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Evaluation and Improvement of the RSSI-based Localization Algorithm

Received Signal Strength Indication (RSSI)

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Abstract

Context: Wireless Sensor Networks (WSN) are applied to collect information by distributed sensor nodes (anchors) that are usually in fixed positions. Localization (estimating the location of objects) of moving sensors, devices or people which recognizes the location's information of a moving object is one of the essential WSN services and main requirement. To find the location of a moving object, some of algorithms are based on RSSI (Received Signal Strength Indication). Since very accurate localization is not always feasible (cost, complexity and energy issues) requirement, RSSI-based method is a solution. This method has two specific features: it does not require extra hardware (cost and energy aspects) and theoretically RSSI is a function of distance.

Objectives: In this thesis firstly, we develop an RSSI-based localization algorithm (server side application) to find the position of a moving object (target node) in different situations. These situations are defined in different experiments so that we observe and compare the results (finding accurate positioning). Secondly, since RSSI characteristic is highly related to the environment that an experiment is done in (moving, obstacles, temperature, humidity …) the importance and contribution of "environmental condition" in the empirical papers is studied.

Methods: The first method which is a common LR (Literature Review) is carried out to find out general information about localization algorithms in (WSN) with focus on the RSSI-based method. This LR is based on papers and literature that are prepared by the collaborating company, the supervisor and also ad-hoc search in scientific IEEE database. By this method as well as relevant information, theoretical algorithm (mathematical function) and different effective parameters of the RSSI-based algorithm are defined. The second method is experimentation that is based on development of the mentioned algorithm (since experiment is usually performed in development, evaluation and problem solving research). Now, because we want to compare and evaluate results of the experiments with respect to environmental condition effect, the third method starts. The third method is SMS (Systematic mapping Study) that essentially focuses on the contribution of "environmental condition" effect in the empirical papers.

Results: The results of 30 experiments and their analyses show a highly correlation between the RSSI values and environmental conditions. Also, the results of the experiments indicate that a direct signal path between a target node and anchors can improve the localization's accuracy. Finally, the experiments' results present that the target node's antenna type has a clear effect on the RSSI values and in consequence distance measurement error. Our findings in the mapping study reveal that although there are a lot of studies about accuracy requirement in the context of the RSSI-based localization, there is a lack of research on the other localization requirements such as performance, reliability and stability. Also, there are a few studies which considered the RSSI localization in a real world condition.

Conclusion: This thesis studies various localization methods and techniques in WSNs. Then, the thesis focuses on the RSSI-based localization by implementing one algorithm and analyzing the experiments' results. In our experiments, we mostly focus on environmental parameters that affect localization's accuracy. Moreover, we indicate some areas of research in this context which need more studies.

Keywords: RSSI algorithm, indoor localization, Wireless Sensor Network (WSN), RSSI filtering, RSSI distance error, localization algorithm.

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Acronyms

AN	*Anchor node*
AOA	*Angle of Arrival*
APIT	*Approximate Point in Triangle*
APS	*Ad-hoc Positioning System*
AWCL	*Adaptive Weighted Centroid Localization*
B-MLE	*Biased Maximum likelihood*
CL	*Centroid Localization*
COG	*Center of Gravity*
DB	*Decibel*
DV-Hop	*Distance Vector-Hop*
EPA	*Error Propagation Aware*
FAF	*Floor attenuation factor*
GAs	*Generic Algorithms*
GLRT	*Generalized Likelihood Ratio Test*
GPS	*Global Positioning System*
GQM	*Goal Question Metric*
LAURA	*LocAlization and Ubiquitous monitoRing of pAtients for health care support*
LOS	*Line of Sight*
LR	*Literature Review*
MDS	*Multidimensional Scaling*
MIMO	*Multiple Input Multiple Output*
MISO	*Multiple Input Single Output*
ML	*Maximum Likelihood*
NA	*Network Architecture*

NLOS	*Non Line of Sight*
PDF	*Probability Density Function*
PIT	*Point in Triangle*
PLE	*Path Loss Exponent*
PLTS	*Personal Localization and Tracking System*
PMS	*Personal Monitoring System*
RF	*Radio Frequency*
RSA	*Range Scaling Algorithms*
RSSI	*Received Signal Strength Indication*
SIMO	*Single Input Multiple Output*
SISO	*Single Input Single Output*
SMS	*Systematic Mapping Study*
SN	*Sensor Node*
TDOA	*Time Different of Arrival*
TOA	*Time of Arrival*
TSK	*Takagi-Sugeno-Kang*
WAF	*Wall Attenuation Factor*
WCL	*Weighted Centroid Localization*
WLS	*Weighted Least Square*
WSN	*Wireless Sensor Network*

Chapter 1

Introduction

This thesis and the relevant study are based on collaboration between Software Engineering and Research Lab (SERL) of Blekinge Institute of Technology, Department of Electronics, Information and Bioengineering (DEIB) of Politecnico di Milano and E-LYSIS s.r.l Company. The report encompasses both scientific and industrial aspects. The results are presented in separate chapters.

Localization of an object (a person, fixed or moving object) is one of the significant topics of context aware systems in Wireless sensor networks (WSN) (Barsocchi et al., 2009; Papamanthou, 2008; Rasool et al., 2012; Artemenko et al., 2010; Ahn, 2010; Liu et al., 2012). Since the solution based on Global Positioning System (GPS) is not available in indoor environments (Barsocchi et al., 2009), the issues of complexity, energy consumption and cost efficiency are always significant, Wireless sensor networks (WSN) is considered as a solution to the indoor localization. Therefore, localization algorithms in WSNs are not based on GPS technique and expensive equipment. In WSNs, location estimation of a moving object (sensor with unknown position) is usually based on its communication with some fixed objects (sensors with known position). In one category of localization method (ranging-based), positioning of an object is based on signal propagation time, arrival angel or signal phase difference between unknown and known (anchor) sensors. Each of these methods requires specific support. In the signal propagation, the time should be measured precisely. Signal arrival angle methods require expensive equipments (antenna) and signal phase difference is limited by distance.

Among different algorithms in the context of localization, the RSSI (Received Signal Strength Indicator)-based algorithm is the most popular method with respect to cost, energy and complexity (Ligong et al., 2013). Our focus in this study is on the RSSI-based and multilateral localization methods although different methods are also shortly reviewed in chapter 2.

Received Signal Strength Indication (RSSI) is an indicator of the power that the receiver sensors gain as a valid packet. By the Friis transmission equation, the signal strength that is received by a sensor from another one is a function of its distance. Studies show that localizations based on RSSI are not very accurate since three factors influence RSSI values: path-loss, fading and shadowing effects. In fact, in real situation with people movement, different obstacles and conditions, we will receive different RSSI values that affect positioning accuracy (behavior is not completely same as theoretical formula) (Heurtefeux & Valois, 2012). Different researches and empirical studies try to find ideas or methods to improve RSSI-based localization algorithm and then increase accuracy.

In this study, at first we try to understand the characteristics of the RSSI values and then design different experiments in a laboratory situation to gather enough RSSI values' vectors for further analyses. These experiments encompass different effects such as antenna direction, indoor and outdoor situations, effects of obstacles, sensor positions, time and number of samples, sensors' distances and people movement. Second, we try to analyze the RSSI values. In the analysis phase, software has been developed to implement RSSI algorithms, analyze our experiments data, and try to position a moving object. In fact the main approaches in the software development are both implementation of the analysis phase and then possibility for localization based on further experimental RSSI values. The software separates RSSI values for each anchor in different files and then calculates algorithms' parameters and distances in the relevant files. Also, path-loss effect is one of the significant parameters in the RSSI localization that software focuses on, to find and filter the best values. Moreover, this study considers some innovative methods of the RSSI localization with respect to RSSI limitation. Since contribution of empirical papers is important to find better solutions, this study systematically researches in the previous empirical papers to see the contributions in the context of the RSSI algorithm and environmental conditions' effects.

This thesis aims to work on one RSSI-based location algorithm and develop a server application to analyze data and compute the location of a moving object. After developing the basic location algorithm, we consider improvement of the algorithm with respect to calibration, Path Loss Exponent and environmental condition. Although different experiments have been carried out to consider localization with various standpoints, working on the algorithm based on indoor environmental conditions like light, place of windows and place of other objects is still demanded. At the end, results of the experiments and systematic mapping research, separately, try to the answer research questions and how this study contributes to the state-of-art.

1.1 Scope of the Study

This study focuses on a specific algorithm in the RSSI-based localization in indoor WSN. To perform this study and relevant analysis, initially the simple part of the algorithm is implemented as a server application to analyze the results of the experiments. To improve the precision of the localization algorithm, the results of experiments are evaluated and also the main effective parameter (Path-loss exponent and its relation with environmental condition) is considered. To show importance of the topic in previous research papers, the study also assesses, systematically, relevant papers which considered empirical studies in this context.

Since this study is a continuation of the previous study in the Politecnico laboratory and company, it (this study) utilizes the network, sensors and developed software in the laboratory, applies 868 MHz radio signal frequency and Concentrator V1.0 as the sensor module (for moving object, fixed object, anchors and master node). The radio signal frequency (868 MHz) has been selected in previous studies due to points of energy consumption and low sensitivity against environmental conditions (Shahnewaz & Tabibi, 2012).

1.2 Aims and Objectives

The main aim of this thesis is to develop an RSSI-based localization algorithm to find a precise location of a moving object in a warehouse and improve this localization by considering environmental conditions. In particular, the objectives are to:

- Study and describe the RSSI-based localization algorithms, focusing on environmental conditions improvement.
- Describe and evaluate different methods which can improve the localization precision.
- Develop a server application to carry out the analysis phase.
- Compare the achieved results from different experiments to see the worst and best Situations and distance errors.
- Find some research areas (based on the mapping study) in the context of the RSSI-based localization in which there is a lack of studies.

1.3 Research Questions

Since, this thesis supports both experimental and research based parts, therefore our research questions cover both aspects. The answers of the RQs also come separately in the relevant parts.

1. What are the most frequently applied research methods in the context of the RSSI-based localization?

    Description: the goal is to identify which research methods are commonly applied and which research methods are not covered well and there is a lack of studies.
2. In which application fields (such as healthcare, target tracing, environment monitoring …) is RSSI-based localization applied and how many articles are available in these fields?

    Description: Wireless Sensor Networks can monitor an area and be used in different fields. The answer to this question will present the application fields in the RSSI-based localization which are regarded and the fields that need more attention by the researchers and companies.
3. In how many papers in the context of the RSSI-based localization "computational effort" with respect to energy consumption has been considered?

    Description: this question intends to know how much previous studies considered the issue of computational effort. Since applying complex mathematical models and distance calculations can affect the energy consuming by the sensors.
4. What are the environments (indoor environment or outdoor) considered by experiments and how many studies reported the comparison between the accuracy of the experimental results?

    Description: the answer of this question can demonstrate which environment was more regarded in experiments and is there any comparison between the gained results. Which one (results of indoor or outdoor) is more accurate?
5. How many studies pay attention to the effect of the number of anchors (anchor density) on improving accuracy?

Description: the number of anchors is an effective parameter in localization. Since they affect the number of received RSSI values for analysis. By this question it is intended that the number of articles that study anchor density and limitation of the anchor numbers.

6. How frequently do RSSI-based experiments report effects size as an evaluation result?

   Description: when we intend to assess the differences between two groups, effect size is a manner of quantifying the differences between them. By this question we aim to know how frequent is calculating effect size in the RSSI-based experiments.

7. How prevalent is consideration of environmental conditions (models for the power received form anchors) and its effect on improving accuracy in publications?

   Description: there are mathematical models to consider environmental conditions in the RSSI-based algorithms. This question aims to see how many studies assess these models and their effects on the localization accuracy.

8. What effect does environmental condition have on the precision of localization?

   Description: considering environmental conditions will make our algorithm and also our calculation more complex. In fact, the environment also affects the power received from the sensors. Therefore it is needed to evaluate the effect of these conditions on the accuracy of localization. Qingxin et al. (2010) explain propagation of wireless signals and various interference factors that can affect this propagation in indoor environment. They consider factors such as temperature, multipath signals, diffraction, distraction, obstacle and humidity and they represent that RSSI values should be optimized at first to calculate the precise location. They study the effect of the Gaussian model to improve precision of localization. Also Barsocchi et al. (2009) consider obstructions and parameters such as wall attenuation factor (WAF) and floor attenuation factor (FAF) in the path loss model. They show that the RSSI is dependent on the environmental conditions and propose a novel localization algorithm.

9. To what extent do different conditions influence the localization accuracy of RSSI-based algorithms?

   Description: these parameters are considered in the experiments,

   - Number of anchors: the number of anchors is a selected parameter to observe how effective the density of anchors is on the accuracy.
   - Position of anchors: the importance of this parameter is due to this fact that the direction of anchors' antenna and signal propagation can affect the reliability of communication and localization accuracy (Shahnewaz & Tabibi, 2012).
   - Path loss exponent factor: totally, path loss shows the signal attenuation and it is the difference between sent and received power (Shahnewaz & Tabibi, 2012). This parameter is a basic parameter in our localization algorithm and we aim to calculate it.
   - Zero-mean Gaussian random variable: we aim to consider this parameter to improve our basic algorithm and observe the effect of that in localization accuracy. We intend to apply this variable to model the environmental condition.

1.4 Research Methods

Localization in WSNs is a wide concept with different methods and algorithms. Different experiments and studies try to find more precise position of a moving object.
In this study, initially a common Literature Review (LR) is carried out to find out general information about “localization algorithms”, “Wireless Sensor Networks” and “RSSI-based method”. This LR is based on papers and literature that are prepared by the collaborating company, the supervisor and also ad-hoc search in scientific databases. Moreover, this LR continues during the software design, implementation and experiments.
To support scientific phase of this study, “Systematic Mapping Study” forms the basis of our experiment. A close relation between different research methodologies in this thesis is made by: defining of dependent and independent variables (that are used in the planning phase of the experiments), considering different mathematical models for the environmental condition, how frequent is “applying experiment method” in the context of the RSSI-based localization and how frequent is “consideration of environmental condition effects” in the previous experiments. With this method we concentrated on three issues; thematic analysis, classification and identifying publication forums.
The last research method is experimentation. We wanted to develop software and analyze the results in limited scope and laboratory condition. Each experiment includes five steps: definition, planning, operation, analysis and package. The results of the experiments represent how accurate our localizations is and how much the distance error, with respect to different experiment planning, is.

1.5 Contributions

This study has two main contributions. Firstly, implementation of an RSSI-based algorithm which makes possible to define the experiments as a resource of data, prepare condition for different analyses on path-loss exponent, measure distances and filtering based on different parameters of the algorithm and finally position the moving object on a map. The second contribution is studying previous empirical papers in this context and demonstrating the importance of RSSI-based localization, improvements and effects of environmental conditions on the accuracy of localization in the relevant studies. Also in this study we can see the results of 30 experiments that analyzed by the developed software.

1.6 Structure of the Report

In chapter 2, we present a brief explanation of WSN and localization methods, RSSI and its underlying algorithm, and related work. In chapter 3, research methodology of this study is discussed. Chapter 4 represents localization steps and some innovative ideas to find a precise location. Chapter 5 contains explanation of hardware and software of our localization system. Chapter 6 explains our experiments' design and goals as well as their results and answers to the relevant research questions. In chapter 7, we explain the design, results and research questions relevant to the SMS method. In chapter 8, we have a discussion about our findings in this research (in both mapping study and experiments) and finally chapter 9 presents conclusions of this study, its results and suggests future work.

Chapter 2

Background and Related Work

In this chapter we have a top-down view on the concept of localization in Wireless Sensor Networks (WSNs). We explain background regarding the (WSNs) in Section (2.1), and point out their constraints in Section (2.2). In Section (2.3), different network management approaches are presented and Section (2.4), studies wireless node positioning techniques and different algorithms relative to Range-based and Range-free methods. Section (2.5), is allocated to considering the RSSI concept (limitations, algorithm and characteristics). In Section (2.6), explanation of some innovative related work and a table of summary are given. Finally, Section (2.7), describes contributions of the related work to this thesis.

