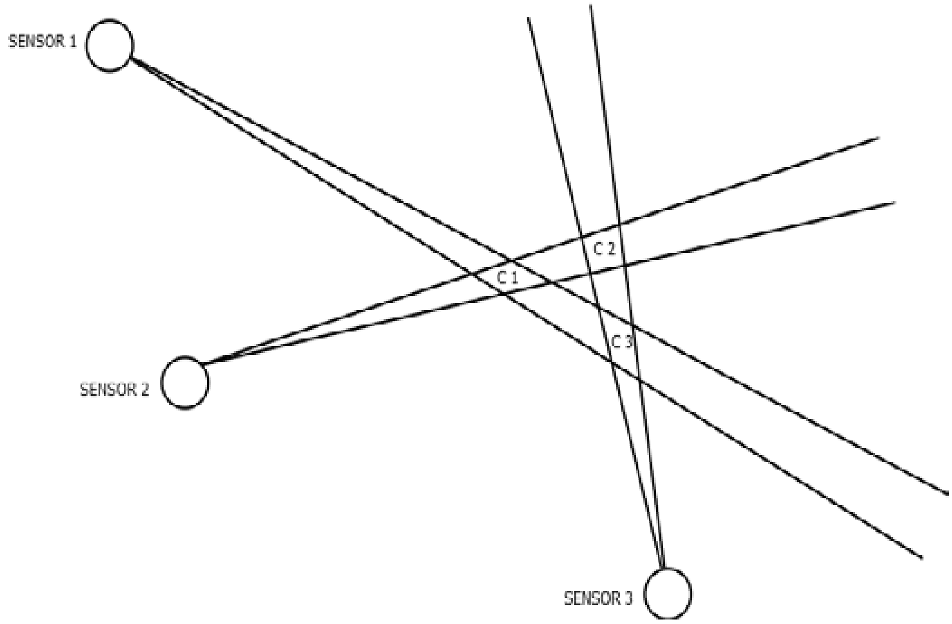

Figure 3.23 Three SRs - three non TRN close intersections polygon areas

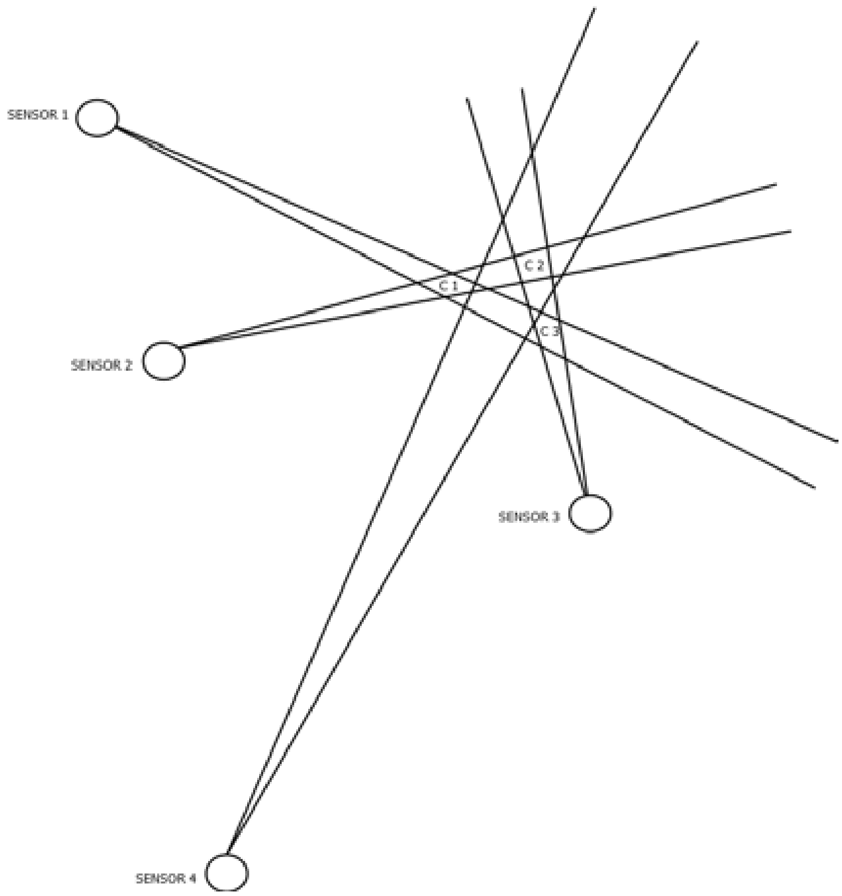

Figure 3.24 - Great SR distance irregular case

In such a case a filter related with SRs detection distance from a defined TRN area that resulted from an initial state 1 should be implemented. To that, we can add that the distance between a SR and a TRN area, or a *“Close Polygon Areas irregular case”* might be implemented as an additional parameter in the procedure of searching for new TRs for creating a new state 2. Last but not least, as a TR with high power might more easily be detected from a SR at a great distance as depicted in Fig.3.25 where the SR4 detects TR1 the system has to check for high power TRs in the area and exclude SRs at great distance from them. This irregular case is the *"High power TR detection from SRs at great distance*" and this case might also be implemented in the system in order to avoid system overload due to high processing of many False triangulations (FTRNs). It is assumed that TRs with high power will be detected more easily from SRs at a great distance.

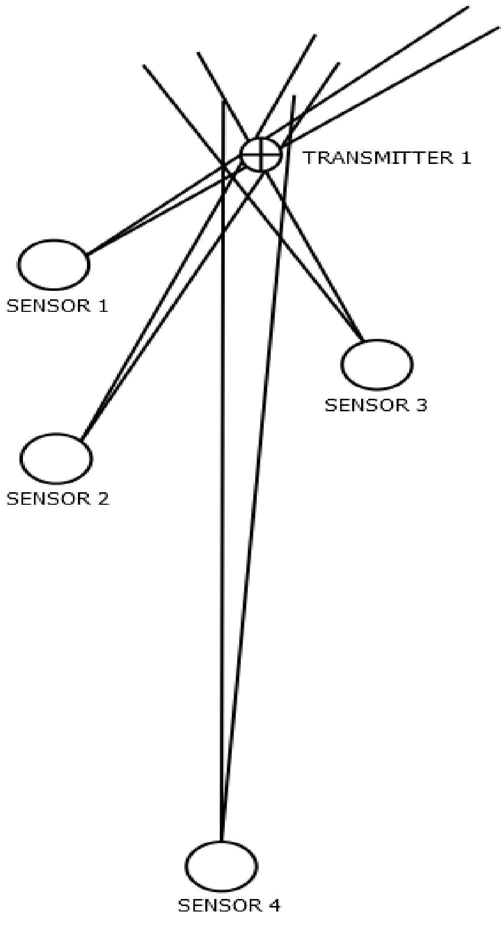

Figure 3.25 TR high power detection at great distance

3.8.1 Long Distance Sensors

As it was mentioned before and shown in Fig.3.24 a SR whose position is at a great distance (more than 50 Km) from a non triangulation area may overlap the triangular regions of intersection and provide false results to the system. In Fig.3.26 we see three SRs and lines (bearings) in the north area of Crete island. The lines depicted are lines with error (plus-minus error and the bearing. Minus bearing is depicted in red, bearing in orange and plus error is colored in black.

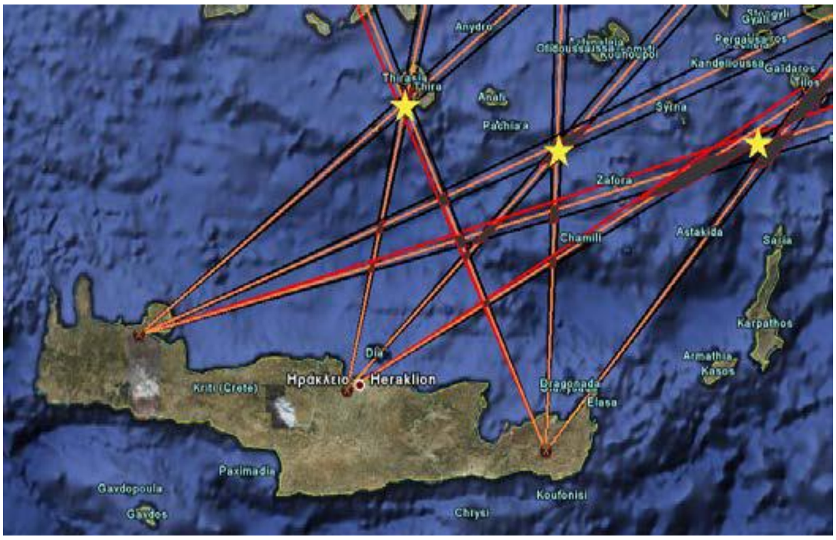

Figure 3.26 TRNs areas North of Crete island [3.16]

The polygon area of non-triangulation case is depicted more clearly in the following Fig.3.27**.** This figure resulted by from testing some sensors with a large radius R and it can be seen clearly how the complex web of intersections and triangulations is formed, using only a few sensors and transmitters. The areas of bearing intersections are grey colored. Wherever there is a TRN of three or more bearing lines it is depicted with a yellow colored star.

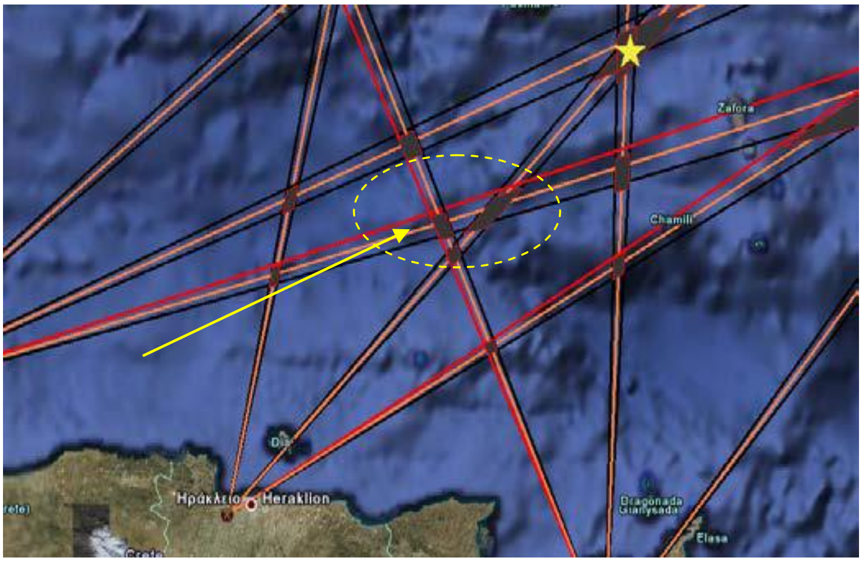

Figure 3.27 Non TRN areas of intersection lines North of Crete island [3.16]

In Fig.3.28 below, we see another SR that has a bearing that passes over the Non-TRN area but its position is at a long distance from that area. The outcome of that intersection is that in the system a number of false TRNs (FTRNs)is added as pairs(in this case we have three more false TRNs, although there is no real TRN case in that area. This problem has to be tackled adequately as if this condition appears in many similar areas and with many SRs whose bearings are passing over them will overload the system with false TRNs.

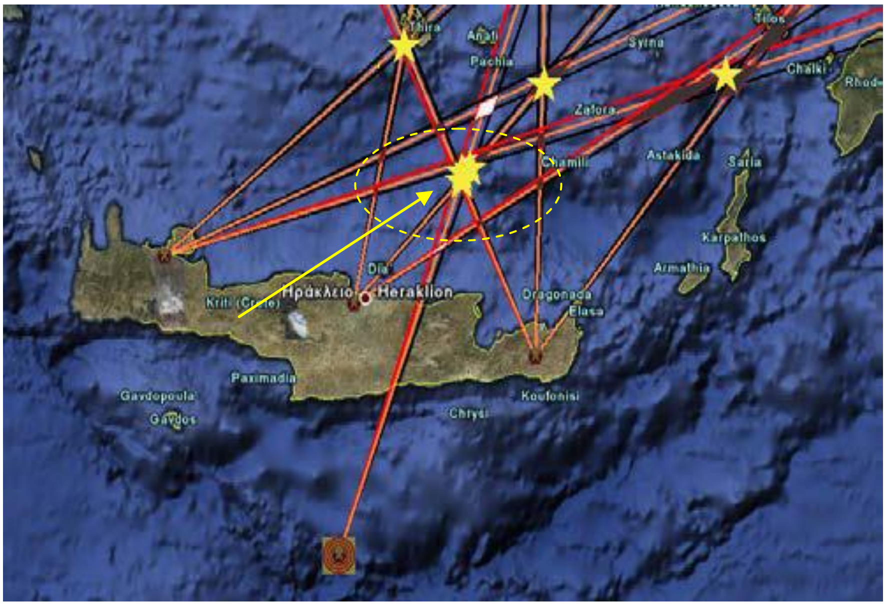

Figure 3.28 False TRNs as an outcome of long distance detection [3.16]

In Fig.3.29 that area is depicted more clearly and that area is problematic for every bearing that passes over it. We call that area, “TRN Problematic Area” as it might easily overload the system with false TRNs.

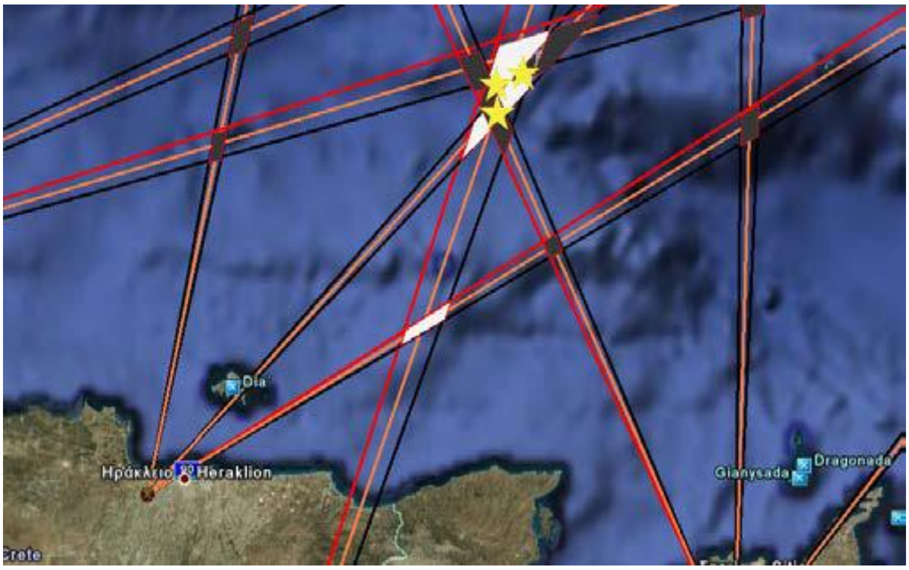

Figure 3. 29 TRN Problematic Area with a large number of false TRNs [3.16]

3.8.2 Increased Beam Error

Another similar case is the case which is depicted in the following Fig.3.23. Here it is depicted the TRN which results from the error parameter change, (the SRs beam error is increased). As the error is increased, the width of the beam is increased and the three areas intersect as a result of the area enlargement. Again the TRN which is depicted is a false triangulation - FTRN. By that way and by increasing the error of the beam we can also distinguish FTRNs in which beams are close to each other but don’t intersect. We might increase the error (the error takes a theoretical value) gradually in order to see the polygons intersections which are close to each other as it was showed in Fig.3.24 and Fig.3.26. The system is able to count the number of FTRNs in relevance to the SRs beam width. In Fig.3.30 we clearly see how the size of the error polygons C1,C2,C3 is increased (red colored lines) after the error beam increases.

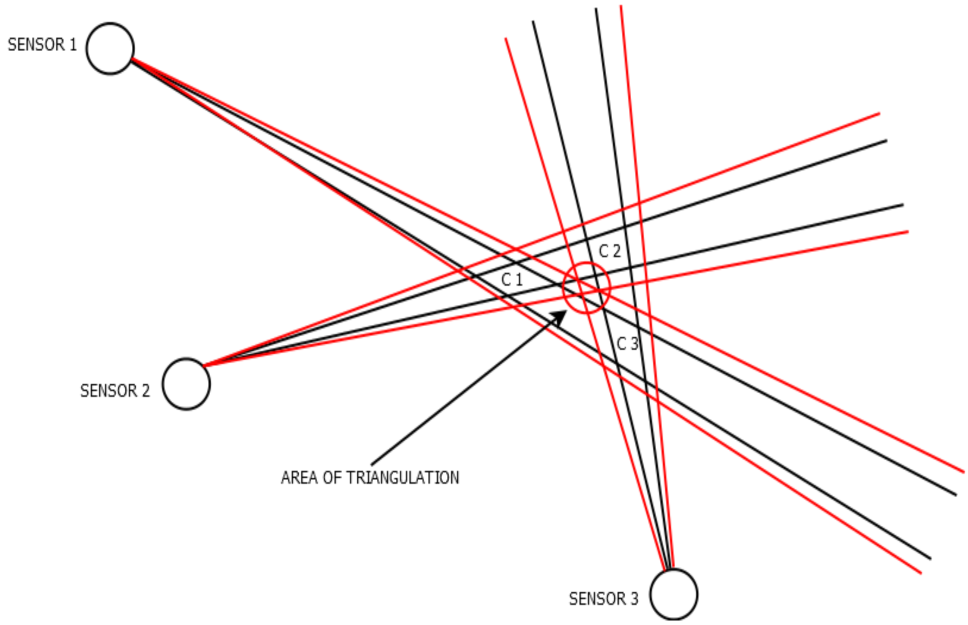

Figure 3.30 Intersection area enlargement due to beam error increase

3.8.3 Multiple Transmitters alignment Problem

In the TRN area which is depicted in Fig.3.31, SR1, SR2, SR3 bearings intersect and triangulate and detect TR1. There is another TR2 which lies close to that area and on the extension bearing line of SR1,SR2 and SR3 second bearings. In this case, TR2 might be rejected by the system and the triangulation area might be rejected by the system as well, as it is aligned with the TRN area related to transmitter 1. This problem can be tackled by activating a SR or SRs close to that area. If SR6 intersects with the SR4 and SR5 at that point then the system will confirm that we have a true TRN and a new TR, Fig.3.32.

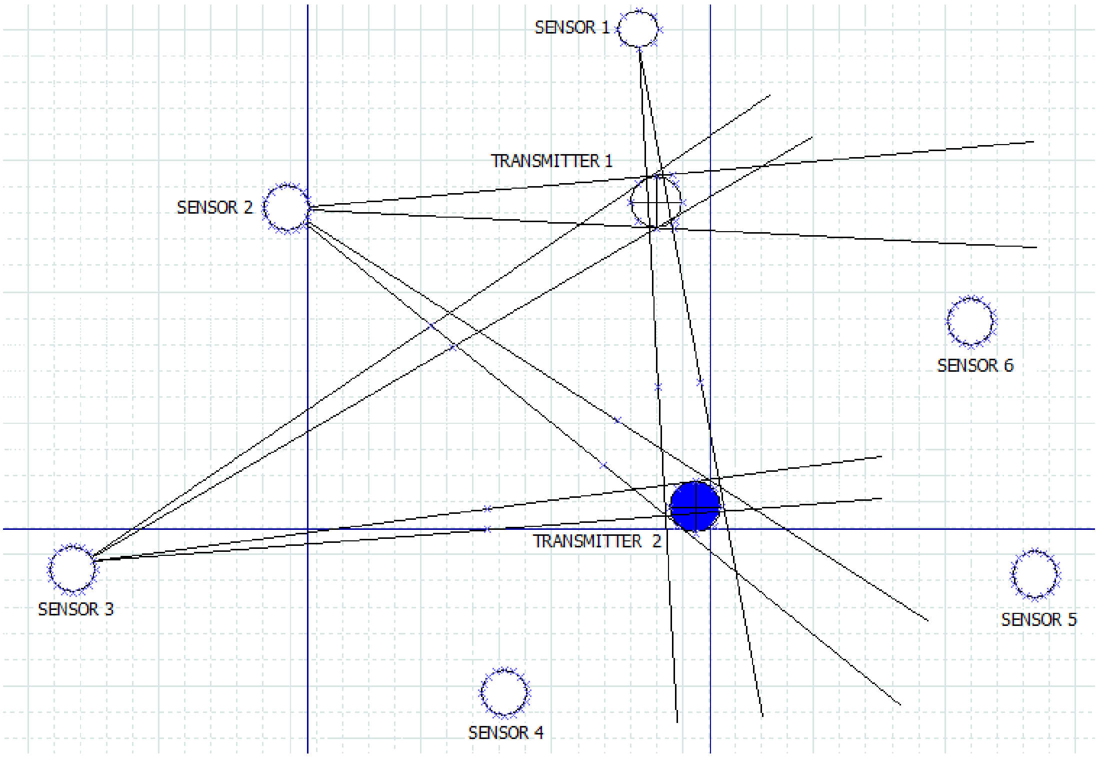

Figure 3.31 TRN rejection problem due to transmitters alignment line problem

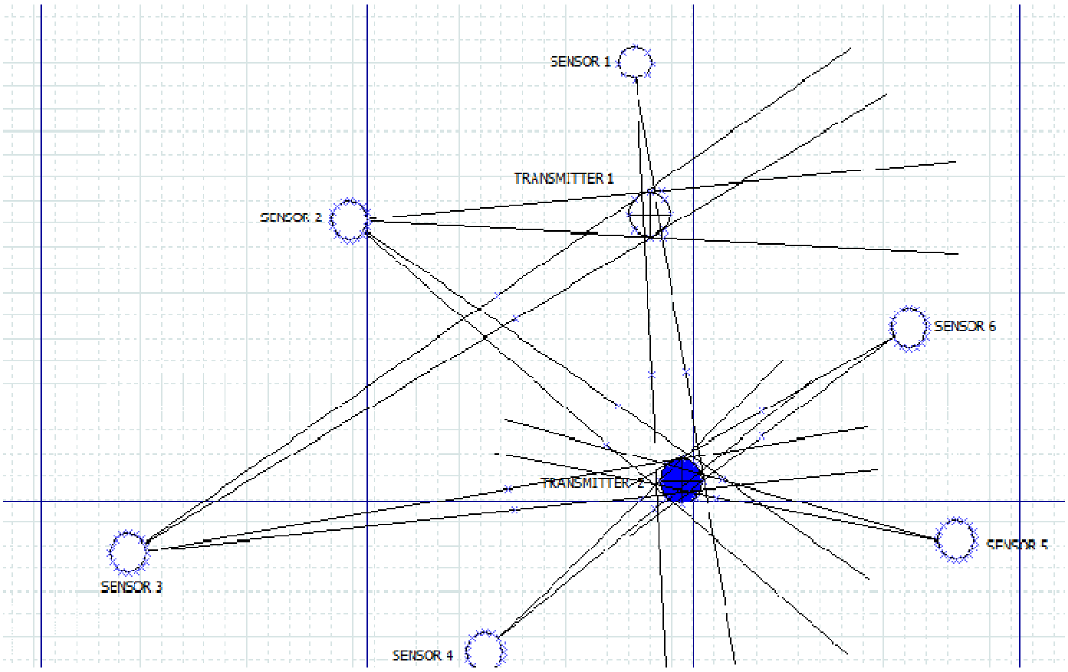

Figure 3. 32 TRN system confirmation due to other SRs intersections

3.8.4 Transmitters multiple Sensor alignment Problem

As it is depicted in the following Fig.3.33 in this case we have many intersections of beams between the SR2 and the SR3 due to the fact that SR2 bearing is pointing towards the SR3. The SR3 bearings 1,2,3, and 4 will intersect with the SR2 bearing and provide intersections. In Fig.3.31 we see how another SRs bearing SR4 which also is pointing towards SR3 will result in many FTRNs. And as other SRs bearings will be passing through that area then the situation will become more complicated and will overload the system with thousands of calculations and data that aren't needed. Bearing in mind that having hundreds or thousands of SRs providing their data in an area with a great number of irregular intersections, the result will be the rapid increase of the FTRNs number.

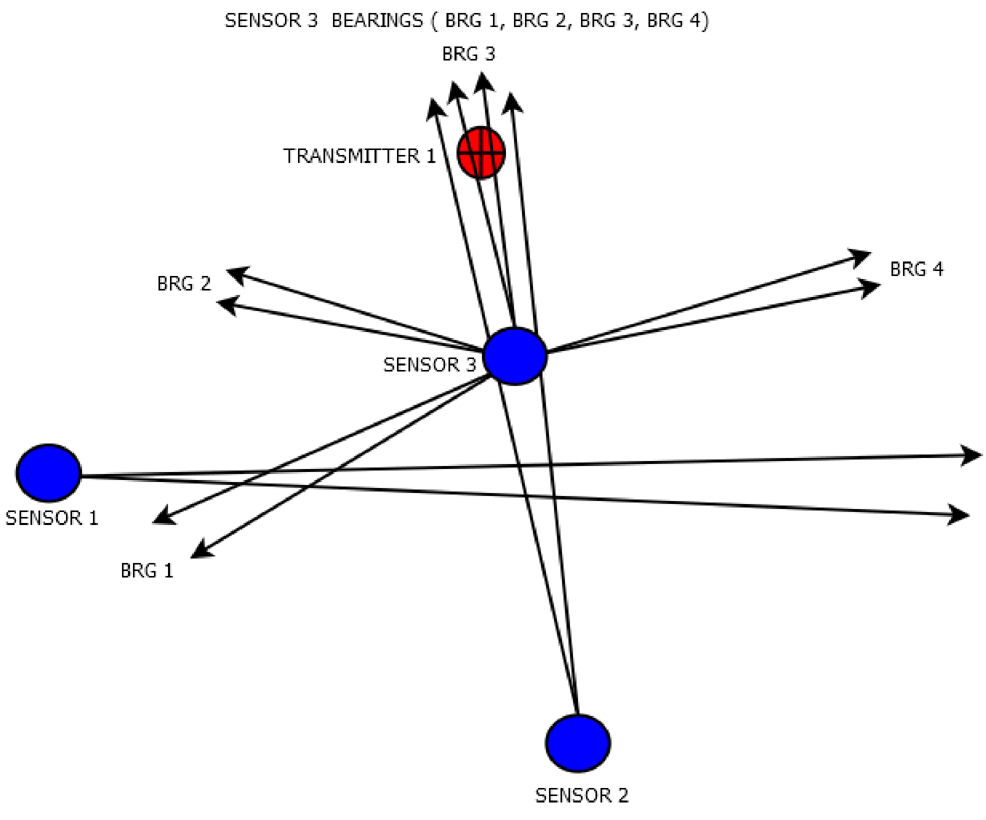

Figure 3.33 SR to SR bearing FTRNs Problem

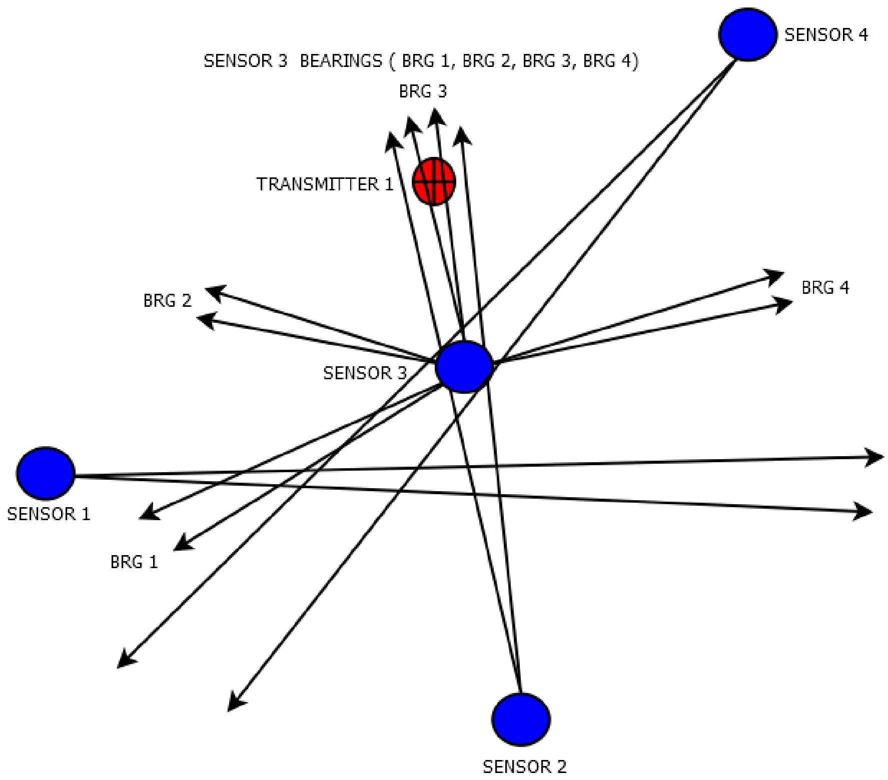

Figure 3.34 SR4 to SR3 bearing cause increase of FTRNs

3.8.5 Multiple TRs in the TRN Area

If more than one TRs lies within the TRN area, then the detection issue becomes more complicated for the network. As it can be seen in Fig.3.35 TR1 is detected whilst TR2 is covered inside the TRN area. The way to tackle this problem is another SR which is close to the TRN area. That SR due to its low beam coverage (as it is close to the TRN area) might detect TR2. The distance of SRs that will be able to detect TR2 can be calculated, as it is analogous to the distance of the TRN area. Knowing that a SR close to the TRN area detects another TR then we might easily find the other SRs which will also be able to detect TR2.That means that with adequate level of coverage in one area we can use other SRs data depending on their distance from the area of interest. In Fig.3.35, we see a circle and a SR which lies out of that circle. SRs that lie within the circle are close to the TRN area and will be able to detect the second TR. SRs that lies out of that circle will detect at least one TR like SR4. In Fig.3.28 we also see the problematic areas within the circle which will provide irregular areas of TRN. Those areas are those which exists inside other SR's beams. And SRs that are outside that areas will not be able to detect the extra TRs in that area.

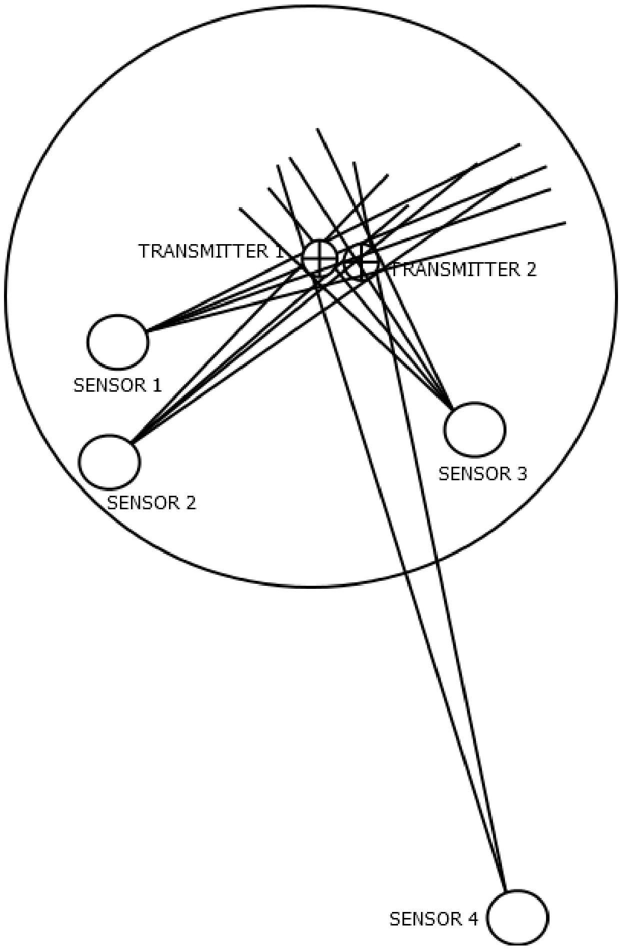

Figure 3.35 More than one TRs in TRN area and SRs distance relation with a TRN

In [3.2], an algorithm for detection and tracking of multiple targets by using bearings measurements from several sensors was developed. The algorithm is an implementation of a multiple hypothesis tracker with pruning of unlikely hypotheses. Tracking conditional on each hypothesis could be performed by using any suitable filtering approximation. Also, a range parameterized unscented Kalman filter was used. Each hypothesis described a track collection with varying number of targets. Final track estimates were obtained by weighed clustering according to hypothesis probabilities and clustered track states. Simulation experiments included arbitrary setup of multiple targets and multiple moving receiver platforms (sensors).In [3.4] Bishop et al. examined the problem of optimal bearing-only localization of a single target by using synchronous measurements from multiple sensors. They approached the problem by forming geometric relationships between the measured parameters and their corresponding errors in the relevant emitter localization scenarios. They derived a geometric constraint equation on the measurement errors in such a scenario. They formulated the localization task as a constrained optimization problem that can be performed on the measurements in order to provide the optimal values such that the solution is consistent with the underlying geometry. They also illustrated and confirmed the advantages of their approach through simulation, offering detailed comparison with Traditional Maximum Likelihood estimation TML.

3.8.5.1 False triangulations

False triangulations (Ghosts targets) are a phenomenon that occurs for bearing only sensors and many methods can be used for elimination or reduction of them [3.6].In [3.5], some theoretical conditions for unique localization of multiple targets using the intersection of multiple bearing lines in the presence of the data-association problem are discussed. Mazurek et al in [3.6] have discussed necessary theoretical requirements to solve the so-called "*ghost node problem"*, which appears in Fig.3.36, and it illustrates that it is by no means possible to assume that three spatially distinct bearing sensors are sufficient to eliminate the so-called "*ghost node problem*". In Fig.3.37 and in Fig.3.38 the definition of false triangulations is clearly depicted (ghost emitters) with two and three SRs respectively.

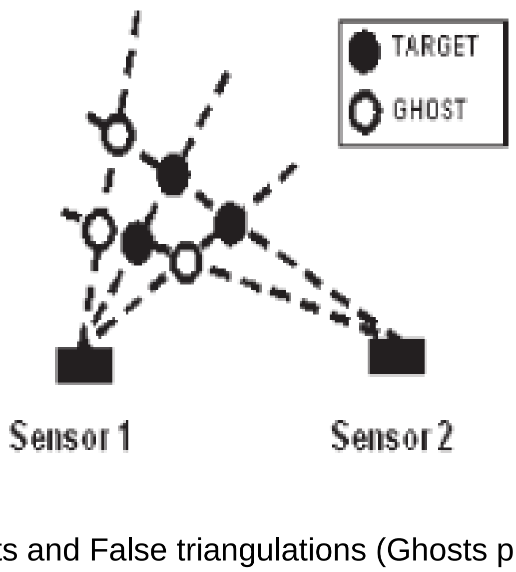

Figure 3.36 Targets and False triangulations (Ghosts problem) -[3.5]

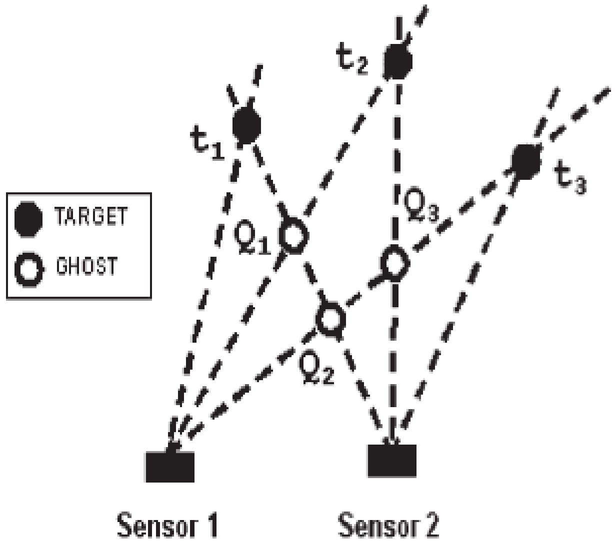

Figure 3.37 Two SRs targets and False triangulations (Ghosts) problem [3.5]

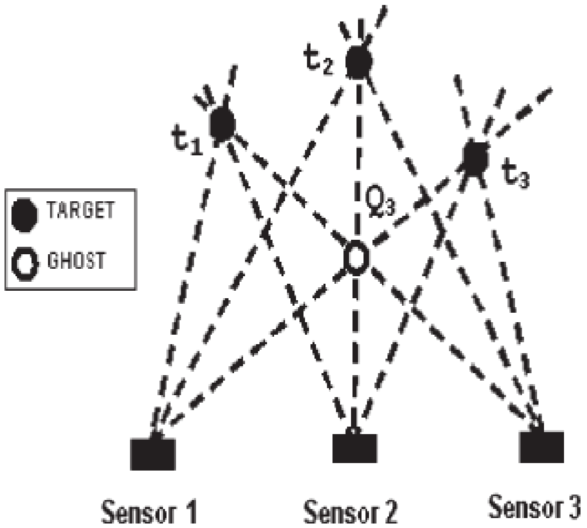

Figure 3.38 Three SRs targets and False triangulations (Ghosts targets) problem [3.5]

Also, theoretical conditions which are required to solve the ghost node incarnation of the so-called data association were explored and a maximum bound on the required number of ideal measurements was derived, along with a probabilistic model that shows the decay of the number of ghosts as a function of the measurement (sensor) numbers via simulation and ghost suppression techniques were presented related to the target area, Fig.3.39 and Fig.3.40.

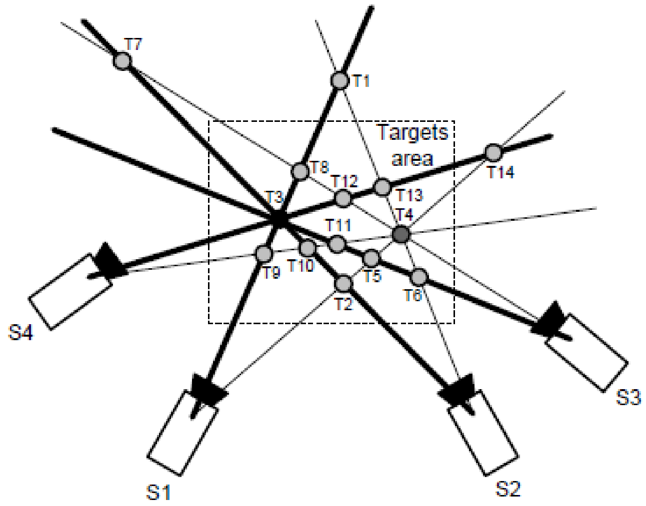

Figure 3.39 False triangulations (Ghost) suppression technique with SRs number increase [3.5]

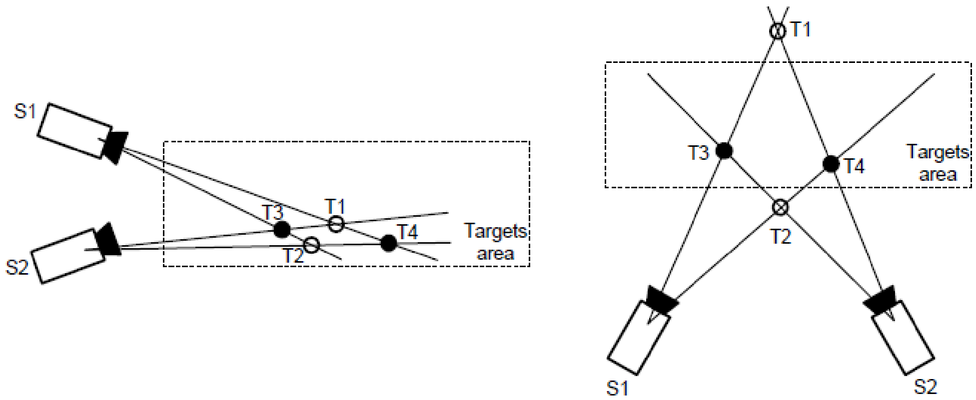

Figure 3.40 False triangulations (Ghost targets) - Suppression related to target area [3.5]

In addition to that, it was commented that ghosting is a very serious problem for serious application and that for a specific case one method can be better in comparison to others but can fail in another case and all of them should be used carefully. *Deghosting methods* were used with Track-Before-Detect-TBD algorithms directly, without additional post processing. In [3.5], a novel multitarget bearings-only tracking algorithm that combined the fuzzy clustering data association technique together with a Gaussian Particle Filter (GPF) that was presented. To deal with the data association problem that arises from the uncertainty of the measurements, the fuzzy clustering method with the maximum entropy principle was utilized, and a GPF was employed to update each target state independently. Moreover, in a multisensory scenario, a statistic test method based on the cotangent values of bearings was proposed, for associating the target bearing data observed at each sensor. Simulation results demonstrated the effectiveness of the algorithm.

3.8.5.1 False triangulations - Missing Transmitter Problem

In an area that we have a lot of SRs and TRs there are special cases where real TRs might be rejected from the system as they might be taken as a result of FTRNs (ghosts). One such case is also depicted in the following Fig.3.41. We see that SR1,SR2,SR3 and SR4 are detecting TRs in an area and their bearings intersect in the center of a circular type area. That happens when some TRs are placed in a circular manner around another TR. Here the system rejects the TR in the center of the area as it is assumed to be a False triangulation (ghost target). If then the system doesn't use adequate data association (with other SRs data) that transmitter might be missed. The system assumes that the suspected transmitter is a false triangulation (ghost target) as it is aligned with other transmitters around the circular area. The difference with the multiple TRs alignment to a SR, is that in this specific case scenario we have multiple TRs alignment with many SRs involved synchronously, in a relatively small sub-area of the AOI.

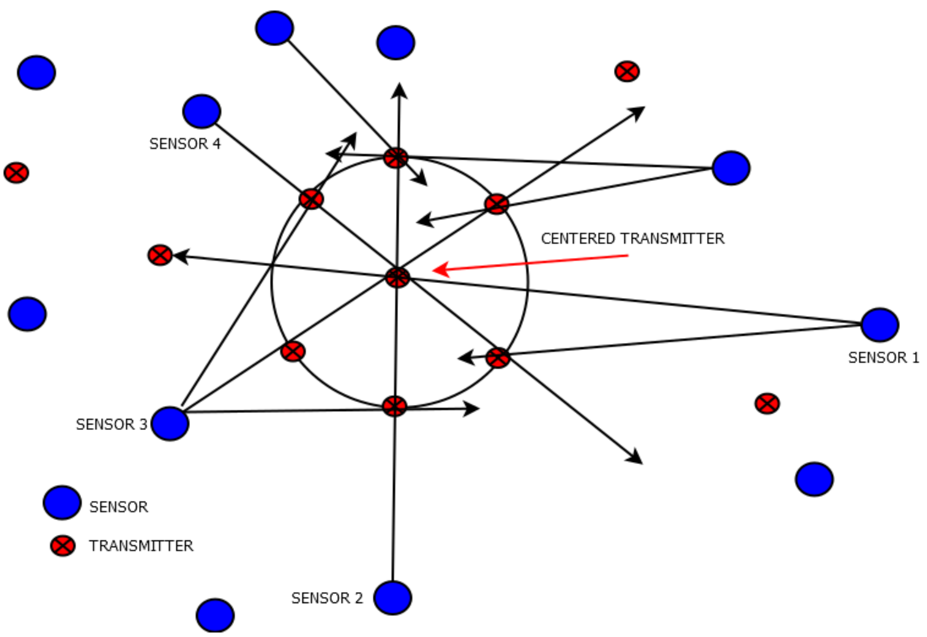

Figure 3.41 False triangulations (Ghosts target) due to high number of transmitters aligned with certain sensors

3.9 *Detection Area*

Inside the detection area, the Area Of Interest AOI, there might also arise cases of uncovered areas, irregular areas and hole problems. All these cases deteriorate the network performance decreasing its ability to find a new TR. And as for the FSN the new TR detection in a new state is of vital importance, network topology should be carefully designed in order to deal with those problems in combination with relative software ways to process the data and provide true TRNs. Network architecture and scalability also should be taken into consideration as undesirable TRNs which will provide false results overload the system and eventually might supplant the network's overall performance.

