Area Coverage improvement of a Fixed Sensors Network System using Fuzzy Control

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Abstract: - This paper presents a novel work on localization of transmitters using triangulation with sensors at fixed positions. This is achieved when three or more sensors cover the whole area, a factor which enables the system to perform localization via triangulation. The network needs to keep a high detection rate which, in most cases, is achieved by adequate sensor coverage. Various tests using various grids of sensors have been carried out to investigate the way the system operates in different cases using a lot of transmitters. Detection complexity is tackled by finding the optimal detecting sensor radius in order for the network to continue operate normally. The coverage quality changes in the area of interest and the network is able to detect new transmitters that might enter the area of interest. It is also shown that as the number of transmitters increases the network keeps its high performance by using additional groups of sensors in a sub-region area of that of interest. This way, even when the network is saturated by many transmitters in one region, new transmitters can still be detected.

Keywords: Fixed Sensors Network, Triangulation, Localization, Sensor Blindness, Detection Range.

Received: July 13, 2021. Revised: May 26, 2022. Accepted: June 19, 2022. Published: August 3, 2022.

1.Introduction

In this research we are providing a solution to the problem of localization with the process of triangulation. The process of positioning with triangulation is currently under research for 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 was a fundamental research issue in WSNs. It was considered to be the measure of QoS for the sensing function of a sensor network [1]. The sensors are in fixed and known positions. So, we don't have to process the SRs positions which is also an issue of extensive research. The system has to process its state and acquire possible problematic areas of no-coverage to 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 adapt 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. In this paper, we'll 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 no coverage.

2. Related work

The issue of network Area of Interest - AOI coverage is of prime importance in order a FSN system of this type to be able to perform localization with triangulation. The deterioration of its performance based on coverage problems due to possible obstacles in the AOI and network is one of the main topics of this research. The fact that every SR of the FSN system participate individually on every single detection problem might arise for a number of existing TRs in its surrounding area. As shown in [1] SR blindness and Network blindness are two strongly bonded concepts with TRs detection. In WSNs systems used for positioning and localization, there are several factors of uncertainty which influence the Network detection performance, *Communication uncertainty, Sensing uncertainty and Data uncertainty* [2]. Among them the *Sensing uncertainty* is the category that we consider as the main problem that the FSN system of this type should focus aiming to a high detection rate with triangulation. Current research which implements Fuzzy logic theory for detection exists in many sectors including warning systems. Among them there is also the fire detection and warning systems. In [4], a Fire Monitoring and Warning System (FMWS) is presented based on Fuzzy Logic for the identification of a true existent and dangerous fire event sending alerts to the Fire Management System (FMS). Another important problem which exist in WSNs is energy consumption that has a direct effect on network operation and lifetime. In [5], a novel energy-efficient method which uses fuzzy logic applied on cluster heads (CH) of WSNs focusing on cluster formation process was presented. The proposed model, compared with the low-energy adaptive clustering hierarchy protocol, demonstrated that the proposed protocol improves network lifetime. In [6] authors estimated WSNs sensor node positions using a fuzzy logic algorithm. Although that a fuzzy controller and a specific defuzzification method was used, it was noted that there are still many fundamental problems which has to be solved for the development of WSNs technologies. In [7] a Fuzzy Logic Cluster Leach Protocol (FUZZY-LEACH), was applied that used a Fuzzy Logic Inference System (FIS) in the cluster process. It was demonstrated that by using multiple parameters in the cluster reduces energy consumption. Fuzzy logic in WSNs, improves decision-making, contributes to resource consumption and generally increase network performance through efficient deployment, localization, selection of cluster head, security, etc.[8]. And it was proved in [9] that fuzzy logic can provide more accurate event detection in a WSN that monitor a fire event (fire and smoke).

By far, the most fuzzy-based reasoning incorporated into fuzzy-based positioning systems is the Fuzzy inference. The most commonly employed aggregation functions are the Mamdani-type fuzzy inference system and weighted average (based on membership grade) in Takagi–Sugeno fuzzy inference system [12]. In [13] overlap functions and overlap indices were used to introduce a specific generalization of the Mamdani inference system. The Fuzzy method offered based on overlap indices aims for fire detection improvement through the use of a WSN and analysis of fire lightness and distance. Likewise, two Fuzzy techniques based on temporal properties are proposed in [14] for this aim. Again through the use of a WSN and the incorporation of Fuzzy logic in SR nodes evidence of fire are analyzed. But this time previous and present temperatures are evaluated and compared.