2.1 Wireless Sensor Networks (WSNs) and localization

In the recent years, a great improvement in wireless communication, sensing technology and micro sensors, embedded systems and relevant software has been attained (Sugano et al, 2006; Ahn, 2010). Considering these advances, low complexity networks like Wireless Sensor Networks (WSN) can be used in a wide range and different application's fields (Rasool et al., 2012) such as: monitoring environment and air (Sugano et al., 2006), context-aware applications in ubiquitous computing environments (Sugano et al., 2006; BARSOCCHI et al., 2009; Redondi et al., 2010), supporting health-care systems and patient tracking in hospitals (Redondi et al., 2010), traffic monitoring, fire detecting, and seismic activity detection (Ahn, 2010).

WSN is developed by some battery-powered and inexpensive sensors (usually setup randomly), embedded system, wireless communication systems and multi-processors with self-organizing characteristics which can communicate, collect, process, store and transfer data of specific sensor nodes (SN) in a region. So a wireless sensor node has capability of physical sensing, computation and networking. Type of sensors in WSNs can be passive or active. Passive sensors include, among others, seismic, acoustic, strain, humidity, and temperature measurement nodes and active sensors contain radar and sonar (Pal, 2010).

Collecting data of an object (SN) in an indoor environment is a basis of finding the position of it. Therefore, estimating the location of a moving object (sensor) is the main requirement for wireless sensor networks applications (Rasool et al., 2012).

Using GPS for an ad-hoc network with a lot of sensors is not possible since 1) different obstacles can block the line-of-sight signals, 2) energy consumption of GPS decreases lifetime of the network, 3) in these kinds of networks (with lots of sensors) applying GPS is costly and finally 4) sensors need to be small but using GPS equipments increases the size of sensors (Pal, 2010).

In the WSNs localization we have a set of sensors ("N" sensors, {S1, S2, ….. Sn}) a subset of which knows their positions ("A" sensors which named anchors or beacons) and the rest of them

(“N-A” sensors) have unknown positions that we want to find (X, Y, Z coordinates) with the help of the other known-position sensors. If we put 0 for Z-coordinate, we will have 2D version of localization (Pal, 2010).

Nowadays, many applications want to know the position of a moving object that transmits the information, and Wireless Sensor Networks are able to satisfy this need for applications. Node localization solutions estimate the location of a moving object (unknown sensor) based on anchors with known location. These nodes (anchors) are receivers of the signals which are transmitted from moving objects (in some protocols anchors are transmitters). In accordance with some protocols, the power, angle and time of the transmitted signal can be used to estimate the distance between sensors and anchors.

WSN applications consider energy, cost and size of nodes, so it is utilized in large-scale systems for long time (Pal, 2010).

2.2 WSNs and Constraints

Studies demonstrate that the topology and network structure have a significant effect on localization, number of sensor nods and energy consumption. For instance a tree topology is suggested for energy saving instead of full mesh in WSNs. Localization approach in WSNs simply has two steps: collecting data to estimate a distance or angle and then combining this information (distance or angle) by an algorithm to estimate the position of an unknown object (sensor). Therefore, in localization process relation among network protocol, algorithm and sensor lifetime is important.

First aspect of constraints in WSNs is energy management (Dalce et al., 2012). In the context of energy constraint, the amount of data that is exchanged between sensors is significant. From the data point of view, data redundancy between sensors affects energy consumption and data aggregation is a solution with respect to data synchronization (Awang et al., 2013). From the protocol point of view, firstly, overloading of exchanged data and traffic limitation are considered on the topic of *localization overhead*. Specific implementation (protocol) can benefit the data exchanging in a network and affect energy consumption. Secondly, *idle listening* in a network is another factor in energy saving since in the listening time energy consumption is more than the emitting time. So in the protocol implementation, reduction of idle listening is necessary. Thirdly, the approach to computing (*centralized or distributed)* in the network is another influential factor in the energy context. In the centralized approach (what we also used in this study) there is a node that receives raw data and then estimates the position of a moving object. In this approach, because of a server, we can compute more complicated algorithms, provide user interface and also results (estimated position) can be used by the other applications. However, in the distributed approach, sensor nodes are responsible for doing simple computation for localization. In the real world there is a possibility of “radio link failure” between sensors and a server and consequently frame loss rate. So, although in centralized approach we can have more complex computation which results in better positioning (in a unique node), the failure in communication affects our service and lifetime of the network (Dalce et al., 2012).

Second aspect is about algorithm. To run an, algorithm both memory management and complexity are considered. Based on what mentioned above, the protocol of the WSN identifies that the process will be done in each sensor nodes or in a server. So the size of memory and power of the processor in the sensors (in distributed approach) affect the algorithm for localization, since the memory should be shared between localization functions (limited space) and network. Also selected microcontrollers in the sensors can affect the number of libraries and operations that a developer can use (Dalce et al., 2012).

The third aspect of WSN constraint is about *anchor accessibility.* This matter (topology of the network) is important in localization performance and service availability (Anchor accessibility is one of the important factors during our experiments in the laboratory). This is because, for a short period of time the moving object does not have any connection to the anchor nodes. In this case making a decision about topology is necessary. Considering a mesh network with a sufficient number of anchors helps our moving object be able to have connection to any accessible anchor, however, synchronization is still an issue. On the other hand, a tree network can solve synchronization but affects anchor accessibility. Finally, considering correction method in the real world based on the signals in specific environment can improve the location estimation (Dalce et al., 2012).

2.3 Different Network Management Approaches

As mentioned in section 2.2, localization in WSNs can be categorized in two network management approaches: centralized and distributed localization. Generally, centralized algorithms can be used when we need more accuracy while distributed algorithms have better scalability (Pal, 2010).

2.3.1 Centralized localization

In this approach we have a powerful central-base node that the other sensor nodes communicate with and the central node does the computation and sends localization information to the sensor nodes. In this method, after sending data (measurements) from sensors to the server (it needs a database for saving received signals and computational data), they must receive acknowledge. This method reduces the problem of computation in sensor nodes and gives possibility to execute more complicated algorithms. However, the communication cost and scalability are some limitations and possibility of sensor node or central node failure are two issues. In some applications such as monitoring patients, controlling home, monitoring humidity and temperature in precise agriculture with central architecture, it is easy to use centralized localization. In the following paragraph, we study three algorithms in centralized localization (Pal, 2010).

A. MDS-MAP: this is a centralized algorithm for localization which has three steps:
   1. *"Compute shortest paths between all pairs of nodes in the region of consideration. The shortest path distances are used to construct the distance matrix for MDS.*
   2. *Apply classical MDS to the distance matrix, retaining the first 2 (or 3) largest eigenvalues and eigenvectors to construct a 2-D (or 3-D) relative map.*
   3. *Given sufficient anchor nodes (3 or more for 2-D, 4 or more for 3-D), transform the relative map to an absolute map based on the absolute positions of anchors"* (Pal, 2010).

B. Localization node based on simulated annealing: This algorithm has access to the estimated location and other information of the neighbor nods that are localizable in the system. This algorithm has two steps and it is useful for medium and high density sensor network:
   1. *"The algorithm is used to obtain an estimate of location of the localizable sensor nodes using distance constraints.*
   2. *In the next step the error caused by flip ambiguity is eliminated"* (Pal, 2010).

C. A RSSI-based centralized localization: this algorithm is based on signal attenuation to find distance. It is practical and self-organized program but uses more power to send much information to the central server. It has three steps:
   1. *"RF (Radio Frequency) mapping of the network: It is obtained by conveying short packets at different power levels through the network and by storing the average RSSI value of the received packets in memory tables.*
   2. *Creation of the ranging model: All the tuples recorded between the two anchors are processed at the central unit to compensate the non linearity and calibrate the model. Let a generic tuple (i, j, P_{tx}, P_{rx}) comes from the RF mapping characterizing stage, where i is the transmitting node and j is the receiving node. Now first the algorithm corrects the received power as P_{rx}' =f(P_{rx}, P_{tx}), f() is a function which takes into account the modularity effects. So, the estimated distance between the nodes will be $rij^0 = m^{-1}(P_{rx}')$*
   3. *Centralized localization model: An optimization problem is solved and provides the position of the nodes. The final result can be obtained by minimizing the function E=Σi=1 to nΣj=1 to n (ki,jai,j (rij-rij0)2) , rij = d(i, j) when i and j are anchors. Where N is the number of nodes, ai,j is 1 when the link is present and 0 otherwise"* (Pal, 2010).

2.3.2 Distributed Localization

Distributed localization computation for positioning does not rely on one single node. Each sensor node has small memory and small processing time (limited processing potential). It means that the solution (algorithm) is simpler than centralized approach and sensors communicate with each other to find their location in the network. There are six classifications in this method.

Beacon-based distributed algorithms: in these algorithms some group of beacon nodes with unknown positions find their locations by using measured distance to the other beacon nods. These algorithms classified in Diffusion, Bounding Box and Gradient (Pal, 2010).

Relaxation-based distributed algorithms: these algorithms use coarse algorithm with some refinement stages to reach an optimal solution. Spring model and Cooperative Ranging Approach are in this category (Pal, 2010).

Coordinate system stitching based distributed algorithms: in these algorithms, an area of sensors is firstly divided into small overlapping optimal local maps and then these local maps merge and make a single map. Cluster based approach is in this category (Pal, 2010).

Hybrid localization algorithms: these algorithms use two different localization techniques to decrease communication and computation cost. Like composing MDS (multidimensional scaling) and APS (ad-hoc positioning system) (Pal, 2010).

Interferometric ranging based localization: the idea in this method is to use two transmitters to create interference signals and then measure the composite signal frequency. Although in this method measurement is very precise, since Interferometric ranging needs a large set of measurements, this matter limits localization to the small networks (Pal, 2010).

Error propagation aware localization: this algorithm works based on integration of path loss and distance measurement error model. When a sensor node (with unknown position) finds its position with WLS (weighted least square) the algorithm becomes an anchor node (with known position) and broadcasts its information. This process continues until all sensors become anchors (Pal, 2010).

2.4 Wireless Node Positioning Techniques' Classification

All localization algorithms in WSNs are totally classified in two groups of "range-free" (algorithms not based on distance measurement) and "range-based" (based on distance measurement) localization. Usually the range-based technique requires extra hardware for localization and the accuracy is better than range-free method. However, range-free method is cost-effective especially for large-scale networks (He et al., 2003).

2.4.1 Range-free

Range-free is a technique that uses content of messages (estimated distance instead of range measurements or angle) and relies on network connectivity (*predefined hop-size, node spatial distribution…*) without using additional hardware and complicated computation and there are several approaches to reducing localization cost in the networks (in comparison to range-based). Since in this technique (range-free) the accuracy is not high, it depends on deploying a large number of anchor nodes to increase accuracy. It is considerable that researches in this technique mostly concentrate on algorithms that are not very practical. DV-Hop algorithm, Amorphous algorithm and APIT algorithm are typical range-free algorithms (He et al., 2003).

2.4.1.1 DV-Hop algorithm

Generally DV-Hop assumes a heterogeneous network consisting of sensors (unknown nodes) and anchors where the algorithm has three steps. In the first, step all anchors in the network gain the minimum "hop count" from the other anchors. For this, each anchor sends a package with its ID, position and hop count to its neighbor anchors. Receiving anchors save minimum "hop count" from each anchor and give up the package with larger "hop count" from the same anchor. After that anchor increases the hop count by one and send it to its neighbor anchors. In the second step, the anchor can calculate (by using the received position and hop count of the other anchors) the average hop-size for one hop from the other anchor. Then each anchor sends its hop-size by controlled flooding. The following formula is applied for the calculation of the average hop-size (Jun Xiang & Wei Wei Tan, 2013).

$$\mathrm{hopsize} = \frac{\sum_{\mathrm{i}\neq\mathrm{j}}\sqrt{(\mathrm{x_i}-\mathrm{x_j})^2+(\mathrm{y_i}-\mathrm{y_j})^2}}{\sum_{i\neq j} hij}$$

In the above formula, (x_i,y_i) and (x_j,y_j) are the coordinates of the anchor i , j and h_{ij} is the minimum hop count between them. Each unknown sensor receives the average hop-size from the nearest anchor and calculates the distance between itself and the other anchor by the following formula (Jun Xiang & Wei Wei Tan, 2013).

$$d_{ij} = hopsize_p \times h_{ij}$$

Where $hopsize_p$ is the average hop-size (the unknown sensor gains it from the nearest anchor "p") and h_{ij} is the minimum hop count between the unknown sensor i and anchor node j. Finally, in the third step the position of the unknown sensor can be estimated by the polygon method when the unknown sensor gains at least three (to find the 2D position in this method we need at least three distances) distances between anchors (Jun Xiang & Wei Wei Tan, 2013).

2.4.1.2 APIT Algorithm

APIT is an area-based range-free method that needs a heterogeneous network of sensors which a small group of these sensors are high-powered transmitters and have known positions (anchors). This is an area-based method since localization is based on isolated environment which is into triangular areas among the beacons (figure 1). The algorithm works based on that the unknown node is inside or outside of these triangular areas and with the help of the anchors' positions, the scope of the estimated area of the sensor (with unknown position) can be decreased for better location estimation (He et al., 2003).

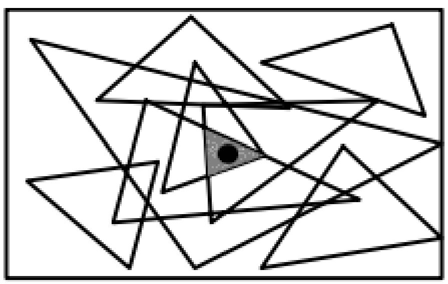


Figure 1: Area-based APIT (He et al., 2003)

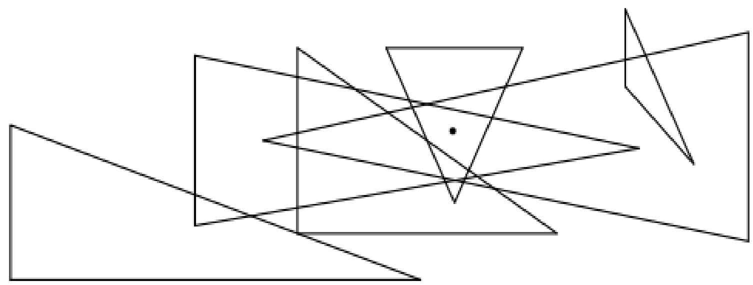


Figure 2: APIT location algorithm diagram (Tie-zhou et al., 2013)

This algorithm tries to shorten the area of the target node (node with unknown position), which is called Point-In-Triangulation Test (PIT). Firstly, a sensor node selects three anchors of all detectable anchors around it and checks if it is inside or outside of the triangle from connecting of these three anchors. APIT repeats this PIT test by different combinations of other detectable anchors until all combinations are checked or we reach desirable precision. Then the algorithm calculates the COG (Center of Gravity) of the intersection of all of the triangles in which the target node is to indicate its estimated position (He et al., 2003). Totally, the APIT algorithm has four steps: 1) Beacon exchange, 2) PIT testing, 3) APIT aggregation and 4) COG calculation. The following algorithm demonstrates these steps:

"Receive location beacons (X_i, Y_i) from "n" anchors
InsideSet = Φ // the set of triangles in which i reside
For (each triangle $T_i \in \binom{n}{3}$ triangles) {
If (Point-In-Triangle-Test (T_i) == TRUE)
    InsideSet = InsideSet $\cup \{T_i\}$
If (accuracy (InsideSet) > enough) break;
}
/ Center of gravity (COG) calculation */*
Estimated Position = COG ($\cap T_i \in$ InsideSet);" (He et al., 2003)

2.4.2 Range-based

The range-based algorithms are built on measurements to calculate the distance or angle between sensors (point-to-point measurement) and usually need extra hardware for localization and provide information on a specific signal. In fact, since this measured signal is used for range estimation, its name is range-based method. The localization accuracy in these algorithms is better than range-free algorithms and algorithms are more complicated. Usually range-based methods apply a server for localization and they have energy-saving strategy. In range-based method, localization is done by two steps: ranging and position computation. In ranging step the distance between two nodes (unknown position sensor and known position sensor) obtains by some method such as TOA (Time of Arrival), TDOA (Time difference of Arrival), RSSI (Received Signal Strength Indicator) or AOA (Angel of Arrival). In the positioning step the location of unknown node calculated by some methods such as Trilateration or Triangulation (based on geometric principle in triangles by using distance or angle information). TOA and TDOA methods require additional acoustic hardware and AOA method needs additional antenna array however RSSI method does not need additional hardware and its accuracy is not enough (Wang et al., 2012).