3.9.1 Detection Area Partition

A way to enable the network to work more properly and offer better TRNs is area partition. As the whole detection area will have problematic areas, hole problems and irregular TRNs, the detection area should be divided in sub-areas for TRNs processing. In [3.7] a model which divides the wireless sensor network sensors into groups is shown. These groups communicate and work together in a cooperative way. Thus, they save time of routing and energy of WSN. In addition it is shown how organizing the sensors in groups can provide a combinatorial analysis of issues related to the performance of the network. In [3.8] a strategy for energy efficient monitoring in WSNs that partitions the sensors into covers is examined. Then, the covers are activated iteratively in a round-robin fashion. That approach takes advantage of the overlap created when many sensors monitor a single area. Two deterministic algorithms are presented and simulations indicate that the increase in longevity is proportional to the amount of overlap amongst the sensors. Algorithms are fast, easy to use, and according to simulations executed, they significantly increase the longevity of sensor networks. Also, in [3.6] the fundamental issue of *coverage* in sensor networks is examined, reflecting how well a sensor network is monitored or tracked by sensors. A solution is proposed in order to find out the degree of coverage in a sensor network with irrespective of the same or different sensing range. They consider the intersection area & try to find out in a mathematical way by using a set theory method. Also, they proposed a simple and efficient model in order to find the degree of coverage easily. In our particular case which is different (a typical FSN for detection with TRN is depicted in Fig.3.42) we see that the detection area is divided into four large square sub-areas which are numbered from one to four and each of them is also divided into two other smaller areas which are numbered 1.1, 1.2, 4.1 and 4.2. That way we have a total of eight triangular shaped small areas. This area partition can be used to process the data for TRNs, avoid false TRNs and synchronously detect hidden TRs which are the cases previously mentioned. Each area includes a number of SRs. When the system collects all the data, the set of BRNGs of the SRs, then it is better for the software not to use all of them in order to provide TRNs. Processing should be performed in different stages and area by area, which leads to more accurate results.

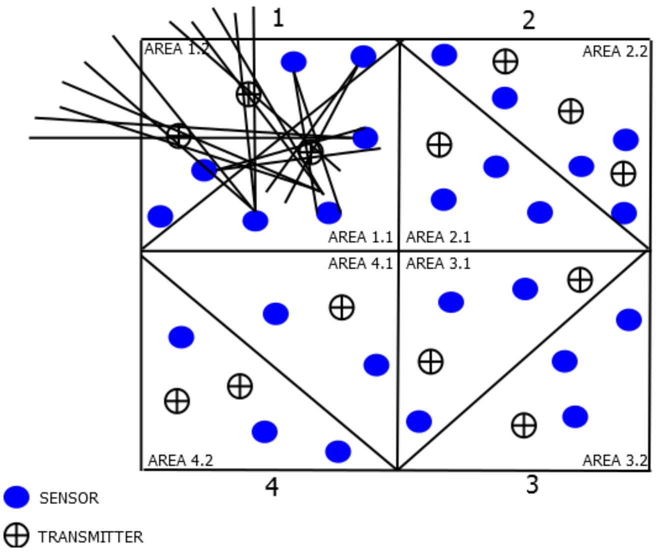

Figure 3.42 - Area detection Partition

3.10 Network Triangulation Algorithm

Here an algorithm enables the previously mentioned network with eight triangular shaped areas for finding TRNs Fig. 3.42. That algorithm uses data for processing in different steps and provides more true TRNs whilst synchronously diminish false TRNs.

One such algorithm is the following:

Area for detection: Area 1

-SRs BRNGs for calculation; SRs of squares 2,3,4

-TRNs results 3

-TRNs in area 1.1 1

-TRNs in area 1.2 2

-SRs in area 1.1 3

-SRs in area 1.2 4

-SRs in area 1.1 search for TRNs in area 1.2

-SRs in area 1.2 search for TRNs in area 1.1

As it can be seen ,the algorithm might process the data in various stages. While searching for detection TRs in area 1, at first stage the data of the other three areas, two, three and four are also calculated. At the next stage the data of the triangular shaped sub-areas 1.1 and 1.2 are implemented. In this stage the TRNs of SRs that lie within area 1.1 are used for detection of TRs inside area 1.2.Respectively, data of SRs of area 1.2 are processed for detection of TRs inside area 1.1. By that way TRs that haven't been detected by the SRs of the other areas (2,3,4) will be detected due to the low width of area 1 SRs beam that are close to them. At the same time, in the second stage of processing real TRNs will be confirmed whilst false TRNs will be rejected. This method might also be implemented in various applications [3.9] and [3.10].

3.11 Chapter contribution

The 1st contribution is the methodology of how to find the position of a new TR entering an area, where:

1) The position of the existing TRs is known.
2) The position of the SRs is **fixed.**
3) The SRs detect only the bearing of a TR(not the distance)-Range free.
4) The detected bearing is with an **accuracy** of x degrees.

In the existing bibliography we have many examples of similar or relevant approaches but not an approach of localization with triangulation of TRs like in this research theme. Bibliography related to detection localization and network coverage is analyzed in previous chapter 2 and in chapter 5. The main problem that this research is trying to solve is (finding) to find a real TRN in an area where hundreds or thousands of SRs bearings lines intersections exist that might be taken as TRNs. In this chapter the methodology which the FSN system uses, in order to find TRNs areas is presented. The system finds all the intersections of bearing lines one by one. Then it examines if in an area where two polygons intersect (the polygon results from a pair of SRs) with a bearing from another SR is having intersections within that common area. The problem is that as the number of SRs increases in combination with an increase in the number of TRs, then the number of intersections and TRNs increase. For that reason, the FSN system has to apply additional methods during data analysis in order to reject FTRNs. This issue is also examined and the system increases its performance by applying adequate methods. Existing research does not approach this particular perspective of the problem and lacks analysis of a whole system during its operation from state to state and the potential problems that the system might face during the scale to scale data analysis. Most of the existing research deals with problems of finding WSNs nodes and anchor nodes' unknown position which is a vital issue for WSNs. In [3.12] it is presented the state-of-the-art research results and approaches proposed for localization in WSNs (position of SRs) in combination with recent advances on localization techniques. It is also commented that a single localization technique that affects the overall performance is not sufficient for all applications.

But all this research for localization in WSNs is irrelevant and with minor common characteristics with this research. The main goal of this research is finding new TRs in an AOI with static SRs while continuously monitoring the FSN system state. In [3.13] an anchor free localization method of WSNs is presented, in which localization *of non-adjacent nodes* has been performed using local information collected by sensor nodes. This algorithm assumes shortest path lengths as distances between non-adjacent nodes but more compact algorithms are required for a better usage of non-adjacent nodes that may improve localization accuracy.

In [3.14] the potential benefit of triangulation techniques in localization for WSNs is examined. It is found that triangulation obtains better results while saving costs, because no change in the network or outer process is required for its operation. Compared to the actual route, enhanced triangulation achieves a mean error of 100m whereas fingerprinting gets worse results (149m). It is concluded, that in order to choose one specific localization method it seems reasonable to make use of enhance triangulation in current wireless networks. Another research in which triangulation, as a localization method, is proposed is the [3.15]. Specifically, a multi-robot triangulation method as a novel sensor to be combined with a decentralized stochastic filter is suggested. The method was evaluated with simulations and field experiments where a team of aerial and ground robots with cameras performs a task of tracking a dynamic target. The results showed how the multi-robot triangulation allows to ensure a correct filter initialization. But, although triangulation method is implemented here, the goal of this research uses triangulation in a different perspective. Likewise, in [3.17] it was proposed a two-dimensional localization strategy which have been tested for deployment of a small number of nodes in a small regularly shaped region. It was suggested to localize the sensor nodes and choose anchor nodes using the two algorithms countLocalized and countAnchor. The foundation criterion proposed for localization was the triangulation uncertainty. But this work was scaled to a small number of nodes deployed in a fixed region and it was mentioned that the proposed method needs to be researched further for testing on a larger number of nodes. In [3.18] a new range free algorithm, the cooperative range-free wireless sensor network positioning algorithm (CRWSNP) was proposed. This algorithm makes use of convex optimization techniques. The suggested technique surpasses earlier well-known range-free algorithms in terms of location estimation mean error and maximum error when tested in various network topologies. The benefits of the algorithm include a straightforward implementation of CRWSNP and a small number of parameters that need to be changed, but future work is required for locating target nodes' outside approximations with more accuracy and less computing complexity. Meaning that this work needs further research and investigation in order to provide more accurate results.

In [3.19]. it is proposed strategy based on the Receive Signal Strength Indicator (RSSI), and there's no prerequisite of additional hardware and communication of information among the sensor hubs. The tests which were conducted investigated the localization precision of an unknown node localization (UNL) strategy, and showed with relevant analysis that the proposed method is simple as there's less computation and communication overhead. The proposed calculation was further compared with other existing localization strategies for the exact estimation of obscure nodes. The proposed algorithm uses the minimal connectivity of the unknown node and the information of proximity in a network to estimate its position. The experimental results of the proposed algorithm showed good localization accuracy without compromising complexity or cost. Nevertheless, the tests can be further amplified by giving security to the framework by utilizing some security calculations with security algorithms to enhance the system level of security along with improvement of energy calculations. Meaning that the algorithm needs further improvement and in order to perform more accurately without including any optimization technique resulting in a questionable localization strategy. In [3.20], there are proposed four new localization algorithms for performing range free localization, WDV-Hop, HWDV-Hop, WDV-HopPSO and HWDV-HopPSO, respectively. Generally speaking, the simulations performed showed that the HWDV- HopPSO and HWDV-Hop performance was higher compared to the DV-Hop and the other calculations in SWSNs according to uniform random, various shaped networks in terms of localization accuracy respectively. Nevertheless again in this work issues of network saturation due to transmitters presence aren't included and thus the value of saturation phenomena isn't noted. Furthermore, in [3.21], a new DV-Hop version was presented. The process of localization combines two well known algorithms, the Molecule Swarm Optimization (PSO) and shuffled frog leaping algorithm (SFLA). It was demonstrated with simulations tests that the algorithm introduced outperforms the DV-Hop algorithm, thus minimizing the error of localization. But similarly, this work doesn't include issues of saturation and blindness that affect the network performance.

Also, authors in [3.22] presented another form of DV-Hop for localization precision improvement. But instead using the least square technique it was used the Sparrow Search Algorithm (SSA). Simulations performed showed that the new proposed algorithm was performing better than the basic DV-Hop, but again issues of saturation and blindness due to transmitters presence were omitted. The same thing happens with most of the existing research which places the current research and triangulation methodology for TR detection as a new contribution. This is also enhanced by the fact that the main subject of this research is completely irrelevant with existing research of localization in WSNs, as it was previously mentioned. In the present research, as scalability plays an important role during system operation the system is applying methods of splitting areas with groups of SRs which process FSN sub-areas data. This method enhances the system performance to face saturation and coverage problems in combination with finding the real TRNs. So, we have a methodology to find TRNs in combination with rejection of FTRNs with ways of scalability. Also, the software allows the system to be more scalable and flexible as it is more adaptable to increased demands. Furthermore, issues of saturation and coverage which are strongly related with FSN system performance are researched thoroughly in chapters 4 and chapter 5 respectively.

3.12 Conclusion

In conclusion, we can mention that for a sensor network system, performing autonomously a lot of parameters should be examined carefully and ways to improve the network's performance and reliability minimizing the chances of detecting false positives requires adequate processing [3.16]. Furthermore, the arrangement of nodes is also related to the efficiency of a FSN, and a proper arrangement can increase its performance. We saw that in order for a sensor network system to be accurate it should be able to calculate the data of many SRs whilst synchronously process them in various stages and steps, as many irregular cases of TRNs will affect its performance. Data association in combination with processing in different stages is possible to bring accurate results. In the next chapter other network attributes like topology, SRs detection radius, SRs blindness and network saturation are examined.

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Chapter 4 Methodology to assess network state and it's detection performance

4.1 Introduction

While the problem of localization is still being under research and the applications of Sensors Networks are spreading in many fields these days, ways to find the position of a Sensor or a transmitter accurately are still being tested with its positioning still remaining of great importance. One of the localization techniques is the process of Triangulation which was analyzed in [4.1]. It was also shown that in a large network with a great number of Sensors (SRs) there are cases of pseudo transmitters (PTRs) which need to be examined on a case by case basis. PTRs are the false TRs that the system has to determine as those. The scope of this chapter is to shed light on various issues that should be put into consideration when a Sensors Network (SN) has to work as an automated system. Various cases will be analyzed and it will be shown that for an automated network with many SRs and a great number of TRs that operate in an area of interest, there are attributes that should be carefully attended and examined and finally integrated in the system. A fixed stations network isn't able to move its SRs but with logical programming it can analyze and combine the SRs data and provide valuable results. When results with high accuracy are collected the positions of new transmitters that entered the AOI will be acquired. So far, the range free (bearing only) estimation is one of the fundamental and challenging problems in target tracking. Multitarget tracking (with bearing only type of sensors) is a challenging issue with many possible applications [4.5],[4.6],[4.7],[4.8].But the level of possible detection is strongly related with the QoS and the coverage holes that exist inside the AOI. That means that if a SR or some of the network SRs are blinded the system performance will deteriorate resulting in poor performance. Also, in a WSN in order to achieve a target monitoring on a satisfactory level, each target point within the zone of surveillance should be monitored by at least one SR nod. Thus, all the information produced by each target will be collected from the system for evaluation and processing [4.9]. Moreover, one of the main aims of a WSN is the usage of the least number of SR nodes for targets monitoring and in the AOI always combined with the avoidance of blind non covered areas resulting from SR problems [4.10]. For that reason a lot of current research is seeking to solve coverage problems that frequently arise during system operation. In [4.11] authors proposed an algorithm for repairing a problematic blinded area of coverage and the simulations performed showed the effectiveness of the algorithm to repair a blinded area, in combination with the maintenance of a high network coverage. Authors in [4.12] in order to solve the coverage problem of WSNs, proposed an algorithm for monitoring the coverage area based on nodes position control. Simulation results showed that the coverage impact is enhanced while node moving distance is decreased by obtaining the nodes motion scheme, calculation of their positions and nodes gradually disperse. But the problem of coverage and its relation with the sensors of a wireless sensors network can be found in many applications. Authors in [4.13] research the barrier coverage phenomenon and its role with camera SRs responsible to monitor and seek to detect targets that might penetrate in one area. In this research the full-view coverage looked as the most promising approach of camera barrier coverage capturing several angles of targets passing through the protected region. Having employed the Dijkstras algorithm and relative coverage models, the simulation and theoretical results, showed that coverage probability might be increase with the requirement of fewer camera sensors.

4.2 Sensor Blindness

Every Sensor- SR in the network collects data of Bearings-BRNGs from Transmitters-TRs detected in one area. Each SR has a circular region of view with radius R for detection. As the number of existing TRs increases, the SRs become blind and many new TRs in its view might not be detected. As shown in Fig.4.1, SR1 and SR2 have a number of bearings which appear in black. Each bearing of detection forms a sector with a certain number of degrees which appear in black. For example, a SR with a bearing of 280^0 degrees and a plus-minus error of 5 degrees, will form a sector of 275^0 (280^0-5^0) and 285^0 (280^0+5^0) in the system. Thus, a TR detection in 280^0 degrees will form a black colored sector of 10^0 degrees for the system. The fact is that if a new TR enters a SR’s viewing radius, in the bearing of that sector, then it might only be detected by another SR. In Fig.4.2 SR1 and SR2 have certain sets of BRNGs. Then two new TRs appear in the area, TR3 and TR4 which are detected by SR2 Fig.4.3 SR1 have already BRNGs at those radials.

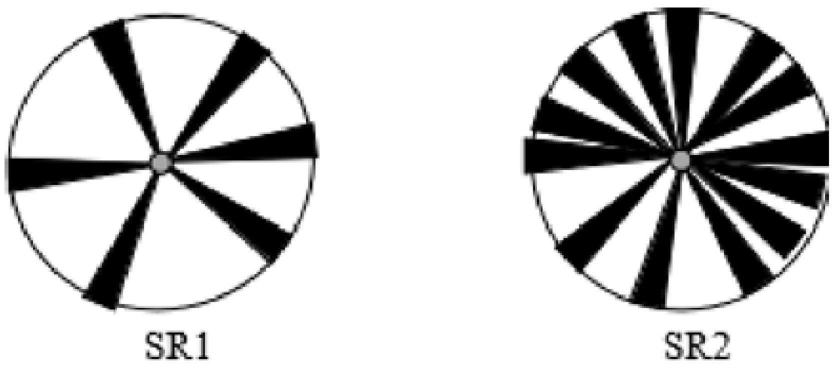

Figure 4.1 SR1 and SR2 with sets of bearings for transmitters in its field of view

For that reason we have to define a SR parameter that affects the detection through TRN and which is the Sensor Blindness - SR_{BL} which value presents the blindness of a SR. SR_{BL} is related to the number of BRNGs already acquired and the SR detection accuracy error. We assume an average network error for detection for each SR ,SR_{ER} which might be 2^0 to 5^0 degrees.

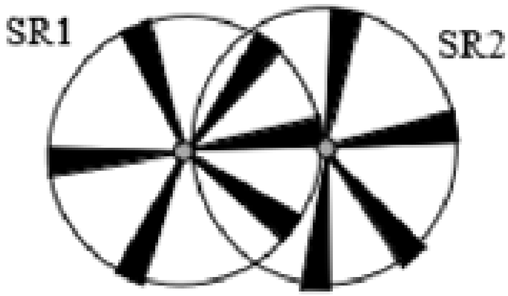

Figure 4.2 SR1 and SR2 with sets of bearings for transmitters (initial state)

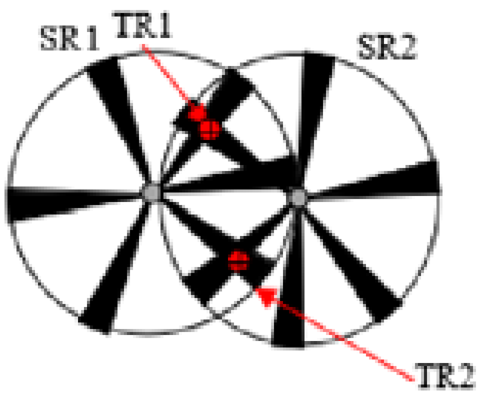

Figure 4.3 SR1 and SR2 with two new TRs

Sensor Blindness, SR_{BL}, is defined as in equation 4.1:

$$SR_{BL} = R_{SRs} \times 2SR_{ER}/360 * 100\% \qquad (4.1)$$

where:

R_{SRs} is the number transmitters detected for a Sensor

SR_{ER} is the detection error in degrees.

For example ,if a SR has 6 bearings of TRs detection BRNGs (30,60,120,224,330,10) and the network has an average detection error of 4^0 for each SR, then the SR blindness will be:

SR1 Blindness: $6 \times (2 \times 4^0)/ 360^0 \quad * 100 = 13.33\%$

That means that at a percentage of 13.33%, SR1 will not detect a new TR, but only another SR within its detection region will detect that new TR. In Fig.4.1, SR2 has a high level of blindness of 28.8%.

4.3 Network Parameters

A FSN in order to be operational a lot of parameters should be examined and checked not only before its operation but also when it operates. A lot of parameters should be examined and checked not only before its operation but also while in operation in order to be fully functional and operational. SRs characteristics should be checked not to mention that its topology need to be carefully designed as problematic areas might degrade its performance. A SR won't be able to detect a new TR on an existing detection sector. When SRs possess many existing detection sectors then the system performance might easily deteriorate. For that reason parameters like Network Blindness, Network Saturation, are examined thoroughly below in order to enable the network to validate its status. That is why the system should be flexible to changes.

4.3.1 Network Blindness

As previously mentioned, every SR of the network has a level of blindness. Summing the blindness of all the SRs then we have a picture of the network Blindness, which is a factor that characterizes the detection performance of the network. In Fig.4.5 and in

Fig.4.6 we see two examples of a grid network with SRs. Comparing the two grids we see that in Fig.4.6 it is more saturated and that way the process of detection is more complicated. Network Blindness - N_{BL} definition is given in the following equation (4.2), where n is the number of SRs.

$$N_{BL} = \frac{SRBL_1 + SRBL_2 + \cdots + SRBL_i}{n} \qquad (4.2)$$

where:

N_{BL} is the overall Network blindness of a FSN system with a number of n SRs.

$SRBL_i$ is the blindness of SR_i , i=1,...,n.

n is the number of SRs.

(**Example 1** Sensor Network Blindness)

We have a Network of 4SRs (n=4), (SR1,SR2,SR3 and SR4) with various bearings BRNGs

[SR1,4(170,200,320,46),SR2,6(30,60,120,224,330,10),SR3,3(210,240,300), SR4,2(18,70). SRs The average network error is SR_{ER} =4^0 degrees.

The total number of SRs BRNGs, for that particular state of the network is:

BRNGs Total : 4 + 6 + 3 + 2 = 15 BRNGs

N_{BL} is the sum of all the SRs blindness of the network
divided with the number of SRs n.

$$N_{BL} = \frac{SRBL_1 + SRBL_2 + \cdots + SRBL_i}{n}$$

We calculate each SR Blindness with the equation 4.1.

SR1 Blindness = SR_{BL1} **:** 4 x (2 x 4^0) / 360^0 * 100 = 8.88%

SR2 Blindness = SR_{BL2} **:** 6 x (2 x 4^0) / 360^0 * 100 = 13.33%

SR3 Blindness = SR_{BL3} **:** 3 x (2 x 4^0) / 360^0 * 100 = 6.66%

SR4 Blindness = SR_{BL4} **:** 2 x (2 x 4^0) / 360^0 * 100 = 4.44%

N_{BL} = 8,88 + 13,33 + 6,66 + 4.44/4 = **8.32%**

So, the overall Network Blindness is: N_{BL} = **8.32%**

In the following Fig 4.4 we have the depiction of a FSN with 25 SRs and a certain level of blindness for each SR. We see that the higher Network blindness N_{BL} is 80.16 as a result of the high SRs blindness of SRs for that particular network. It becomes evident that as SRs blindness is increased then the overall Network blindness is increased respectively.

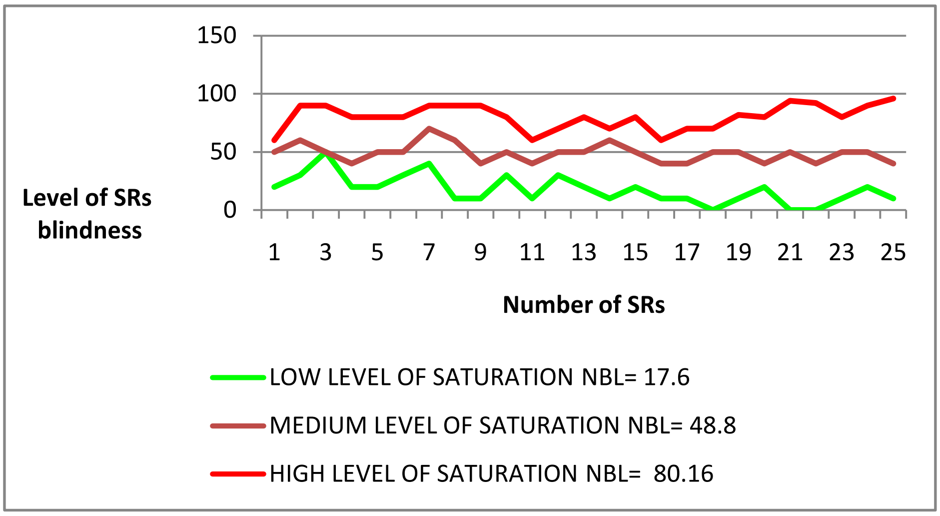

Figure 4.4 SRs blindness resulting in Network saturation

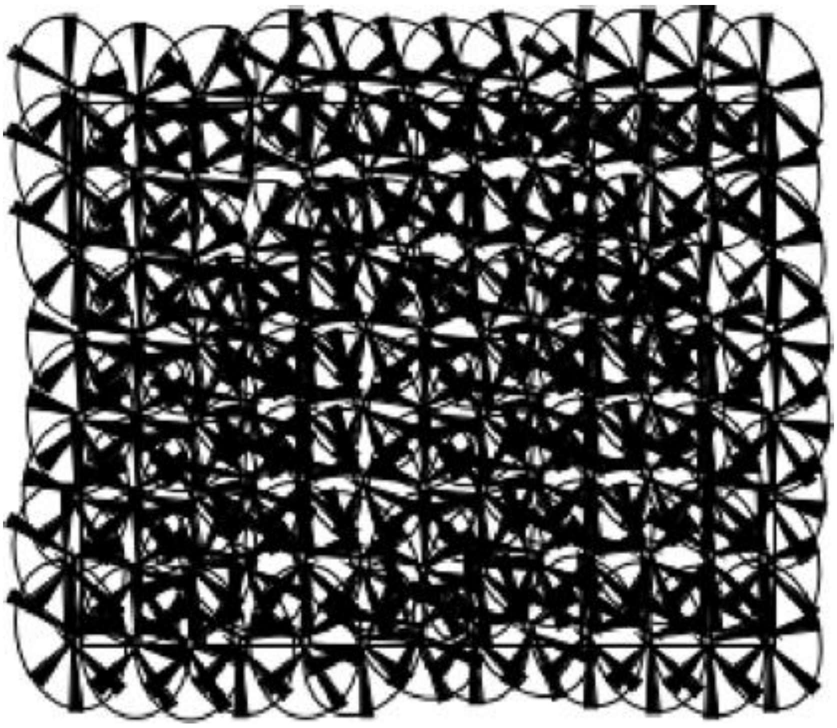

Figure 4.5 A FSN with a low level of blindness

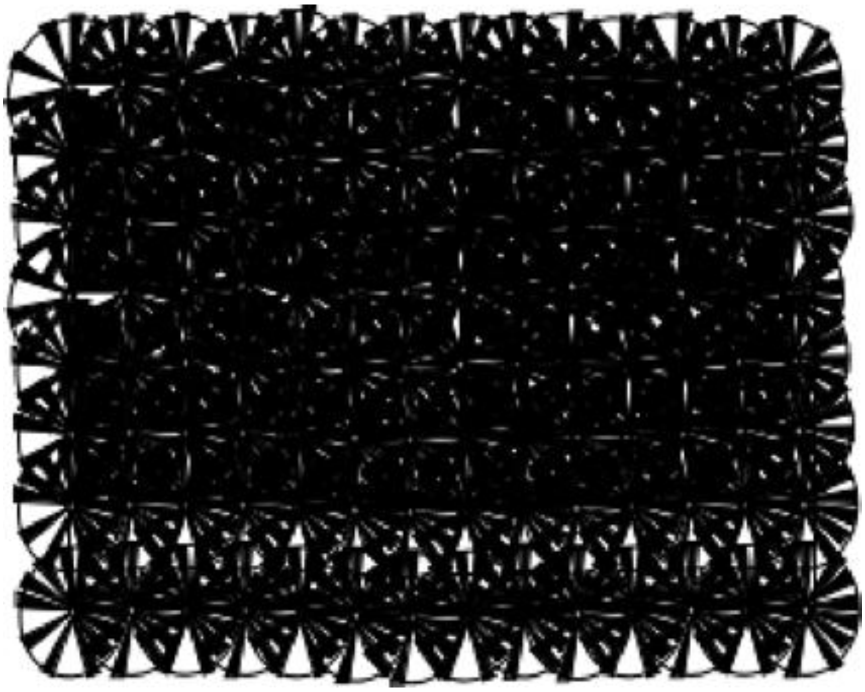

Figure 4.6 A FSN with a high level of blindness

In the following Fig.4.7 we have a depiction of a FSN grid with SRs AOI coverage. It is assumed that in each sub-area there exist seven SRs.

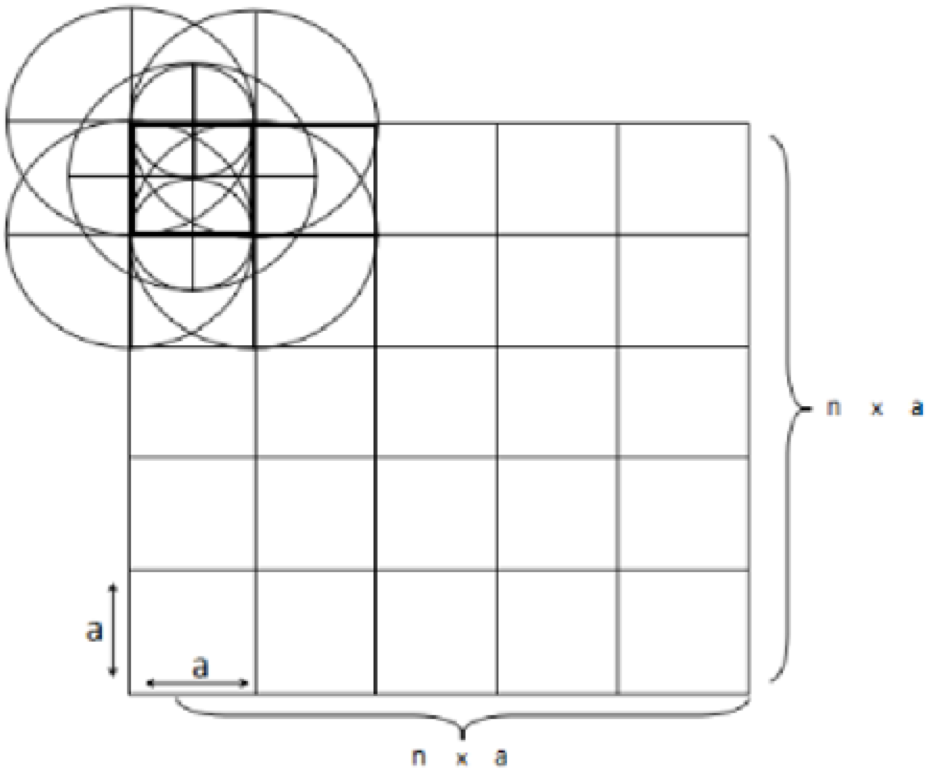

Figure 4.7 Network Area of Interest - AOI with SRs Clusters

4.3.2 Network Saturation

Another network attribute, which needs further analysis is the number of TRNs. As the number of TRNs in the network Area of Interest (AOI) increases, the network approaches a saturation state that degrades its performance. We define the network saturation state for a sub-area of the network with the following parameters:

N_{AST} : Network Sub-area Saturation Status
A_S : Area Size

$$N_{AST} = \text{Total Area of TRNs in a sub-area/Sub-Area Size}$$

So, N_{AST} is given by the equation 4.3,

$$N_{AST} = \sum_{i=1}^{n} \frac{TRNi}{As} \qquad (4.3)$$

where:

- TRN_i is the area covered by triangulation i (i=1,2,3...n).
- n is the number of TRNs of the network in that particular state.
- A_S is the Area Size.

In order to deal with the various cases of TRNs the system has to find the number of TRNs in each sub-area of the grid and then process the Network Area Saturation Status - N_{AST}, for that sub-area. Assuming that an AOI of the Network has n sub-areas,(n is the number of AOI sub-areas) then the Total Network Saturation Status, N_{TAST} is given by the following equation 4.4,

$$N_{TAST} = \sum_{i=1}^{n} \frac{N_{ASTi}}{A_{TS}} \qquad (4.4)$$

where:

- A_{TS} is the total Area size
- N_{AST} is the Network Sub-area Saturation Status

We assume that we have an AOI grid of the size 1000 x 1000 = 1.000.0000 m^2. The grid is formed from 10 x 10 = 100 cells Fig.4.8. Each cell has a size of 100 x 100m = 10.000 m^2. Each cell is formed from 4 x 4 = 16 sub cells Fig.4.9. Each sub cell has a size of 25 x 25 = 625 m^2. For simulation purposes, we assume that each of the sub cells can correspond to only one triangulation area where a transmitter TR exists. As the Area of Interest AOI has a size of 1.000.000 m^2 two examples of saturation with TRs will be provided.

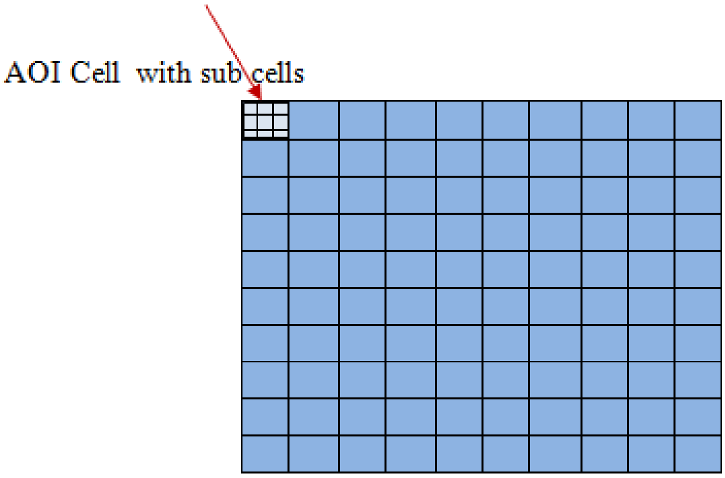

Figure 4.8 FSN AOI with 100 cells

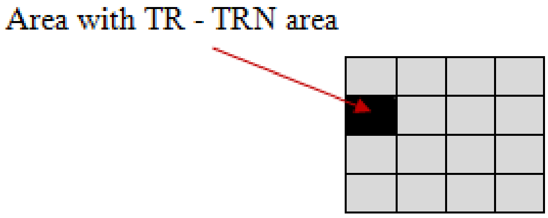

Figure 4.9 FSN AOI cell with 16 sub cells

Example 1

Assuming that in the AOI we have 300 existing TRs and 300 triangulation areas TRN_i exist. As it was mentioned above, for simulation purposes, we assume that each of the sub cells can correspond to only one triangulation area where a transmitter TR exists. Then i=300 and the network saturation status is given by the pre mentioned formula 4.4.

So, N_{TAST} = 300 x 625/1.000.000 = 18.75%

Example 2

Assuming that in the previously mentioned AOI we have 800 transmitters and 800 triangulation areas TRN_i exist then i=800. The network saturation status is given by the formula 4.4.

$$N_{TAST} = 800 \times 625/1.000.000 = 50\%$$

So, we see that when the number of TRs reaches the value of 800 then in a 50 percentage the whole network is saturated. With these two simple examples, it is shown that as the level of TRs and the relative TRNs is increased, then respectively the AOI becomes blocked and saturated. It is worth mentioning that network saturation is related to the size of triangulation areas and their number. For that reason the FSN system should evaluate its status continuously in order to allow the high detection performance. In the following Fig.4.10 it is depicted the Network saturation effect in relevance to the number of triangulations TRNs in the network. We can clearly see, that as the number of triangulations increases the network becomes gradually saturated. According to graph 5.2, when we reach the number of 1300 TRNs in the AOI the system is high saturated with a level of 81.25%. System evaluation and methodologies for network optimization are presented in detail in next chapter 5.

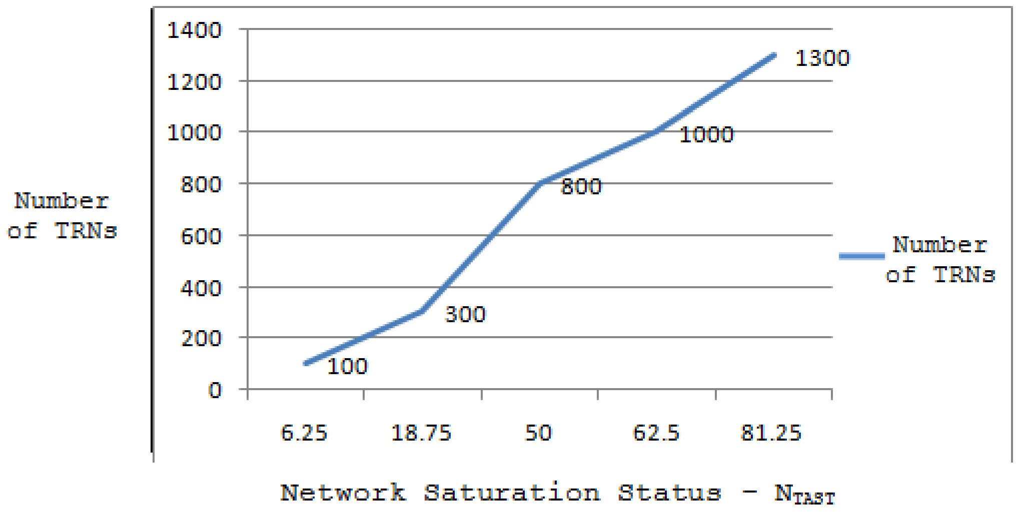

Figure 4.10 Network saturation N_{TAST}

From the above Fig.4.10, it is obvious that as the number of TRs increases the network saturation also increases respectively. The issue of network saturation affects the detection performance of the network as well as the strong probability of detection of a new TR that might enter the Area of Interest - AoI.

4.4. Transmitters probability of detection in the AOI

The detection probability P is strongly related to the position of SRs in the sub-area of the AOI. In the following cases we examine the detection ability of a network topology with SRs located in a sub-area of a rectangular shape. In this section we assume that the SRs have the same probability of detection.

Case 1

The SR1 is located in the center of the AOI sub-area Fig.4.11. The SR1 in the center has 360^0 degrees of possible detection. A SR blindness is given with the equation 4.5

$$SR_{BL} = \frac{RSRs \;\; x \;\; 2SRER}{360} \; x \; 100 \qquad (4.5)$$

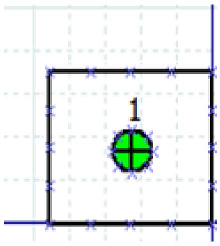

Figure 4.11 SR 1 in the center of the Sub area of the AOI

Case 2

2 SRs (SR 1 and SR 2) in the middle of the external lines. The two SRs in the middle of the external lines have 180^0 degrees of possible detection each Fig. 4.12.

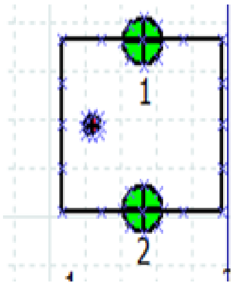

Figure 4.12 SR1 and SR2 are located at the center of the outer lines of the Sub area of the AOI

Case 3

In this case we have 4 SRs (SR1,SR2,SR3,SR4) located at the corners of the Sub area of the AOI Fig.4.13. The four SRs in the corners have 90^0 degrees of possible detection each.

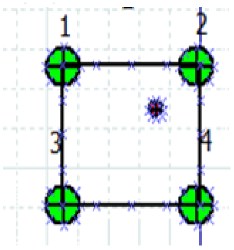

Figure 4.13 SRs (SR 1,SR2,SR3,SR4) are located in the corners of the Sub area of the AOI

Case 4

In this particular case we have 7 SRs in the sub-area of the AOI resulting from the combination of cases 1,2 and 3 Fig. 4.14.

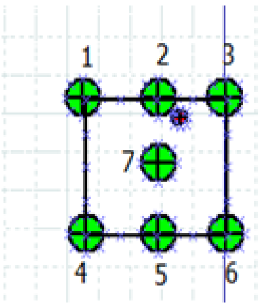

Figure 4.14 7 SRs resulting from the combination of SRs position cases 1,2 and 3

Summing up the previous analysis related with the areas of SRs possible detection we have the following for detection view:

Case 1	360 - SR_{BL}
Case 2	180 - SR_{BL}
Case 3	90 - SR_{BL}
Case 4	Case 1 + Case 2 + Case 3

In order to achieve a detection of a transmitter with triangulation, we need at least three SRs, (k≥3) to detect a TR. If we have seven SRs in a sub-area of the AOI then 3 of the 7 should detect a TR in order to have a triangulation provided that their lines of bearings will converge. So, the probability P of detection exactly x out of n is given by the equation 4.6, where p is the level of possible detection.

$$\text{P(exactly x out of n)} = p^x * (1-p)^{n-x} \qquad (4.6)$$

where x = 3 and n = 7.

But there are cases according to which more than three SRs bearing lines will converge and triangulate like 4,5,6,7 lines of the SRs bearings. In that case, a TR to detect those probabilities and calculate the total sum of occurrences of three or more lines is needed. In that case, the following equation 4.7 is used:

$$\text{P(at least x out of n)} = \sum_{q=0}^{n-x} p^{x+q} \ (1-p)^{n-(x+q)} \qquad (4.7)$$

In the following example we will show how the probability of detection arises for any sub-area of a certain FSN and for the network as a whole. In Fig.4.11 we have a depiction of a FSN with 25 SRs and a number of 11 TRs spread in the AOI.

Case 3

In this case we have 4 SRs (SR 1,SR2,SR3,SR4) located at the corners of the Sub area of the AOI Fig.4.15. The four SRs in the corners (has) have (each one) 90^0 degrees of possible detection each.

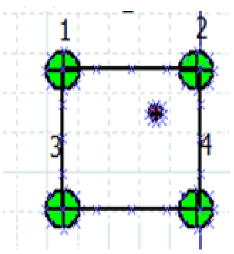

Figure 4.15 SRs (SR 1,SR2,SR3,SR4) located at the corners of the Sub area of the AOI

This network topology has 16 sub-areas where 4 SRs in each sub-area operate as clusters for detection in each and every one of them. In the FSN depicted in Fig. 4.16 there are several TRs in some sub-areas.

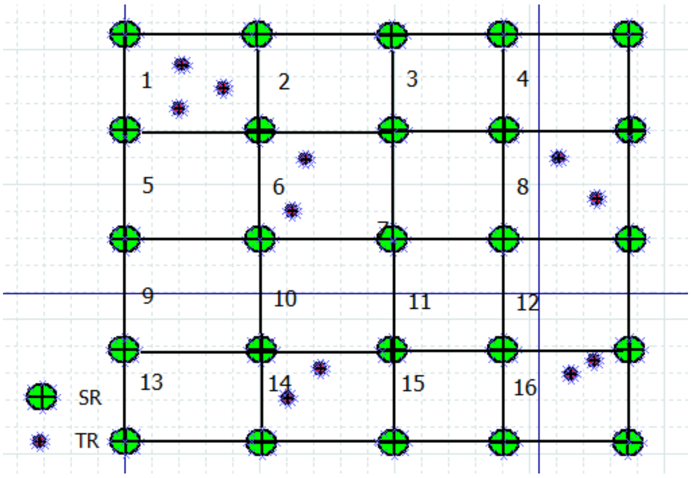

Figure 4.46 A FSN topology with 25 SRs and 11 TRs. The network has 16 sub-areas

The most saturated sub-area in the above Fig.4.16, is the sub-area number 1 with 3 TRs. The four SRs of the sub-area 1 has each one a sector of detection of 90^0 degrees, like in Fig. 4.13. There are three TRs inside the sub-area 1 which means three TRNs. For that reason each SR has the relative blindness as it arises from equation (4.1). The SR_{BL} for each of the four SRs of sub-area 1 which are operating the way it is shown in Fig.4.13, meaning that they have 90^0 degrees of detection capability in its sub-area which arises from the following equation of 360^0 applied for 90^0 degrees.

$$SR_{BL} = \frac{RSRs \ \text{x} \ 2SRER}{360} \ \text{x} \ 100$$

Thus, as the SR_{BL} is calculated for only a sector of 90^0 degrees which is the maximum detection capability in each sub-area of the Fig.4.9 and the topology of the FSN system which appears in Fig. 4.16, we have the following equation 4.8:

$$SR_{BL} = R_{SRs} \ \text{x} \ 2SR_{ER}/90 * 100\% \qquad (4.8)$$

where: R_{SRs} is the number transmitters detected for a SR

SR_{ER} is the detection error in degrees.

Thus, as the detection sector is estimated at 2^0 degrees and the sensor error SR_{ER} is evaluated at 2^0 degrees respectively, and as there are three bearing lines, the SR_{BL} by applying equation 4.8 is:

$$(3 \times 2 \times 2)/90 * 100 = 13.33$$

then the level of possible detection will be:

$$(90 - 12)/90 = 78/90 = 0.87$$

So the probability for the pre-mentioned SRs is p = 0.87 out of 1, or the probability of detection has a percentage of detection of 87%. If a SRs detection area is clear then $SR_{BL} = 0$ and the level of possible detection is 1.The probability of detection arises after applying equation (4.3) for this sub-area with 4 SRs. In order to achieve a triangulation there are two possibilities. The first probability of detection is to achieve a TRN with 3 SRs and the second probability is the detection with all the 4 SRs as three or more SRs detection lines for TRN are required.