In [15] energy consumption of a WSN was explored by using a Fuzzy Genetic Algorithm (GA) Clustering and Ant Colony Optimization (ACO) routing. Fuzzy logic implementation designed to form the clusters and for clusters head selection. GA used for optimum fuzzy rules generation and tuning the output value of fuzzy logic's memberships whilst the proposed ACO used to route the information in the shortest path between the cluster heads to the base station (BS). The results showed that the energy level of single node was improved and the overall network lifetime was enhanced.

3. Problem Statement

This paper investigates how Fuzzy logic theory can be employed in this type of FSN system for localization with triangulation, aiming to increase its detection performance. In [1] it was shown that network saturation due to the presence of multiple TRs decrease network performance. Thus, we have to consider increasing network detection coverage and maintain detection performance in highly saturated environments due to multiple TRs. In WSNs Network coverage definition presupposes that each point in the Area of Interest AOI to be covered by at least one SR, ($k \geq 1$), were k is a constant representing the minimum required value of coverage [2]. In this particular type of FSN system the value of k should remain as possible in a value of k were $k \geq 3$ in the whole AOI, resulting in a high quality of network coverage. In this work it is shown that Fuzzy logic theory implementation is able to increase the FSN system coverage performance.

4. Network model and Grid topology

During various tests, the basic parameter used was the SR bearing which identifies a sensor (the bearing by which a SR detects a TR), which is considered to have a detection error $\pm D_{ER}$ for each SR. For this research many different grids were used for tests. Among them the most commonly used grids were: 1000 x 1000 m and 400 x 400 m grids. The m denotes a unit of length. The FSN system needs to have a high detection performance and deal with the phenomenon of saturation. The relevant optimization techniques and the network grid characteristics where presented in [10]. It was also shown that with extra SRs the system might increase detection rate thus enhancing performance. But it is vital for the network to develop more flexible ways by combining its adaptability with fuzzy logic theory to have a high detection rate.

5. Fuzzy logic based localization to minimize system saturation

As analyzed in [1], one of the fundamental issues the system has to deal with is the saturation issue. 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 need to examine automatically the saturation level and intervene appropriately. Blindness of SRs due to saturation needs to be processed continuously and on a case by case basis, allowing for system intervention. A Fuzzy logic method is then applied to the system keeping its operational performance on a satisfactory level.

5.1 Working Principle

In the FSN system for localization, sometimes we have to face the high saturation rate. This concept is similar with the problem of heat in a room. As with the case in which a system is monitoring a room temperature and has to deal with an increase in the room temperature, the FSN system has to deal with area saturation and detection degradation. That presupposes that the sensors network will acquire enough data inputs in order to define the relevant level of saturation.

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 shown in Fig.5.1, [14].

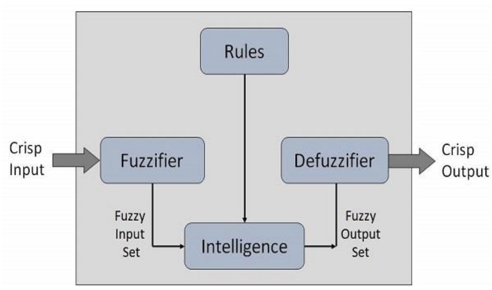

Figure 5.1 - Fuzzy logic system [10]

5.2 FSN fuzzy logic Saturation Control System

Fig.5.2 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.

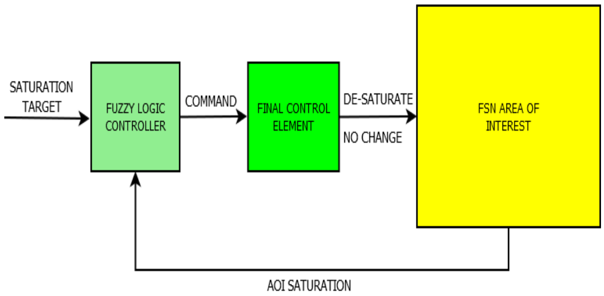

Figure 5.2 - FSN fuzzy logic Saturation Control System

In Table 5.1 depicted below, we have the Fuzzy logic algorithm that the system applies in order to perform de-saturation.