2.4.2.1 Time-based Approach

TOA and TDOA are two algorithms in this approach. Both of them work on the basis of light speed propagation and LOS (line of sight) propagation path. Therefore, signal time delay is related to LOS distance.

TOA (Time of Arrival): TOA is working based on the propagation time signal communication with respect to the speed of light and LOS propagation assumption. In fact this equation can explain the distance between transmitter and receiver where d is the distance, v is the velocity of light and t is the estimated propagation time (S. Chaurasia, 2011; R. Kaune, 2012; (Wang et al., 2012)):

$$d = v \times t$$

The sensors in this technique must be time synchronized. For distance calculation, transmitted and received times are used by the sensors. The TOA in the sensor *i* is

$$TOA = t_0 + \frac{r_i}{c}$$

TOA is emitting time plus signal time propagation between two sensors (sender and receiver) and *c* is the speed of light. Also r_i is:

$$r_i = \|X - X_i\|$$
$$r_i = \sqrt{(x - x_i)^2 + (\mathrm{y} - \mathrm{y}_i)^2} \qquad i = 1, \dots, M$$

Regarding $r_0 = ct_0$ and multiplication TOA measurement in time (based on speed of light *c*) the range measurement formula is:

$$h_i = r_0 + r_i$$

When we consider noise in the above formula as Gaussian noise with standard deviation σ_i, for i=1… M, we have:

$$z_i = h_i(X) + \vartheta, \quad \vartheta \sim N(0, \sigma_i^2)$$

TDOA (Time Difference of Arrival) (Wang et al., 2012)*:* this method is based on measurement of time difference of one signal between two reception sensors. In this method also propagation time (based on light speed and LOS propagation) is used in our distance measurement. If t_1, t_2 are time of arrival of a signal from a sensor (with unknown position) in two anchors (with known position), the difference of the distance from the sensor to the two anchors is speed of propagation multiplied by difference of t_1 and t_2 in following formula:

$$v(t_1 - t_2) = v\Delta t_{1,2} = d_{1,s} - d_{2,s}$$

If two anchors and the sensor are in the same plane, therefore, the graph of the equation is almost a V-shaped hyperbola. When several pairs of anchors receive the same signal, there is the intersection at the sensor position between several hyperbolas (Wang et al., 2012).

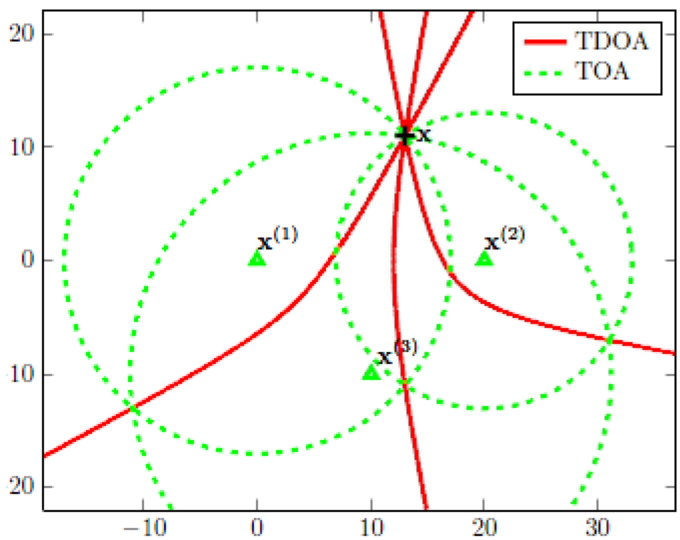


Figure 3: Possible emitter location based on TDOA, TOA measurement with hyperbola and circle in Multilateration (R. Kaune, 2012)

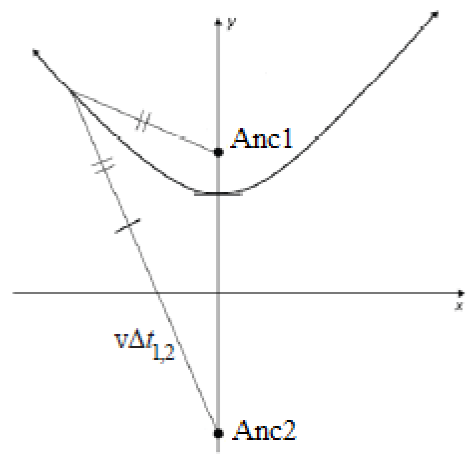
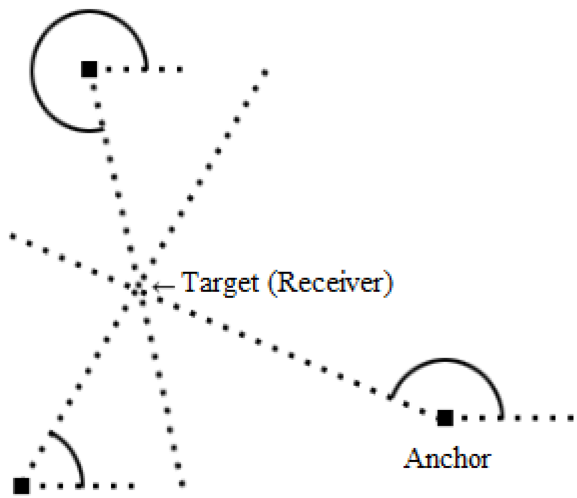


Figure 4: Hyperbola with two anchors and one sensor in the same plane (Wang et al., 2012)

Both TOA and TDOA methods need high-resolution timing system (more physical layer equipments such as time-synchronized sensors) for precise measurement.
Totally, TDOA is named hyperbolic positioning and for a noiseless signal in figure 3 it is demonstrated by red line and TOA define circles to find the possible location of sensor nodes with unknown position (figure 3, green lines) (R. Kaune, 2012).

2.4.2.2 Angle of Arrival (AOA) Approach

This method is also named DoA (Direction of Arrival) and have iterative and non-iterative methods. We can detect and measure the direction (or orientation) of a received signal by applying specific antenna (antenna array on each sensor node). So in localization, it (AoA) can estimate the position of a target node on a point in a line by measuring the angels between target node and reference node (figure 6). Therefore, if we have more than one antenna in different position, location of the sensor node (with unknown position) is a cross point of two (or more) lines and improve the accuracy (figure 5) (D. Niculescu & B. Nath, 2003; C. Y. Park et al., 2010).



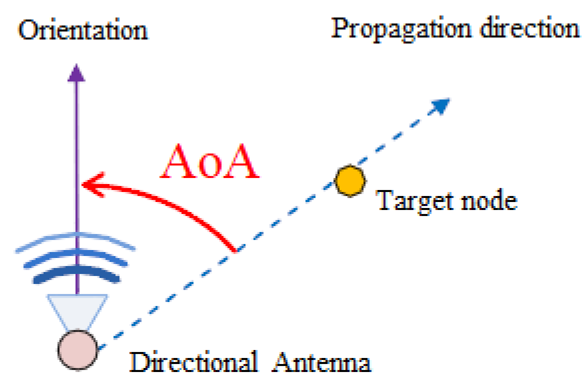


Figure 5: Geometry of AoA (C. Y. Park et al., 2010)

Figure 6: Directional antenna and AoA (Jehn-Ruey Jiang et al., 2012)

Utilizing AOA create possibility for each node to angel measurement to its neighbor nodes with respect to a node's own axis. In fact the positioning in AoA is based on triangulation. As it is illustrated in figure 7, if we know the angles that an interior point (a node with unknown position) in a triangle sees the vertices and the position of triangles' vertices, we can find the location of the interior point (D. Niculescu & B. Nath, 2003). In other words, in figure 7 we can find the position of node *D* by two ways:

- Triangulation: knowing the coordinates of A, B, C (anchor nodes) and the angels $\angle BDA$, $\angle ADC$ and $\angle CDB$.
- Trilateration: knowing the coordinates of A, B, C (anchor nodes) and distances *DA*, *DB* and *DC.*

Then through the intersection of three circles with the center A, B and C (anchors) and angles the positioning is done (D. Niculescu & B. Nath, 2003).

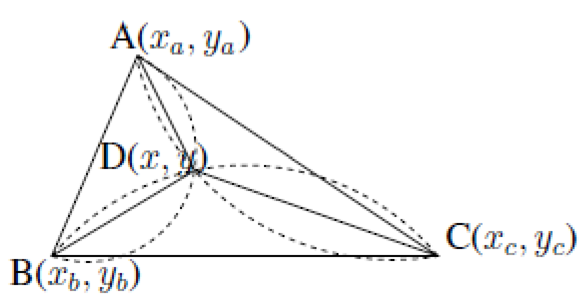


Figure 7: Positioning with triangulation method (D. Niculescu & B. Nath, 2003)

2.4.2.3 Received Signal Strength (RSS) Approach

This method is based on a propagation signal model to estimate the distance between a sensor node and receiver with an antenna which can accurately measure the signal strength. So, knowing the transmitted signal power, antenna gained power and effects of different source of propagation error make possibility for localization. The relation between signal strength and distance is ($Signal\ Strength \propto \frac{1}{d^2}$) which we study it deeply in the next part (Chuan-Chin Pu et al., 2011).

2.5 Received Signal Strength Indicator (RSSI)

2.5.1 Introduction

RSSI: is a measurement to show the condition of received power in the anchor nodes and it is used in most of the wireless communication standard.
RSSI: is an indication that demonstrates the size of electromagnetic wave energy in a media (received by antenna in our sensor nodes) and the most wireless devices can measure received signal strength (Wu et al. 2008).

Theoretically, RSSI is a function of distance and generally are affected by environment (and any changes in the environment). In the RSSI method, the unknown sensor node broadcast frames to the whole network and the other sensors in the communication area and then the distance calculates based on received RSSI values. The frame structure is illustrated in figure 8 (Wang Jian-guo et al., 2011; Heurtefeux & valois, 2012).

Packet_Type	Node_ID	RSSI	Other

Figure 8: The structure of RSSI frame (Wang Jian-guo et al., 2011)

Where the Packe_Type shows the type of frame, the Node_ID expresses id of the sender sensor, the RSSI demonstrates the RSSI value that unknown sensor sends to the receiver and other field is used for sending other relevant information (Wang Jian-guo et al., 2011).
When the distance between unknown node and anchor increases, the value of the RSSI will decrease and when the unknown node is close to the anchors the RSSI value is high. Based on theory the received signal strength from a sensor is monotonically decreasing function, considering following equation (Heurtefeux & valois, 2012):

$$P_r(D) = P_t + G_t + G_r + 20\log_{10}(\frac{\lambda}{4\pi D})$$

In the above formula P_t and G_t are transmission power antenna and antenna gain of transmitting signal respectively in *dBm*, P_r and G_r are reception power antenna and receiving gain antenna, λ is the signal wavelength and D is the distance between two antennas. This formula is an idea case to use for distance measurement. In real experiments localization based on RSSI is not very accurate since environment condition and changes affect the RSSI values and it is difficult to determine antenna gains. Therefore, the following simplified formula is used to explain the relation between distance and received signal strength (Heurtefeux & valois, 2012).

$$P_r(D) = P_{r1} - \beta.\log_{10}(D)$$

Where P_{r1} is the received power in a specific distance (one meter) in dBm, β is path loss parameter and D is distance between transmitter and receiver. P_{r1} and β are determined empirically and we consider it as a one of important requirements in our software and completely explain the method of its calculation in the next chapters. Figure 8 illustrates the second formula (Heurtefeux & valois, 2012).

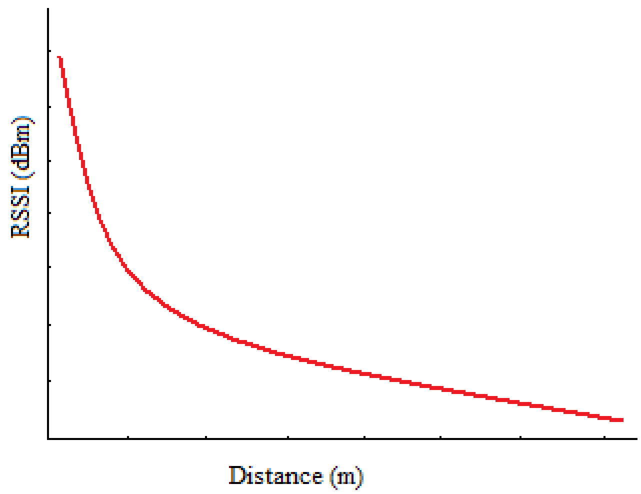


Figure 8: Relationship between RSSI and distance (Heurtefeux & valois, 2012)

In fact the RSSI method finds the distance based on comparing the difference between transmission power and received power which named "path loss" or signal attenuation. In real world with different environments, the increment of path loss is different because of different distance. So the environment characteristics can be demonstrated as "path loss exponent (β)" in RSSI formula. Path loss exponent is one of the significant parameters and the changes of the value of that have considerable effects in distance measurement. The figure 9 illustrates the relationship between RSSI values and distance in different value of "β" (Heurtefeux & valois, 2012; Zhang Zhenghua et al., 2013).

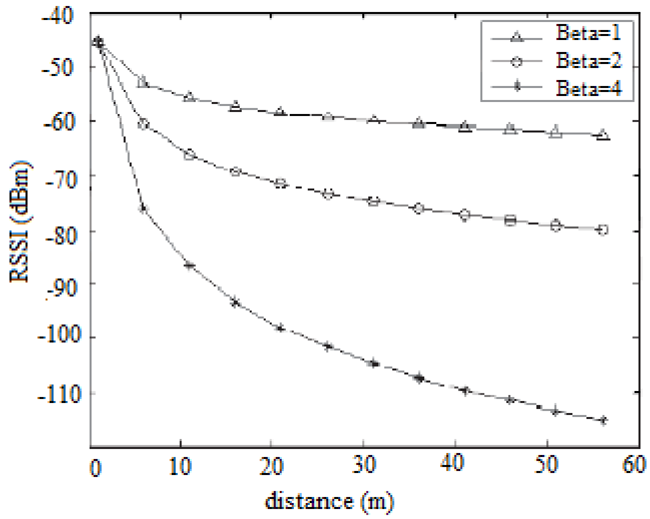


Figure 9: Relationship between RSSI values and distance with respect to different path loss exponents (β) (Zhang Zhenghua et al., 2013)

As we can see in the figure 9, all of the curves have the same starting point which explains the fixed point P_{r1} in the formula. Therefore P_{r1} is another significant parameter that can be explained in different environments (Zhang Zhenghua et al., 2013).
In the context of RSSI measurement method consideration of indoor or outdoor location tracking is important. Since, different location scenarios (indoor or outdoor) influence in path loss model (linear or non-linear), accuracy (in small indoor places is very considerable), space, deployment (find and put the anchors in strategic places to simplify estimation algorithm), map and transmission power (having minimum power for Link Quality Indicator in outdoor location is higher for the respect to quality of wireless communication. Also having a suitable power level is important in indoor location to avoid interference between anchor nodes) (Chuan-Chin Pu et al., 2011).

2.5.2 RSSI Characteristics

To understand the RSSI characteristics we should consider for signal propagation between transmitter and receiver and multipath fading effects. In fact electromagnetic waves go in different paths of varying length and gained in different time because of multiple reflections. The reflection is due to different objects and obstacles in an environment. The interaction of these waves causes multipath fading which affects the strength of the signal (decrease the strength) based on the distance between transmitter and receiver. Reflection, diffraction and scattering are the important concepts in signal propagation. Fading is divided into long-term fading and short-term fading (Wu et al. 2008).
RSSI values are significantly affected by the location of experiment and multipath fading. In point of fact RSSI is environment dependent. Studies present that by a little change in the position, signals' waveforms are greatly different. It is because of changes in receiving distance, path and angel. Since multipath fading and changes in environment have the significant effects on RSSI values, even with a lot of attempts to maintain the environment unchanged, there is not any repeatability and regularity in the RSSI values. Therefore and based on studies, in time and frequency domain RSSI signals are not periodic, RSSI signal variance is not directly related to its

strength but both of them (variance and strength) are depended on environment condition. Figure 10 illustrates the relationship between distance path loss and fading effect (Wu et al. 2008; Fink & Beikirch, 2009).