Detection Probability 1 - Detection of 3 out of 4 SRs

$$P_1 = p^3 (1-p)^{4-3} = 0.87^3 \times 0.13$$

$$= 0,085$$

where 0.13 = 1-0.87 and 0.13 out of 1 or 13% is the probability percentage of no detection.

Also, the value of P_1 is: $P_1 = p^3 (1-p) = p^3 - p^4$

Detection Probability 2 - Detection of 4 out of 4 SRs

$$P_2 = p^4 (1-p)^{4-4} = p^4 = 0.547$$

The sum of these two detection probabilities (1 and 2) provides the probability of detection for this particular sub-area Fig.4.14, with four SRs.

$$\Sigma = P_1 + P_2 = p^3 - p^4 + p^4 = p^3 = 0.87^3 = 0.65$$

So, 0,65 is the total probability of detection <u>of at least 3 out of 4</u> SRs to detect a new transmitter in a sub-area where **three TRs** already exist, (where the probability of one SR to detect a transmitter is 0.87). When we have to calculate the case of **two existing transmitters** in a sub-area then the probability of detection of one TR is p = 0.91 out of 1, or the probability of detection has a percentage of detection of 91%. In order to find the probability for detection in a sub-area with two TRs we apply again the previous procedure.

So, for the particular case of two existing TRs the two detection probabilities (1 and 2) are the following:

Detection Probability 1 - Detection of 3 out of 4 SRs

$$P_1 = p^3 \ (1-p)^{4-3} = 0.91^3 \times 0.09$$
$$= 0{,}0678$$

where 0.1 = 1-0.91 and 0.09 out of 1 or 9% is the probability percentage of no detection.

Also, the value of P_1 is: $P_1 = p^3 (1-p) = p^3 - p^4$

Detection Probability 2 - Detection of 4 out of 4 SRs

$$P_2 = p^4 \ (1-p)^{4-4} = p^4 = 0.685$$

The sum of these two detection probabilities (1 and 2) provides the total probability of detection for this sub-area Fig.4.14, with four SRs.

$$\Sigma = P_1 + P_2 = p^3 - p^4 + p^4 = p^3 = 0.91^3 = 0.75$$

So, 0,75 is the total probability of detection of at least 3 out of 4 SRs for this particular FSN topology and at this particular state with existing TRs, to detect a transmitter in a sub-area **where two TRs** already exist, (where the probability of one SR to detect a transmitter is 0.91). The probability case of detection for a network with four SRs in every sub-area of this type of topology provides the total probability P_T of detection with the equation (4.9).

$$P_T = \frac{\sum_{i=1}^{n} P_i}{n} \qquad (4.9)$$

In this particular type of FSN we have n =16 as there are 16 sub-areas. Five of the sub-areas are already having TRs and the rest of them are free from TRs. After applying the equation 4.9 and calculating the probabilities of detection for each of the FSN sub-areas and adding the sub-areas which are clear from TRs we have the following results:

$$P_T = 0.915$$

That means that the FSN has a total of 0.91 out of 1 probability to detect a new TR entering its AOI, for this particular FSN topology and at this particular state with existing TRs, whilst this probability varies for each of its sub-areas as depicted in the following Table 4.1.

AOI Sub-Area	TRN Lines	P
1	3	0.65
2	0	1
3	0	1
4	0	1
5	0	1
6	2	0.75
7	0	1
8	2	0.75
9	0	1
10	0	1
11	0	1
12	0	1
13	0	1
14	2	0.75
15	0	1
16	2	0.75
P_T Total Network Probability of TR detection		**0.915**

Table 4.1 Detection probability of new TRs in a network sub-area and total network probability

4.5 Network Grid topology

The Fig.4.15, shows the Area of Interest - AOI for detection. In this area we see a grid perspective of squares where clusters of SRs cover the whole area and form regions of coverage. In each individual square there are seven circles (seven SRs detection circles with radius R) which cover each sub-region, as shown in Fig.4.15.

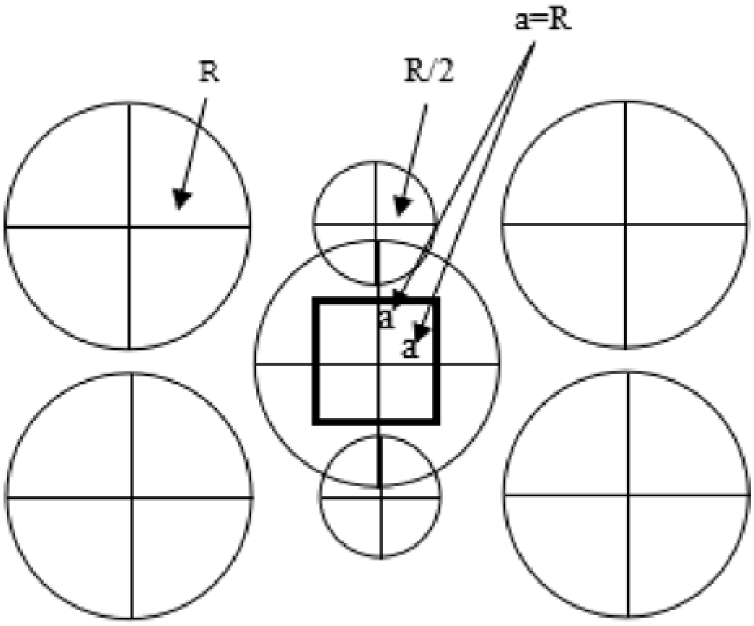

Figure 4.5 Seven circles of SRs coverage in each individual square of AOI

Their coverage intersect with each other and by that way the whole area is monitored, Fig.4.8. Each circle is the coverage boundary of a SR. There are two types of SRs. One type that has a circular coverage of radius r, where r=a, and a second type with a circular coverage of radius r/2=a/2. That means that SRs with a small radius coverage are minimizing the area of TRN in each square. Additionally, SRs with radius coverage a, can monitor four square regions by each of their four quadrant, except circles that are located in the peripheral area of the grid which monitor two squares. Circles located at the AOI grid corners monitor only one quadrant. Fig.4.16 shows a Grid with twenty five subareas.

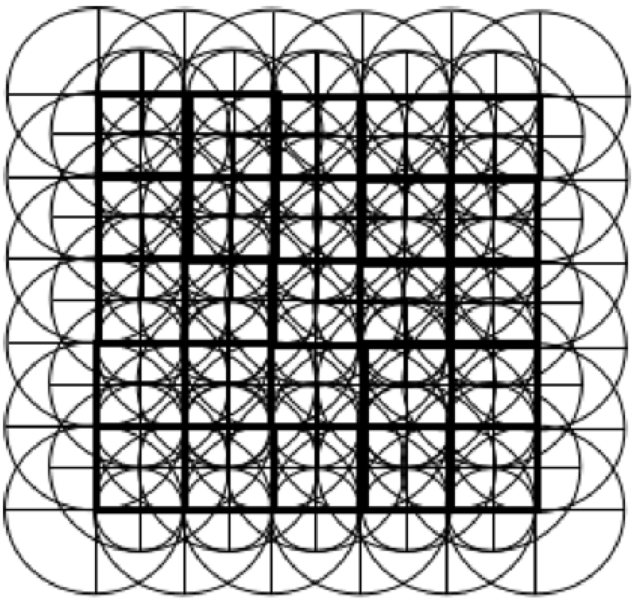

Figure 4.6 A FSN grid with twenty five individual squares of the AOI covered by SRs clusters

Each sub-area is monitored by the seven SRs as depicted in Fig.4.17. A similar splitting procedure is applied in a GSM network, where an area is monitored by transmitters that operate in hexagonal cells as shown in Fig.4.18. The actual radio coverage of a cell is called footprint. The radio network operates over different frequencies, in this case (A,B,C,D,E,F,G) Fig.4.18 [4.2],[4.3],[4.4].

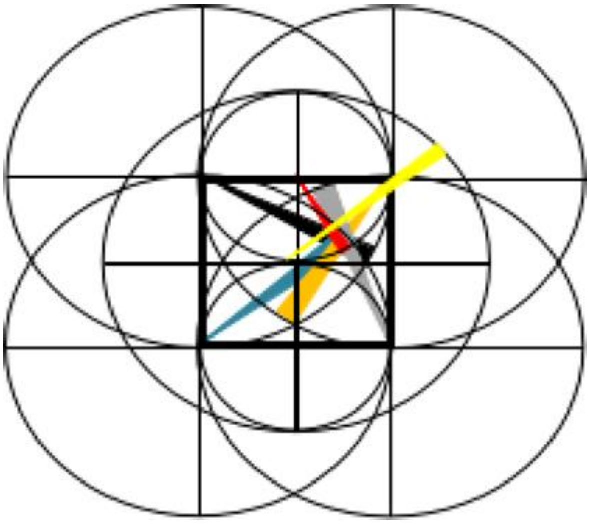

Figure 4.7 A FSN individual square SRs beam intersections

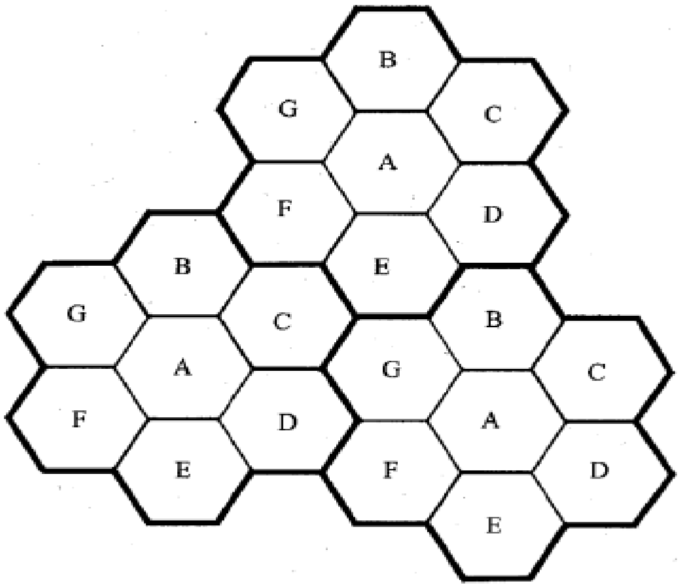

Figure 4.8 GSM network area monitoring with hexagonal cells [4.2],[4.3],[4.4].

The size of cells may vary and/or often divided. With Cell division (split) Fig.4.19, capacity improvement is achieved with the method of rescaling the system and the number of times that channels are reused is increased. Due to smaller cells, capacity increases and that is due to additional number of channels used per unit area [4.3].

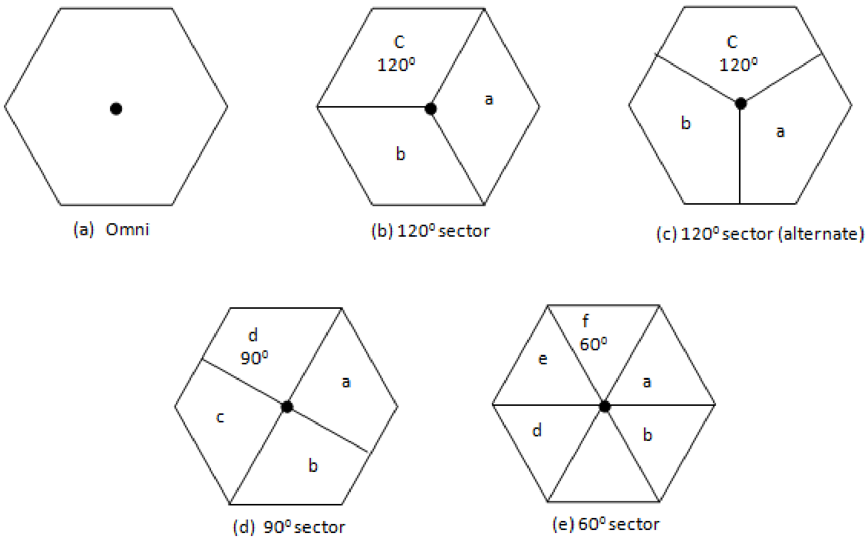

Figure 4.9 GSM network area hexagonal cells splitting for capacity improvement [4.2],[4.3] and [4.4].

During processing of data acquired, every area is processed independently from the other. All the parameters of the network are also acquired and at the same time the SRs parameters are checked. If a SR deals with any kind of problem inside an area of high blindness then its operation might be degraded. Thresholds of blindness have to be applied for each SR.

4.6 Factors affecting the Network Detection Performance

In the following figures, Fig.4.20 initial State, and Fig.4.21, actual State 1, triangulations TRNs are depicted in red, FTRNs in black and new TRNs in green. As the number of TRNs and FTRNs is increased the detection procedure becomes more complex and difficult. This happens, as the network coverage is affected, blindness and saturation are increased and the Network probability of detection is significantly reduced as it was shown in previous sections. Though, the system has to deal with the detection of new TRs while the areas of TRNs and False TRNs (FTRNs) that probably exist, have to be tackled with on a case by case basis. There is a high probability that the number of TRNs and FTRNs will be increased, as it arises from Fig.4.14, we see that TRNs and FTRNs are increased and that presupposes that every area should be monitored by a minimum number of SRs. These SRs should be able to find a new TR and synchronously reject a FTRN. In Fig.4.14 it is depicted the actual state 1 which is a problematic area with FTRNs and new TRs that entered the area. Clusters of existing SRs or extra SRs should cooperate in order to provide data analysis in a saturated area and detect the real TRs. A problematic situation also appears when SRs have a high rate of saturation which also means that the area is saturated. For these reasons, like in the case of Centralized Intrusion Detection Systems - CIDS where a centralized computer monitors all the activities in the network and detects intrusions by analyzing the monitored network activity data, SRs Clusters should monitor each area and send their data to a central computer. Data fusion and adequate data analysis should provide results in high accuracy. The problem of target tracking with the process of triangulation deteriorates more (in the case that there are already existing TRNs) every time a lot of TRNs appear and block detection beyond the area of TRN, as it was depicted in Fig.3.22 in chapter 3. In the next chapter 5, relative tests and simulation experiments have shown how the network performance is decreased and deteriorated by all the pre-mentioned factors as well as due to the presence of TRs in the AOI. The problem of non coverage ($k<3$) for this particular type of network that needs at any point of the AOI. a minimum of three SRs coverage $k \geq 3$ has been clearly shown, which is vital for this particular type of network for triangulation.

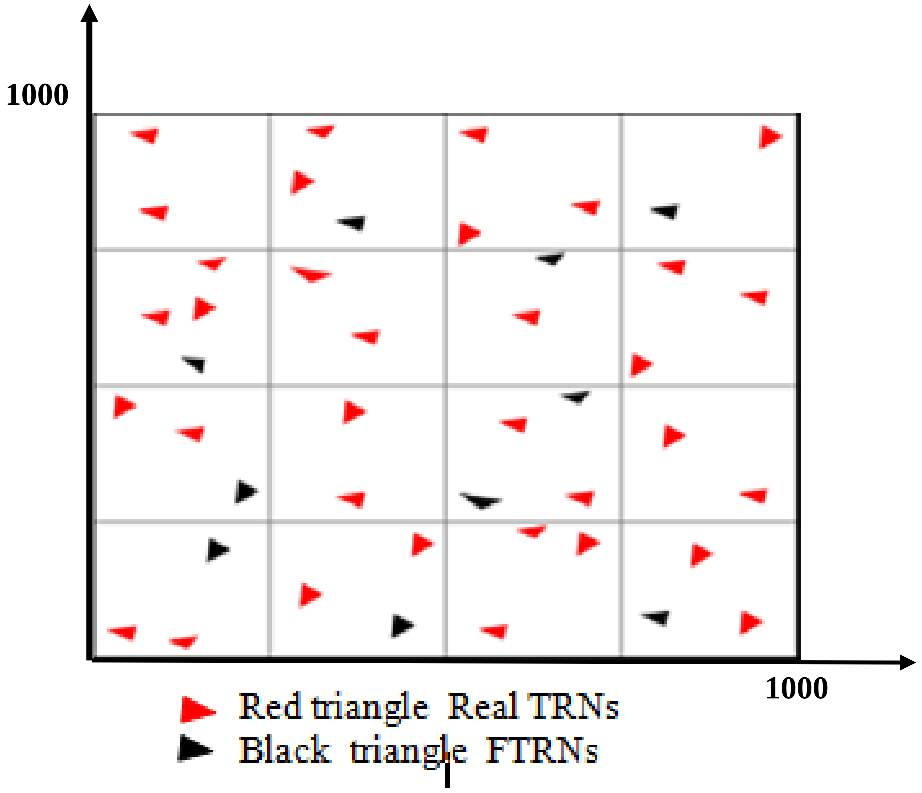

Figure 4.10 FSN initial state with a certain number of TRNs and FTRNs

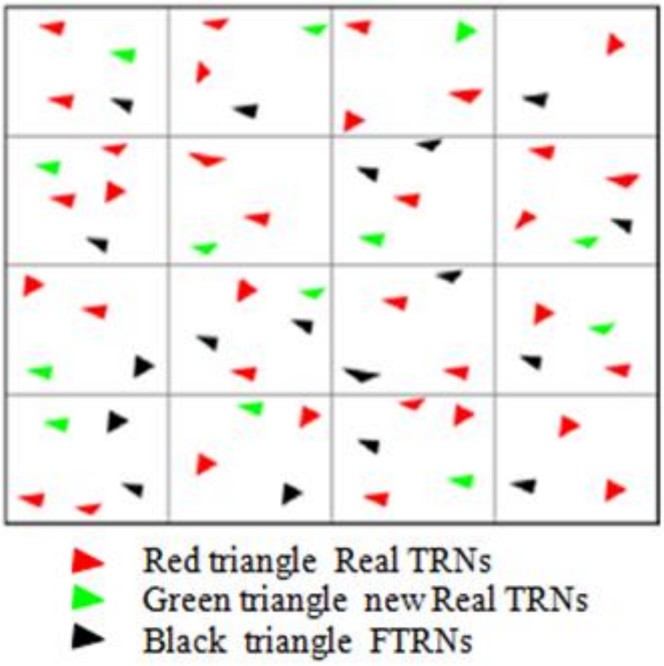

Figure 4.11 FSN new state with increased number of TRNs and FTRNs after the appearance of new TRs in the AOI

4.6.1 Case Scenario of the Factors affecting the Network Detection Performance

In this scenario we have a certain network topology with a number of SRs and TRs. For this scenario the following assumptions are made:

Assumption 1

We have an AOI of 1000 x 1000m (m is a units number).

Assumption 2

For this AOI the network uses 121 SRs for coverage in a square grid topology and 10 TRs at random locations as it appears in the following Fig.4.22.

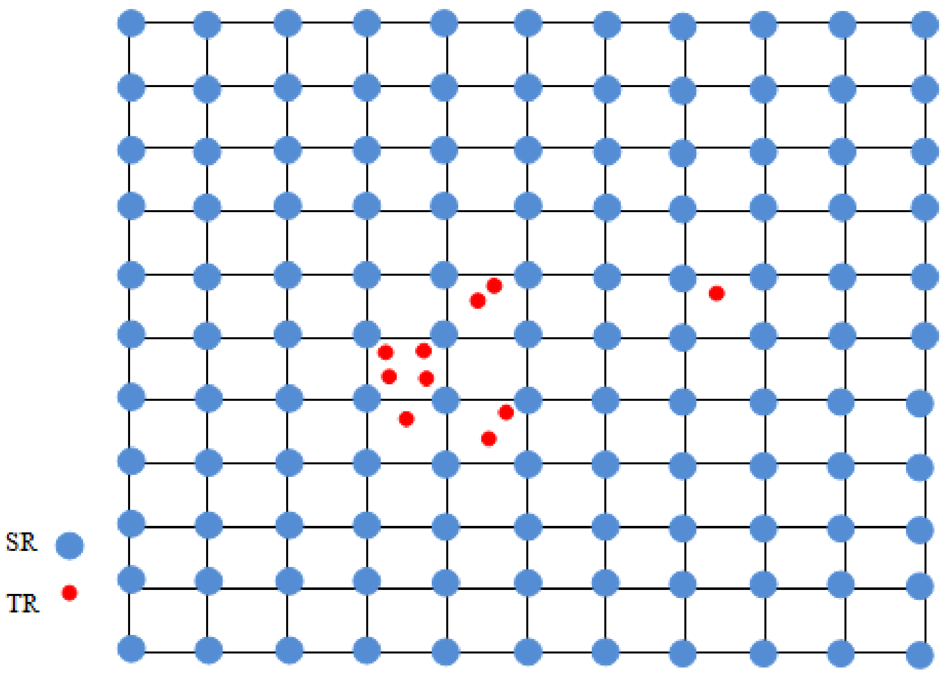

Figure 4.12 AOI with 121 sensors and ten transmitters

For this scenario the following calculations are presented:

1) Calculation of Sensor blindness for a SR in the middle of the AOI.

2) The overall Network blindness.

3) The overall Network saturation at this particular state.

4) Probability of detection at this particular state.

1) Calculation of Sensor blindness for a SR in the middle of the AOI.

Sensor Blindness, SR_{BL}, is defined in equation 4.1 as:

$$SR_{BL} = R_{SRs} \times 2SR_{ER}/360 * 100\%$$

where:

R_{SRs} is the number transmitters detected for a Sensor

SR_{ER} is the detection error in degrees.

In our case we will calculate the SR blindness of the SR(5,5) which lies in the middle of the grid topology depicted in the above Fig.4.15. The SR(5,5) has 7 bearings of TRs detection BRNGs(290^0,315^0,330^0,350^0,230^0,120^0,135^0).

We assume that the network has an average detection error of 3^0 for each SR. Then the SR blindness will be:

SR(5.5) Blindness**:** $7 \times (2 \times 3^0) / 360^0 * 100 = 11.6\%$

That means that at a percentage of 11.6% SR(5.5)it will not detect a new TR, but only another SR and that only within its detection region it will detect that new TR. This level of blindness is related with the four quadrants of 90^0 degrees.

2) Calculation of overall Network blindness

For the calculation of the overall blindness we firstly have to (firstly) to calculate the blindness of each individual of SR of the network which is affected. Then for this particular case scenario we apply the following equation:

$$N_{BL} = \frac{SRBL_1 + SRBL_2 + \cdots + SRBL_i}{n}$$

where:

N_{BL} is the overall Network blindness of a FSN system with a number of n SRs.

$SRBL_i$ is the blindness of SR_i , i=1,...,n.

n is the number of SRs.

We have a Network of 121 SRs (n=121), (SR1,SR2,SR3...SR121) with various bearings (BRNGs) in some of the SRs of this network. The SRs which have detected the ten TRs, are depicted with their sets of bearings in the following Table 4.2:

	Sensor Number (R,C)*	Sensors bearings detected														Total Number of bearings
		1	2	3	4	5	6	7	8	9	10	...	20	...	40	
1	(5,4)	10	20	40	55	120										5
2	(5,5)	290	315	330	350	230	120	135								7
3	(6,4)	45	170	100	120											4
4	(6,5)	40	25													2
5	(4,4)	40														1
6	(4,5)	325	45	30												3
7	(4,6)	315	350													2
8	(5,6)	225	215													2
9	(6,5)	40	30													2
10	(6,6)	340	350													2
11	(7,5)	100	140													2
12	(7,6)	245	260													2
13	(6,8)	40														1
14	(6,9)	310														1
15	(7,8)	140														1
16	(7,9)	230														1
. . .																0
121																0

Table 4. 2 Sensors bearings detected sets

As it arises from the Table 4.1 above in order to calculate the overall network blindness, each SRs blindness should be calculated. So, $SRBL_1$ counts for SR (5,4) B_2 counts for SR (5,5)..B_{16} counts for SR (7,9). We assume that the average network error is SR_{ER} =3^0 degrees. So, we have the following Table 4.3 of results:

Sensor blindness	Sensor blindness calculation	Sensor blindness value
$SRBL_1$	SR(5.4) Blindness :5 x (2 x 3°) / 360° * 100 = 8.3	8.3
$SRBL_2$	SR(5.5) Blindness :7 x (2 x 3°) / 360° * 100 = 11.6	11.6
$SRBL_3$	SR(6.4) Blindness :4 x (2 x 3°) / 360° * 100 = 6.6	6.6
-	SR(6.5) Blindness :2 x (2 x 3°) / 360° * 100 = 3.3	3.3
-	SR(4.4) Blindness :1 x (2 x 3°) / 360° * 100 = 1.66	1.66
-	SR(4.5) Blindness :3 x (2 x 3°) / 360° * 100 = 4.9	4.9
-	SR(4.6) Blindness :2 x (2 x 3°) / 360° * 100 = 3.3	3.3
	SR(5.6) Blindness :2 x (2 x 3°) / 360° * 100 = 3.3	3.3
	SR(6.5) Blindness :2 x (2 x 3°) / 360° * 100 = 3.3	3.3
	SR(6.6) Blindness :2 x (2 x 3°) / 360° * 100 = 3.3	3.3
	SR(7.5) Blindness :2 x (2 x 3°) / 360° * 100 = 3.3	3.3
-	SR(7.6) Blindness :2 x (2 x 3°) / 360° * 100 = 3.3	3.3
-	SR(6.8) Blindness :1 x (2 x 3°) / 360° * 100 = 1.66	1.66
-	SR(6.9) Blindness :1 x (2 x 3°) / 360° * 100 = 1.66	1.66
$SRBL_{15}$	SR(7.8) Blindness :1 x (2 x 3°) / 360° * 100 = 1.66	1.66
$SRBL_{16}$	SR(7.9) Blindness :1 x (2 x 3°) / 360° * 100 = 1.66	1.66
	Sum of SRs blindness $(B_1 + B_2 + ... + B_{16})$	62.8

Table 4.3 Sensor blindness calculation results

The level of blindness for the rest 84 SRs of the network is 0, as there aren't any TRs in their surveillance area.

$$\text{So,} \quad N_{BL} = \frac{SRBL_1 + SRBL_2 + \dots + SRBL_i}{n} = 62.8/121$$

which result in $N_{BL} = 0.52$

From this result we see that the overall blindness is very low for a network of 121 SRs and only 10 TRs appear to have a low efficacy in the network. But this is not the case as the number of TRs increases. In the following Table 4.3 we have various combinations of TRs increase and we see that the overall network blindness of the system might deteriorate heavily when the number of TRs increases. We assume that all the 121 SRs of the FSN system have the same number of TRs (20,30,40,50) inside their area of detection of 360^0. In the following Table 4.4 we see how the level of network blindness N_{BL} increases gradually based on the previous assumption.

Number of TRs per SR	Sensor blindness calculation	Sensor blindness value	N_{BL}
20	SR Blindness :20 x (2 x 3°) / 360° * 100 = 33.3	33.3	33.3
30	SR Blindness :30 x (2 x 3°) / 360° * 100 = 50	50	50
40	SR Blindness :40 x (2 x 3°) / 360° * 100 = 66.6	66.6	66.6
50	SR Blindness :50 x (2 x 3°) / 360° * 100 = 83.3	83.3	83.3

Table 4. 4 Network blindness increase analogous with the number of TRs increase in the FSN system

3) Calculation of the overall Network saturation at this particular state.

It was mentioned previously that network saturation N_{AST} is given by the equation 4.3:

$$N_{AST} = \sum_{i=1}^{n} \frac{TRNi}{As} \qquad (4.3)$$

where:

- TRN_i is the area covered by triangulation i (i=1,2,3...n).
- n i s the number of TRNs of the network in that particular state.
- A_S s the Area Size.

It was also pinpointed that an AOI of a Network might have n sub-areas,(n is the number of AOI sub-areas) then the Total Network Saturation Status, N_{TAST} is given by equation 4.4:

$$N_{TAST} = \sum_{i=1}^{n} \frac{N_{ASTi}}{A_{TS}} \qquad (4.4)$$

where:

- A_{TS} is the total size
- N_{AST} is the Network Sub-area Saturation Status

In this case scenario where we a have a network AOI of 1000 x 1000m (m is a units number), the AOI has the size of 1.000000m^2.

Again, as in Fig.4.6 the AOI is divided in 100 cells, but in this scenario we assume that each cell is divided in 64 sub-cells of a size 12.5 * 12.5 = 156.25m^2 as it is depicted in Fig.4.23 below. So, 64 sub-cells in each cell have a size of 10.000m^2 of the 1.000000m^2.

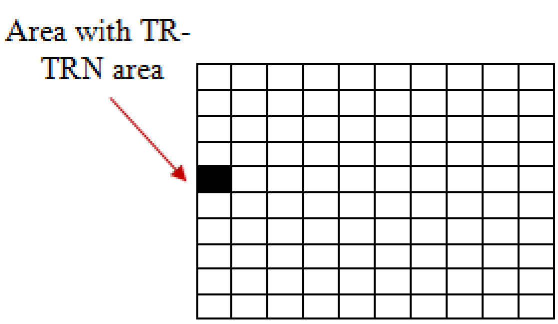

Figure 4.13 64 Sub-cells of a cell of the AOI with a size each of 12.5 * 12.5 = 156.25m^2

In this case scenario we have only 10 transmitters -TRs in the whole AOI of the FSN system and 10 triangulation areas TRN_i exist. Again, for simulation purposes we assume that each of the sub cells corresponds to only one triangulation area where a transmitter exists. Then i=10 and the network saturation status is calculated as:

$$N_{TAST} = 10 \times 156.25/1.000.000 = 0.156\%$$

The above result of N_{TAST} means that the level of saturation with only ten TRs for this type of network is minimum. But even if we had a number of 1000 TRs in the AOI of this network the level of saturation would be 15.6% (100 x 0.156 = 15.6). But we have to pinpoint that it is a quite different issue if these 1000 TRs were spread in the whole AOI instead of being located in only some of the hundred cells of the AOI causing significant problems of sub-area saturation and SRs blindness. This issue is going to be further investigated and presented in the next chapter 5.

4) Probability of detection at this particular state.

In this particular state of the network we have only five sub-areas of the FSN with ten transmitters TRs in total. That means that the level of saturation and blindness is low as it was showed before. So, the level of the probability of detection might respectively have a high value. In order to estimate this particular value we should first calculate the SRs blindness for each sub-area and then calculate the relative detection probability. In sub-area 44 (counting from left to right and starting from the first line (and) on the left (column)) we have **four transmitters-TRs** and the SR_{BL} is the following:

$$SR_{BL} = R_{SRs} \times 2SR_{ER}/360 * 100\%, \text{ applied for } 90^0 \text{ degrees.}$$

Thus, as the SR_{BL} is calculated for only a sector of 90^0 degrees which is the maximum detection capability in each sub-area of the Fig.4.9 and the topology of the FSN system which appears in Fig.4.19, we have the equation 4.8:

$$SR_{BL} = R_{SRs} \times 2SR_{ER}/90 * 100\% \quad (4.8)$$

where: R_{SRs} is the number transmitters detected for a SR

SR_{ER} is the detection error in degrees.

Thus, as the sector of detection is assumed / estimated at 2^0 degrees and the sensor error SR_{ER} is evaluated as 2^0 degrees and we have four bearing lines, the SR_{BL} by applying equation 4.8 is valued:

$$(4 \times 2 \times 2)/90 * 100 = 17.77$$

then the level of possible detection will be:

$$(90 - 16)/90 = 74/90 = 0.82$$

So the probability for the pre-mentioned SRs is p = 0.82 out of 1, or the probability of detection has a percentage of detection of 82%.

If a SRs detection area is clear then $SR_{BL} = 0$ and the level of possible detection is 1 or 100%. The probability of detection arises after applying equation (3) for this sub-area with 4 SRs. In order to achieve a triangulation there are two possibilities. The first probability is to achieve a TRN with 3 SRs and the second with all the 4 SRs as there are required <u>three or more SRs</u> detection lines for TRN.

Detection Probability 1 - Detection of 3 out of 4 SRs

$$P_1 = p^3 (1-p)^{4-3}$$
$$= p^3(1-p) = p^3 - p^4$$
$$= 0.82^3 \times 0.18$$
$$= 0,1$$

where 0.18 = 1-0.82 and 0.18 out of 1 or 18% is the probability percentage of no detection.

Detection Probability 2 - Detection of 4 out of 4 SRs

$$P_2 = p^4 (1-p)^{4-4}$$
$$= p^4$$
$$= 0.45$$

The sum of these two probabilities (1 and 2) provides the probability of detection for this sub-area Fig.4.19, with four SRs.

$$\Sigma = P_1 + P_2 = p^3 (1-p) + p^4 = p^3 - p^4 + p^4 = p^3 = 0.82^3 = 0.55$$

So, 0.55 is the probability of detection **of at least 3 out of 4** SRs for this particular FSN topology and at this particular state with existing TRs, to detect a transmitter (where the probability of one sensor SR to detect a transmitter is 0.82).

Applying the previous methodology for detection of a TR in sub-areas **with two and one TRs respectively**, we have the values of 0.72 and 0.85 respectively.

The total probability of detection case for a network topology with four SRs in every sub-area of that type provides the previously mentioned equation (4.9).

$$P_T = \frac{\sum_{i=1}^{n} P_i}{n} \qquad (4.9)$$

In this particular type of FSN we have n=100 as there are 100 sub-areas. Five of the sub-areas are already having TRs and the rest 95 of them are without TRs. After calculating the probabilities of detection for each of the FSN sub-areas and adding the sub-areas which are clear from TRs we have the results depicted in Table 4.5:

AOI Sub-Area	TRN Lines	P
1	0	1
2	0	1
3	0	1
.	0	1
.	0	1
.	0	1
34	1	0.85
35	2	0.72
.	0	1
44	4	0.55
.	0	1
.	0	1
55	2	0.72
.	0	1
58	1	0.85
.	0	1
.	0	1
.	0	1
99	0	1
100	0	1
P Network Probability of TR detection		**0.98**

Table 4.5 Detection probability of new TRs in a network sub-area.

So, $P_T = P_1 + P_2 + P_3 + ... + P_{100}/n$

$P_T = 0.98$

That means that the FSN system has a total of 0.98 out of 1 or a percentage of 98% probability to detect a new TR entering its AOI, whilst this probability varies for each of its sub-areas as depicted in the above Table 4.5.

4.6.2 Case Scenario with various sensors probability in a sub-region of the Network

In the above case presented it was assumed that all the SRs in the sub-area have the same probability of detection. But this is not always the case as in some cases the probability might vary from sensor to sensor. In the next scenario (it is presented) a various probability for the sensors of the sub-region is presented.

Case scenario 1

In this case scenario a different value of p will be calculated for the sensors of the sub-area. In the following Fig.4.24 we have a sub-area with four transmitters and four sensors. In this case we see that the area is low saturated as we have a small number of transmitters. The difference in this case is that some sensors due to transmitter alignment have different probability of detection. The sensor with the higher problem is sensor 1 which can detect only two of the four transmitters.

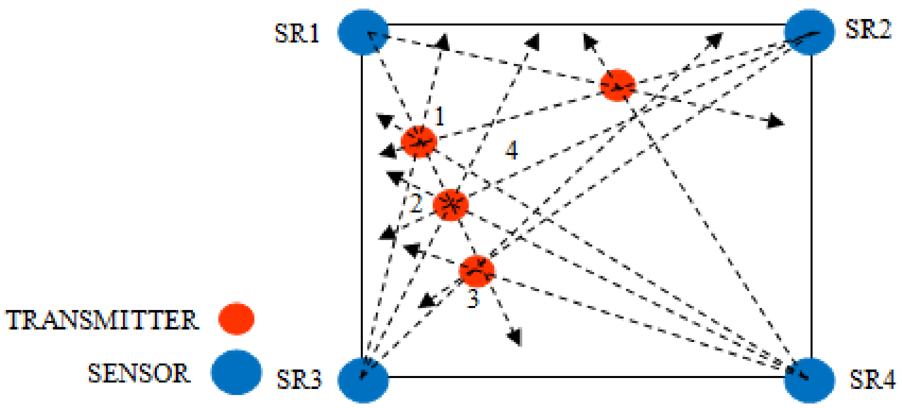

Figure 4.14 A network sub-area with four sensors and eleven transmitters with high level of saturation and a high saturated sub-region.

After applying the equation 4.8 for SR blindness we have the following results:

SR1 has two bearings so

$$(2 \times 2 \times 2)/90 * 100 = 8.88$$

$SR1_{BL} = 8.88\%$

For SR1 the probability of detection is the following:

90-8 = 82/90

So, p1 = 82/90

(Same) Similarly for the rest of the SRs and as SR2 and SR3 have three bearings and SR4 four bearings we have:

SR2 has three bearings so

$$(3 \times 2 \times 2)/90 * 100 = 13.33$$

$SR2_{BL} = 13.33\%$

For SR2 the probability of detection is the following:

90-12 = 78/90

So, p2 = 78/90

As SR3 has the same number of bearings with SR2 we have:

$SR3_{BL}$ = 13.33%

p3 = 78/90

For SR4 which have four bearings we have:

$$(4 \times 2 \times 2)/90 * 100 = 17.77$$

$SR4_{BL}$ = 17.77%

For SR4 the probability of detection is the following:

90-16 = 74/90

So, p4 = 74/90

Case scenario 2

In this case scenario with more transmitters a different value of p will be calculated for the sensors of the sub-area. In the following Fig.4.25 we have a sub-area with eleven transmitters and four sensors. In this case we see that the area is highly saturated. The difference in this case is that some sensors are more saturated than others which means that the probability of detection is different. The sensor with the higher problem is sensor 2 and the second sensor with low detection probability is sensor 3. Assuming that these two sensors are high saturated the probability of detection of a new transmitter in this particular sub-area is low. The four sensors will detect the following sets of TRs:

- SR1 will detect seven TRs (1,3,7,4,9,5,2) - (6,8,10,11)
- SR2 will detect six TRs (3,2,6,7,10,11) - (1,4,5,8,9)
- SR3 will detect eight TRs (2,1,5,6,7,10,8,9) - (3,4,11)
- SR4 will detect five TRs (1,5,9,8,11) - (2,3,4,6,7,10)

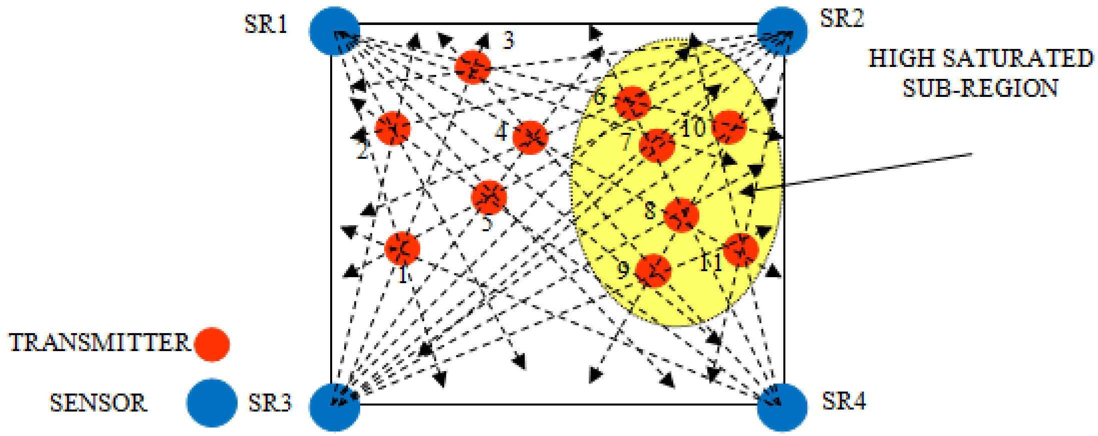

Figure 4.15 A network sub-area with four sensors and eleven transmitters with high level of saturation and a high saturated sub-region

In the sub-area of the above Fig.4.25 we have eleven TRs and the SR_{BL} for the four sensors is the following:

For sensor 1

$$SR1_{BL} = R_{SRs} \times 2SR_{ER}/360 * 100\%, \text{ applied for } 90^0 \text{ degrees.}$$

Thus, as the SR_{BL} is calculated for only a sector of 90^0 degrees which is the maximum detection capability in each sub-area of the Fig.4.22 and the topology of the FSN system which appear in Fig.4.22, we have the equation 4.8:

$$SR_{BL} = R_{SRs} \times 2SR_{ER}/90 * 100\% \quad (4.8)$$

where: R_{SRs} is the number of transmitters detected for a SR

SR_{ER} is the detection error in degrees.

Thus, as the sector of detection is assumed 2^0 degrees and the sensor error SR_{ER} is evaluated as 2^0 degrees and we have to calculate the bearing lines for each sensor and apply the SR_{BL} equation 4.8. So, for this particular case with high level of saturation and due to some transmitters alignment the SRs are having a different level of blindness. We assume that due to transmitters alignment SR1 has only 7 bearings of triangulation (1,3,7,4,9,5,2) and TRs(6,8,10,11) will be missed.

The SR_{BL} for SR1 is the following:

$$SR1_{BL} = (7 \times 2 \times 2)/90 * 100 = 31$$

then the level of possible detection will be:

$$p1= 90-28/90 = 62/90$$

(So the probability for SR1 is p1 = 0.69 out of 1, or the probability of detection has a percentage of detection of 69%.

For SR2 due to transmitters alignment we assume that SR2 will detect six TRs (3,2,6,7,10,11) and TRs(1,4,5,8,9) will be missed.

For that reason SR2 blindness is calculated for 11-5 = 6 triangulations. So, for SR2 blindness we have:

$$SR2_{BL} = (6 \times 2 \times 2)/90 * 100 = 22$$

then the level of possible detection will be:

$$p2 = 90 - 24/90 = 66/90 = 0.73$$

So the probability for SR2 is p2 = 0.73 out of 1, or the probability of detection has a percentage of detection of 73%. The fact here is that although SR2 lies in a high saturated sub-region it seems that it has a high level of detection. Same as previously, for SR3 due to transmitters alignment we assume that SR3 will detect the TRs (2,1,5,6,7,10,8,9) and TRs (3,4,11) will be missed. For that reason SR3 blindness is calculated for 11-3 = 8 triangulations.

So, for SR3 blindness we have:

$$SR3_{BL} = (8 \times 2 \times 2)/90 * 100 = 27$$

then the level of possible detection will be:

$$p3=90 - 32/90 = 58/90 = 0.64$$

So the probability for SR3 is p3 = 0.64 out of 1, or the probability of detection has a percentage of detection of 64%.

Same as before, for SR4 due to transmitters alignment we assume that will detect the TRs (1,5,9,8,11) and TRs (2,3,4,6,7,10) will be missed. For that reason SR4 blindness is calculated for 5 triangulations.

So, for SR4 blindness we have:

$$SR4_{BL} = (5 \text{ x } 2 \text{ x } 2)/90 * 100 = 22$$

then the level of possible detection will be:

$$90 - 20 /90 = 70/90 = 0.77$$

So, the probability for SR4 is p4 = 0.77 out of 1, or the probability of detection has a percentage of detection of 77%. In order to find the probability of detection for this particular sub-area where p varies for different sensors we apply the equation 4.10

$$P = p1*p2*P*p3*...pi \qquad 4.10$$

where P is the total probability of detection for that particular sub-area, where i is the number of sensors of that sub-area.

So, for the previous high saturated case scenario the detection probability of a new transmitter is the following:

$$P = p1*p2*p3*p4 = 0.69*0.73*0.64*0.77$$

$$P = 0.25 \text{ or the percentage of } 25\%.$$

The probability of three SRs to detect a new TRs is the following:

$$P = p1*p2*p3 = 0.69*0.73*0.64= 0.32$$

So for three SRs, SR1,SR2 and SR3 we have: P = 32%

and this value varies depending on which combination of three SRs will participate in the triangulation procedure. Taking into consideration these results, we assume that as the number of transmitters in a sub-region increases then the various detection probability equation 4.10 might be applied which proves the low detection performance. The previous outcome value is obvious as in a high saturated with TRs sub-region the detection probability is lower and new transmitters detection becomes more complicated.