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 5.1 : Fuzzy logic algorithm

5.3 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 [17]. Membership classification is shown in Table 5.2 for the FSN system considered in this paper:

	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 5.2 - FSN system membership classification

5.4 Membership Functions

In Fig.5.3 it is depicted the membership for the FSN system considered. The membership sets appear with different colors and we can clearly see that the worst case of a very high saturated area is shown with red color.

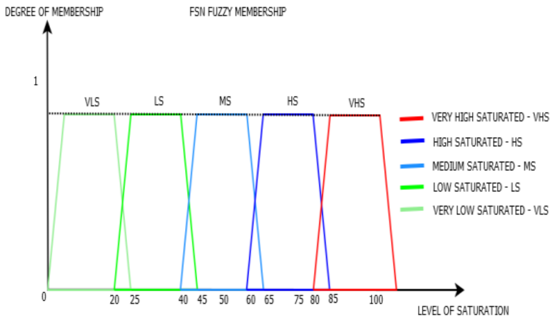

Figure 5.3 Membership Functions for S (Saturation) = {Very Low Saturated - VLS, Low Saturated - LS, Medium Saturated - MS, High Saturated - HS, Very High Saturated - VHS}

5.5 Fuzzification of Input

As shown in Fig.5.1, a fuzzy logic system has the stages of Fuzzification and Defuzzification. 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 the range of fuzzy variables according to the crisp inputs is the primary requirement for proper running of the fuzzier program.

5.6 Fuzzy Membership Functions for Outputs

The output linguistic variables express linguistically 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 shown below in table 5.3 and we can see that the range of 80 to 100 percentage corresponds to a very high saturated VHS state.

	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 5.3 - Output linguistic variables.

5.7 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 5.4, we have a sample of the fuzzy rules for the FSN for localization via TRN control system. Table 5.5, is a matrix representation of the fuzzy rules for the said Fuzzy logic. Row captions in the matrix, contain the values that the current saturation levels. Column captions contain the values for target saturation levels. 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 the current saturation is MEDIUM and target required is LOW then the command Decrease R (de-saturate by decreasing the radius of coverage) 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 5.4- 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 5.5 - Matrix representation for the FSN saturation Control System

5.8 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 minimal time of reaction as well as a minimal value of saturation which might be achieved, combined with best possible coverage. Except from the case that 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 in the whole AOI.

5.9 Defuzzification

The Fuzzy Logic Controller forwards data information to the Defuzzifier which performs initial processing of the system status and afterwards feed with information the central hub. As shown in Fig.5.4, the central hub initiates the AOI de-saturation procedure if necessary. The system gradually decreases the radius of coverage, 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 system applies the same methodology with the one presented in [16] whilst in this case its application results in de-saturation in combination with system 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 saturation level and finds the current system saturation level.

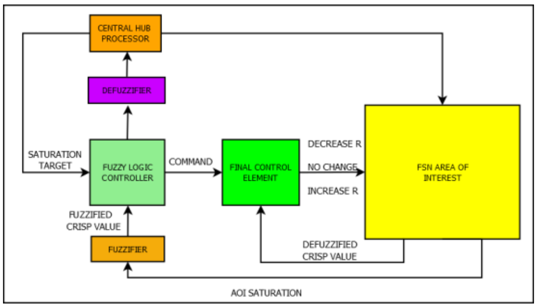

Figure 5.4 - FSN Defuzzication flow diagram

If current saturation level lies within the desired output Fuzzy values, then the crisp blindness value is the crisp

WSEAS TRANSACTIONS on SYSTEMS and CONTROL
DOI: 10.37394/23203.2022.17.39

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output value of the system. This methodology is named as, Fuzzy Logic Saturation Control System FLSCS for Fixed Sensors Network -. Fig.5.5 shows the FSN Defuzzification Radius mode of operation for De-saturation. The seven SRs for each square of the AOI are depicted in Fig..5.5.

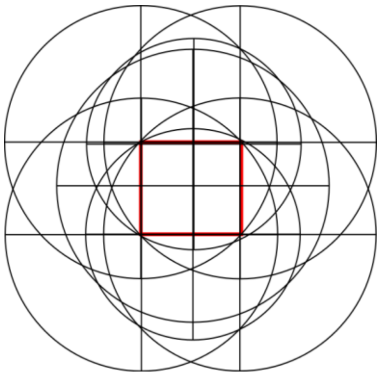

Figure 5.5 - FSN Defuzzification mode for De-Saturation

The radius R of the five SRs (four are placed in the corners of the square depicted above in Fig.5.5 and the fifth in the center of the square) is increased to a value till the diagonal corner of the square. The other remaining two of the seven SRs lies on the center of the two opposite sides (upper and lower) of the square, increase their radius R also till the opposite corner as it is depicted in Fig.5.6 below.