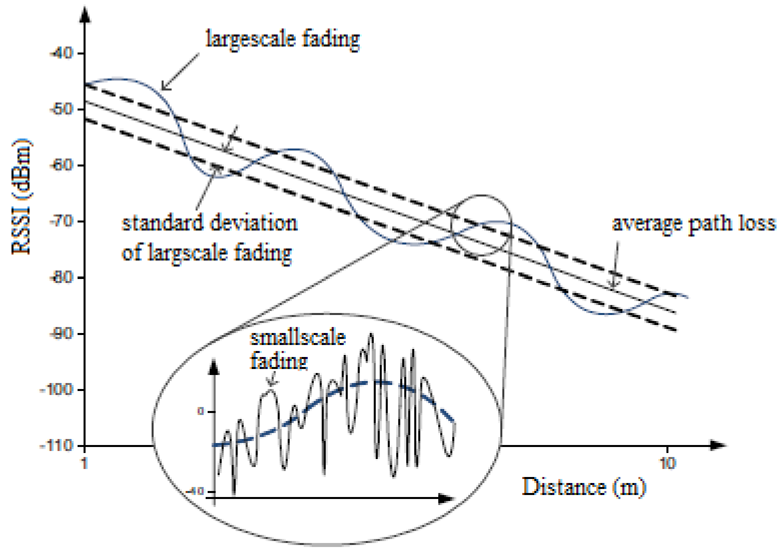


Figure 10: Distance path loss and the effects of signal fading (T. Benkner, 2007)

As a solution for this problem (effects of multipath fading), in the wireless system platform a preliminary calibration of propagation model is done. Calibration has training phase and estimation phase. In the training phase, we measure the RSSI values at a grid of points in the area of experiment and in the estimation phase based on the gained information we estimate the propagation model parameters.

2.5.3 Algorithm

The performance of localization is directly related to radio propagation model and one of these models is used in our computer simulation to use RSSI values for analysis. To characterize radio propagation we these models (Michael Tsai, 2011):

The free space propagation model: this model explains the received signal strength when between transmitter and receiver there is line of sight path without any obstacle. The ration of received to transmitter power and therefore received power by receiver antenna is (Michael Tsai, 2011):

$$\frac{P_r}{P_t} = [\frac{\sqrt{G_t \times G_r}\lambda}{4\pi d}]^2 \quad \rightarrow \quad P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2}$$

Where $P_r(d)$, P_t are received and transmitted power respectively, G_r, G_t are receiver and transmitter antenna gain respectively and λ is the wavelength in meters.
The above equation is not accurate in most case when used alone because in the radio channel propagation, a single direct path between sender and receiver is infrequent.

The two-ray received power model: this model is based on geometric optics and pays attention to ground reflected path as well as direct path between transmitter and receiver. The predicted signal strength in this model is more accurate than free space model (Michael Tsai, 2011).

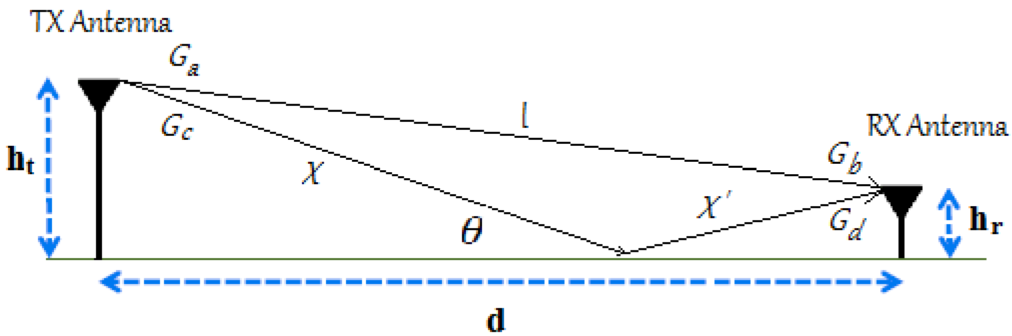


Figure 11: Two-ray model (Michael Tsai, 2011)

The received power in this model is:

$$P_r(d) = P_t G_a G_b \frac{h_t^2 h_r^2}{d^4}$$

G_a, G_b like free space model are receiver and transmitter antenna gain respectively, based on the figure 11, h_t, h_r are the height of transmitter and receiver antenna respectively. With regard to the model and the relation between received power and distance ($P_r \propto \frac{1}{d^4}$) we have a rapid path loss in the two-ray model (Michael Tsai, 2011).

Simplified Path-loss model: the following formula explains the simplest path-loss model (Michael Tsai, 2011).

$$P_r = P_t K \left[\frac{d_0}{d}\right]^{\gamma}$$

Where d_0 is the reference distance (usually 1-10 meter in indoor environments) that is specified and measured close to the transmitter, K is a constant path-loss factor, γ is path-loss exponent, P_r and P_t are received and transmitted power (Michael Tsai, 2011).

Since in the same T-R distance usually we can see different path loss, it is required to consider "shadow fading" factor. In fact, simplified path loss model shows an average value and it does not consider surrounding environment. The ratio of transmit-to-receive power (P_t/P_r) is considered to be random (Gaussian random variable in decibels that mean is zero and its standard deviation is usually 4-10) with log-normal distribution (based on empirical measurement) (Michael Tsai, 2011).

$$f_X(x;\mu,\sigma^2) = \frac{1}{x\sigma\sqrt{2\pi}} \exp\left(-\frac{(\log x - \mu)^2}{2\sigma^2}\right)$$

Where x is our random variable, μ is mean and σ^2 is variance in decibels.

Now with combining simplified path loss and shadow fading effect we have an applicable propagation model which considers surrounded environment (Michael Tsai, 2011).

Path-loss normal shadowing model (Michael Tsai, 2011; Mehra & Singh, 2013)*:* in this model the relationship between distance and received power can be shown by the following formula:

$$P_L(d) = P_L(d_0) + 10\beta \log\left(\frac{d}{d_0}\right) + X_\sigma$$

In the above formula P_L (d) is the path loss in specific distance *d* in decibels. In fact P_L (d) is $\log(\frac{P_t}{P_r})$ where P_t and P_r are sender and receiver power in watts. P_L (d_0) is the path loss for the specific distance d_0 (in practical indoor system d_0 is one meter). β is path loss exponent and X_σ is random shadowing effect ($X_\sigma \sim N(0, \sigma^2)$) with zero mean and σ^2 variance. This is the model that we applied in our computer simulation to find the distances of an object to anchors and analysis the results. Also to find out the power in the reference distance d_0 we can measure the signal power in d_0 or use free space formula with d = 1 meter ($\frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2}$) (Michael Tsai, 2011).

With respect to path-loss normal shadowing model, if the sensor has transmitted power P_t, received power in the anchor node at the distance *d* is:

$$P_r(d) = P_t - P_L(d) \rightarrow$$
$$P_r(d) = P_t - P_L(d_0) - 10\beta \log\left(\frac{d}{d_0}\right) - X_\sigma$$

In the above formula $P_0 = P_t - P_L(d_0)$ is the average received power in 1 meter (d_0) (Michael Tsai, 2011).

2.5.4 RSSI Limitations and Challenges

As mentioned in section (2.5.2), it is also hard in the real world we see the relationship between RSSI and distance based on the function illustrated in the figure 8. Since signal strength is affected by path loss, fading and shadowing effects (Heurtefeux & valois, 2012).
Path loss is the reduction in power of signal when it propagates through space. This attenuation is demonstrated by the "Path loss exponent (β)" and its value is various in different environments. Table 1 and 2 represent different values of path loss exponent and its relation with standard deviation in different WSN environment (Mehra & Singh, 2013).

Environment	Path Loss Exponent
Free space	2
Urban area cellular radio	2.7 ~ 3.5
In-building LOS	1.6 ~ 1.8
Obstructed in-building	4~6
Shadowed urban area cellular radio	3~5

Table 1: Different values of path loss exponent (Beta value) in different environments (Mehra & Singh, 2013)

Environment	Path Loss Exponent	Standard Deviation
Free space	2	-
Retail store	2.2	8.7
Grocery store	1.8	5.7
Office, hard partitions	3	7
Office, soft partitions	2.6	14.1

Table 2: Relation between Beta value and standard deviation in different environment (Mehra & Singh, 2013)

Fading is deviation of the attenuation in a signal and geographical position, radio frequency and time affect it. Fading is often considered in the random process and as a consequence it can have constructive or destructive interferences in the signal power at the receiver (Heurtefeux & valois, 2012).

Shadowing is loss of signal between transmitter and receiver because of different obstacles such as walls, trees, buildings and etc. one of important reason of shadowing effect is people movement (up to -21 dB of variation) in an uncertain way (Heurtefeux & valois, 2012).

RSSI also has some limitations as a distance metrics. Firstly, the RSSI-Distance ratio which shows the RSSI values spread throughout minimum and maximum values for whatever distance and the average RSSI-distance ratio is different platforms. The reason is that RSSI is depended to deployment environment. Secondly, signal strength can be asymmetric in a bidirectional link and it can increase the received power. It means that in a link between sensor node A and sensor node B, the number of received packets from A by B is larger than received packets from B by A. difference in the number of received packets means that the link quality is not symmetric even if the RSSIs are almost identical. Thirdly, some studies show that anisotropic radiation behavior in RSSI values and it can be the reason of asymmetric and unidirectional features in RSSI values. "*Isotropic radiation means the antenna broadcasts power equally in all direction and an isotropic radiation has the same intensity regardless of the measurements direction*". Fourthly, there is a dynamics in the links' quality in terms of RSSI stability. In fact, we can again see different behaviors in the RSSI stability in different WSN environment (Heurtefeux & valois, 2012).

Based on the different characteristics that were mentioned above, using RSSI method has some challenges with respect to accuracy and stability. Therefore, consideration of following factors can improve the accuracy:

- *"measure RSSI on several frequency;*
- *average an important number of RSSI measures to be able to smooth variations;*
- *caliber sensor radios to obtain a comparable emission power and reception sensitivity;*
- *have a high-quality antenna;*
- *be able to minimize interferences and network environment dynamics (mobile objects, rain, doors, electronic equipments, etc.)* (Heurtefeux & valois, 2012)*."*

2.6 Related Work

The topic of WSNs, localization and different methods and techniques includes a vast domain of studies. Therefore, in this part we just focus on some literature that covers RSSI-based technique in localization (different RSSI methods, advantages, disadvantages and different approaches to improve RSSI localization accuracy).

(Sugano et al., 2006) implemented their experiments in an indoor situation based on ZigBee standard and focus on density of anchors in WSN deployment and its relation to the accuracy. The target node (sensor with unknown position) is a wireless sensor node which sends its packet to at least three or more anchor nodes. For more than one target node, packets include ID of each target node. The anchors are assumed with known and fixed position (without movement) and position estimation method is ML (maximum-likelihood). Then the authors proposed an effective data collection method in which target node in different environment send different number of data to gain a certain level of accuracy (control the threshold of collected RSSI). Since RSSI signals propagation is depend on the environment of the experiment, if the results show less accuracy than what it is required, the target node can increase the number on sending data. Also anchors can measure the deployment density (number of anchors) around themselves. The deployment density around anchor node "i" is:

$$D = \frac{M_i}{\pi R^2}$$

Where R is the range of communication and M_i is the number of anchors from anchor node i in the range of R. Then the authors define Z as the number of data (RSSI values) that system required to collect. Therefore Di depends on the density around anchor node i and is:

$$\frac{M_i}{\pi R^2} = \frac{Z}{\pi D_i^2} \rightarrow D_i = R\sqrt{\frac{Z}{M_i}}$$

Finally the author demonstrates that when the density of anchors is 0.27nodes/$m^{2,}$ localization estimation error can be decreased to 1.5-2 m (Sugano et al., 2006).

(Barsocchi et al., 2009) propose an approach that selecting the RSSI values is based on their strength and then they use a propagation model to apply the RSSI values and calculate the distance. Also in their algorithm there is a virtual calibration which it works without any human intervention. Moreover, they show their localization algorithm performance rises in comparison to usual least mean square algorithm. Again the anchors are fixed in the known position and computation is done in a localization server. The localization has two different phase; training and localization phase. In the training phase virtual calibration is done to adapt the propagation model to its environment. In this phase reciprocal RSSIs among anchors is measured and the server uses these information to calibrate the propagation model. The authors use a model which considers WAF (wall attenuation factor) and FAF (floor attenuation factor).

$$L(d) = l_0 + 10\beta \log(d) + WAF + FAF \quad , \qquad WAF = \sum_{i=1}^{N} k_i l_i$$

In this model L(d) is path loss, l_0 path loss in reference distance and β is path loss exponent. Also for simplifying the model the authors just consider WAF parameter which k_i is the number of walls of type i and l_i is the attenuation on the wall. Then they calibrate the above model (the

parameters β and l_i) by applying *global virtual calibration* (G-procedure) and *per-wall virtual calibration* (W-procedure).
In the second phase (localization phase), the server accumulates the entire RSSI values received form mobile node (node with unknown position). But only select the values which coming from the three anchors that have greatest RSSI values to estimate the distance and calculate the position of moving object (Barsocchi et al., 2009).

(Artemenko et al., 2010) propose a technique to improve accuracy of position estimation. They explain that their technique can be used by different localization method such as RSSI based, TDoA, ToF, etc (the idea is independent of selected algorithm). They give additional information to the system about the unknown nodes. This information is priori known distance between couple of mobile nodes (node with unknown position).
The point in this technique is, when we want to track for example a person, we can attach two or three sensors in different part of his body that although we do not know the position of these nodes in an environment when that person is moving, these sensors have fixed predefined position to each other. We can use this information in refinement process. When the positions of mobile nodes are calculated we can see if the distance between them is bigger or smaller than predefine distance between them (Artemenko et al., 2010).

(Barralet et al., 2009) evaluate the effects of antenna polarization on the localization accuracy in an indoor environment. In fact, the accuracy of localization is significantly related to the precision of range measurement (finding the distance based on propagation model). Their experiments show that antenna polarization angel affect the RSSI values and the final results (localization). The practical method to find the polarization angel is with an accelerometer. Then they suggest semi-automatic trial and error technique for calibration the system (in calibration phase they define two important parameter of the propagation model) and in their approach each room or place has separate set of calibration parameters to improve the accuracy (Barralet et al., 2009).

(Jia Chen et al., 2009) present the new method to improve RSSI-based localization algorithm for park lighting and children tracking based on distributed localization. The new algorithm can decrease computational complexity and cost and prepare suitable accuracy in an outdoor environment (about 4 meter in an area of 60×60m for child tracking). In the basic algorithm, in the range measurement phase, log-normal model is usually used. Also in the location estimation phase Maximum likelihood method is commonly applied. The new algorithm avoids communication bottleneck, network traffic and energy consumption when we have multiple unknown nodes for localization and reduce complexity (which makes possibility to use the system in big networks with more sensor nodes). The new algorithm firstly establish Piecewise linear RSSI path-loss model instead of logarithmic model (figure 12). In this phase unknown-position (blind) node do linear operations. Then compare with logarithmic model, piecewise linear model can be more precise by using enough signal propagation exponents (n_1, n_2, …, n_n) .

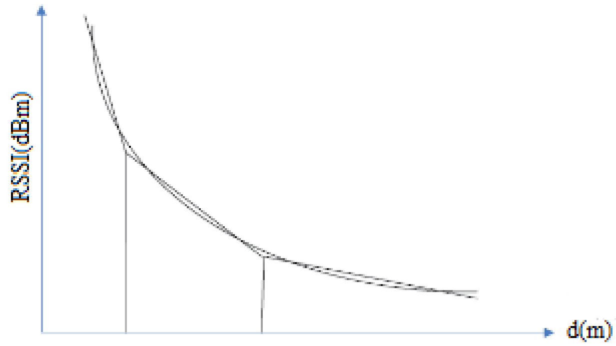


Figure12: Piecewise RSSI path-loss model (Jia Chen et al., 2009)

Secondly, the new algorithm uses Min-max model. The idea to find the position of the blind node is overlapping three or more rectangular areas which are determined by the reference nodes and their distances to the blind node (figure 13).