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Chapter 5 Triangulation based Coverage for a range free Sensors Network

5.1. Introduction

In this research it is provided a solution to the problem of localization with the process of triangulation. The process of positioning with triangulation is currently under research regarding a large number of applications. In our case we use various grids of fixed Sensors - SRs in order to detect possible transmitters (TRs) which might enter an area. In the last decade, coverage research issue was a fundamental research issue in WSNs. It was considered to be the measure of QoS for the sensing function of a sensor network [5.1]. The sensors are in fixed and known positions. So, we don’t have to process the SRs positions which still is also an issue of extensive research. The system has to process its state and acquire possible problematic areas of no-coverage, make relevant changes in order to increase the detection performance rate, in case a new TR enters its area of coverage. One of the changes that a network has to execute is to find the optimal radius of detection which will enable it to preserve a high detection rate. That means that from an initial state 1 to a new state 2 etc, the network has to perform a kind of adaptation to the new circumstances and change its parameters. That might also include additional groups of SRs to be used in order to achieve TRs detection with triangulation. We will also show how additional groups of SRs activated close to a problematic area will increase the network performance. We assume that the visualization of changes in the network performance, plays a significant role in order to tackle problematic areas of non coverage.

5.2. Related work

Over the last decade, authors have been thoroughly exploring localization systems and applications of learning algorithms related to localization based on radio frequency and inertial sensors. It was noted that localization issues related to availability, scalability, privacy and security will address new challenges in upcoming 5G communication industry trends [5.2]. Furthermore, as localization and positioning research in WSNs is more and more deepening a wide range of applications, such as target tracking habitat monitoring and intelligent environments require precise positioning of the global coordinate system in order to provide meaningful information and propagate efficiently data over the network [5.3]. Brief reviews on enabling wireless technologies for localization in indoor tracking and positioning systems (IPSs) and localization techniques for WSNs are available in [5.4], [5.5], and [5.6] where (it can be seen) the significance of SRs topology network coverage and their impact on network performance can be seen. Over the past few years, the researchers and engineers' attention was captured by the idea of developing systems for tracking and navigation due to the high consumer penetration of sensor-rich mobile devices and the ubiquity of WSNs systems for localization. These systems span different application domains. So, various systems appeared, from emergency call positioning, such as E911 in the U.S.A. and E112 in EU to customer-centric location-based services, such as mobile advertising, behavioral retail analytics to resource allocation [5.7]. Moreover, a new era of crowd sensing WSNs appears nowadays. This happens as modern mobile devices have higher processing capabilities in combination with a wide availability of sensing modules. Also, and as networks of SRs appear more and more in our daily life in smart homes, smart cars etc, this results in a new type of wide-area WSN-crowd-based communication technologies paving the way to new and innovative applications [5.8]. An extended analysis of coverage problems is provided in [5.9].

Nowadays, as a great number of sensors - SRs forming a network are deployed in an area collecting data, a target'(s)/targets' position is acquired by transmitted data processing. Nevertheless, and as more and more localization systems are developed based on different approaches and techniques of positioning, a localization technique appropriate for an application might be completely inappropriate for another. Meaning that a localization system used, for example, for determining a cars position during its movement might be completely different from an indoor WSN system that deals with interactive tour guidance. Although both systems require localization information the algorithms used and the philosophy of operation of the systems are completely different [5.10].

Additionally, position information is crucial in many other location-based applications. Among them there are the domain of autonomous logistics, search-and-rescue services and security of buildings [5.11]. Currently, localization is an important technique in WSNs and recently a great number of researchers have showed their interest in localization through WSNs recently. Also, indoor localization by using WSNs became a reality by the advancement in electronics in wireless communications [5.12].

Also, localization is used for many other purposes, including surveying, navigation, metrology, astrometry, model rocketry, binocular vision and gun direction of weapons [5.13]. Furthermore, WSNs offer(s) a variety of applications and solutions. In order to achieve network performance optimization a counterbalance between power consumption and area coverage is required. Also, network overage optimization requires nodes topology in such a way that maximum area coverage is achieved with a minimum number of nodes [5.14]. Moreover in current research, more and more researchers seek to solve the problem of localization for various applications and systems, and network coverage is an issue of vital importance. As far as network coverage is concerned it is categorized in three types: Area coverage, target coverage and barrier coverage [5.15-5.22]. Network coverage in WSNs is defined as each point in the ROI is covered by at least one SR, (k ≥1) [5.23].Thus the performance of WSNs is strongly related (with) to the quality of area coverage and many researchers seek for ways to optimize network performance. Also, the type of network topology followed is affecting network performance and has to be examined thoroughly [5.24-5.26]. SRs relocation problem for RSSI-based target localization in WSNs was examined in [5.27]. Problem tackling included various methods and the movement of SRs to relative points of interest in the ROI with satisfactory results. Moreover, the practical use in a great deal of special domains which included the military, environmental, and (the) health sector etc. was examined in [5.28]. The outcome of this examination was that WSNs technology might lead to innovative ways of tackling problems compared with traditional methods previously used. In [5.29] authors presented a sensor-fusion-system for automatically tracking sheep localization and behavior. The proposed system was able to detect sheep standing and resting behaviors and track individual animal's location in the production environment. Yu et al. in [5.30] proposed a method of low-speed impact (LVI) monitoring system. The presented methodology is reducing the average error of positioning proving the effective means of LVI positioning. Target localization appears also in vehicles that might act a SRs with a relative deployment. Another issue that seriously affects (seriously) a WSNs area coverage and network performance is the area coverage holes. A great deal of research nowadays focuses (to) on solving (solve) the problem of coverage holes in the ROI. The performance of WSNs in terms of area coverage is a critical issue that needs extra attention and research. In [5.31] seeking for the maximization of area coverage and k-coverage, a genetic algorithm and a particle swarm optimization algorithm were used. Although the results were promising it was mentioned that there are many other problems that generally obstruct the network operation either directly or indirectly affecting the optimization of performance. For that reason coverage performance optimization should be pursued by taking into consideration energy conservation and SRs connectivity preservation.

In [5.32] the optimal deployment of n vehicles with circular formation for 2D bearings-only multi-target localization is presented. In order to track the assigned target, n mobile vehicles are first distributed randomly in the region of targets, then the vehicles are redeployed and forced to be gathered around the assigned target with circular formation to estimate the target location. An explicit formula of GDOP is used to evaluate the localization accuracy with different sensor-target geometries. Also, an efficient optimal deployment algorithm of vehicles is developed for multi-target localization. Another issue that affects seriously the WSN coverage area and the network performance is the coverage holes. Authors in [5.33] proposed a NLCHR (Neighbor node Location-based Coverage Hole Recovery) that recovers coverage holes by adding mobile SR nodes at an optimal location using a minimum amount of resources in exchange of information with neighbor boundary nodes. The proposed method adds the mobile SR node to the optimal location based on the location of two adjacent hole boundary nodes, and reliably recovers the entire coverage hole through an iterative round. In [5.34], the coverage model of RSSI-based positioning technology was explored, and the RSSI-based positioning was enhanced through the detection and recovery of coverage holes. It is also proposed an algorithm inspired by Voronoi tessellation and Delaunay triangulation to detect and recover coverage holes with very good results. In [5.35] a new game theory approach based on reinforcement learning to recover Coverage Holes in a distributed way is suggested/introduced. For the formulated potential game, SR nodes can recover Coverage Holes using only local acquaintances. Coverage gaps are reduced by combining node reposition and detection range adjustment by each sensor node. Unlike previous methods' simulation results proved that the proposed method can sustain a high network coverage in the presence of random damage events.

In [5.36] all the coverage holes in the network are identified and classified as closed holes or open ones with the CBHD method. With the CBHC method it is demonstrated that a coverage hole can be recovered efficiently by using the minimum number of additional SR nodes and with the minimum coverage area overlap. These holes detection and hole covering methods might be used effectively in any type of ROI to detect coverage holes, demarcate the boundary of network and heal the sensing coverage holes. Also, WSNs are often deployed for event detection and environmental monitoring. However, it is mentioned that their success in providing a high quality of service can only be ensured if the network does not have any sensing coverage holes. And frequently, the existence of sensing coverage holes is unavoidable due to various factors such as environmental disasters, random deployment and hardware failure of the SR node [5.37]. Authors in [5.38] have raised a few research queries which included the automated coverage control which is directly associated with the QoS of WSNs. Hole-clustering and hole-area estimation are also tightly bound up with coverage and connectivity issues. Network coverage optimization is among the key factors in designing efficient algorithms and adequate SR deployment for WSNs. In [5.39] Gupta et al. proposed a meta-heuristic approach on the basis of Genetic Algorithm (GA) to identify the position of the SR nodes to be placed so that all target points are k-covered and nodes are m-connected. The *k* - coverage of the targets, means that each of the target points must be covered by at least *k* SR nodes. In this work (it isn't analyzed) we do not analyze network coverage performance deterioration due to existing targets and/or the issue of blindness.

Moreover, in contemporary literature exists a great variety of different approaches for network coverage holes healing and recovery, holes identification and detection, aiming at diminishing the problem of Hole Coverage. For a hybrid sensor network, a computational geometry based approach was proposed for network hole-detection and boundary identification [5.40]. At first stage, static SRs estimate the size of coverage-hole based on DT construction. Afterwards, mobile SRs are moved to optimal locations to heal the coverage holes and with computational geometry the required number of extra SRs is determined. The problem of network area hole coverage and ways for recovery through the usage of computational geometry is also examined in [5.41]. Significant work on methodologies and applications of algorithms to solve this problem appears at this point. It also appears that it tries to drive attention on computational geometry field suggesting that its inclusion might enhance confrontation of challenges in WSNs. In addition, it is mentioned that SRs detection and communication range, are strongly related to the detection of coverage holes in the network and their recovery. But in all the work previously mentioned, the issue of network whole coverage deterioration due to possible obstacles in the ROI and SRs detection problems that might arise from a number of existing TRs is not actually included.

5.3. Problem Statement

Nowadays, there is a wide variety of applications and systems which seek for accurate localization. At the same time, a network with a low rate of coverage and a high number of coverage holes, certainly won't operate normally. In [5.42] Li Q. et al., by designing a reasonable scheme of moving nodes, applied an algorithm which gradually disperses the SRs nodes and improves the coverage effect in the monitoring area. The algorithm used performed well, reducing the moving distance of nodes resulting in overall network coverage improvement. But, although the results are promising, this work doesn't include the coverage decrease effect of existing TRs in the AOI. As it was shown in [5.6], network performance and coverage is strictly affected by possible obstacles (TRs) around the SRs of the network. Also, in several existing networks a SRs detecting range has a fixed value. A degradation in QoS is translated in less monitoring and tracking capability by the network of SRs. Thus, for a sufficient level of surveillance each network point should be monitored by a minimum number of k sensors. The value of k is a parameter representing the quantity of SRs which are required for a satisfactory level of coverage. A number of k bigger than one might result in higher QoS [5.8]. So, in our case and for the procedure of triangulation where a coverage of at least three SRs is needed ($k \geq 3$), the issue of detection of TRs within a saturated network is a far more complicated issue. Our case of coverage problem can be described as follows: In a two dimensional area A of a certain size we have a set of SRs Si = SR_1, SR_2, . . . , SRn. The size of A might vary as the number of SRs that are used in Si varies as well. Each SR of Si, SRi where i= 1,2,. . . ,n is located at coordinates (xi , yi) inside A and has a sensing range of radius R. The SRs of Si have fixed positions, are placed on a grid and monitored around in a range R. In area A a number of TRs also exists which is a set Tm = TR_1, TR_2, . . . , TR_k.. Each SR of the grid in A is detecting none or some TRs, but the monitoring area of each SR is blocked by existing TRs and this issue is analyzed further. The network has to find the optimal radius Ropt to apply on the Sensors Network - FSN, in order to achieve best coverage. Another option that might be used is to activate additional network SRs in order to achieve coverage of at least 3 or more SRs in each sub-region of the network.

So, the basic hypotheses that are taken for granted in advance for the network and characterize the way the network acts as an operating system, are the following:

Hypothesis 1. All network SRs of the network have fixed positions.

Hypothesis 2. Each network SR has a 360 degrees field of view and is assumed to detect a TR with

a bearing of θ with detection error D_{ER} ,of plus-minus *δ* degrees.

Hypothesis 3. All the SRs have the same Radius R.

Hypothesis 4. The positions of existing TRs are known. In order to approach this problem and make it more easily understood we give the following definitions:

Definition 1. A location in A is said to be covered by a SRi if it is within the SRi's detection radius R.

Point A is said to be k-covered if it is within at least k SRs detection radius.

Definition 2. A sub-region Bk in A is a set of points which form a sub-area of A and is covered by at least k SRs.

Definition 3. A point in any position of the area A can be monitored and a TR can be tracked if it is placed at that particular point, if and only if, Definition 1 and 2 are true and that point is not blocked by TRs around it. (A SRi isn't able to detect a TRj beyond a TRi that is detected at a certain bearing θ_i and by that way it is blocked in that particular bearing θ_i .

5.4. Network model

During various tests, the basic parameter used was the SR bearing (the bearing by which a SR detects a TR), which is considered to have a **detection error** D_{ER} . We assume that each SR has a certain type of D_{ER} . For example, if a SR reports detection of a TR at bearing 340^0 and the D_{ER} is 3 degrees then the network will use the sector 337^0-343^0 degrees. Thus it will perform data processing taking into account that particular sector. The same applies for each bearing of each SR of the FSN. Another parameter of interest is the detection radius R for each SR. Analyses have been carried out with all SRs having the same value of R, as mentioned in the third Hypothesis. Then, as the network adapts itself to a new state it applies the same optimal Radius, Ropt for each SR. Let us consider, for example, two different scenarios, namely scenario 1 and scenario 2: State 1 *Si* = $SR_1, SR_2, \ldots, SRn,$ same radius R. scenario 2 *Si(opt)* = $SR_1, SR_2, \ldots, SRn(opt)$, same radius Ropt. After applying the Ropt the network achieves higher detection levels.

5.4.1. Network Grid topology

There are many grids used for tests in this research. Among them the most commonly used were, the grid of size 1000 x 1000 units and a grid of 400 x 400 units. . The first grid includes 121 SRs and various sets of TRs. As shown in Fig.5.1, 80 TRs imply few areas not covered (in blue). In Fig.5.2 the number of TRs is increased to 120, and we can clearly see that the size of the problematic (no coverage) areas increased, especially in areas which TRs are closer to each other and denser. In an area of size 400x400 units we have a grid of 25 SRs and 50 TRs. The grid of 25 SRs is adequate for testing as the increasing number of the SRs is overloading the system causing delays and this is inappropriate for our research. In Fig.5.2, the non coverage areas are shown in blue, while the areas with coverage of three or more SRs are in brown. The SRs are depicted as large stars, whilst the TRs as small stars as shown on Fig. 5.17. By adding a number of extra SRs, we see that the blue (non coverage) area has been significantly reduced in Fig.5.4 compared to Fig.5.3. In this case the network has become able to detect new TRs. These extra SRs have been added in the areas that needed detection support and extra processing. These SRs are positioned in areas close to dense TRs as their detection beam should not be wide, in order to detect the inside of those problematic areas. Those SRs groups are inside the areas in yellow. Each extra SR which is assumed as a member of the network, transmits the required data to the system and central processing begins. With the extra SRs the system is increasing the detection rate thus enhancing performance. It is vital for the network to change its parameters in order to become able to detect new TRs that might enter its area of responsibility.

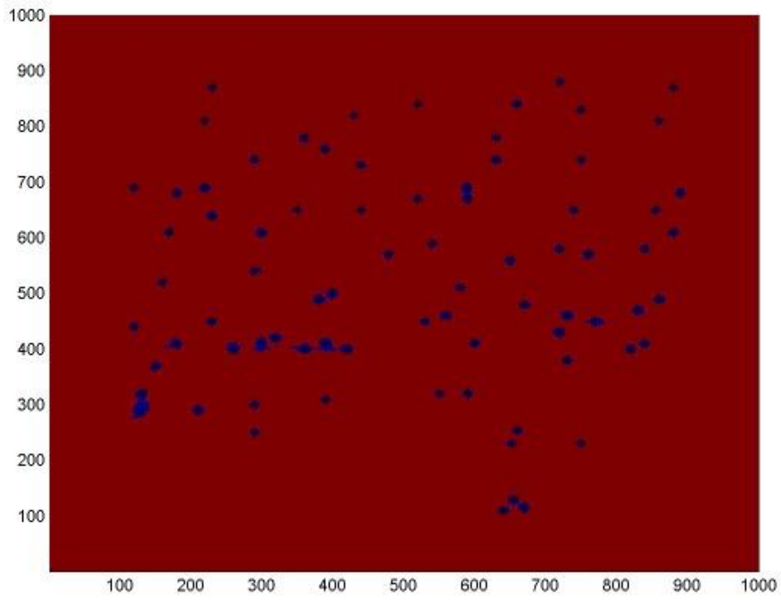

Figure 5.1 Coverage with 121 SRs and 80 TRs, no coverage (coverage is less than 3 SRs K<3) is indicated in blue and TRs are shown with small stars

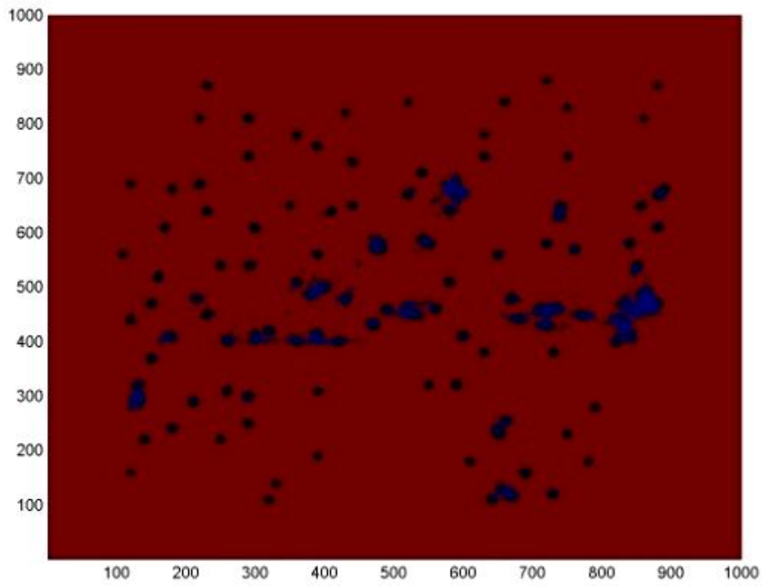

Figure 5.2 Coverage with 121 SRs and 120 TRs (same as previous figure 5.1, no coverage is indicated in blue and TRs are shown with small stars)

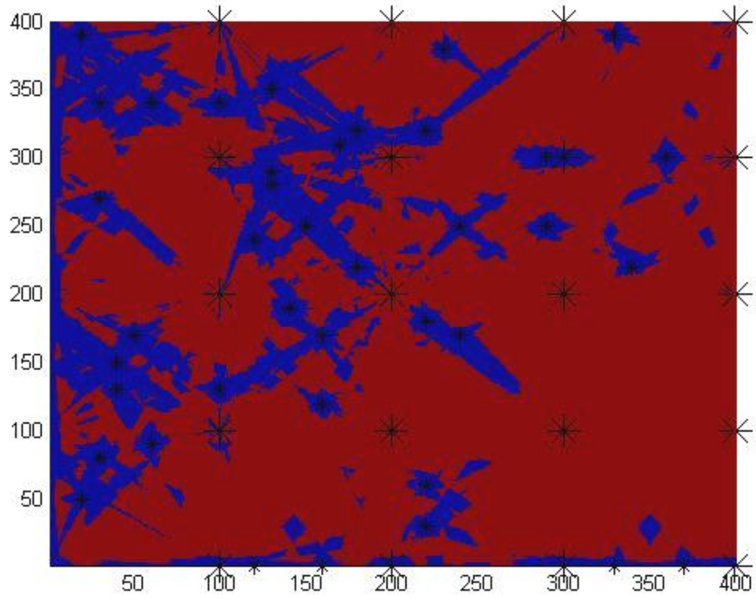

Figure 5.3 Coverage with 25 SRs and 50 TRs (same as previous figure 5.1, no coverage is indicated in blue) SRs are depicted as big stars and TRs as small stars

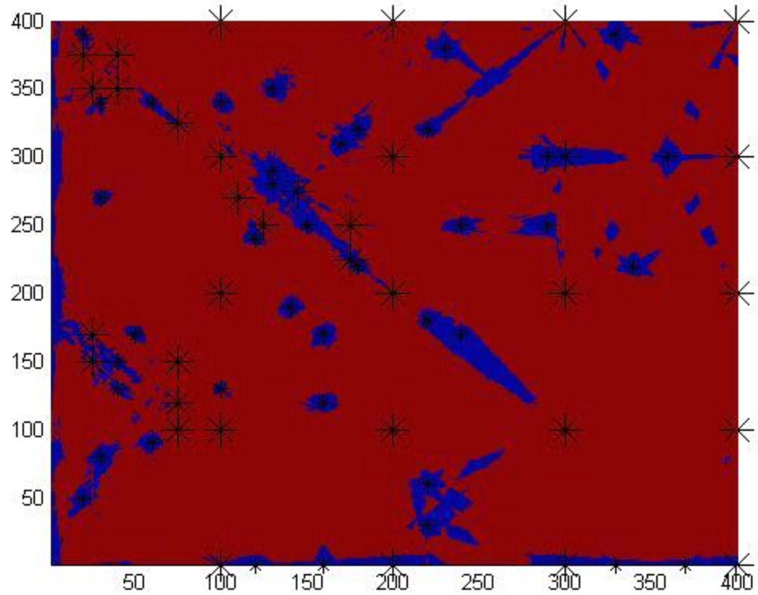

Figure 5.4 Coverage with 40 SRs (25 + 15 SRs Cluster) and 50 TRs (same as previous figure 5.1, no coverage is indicated in blue) SRs are depicted as big stars and TRs as small stars

5.4.2 Network Sensors Blindness

SRs view is affected by the number of TRs around it. We will show how SRs blindness has also a significant impact on network detection, leading to network blindness resulting in network coverage performance decrease [6]. A quantification analysis is also presented. We have visualized the gaps in area of coverage that need to be tackled by the network. The software used for the simulations was MatLab version 77 2016b. Knowing the status of the network in advance we were able to apply changes in order to increase its performance. We additionally note that the visualization of coverage gaps is the first step towards the handling of coverage issues. By applying the correct modifications on the FSN and by adding appropriate groups of SRs, any coverage problems are solved thus keeping the FSN performance in high levels. In the following we also show that a problematic area can be covered by other nearby SRs, by increasing their detection radius or by activating groups of SRs that are located close to this problematic area.

5.5. Experiments and discussion

As it was shown in Fig.5.4, additional SRs can increase the network performance. The combination of adding extra SRs and changing the detection range R is a method that can provide better coverage. This method, however, presupposes that the optimal detection radius R is already known. In order to identify the optimal detection radius, the FSN gradually increases the R, finally finding the R that provides optimal detection for the whole network. In Fig.5.5 we can see the value of optimal R which, in this particular case, is found to be 150 m. The system calculates the level of network coverage by changing gradually the value of R. The value of R that gives the best coverage is the optimal R. Processing all these combinations of data requires exhaustive computation. Meaning that the FSN system has to combine each value of SR Radius R applied to each SR, with the resulting Network coverage.

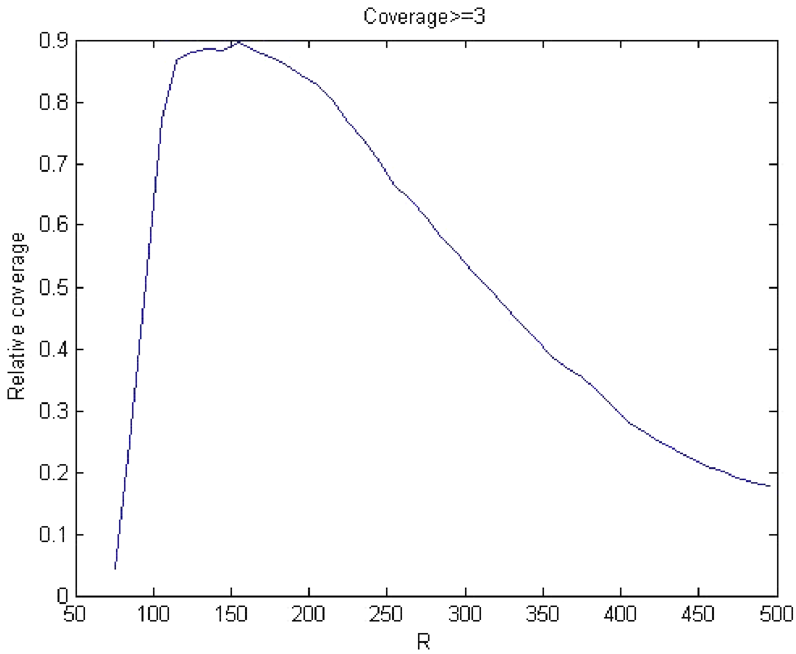

Figure 5.5 Radius vs Coverage Curve with 25 SRs

The results produced are forming the figures with curves where we can see the optimal Radius R_{opt}. In y-axis we can see the relative percentage of area coverage in normalized scale 0-1. This optimal value of R is then applied to the FSN and better coverage is achieved. The extra SRs which were activated by the FSN had not been included in the beginning of data processing. These extra SRs are only activated in case extra processing is needed in order to fill gaps in the FSN. Here the network can apply certain algorithms of SRs clusters activation or even add new SRs around an area. This means that the network is then working as a FSN with additional SRs. The new FSN is having a form similar to what shown in Fig.5.6 (some groups of the 15 SRs are shown). By applying a different test in a grid with 25 SRs and 50 TRs and after adding a group of 15 SRs we can see the difference in coverage performance in Fig.5.7. We can see

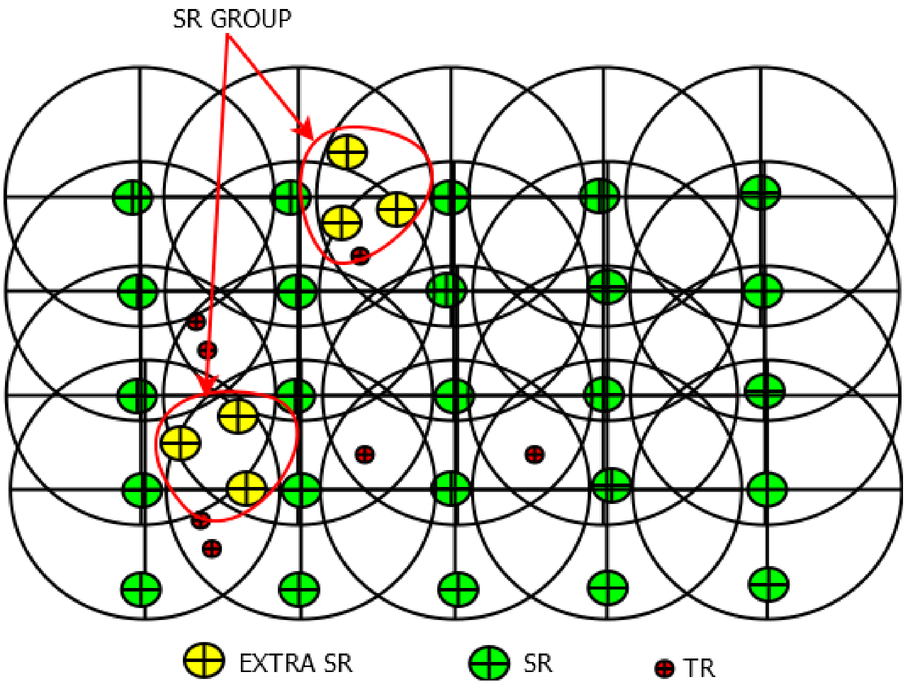

Figure 5.6 25 Sensors Grid with Extra Sensors

that the performance of the network is reached almost hundred percent when we applied the optimal radius. The visualization of the network status allows us to see clearly the areas of non coverage. Then by adding extra groups of SRs and applying the optimal Radius we can further increase performance. In Fig. 5.8 we see how the Radius vs Coverage Curve for 25 SRS and 100 TRs and 25 SRs and 100 TRs with extra SRs is lowered due to the increased number of TRs, from 50 to 100 TRs. In Fig.5.9 we can see a grid of 25 SRs, including a number of TRs in the area. The SRs can increase the radius of detection R in order to increase performance. As we can see in Fig.5.10, in this case each SR has a larger coverage area. This way the network will cover probable problematic areas while, at the same time, a sub-area of the FSN will be covered by more SRs, thus increasing its detection capability.

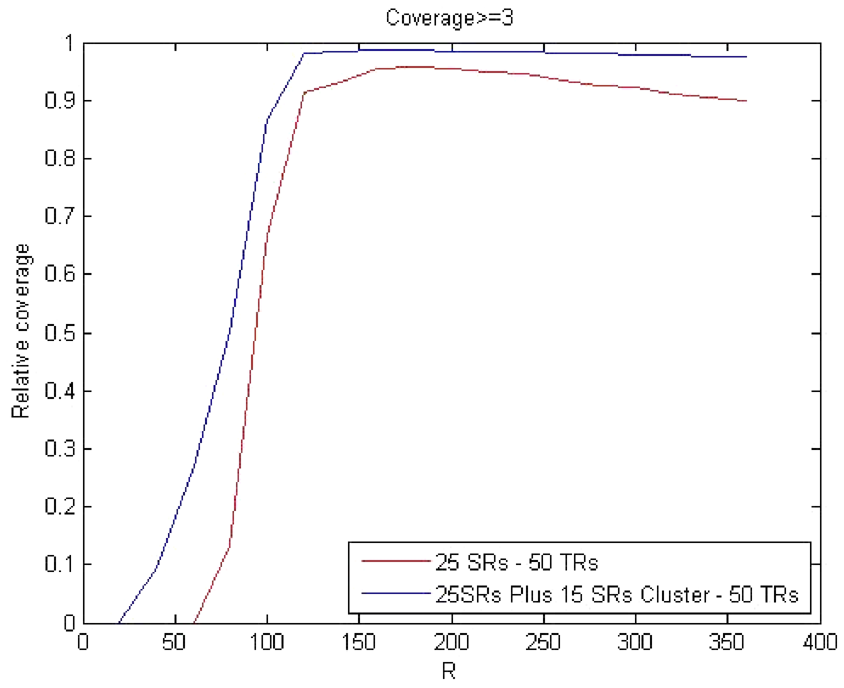

Figure 5.7 Radius vs Coverage Curve for 25 SRS and 50 TRs and 25 SRs and 50 TRs with extra SRs

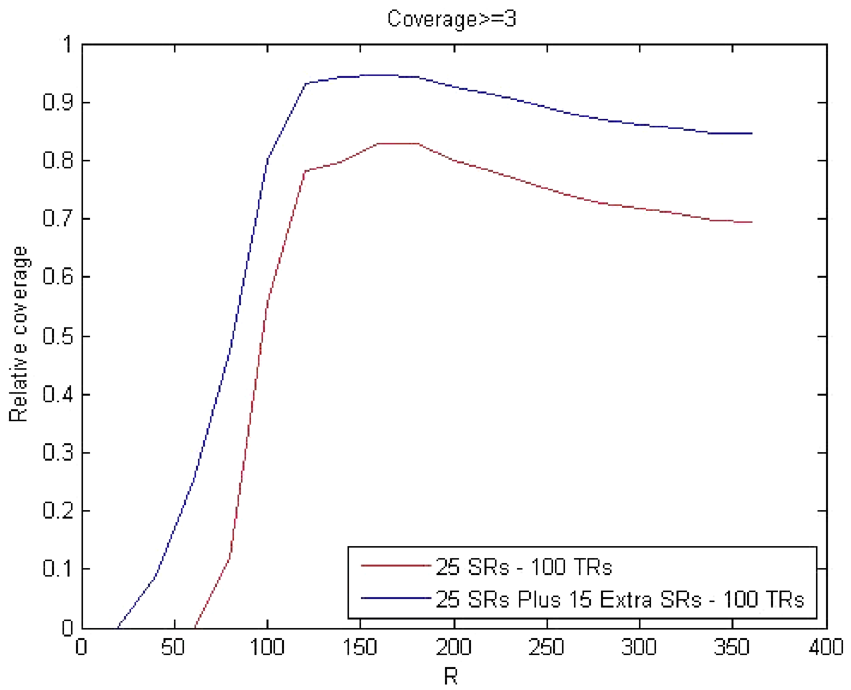

Figure 5.8 Radius vs Coverage Curve for 25 SRS and 100 TRs and 25 SRs and 100 TRs with extra SRs

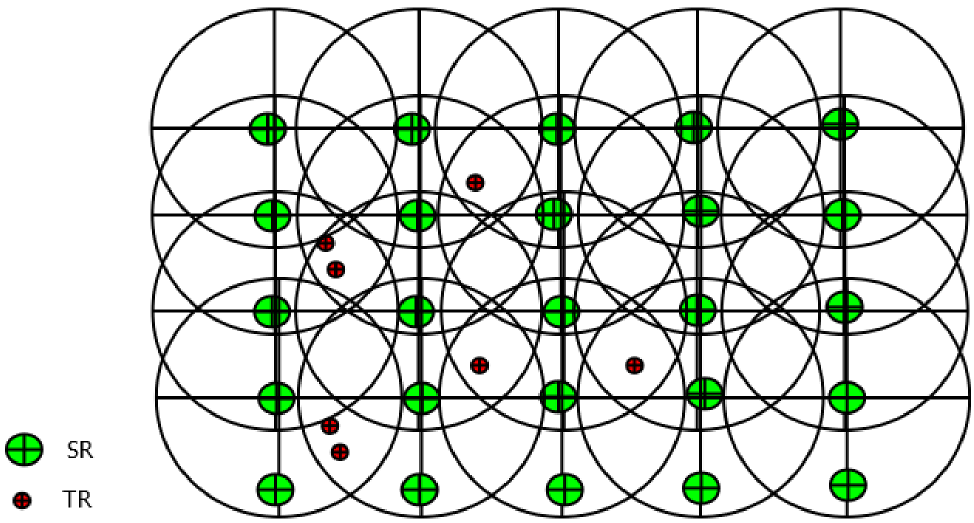

Figure 5.9 25 Sensors Grid visualization example with and 7 TRs and radius R1

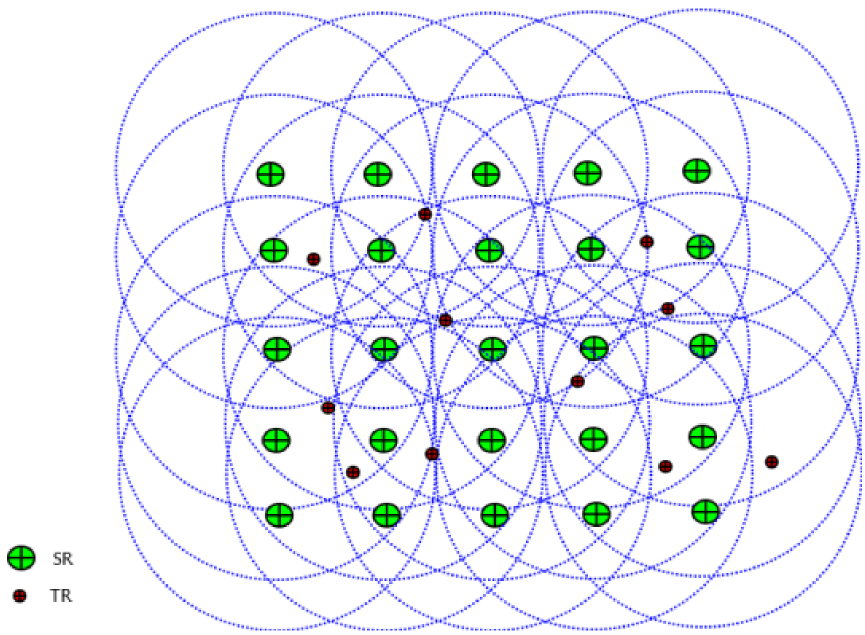

Figure 5.10 25 Sensors Grid visualization example with increased R (R2=2*R1) and more TRs

5.5.1. Network Detection Performance

Network detection is affected by a number of factors that might alter its accuracy and its performance. As the network has to operate as a system, the user has to be aware for any possible changes well in advance. As it was shown before, as the number of

TRs is increased in the area, the system has to apply changes in order to keep a high detection rate. In Fig.11 we have a network grid of 25 SRs. We will show how detection performance is lowered due to TRs blockage in the area. In Fig.12, we have a network grid of 25 SRs and 12 TRs. Here, we can see the sectors of detection beams assuming that we have an error of plus-minus 2 degrees. As we see in Fig.12, SRs 1, 2, 3, 4, 6, 7, 8, 9 . . . , 11 till 14 and 16 are having beams detecting TRs.

A way to assess the network performance is detection rate (*NDrate)* index is presented in [5] and it is presented in Appendix B. The existing bearings and the existing triangulations, ETRNs are the basic parameters that affect the detection rate index.

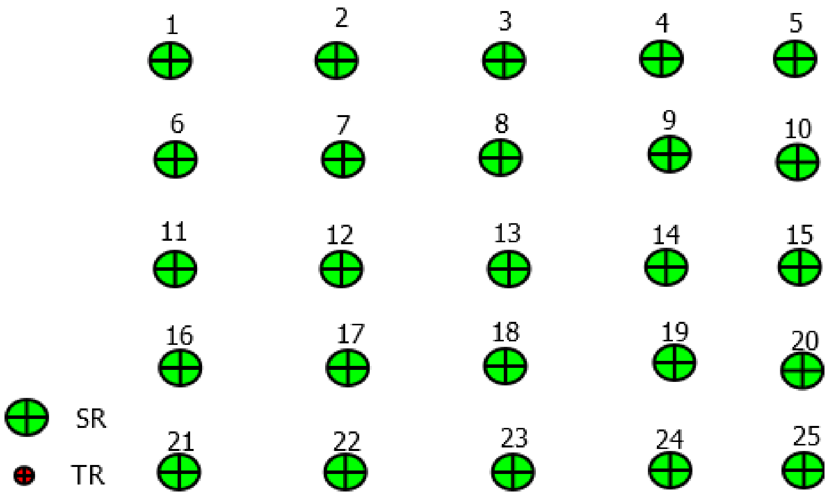

Figure 5.11 25 Sensors Grid

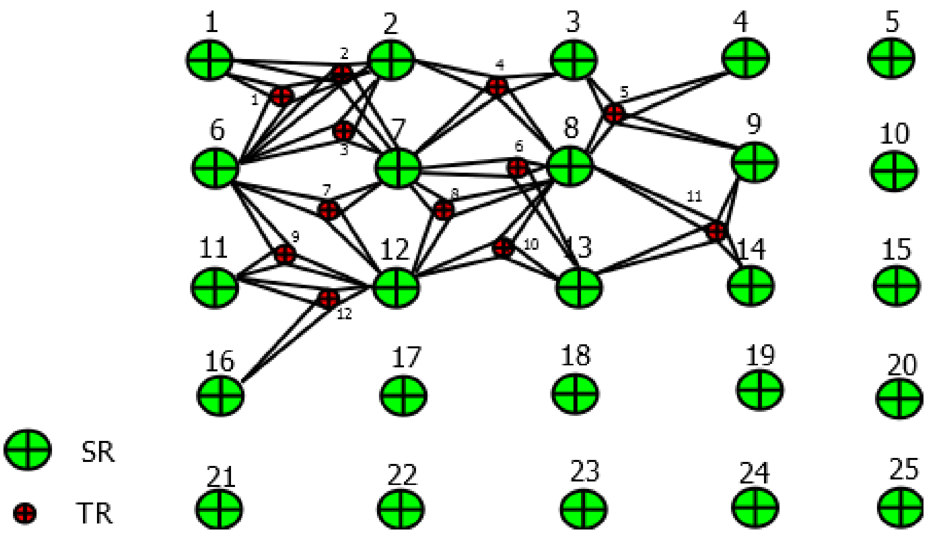

Figure 5.12 25 Sensors Grid with TRs and plus-minus beam detection error

Another parameter is the Network blindness NBL, which is given by equation 5.2 and it is defined as the sum of blindness of each SR divided by the number of SRs, and was presented in [6].

$$N_{BL} = (B1 + B2 + B3 + ... + B_n)/ n \qquad (5.2)$$

where $B_1 + B_2 + B_3 + … + B_n$ is the sum of blindness of each SR and

where n is the number of SRs with bearings.

Another significant parameter is the number of the existing triangulations ETRN in the network.
In this case we have:

$$ETRNs = 12,$$

so the number of existing triangulations ETRNs is 12.

Blindness for each SR was defined in [6] and appear in the following equation (5.3).

$$SR_{BL} = R_{SRs} \times 2 * SR_{ER} /360 * 100\% \qquad (5.3)$$

Where R_{SRs} is the number of radials per SR and SR_{ER} is the common bearing error for each SR of the network. The number 360^0 is related to the 360^0 degrees coverage for a SR. With formula 5.3 we define each SR's blindness as a percentage. We assume that our network has a network error of plus-minus 2^0 degrees. We have a grid of 25SRs, but not all of them will detect TRs. The SRs that have bearings sectors are:

$SR_1, . . . , SR_2, SR_6, . . . , SR_9, SR_{11}, . . . , SR_{14}$ *and* SR_{16}, a total of 13 SRs. Hence, n = 13.
The FSN system has to calculate overall blindness using data from all sensors. After applying the formula (5.3) for each SR we can find the network blindness

$$NB_{BL} = (B_1 + B_2 + B_3 + B_4 + B_6 + B_7 + B_8 + B_9 + B_{11} + ...B_{12} + B_{13} + B_{14} \ ... + B_{16})/n,$$

$$NB_{BL} = 39.96/13 = 3.07$$

In this case SR_{DF} will also be increased. In Fig.13 we have added 2 more TRs resulting in 14 TRs. Here, we can see the sectors of detection beams assuming that we have an error of plus-minus 2 degrees. Since these two TRs are blocked by other TRs, we need to detect them using other SRs of the grid. SRs 1,6,7 are blocked by other TRs while there is a low probability that SR_2 will detect TR_{13}.The same problem appears to happen on TR_{14} where SRs 7 and 13 are blocked. In this case the network has to change its parameters and apply different radius for some SRs of the network. Otherwise we won't be able to apply the triangulation procedure and detect them.

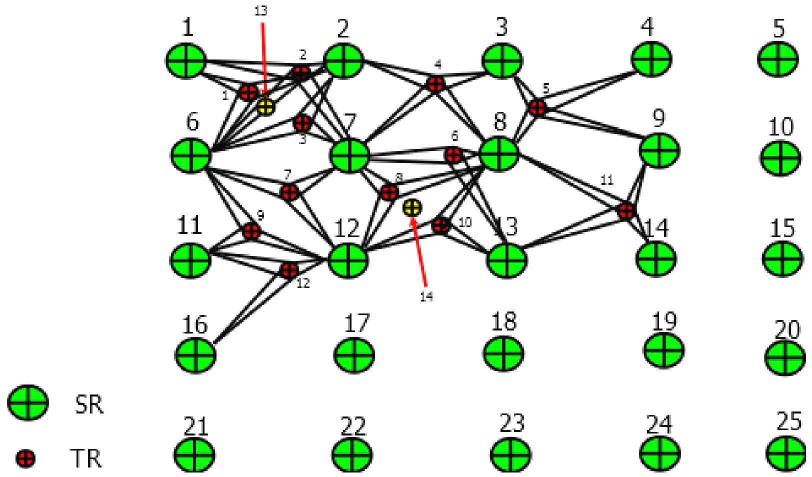

Figure 5.13 25 Sensors Grid with TRs detection beams and extra TRs

5.5.2. Network performance with Bearing detection error

As previously mentioned, one of the fundamental characteristics that affect the network detection performance is the error in bearing detection. In Fig.5.14, a and b, we have four different curves of bearing errors at 2, 4, 6 and 8^0 degrees. The Fig.5.14 resulted from a grid of 25SRs and 10TRs, whilst Fig.5.15 resulted from a grid of 25SRs and 30TRs and Fig.5.16 resulted from a grid of 25SRs and 50TRs So, we draw the conclusion that, as the beam error is gradually increased, the coverage is reduced. In addition, by adding a number of extra TRs, (10 to 50) we see that the quality of coverage is significantly reduced.