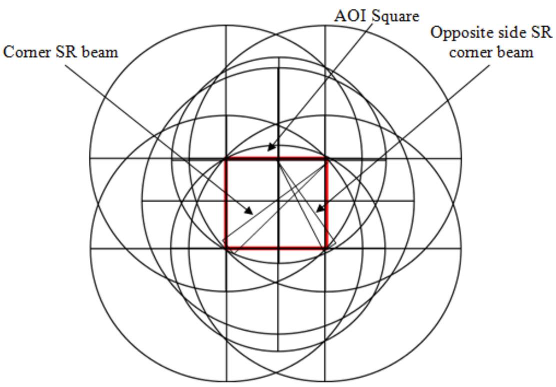

Figure 5.6 - FSN Defuzzification mode for De-Saturation

5.10 Fixed Sensors Network - FSN AOI partition

Fig.5.7 shows the FSN AOI divided in four main sub-areas. In order to simplify the procedure, the FSN system process each subareas individually and report the status to the controller . The algorithm used for this process is shown in Table 5.6.

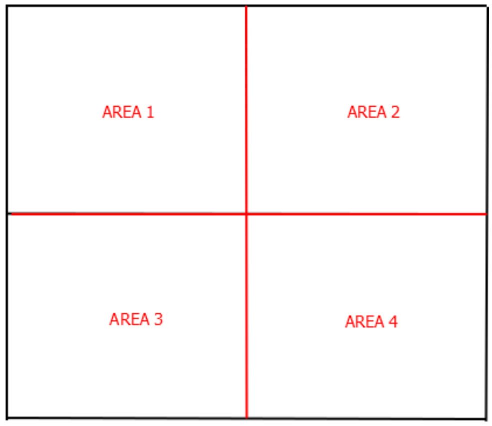

Figure 5.7 - FSN division of AOI. System applies Fuzzy logic algorithm for de-saturation in each main sub-area.

	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 5.6 - FSN Fuzzy logic de-saturation Algorithm

6. FSN Fuzzy logic De-Saturation Methodology of adjacent areas

Fuzzy systems have the capability to operate as stand-alone systems or be combined with other systems. Additionally, they are able to supplement fully or partially other systems or even more to be combined with them (neural networks, evolutionary algorithms etc.) resulting in hybrid systems [15]. Fuzzy systems already have a significant participation in positioning systems. In our case the FSN has a number of SRs which are shown in Fig.5.8. Each of the four pre-mentioned sub-areas is further divided to four cells, were there are participating seven SRs for localization via triangulation in each cell of these sub-areas. So, the whole AOI is divided further in sixteen cells, The SRs mode of operation was analyzed in section 5.10. Fig.5.9 below, shows the saturated sub-areas of the AOI. The remaining sub-areas are LOW saturated. All the depicted saturated sub-areas belong to area 3 of the AOI.

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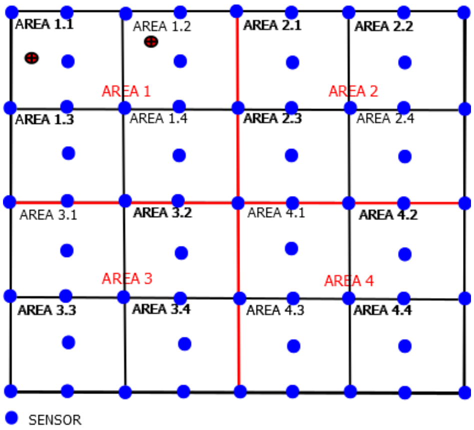


Figure 5.8 - FSN AOI divided in sixteen cells with SRs. Each cell square has seven SRs for TR detection via TRN.