Rectangular area: $[x_a - d_a, y_a - d_a] \times [x_a + d_a, y_a + d_a]$

Overlapping area: $[\max(x - d), \max(y - d)] \times [\min(x + d), \min(y + d)]$
Where $x \in \{x_a, x_b, x_c\}, y \in \{y_a, y_b, y_c\}$

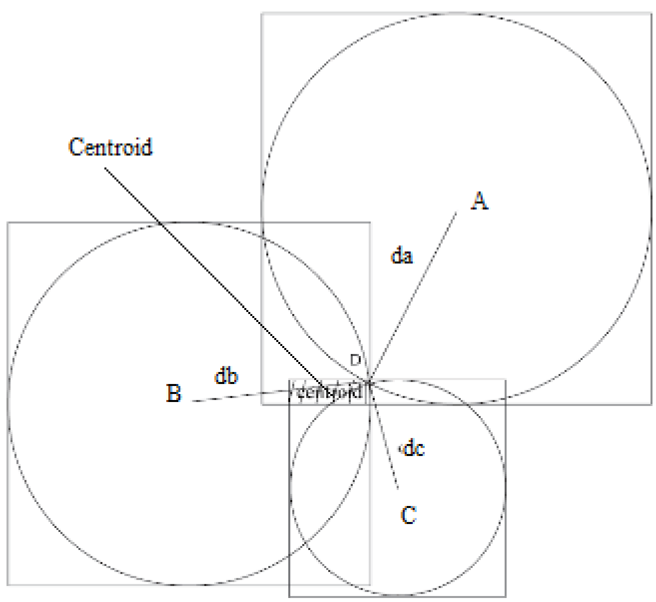


Figure 13: Min-max method (Jia Chen et al., 2009)

(Chuku et al., 2013) proposed an effective range-based self-localization method to alleviate the effects of obstacles (shadowing effects) in RSSI signals and improve localize accuracy. The authors explain their experience and techniques based on a real–life 122-node WSN for monitoring the health of equipment in a power substation in Kentucky. In their experience there are some large objects that can cause important RSSI error in distance measurement (objects disturb the signal path between anchors and unknown node). In their method they select a random subset (M) of all anchors (B) and apply multi-lateration localization technique for each subset to get the location estimations (maximum $\binom{B}{M}$ multi-lateration that results a lot of location estimations for each node). Then they use a clusterization technique to select the final location. Their algorithm has three stages. Firstly, it forms all combinations of M (they use M=3) non-collinear anchors that sent their RSSI values from their positions. Secondly, for each combination in the first stage, position estimation is done (using linear least square method). Thirdly, the algorithm distinguishes among different estimated position which affected by obstacles. In fact this algorithm filter RSSI values that affected by shadowing effects (Chuku et al., 2013).

(Yun et al., 2007) explain a localization method based on TSK (Takagi-Sugeno-Kang) fuzzy modeling and GAs (Genetic Algorithms). Their algorithm has two steps. At first it finds adjacent anchors that are connect to the blind node. In the second step the fuzzy membership function based on RSSI values is implemented. In this step TSK fuzzy function is used to estimate edge weights and Gas is used to optimize fuzzy function. Finally they apply weighted centroid localization method to find the position of blind node (Yun et al., 2007).

(Heurtefeux & valois, 2012) studied RSSI method in three large scale WSNs with different experiments to determine whether or not this approach of localization is sufficiently accurate. Based on their results, RSSI method with regard to accuracy and stability is not a good candidate for localization. They used three SensLab test-bed platforms and each of them has more than 250 sensors. They showed that increasing the number of anchor nodes does not definitely cause better average accuracy and more than 50 anchors decline the average accuracy (figure 14). Also they showed even with considering good condition in RSSI method, the localization is not good with respect to deployment area.

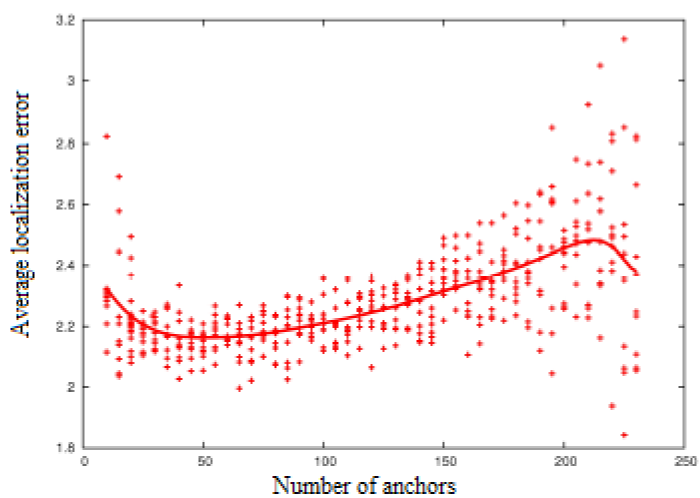


Figure 14: Localization error regarding number of anchors (Heurtefeux & valois, 2012)

(Dieng et al., 2012) proposed biased log-normal shadowing model to mitigate the effects of multipath in RSSI signals and showed that Biased-MLE has better result (improve accuracy) than classical MLE (Maximum likelihood estimation). They explained since the average value of RSSI at different positions do not always reduce as a function of distance, the parameters of propagation model change from one anchor to another one. It means that we should not consider equally to each anchor in a statistical estimation. This bias can explain the reason of difference that affects reported RSSI values on a wireless sensor node. Their results showed increased number of sensor node with lots of exchanged packet reduces the estimated error and increase accuracy. Also B-MLE reduces mean distance error and improves accuracy than MLE (Dieng et al., 2012).

(Y. Chen et al., 2012) present a mechanism for distance measurement that apply dependable RSSI which defining a threshold for dependable RSSI is based on practical experiment. Then they use shortest path algorithm to find the distance between anchors and blind node. The idea of defining a threshold for RSSI value is depending on two reasons. First, a small RSSI value shows a high noise-to-signal ratio. So, small RSSI values are not appropriate for log-normal path loss model. Second, based on RSSI distance model, the curve in the diagram shows small RSSI values are in the flat part of the diagram and it means a small error in RSSI value cause a large error in distance estimation. Therefore, if we want precise distance estimation we need to ignore small RSSI values. By defining a threshold we can select dependable RSSI values (dependable RSSI refresh every 10 seconds) and calculate the distances (Y. Chen et al., 2012).

(Yanjun Chen et al., 2010) explain a new algorithm with considering path loss exponent in propagation model. AWCL (Adaptively Weighted Centroid Localization) is their model with two steps. At first in accordance with the environment of target node, a rational attenuation exponent is adaptively recognized. Then the position of target node with using weighted centroid method is calculated. CL (Centroid Localization) based on the following formula uses the location information of all sensor nodes in its communication range to find its position as the centroid.

$$P_m(x,y) = \frac{1}{S}\sum_{i=1}^{S} B_i(x,y)$$

Where $P_m(x, y)$ is the position of *m*th target node, *S* is the number of anchor nodes which are in communication area of target node and $B_i(x, y)$ is the position of *i*th node. But since accuracy in CL is not high, WCL (Weighted Centroid Localization) algorithm with respect to anchor node qualification is introduced. In fact the nearer anchors have more influence (considering Link Quality Indicator). So the distance between anchor and target node is used to evaluate the weight of each anchor node. The qualifier for the weight concept is defined as (Yanjun Chen et al., 2010):

$$W_{i,m} = \frac{1}{(d_{i,m})^g}$$

Where $W_{i,m}$ is qualification of *i*th anchor node used by *m*th target node, $d_{i,m}$ is the distance between *i*th anchor node and *m*th target node and *g* is symbols a degree. Based on this qualification positioning formula is (Yanjun Chen et al., 2010):

$$P_m(x,y) = \frac{\sum_{i=1}^{S} W_{i,m} B_i(x,y)}{\sum_{i=1}^{S} W_{i,m}}$$

Since the value of RSSI depends on its environment, when a target node moves from boundary of two different environments localization parameter should be calculated again and the weight calculated by above formula is changed adaptively according the new situation. This method of localization is named AWCL (Yanjun Chen et al., 2010).

(Golestani et al., 2014) propose a method which divides anchors into different groups and each group has its PLE (Path Loss Exponent). They introduce a client-server architecture for the localization and communication system. Their web server manages the users' authentications and users have access via a smart-phone or computer. The users based on their right can add new anchor, edit configuration or just view the localized tags. They implement MLE, multilateration and extended Kalman filter and consider the impact of walls in their calibration phase. Their grouping algorithm sets up groups of anchors and calculates path loss exponent for each group by using fixed object named measurement tag. The path-loss exponents of groups are constantly updated and new groups are established if necessary. This method increase accuracy and stability of their system (Golestani et al., 2014).

(Choi et al., 2012) present a method that a sensor node can estimate iteratively the PLE from the anchor node of interest and based on this self-estimated PLE, calculate its position. Since sensor node iteratively calculates the PLE, reproduces its position based on new estimated PLE. In addition, they use APIT algorithm to find the optimal triangle (based on selecting three anchors, we have many possible triangle and selecting the proper triangle is significant for iterative PLE estimation) for positioning and finding the blind node is located inside or outside of the triangle. Recalculating of PLE and new position estimation continue until to reach the distance threshold. They use two criteria to select optimal triangle: first, the area of the triangle, second, the minimum angel of a triangle. Selecting an optimal triangle based on area and minimum angle (θ_{system} is an angle threshold generated by system) is important since the small area is better for blind node to estimate PLE but if in a triangle two anchors are far from each other, the probability the PLE have different values within the triangle can be very high even the area is small. In figure 15 although the blind node U is in the both triangle and $\Delta A_1A_2A_3$ is smaller, the triangle $\Delta A_1A_2A_4$ is the optimal one.

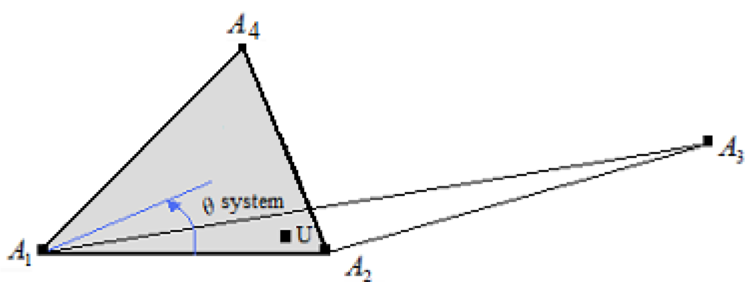


Figure 15: Selection of optimal triangle based on θ (Choi et al., 2012)

(Shirahama & Ohtsuki, 2008) present a grid-based centralized localization method based on maximum and minimum of path loss exponent in an environment and improve the localization accuracy. Their method consider all combinations of path loss exponent for each link (the relation between target and anchor) and estimate the target location by averaging of locations calculated by path loss exponents. Their algorithm at first set minimum and maximum distance for each receive node *i*. Then the algorithm calculate the distance $d_{i,(k,l)}$ between candidate target location and each receive node *i*. if $d_{i,min} \leq d_{i,(k,l)} \leq d_{i,max}$ vote the grid (*k*, *l*) and this process continues for all receive nodes. The target position is the grid point with maximum vote. These steps demonstrated in following procedures:

Step1: (Shirahama & Ohtsuki, 2008)

```
for(k = 0;  k < X+1;  k++){
    for(l = 0;  l < Y+1;  l++){
        for(I = 0;  i < N;  i++){
            if(d_{i,min} < d_{i,(k, l)}  <  d_{i, max}){
                vote the grid point (k, l);
            }
        }
    }
}
```

Step2:

$$(x, y) = (\frac{x_1 + x_2 + \cdots + x_k}{K}, \frac{y_1 + y_2 + \cdots + y_k}{K})$$

Where $d_{i,(k, l)}$ is the distance between grid point (k, l) and node *i* and K is the number of grid points with maximum vote (Shirahama & Ohtsuki, 2008).

Different methods and algorithms reviewed in the related work part with respect to their focus and results are summarized in the table 3.

Author	***Focus***	***Experimental environment***	***Database***	***Result***
Sugano et al., 2006	Sensor density and effective data collection	Limited anchor nodes and target nodes	IEEE	Reducing estimation error based on density of sensors
Barsocchi et al., 2009	RSSI selection, specific propagation model, virtual calibration	Small lab that is harsh for wireless communication and possibility of electronic interference	IEEE	Improving algorithm performance and reaching interested accuracy based on anchor density
Artemenko et al., 2010	Refinement technique suitable for different localization algorithm, targets with priori known distance	Small lab with different stuffs, limited anchor and target nods	IEEE	Improvement accuracy until 0.5 m precision
Barralet et al., 2009	Effect of antenna polarization on RSSI values and final outcome	Small lab, clear, eight anchors	IEEE	Showed the range measurement mostly affects localization accuracy and antenna affects range measurement

Jia Chen et al., 2009	Piecewise linear model for RSSI values and Min-max method for localization	Outdoor environment, child tracking and lighting control in a park	IEEE	Reducing computational complexity, precision about 4 m in 60×60m
Chuku et al., 2013	Self-localization scheme with respect to large scale deployment and energy conserving	Outdoor environment, power substation, 122 anchors, large objects and significant shadowing effect	IEEE	Improve accuracy in an abstracted sensor network
Yun et al., 2007	Using TSK fuzzy modeling and optimizing by GAs	121 anchors and 60 blind nodes in 100×100 m	IEEE	Average error: 0.77m Lowest error: 0.01m Highest error 1.92m
Heurtefeux & valois, 2012	RSSI as a distance metrics has specific limitation, the effect of number of anchors, spring-relaxation technique	Three indoor lab with more than 250 anchors	IEEE	RSSI limitation in stability and reliability and accuracy, range-free algorithm gives useful metrics
Dieng et al., 2012	Biased log-normal shadowing model and biased maximum likelihood estimation	Indoor 8.77×6.46m, eight fixed anchors and one mobile, with effect of people movement in the environment	IEEE	B-MLE improve localization accuracy, increasing number of anchors shall improve accuracy of localization
Y. Chen et al., 2012	Definition of dependable RSSI values, shortest path algorithm	Outdoor: 100×100 m Indoor: 10×10 m Four anchors and 11 blind nodes	IEEE	Improving accuracy, Indoor location error:0.77m and outdoor error: 5.91m
Yanjun Chen et al., 2010	Adaptively weighted centroid localization	100×100 m with 100 anchors, target node: one and two in different scenarios	IEEE	Good localization performance with high complexity and cost

Golestani et al., 2014	Considering PLE in a grouping method	Client server architecture, nine anchors	IEEE	Improving precision and reducing error to three meters
Choi et al., 2012	Iterative PLE estimation, APIT algorithm, selection of optimal triangle	100×100 m Between 50 to 400 anchors in different experiments	IEEE	Localization accuracy improvement, large number of anchors can reduce distance error
Shirahama & Ohtsuki, 2008	Grid-based localization, different PLE	10×10 m, eight anchors and one target node	IEEE	Improvement of localization accuracy in uniform PLE distribution

Table 3: Summarized related work

2.7 Contributions of the Related Work to the Thesis

The related work and table 3 in section (2.6) are based on some selected papers in the literature review phase which prepared innovative approaches in the localization system (e.g., improving measurement accuracy or geometric solution in positioning phase …).

Since the literature review was an applied method before the experimentation phase and concurrent with the implementation phase (chapter 3 discusses the research methodology in detail), we tried to utilize some of these ideas in our experiments or implementation. For instance, the research of (Golestani et al., 2014) guided us into path loss exponent grouping and designing some experiments. Also, (Shirahama & Ohtsuki, 2008) explain a good idea about grid-based localization which helps us in some of our experiments (the design and results of the experiments are presented in chapter 6).

In the implementation phase, we used some ideas in the related work and utilized them in the requirement analysis part. For example, based on the (Sugano et al., 2006) the anchors' density can affect accuracy. Therefore, we considered this idea in one of our software requirements (possibility to define different number of anchor and calibration nodes). Moreover, studies of (Barsocchi et al., 2009) and (Y. Chen et al., 2012) were helpful to develop functionality in the distance measurement part.