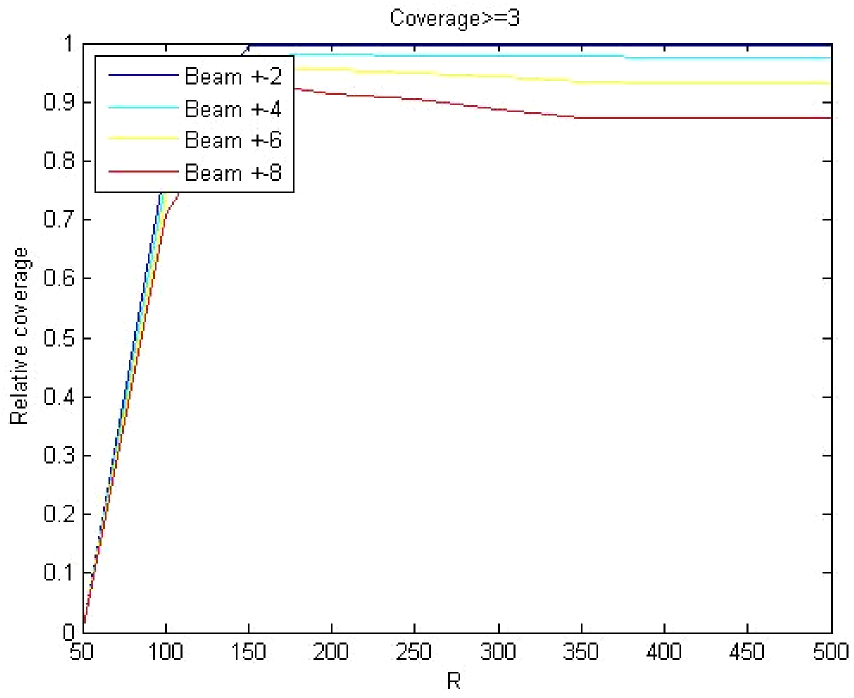

Figure 5. 14 Coverage Curves with different beam errors with 25 SRs and 10 TRs

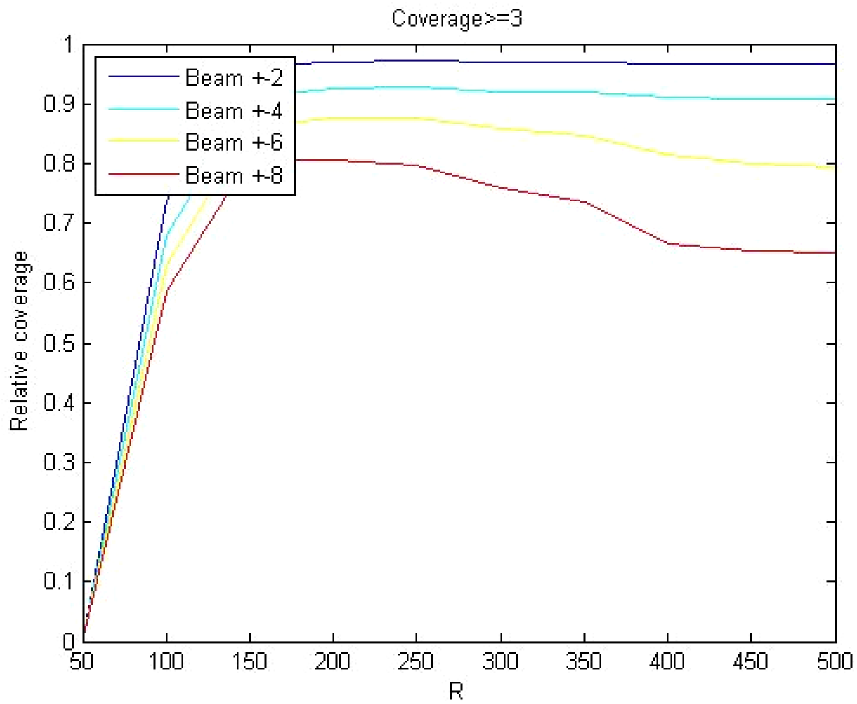

Figure 5.15 Coverage Curves with different beam errors with 25 SRs and 30 TRs

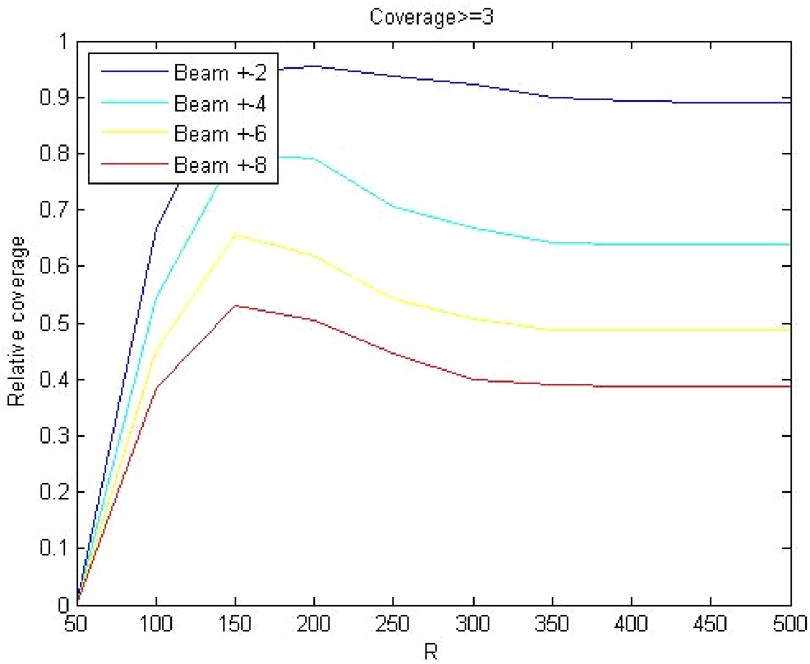

Figure 5.16 Coverage Curves with different beam errors with 25 SRs and 50 TRs

Also, the size of no coverage areas is gradually increased as the beam error is increased as well. In Fig.5.17 - Fig.5.20, we see this gradual change when we change from 2^0 to 4^0, 6^0 and finally 8^0 degrees. It is obvious that the FSN is becoming blind and detection becomes impossible in its interior, when beam error is high as shown in Fig.5.19. With this visualization tool we can easily control the effect of beam error in the network and its coverage performance. Mostly, beam error of maximum 4^0 degrees is used for the processing of data as a great amount of error is also affecting the triangulations resulting in a high number of false triangulations, an additional problem which has to be dealt with. This phenomenon was presented and analyzed previously in chapter 3 paragraph 3.8.2 and Fig.3.24.

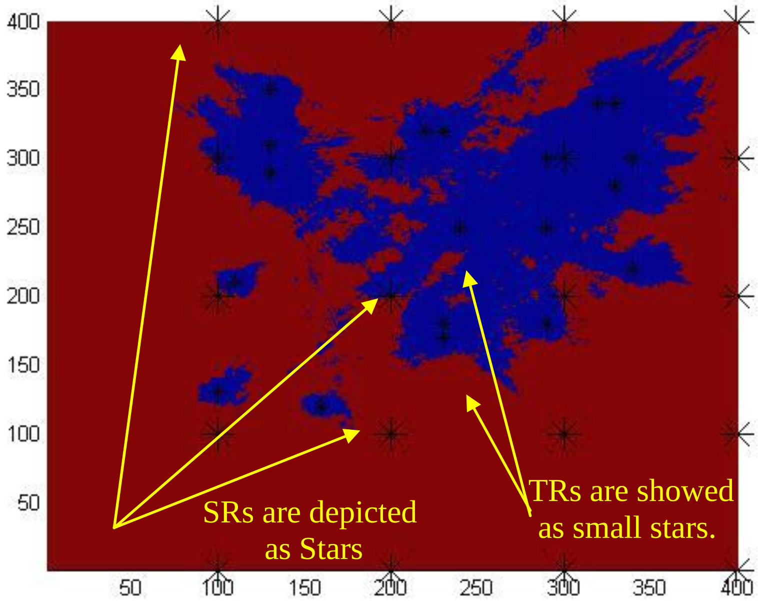

Figure 5.17 Coverage with beam error of 2^0 degrees (no coverage is indicated in blue)

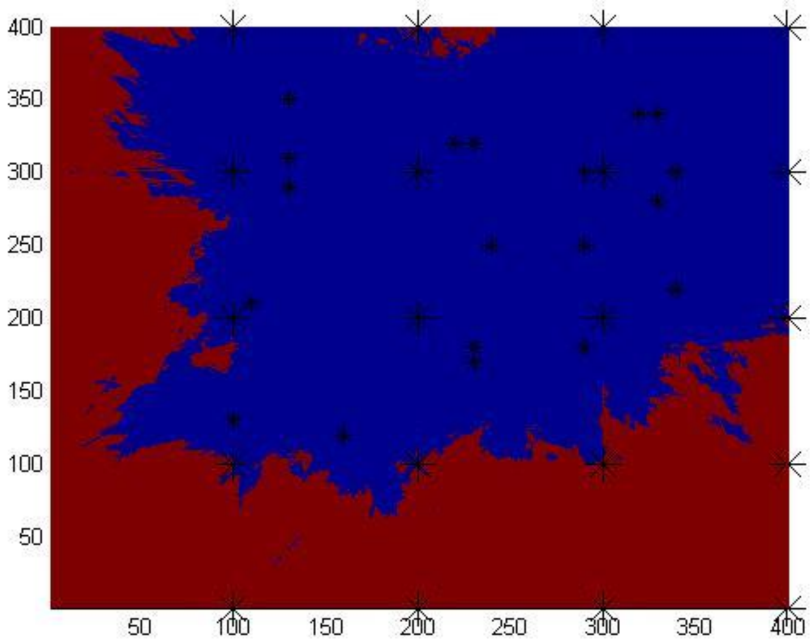

Figure 5.18 Coverage with beam error of 4^0 degrees (no coverage is indicated in blue)

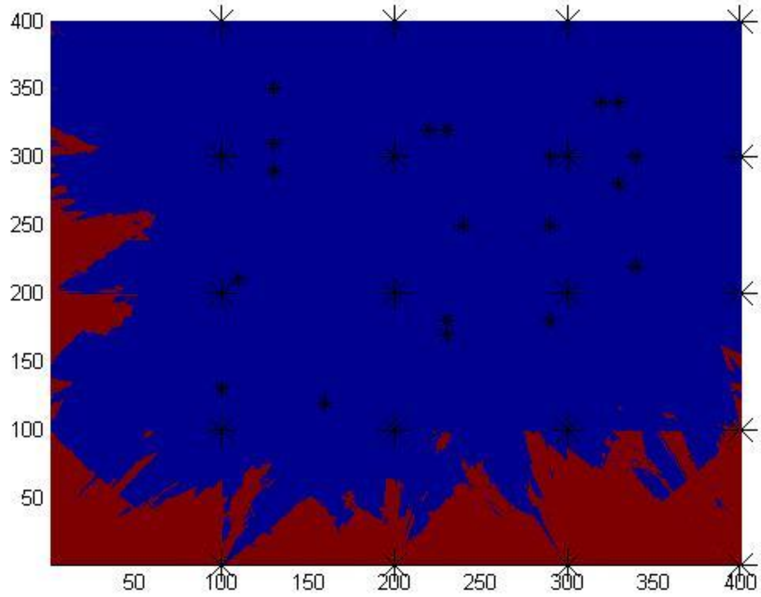

Figure 5.19 Coverage with beam error of 6^0 degrees (no coverage is indicated in blue)

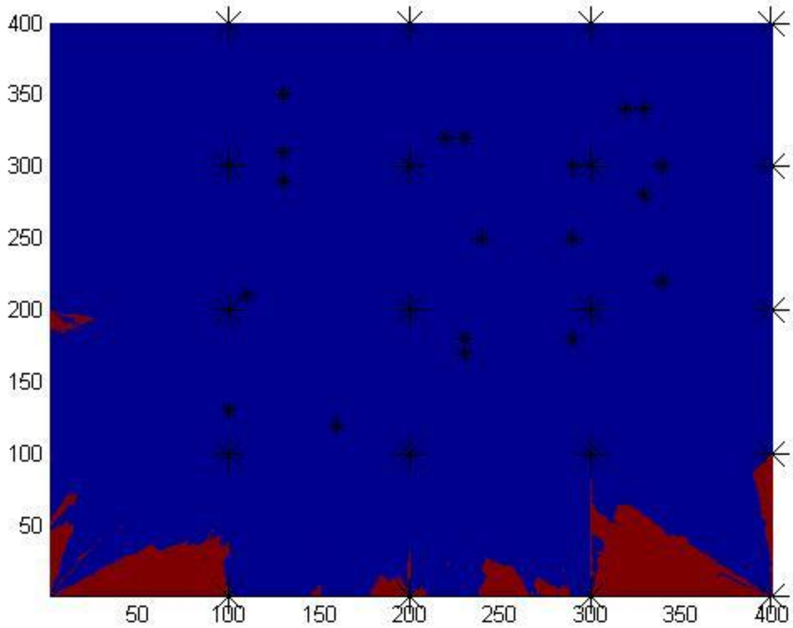

Figure 5.20 Coverage with beam error of 8^0 degrees (no coverage is indicated in blue) degrees (no coverage is indicated in blue)

Also, and as we can see in Fig.5.21 where the coverage-Radius curve of 8^0 degrees error is shown, we see that we have a sharp decrease when the Radius is increased beyond 130 units. That means that the network becomes almost blind beyond that limit of R. This information is significant as we can apply the required changes to the system, enabling us to keep its performance high. In this case as it was mentioned earlier, we use the same radius R for each SR. In the next section there is a number of tests which were executed in order to present the network changes with varying topologies and different SRs number combined with varying radius of three values.

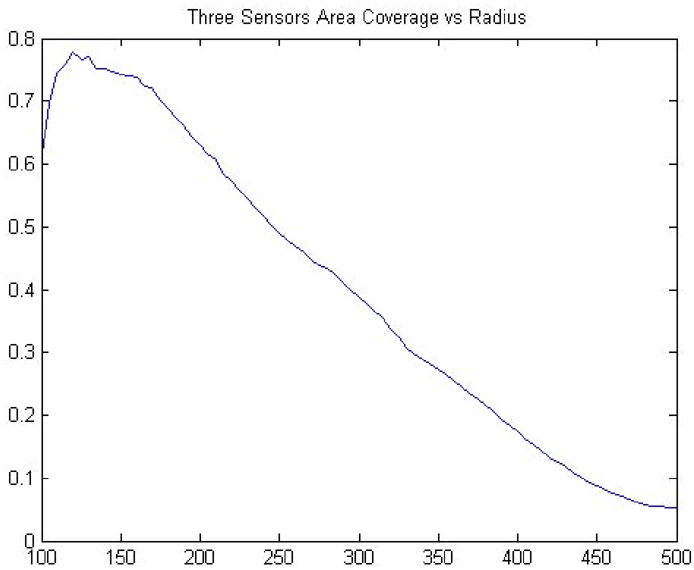

Figure 5.21 Radius vs Coverage plot with 25 SRs, 50 TRs and 8^0 degrees beam error

5.5.3. Network performance with different sensor radius R.

In Fig.5.22, we can see coverage with different fixed radiuses (Small - S, Medium M and Large L) modes in a grid with 25 SRs. Here, with different tests we will show how network coverage is affected when all the SRs have a fixed radius R with increasing number of TRs in the area. We will apply this mode in a network grid with 6 SRs, as in Fig.5.23 after adding 10, 20, 30 TRs. We use for radius R a values range of 450 units and then we split the 450 units radius range into three values of Small-Medium-Large S-M-L, where Small S = 150 units, Medium M = 300 units and Large L = 450 units.

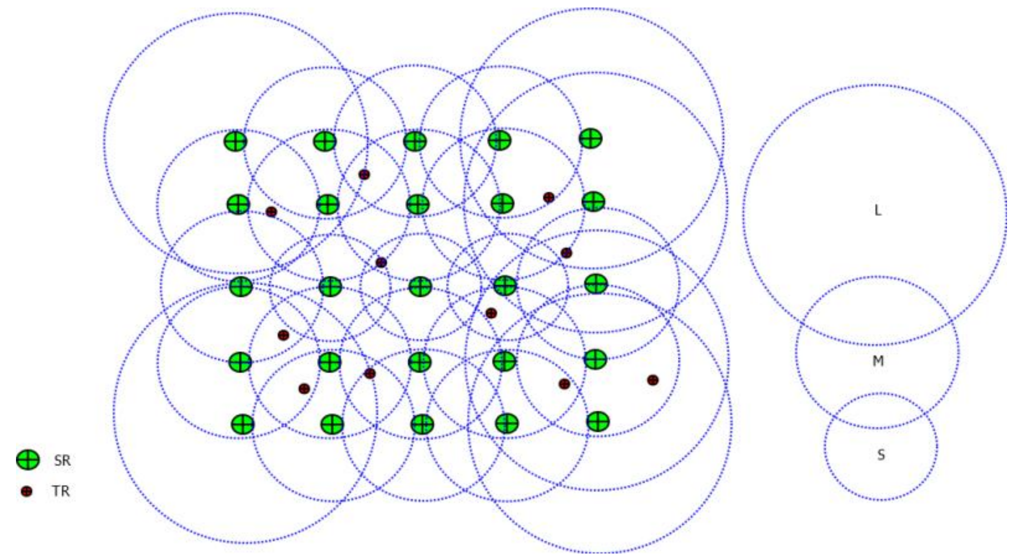

Figure 5.22 25 Sensors Grid with S-M-L Radius mode

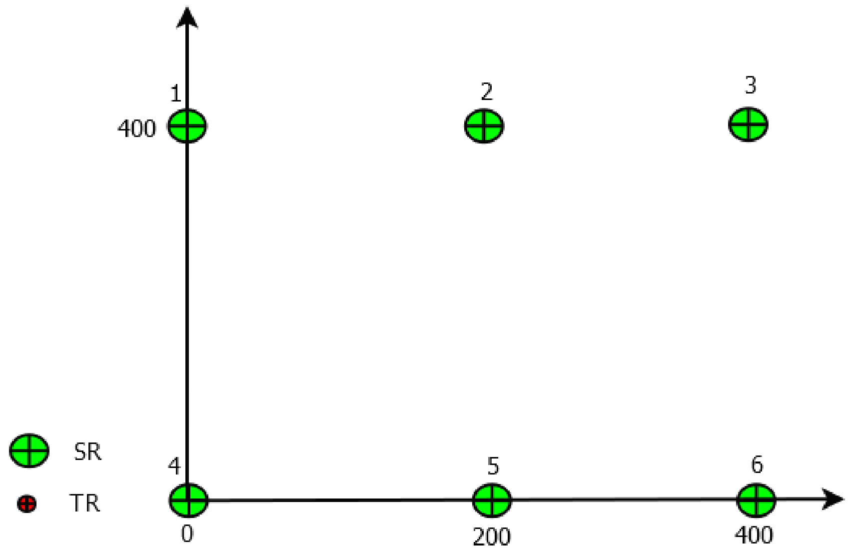

Figure 5.23 6 Sensors Grid with S-M-L Radius mode

The following Table 5.1 is depicting the results with 10 TRs where the optimal combination gives a coverage of 85.5%.

TEST 1			
Radius Combination	S S S S S S	M M M M M M	L L L L L L
Relative Coverage(>=3)	0.239200	0.700519	0.855656
Number of SRs	6		
Number of TRs	10		
Optimal Relative Coverage >=3			0.855656

Table 5.1 Test results 6 SRs and 10 TRs

Fig.5.24 shows the network coverage with radius R, Large - L which provides the optimal value of 0.855656 of coverage for the network.

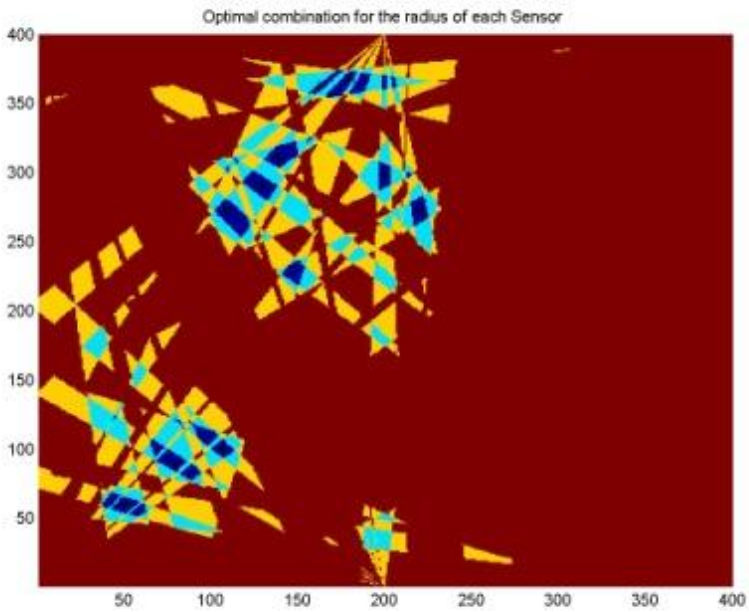

Figure 5. 24 Coverage with 6 Sensors 10 TRs, S-M-L Radius mode Dark blue Zero: coverage, Light blue: Coverage with one SR, Yellow: Coverage with two SRs, Red: Coverage with three or more SRs.

After increasing the number of TRs to 30 we had the results depicted in Table 5.2.

TEST 3			
Radius Combination	S S S S S S	M M M M M M	L L L L L L
Relative Coverage(>=3)	0.127200	0.317294	0.470994
Number of SRs	6		
Number of TRs	30		
Optimal Relative Coverage >=3			0.470994

Table 5.2 Test results 6 SRs and 30 TRs

Fig.5.25 shows the network coverage with radius R, in L mode. We see clearly that the area of 3 SRs coverage with 20 TRs is reduced significantly compared to Fig.5.24.

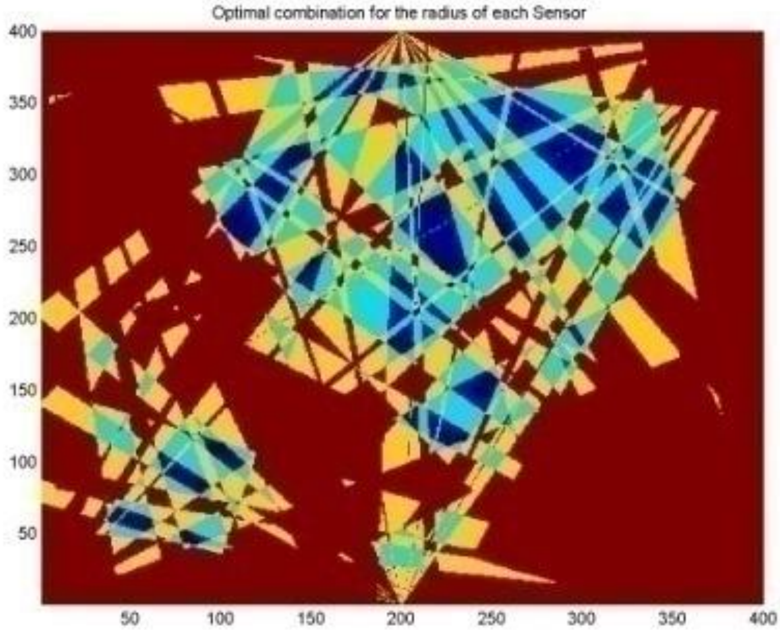

Figure 5. 25 Coverage with 6 Sensors- Grid - 20 TRs, S-M-L in L mode Radius mode - Colors definition same as previous figures.

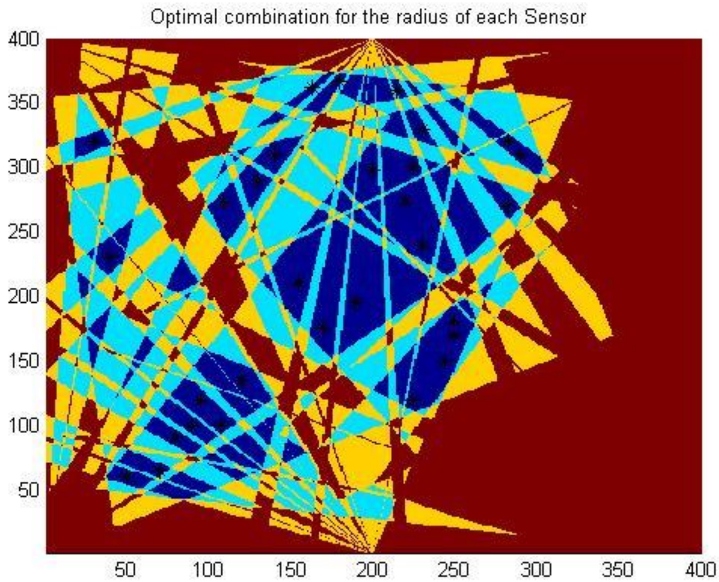

Figure 5.26 Coverage with 6 Sensors - Grid - 30 TRs, S-M-L and L mode Radius mode - Colors definition same as previous figures.

In Fig.5.26 we have the visualization of network coverage with these parameters in L mode and we see that the covered area is reduced significantly in blue with 30 TRs and more SRs are needed in order to tackle the network saturation and the non coverage problem that arises.

5.5.4. Network performance with three sensor detection radiuses (Small(S), Medium(M), Large(L))

As every change in R is affecting each SRs coverage resulting in network coverage change, we should note that a fixed radius R, might not be the best option, when optimal coverage is to be achieved. For that reason we decided to examine and test the option of a mode for detection with each sensor having one of three fixed radiuses, resulting in different radiuses at the same time (S-M-L).That way the Hypothesis 3, “All the SRs have the same Radius R” is changed to “Each SR of the system might have a varying radius R, S-M-L”.

Here, after executing some tests we will show that a different combination of SRs radius R gives us the best coverage. In the previous tests from one to three we saw that the system has the optimal coverage when increasing the radius of the SRs and the system applies large L radius for the whole network. In this case we will show that the system might use a varying radius R applied on each SR and this combination is the optimal key for the network. The varying radius R for each SR can take three values S-M-L. In these tests, (tests 4,5,6 and 7) we used two network grid topologies, one with 10 SRs in a 400 x 400m^2 area and one with 15 SRs spread in a similar area which is depicted in Fig.5.27 and Fig.5.28 respectively. In Table 5.3 we have the result of the optimal various radius R key with ten SRs and ten TRs.

TEST 4	
	SRs Optimal Key
Radius Combination	L S L L M M M L L L
Number of SRs	10
Number of TRs	10
Optimal Relative Coverage >=3	0.961219

Table 5.3 Optimal various radius R key results 10 SRs and 10 TRs

All combinations were tested to find the optimal relative coverage for the network. This exhaustive search approach usually takes days to find the optimal combination with large (high) numbers of SRs and TRs.

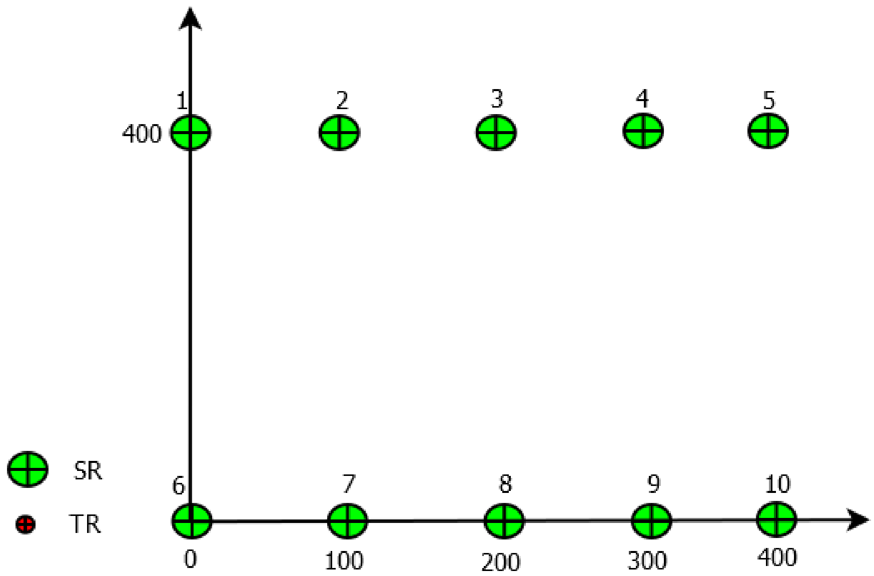

Figure 5.27 10 Sensors Grid with S-M-L Radius mode

In the next Tables 5.4 and 5.5 we have the results of the optimal various radius R key with ten SRs and twenty TRs and ten SRs and thirty TRs respectively. We can see how the optimal relative coverage is reduced analogically to the increase in the number of TRs.

TEST 5	
	SRs Optimal Key
Radius Combination	L S M L L M M M L L
Number of SRs	10
Number of TRs	20
Optimal Relative Coverage >=3	0.869519

Table 5.4 Optimal various radius R key results 10 SRs and 20 TRs

TEST 6	
	SRs Optimal Key
Radius Combination	L S S L M M M S L L
Number of SRs	10
Number of TRs	30
Optimal Relative Coverage >=3	0.753813

Table 5. 5 Optimal various radius R key results 10 SRs and 30 TRs

In the previous tests 4,5,6 we saw that every time we added 10 more TRs the Optimal Relative Coverage was lowered by 10 percent. In (the next) test 7 we will show that by adding only 5 more SRs the system rises its performance at a high level even with 30 TRs. By that way, the significance of the number of SRs in this particular type of FSN for localization with triangulation becomes obvious. The results of test 7 are depicted in Table 5.6.

TEST 7	
	SRs Optimal Key
Radius Combination	S M S M S S S S S S S S S S S
Number of SRs	15
Number of TRs	30
Optimal Relative Coverage >=3	0.928988

Table 5.6 Test results 15 SRs and 30 TRs

In the previous tests it was shown that the system can decrease the radius of some SRs from L to M or S in order to tackle the saturation and find the optimal key of SRs radius which gives us the optimal network coverage. In this case with 15 SRs the number of permutations to be executed by the system is really high and it took several days of running in order to receive the results. But the difference of coverage compared with the previous grid of 10 SRs is great and then we achieved a high level of coverage, a percentage of 92% after increasing the SRs from ten to fifteen and applying the optimal radius key to the SRs of the network.

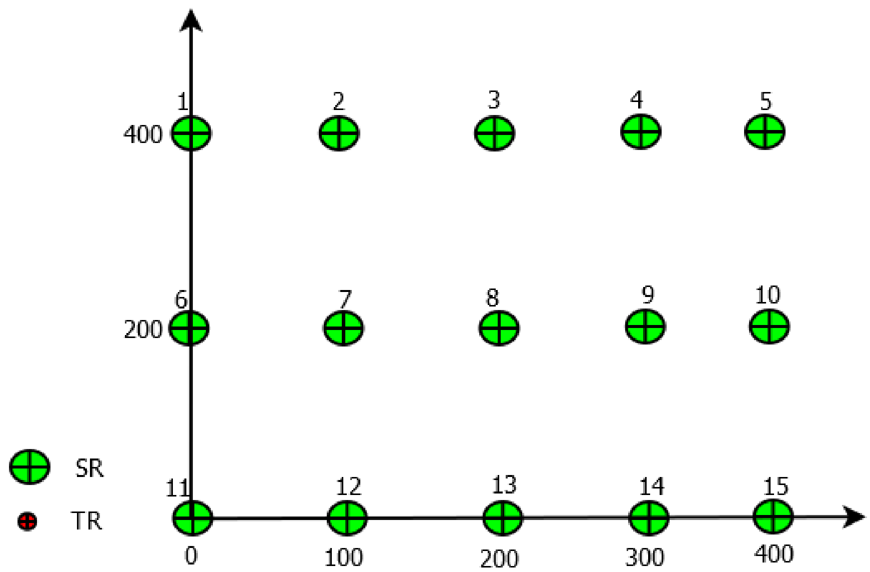

Figure 5.28 15 Sensors Grid -S-M-L Mode

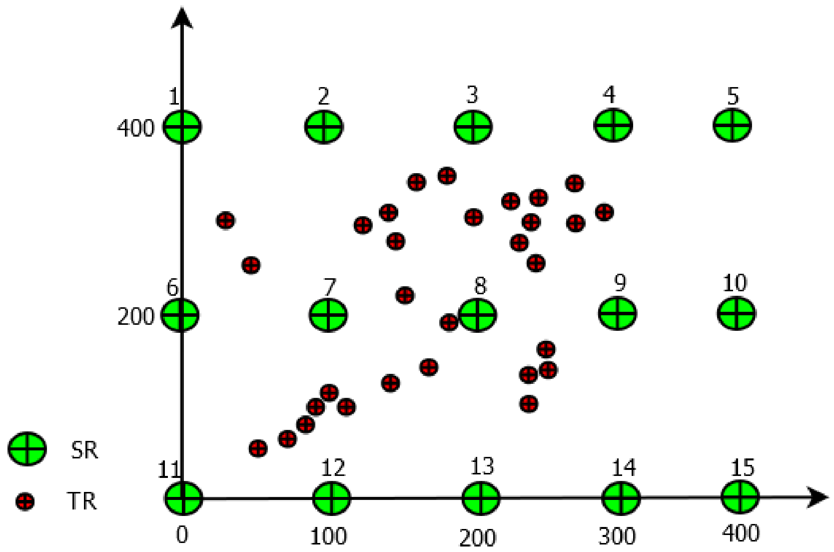

Figure 5.29 15 Sensors Grid 30 TRs - S-M-L Mode

In Fig. 5.30 we have a depiction of how coverage is affected when more TRs enter the area in each grid. We see that for the grid of 6 SRs, a ten TRs increase, results in a coverage decrease of twenty percent. While for the grid of ten SRs, after adding ten TRs, the decrease reaches ten percent.

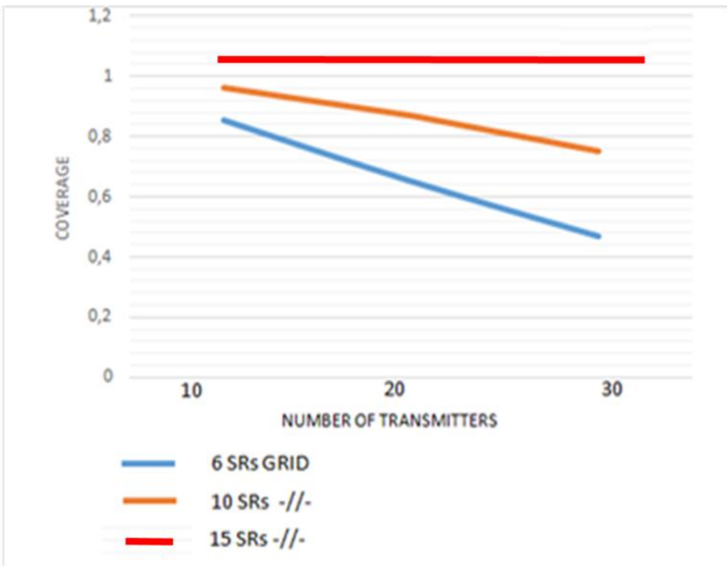

Figure 5.30 Transmitters-Coverage Chart with varying Grids radius R key

As far as the grid of 15 SRs coverage percentage is concerned, only the value related to 30 TRs is shown, as only one test was performed to prove that network coverage increases due to the increased number of SRs. With 15 SRs and 30 TRs or more the system needs days of running. The case where a different R is to be applied for each SR as shown in Fig.5.31 needs further examination.

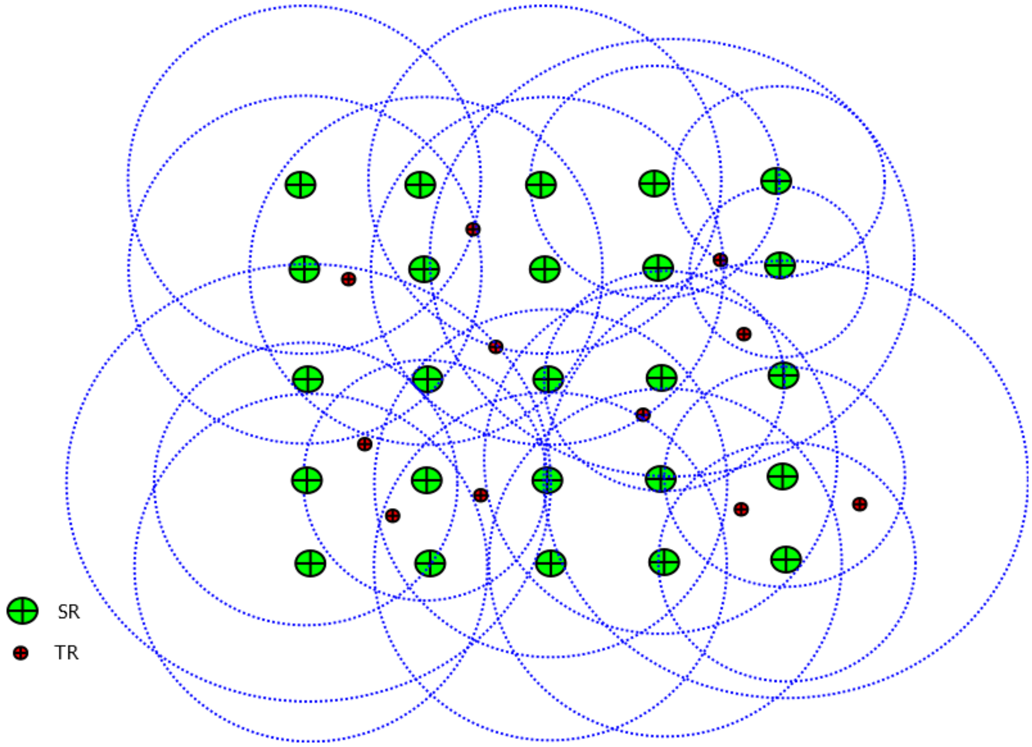

Figure 5.301 26 Sensors Grid with varying Radius

So, it is quite clear that the detection of TRs in the AOI is seriously affected by the presence of existing TRs. For that reason the concept of DC which was introduced in the previous chapter is related to the level of saturation and blindness of the network. It also becomes evident that in a saturated with TRs area, the detection becomes more complex and the FSN system has to apply additional methods to tackle a high level of Detection Complexity in order not to miss to detect OR detecting new TRs that might enter the AOI.

5.10. Contributions

The contributions of this chapter work is the development of a methodology to evaluate the performance of this particular type of FSN, based on the problem statement. Network Area Coverage Holes are identified and areas of non coverage of three or more SRs for triangulation are visualized for a system user. That way it is performed an evaluation of network status and its problematic areas in any state and with a certain number of existing TRs.

1. Whereas most previous works focused on considering a sub-area or a network hole [5.20], [5.25],[5.28] etc, in this work the whole FSN AOI is considered but this time by taking into consideration the existence of previous TRs which operate as obstacles in the area and affect the FSN coverage. This is far more different from previous works which mainly focus on coverage of region or sub-region by a single SR ($k \geq 1$) and not by three minimum SRs ($k \geq 3$) which will perform localization with triangulation of a new TR.

2. Furthermore, instead of trying to cover an area by adding more SRs in a sub-area of the FSN the system applies optimization of coverage by two different ways.

   a. Firstly, by finding and applying an optimal radius R same for each SR.

   b. Secondly, by finding and applying an optimal combination of different R for each SR of the network which we name "key".

3. In earlier works [5.33], [5.38], [5.41], authors were seeking for coverage holes and coverage healing by adding a SR or some SRs that might cover an area or a sub-area in the Region of Interest (ROI). This is different from our work in which the FSN is self-aware of its state continuously, and it can apply changes from state to state in order to achieve a high level of coverage in a region by a minimum number of SRs and $k \geq 3$.

4. Also, in this work new knowledge is added to existing knowledge with the new concept of FSN blindness N_{BL} for a FSN for localization with triangulation with a certain fixed error for each SR_{er} in an area with existing TRs which is for the first time presented.

5.11 Conclusions

In this chapter we examined the problem of coverage of a FSN where a number of TRs exist in an *AOI.* We presented a new approach of increasing the coverage performance of the network by finding and applying an Optimal value of radius R. We also presented a combined mode of operation with additional SRs, modifying the network to a Fixed Sensors system to one with a group of extra SRs. From the tests that have been carried out we conclude that the quality of coverage is affected when the beam error is gradually increased and as well as when the SRs Radius is increased beyond the optimal point, and the network performance is reduced. This means that any changes that might be applied to the FSN have to be tested and thoroughly pre-examined, as they can significantly reduce the FSN performance. On the other hand, the network can reach a certain limit of optimal performance if the optimal R value is applied. It was also shown that by applying varying radius R in the system with values S-M-L and finding the optimal key, with the optimal radius R for each SR, then the network keeps a high quality of coverage. The system by applying the algorithms which were previously analyzed, is able to react and intervene not only in one area but in every sub-area of its AOI, enabling the maintenance of high detection performance. Bearing in mind that, that way the system is having the ability of adaptation and reaction in each state we conclude that the FSN is able to perform a high level of detection and localization via TRN which is, so to speak the fundamental outcome of this research.

Future work is in need in order to investigate how the change of applying a different, optimal, value of R by examining all the possible values of R and not only three variations for each SR of the FSN might affect the QoS of the network. It is assumed that this mode of operation might increase the system's validity and performance more. Finally, a fuzzy logic implementation scheme for this particular type has been investigated as it appears in the Appendix B. It was examined the implementation of Fuzzy logic theory in the FSN system and how this implementation might increase the system performance. The system depends on continuous surveillance of its status and the level of its saturation is under processing. It is also studied and presented that the adjacent areas algorithm used along with its enhancing result indicate that the idea of implementing fuzzy logic in the FSN system is crucial. But all these findings need further study and experimentation.

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Chapter 6 Results and Discussion

6.1. *FSN Coverage*

In this research, substantial work has been done related to the issue of Network coverage in the Area of Interest - AOI. In previous chapter 5 it was examined the problem of coverage of a FSN where a number of TRs exist in an *AOI.* It was presented a new approach of increasing the coverage performance of the network by finding and applying an Optimal value of radius R but also by calculating and applying a varying radius R which is the optimal radius R for each SR. Thus the system is having the ability of adaptation and reaction from state to state. Also, it has been found that detection of new TRs is affected gradually as new TRs enter the area. In this chapter 6 more tests and results are acquired strengthening more the value of this research. In the following figures we have the depiction of some tests executed related to the problem detection degradation. There are various cases which are categorized as follows:

6.1.1 Case 1 - 4SRs and 6ETRs

In an area with 6 Existing TRs(ETRs) where 4 SRs are placed the system can withstand 5 *new TRs* (NTRs) with a *successful detection* (SD) of 75 percent Fig.6.1. In Fig.6.2 we increase the number of new transmitters NTRs to 24 and we see that the SD drops to 10 percent detection.