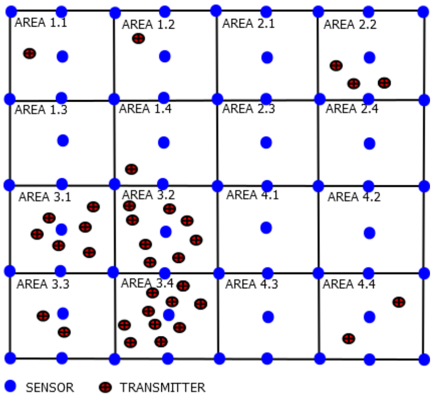


Figure 5.9 - FSN AOI saturated case. Area 3 is saturated with many TRs as three of the four cells (3.1, 3.2 and 3.4) have many TRs.

6.1 Adjacent areas Algorithm

The Adjacent areas Algorithm as its name suggests is related to the activation of adjacent SRs to a problematic area. Meaning that the surrounding SRs close to a problematic area might seek for any new TRs as the existing SRs responsible for the saturated cells monitoring might fail to detect a new TR. By that way the system after applying fuzzification and defining the saturated areas and cells in the AOI, activates more SRs to seek in those areas aiming at reducing any existing coverage problems.

6.1.1 Adjacent Areas Algorithm AAA pseudo code

The following pseudo code represents how the system is applying the AAA in order to face any saturation problems.

Step 1
DO Seek and define adjacent SRs surrounding the saturated cell.
Step 2
DO Count the number of the adjacent SRs.
Step 3
DO Activate these adjacent SRs for detection of any new TRs in the problematic area.
Step 4
DO Calculate the new FSN coverage in the particular problematic cell.
Step 5
THEN Inform the system for the new improved and lowered saturation level.
Step 6
Seek for any further activation at another cell.
IF the answer is YES apply AAA to the new set of adjacent SRs.
IF NO then apply AAA only for the previous required cells.
Step 7
DO Continue applying the AAA for any saturated cells.
DO Continue reporting to the system.

Concerning the previous case depicted in Fig.5.8, the system in order to deal with the saturation problem applies the adjacent areas methodology to decrease the saturation problem which is shown below in Fig.5.10. SRs apply the mode of operation which was described in the de-fuzzification process in section 5.10 and the FSN system achieves de-saturation in combination with better coverage. This case of saturation is a case related with the one fourth of the AOI.

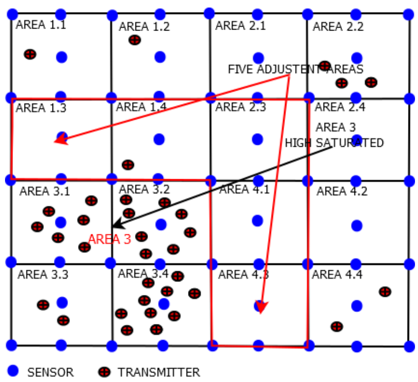


Figure 5.10 - FSN AOI saturated case after applying Adjacent Areas Algorithm AAA. Area 3 is saturated with many TRs.

The system applies the methodology of adjacent areas to decrease the coverage problem. In other cases where there is saturation in a single cell of the AOI, the system applies a different analogous approach to the adjacent areas methodology. A different case where we have a combination of two saturated cells is depicted in Fig.5.11. 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 cell 2.2 it uses three adjacent cells (cells 2.1,2.3 and 2.4) and for the cell 4.1 uses other three cells (cells 3.2,3.4 and 4.3). Those SRs extend their radius R till the diagonal corner of the saturated area.

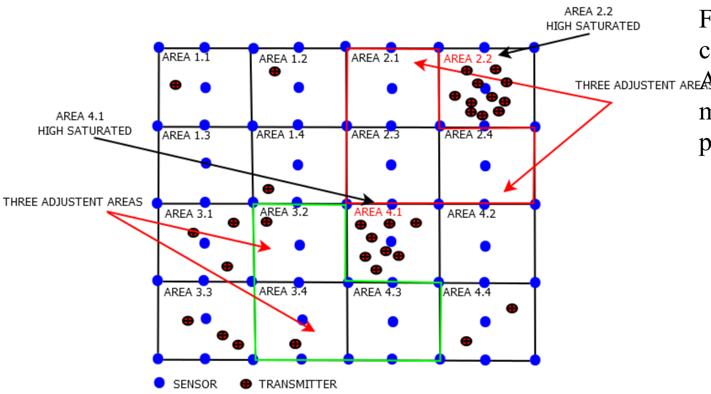


Figure 5.11 - FSN AOI saturated case. Two cells -cell 2.2 of area 2 and cell 4.1 of area 4 are saturated with many TRs. The system applies the method of adjacent areas to decrease the coverage problem.