Chapter 3

Research Methodology

3.1 Introduction

Since the main goal of this thesis is studying an RSSI-based localization algorithm and development of a server side application to analyze the results of different experiments, the following research questions are defined. Analyzing the achieved results will guide us towards finding more accurate location of a moving object (target node or blind node or a node with unknown position) and the major factors that affect the RSSI signals (as a measurement) and final precision results. Table 5 presents an overview of research questions, relevant research methods and the aims that are accomplished with the answer to these research questions.
Briefly, the main objectives of this thesis are summarized in table 4:

#	Objectives
O1	Studying and describing the RSSI-based localization algorithms, focusing on environmental conditions' parameters.
O2	Describing and evaluating different methods which can improve the localization precision.
O3	Developing a server application to carry out the analysis phase and localization.
O4	Comparing the achieved results with the results without considering environmental conditions.

Table 4: The aims and objectives in this research

#	Research Question	Research Method	Aim
RQ1	What are the most frequently applied research methods in the context of the RSSI-based localization?	SMS	O1, O2
RQ2	In which application fields (such as healthcare, target tracing, environment monitoring …) is the RSSI-based localization applied and how many articles are available in these fields?	SMS	O1
RQ3	In how many papers in the context of the RSSI-based localization "computational effort" with respect to energy consumption has been considered?	SMS	O2
RQ4	What are the environments (indoor environment or outdoor) considered by experiments and how many studies reported the comparison between the accuracy of the experimental results?	SMS	O1, O2, O4
RQ5	How many studies pay attention to the effect of the number of anchors (anchor density) on improving accuracy?	SMS	O1

RQ6	How frequently do the RSSI-based experiments report effect size as an evaluation result?	SMS	O1
RQ7	How prevalent is consideration of environmental conditions (models for the power received form anchors) and their effect on improving accuracy in publications?	SMS	O1, O2, O4
RQ8	What effect does environmental condition have on the precision of localization?	Experiment, SMS	O2, O3, O4
RQ9	To what extent do environmental conditions influence the localization accuracy of the RSSI-based algorithms?	Experiment	O3, O4

Table 5: Research questions and relevant research methods

Based on preliminary study (reading relevant papers and some consulting-training sessions with the company supervisor) the main goal in the research questions was focused on accuracy and environmental conditions. Then, the distinct and clear research questions were made based on the SMS research approach and the university supervisor's advice. Therefore, the research questions and their answers (results) try to fulfill both scientific and industrial research aspects.

To answer the above research questions and achieve the aims of the research, a combination of research methods were applied. Using the different methods and data collection were in most time concurrent. Only in the period of the beginning and end, a sequential strategy was done. At the beginning because of the necessity of being familiar with significant concepts, terms and environment of the company and at the end due to achieving the final results of experiments based on the developed software for new solutions. Figure 16 illustrates the activities in the research methodology as well as data analysis phase in this thesis.

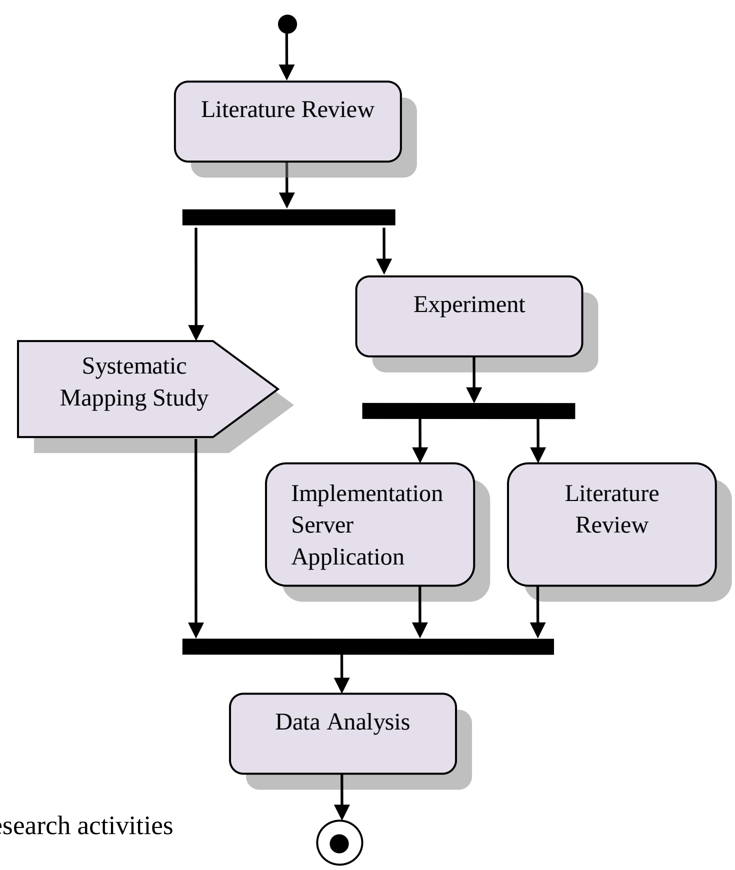


Figure 16: Diagram of the research activities

3.2 Steps

Based on figure 16, the author applied literature review, systematic mapping, experiment and implementation methods in this thesis. The reasons that the experimental method was selected are as follows:

- The company wanted to achieve the data of the limited number of sensors in the laboratory condition to measure the localization accuracy with respect to different effective parameters.
- It was important that each experiment can be repeatable (to analyze the results). Since we required to verify the results of some experiments.
- Most of the relevant papers that were studied in the first and second LR had applied the experimental method.

Moreover, systematic literature review (SLR) was not selected since:

- It is not required to evaluate the papers in detail (in the systematic mapping we can consider more papers and study more different solutions in the context of the RSSI localization.).
- Outcome and quality assessment in the SLR increase the depth and effort of the research and it would affect the time of the other necessary methods (the experiment and implementation).

Finally, implementation of the server application was utilized since:

- An interface of the localization system was required.
- Managing and analyzing data to find the best solution to improve the accuracy were required.

In the following parts we consider the applied methods in detail based on their relationship in the research activity diagram (Figure 16).

3.2.1 Literature Review

A Literature Review (LR) is defined as a written summary of journals, articles, books and papers that describe the past and the current state of information (Dwason, 2005). Initially, a common LR was carried out to find out general information in particular domain of knowledge about “localization algorithms and methods”, “Wireless Sensor Networks”, “RSSI-based method”, “range-based and range-free methods”. This LR was based on the papers and literature that were prepared by the collaborating company, the supervisor and also ad-hoc search in scientific databases. The main aims of this step were: being familiar with the mentioned concepts (general perception) and observing different experiments’ parameters in the context of the RSSI-based method in the previous studies. These two aims helped the author in the planning phase of the experiment and find inclusions and exclusions in the screening phase of the SMS. In this phase, the author found it useful to exclude papers which focus on the “passive object localization”. The second LR phase has been done after the experiments since the study on “RSSI characteristics”, “RSSI distribution” and accuracy improvement (based on results of the experiments) became practical necessity in server development and analysis of the results.

3.2.2 Experimentation

The experiment method, as defined by Dawson (2005), is a research method that is based on observed and measured phenomena. Experiment methods are usually performed in development, evaluation and problem solving research (Wohlin et al., 1999). Experiments are referred to as research-in-the-small, since they are concerned with a limited scope and most often are run in a laboratory setting (Montgomery, 1997). They are often highly controlled for instance in subjects, objects and instrumentation. The main advantages of the experiments are the possibility to do statistical analysis and the potential for future replication (Wohlin et al., 1999). In this study 30 experiments have been done some of which were parallel with the systematic mapping study method. To do an experiment, five steps should be considered. These steps form the process of executing the experiment (Wohlin et al., 1999). Figure 17 demonstrates these steps.

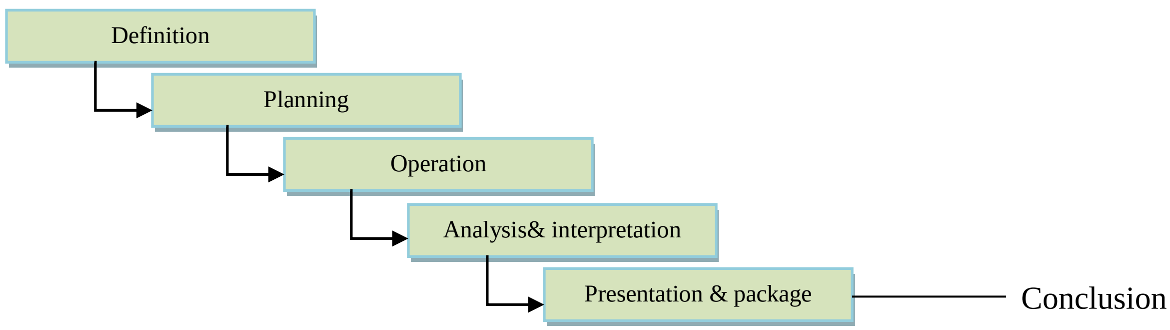


Figure 17: The experiment process (Wohlin et al., 1999)

Definition: the goal of our experiment is defined in this phase. So, before doing the planning and operation phase the necessary aspects of the experiment are defined. Based on GQM template (Wohlin et al., 1999) the experiment can be summarized as: analyzing *the RSSI-based localization algorithms* for the purpose of *evaluating different algorithms* with respect to *effective parameter in accuracy* from the point of view of *the researcher* in the context of *M.Sc. student doing a (master's thesis) research and software development in the company*.

Planning: Planning phase is conducted to answer how the experiment is done and controlled (Wohlin et al., 1999).
In this phase, to design the experiment we have used some results of the SMS method to define independent and dependent variables and also different mathematical methods to calculate the location of a moving object. These experiments have been done in a laboratory condition and they were off-line (not industrial software development) and have been conducted by the author. These experiments tried to address a real problem about accuracy issue in the RSSI-based localization. The independent variable consists of the different algorithms, with and without considering environmental condition as a parameter; accuracy is the dependent variable. The type of design is "one factor with more than two treatments". The factor is, the RSSI-based algorithms with and without considering the environmental condition as treatment. The accuracy of the localization is measured based on the difference between the real position of a moving object (which we know and calculated before the experiments) and the position that has been calculated by the software. The prepared instrument for these experiments is Concentrator V.1.0 which is

used as the mobile object, anchors, target node and the master node with distinctive firmware. Data of sensors has been collected in the text files for further calculation and analysis.
Operation: in this phase the explained treatments are applied to the subjects of our experiments (Wohlin et al., 1999). Required hardware, relevant firmware and a part of software were prepared in the preparation step. The relevant tools for measuring the RSSI signals and distance, the method of data collection and related guidelines were also prepared. Moreover, the experimental environment is controlled (nobody can come or move in the room to disturb the antenna signals unless in the planning phase was defined) to improve the validity of the collected data. The collected data in our experiment are filtered to remove irrelevant data before analysis (one way to remove irrelevant data was defining RSSI threshold in the software to filter the independent RSSI values).

Analysis: this phase has been done after data collection to interpret the collected data from the experiments. Statistical tests and graphical visualization techniques (in MATLAB) have been used in this phase (Wohlin et al., 1999). The result of the analysis phased is discussed in chapter 6.
Presentation & Package: this phase has been done at the end to prepare the final report of our experiments (Wohlin et al., 1999).

3.2.3 Systematic Mapping Study (SMS)

This method is utilized to prepare a classification scheme (categorizing) and structure an area of knowledge in software engineering. In fact in this method we concentrate on three issues; thematic analysis, classification and identifying publication forums. In the SMS method, although the study of literature is not performed in detail, it can assist us in finding a research gap in an area. In the SMS, the number of publications in different categories can be an indicator to show which areas have been covered properly and in which topic areas there is a lack of papers (Petersen et al., 2008). The focus in this study was on the "RSSI-based algorithm" in "localization" in "WSN" area and the main inclusion requirement for screening was "empirical method or experimental study". As it is illustrated in Figure 16 the SMS method has been done concurrently with experiment and the second literature review. In fact the systematic mapping method (especially classification scheme phase and studying abstracts) support the second literature review phase. In the second LR, all the papers that proposed "innovative" measurement or calculation method in their abstracts were fully read and some of the creative methods were considered in the implementation phase of the software. Figure 18 (Petersen et al., 2008) demonstrates five steps in the systematic mapping study process and their relevant outcomes.

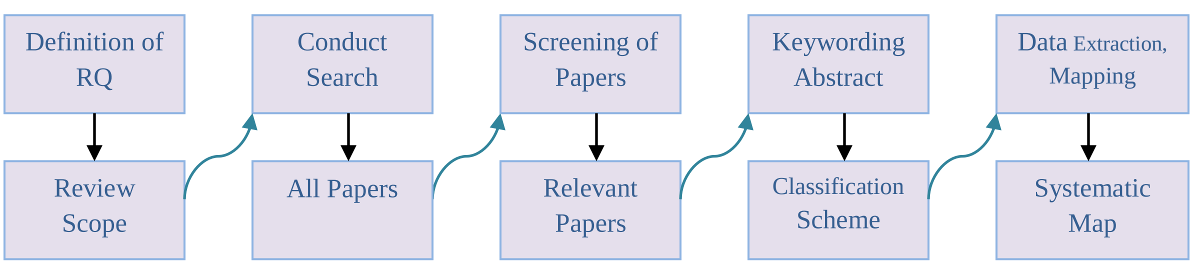


Figure 18: The Systematic Mapping Process (Petersen et al., 2008)

Definition of research questions: in fact we define the scope of our research. In this study and in the SMS part, we consider to map the frequency of papers in the area of the "RSSI-based localization in WSN" to see the quantity, type of research and results with respect to accuracy in localization.
In the conducting search phase and primary studies IEEE Xplore, Engineering Village (Inspec) and Scopus were selected. The relevant search string for the research is:

- RSSI-based localization algorithm in WSN: ("RSSI" OR "RSSI-based") AND ("localization" OR "location" OR "position") AND ("algorithm" OR "model") AND ("wireless sensor network" OR "WSN")

In the screening phase we want to find the relevant papers (to answer our research questions) based on inclusion and exclusion criteria. "Empirical method or experimental study" is an important inclusion requirement of our research and studies that did not report experimental findings or the papers that considered "Range-free algorithm" were excluded. The other inclusion criteria are:

- the paper should be written in English
- full text is available
- the papers should consider the RSSI-based localization algorithm solely or a combination of the RSSI method with the other method (the papers' abstracts should explicitly mention that applying the RSSI method in the localization algorithm)
- the papers should be peer-reviewed

Key-wording of abstracts or classification scheme firstly shows the contribution of the papers and secondly the combination of selected keywords from the papers gives a high level understanding about the nature of the research. In this study the contribution of the RSSI concept, localization and the related keywords has been considered in abstracts, conclusions and sometimes introductions (it depends on the quality of the abstracts to select meaningful keywords).

The data extraction for mapping of studies has been done based on the eight relevant research questions and their answer. The author applied an Excel file in the data extraction phase. In fact the file contains each research question category and short rationale data of each paper in the relevant category. Then the file can be used to count the number of papers in each category to indicate possibilities for the further researches.

3.2.4 Implementation Server Application

After finishing experiments, a server application was developed to interpret the results from the experiments (analysis) and implement the basic algorithm of localization. The software prepares different possibilities to manage row data and to filter, calculation of path loss exponent and distance and finally localization. In fact the software can be an instrument of measuring distance and positioning based on the RSSI algorithm with respect to environmental condition. The main requirements' specification, motivation and their relevant features is discussed in chapter 5.

3.3 Validity Evaluation

Before doing the mapping study, we gained enough knowledge about the RSSI context from the company to reduce the threat of internal validity on the SMS. In this case, we considered firstly our applied keywords in the search string. We utilized the "RSSI" keyword as an indicator in our search string. Secondly, in our primary study, we focused on three main databases: IEEE, Engineering Village and Scopus which have the most important papers in the field of software engineering. So, we had enough relevant papers to analyze. Finally, we studied all abstracts, titles and keywords of the selected papers for keywording with respect to our accepted research questions. In cases which abstracts were not clear and informative enough, we studied introduction and conclusion parts. However, there is a risk of judgmental error since we could not read the papers completely and all the evaluation has been done by one person. Also, in the conclusion part we only focused on the RSSI-based localization and specified the lack of research in different areas of this context.