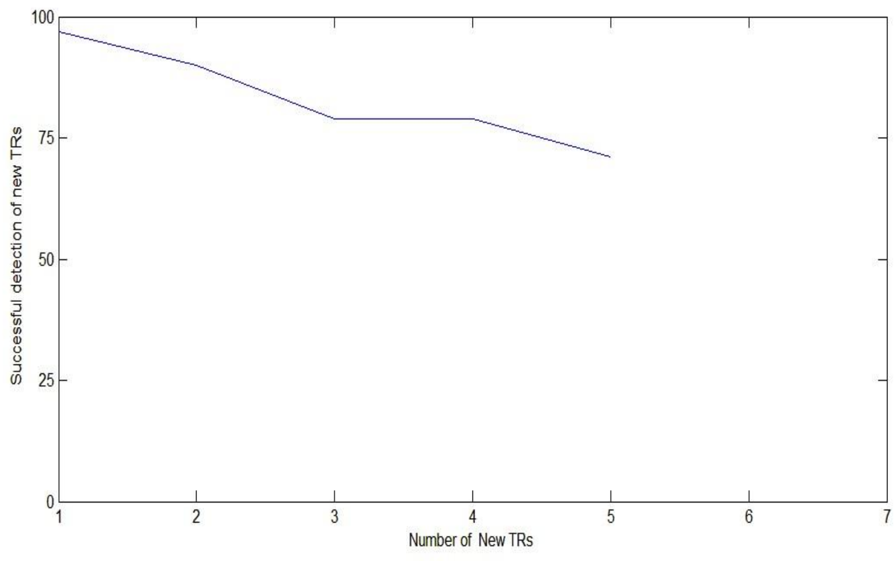

Figure 6.1 Case 1 - 4 SRs - 6 ETRs - 5 NTRs

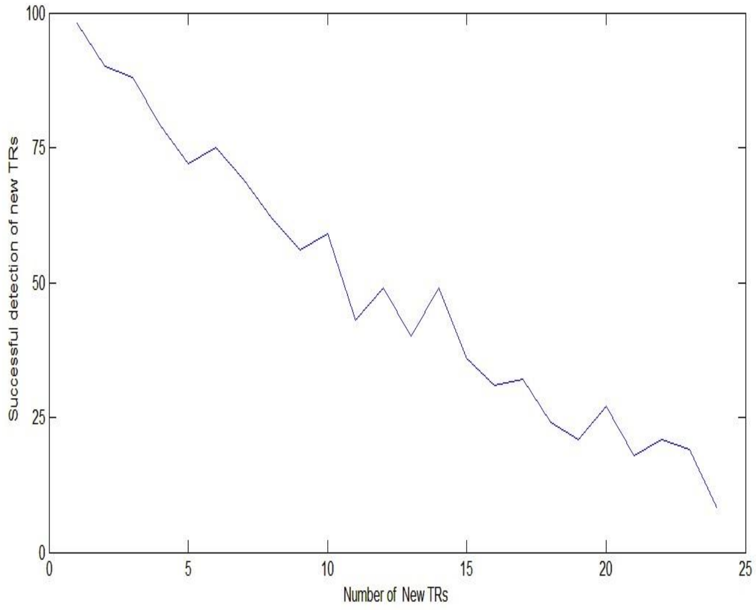

Figure 6.2 Case 1 - 4SRs - 6ETRs - 24NTRs

In Fig.6.3, we see how rapidly the successful detection SD is decreasing when we increase the number of NTRs to 30. For 25 NTRs the SD falls to the percentage of ten and we notice that the system becomes saturated in a case with 4SRs 6ETRs and above 20 NTRs. Here the system performance is not accepted. Comparing the three curves in Fig.6.4 we have an overall picture of how system performance is degraded starting from 5 NTRs to 30 NTRs.

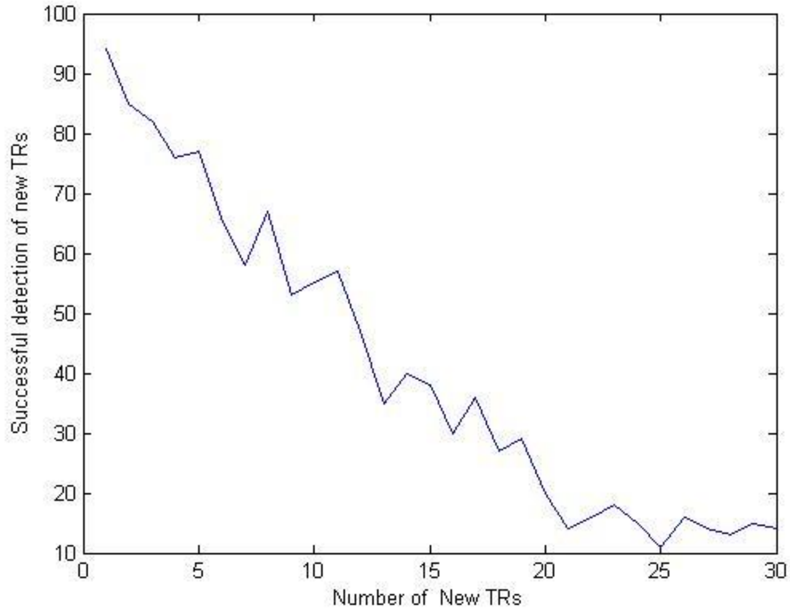

Figure 6.3 Case 1 - 4SRs-6ETRs-30 NTRs

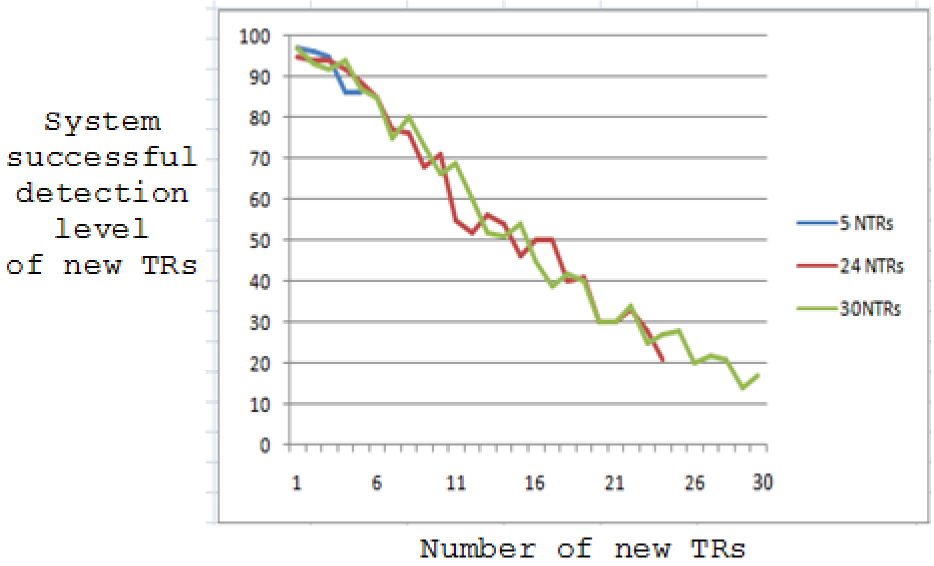

Figure 6.4 Case 1 - 14SRs - 6ETRs - 5-24-30 NTRs Curves. Each curve color represent a number of new TRs. Blue for 5 TRs red for 24 TRs and green for 30 TRs.

6.1.2 Case 2-4 SRs and 10ETRs

In this case we see how the SD is reduced by adding ten new TRs. We see how the SD is changing comparing Fig.6.5 and Fig. 6.6 . So, while the SD reaches the value of about 70 in Fig. 6.5, in Fig.6.6 it is falling from 70 to about 35 percent. The situation is further worsening when ten more TRs are added resulting to 30 TRs Fig. 6.7 where the SD falls to the percentage of 10. These results are shown the significance of network detection deterioration as new TRs enter the FSN AOI. And it becomes clear that the AOI will be further deteriorated if many new TRs appear. In Fig. 6.8 it is depicted the combination of the three curves and we can evaluate that the 4 SRs are not able to deal with a high number of TRs and more SRs are needed to keep high the system detection performance.

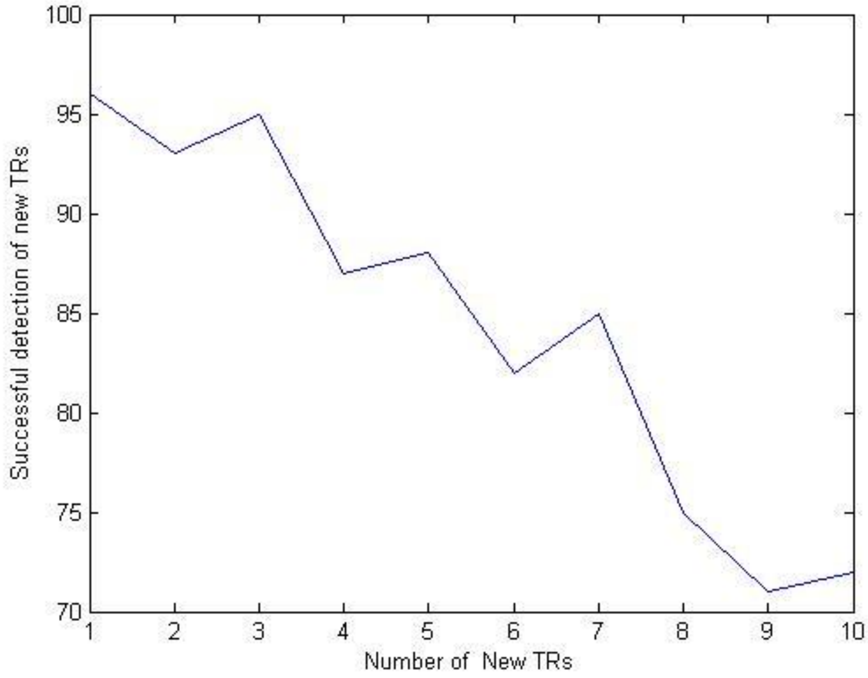

Figure 6. 5 Case 2 - 4SRs - 10ETRs - 10 NTRs Plot

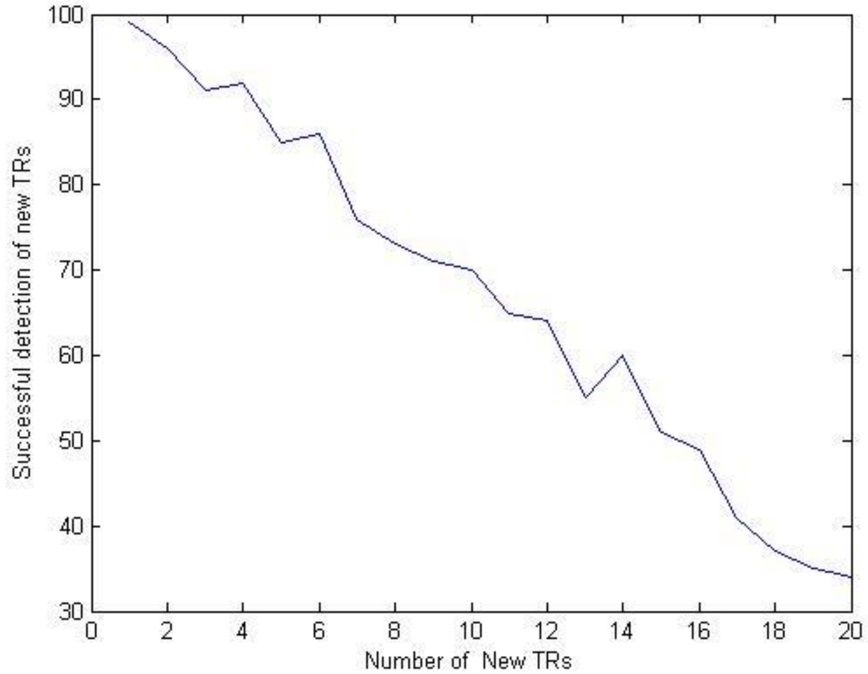

Figure 6.6 Case 2- 4SRs - 10ETRs - 20 NTRs Plot

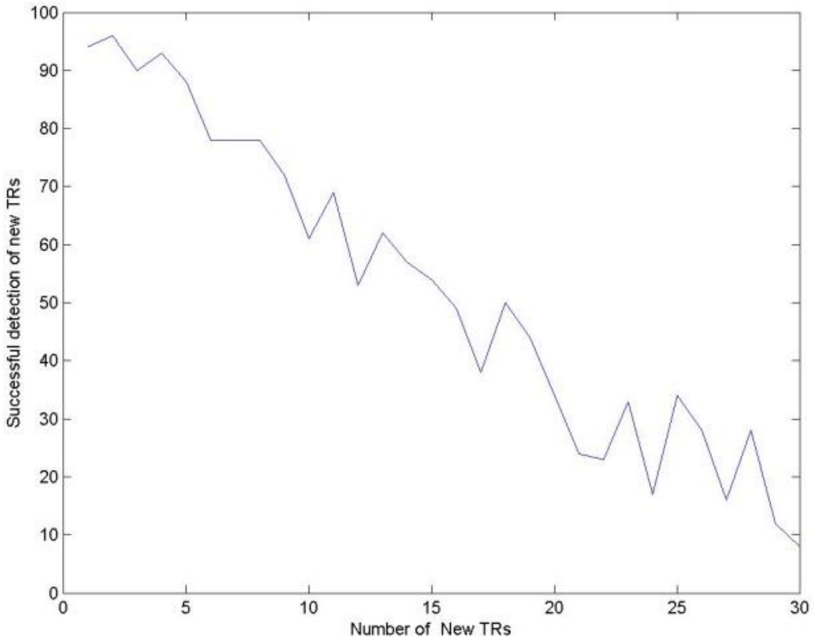

Figure 6.7 Case 2 4SRs - 10ETRs - 30 NTRs Plot

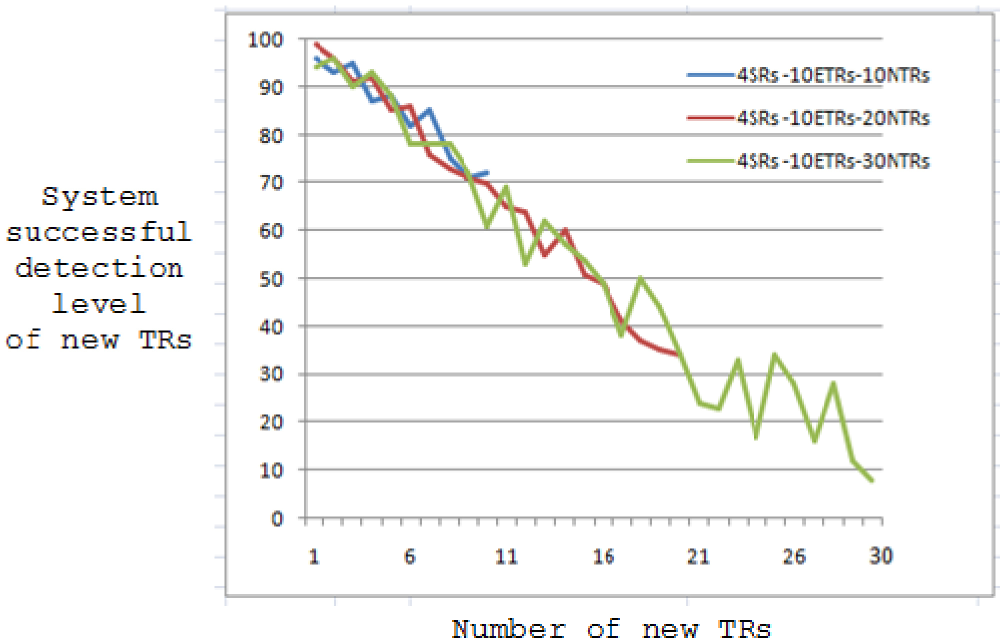

Figure 6.8 Case 2 4SRs - 10ETRs - 10-20-30 NTRs Curves

6.1.3 Case 3 - 15SRs   Various ETRs -NTRs

In this case by increasing the number of SRs to 15 we see that the successful detection SD, even with 25 ETRs, remains high at 98 percent Fig.6.10. In Fig. 6.10 we increase the number of NTRs to 20 by adding 10 more NTRs and the system still has a high SD in a level above 88 percent.

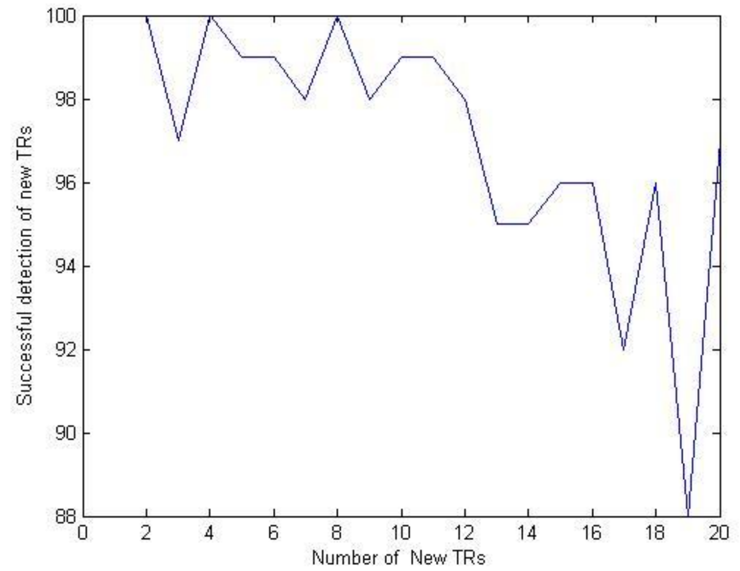

Figure 6.9 Case 3 - 15SRs - 25 ETRs-20 NTRs

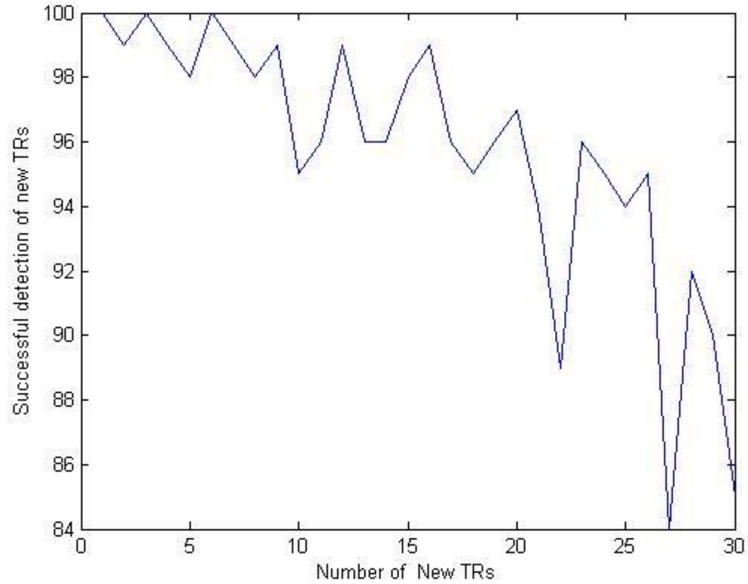

Figure 6.10 Case 3 15 SRs-25 ETRs-30 NTRs

In Fig.6.10 above, we see that even by having a network with 15 SRs after increasing the number of NTRs to 30 the SD falls to the percentage of 84 percent. Also, it is analyzed in Chapter 4 that the network coverage quality is related to the number of pre-existing TRs in the AOI. Meaning that if the system is already saturated then it is less probable for a TR to be detected. Furthermore, it has been found that if a saturated sub-area exists in the AOI, the problem of coverage around that specific sub-area is decreased if new SRs are added in that particular area and then we achieve a coverage increase. In chapter 5 also it is shown that with a high number of TRs and a group of new SRs added the problem of coverage decreases.

6.2. Network Detection Performance/Degradation

Furthermore, based on scientific results and numerous tests, it has been found that the system detection performance is seriously affected when a large number of TRs exist/appear in the FSN. This problem leads to detection degradation and eventually results in losing new TRs that might enter the AOI.

6.3. New TRs load system adaptability and susceptibility

In chapter 4 it has been found and analyzed with the use of certain methodology, that at any particular time during system operation the user is able to have a visualization of system status and is able to apply optimization in order to acquire the best coverage resulting in increase of detection performance of new TRs. Also, it has been found and analyzed in chapter 5, that this particular type of FSN system has significant adaptability and susceptibility as it is able to adapt to changes in its status and apply changes during detection by using triangulation for localization of the new TRs. Also, the system is able to monitor continuously its status (SRs and Network saturation, sub-areas saturation) and apply relative changes. This issue adds to the system adaptability and susceptibility resulting in system flexibility to detect new TRs. It is vital for this particular FSN system of localization with triangulation to be flexible and resistant to changes that might overload it and eventually result in missing new TRs. All these findings are the benchmarks of this research and are strongly related with a particular type of FSN with certain accuracy of x degrees. This type of automated system for localization via triangulation for wide area of coverage is a type of system that hasn't been researched previously. The whole problems that the system has to deal with, in combination with its topology, system status and performance and their change as new TRs enter the area form a new topic of research. Furthermore, the issue of saturation and blindness for the FSN system are also benchmarks of this research as these issues haven't been studied before.

Chapter 7 : Conclusion

7.1 Thesis Overview

This thesis consists of seven chapters. This chapter presents the thesis contributions, and the research aim with its objectives revisited. Also, it highlights limitations and future research directions for this research. An overview of the previous six chapters is outlined below:

Chapter 1 presents the introduction for this thesis, in which the motivation of this research is addressed. Basic concepts related to a FSN for localization with triangulation are presented. Also, the general methodology followed during the research and its contributions to knowledge are described here.

Chapter 2 examines the problem of localization and current research related to its applications on Sensors Networks. Varying localization techniques related to the process of triangulation were analyzed. Also, it was shown that in a large network with a great number of Sensors - SRs there are cases of pseudo Transmitters PTRNs which need to be examined on a case by case basis.

Chapter 3 examines the basic problem of localization with triangulation. The problem is examined thoroughly and it is proved that as the number of TRs in the AOI is increased, the system has to implement the right methodology in order to detect TRs and perform real TRNs. A methodology for real TRNs in the AOI which enables the network to acquire a higher detection rate whilst synchronously rejects the false triangulations is presented.

Chapter 4

The scope of this chapter is to shed light on various issues that should be put into consideration when a Sensors Network (SN) has to work as an automated system. Various cases were analyzed and it was shown that for an automated network with many SRs and a great number of TRs that operate in an area of interest, there are attributes that need a lot of attention and also need to be examined and integrated in the system. Detection Complexity - DC is defined as the level of easiness to detect a new TR in the area. The issues of SRs blindness, Network saturation and Network detection rate are introduced as they are of great importance for the network coverage and its quality of performance.

Chapter 5

This chapter examined the problem of coverage of a FSN where a number of TRs exist in an *AOI.* A new approach of increasing the network coverage performance is presented by applying an Optimal value of radius R and the combination of a varying value of SRs radius R, with one of the three values S-M-L. Also, it is presented a combined mode of operation with additional SRs, by modifying the network to a Fixed Sensors one with groups of extra SRs is presented. Various tests were executed and their results for the operation of this particular FSN system were quite significant. Also, the implementation of Fuzzy logic theory in the FSN system and how this implementation might increase the quality of system operation and its detection performance was examined and it is presented in Appendix B.

Chapter 6

This chapter consists of the results and discussion chapter with the thesis scientific results. The previous chapters 4 and chapter 5 are overviewed and it is proved that a FSN system for localization with triangulation by applying the methodologies presented is able to keep a high rate of performance. Also and as the FSN needs flexibility the system should also acquire adaptability together with susceptibility in order to keep its high performance. All these findings form the benchmarks of this research and are strongly related to this particular type of FSN with certain accuracy of x degrees. This type of automated system for localization via triangulation for a wide area of coverage is a type of system that hasn't been researched previously and from this perspective.

7.2 Research Contribution

The study of this thesis produces four significant contributions. These contributions are distinguished into different themes and they are analyzed in the following paragraphs.

- Formulated a methodology to find the position of a new transmitter entering an area with existing transmitters. This methodology was presented in Chapter 3 and chapter 4 and it is formulated with the following assumptions:
  - The position of the existing TRs is known.
  - The position of the SRs network is known and fixed**.**
  - The SRs detect only the bearing of a TR(not the distance)- Range free system.
  - The detected bearing BRNG is within an **accuracy** of x degrees

- Formulated a methodology to assess Sensors Network system performance based on saturation and blindness aspects. It is vital for the system to have the ability to assess its state at single sensor to the network level. These features enable system changes at local area levels in order to maintain a high detection performance. Results related with this contribution were presented in Chapter 4 and it was shown how network blindness network saturation might affect network performance. Also, it was shown the probability of detection of a new TR and how it varies as more and more TRs appear in the AOI.

- In Chapter 5 formulated a technique to maximize coverage for fixed sensor network triangulation schemes and results were presented. Additionally, the system maximizes coverage by:
  - Finding network coverage with a fixed Sensors radius R.
  - Maximizes network coverage by applying different sensor radius of coverage for each sensor by choosing among three coverage radius values, Small-Medium-Large, S-M-L.
- Significant results were also found and presented in Chapter 6 were it was shown how the increased number of TRs might affect the successful detection of the system.

7.2.1 Methodology Contribution

The methodology of how to find the position of a new TR entering an area with existing TRs, where**:**

1) The position of the existing TRs is known.

2) The position of the SRs network is known and fixed**.**

3) The SRs detect only the bearing of a TR(not the distance)- Range free system.

4) The detected bearing BRNG is within (an) **accuracy** of x degrees.

7.2.2 Methodology Contribution

Methodology to assess the Sensors Network **-** FSN system saturation and blindness, whilst synchronously the Sensors Network is able to monitor its detection performance. It is vital for the system to have the ability to assess its state from the level of a single SR to the level of a network. By that way system changes might be applied to problematic areas in order to maintain a high detection performance. Also, in each state the system is able to find the probability of detection of a new TR thus having an additional tool to assess its performance.

7.2.3 Methodology Contribution

The methodology of how to find the optimal coverage of the Sensors Network triangulation system. The system finds the optimal coverage with two ways:

1) Firstly, it finds the optimal network coverage with a fixed Sensors radius R.

2) Secondly, it finds the optimal network coverage by applying a various Sensors radius R different for each SR choosing between three values, Small-Medium-Large, S-M-L.

7.3 The Research Aims and Objectives Revisited

This research related to a Sensors Network FSN system which is able for detection of TRs in an area which might have a great number of previously existing TRs is a complicated issue. The problem of detection and its complexities from the level and perspective of a system was examined. For that reason, starting from the issue of a single TRN in combination with false TRNs cases that might exist in an area the methodology for a single real TRN to the level of adequate system coverage which will enable a high level of detection was studied. Various topologies and combinations of SRs and TRs were examined. System optimization and its complexities were tested as well and we, subsequently found a methodology to optimize area coverage whilst synchronously locate and visualize areas of non coverage, which is of vital importance for the system. Moreover, the issue of saturation due to existing TRs was examined thoroughly and I strongly believe that it is a novel founding of this research the fact that for TRs detection it is significant to process the level of system saturation of existing TRs in every state. In the following table (it is presented) the core chapter achievements of this thesis and how it was successfully met the research objectives specified in each section are presented.

Objective	Chapter Achievements
Objective 1: To Conduct literature review to evaluate current and previous research related (on) to the concept of localization with triangulation. Also, to examine the varying methodologies and approaches that are used for TRs detection with the method of triangulation. The results of this research set the cornerstone for developing the approach and methodologies of this study.	The first objective was achieved in Chapter 2. Several issues and techniques related to the process of localization with triangulation were highlighted. Also, with this research it was identified that the process of triangulation is applied to a wide number of applications and different approaches are used on a case by case basis.
Objective 2: To Investigate and identify the varying cases of false triangulations that might affect the FSN system performance during its operation for localization with triangulation. Also, design a methodology for performing localization with TRN by having a certain number of SRs and TRs. By using varying topologies and sets of SRs and TRs the FSN system should be able to identify if there (exists) is a real triangulation.	The second objective was achieved in Chapter 3. A methodology was designed with satisfying results with which the FSN system, is able to identify if by entering varying sets of bearings for each SR of the FSN system, after processing the system is able to provide valuable results and a certain number of real triangulations.

Objective 3: To Examine the saturation effect that is caused inside a network due to the presence of existing TRs. As the existing TRs presence is affecting the system's performance and synchronously the network coverage, is of high priority.	The third objective was achieved in Chapter 4. A methodology was designed with satisfying results with which the FSN system, is able to assess its saturation level detection performance and its status due to the presence of existing TRs. As it is vital for the system to find new TRs in the AOI with this methodology the FSN system might apply changes(adding new SRs or change radius R for a group of SRs) in order to increase network coverage and its detection performance with triangulation.
Objective 4: Every network in order to keep a high rate of performance and detection, requires a high level of coverage. After the entrance of TRs in the network its coverage is affected. For that reason network optimization is vital from state to state, in order to keep network coverage and detection high.	The fourth objective was achieved in Chapter 5. In order to perform network optimization two methodologies where developed. The first is by finding and applying the same optimal radius R for each SR of the network. The second is by finding and applying the optimal of three values of radius R for each SR of the network. A lot of network topologies and combinations of SRs and TRs sets were tested with satisfying results. With network optimization the FSN system is able to achieve a high network coverage keeping a high level of performance. As for the process of localization with triangulation $k \geq 3$ is needed.

Table 7.1 Research Objectives vs Chapter Achievements

7.4 Research Limitations and Future Directions

This research was conducted in the view of some assumptions and considerations that entail some research limitations listed as follows:

This study focuses mainly on the issue of detection of TRs taking into consideration a certain level of topologies which were tested with a certain number of SRs and TRs. It was shown through testing that as the number of SRs and TRs is increased the system requires high level of processing and more time in order to provide results. So, it's worth studying different topologies using more TRSs and SRs with systems with increased processing capability. That way, the system will be tested on its limitations and further valuable results will be acquired.

Furthermore, the system optimization was examined with the implementation of a varying radius R but not all the combinations of varying radius R taking values from a chosen and predefined set of values. What looks promising and needs further study is the level of optimization change that might be acquired with a set of R values in the AOI or in sub-areas of the system.

Additionally, system adaptability and implementation of changes by applying fuzzy logic theory is examined on this particular FSN system for localization with triangulation, tests appear in Appendix B. However, it needs further testing in order to become clearer how and in what level this theory implementation might differentiate system performance from state to state.

Finally, in this research the application of a varying radius R for each SR in order to achieve network coverage optimization was inquired. Nevertheless, it should be mentioned that a varying Radius R for each SR in combination with bearing variation of 360^0 for each particular SR in the network was not examined. It is expected that this issue might add value in FSN performance.

7.5 Concluding Remarks

In this section some directions for future research will be also briefly discussed. Although there were promising results, the system still requires human intervention in order to apply topology changes in the system, in case of a low detection performance. Therefore, further testing and future research could be regarded as an interesting topic for increasing network performance and its adaptability to changes due to TRs intervention. Based on our optimization approach, by combining various radius for each SR further research is required in applying a varying value of radius R analogically. This can be done not by choosing and applying one of the three values S-M-L for each SR but finding and applying the best value of R for each SR from a set of predefined values ($R_{0...}R_{n)}$ where the user will choose the size of each set for each SR of the network.

Additionally, the implementation of Fuzzy logic in the system was examined. This methodology looks very promising for the automatization of this system. For that reason further research is required. on this methodology for this type of system in order to increase its adaptability and become even more flexible.

Last but not least, the recommended methodologies for a FSN system for detection of TRs with the process of triangulation of this particular type is a research topic that hasn't been researched yet thoroughly. For that reason, it is suggested that this research is quite promising and requires further research and testing. Thus new knowledge will be added to the existing knowledge.

Appendix A

In the following tests the test area is in the Aegean sea and some small Greek islands are the TRN areas. There is also one test, TEST4 in the central area "Thessaly" of Greece. The system accuracy for each bearing detection is 2^0.

TEST 1

SRs: FYRA,MILOS,HERAKLION.

TRIANGULATION AREA CHRISTIANA

****

FYRA 227 MILOS 127 HERAKLION 2.8 TRN: CHRISTIANA

****

Intersection between Sensors:

Sensor: FYRA Cooordinates LAT: 36.416777 LON: 25.4324 Bearing: 225.0

and Sensor: HERAKLION Cooordinates LAT: 35.338838 LON: 25.144451 Bearing: 4.8

TRIANGULATES

with the intersection between Sensors:

Sensor: MILOS Cooordinates LAT: 36.696893 LON: 24.474963 Bearing: 125.0

and Sensor: HERAKLION Cooordinates LAT: 35.338838 LON: 25.144451 Bearing: 4.8

****

FYRA 227 MILOS 127 HERAKLION 2.8 TRN: CHRISTIANA

****

Sensor: FYRA Cooordinates LAT: 36.416777 LON: 25.4324 Bearing: 225.0

and Sensor: MILOS Cooordinates LAT: 36.696893 LON: 24.474963 Bearing: 129.0

TRIANGULATES

with the intersection between Sensors:

Sensor: FYRA Cooordinates LAT: 36.416777 LON: 25.4324 Bearing: 225.0

and Sensor: HERAKLION Cooordinates LAT: 35.338838 LON: 25.144451 Bearing: 4.8

TEST 2

SRs: FYRA, SITIA, HERAKLION.

TRIANGULATION POINT: SYRNA

****

FYRA 94 SITIA 22 HERAKLION50.5 TRN: SYRNA

****

TEST RESULTS

Intersection between Sensors:

Sensor: FYRA Cooordinates LAT: 36.416777 LON: 25.4324 Bearing: 96.0

and Sensor: SITIA Cooordinates LAT: 35.338838 LON: 25.144451 Bearing: 24.0

TRIANGULATES

with the intersection between Sensors:

Sensor: FYRA Cooordinates LAT: 35.20878 LON: 26.105192 Bearing: 96.0

and Sensor: HERAKLION Cooordinates LAT: 35.338838 LON: 25.144451 Bearing: 52.5.

****

FYRA 94 SITIA 22 HERAKLION 50.5 TRN: SYRNA

****

Intersection between Sensors:

Sensor: FYRA Cooordinates LAT: 36.416777 LON: 25.4324 Bearing: 96.0

and Sensor: HERAKLION Cooordinates LAT: 35.338838 LON: 25.144451 Bearing: 52.5

TRIANGULATES

with the intersection between Sensors:

Sensor: SITIA Cooordinates LAT: 35.20878 LON: 26.105192 Bearing: 24.0

and Sensor: HERAKLION Cooordinates LAT: 35.338838 LON: 25.144451 Bearing: 52.5

TEST 3

SRs: FYRA, SITIA, HERAKLION,

TRIANGULATION POINT: OFIDOUSSA

****

FYRA 76 SITIA 1 HERAKLION 33.4 TRN: OFIDOUSSA

****

TEST RESULTS

Intersection between Sensors:

Sensor: FYRA Cooordinates LAT: 36.416777 LON: 25.4324 Bearing: 78.0

and Sensor: HERAKLION Cooordinates LAT: 35.338838 LON: 25.144451 Bearing: 35.4

TRIANGULATES

with the intersection between Sensors:

Sensor: SITIA Cooordinates LAT: 35.20878 LON: 26.105192 Bearing: 3.0

and Sensor: HERAKLION Cooordinates LAT: 35.338838 LON: 25.144451 Bearing: 35.4

****

FYRA 76 SITIA 1 HERAKLION 33.4 TRN: OFIDOUSSA

****

Intersection between Sensors:

Sensor: FYRA Cooordinates LAT: 36.416777 LON: 25.4324

Bearing: 74.0

and Sensor: HERAKLION Cooordinates LAT: 35.338838 LON: 25.144451 Bearing: 31.4

TRIANGULATES

with the intersection between Sensors:

Sensor: SITIA Cooordinates LAT: 35.20878 LON: 26.105192 Bearing: 359

and Sensor: HERAKLION Cooordinates LAT: 35.338838 LON: 25.144451 Bearing: 31.4

TEST 4

run:

Welcome to the JavaGeodesy Computer

Enter the system's accuracy

2

How many sensors do you want to calculate?

5

Reading File from Java code

2.0

190.0

184.5

39.382318

22.2507

2.0

245.0

261.5

39.214878

22.563111

2.0

136.0

118.0

39.332007

21.460192

2.0

129.0

100.0

39.215116

21.551476

2.0

262.0

292.0

39.105552

22.453287

Sensors Coordinates are: 39.382318

Sensors Coordinates are: 22.2507

Sensors Coordinates are: 39.214878

Sensors Coordinates are: 22.563111

Sensors Coordinates are: 39.332007

Sensors Coordinates are: 21.460192

Sensors Coordinates are: 39.215116

Sensors Coordinates are: 21.551476

Sensors Coordinates are: 39.105552

Sensors Coordinates are: 22.453287

Enter the name for each Sensor

LARISSA

VOLOS

TRIKALA

KARDITSA

ALMIROS

How much should be the maximum intersections distance? - Enter a value bigger than 5

6

Sensor names are:

LARISSA

VOLOS

TRIKALA

KARDITSA

ALMIROS

Elements θ23:120.0

Element φ1:39.382318

Element λ1:22.2507

Element φ2:39.01984608634805

Element λ2:22.151544962397676

Element φ3:39.332007

Element λ3:21.460192

******************Bearing1 = true*******************

**********************Before if loop CheckBrng1:192.0000000000002

******************Bearing2 = true*******************

******************Before if loop CheckBrng2:119.99999999999994

θ13: 190.0

CheckBrng1 if loop: 192.0000000000002

θ13 - x: 188.0

θ13 + x: 192.0

θ23: 118.0

CheckBrng2 if loop: 119.99999999999994

θ23 - x: 116.0

θ23 + x: 120.0

****

THE POINT IS INSIDE THE POLYGON*

****************************PLUS PLUS INTERSECTION POINT IS ON OR WITHIN BEARING LINES***************************

****

****

Intersection between Sensors:

Sensor: LARISSA Cooordinates LAT: 39.382318 LON: 22.2507 Bearing: 192.0
 and Sensor: TRIKALA Cooordinates LAT: 39.214878 LON: 22.563111 Bearing: 263.5

Coordinates of Sensors Intersection point are: LAT: 39.18185551980094 LON: 22.195733766883578
TRIANGULATES
Third Sensor name is: KARDITSA
Third Sensor name is: KARDITSA
 with the intersection between Sensors:
Sensor: LARISSA Cooordinates LAT: 39.382318 LON: 22.2507 Bearing: 192.0
  and Sensor: KARDITSA Cooordinates LAT: 39.332007 LON: 21.460192 Bearing: 120.0
Intersection point Coordinates are: LAT: 39.01984608634805 LON: 22.151544962397676
Bearing from previous point and point 2 is:119.99999999999994
IntersectionsCounter is:0
------------------------IntersectionsCounter is--------------------------:1
38.78656955750972
22.088279996927447
inner loop:1
Elements θ13:264.0
ELEMENT g OUTER LOOP:2
Elements θ13:294.0
****
******
------------------NUMBER OF TOTAL PLUS PLUS INTERSECTIONS IS:------------: 1
****
******

Sensor names are:
LARISSA
VOLOS
TRIKALA
KARDITSA
ALMIROS

38.858700966717564
22.15620457131311
2.0
Distance between Sensors intersection points is:2.0
*********The distance between the intersection points is within given limit**********
****
***   "TRIANGULATION   IS   HIGH"
****
****
****

IntersectionPointCounter32

39.14181186679939
22.207120445775455
5.0
Distance between Sensors intersection points is:5.0
*********The distance between the intersection points is within given limit**********
*******************Triangulation is MEDIUM   *************************
39.17316618045009
22.21278474088651
1.0
Distance between Sensors intersection points is:1.0
*********The distance between the intersection points is within given limit**********
****
"TRIANGULATION IS HIGH" **********
****

39.084223326424215
22.233932868758302
2.0
Distance between Sensors intersection points is:2.0
*********The distance between the intersection points is within given limit**********
****
** "TRIANGULATION IS HIGH"
****
****

IntersectionPointCounter64
FourPlusIntersecionCounter is: 0
39.167800601146304
22.238619530397415
1.0
Distance between Sensors intersection points is:1.0
*********The distance between the intersection points is within given limit**********
****
*** "TRIANGULATION IS HIGH"
****
****
****
IntersectionPointCounter72
FourPlusIntersecionCounter is: 0
38.821153673678694

22.21925322769272

3.0

Distance between Sensors intersection points is:3.0

*********The distance between the intersection points is within given limit**********

*** Triangulation is MEDIUM

****

Elements θ23:120.0

Element φ1:39.382318

Element λ1:22.2507

Element φ2:39.13838355644321

Element λ2:22.236968676471474

Element φ3:39.332007

Element λ3:21.460192

******************Bearing1 = true*******************

******************θ13 - 2*x - epsilon = :182.0

******************θ13 + epsilon = :187.0

**********************Before if loop CheckBrng1:182.49999999999935

******************Before if loop CheckBrng2:107.5931299581888

The point is out of the Polygon

39.13838355644321

22.236968676471474

6.0

Distance between Sensors intersection points is:6.0

Triangulation is LOW

39.0752502388865

22.233430356842653

15.0

Distance between Sensors intersection points is:15.0

39.16596187923534

22.2385163027484

1.0

Distance between Sensors intersection points is:1.0

*********The distance between the intersection points is within given limit**********

****

** "TRIANGULATION IS HIGH"

****

****

****

IntersectionPointCounter120

FourPlusIntersecionCounter is: 0

38.96789564931612

21.943805500463757

14.0

Distance between Sensors intersection points is:14.0

39.05988028009853

22.172992206454786

7.0

Distance between Sensors intersection points is:7.0

Elements θ13:247.0

Elements θ23:138.0

Element φ1:39.214878

Element λ1:22.563111

Element φ2:38.97468483473624

Element λ2:21.960662862520508

Element φ3:39.332007

Element λ3:21.460192

******************Bearing1 = true*******************

******************θ13 - 2*x - epsilon = :242.5

******************θ13 + epsilon = :247.5

**********************Before if loop CheckBrng1:243.0000000000007

******************Before if loop CheckBrng2:132.4778219784423

The point is out of the Polygon

38.97468483473624

21.960662862520508

0.0

Distance between Sensors intersection points is:0.0

*********The distance between the intersection points is within given limit**********

****

** "TRIANGULATION IS HIGH" ***********

****

****

39.07056661276179

22.19972954182481

12.0

Distance between Sensors intersection points is:12.0

Elements θ23:102.0

Element φ1:39.214878

Element λ1:22.563111

Element φ2:39.13292002036177

Element λ2:22.35620672473144

Element φ3:39.215116

Element λ3:21.551476

******************Bearing1 = true*******************

******************θ13 - 2*x - epsilon = :242.5

******************θ13 + epsilon = :247.5

**********************Before if loop CheckBrng1:243.00000000000182

39.13292002036177

22.35620672473144

0.0

Distance between Sensors intersection points is:0.0

*********The distance between the intersection points is within given limit**********

****

****

************ "TRIANGULATION IS HIGH" ************

****

Elements θ13:263.5

:1

Elements θ23:138.0

Element φ1:39.214878

Element λ1:22.563111

Element φ2:39.095860174172046

Element λ2:21.75508906631919

Element φ3:39.332007

Element λ3:21.460192

******************Bearing1 = true*******************

******************θ13 - 2*x - epsilon = :259.0

******************θ13 + epsilon = :264.0

**********************Before if loop CheckBrng1:259.4999999999999

******************Bearing2 = true*******************

******************θ23 - 2*x - epsilon = :133.5

******************θ23 + epsilon = :138.5

******************Before if loop CheckBrng2:135.85160923489173

Bearing θ13 is: 261.5

CheckBrng1 if loop: 259.4999999999999

θ13 - x: 259.5

θ13 + x: 263.5

θ23: 136.0

CheckBrng2 if loop: 135.85160923489173

θ23 - x: 134.0

θ23 + x: 138.0

****

THE POINT IS INSIDE THE POLYGON*

*********MINUS MINUS INTERSECTION POINT IS ON OR WITHIN BEARING LINES***************

****

****

Intersection between Sensors:

Sensor:VOLOS Cooordinates LAT: 39.214878 LON: 22.563111 Bearing: 259.5

and Sensor:TRIKALA Cooordinates LAT: 39.332007 LON: 21.460192 Bearing: 134.0

Coordinates of Sensors Intersection point are: LAT: 39.09832843543123 LON: 21.77144324631195

TRIANGULATES

Third Sensor name is: KARDITSA

Third Sensor name is:KARDITSA

with the intersection between Sensors:

Sensor: VOLOS Cooordinates LAT: 39.214878 LON: 22.563111 Bearing: 259.5

and Sensor: KARDITSA Cooordinates LAT: 39.215116 LON: 21.551476 Bearing: 127.0

Intersection point Coordinates are: LAT: 39.095860174172046 LON: 21.75508906631919