6.2 Results of Fuzzy Logic implementation on the System

Network Topology

Two network grids were employed to prove the Fuzzy Logic concept on this particular FSN system., In the first scenario the network grid has only seven SRs in a subarea similar to Fig.5.8. The second is one fourth of the full AOI of the network where 18 more SRs participate by applying the adjacent areas algorithm on the saturated area of Fig 5.11. The SRs of area 3 aren't counted in the procedure of AAA. Fig. 5.12 shows the coverage of the sub-area of the AOI with 7 SRs and 5 TRs.

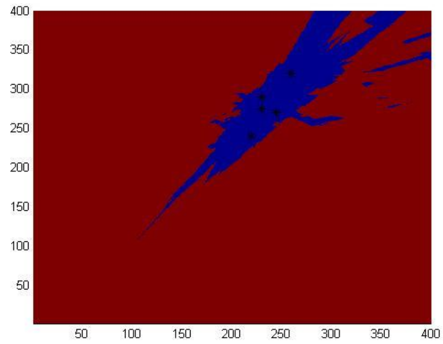


Figure 5.12 Sub Area Coverage with 7 SRs - 5 TRs, Coverage - Radius 350 m (no coverage is indicated in blue)

Fig 5.13 shows how system increases its performance of coverage by activating the Adjacent areas Algorithm AAA. These results clearly show the benefit of this methodology and how the AAA algorithm can provide positive results increasing the FSN system performance.

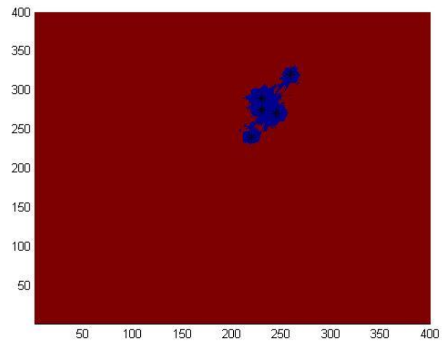


Figure 5.13 Sub Area Coverage with Adjacent Areas Algorithm with 19 SRs and 5 TRs, Coverage Radius 350 m (no coverage is indicated with blue colour)

Fig. 5.14 below shows the coverage with two additional TRs, (7SRs, 7TRs) These results illustrate that a number of SRs in the sub-area have lost their detection capability to a greater extend.

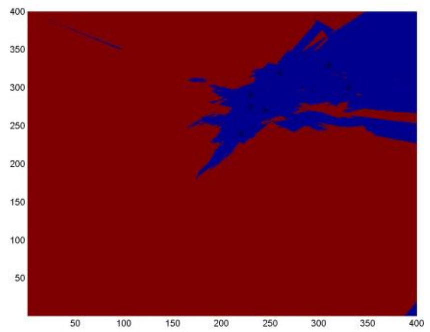


Figure 5.14 Sub Area Coverage with 7SRs-7TRs, Coverage Radius 350 m (no coverage is indicated with blue color)

The network coverage with different sensor coverage radius R for different number of TRs are shown in Figures 5.15,5.16 and 5.17. These results show, a coverage radius around 400 m provides better coverage performance and depending on the number of TRs a better coverage radius can be identified.

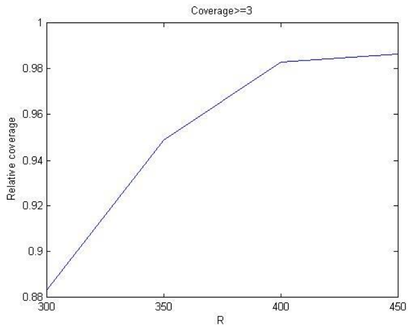


Figure 5.15 Area of Interest- AOI Coverage Plot 7SRs - 7TRs with SRs Radius 350 units

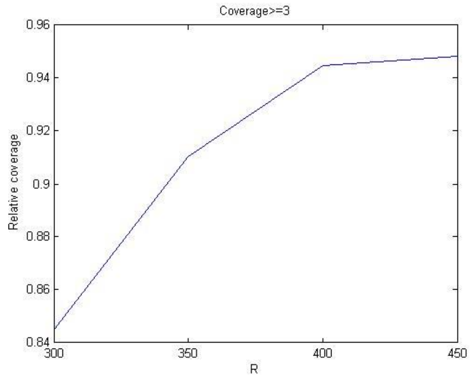


Figure 5.16 Area of Interest- AOI Coverage Plot 7SRs - 12TRs SRs is Radius 350 units