In our experiments, although we tried to run the experiments in a well and controlled situation (design of the experiments, variable measurements …), there were parameters that can affect our experiments' results. The target node had a battery whose voltage was not always enough, although we renewed the battery constantly. All the experiments have been done by a 12 volt power supply and we did not test the other voltages. The sampling times were sometimes too short and with respect to the RSSI characteristic, they can affect the results. We only had three sensor nodes (the minimum number of anchors for doing localization experiment) while we knew how effective is anchor density in this context. Moreover, our sensors did not have suitable antennas (however, antenna's type has a considerable effect on the experiments' results). Finally, as we mentioned in chapter 2, people's movement has clear effect on the accuracy of the RSSI sample, but in rare experiments we had uncontrolled and unintentionally office staff's movement.

In the literature review phase, firstly we focused on the papers that the company specified for the author. All these papers were from valid sources, peer reviewed (journals and conferences), related to our purpose of the research and in the scope of RSSI-based localization. Based on the gained knowledge at the first LR, the author became familiar with the context, the research background and related work. In the second LR, the focus was mostly on learning the significant concepts and theories, new solutions and algorithms, and utilizing the ideas proposed by the literature in our software (defining new requirement). In addition, all the applied literature in the second LR was peer reviewed.

Chapter 4

Localization Process

*The aim of this chapter is to present practical steps of implementing a localization system. The content is based on the literature review. The introduction (4.1) encompasses (Baunach et al., 2007) localization parameters, simplified measurement formulas which were studied in chapter 2 (background), different localization approaches and considering antennas' types based on the classification of (*Hamdoun *et al., 2014). Section (4.2) considers localization steps with focus on channel identification and its effects on mathematical formulas of measurement, Path loss exponent calculation and the RSSI optimization. Section (4.3) studies positioning algorithm with respect to solving linear equation and triangle centroid location algorithm presented by (Jungang Zheng et al., 2010). Section (4.4) considers an innovative positioning algorithm proposed by (Zhang et al., 2011) to reduce the ranging error. Finally, section (4.5) presents a metric for the localization accuracy.*

4.1 Introduction

(Baunach et al., 2007) identify eight parameters to describe localization systems:

- The localization of objects in the system can be relative to each other or absolute (based on anchors with known position)
- The process of localization can be done periodically or based on specific requirement (occasionally)
- The initiator of the process can be target node or the anchor nodes
- The localization approach can be active (the surrounding objects determine the location of target node), passive (target node determines its location) or interactive (combination of the mentioned approaches)
- The implementation algorithm can be two dimensional or more
- The localization system can be fast to track moving object just position static objects
- The anchors in the system can be tightly coupled (wired to the central unit) or loosely coupled (with wireless communication)
- The system can be centralized (with a central unit for measurement and positioning) or decentralized (with considering the network traffic management)

In the RSSI-based localization, as mentioned in chapter 2, distance measurement is a significant phase and path loss shadowing model is used as the mathematical algorithm for measuring distance. Based on the path loss shadowing model and in the initial phase (calibration phase) path-loss exponent (to adaptive the system with the environment) and path loss offset (measured in 1 meter reference distance) are calculated. Then with calculated parameters (path loss exponent is the propagation coefficient parameter) the distance is calculated. The following formulas explain the method (discussed in chapter 2) (Fink & Beikirch, 2009; Chongburee et al., 2009).

Path loss shadowing mode: $P_L(d) = P_L(d_0) + 10\beta \log\left(\frac{d}{d_0}\right) + X_\sigma \rightarrow$

Path loss exponent parameter when d_0 is 1m: $\beta = \frac{P_L(d) - P_L(d_0) - X_\sigma}{10 \log(d)}$

Distance: $d = 10^{\left(\frac{P_L(d) - P_L(d_0) - X_\sigma}{10\,\beta}\right)}$

Xσ (zero-mean Gaussian random variable with standard deviation σ) in the above formulas indicate the shadowing effect. Multipath fading because of objects that obstructing the signal propagation path between transmitter and receiver causes this effect. Totally, shadow fading can be studied in two different types; path loss dependent and path loss independent (out of the context of this study) shadow fading. Path loss dependent shadow fading is the residual error when we fit path loss model ($A + m\log(d)$) to the measurement. Since this kind of shadow fading depends on path loss law model and the method of fitting, therefore different path loss model have different shadow fading results (Salo et al., 2005). In this study and in the experiment phase, because of simplicity, we disregard *Xσ* parameter in the above formulas and apply following formulas to calculate the path loss exponent and distance.

$$\beta = \frac{P_L(d) - P_L(d_0)}{10 \log(d)}, \; d = 10^{\left(\frac{P_L(d) - P_L(d_0)}{10\,\beta}\right)}$$

Basically, localization approach has two phases: distance or angle measurement (based on mentioned formula) and distance or angle combination (using geometrical principles). In the combining phase hyperbolic Multilateration (this technique is named trilateration when three reference nodes is used. Positioning by finding the intersection of three circles around each reference node, figure 19(a)), triangulation (positioning by applying trigonometry laws in methods such as AoA, figure 19(b)) and maximum likelihood (positioning by minimizing the differences between measured and estimated distances, figure 19(c)) are three popular methods (Pal, 2010).

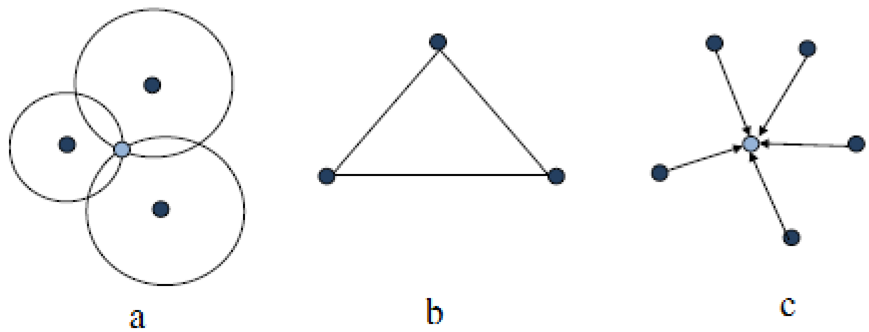


Figure 19: Three different methods in the localization combining phase (Pal, 2010)

The accuracy is a significant metric in the context of localization and different methods and techniques tries to improve the accuracy. As well as the different techniques, hardware and specifically antenna type has considerable effect on position accuracy in localization. (Hamdoun et al., 2014) focus and compare different antenna systems and different diversity combining techniques to evaluate the effect of antenna type on the reliability of wireless link and localization performance. The reason of their research is the distance estimation with RSSI measurement in an indoor situation is effected by propagation environment. The effect of using multiple antennas in three system communication models was evaluated (Hamdoun et al., 2014).

- (SIMO) Single Input Multiple Output: the transmitter has single antenna and receiver has multiple antennas (figure 20(a)). Therefore, the receiver can mitigate the fading effects by receiving N independent copies of the transmitted signal.
- (MISO) Multiple Input Single Output: the transmitter has multiple antennas and receiver has single antenna (figure 20(b)). In comparison with SIMO model, the process is done in transmitter instead of receiver.
- (MIMO) Multiple Input Multiple Output: in this model both receiver and transmitter have multiple antennas (figure 20(c)) (Hamdoun et al., 2014).

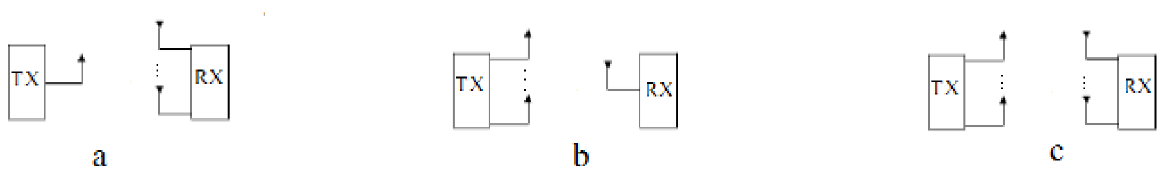


Figure 20: SIMO (a), MISO (b) and MIMO (c) systems (Hamdoun et al., 2014)

Due to apply multiple antennas in the receivers (Hamdoun et al., 2014) applied three diversity combining techniques and then the RSSI values were used in the distance measurement.

- SC (Selecting combining method) which select maximum RSSI value among the N receiver's antennas ($RSSI_{max} = \max\{RSSI_1, \dots, RSSI_N\}$).
- EGC (Equal Gain Combining method) which averages between received RSSI values ($RSSI_{avg} = \frac{1}{N}\sum_{i=1}^{N} RSSI_i$).

- MRC (Maximum Ratio Combining method) with ($RSSI_{mrc} = \frac{1}{\sum_{i=1}^{N} RSSI_i} \sum_{i=1}^{N} RSSI_i^2$).) formula (Hamdoun et al., 2014).

Figure 21 demonstrate localization based on trilateration with applying different antenna models.

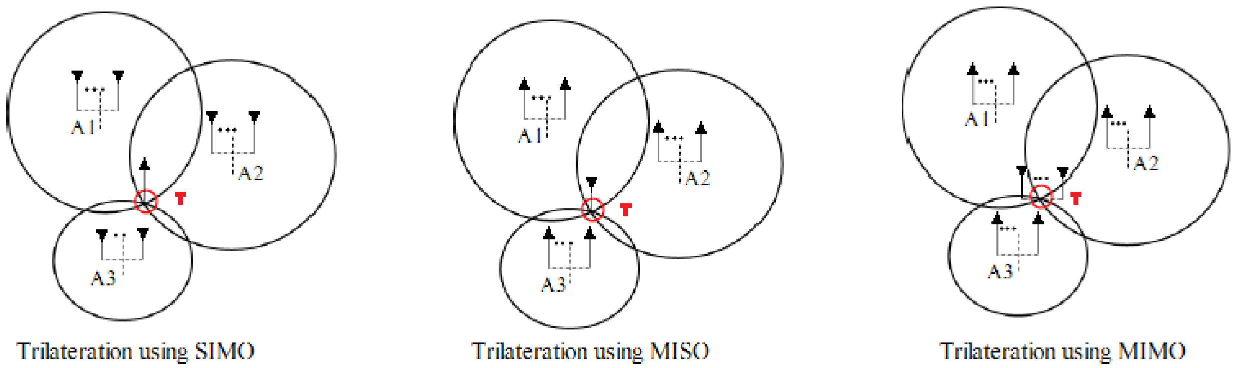


Figure 21: Trilateration method using SIMO, MISO and MIMO antenna model (Hamdoun et al., 2014)

Based on the results SISO (Single Input Single Output antenna) has the worst and MIMO has the best localization accuracy. Although increasing the number of antennas improves the accuracy, it can increase the complexity of system. Also they explain that among different diversity combining methods, MRC has the best performance (Hamdoun et al., 2014).

4.2 Localization Steps

Based on (Chuan-Chin Pu et al., 2011) location tracking system includes three steps: signal and information processing, realization of the system by implementing different techniques and finally storing, analyzing, monitoring and displaying the relevant localization information in a centralized server. The third step is defined in chapter 5. Data mining and signal processing form the first task (information handling) in the localization system design. Moving from raw RSSI values to find location coordinate has some steps (Fink & Beikirch, 2009) that figure 22 can illustrate them.

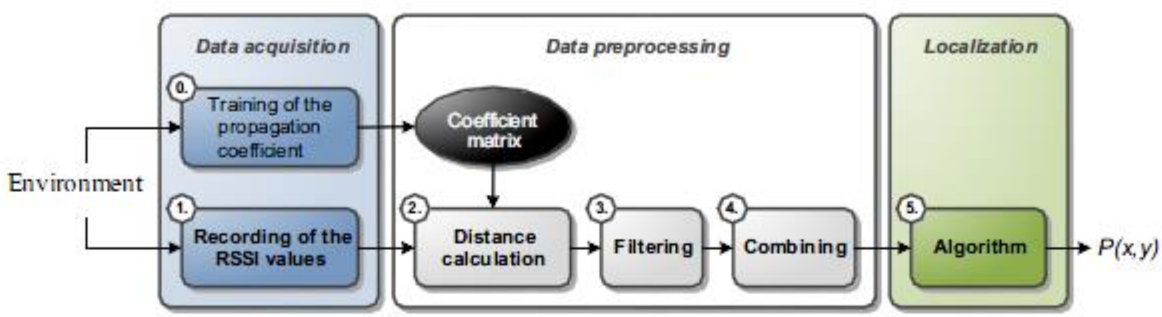


Figure 22: Structure of localization system (Fink & Beikirch, 2009)

Firstly, in the data acquisition phase, RSSI values are collected from the anchors. These RSSIs are used to find the suitable environmental parameters (system calibration). Theses environmental parameters are fixed during the localization unless considerable changes occur in the environment. After calibration the anchors receive continuous RSSIs from the target nodes and then with both environmental parameters and RSSI values (and using techniques to RSSI signal improvement, optimization, filtering) we can measure distances by using path loss model. Finally, the distances between anchors and target nodes are used by geometrical techniques such as trilateration to find the position of the target sensor node in an environment (Fink & Beikirch, 2009).

Since this technique uses RSSI values to distance estimation, the level of RSSI is significant. Based on the RSSI characteristics and models that mentioned in the previous chapters, these values of measuring are very volatile with variation in indoor environment. The reasons of this variation can be categorized in three models (C. C. Pu et al., 2012):

- *"Small scale multipath fading (small-scale fading explains the rapid fluctuation of received power because of small sub wavelength changes in the receiver position. This effect occurs because of constructive and destructive interference of multipath waves.)*
- *Medium scale shadowing model* (because of different obstacles) and
- *Large scale path loss model (path loss: the difference between transmitter and receiver power)"* (C. C. Pu et al., 2012).

Therefore, different methods in the different steps of localization try to improve the accuracy of RSSI ranging. RSSI signal improvement concentrate on noise and small scale fading to increase stability of the RSSI signal (C. C. Pu et al., 2012).

In the calibration phase (environmental characterization) defining the suitable parameters is significant since the accurate value of the path loss exponent (β) has important effect on precision of the distance and consequently the localization accuracy. In the path loss exponent measurement waves' reflection can bring down the accuracy. Therefore, channel identification (identifying the receive data from transmitter is LOS (Line of Sight) or NLOS (Non-line of Sight)) is important to mitigate this effect.

Channel Identification:

Propagation condition in a wireless communication is divided into LOS and NLOS channels and affects the accuracy of the moving object positioning. If the propagation is LOS between receiver and transmitter we can achieve high accuracy in localization, however in an indoor places we have different obstacles and people movement which can block the path between anchors and target node (receiver and transmitter). These obstacles can cause NLOS error (because of signal reflection and diffraction). If the measurement of more than three anchors are available and at least three of them are LOS, the range measurements of NLOS anchor nodes can be ignored in moving object positioning. However, if there are the measurements of only three anchor nodes and one of them is NLOS, some algorithm such as Range Scaling Algorithms (RSA) can be used to alleviate the NLOS error (Venkatraman & Caffery, 2002; Wang et al., 2013; Kegen Yu et al., 2009).

There are different techniques for localization algorithm to improve their tolerance in NLOS condition. These techniques are divided into two categories. First category includes techniques that intend to identify NLOS channel to mitigate its negative effects on localization. The second category includes techniques that directly alleviate the NLOS error in range or location estimations. Since there is a mutually exclusive relationship between LOS and NLOS, the channel identification is a binary hypothesis test. Considering, hypothesis testing for LOS/NLOS applies probability distribution and compares NLOS and LOS with each other it is necessary to consider time consumption and complexity factors (Venkatraman & Caffery, 2002; Wang et al., 2013; Xiao et al., 2013). In the hypothesis testing approach (Xiao et al., 2013; Wann & Chin, 2007) describe hypotheses for LOS/NLOS based on:

$$H_l: \alpha \leq \alpha_t \rightarrow LOS\ conditions$$

$$H_n: \alpha > \alpha_t \rightarrow NLOS\ conditions$$

Then to identify the correct channel, they determine specific function for "α" and a threshold for "α_t". Therefore, the distance estimation model (log-normal shadowing model) based on LOS/NLOS is:

$$P_L(d) = P_L(d_0) + 10\beta_{los/nlos} \log\left(\frac{d}{d_0}\right) + X_{\sigma(los/nlos)}$$

Based on the channel identification and above formula, the distance measurement and path loss exponent calculate differently in LOS or NLOS conditions.