Bearing from previous point and point 2 is: 135.85160923489173

IntersectionsMinusMinusCounter is: 0

---------- IntersectionsCounter is -----------:1

39.095860174172046

21.75508906631919

0.0

Distance between Sensors intersection points is:0.0

*********The distance between the intersection points is within given limit**********

****

*** "TRIANGULATION IS HIGH" **************

****

Elements θ23:120.0

Element φ1:39.214878

Element λ1:22.563111

Element φ2:39.15115327800017

Element λ2:22.125436736000445

Element φ3:39.332007

Element λ3:21.460192

******************Bearing1 = true******************

******************θ13 - 2*x - epsilon = :259.0

******************θ13 + epsilon = :264.0

**********************Before if loop CheckBrng1:259.4999999999993

******************Before if loop CheckBrng2:109.13150161145887

The point is out of the Polygon

39.15115327800017

22.125436736000445

6.0

Distance between Sensors intersection points is:6.0

Triangulation is LOW

Elements θ23:102.0

Element φ1:39.214878

Element λ1:22.563111

Element φ2:39.16715897810219

Element λ2:22.23424239638197

Element φ3:39.215116

Element λ3:21.551476

******************Bearing1 = true******************

******************θ13 - 2*x - epsilon = :259.0

******************θ13 + epsilon = :264.0

**********************Before if loop CheckBrng1:259.5000000000007

******************Before if loop CheckBrng2:94.96257794718912

The point is out of the Polygon

39.16715897810219

22.23424239638197

5.0

Distance between Sensors intersection points is:5.0

*********The distance between the intersection points is within given limit**********

****************** Triangulation is MEDIUM ******************

39.206832543475095

21.627314506254198

28.0

Distance between Sensors intersection points is:28.0

Elements θ13:138.0

Elements θ23:131.0

Element φ1:39.332007

Element λ1:21.460192

Element φ2:39.02414006284698

Element λ2:21.86959961845039

Element φ3:39.215116

Element λ3:21.551476

******************Bearing1 = true******************

******************θ13 - 2*x - epsilon = :133.5

******************θ13 + epsilon = :138.5

**********************Before if loop CheckBrng1:133.99999999999898

```
******************Bearing2 = true*******************
******************θ23 - 2*x - epsilon = :126.5
******************θ23 + epsilon = :131.5
******************Before if loop CheckBrng2:127.63144829540425
Bearing θ13 is: 136.0
CheckBrng1 if loop: 133.99999999999898
θ13 - x: 134.0
θ13 + x: 138.0
θ23: 129.0
CheckBrng2 if loop: 127.63144829540425
θ23 - x: 127.0
θ23 + x: 131.0
******************************************************************************************************************
*******************THE POINT IS INSIDE THE POLYGON****************
***********MINUS MINUS INTERSECTION POINT IS ON OR WITHIN BEARING LINES*******
******************************************************************************************************************
******************************************************************************************************************
Intersection between Sensors:
Sensor:TRIKALA  Cooordinates LAT:  39.332007  LON:  21.460192  Bearing:  134.0
 and Sensor:KARDITSA  Cooordinates LAT:  39.215116  LON:  21.551476  Bearing:  127.0

 Coordinates of Sensors Intersection point are: LAT:  39.043671242686386  LON:  21.843789055359192
TRIANGULATES
Third Sensor name is: ALMIROS
Third Sensor name is: ALMIROS
 with the intersection between Sensors:
  Sensor:  TRIKALA  Cooordinates LAT:  39.332007  LON:  21.460192  Bearing:  134.0
  and Sensor: ALMIROS  Cooordinates LAT:  39.105552  LON:  22.453287  Bearing:  260.0
Intersection point Coordinates are: LAT:  39.02414006284698  LON:  21.86959961845039
Bearing from previous point and point 2 is: 127.63144829540425

IntersectionsMinusMinusCounter is: 1

-----------          IntersectionsCounter is          ----------------:2
39.02414006284698
21.86959961845039
1.0
Distance between Sensors intersection points is:1.0

*********The distance between the intersection points is within given limit**********
*********************************************************************************************************************
*********************
```

************ "TRIANGULATION IS HIGH" ************
****
****

39.47886714537797
21.09649413913801
4.0
Distance between Sensors intersection points is:4.0
*********The distance between the intersection points is within given limit**********
************** Triangulation is MEDIUM **************
Elements θ13:131.0
Elements θ23:264.0
Element φ1:39.215116
Element λ1:21.551476
Element φ2:-39.109725734001806
Element λ2:-157.51617838792632
Element φ3:39.105552
Element λ3:22.453287
**********************Before if loop CheckBrng1:277.9999999999996
******************Bearing2 = true*******************
******************θ23 - 2*x - epsilon = :259.5
******************θ23 + epsilon = :264.5
******************Before if loop CheckBrng2:259.9999999999629
The point is out of the Polygon
-39.109725734001806
-157.51617838792632
10770.0
Distance between Sensors intersection points is:10770.0

Elements θ23:294.0
Element φ1:39.215116
Element λ1:21.551476
Element φ2:39.11876510768008
Element λ2:22.406462328810814
Element φ3:39.105552
Element λ3:22.453287
**********************Before if loop CheckBrng1:97.99999999999926
******************Bearing2 = true*******************
******************θ23 - 2*x - epsilon = :289.5
******************θ23 + epsilon = :294.5
******************Before if loop CheckBrng2:289.99999999998886
The point is out of the Polygon
39.11876510768008

22.406462328810814

64.0

Distance between Sensors intersection points is:64.0

Elements θ13:102.0

Elements θ13:264.0

Elements θ13:294.0

****

******

-------------   NUMBER OF TOTAL MINUS MINUS INTERSECTIONS IS: --------: 2

****

******

Sensor names are:

LARISSA

VOLOS

TRIKALA

KARDITSA

ALMIROS

Elements θ13:192.0

Elements θ23:247.0

Element φ1:39.382318

Element λ1:22.2507

Element φ2:38.845782593627355

Element λ2:22.10429846992545

Element φ3:39.214878

Element λ3:22.563111

Elements θ13:263.5

Elements θ23:138.0

Element φ1:39.214878

Element λ1:22.563111

Element φ2:39.13440146723301

Element λ2:21.689426578407783

Element φ3:39.332007

Element λ3:21.460192

******************Bearing1 = true*******************

**********************Before if loop CheckBrng1:263.50000000000017

******************Bearing2 = true*******************

******************Before if loop CheckBrng2:137.98591401609156

θ13: 261.5

CheckBrng1 if loop: 263.50000000000017

θ13 - x: 259.5

θ13 + x: 263.5

θ23: 136.0

CheckBrng2 if loop: 137.98591401609156

θ23 - x: 134.0

θ23 + x: 138.0

****

**************   THE POINT IS INSIDE THE POLYGON   *******

******* PLUS PLUS INTERSECTION POINT IS ON OR WITHIN BEARING LINES   ******

****

****

Intersection between Sensors:

Sensor:VOLOS Cooordinates LAT: 39.214878 LON: 22.563111 Bearing: 263.5

and Sensor:TRIKALA Cooordinates LAT: 39.332007 LON: 21.460192 Bearing: 134.0

Coordinates of Sensors Intersection point are: LAT: 39.13730664595106 LON: 21.719745760814078

TRIANGULATES

Third Sensor name is: KARDITSA

Third Sensor name is:KARDITSA

with the intersection between Sensors:

Sensor: VOLOS Cooordinates LAT: 39.214878 LON: 22.563111 Bearing: 263.5

and Sensor: KARDITSA Cooordinates LAT: 39.215116 LON: 21.551476 Bearing: 127.0

Intersection point Coordinates are: LAT: 39.13440146723301 LON: 21.689426578407783

Bearing from previous point and point 2 is:137.98591401609156

IntersectionsPlusMinusCounter is:0

-------------------- IntersectionsCounter is   -------------------:1

Elements θ13:102.0

Elements θ13:264.0

Elements θ13:294.0

****

------------- NUMBER OF TOTAL PLUS MINUS INTERSECTIONS IS: -----------: 1

****

39.0056697758775

22.182584708724992

10.0

Distance between Sensors intersection points is:10.0

Elements θ23:138.0

Element φ1:39.382318

Element λ1:22.2507

Element φ2:38.80988418362973

Element λ2:22.147466572065888

Element φ3:39.332007

Element λ3:21.460192

******************Bearing1 = true*******************

**********************Before if loop CheckBrng1:187.99999999999997

******************Bearing2 = true*******************

******************Before if loop CheckBrng2:134.16135552290916

θ13: 190.0

CheckBrng1 if loop: 187.99999999999997

θ13 - x: 188.0

θ13 + x: 192.0

θ23: 136.0

CheckBrng2 if loop: 134.16135552290916

θ23 - x: 134.0

θ23 + x: 138.0

****

************** THE POINT IS INSIDE THE POLYGON *******

****************************MINUS PLUS INTERSECTION POINT IS ON OR WITHIN BEARING LINES***************************

****

****

Intersection between Sensors:

Sensor:LARISSA Cooordinates LAT: 39.382318 LON: 22.2507 Bearing: 188.0

and Sensor:TRIKALA Cooordinates LAT: 39.332007 LON: 21.460192 Bearing: 138.0

Coordinates of Sensors Intersection point are: LAT: 38.74479136906733 LON: 22.135834023840967

TRIANGULATES

Third Sensor name is: KARDITSA

Third Sensor name is:KARDITSA

with the intersection between Sensors:

Sensor: LARISSA Cooordinates LAT: 39.382318 LON: 22.2507 Bearing: 188.0

and Sensor: KARDITSA Cooordinates LAT: 39.215116 LON: 21.551476 Bearing: 131.0

Intersection point Coordinates are: LAT: 38.80988418362973 LON: 22.147466572065888

Bearing from previous point and point 2 is:134.16135552290916

IntersectionsMinusPlusCounter is:0

--------------- IntersectionsMinusPlusCounter is ---------------:1

38.80988418362973

22.147466572065888

3.0

Distance between Sensors intersection points is:3.0

*********The distance between the intersection points is within given limit**********

****************   Triangulation is MEDIUM   ****************

39.10623144216951

22.200698853264736

6.0

Distance between Sensors intersection points is:6.0

Triangulation is LOW

39.08434172316638

22.19675142569938

16.0

Distance between Sensors intersection points is:16.0

39.18741609085832

22.215360736135736

.0

Distance between Sensors intersection points is:4.0

*********The distance between the intersection points is within given limit**********

***************   Triangulation is MEDIUM   ***************

39.106401972457114

22.235175469170485

2.0

Distance between Sensors intersection points is:2.0

*********The distance between the intersection points is within given limit**********

****

****

************   "TRIANGULATION IS HIGH"   ************

****

****

IntersectionPointCounter64

39.18586391913804

22.239633910100167

1.0

Distance between Sensors intersection points is:1.0

*********The distance between the intersection points is within given limit**********

****

***   "TRIANGULATION   IS   HIGH"

****

****

****

IntersectionPointCounter72

FourPlusIntersecionCounter is: 0

38.98473428680881

22.228368412029766

12.0

Distance between Sensors intersection points is:12.0

Elements θ23:138.0

Element φ1:39.382318

Element λ1:22.2507

Element φ2:38.7627853376492

Element λ2:22.216010921940352

Element φ3:39.332007

Element λ3:21.460192

******************Bearing1 = true*******************

**********************Before if loop CheckBrng1:182.49999999999918

******************Bearing2 = true*******************

******************Before if loop CheckBrng2:133.88105661379336

θ13: 184.5

CheckBrng1 if loop: 182.49999999999918

θ13 - x: 182.5

θ13 + x: 186.5

θ23: 136.0

CheckBrng2 if loop: 133.88105661379336

θ23 - x: 134.0

θ23 + x: 138.0

****

******* THE POINT IS INSIDE THE POLYGON *******

**********MINUS PLUS INTERSECTION POINT IS ON OR WITHIN BEARING LINES*******

****

****

Intersection between Sensors:

Sensor:LARISSA Cooordinates LAT: 39.382318 LON: 22.2507 Bearing: 182.5

and Sensor:TRIKALA Cooordinates LAT: 39.332007 LON: 21.460192 Bearing: 138.0

Coordinates of Sensors Intersection point are: LAT: 38.67832599993973 LON: 22.211328672493455

TRIANGULATES

Third Sensor name is: KARDITSA

Third Sensor name is:KARDITSA

Element o:0

with the intersection between Sensors:

Sensor: LARISSA Cooordinates LAT: 39.382318 LON: 22.2507 Bearing: 182.5

and Sensor: KARDITSA Cooordinates LAT: 39.215116 LON: 21.551476 Bearing: 131.0

Intersection point Coordinates are: LAT: 38.7627853376492 LON: 22.216010921940352

Bearing from previous point and point 2 is:133.88105661379336

IntersectionsMinusPlusCounter is:1

---------- IntersectionsMinusPlusCounter is ----------:2

38.7627853376492

22.216010921940352

5.0

Distance between Sensors intersection points is:5.0

*********The distance between the intersection points is within given limit*********

Triangulation is MEDIUM ***

39.10039651059441

22.234838924606084

6.0

Distance between Sensors intersection points is:6.0

Triangulation is LOW

39.179223118350144

22.239260922756127

4.0

Distance between Sensors intersection points is:4.0

*********The distance between the intersection points is within given limit**********

*************************** Triangulation is MEDIUM ***

Elements θ13:247.0

Elements θ23:138.0

Element φ1:39.214878

Element λ1:22.563111

Element φ2:38.96095918062085

Element λ2:21.92659198798938

Element φ3:39.332007

Element λ3:21.460192

******************Bearing1 = true*******************

**********************Before if loop CheckBrng1:243.00000000000068

******************Bearing2 = true*******************

******************Before if loop CheckBrng2:135.58273025296955

θ13: 245.0

CheckBrng1 if loop: 243.00000000000068

θ13 - x: 243.0

θ13 + x: 247.0

θ23: 136.0

CheckBrng2 if loop: 135.58273025296955

θ23 - x: 134.0

θ23 + x: 138.0

****

**************		THE POINT IS INSIDE THE POLYGON	**************

***********MINUS PLUS INTERSECTION POINT IS ON OR WITHIN BEARING LINES******

****

Intersection between Sensors:

Sensor:VOLOS Cooordinates LAT: 39.214878 LON: 22.563111 Bearing: 243.0

and Sensor:TRIKALA Cooordinates LAT: 39.332007 LON: 21.460192 Bearing: 138.0

Coordinates of Sensors Intersection point are: LAT: 38.95057652362675 LON: 21.900844436196042

TRIANGULATES

Third Sensor name is: KARDITSA

Third Sensor name is:KARDITSA

Element o:0

with the intersection between Sensors:

Sensor: VOLOS Cooordinates LAT: 39.214878 LON: 22.563111 Bearing: 243.0

and Sensor: KARDITSA Cooordinates LAT: 39.215116 LON: 21.551476 Bearing: 131.0

Intersection point Coordinates are: LAT: 38.96095918062085 LON: 21.92659198798938

Bearing from previous point and point 2 is:135.58273025296955

IntersectionsMinusPlusCounter is:2

----------------	IntersectionsMinusPlusCounter is	----------------:3

38.96095918062085

21.92659198798938

1.0

Distance between Sensors intersection points is:1.0

*********The distance between the intersection points is within given limit**********

****

****************	"TRIANGULATION	IS	HIGH"	**************

****

IntersectionPointCounter144

FourPlusIntersecionCounter is: 0

39.1361966931371

22.364451827881332

5.0

Distance between Sensors intersection points is:5.0

*********The distance between the intersection points is within given limit**********

**************Triangulation is MEDIUM	**************

39.09311986496419

21.736951397969705

23.0

Distance between Sensors intersection points is:23.0

Elements θ13:263.5

Elements θ23:138.0

Element φ1:39.214878

Element λ1:22.563111

Element φ2:39.09251922118985

Element λ2:21.732978504391003

Element φ3:39.332007

Element λ3:21.460192

******************Bearing1 = true******************

**********************Before if loop CheckBrng1:259.50000000000045

******************Bearing2 = true******************

******************Before if loop CheckBrng2:138.48401400951997

θ13: 261.5

CheckBrng1 if loop: 259.50000000000045

θ13 - x: 259.5

θ13 + x: 263.5

θ23: 136.0

CheckBrng2 if loop: 138.48401400951997

θ23 - x: 134.0

θ23 + x: 138.0

****

************ THE POINT IS INSIDE THE POLYGON **********

*******MINUS PLUS INTERSECTION POINT IS ON OR WITHIN BEARING LINES******

****

****

Intersection between Sensors:

Sensor:VOLOS Cooordinates LAT: 39.214878 LON: 22.563111 Bearing: 259.5

and Sensor:TRIKALA Cooordinates LAT: 39.332007 LON: 21.460192 Bearing: 138.0

Coordinates of Sensors Intersection point are: LAT: 39.09311986496419 LON: 21.736951397969705

TRIANGULATES

Third Sensor name is: KARDITSA

Third Sensor name is:KARDITSA

Element o:0

with the intersection between Sensors:

Sensor: VOLOS Cooordinates LAT: 39.214878 LON: 22.563111 Bearing: 259.5

and Sensor: KARDITSA Cooordinates LAT: 39.215116 LON: 21.551476 Bearing: 131.0

Intersection point Coordinates are: LAT: 39.09251922118985 LON: 21.732978504391003

Bearing from previous point and point 2 is:138.48401400951997

IntersectionsMinusPlusCounter is:3

------------------IntersectionsMinusPlusCounter is----------------------:4
39.09251922118985
21.732978504391003
0.0
Distance between Sensors intersection points is:0.0
*********The distance between the intersection points is within given limit**********
****
****
*********** "TRIANGULATION IS HIGH" **********
****
IntersectionPointCounter192
FourPlusIntersecionCounter is: 0
39.13619136395419
22.02438721077607
4.0
Distance between Sensors intersection points is:4.0
*********The distance between the intersection points is within given limit**********
************ Triangulation is MEDIUM ************

Elements θ23:294.0
Element φ1:39.214878
Element λ1:22.563111
Element φ2:39.201404327899304
Element λ2:21.634541132704058
Element φ3:39.105552
Element λ3:22.453287
**********************Before if loop CheckBrng1:269.2207096677621

Elements θ23:131.0
Element φ1:39.332007
Element λ1:21.460192
Element φ2:39.05313106241476
Element λ2:21.83128001540731
Element φ3:39.215116
Element λ3:21.551476

******************Bearing1 = true*******************
**********************Before if loop CheckBrng1:133.99999999999966
******************Bearing2 = true*******************
******************Before if loop CheckBrng2:126.64750856908347

θ13: 136.0
CheckBrng1 if loop: 133.99999999999966

θ13 - x: 134.0

θ13 + x: 138.0

θ23: 129.0

CheckBrng2 if loop: 126.64750856908347

θ23 - x: 127.0

θ23 + x: 131.0

****

**********THE POINT IS INSIDE THEPOLYGON***********************

*****MINUS PLUS INTERSECTION POINT IS ON OR WITHIN BEARING LINES *****

****

****

Intersection between Sensors:

Sensor: TRIKALA Cooordinates LAT: 39.332007 LON: 21.460192 Bearing: 134.0

and Sensor: KARDITSA Cooordinates LAT: 39.215116 LON: 21.551476 Bearing: 131.0

Coordinates of Sensors Intersection point are: LAT: 38.783829886132864 LON: 22.185402557295802

TRIANGULATES

Third Sensor name is: ALMIROS

Third Sensor name is:ALMIROS

Element o:0

with the intersection between Sensors:

Sensor: TRIKALA Cooordinates LAT: 39.332007 LON: 21.460192 Bearing: 134.0

and Sensor: ALMIROS Cooordinates LAT: 39.105552 LON: 22.453287 Bearing: 264.0

Intersection point Coordinates are: LAT: 39.05313106241476 LON: 21.83128001540731

Bearing from previous point and point 2 is:126.64750856908347

IntersectionsMinusPlusCounter is:4

------------------ IntersectionsMinusPlusCounter is -------------:5

39.05313106241476

21.83128001540731

23.0

Distance between Sensors intersection points is:23.0

****

----------- NUMBER OF TOTAL MINUS PLUS INTERSECTIONS IS: -------: 5

****

BUILD SUCCESSFUL (total time: 36 seconds)

Appendix B

Network Detection rate index

Another parameter that needs to be defined for a FSN for localization via triangulation is the Network Detection Rate (ND_{rate})index. Every network of SRs is affected by its SRs number and their topology. For this type of research which focuses on a FSN for localization with triangulation, the existing TRNs as it was shown previously affect its performance and might cause network saturation. Combining all these parameters we reach the Network detection rate concept ND_{rate} .

ND_{rate} can be defined as equation (3):

$$ND_{rate} = n - [(SR_{DF} + NB_{BL}(2-k)) + ETRNs]/3 \qquad (4.5)$$

where:

n is the number of SRs. In case we have a network with less than 100 SRs, then n = 100.

SR_{DF} is the Sensors Detection Failure and it is the number of SRs of the Network which will fail to detect TRs.

ETRNs is the number of existing triangulations

We define k as a quotient, $k = \frac{1}{ETRN_S}$ where: $0 < k < 1$,

assuming that as the number of ETRNs increases, then N_{BL} is affected. Assuming that we have a network of 25 SRs and a level of N_{BL} which is increased gradually from 17.6 to 48.8 and finally 80.16% then the Network detection rate is falling gradually as it is depicted in the following Table B-1. The network detection performance deterioration is sharp and the network performance becomes unacceptable.

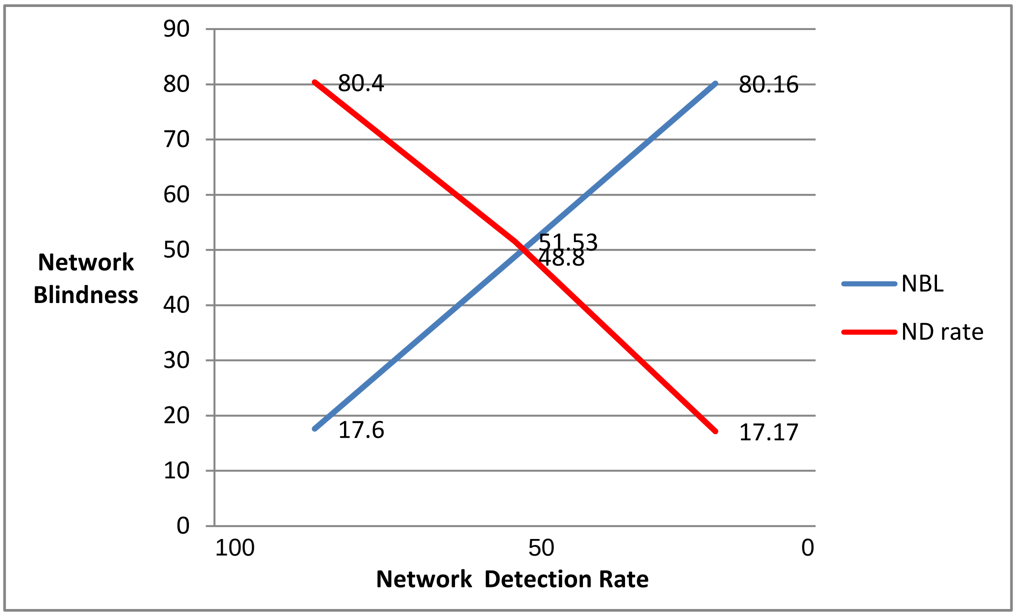

Table B-1 - Network blindness - Network detection rate graph

After applying the formula 4.5

$$ND_{rate} = n - [(SR_{DF} + NB_{BL}(2-k)) + ETRNs]/3 \qquad (4.5)$$

with relevant network blindness we find the Network detection rate NDrate as follows:

1.	**N_{BL} = 9.1%**	68 TRs TRNs	NDrate = 100 -[4 + 9.1(2- 1/68)+ 68]/3	71.31%
2.	**N_{BL} = 18.2%**	136 TRs TRNs	NDrate = 100 -[4 + 18.2(2- 1/136)+ 136]/3	41.25%
3.	**N_{BL} = 36.4%**	272 TRs TRNs	NDrate = 100 -[4 + 36.4(2- 1/272)+ 272]/3	0

1.	**N_{BL} = 9.1%**	68 TRs TRNs	**NDrate = 71.31%**
2.	**N_{BL} = 18.2%**	136 TRs TRNs	**NDrate = 41.25%**
3.	**N_{BL} = 36.4%**	272 TRs TRNs	**NDrate = 0**

In the following Table B-2 it is depicted how the Network detection rate is reduced and eventually becomes zero.

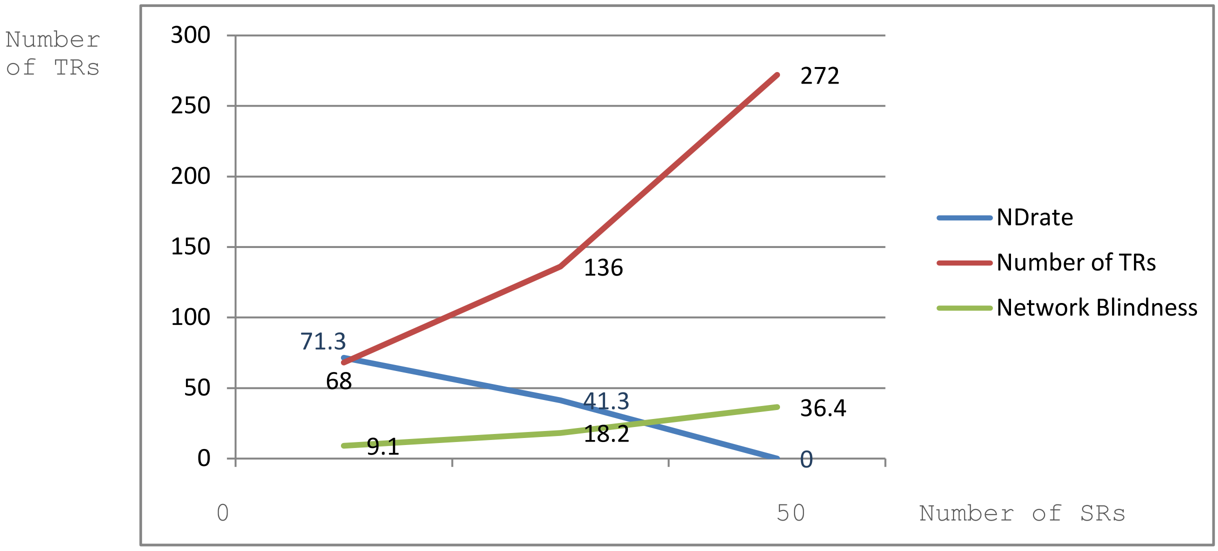

Table B-2 - Network detection rate and Network blindness analogous with the number of transmitters TRs

In the following Figure 1 (it is depicted) the visualization of Veness code for finding the intersection point coordinates of two bearing lines is depicted

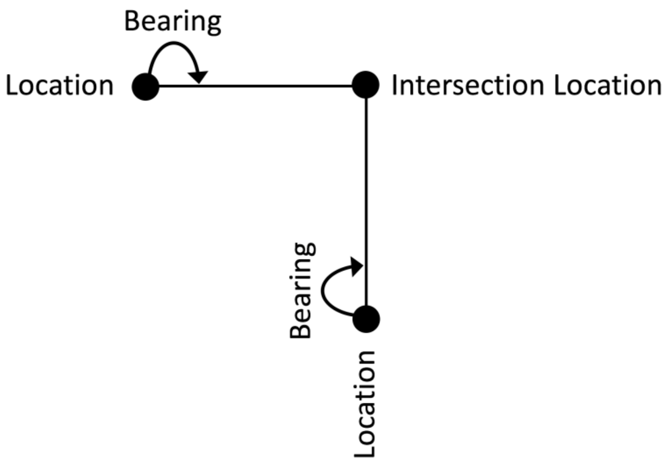

Figure B-1 Veness code used for the triangulations FSN system software

if ((CheckBrng1 == θ13 - x) || (CheckBrng1 == θ13+ x) || (θ13 - x < CheckBrng1) && (CheckBrng1 < θ13 + x)

&&

(CheckBrng2 == θ23 - x) || (CheckBrng2 == θ23 + x) || (θ23 - x < CheckBrng2) && (CheckBrng2 < θ23 + x)) where CheckBrng1 and CheckBrng2 are the bearings θ13, θ23 from Sensor 1 Coordinates, Point 1 and Sensor 2 Coordinates Point 2 related (with) to the intersection point Point 3 as it is depicted in Fig. 3.13 and Fig. 3.14 (a),(b),(c).

Fuzzy logic based localization to minimize system blindness-saturation

As it was analyzed in the previous thesis chapters, one of the fundamental issues with which the system has to deal with, is the problem of saturation. The fuzzy logic theory can enable the system to become more flexible and adaptive, keeping its performance at a high rate. As the system operates and its status changes from state to state, depending on the number of TRs which appear, the FSN ought to examine automatically the saturation level and intervene appropriately. Blindness of SRs due to saturation ought to be processed continuously allowing (for) the system's intervention. A Fuzzy logic method is then applied to the system keeping its operational performance on a satisfactory level.

Working Principle

In this FSN system for localization we have to face the high saturation rate. This concept is similar to the problem of heat in a room. As with the case in which a system has to deal with room temperature, the FSN system has to deal with area saturation and detection degradation.

The Fuzzy logic system consists of four main parts:

· Fuzzifier
· Rules
· Intelligence
· Defuzzifier

In the FSN system a central hub calculates all data from SRs continuously and applies the Fuzzification and Defuzzification process in order to de-saturate the system. The Fuzzy logic methodology dealing with blindness issues is analyzed in this section. The general architecture and the components of a Fuzzy logic system are depicted in Fig. B-2, [44].

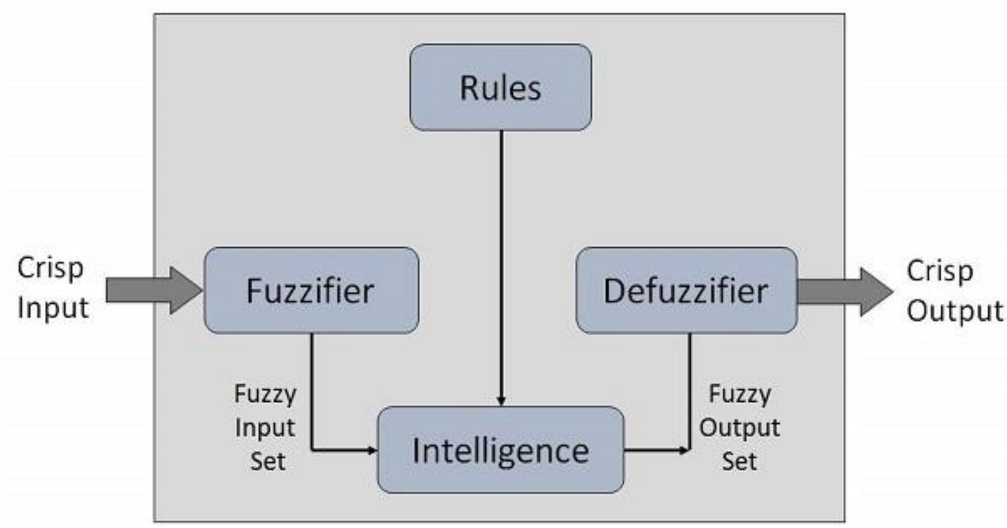

Figure B-2 - Fuzzy logic system [44]

FSN fuzzy logic Saturation Control System

Fig.B-3 shows the FSN fuzzy logic Saturation Control System. The FSN sets a saturation target as an input and the fuzzy controller after comparing that value with the current saturation level instructs the FSN system about de-saturation or no change. In Table B-3 we have the Fuzzy logic algorithm that the system applies in order to perform de-saturation.

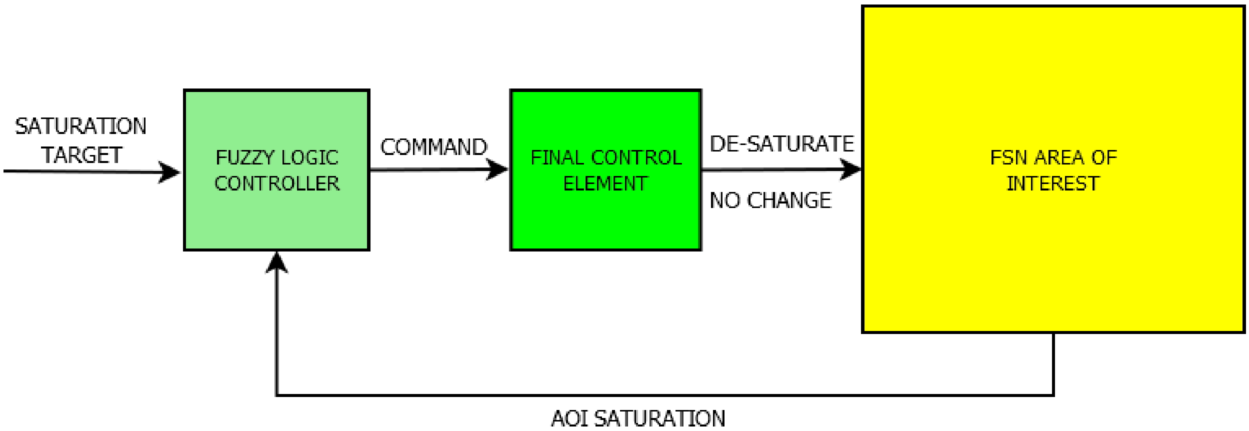

Figure B-3 - FSN fuzzy logic Saturation Control System

Fuzzy logic Algorithm	
1.	Definition of linguistic variables and terms
2.	Membership function construction
3.	Rule base construction
4.	Conversion of crisp data to fuzzy values using the membership function
5.	Rule base evaluation
6.	Rule base results evaluation
7.	Conversion of crisp data to non Fuzzy values

Table B-3 Fuzzy logic algorithm

Fuzzy Set

In Fuzzy logic, a basic concept that needs to be taken into consideration is the concept of Set. Objects having one or more similar characteristics can be collected and classified into a Set. In any system the system designer evaluates the data and its set membership till a satisfactory classification is done. Objects belonging to a set are called members of the set. In fuzzy, a set members have their own membership grade associated with it [43]. In our FSN system membership classification is shown in Table B-4.

Fuzzy variable input range		Fuzzy variable name
1	0-25	Very Low Saturated -VLS
2	20-45	Low Saturated - LS
3	40-65	Medium Saturated - MS
4	60-85	High Saturated - HS
5	80-100	Very High Saturated - VHS

Table B-4 - FSN system membership classification

Membership Functions

Fig.B.4 shows the membership for our FSN system. The membership sets appear in different colors and we can clearly see that the worst case of a very high saturated area is shown in red.

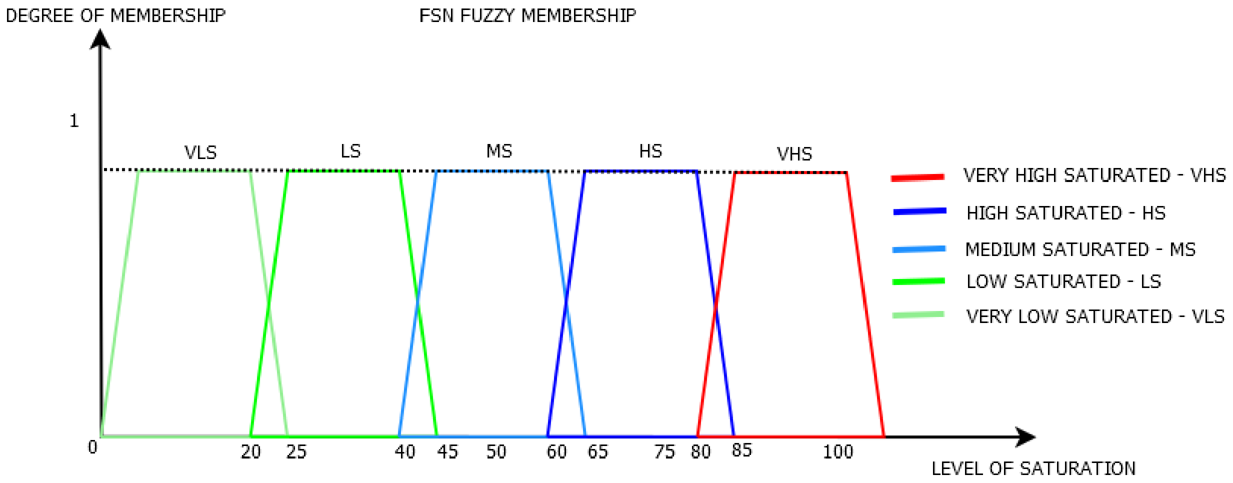

Figure B-4 - Membership Functions for S (Saturation) = {Very Low Saturated - VLS, Low Saturated - LS, Medium Saturated - MS, High Saturated - HS, Very High Saturated - VHS}

Fuzzification of Input

Fuzzification is the process of making a crisp quantity fuzzy and it's done by the Fuzzifier, whilst Defuzzification is done by a decision-making algorithm that selects the best crisp value based on a fuzzy set, and it's done by the Defuzzifier. During the fuzzification process, the real scalar values changes to fuzzy values. Arrangements of Fuzzy variables ensure that real values get translated into fuzzy values. The outcome after translating those real values into fuzzy values, is called “linguistic terms”. The input linguistic variables for Fuzzy Logic implemented in the FSN system suggest two things: **First**, it shows linguistically the difference between the set point and **second,** express the measured and calculated saturation level in one area. For fuzzified input, one triangular function is used. (To determine) Determining the range of fuzzy variables according to the crisp inputs is the primary requirement for proper running of the fuzzier program.

Fuzzy Membership Functions for Outputs

The output linguistic variables express linguistically the applied values to the FSN central processing unit for saturation control. In our case it is essential to attribute fuzzy memberships to yield variable, which has to be identical to the input variable. The fuzzy sets used for our FSN system are depicted in the following Table B-3:

	Fuzzy variable output range	Corresponding	Fuzzy variable name
1	0-25	0-25%	Very Low Saturated - VLS
2	20-45	20-45%	Low Saturated - LS
3	40-65	40-65%	Medium Saturated - MS
4	60-85	60-85%	High Saturated - HS
5	80-100	80-100%	Very High Saturated - VHS

Table B.3 - Output linguistic variables.

Fuzzy Rules

In Fuzzy Logic, a rule base is constructed to control the output variable. A fuzzy rule is a simple IF-THEN rule with a condition and a conclusion. In Table B-5, we have a sample of the fuzzy rules for the FSN for localization via TRN control system. Table B-6, is a matrix representation of the fuzzy rules for the so called, Fuzzy logic. Row captions in the matrix, contain the values that the current saturation can take. Column captions contain the values for target saturation. Each cell (row, column) is the resulting command when the input variables take the values in that row and column. For instance, the cell (4,3) in the matrix can be read as follows: If saturation is MEDIUM and target is LOW then the command Decrease R (de-saturate) is applied to the system.

Fuzzy Rules	IF-THEN rule with Condition and Conclusion
1	IF saturation is MEDIUM AND Target is Low then Command is Decrease R
2	IF saturation is HIGH AND Target is MEDIUM OR LOW then Command is Decrease R
3	IF saturation is VERY HIGH AND Target is MEDIUM OR LOW then Command is Decrease R

Table B-5 Sample fuzzy rules for FSN saturation control system

TARGET NETWORK SATURATION	VERY LOW SATURATED	LOW SATURATED	MEDIUM SATURATED
VERY LOW SATURATED	Increase R	Increase R	Increase R
LOW SATURATED	Decrease R	Increase R	Increase R
MEDIUM SATURATED	Decrease R	Decrease R	Increase R
HIGH SATURATED	Decrease R	Decrease R	Decrease R
VERY HIGH SATURATED	Decrease R	Decrease R	Decrease R

Table B-6 Matrix representation for FSN saturation control system

Rule block

After the fuzzification of the current values of the input variables, the system fuzzy controller continues with the phase of "decision making," or deciding what actions to activate to bring the saturation level to the desired set point value. For the action to be initiated, the measures are of minimal time as well as minimal saturation which might be achieved combined with best possible coverage, except if another input order has been given to the system. The system should execute de-saturation in an area or apply a combination methodology for de-saturation in many sub-areas in order to enable the system to keep its performance high.

Defuzzification

The Fuzzy Logic Controller forward data information to the Defuzzifier which performs initial processing of the system status and afterwards (feed with information the central hub) OR gives feedback to the central hub/ provides feedback to the central hub. As it is depicted in Fig.B-5, the central hub initiates the AOI de-saturation procedure if necessary. The system gradually decreases the radius R of the blinded SRs till their blindness is decreased resulting in area de-saturation. Then the system applies the optimal value of R for each SR in the saturated area in order to achieve the best coverage combined with de-saturation. The key that the system applies is the same with the one presented in chapter 5 paragraph 5.4, whilst in this case its application results in de-saturation in combination with coverage performance maintenance. So the system, produces crisp data as a result of the optimization methodology. Then, the crisp data are forward backwards to the system and the Fuzzy Logic Controller. At the end of this process, the system re-calculates the overall area saturation and finds the system's current value of saturation.

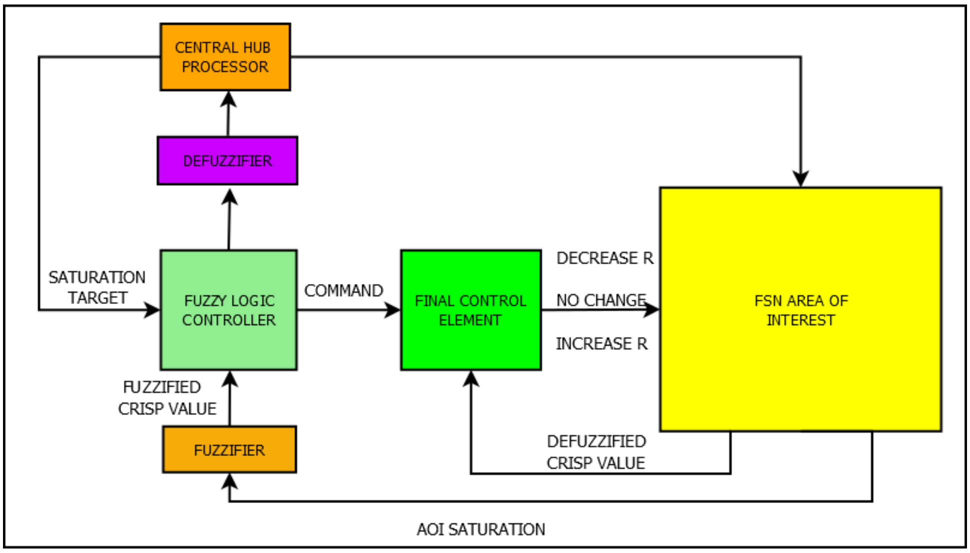

Figure B-5 FSN Defuzzication flow diagram

If that value lies within the desired output Fuzzy values, then that crisp value of blindness is the crisp output value of the system. This methodology is named Sensors Network Fuzzy Logic Saturation Control System - FSNFLSCS. In Fig. B.6 we have the depiction of the FSN Defuzzification Radius mode of operation for De-saturation. The seven SRs for each square of the AOI as it is depicted in Fig.4.8 of the **4th chapter**, increases their radius R.

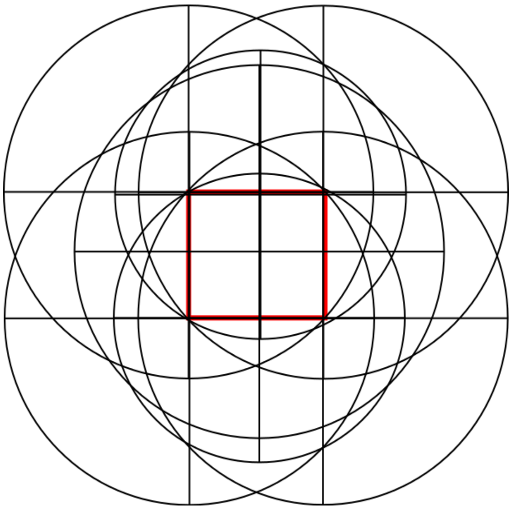

Figure B-6 FSN Defuzzification mode for De-Saturation

The R of the five SRs (four in the corners and one in the middle) is increased till the corner of square diagonal. The other two that lies on the center of the two opposite sides (upper and lower) of the square, increase their radius R also till the opposite corner, Fig.B-7.