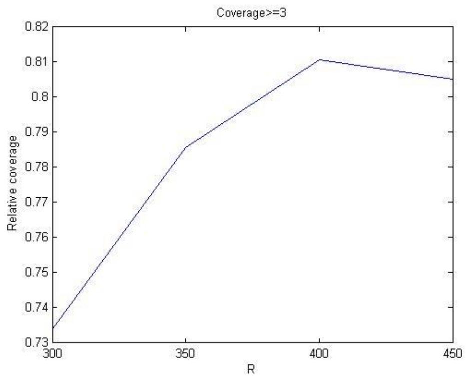
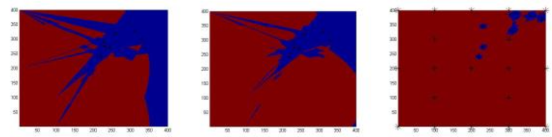


Figure 5.17 Area of Interest- AOI Coverage Plot 7SRs - 20 TRs SRs is Radius 350 units

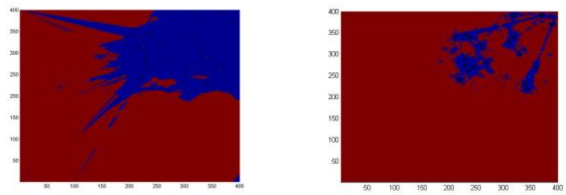
Figures 5.18 (a), (b) shows the effects of loosing sensors in the sub - Area. These results show that the combination of network saturation due to existing TRs and the network performance degradation due to missing SRs (SRs failure) can lead to a very low operational performance . Fig. 5.18 (c) shows how how the network coverage can be improved applying the adjacent areas algorithm.



(a) (b) (c)

Figure 5.18 (a) Area of Interest - AOI Sub Area Coverage 5SRs - 7TRs - Radius 350 units(no coverage is indicated with blue colour)
(b) Area of Interest - AOI Sub Area Coverage 6SRs - 7TRs - Radius 350 units (no coverage is indicated with blue)
(c) Area of Interest - AOI Sub Area Coverage with Adjacent Areas Algorithm 19SRs and 7TRs Radius - 350 units (no coverage is indicated with blue colour)

Fig. 5.19 (a) and (b) shows the effects of network level coverage with more TRs in the AOI(20 TRs) and how the coverage is improved with adjacent areas algorithm applied with an increased radius of coverage (450 m).



(a) (b)

Figure 5.19 (a) Area of Interest - AOI Sub Area Coverage 7SRs and 20TRs SRs is Radius - 350 units (no coverage is indicated with blue colour)
(b) Area of Interest - AOI Sub Area Coverage after activation of the Adjacent Areas Algorithm 19SRs and 20TRs Radius - 450 units (no coverage is indicated with blue colour)

Fig. 5.20 and Fig. 5.21 shows the network level coverage with more TRs in the AOI. We see that the coverage level of the FSN system with 19 SRs, 7 TRs and with R=s 300 mis 98.8% while the same network with 12 TRs falls to around 96%. After increasing the number of TRs to 20, the network coverage further falls to 87.7% as shown in Fig. 5.22. These results shows of the impact of sensor blindness and saturation of the FSN system. In order to overcome these challenges, techniques such as Adjacent logic Algorithm and Fuzzy Logic methodology is required.

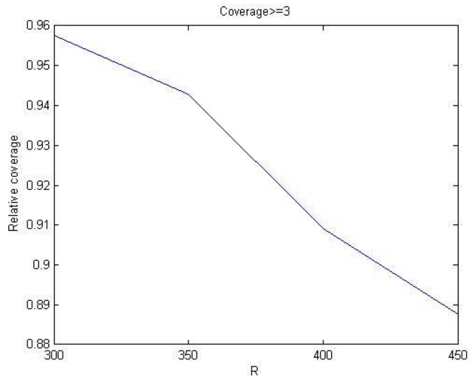


Figure 5.20 Area of Interest - AOI Coverage Plot 19 SRs - 7TRs Radius 350 units

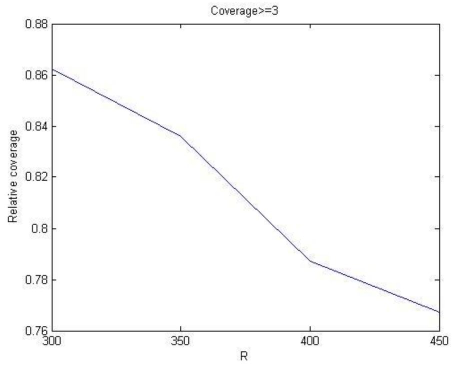


Figure 5.21 Area of Interest - AOI Coverage Plot 19 SRs - 20TRs Radius 350 units

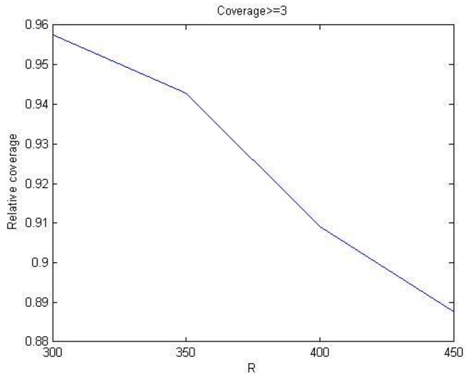


Figure 5.22 Area of Interest - AOI Coverage Plot 19 SRs - 20TRs SRs Radius 350 units

In the following Fig. 5.23 we see that the optimal value of radius R is far different from the previous graphs. It reaches the value of 96.69% in about 300 units and the as the R increases it decreases rapidly. This phenomenon proves that the value of R has a significant role during the operation of the FSN system and it also can affect seriously the quality of coverage from state to state.

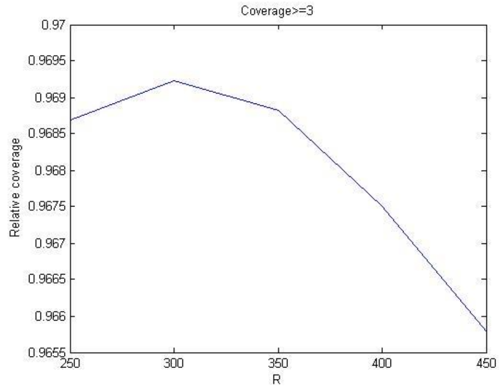


Figure 5.23 Area of Interest - AOI Sub Area Coverage after activation of the Adjacent Areas Algorithm 19SRs and 20TRs Radius - 450 units (no coverage is indicated with blue colour).

6.3 Outcome of FSN saturation control by 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 continuously the system is 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.

7. Contributions

The contributions of this work is the development of a methodology to evaluate and assess the performance of this particular type of FSN, based on the problem statement. Network Area Coverage problematic areas are identified and areas of non coverage of three or more SRs for triangulation are visualized for the system user. The FSN system with implementation of the Fuzzy logic theory evaluates the network status in any state and with a certain number of existing TRs. Additionally, with the novel algorithm of adjacent areas activation the system is able to increase its detection performance in saturated sub-areas of the AOI.

8. Conclusions

This research presents significant work for a FSN system for localization via triangulation. In previous research papers [1], [10] it was shown that as the number of TRs increase in the AOI issues of saturation and SRs blindness appear in the network. In this paper it was shown that the implementation of the Fuzzy logic theory might enhance the capabilities of this particular type of system. The system by applying the methodology presented increases its detection performance and the required coverage for performing triangulations in the AOI or any sub-area. Additionally, it was shown that the probability of detection differentiates from one topology to another and as the TRs cause saturation to the system more and more adjacent SRs might participate in the process of detection and AOI coverage. The issues of blindness and network saturation are strongly related with the detection performance for this type of FSN. These issues haven't been researched up to now and forms a new contribution to existing knowledge.

Author Contributions: Conceptualization, M.S.; Methodology, Simulation and Optimization M.S..; writing—original draft preparation; writing—review and editing, M.S.; supervision, E.A. and N.R.; All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknownledgements

I would like to express my gratitude to Professor Rajagopal and Professor Antonidakis, my research supervisors, for their patient guidance, and useful critiques of this research work. I would also like to thank Professor Zakinthinaki for her valuable contribution in producing the adequate Matlab software for the tests of this research.

Conflicts of Interest
The authors declare no conflict of interest.

Abbreviations
The following abbreviations are used in this manuscript:
FSN Fixed Sensors Network
SRs Sensors
TRs Transmitters
ETRNs Existing Triangulations
QoS Quality of Service

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