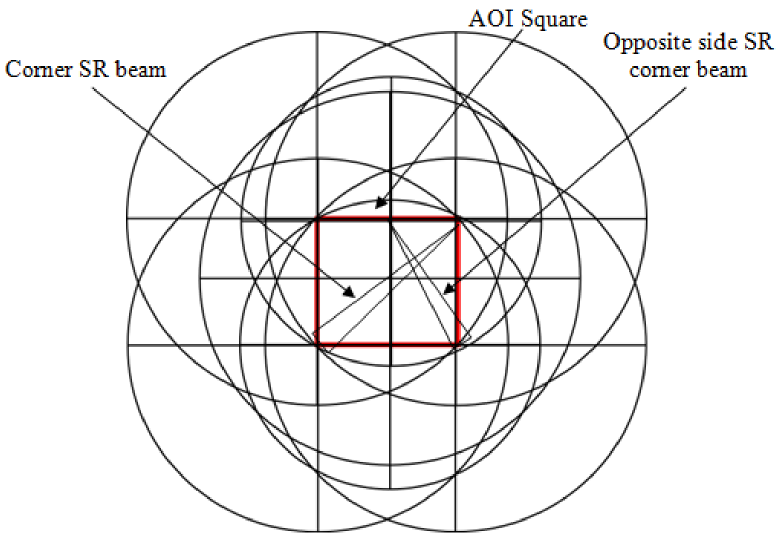

Figure B-7 - FSN Defuzzification mode for De-Saturation - SRs Radius R mode of operation

FSN AOI partition

In the following Fig.5.38 we have the depiction of the FSN AOI divided in four main sub-areas. The FSN system in order to simplify the procedure of network de-saturation is processing each of the four subareas individually, after checking in each state the total network saturation level. The algorithm used for this is depicted in Table B-7.

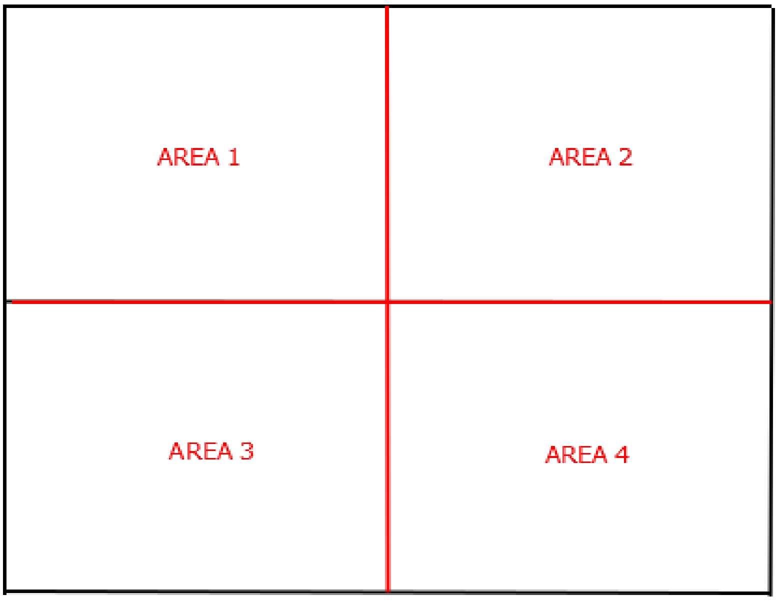

Figure B-8 FSN AOI division. System applies Fuzzy logic algorithm for de-saturation in each main sub-area.

FSN Fuzzy logic de-saturation Algorithm	
1.	System check, the total saturation
2.	If the total saturation is below the chosen value THEN no rules apply. IF the total saturation is bigger than the chosen value the system check each sub-area of the four sub-areas.
3.	System check sub-area 1 SATURATED YES OR NO The System informs the Controller
4.	System check sub-area 2 SATURATED YES OR NO The System informs the Controller
5.	System check sub-area 3 SATURATED YES OR NO The System informs the Controller
6.	System check sub-area 4 SATURATED YES OR NO The System informs the Controller
7.	If the system find a saturated area or areas activates the fuzzy logic methodology implementation for that area.

Table B-7 FSN Fuzzy logic de-saturation Algorithm

FSN Fuzzy logic De-Saturation methodology of adjacent areas

The FSN has a number of SRs which are depicted in Fig.B-9. In each of the sixteen sub-areas seven SRs for localization via triangulation are participating, as it can be seen in chapter 4, Fig.4.8. The SRs mode of operation was analyzed in paragraph 5.10.8. In Fig.B-10 we have the depiction of the saturated sub-areas of the AOI. The remaining sub-areas are LOW saturated. All the saturated sub-areas belong to area 3 of the AOI. The system applies the adjustment areas methodology to decrease the saturation problem which is depicted in Fig.5.41. SRs apply the mode of operation which was described in the de-fuzzification process in paragraph 5.10.8. and the FSN system achieves de-saturation in combination with high performance of coverage. This case of saturation is a case related with the one fourth of the AOI.

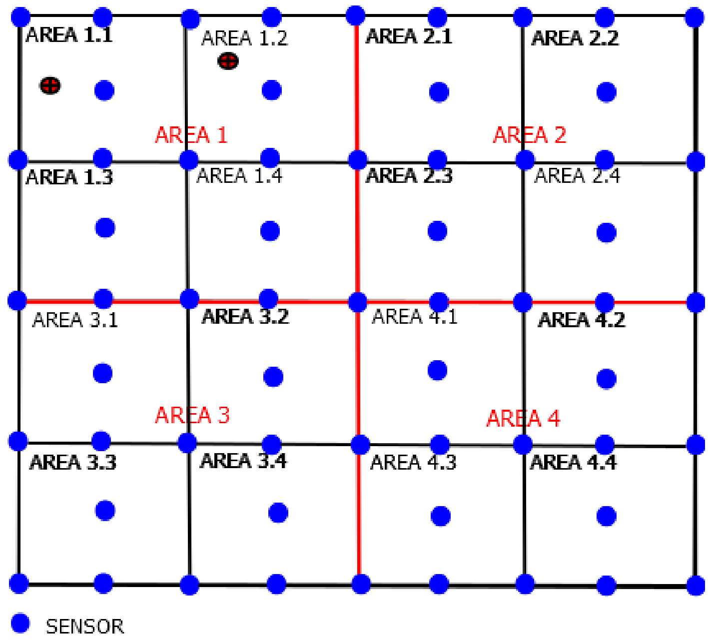

Figure B-9 FSN AOI divided in sixteen sub-areas with SRs. Each square has seven SRs for TR detection via TRN

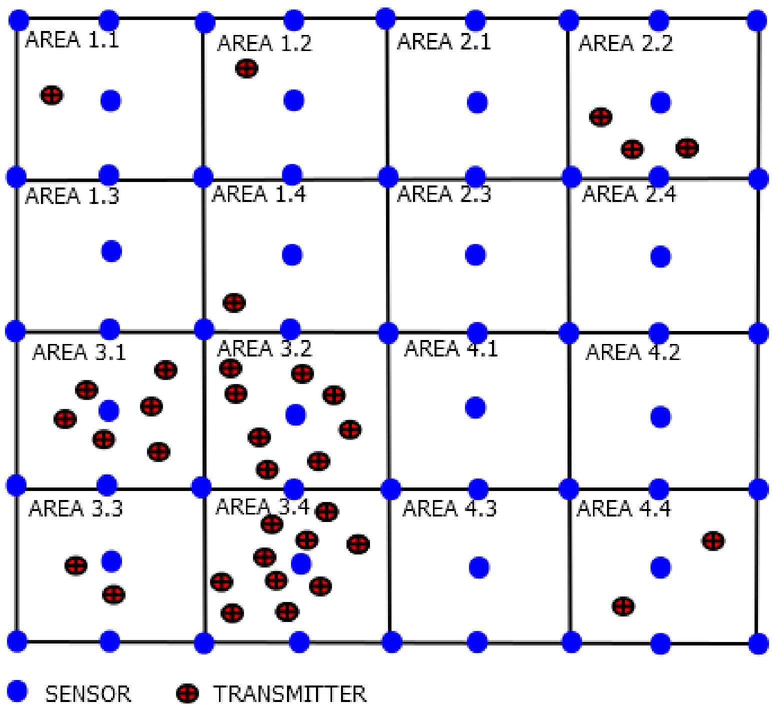

Figure B-10 - FSN AOI saturated case. Area 3 is saturated with many TRs

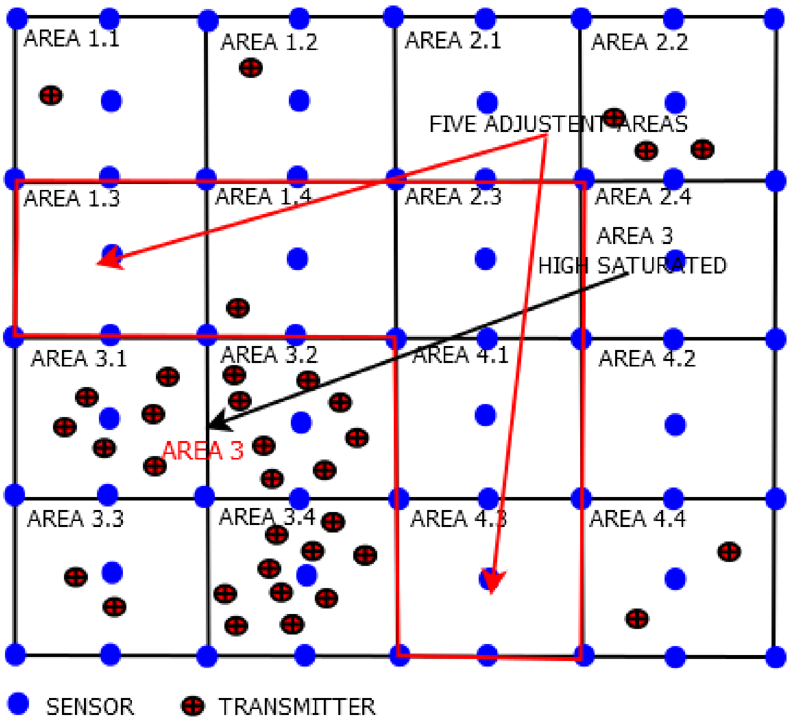

Figure B-11 FSN AOI saturated case. Area 3 is saturated with many TRs. The system applies the method of adjacent areas to decrease the coverage problem.

In other cases that we have saturation of a single sub-area of the AOI, the system is processing a different and analogous approach of the adjacent areas methodology. Such a case where we have a combination of two saturated sub-areas is depicted in Fig.B-12. The system calculates the number of the adjacent areas and use them in order to enable the de-saturation process to be executed. In this particular case it uses the adjacent areas SRs in order to cover the saturated area. For the sub-area 2.2 it uses three adjacent sub-areas (2.1,2.3,2.4) and for sub-area 4.1 uses another three sub-areas(3.2,3.4,4.3). Those SRs extend their radius R till the diagonal corner of the saturated area.

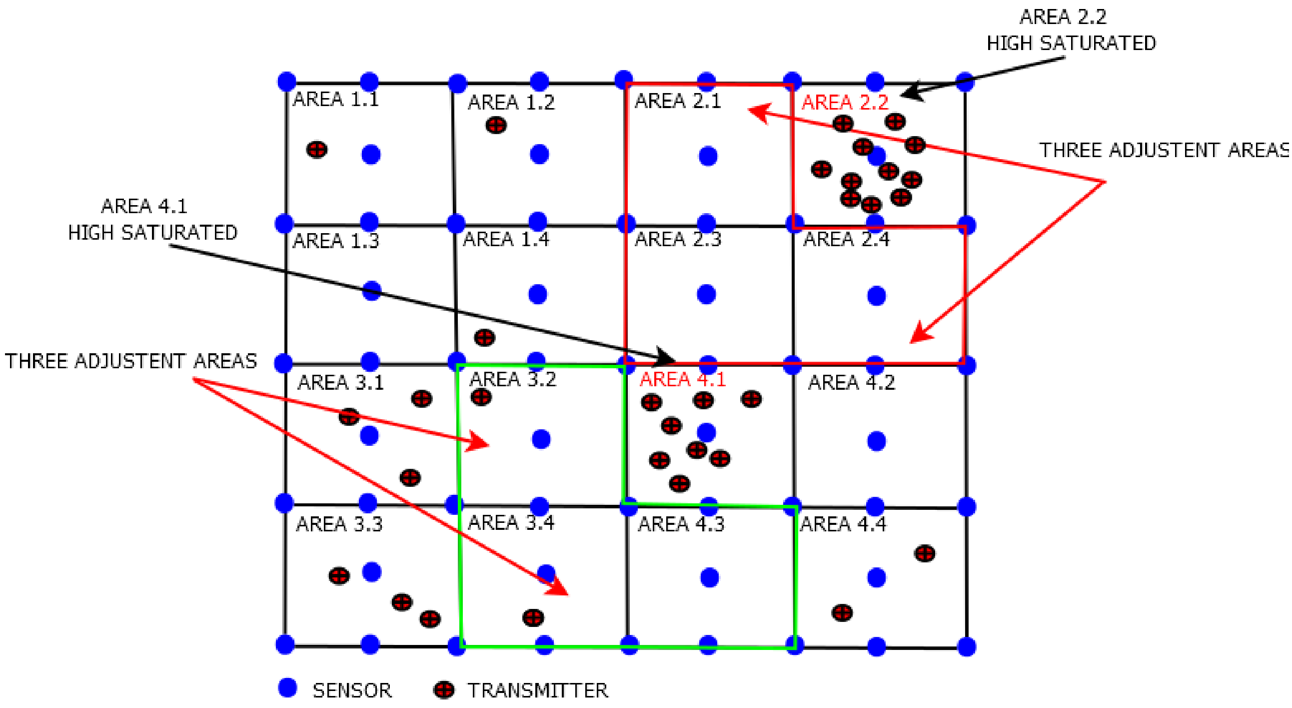

Figure B-12 FSN AOI saturated case. Sub-areas 2.2 and 4.1 are saturated with many TRs. The system applies the method of adjacent areas to decrease the coverage problem.

In the following Fig.B-13 we have the depiction of the FSN system AOI surveillance mode without the adjacent SRs mode.

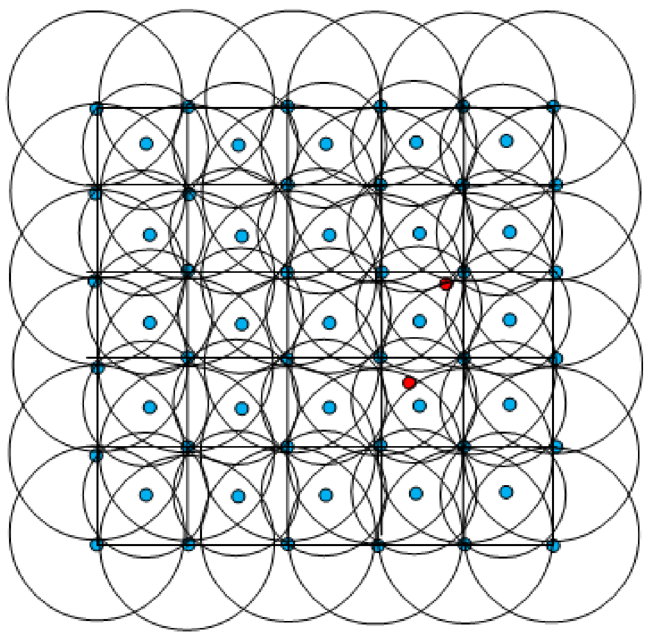

Figure B-13 FSN system surveillance mode without activation of adjacent SRs mode.

When the adjacent SRs mode is activated SRs are doubling their radius R, resulting in additional covered area as it is depicted in Fig.B-14. That way, additional area is covered and problematic non covered areas are covered from adjacent SRs.

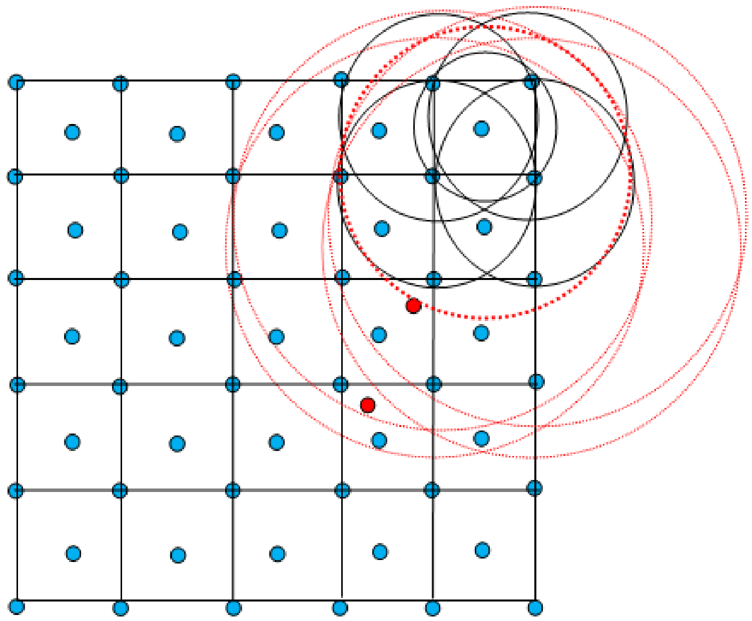

Figure B-14 FSN system radius R, SRs radius increase

In the following Fig.B-15, we have the depiction of a saturated area (TRs are in red) and we see the expanded radius R of the adjacent SRs. The FSN system by applying the expanded radius R covers the problematic area. As we can see, not all the adjacent SRs are activated in this mode, but the system determines the amount of SRs to activate on the basis of the saturation level and area of saturation.

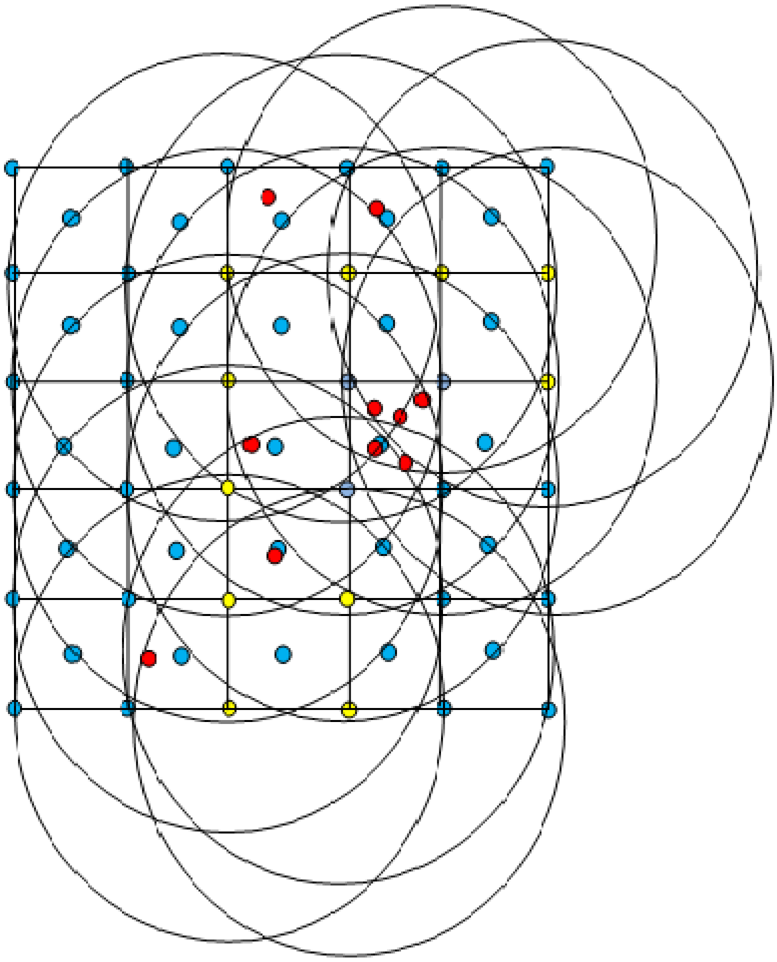

Figure B-15 The FSN system increases the radius R of adjacent SRs to decrease the coverage problem.

Results of Fuzzy Logic implementation on the System

Network Topology

In order to prove the Fuzzy Logic concept on this particular FSN system we used two network grids. The first is a grid subarea of the network with seven SRs, which appears in Fig.B-16. The second is the one fourth of the full AOI of the network where 19 SRs participate by applying the adjacent areas algorithm on a problematic and saturated area Fig.B-17 It is shown that as the system applies this methodology it can achieve de-saturation and keep a high rate of performance.

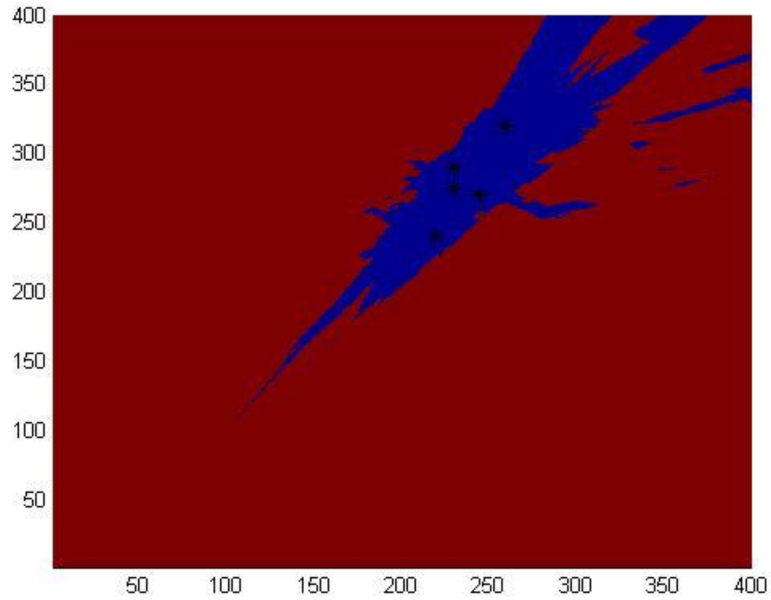

Figure B-16 AOI 7SRs - 5TRs Coverage - Radius 350

In the following Fig.17 we see how the coverage of the AOI and the problematic sub-area is increased after the activation of Adjacent Areas Algorithm.

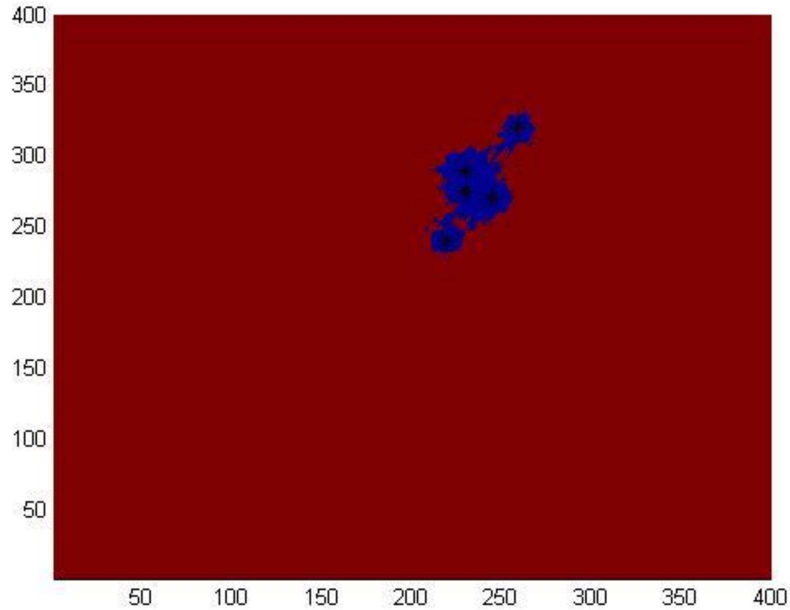

Figure B-17 Adjacent Areas Algorithm AOI Sub Area 19SRs and 5TRs Coverage - Radius 350

In the following Fig. B-18 we see the coverage with 19 SRs and 7TRs. Again we see that we have a high level of coverage.

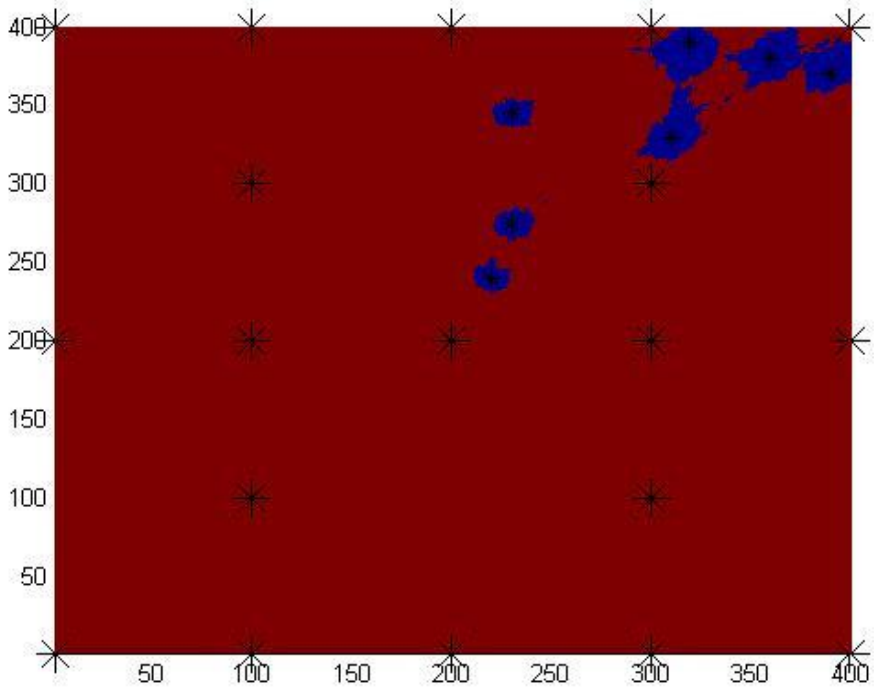

Figure B-18 AOI 19SRs - 7TRs Coverage

In the following Fig. B-19-B-20 we see how coverage is affected with the increase of transmitters.

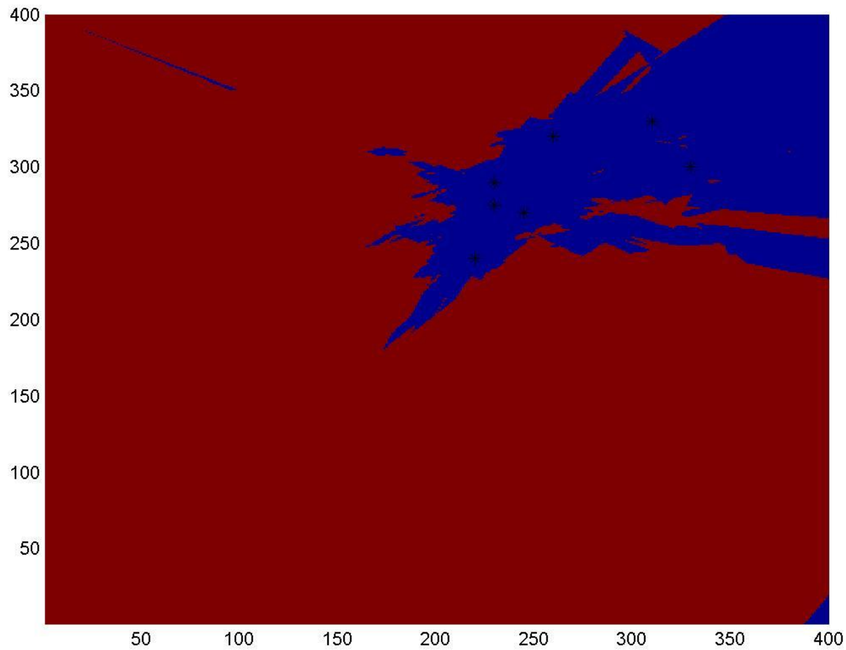

Figure B-19 AOI 7SRs - 7TRs Coverage - Radius 350

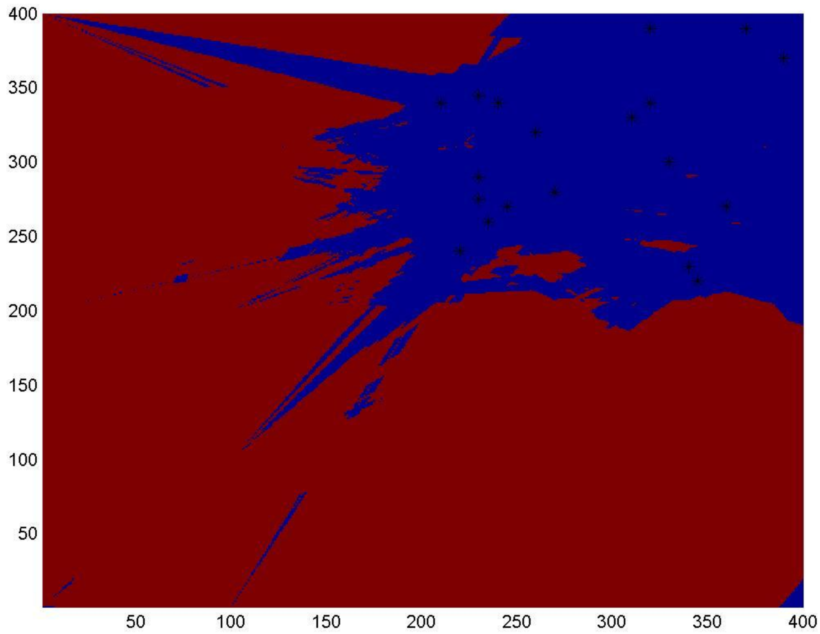

Figure B-20 AOI 7SRs - 20TRs Coverage - Radius 350

In the following figures, Fig B-21 to B-26 we see how the relative coverage in the FSN is affected in relevance with radius R. With various combinations of SRs and transmitters we see that the optimal radius R is varying and it is strongly affected from the number of transmitters.

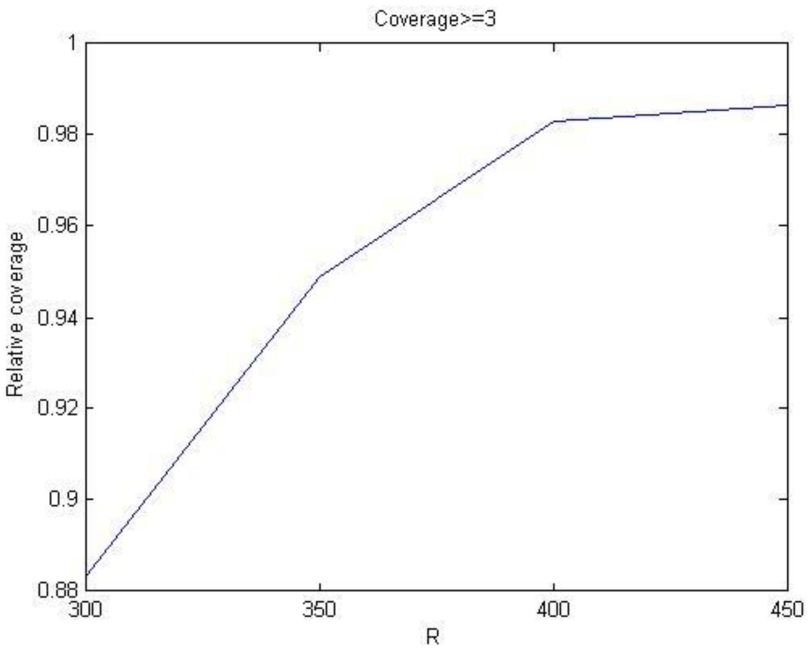

Figure B-21 AOI 7SRs - 7TRs Radius- Coverage Plot

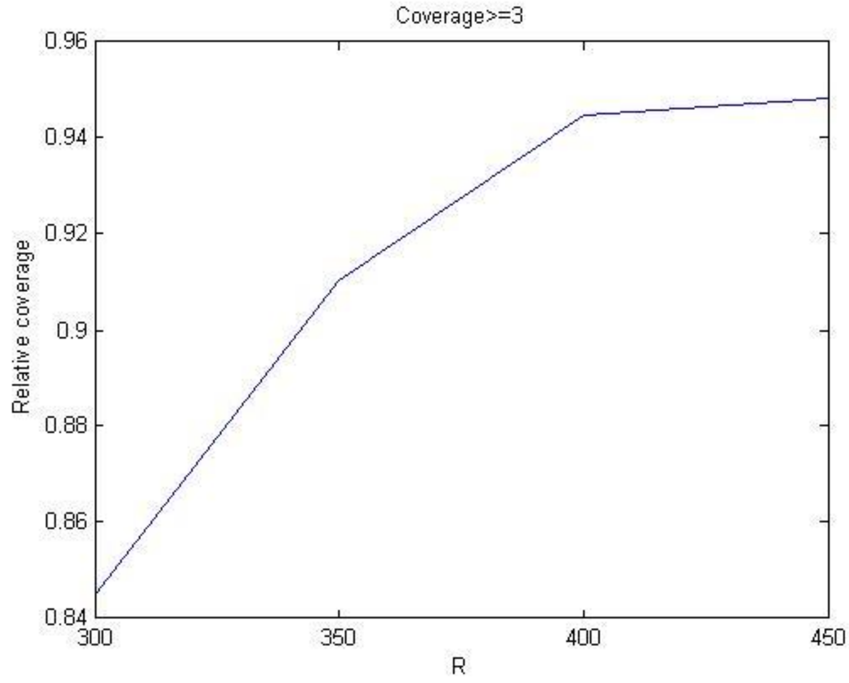

Figure B-22 AOI 7SRs - 12TRs Radius- Coverage Plot

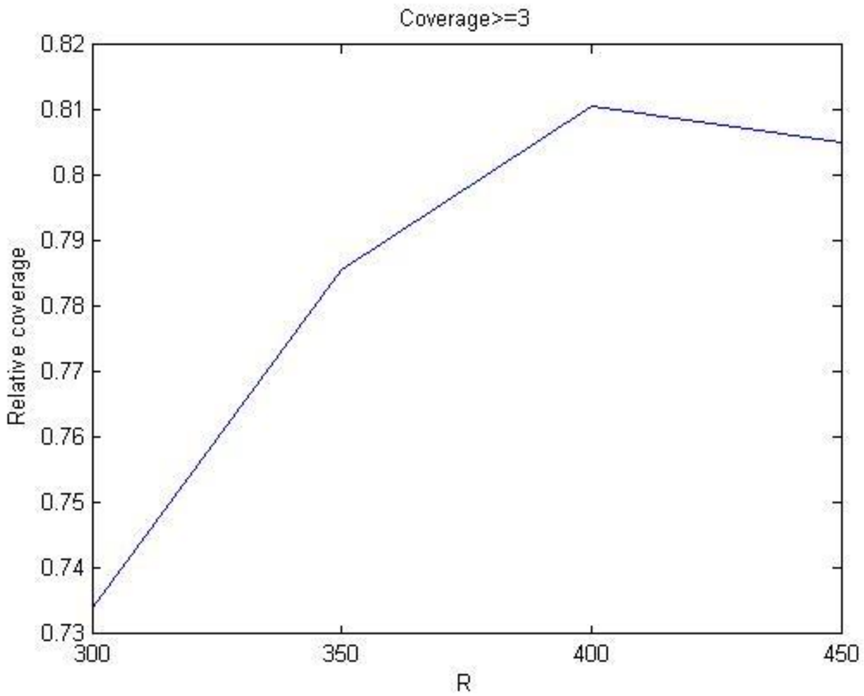

Figure B-23 AOI 7SRs - 20TRs Radius- Coverage Plot

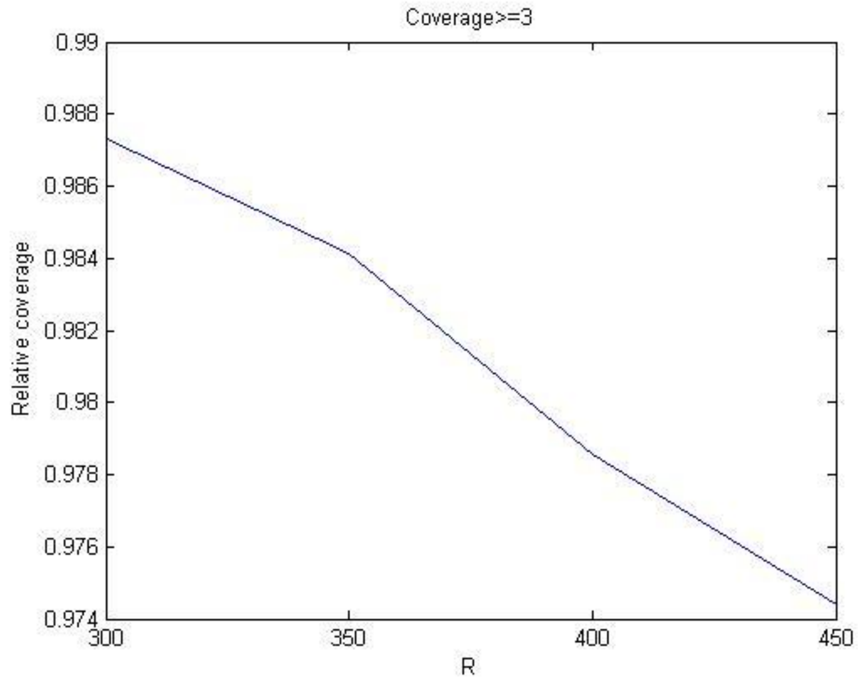

Figure B-24 AOI 19 SRs - 7TRs Radius- Coverage Plot

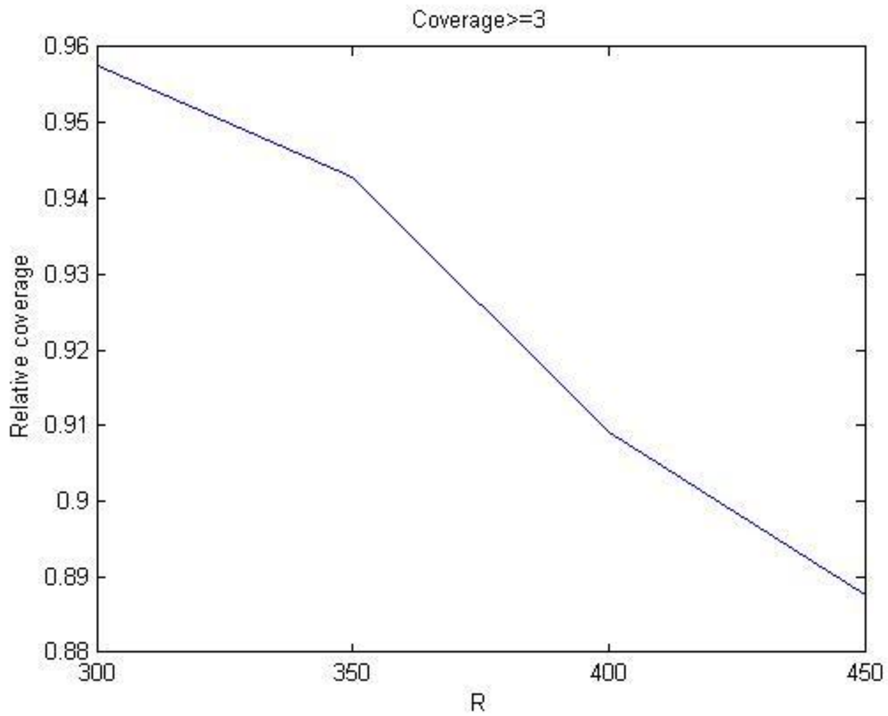

Figure B-25 AOI 19 SRs - 12TRs Radius - Coverage Plot

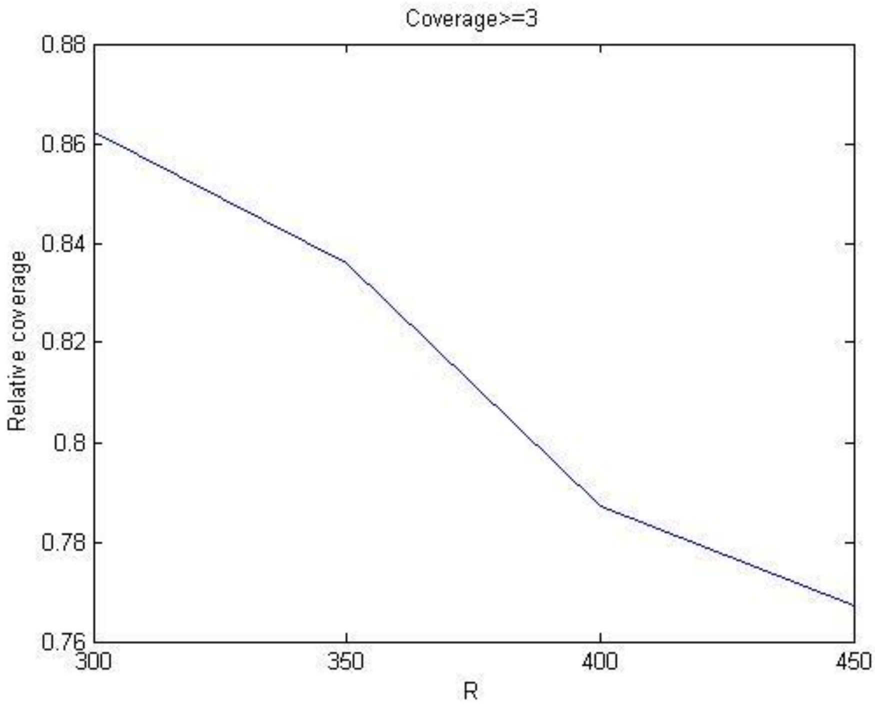

Figure B-26 AOI 19 SRs - 20TRs Radius - Coverage Plot

In the following Fig.B-27 we see that even with the activation of 19 SRs of the adjacent areas the coverage is strongly affected from the high number of transmitters.

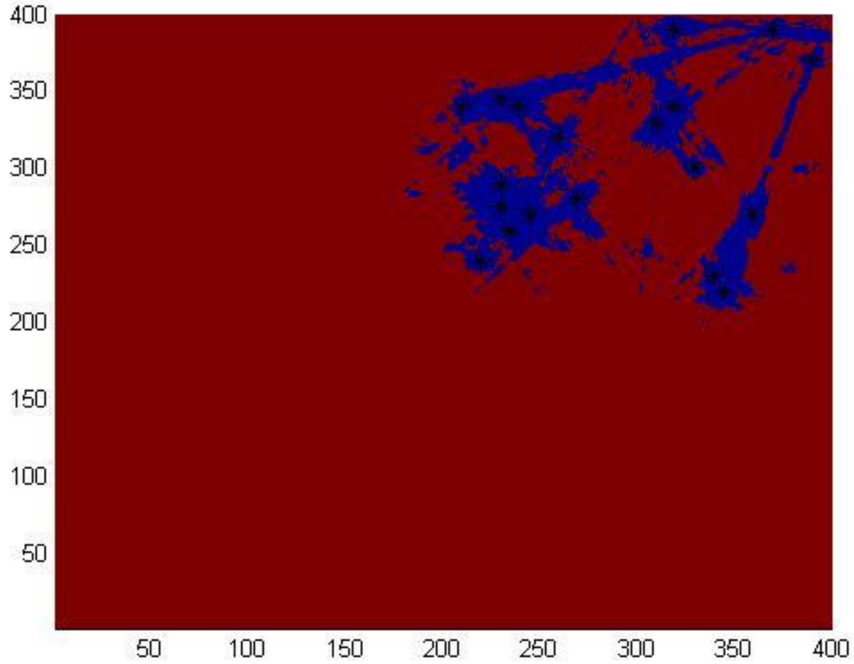

Figure B-27 Adjacent Areas Algorithm AOI Sub Area
AOI 19SRs - 20TRs Coverage - Radius 450

Outcome of FSN saturation control using fuzzy logic

The FSN system in order to perform the localization via TRN of new TRs needs a high level of coverage in combination with a low level of saturation in the AOI. If one of these characteristics is deteriorated, then the possibility of missing a new TR is increased. The Fuzzy Logic theory implementation is enabling the FSN system to react as the level of saturation is increased, determining that coverage won't also decrease resulting in a saturated system with low coverage performance. The system by applying the adjacent area's methodology is enabling the adjacent SRs to cover problematic areas whilst the system is continuously measuring the level of de-saturation in its sub-area. This Fuzzy Logic implementation methodology plays a vital role in the FSN system performance. In every state the system is monitoring its state and from state to state.

Also, and as each sub-area of the AOI is processed, the FSN is able to determine if additional SRs are needed to be activated or the existed SRs are enough to keep the network's performance on a satisfactory level. This Fuzzy logic implementation scheme needs further examination and experiments in order to acquire more results for this particular type of system.