(Kegen Yu et al., 2009) studied LOS/NLOS identification based on the difference probability distribution between these two channels. They used the Generalized Likelihood Ratio Test (GLRT) for identification and choosing one the hypotheses when NLOS error has deterministic mean and variance. Their hypothesis testing is based on knowing the LOS and NLOS probability in advance otherwise the other tests should be selected. Assume that in an experiment L distance measurement sample is available and each distance sample is sum of true distance and distance measurement error:

$$r = [r_1 \quad r_2 \ \dots \ r_L]^T$$

$$r_i = d + \varepsilon_i$$

Where d is true distance and ε_i is error distance. $p(r|\ d, H_l)$ *and* $p(r|\ d, H_n)$ as the conditional probability density function (PDF) of r under LOS (H_l) and NLOS (H_n) hypotheses are respectively (Kegen Yu et al., 2009):

$$p(r|d, H_l) = \frac{1}{\sqrt{2\pi}\sigma_{los}^L} \exp\{-\frac{1}{2\sigma_{los}^2}\sum_{i=1}^{L}[r_i - (\mu_{los} + d)]^2\}$$

$$p(r|d, \mu_{nlos}, \sigma_{nlos}, H_n) = \frac{1}{\sqrt{2\pi}\sigma_{nlos}^L} \exp\left\{-\frac{1}{2\sigma_{nlos}^2}\sum_{i=1}^{L}[r_i - (\mu_{nlos} + d)]^2\right\}$$

Where μ_{los} is the mean and σ^2_{los} is the variance of ε_i in the LOS condition and μ_{nlos} is the mean and σ^2_{nlos} is the variance of ε_i in the NLOS condition. Therefore, based on GLRT, H_n (NLOS hypothesis) is decided if:

$$A(r) = \frac{P(r|\bar{d}_{nlos}, \bar{\mu}_{nlos}, \bar{\sigma}_{nlos}, H_n)}{P(r|\bar{d}_{los}, H_l)} > \frac{P(H_l)}{P(H_n)}$$

Where $\bar{d}_{los}$ and $\bar{d}_{nlos}$ are the maximum likelihood estimates of the unknown LOS and NLOS distances, $\bar{\mu}_{nlos}$ and $\bar{\sigma}_{nlos}$ are unknown noise mean and unknown noise standard deviation, $P(H_l)$ and $P(H_n)$ are the known prior probability of NLOS and LOS conditions (Kegen Yu et al., 2009).

As mentioned before, in the system calibration step (environmental characterization) we intend to determine two parameters; the received power at the reference distance d_0 ($P_L(d_0)$) and path loss exponent (β coefficient in the log normal shadowing model) which is highly dependent on the environment of experiment. The path loss exponent can be calculated empirically by doing M times of measurement. (Y. Chen et al., 2012) calculated (β) value based on the path-loss log normal model ($RSSI_d = -(10\beta \log d) + A$) by applying the Least Square Method as follow:

Path Loss Exponent Calculation (Y. Chen et al., 2012)***:***

$$\begin{cases} RSSI_1 = -(10\beta \log d_1) + A \\ RSSI_2 = -(10\beta \log d_2) + A \\ \vdots \\ RSSI_m = -(10\beta \log d_m) + A \end{cases}$$

After M times measurement we subtract the first equation from the other equations, so we have:

$$\begin{cases} RSSI_2 - RSSI_1 = -\left(10\beta \log \dfrac{d_2}{d_1}\right) \\ RSSI_3 - RSSI_1 = -\left(10\beta \log \dfrac{d_3}{d_1}\right) \\ \vdots \\ RSSI_m - RSSI_1 = -\left(10\beta \log \dfrac{d_m}{d_1}\right) \end{cases}$$

We can write the above equations in the form of a matrix like ($CX = R$) where X = [β], C and R are respectively:

$$C = \begin{bmatrix} -10\log(\frac{d_2}{d_1}) \\ -10\log(\frac{d_3}{d_1}) \\ \vdots \\ -10\log(\frac{d_m}{d_1}) \end{bmatrix} \quad , \quad R = \begin{bmatrix} RSSI_2 - RSSI_1 \\ RSSI_3 - RSSI_1 \\ \vdots \\ RSSI_m - RSSI_1 \end{bmatrix}$$

To solve the mentioned linear equation system by Least Square method, $\|CX - R\|$ is minimized when $C^TCX = C^TR$. Therefore, $X = (C^TC)^{-1}C^TR$ (Y. Chen et al., 2012).

Since there are different factors such as temperature, multipath effects, non-line of sight effect and so on, the propagation of wireless signal is random. Therefore, it is significant to filter the current received RSSI values before substituting into the formula and calculate the distance. In the way of optimizing RSSI values, average statistical model is not always effective for large disturbance (Zhu Minghui & Zhang Huiqing, 2010). Gaussian filter is the model can be used in this step to improve the accuracy of localization. Since, in this model we can select the RSSI values in the high probability areas and then we can apply the mean filter for the optimized RSSI values (Zhu Minghui & Zhang Huiqing, 2010; Qingxin Zhang et al., 2010).

RSSI Value Optimization (Zhu Minghui & Zhang Huiqing, 2010)***:***

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{(x-\mu)^2}{2\sigma^2}} \quad gaussian\ model$$

$$\mu = \frac{1}{n}\sum_{i=1}^{n} x_i \quad , \qquad \sigma^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \mu)^2$$

The received RSSI values should be selected in this range: $0.6 \leq F(x) \leq 1$ where 0.6 is calculated based on the experience of value engineering. (Zhu Minghui & Zhang Huiqing, 2010) show that the RSSI range in this approach of optimization is

$$[0.15\sigma + \mu, 3.09\sigma + \mu]$$

Where σ and μ are respectively:

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(RSSI_i - \frac{1}{n}\sum_{i=1}^{n} RSSI_i)^2} \quad , \qquad \mu = \frac{1}{n}\sum_{i=1}^{n} RSSI_i$$

4.3 Description of the Positioning Algorithm

The positioning algorithm is used to calculate the coordinates of the target node. In two dimensions localization the number of anchor nodes should be at least three (Deng et al., 2008). Maximum likelihood estimation method can be used in this step. In this method we should know the position of the anchors (reference nodes) as (x_1, y_1), (x_2, y_2), …, (x_n, y_n), and their distances from the target node, which is calculated by the log-normal shadowing model, d_1, d_2, …, d_3. If we assume the coordinate of the target node as (x, y), then the following non-linear equations in two-dimensional space exist (Deng et al., 2008):

$$\begin{cases} (x-x_1)^2+(y-y_1)^2=d_1^2 \\ (x-x_2)^2+(y-y_2)^2=d_2^2 \\ \vdots \\ (x-x_n)^2+(y-y_n)^2+d_n^2 \end{cases}$$

Then the last equation is subtracted from the other equations as (Deng et al., 2008):

$$\begin{cases} x_1^2-x_n^2-2(x_1-x_n)x+y_1^2-y_n^2-2(y_1-y_n)y=d_1^2-d_n^2 \\ \vdots \\ x_{n-1}^2-x_n^2-2(x_{n-1}-x_n)x+y_{n-1}^2-y_n^2-2(y_{n-1}-y_n)y=d_{n-1}^2-d_n^2 \end{cases}$$

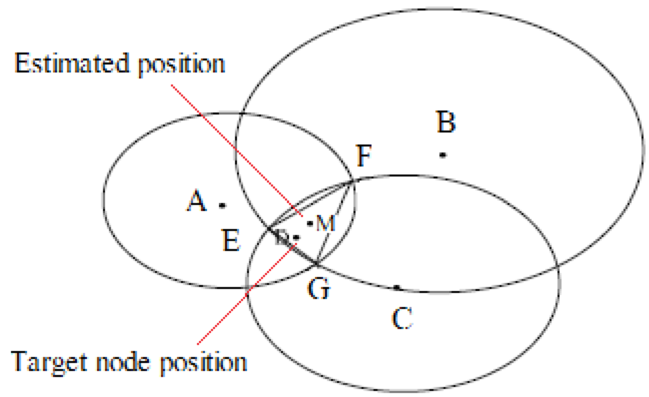
Now there is a linear equation that can be demonstrated as *AX=b*, where *A*, *b*, and *X* are respectively (Deng et al., 2008):

$$A=\begin{bmatrix} 2(x_1-x_n) & 2(y_1-y_n) \\ & \vdots \\ 2(x_{n-1}-x_n) & 2(y_{n-1}-y_n) \end{bmatrix},$$

$$b=\begin{bmatrix} x_1^2-x_n^2+y_1^2-y_n^2-d_1^2+d_n^2 \\ \vdots \\ x_{n-1}^2-x_n^2+y_{n-1}^2-y_n^2-d_{n-1}^2+d_n^2 \end{bmatrix}, \qquad X=\begin{bmatrix} x \\ y \end{bmatrix}$$

The coordinate of the target node can be given by estimation method for standard minimum mean square by: $\hat{X}=(A^TA)^{-1}A^Tb$ (Deng et al., 2008).

(Jungang Zheng et al., 2010) studied another model (triangle centroid location algorithm) to estimate the position of the target node which is based on calculation the center of triangle area of the target node. In this approach (for three anchor) anchor nodes *(A, B, C)* form circle areas that the estimated distances between the anchors and target node (r_A, r_B, r_C) are their radii. The overlapping area of the anchors' circles makes three points which are vertices of a triangle. This area is "target node triangle area" and the center of this triangle is the target node's coordinate (figure 23).



$$\begin{cases} x_m = \dfrac{x_e + x_f + x_g}{3} \\ y_m = \dfrac{y_e + y_f + y_g}{3} \end{cases}$$

Figure 23: Triangle centroid localization model (Jungang Zheng et al., 2010)

(Yingxi et al., 2012) based on the geometrical theory calculated the position of the target node in a randomly distributed sensor network area in R3 Space. The following is the defined vector set for all sensor nodes (n) in the system:

$$X = (x_1, y_1, z_1, x_2, y_2, z_2, \dots, x_n, y_n, z_n)$$

4.4 Adjacent Correction Positioning Algorithm by (Zhang et al.)

(Zhang et al., 2011) proposed an adjacent correction positioning algorithm based on multilateral positioning (applying ML estimation) to reduce unilateral ranging error. Their algorithm improves the accuracy and stability of the localization system. In this approach the anchors send their RSSI values (instead of previous approaches which anchors were receiver) and other network information (their ID and coordinates) to the target node and correction node. The idea of applying the adjacent correction node is to find the correction factors, discrimination coefficient and measure the error between anchor and correction node. The correction node moves to different places on a circle that the target node is in the center. In fact, in this approach we measure the real distance between anchors and correction node in the initialization of network. Then we calculate the mentioned factors based on the real measured distances to use in the target node localization. Figure 24 demonstrates this algorithm where there are eight anchors ($R_n(x_n, y_n)$), one target node ($B(x, y)$) and one correction node ($C(\Delta x, \Delta y)$). The following concept is defined to describe the algorithm (Zhang et al., 2011):

- The actual distance between anchor R_n and correction node is $d_{\Delta n}$.
- The measured distance between anchor R_n and correction node is $d'_{\Delta n}$.
- The measured distance between anchor R_n and target node is d'_n.
- The distance between anchor R_n and target node after correction is d_n.

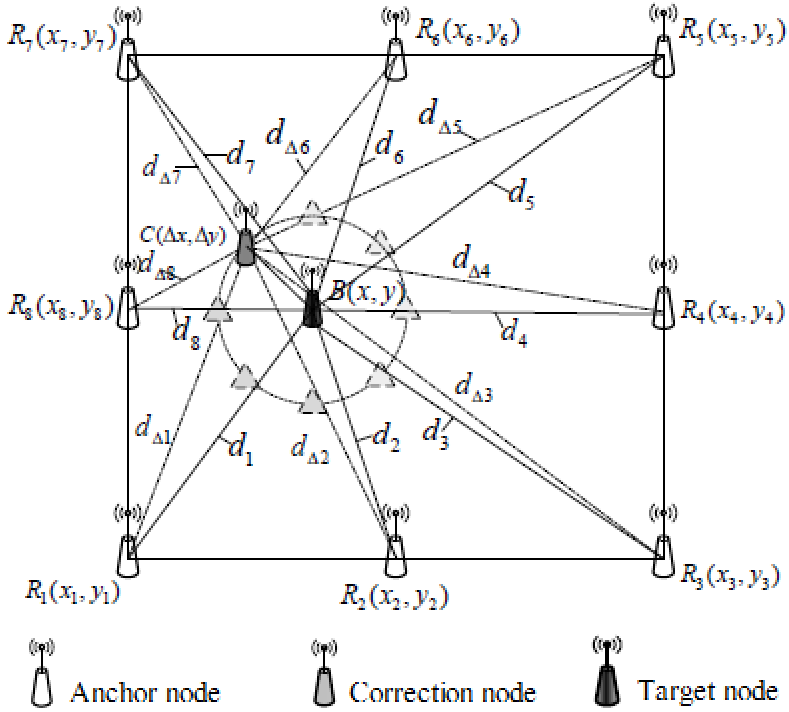


Figure 24: Adjacent correction algorithm (Zhang et al., 2011)

In the positioning step, the correction factor for eight anchors (η) and discrimination coefficient between anchor and target node (μ_n) are defined as:

$$\eta = \left(\frac{d'_{\Delta 1} - d_{\Delta 1}}{d'_{\Delta 1}}\right) + \left(\frac{d'_{\Delta 2} - d_{\Delta 2}}{d'_{\Delta 2}}\right) + \cdots + \left(\frac{d'_{\Delta 8} - d_{\Delta 8}}{d'_{\Delta 8}}\right) = 8 - \sum_{n=1}^{8} \frac{d_{\Delta n}}{d'_{\Delta n}}$$

$$\mu_n = \lambda e^{1 - \frac{d'_n}{d'_{\Delta n}(1-\eta)}}$$

Where λ numeric area is (0, 1) and is based on environment test at the initialization deployment. Now the range error between anchor R_n and correction node is:

$$\varepsilon_n = d'_{\Delta n} - d_{\Delta n}$$

Finally the corrected distance between R_n and target node is:

$$d_n = d'_n - \mu_n \varepsilon_n$$

Now we can use the corrected distance (d_n) in the multilateration positioning algorithm (Zhang et al., 2011) mentioned in Section (4.3).

4.5 Localization Accuracy Metric

In the context of localization accuracy (Wang et al., 2012) presented a metric based on the localization error (LE) between the estimated position and the actual position of the target node. In a two-dimensional positioning it is supposed that there are N anchors and a target node with the actual coordinate (X, Y) and estimated coordinate (X_i, Y_i). Accordingly we have:

$$LE(X_i) = (X - X_i)\,, \qquad LE(Y_i) = (Y - Y_i)\,, \qquad i = 1, 2, \dots, N$$

Then the mean of positioning error is (Wang et al., 2012):

$$ME(X) = \sum_{i=1}^{N} \frac{LE(X_i)}{N}\,, \qquad ME(Y) = \sum_{i=1}^{N} \frac{LE(Y_i)}{N}$$

And the error variance is defined as:

$$\Delta X_i = LE(X_i) - ME(X), \qquad \sigma_{Xi}^2 = (\Delta X_i)^2$$
$$\Delta Y_i = LE(Y_i) - ME(Y), \qquad \sigma_{Yi}^2 = (\Delta Y_i)^2$$

$$\sigma_{XY}^2 = \frac{\sum_{i=1}^{N} \sigma_{Xi}^2 + \sum_{i=1}^{N} \sigma_{Yi}^2}{N}$$

Finally the standard deviation *SD (σ)* gives us the average lower bound variance of the target node positioning error (Wang et al., 2012):

$$SD(\sigma) = \sqrt{\sigma_{XY}^2}$$

Chapter 5

Localization System

5.1 Introduction

The focus of this chapter is on software (both existing and a new developed server side) and hardware was applied in this study. The brief explanation of the existing hardware and software (Section 5.2) is based on materials and information that the company prepared for the author to conduct the relevant experiments and develop the server side application. Also, the brief explanation of the localization server application is based on requirement analysis and implementation of the requirements to analyze the RSSI values, implement the localization algorithm, store the data and present the place of the target node.

5.2 Already Existing Tools

All the experiments have been done in a wireless sensor network with the bus topology and the received data was analyzed in a MATLAB application (figure 25).

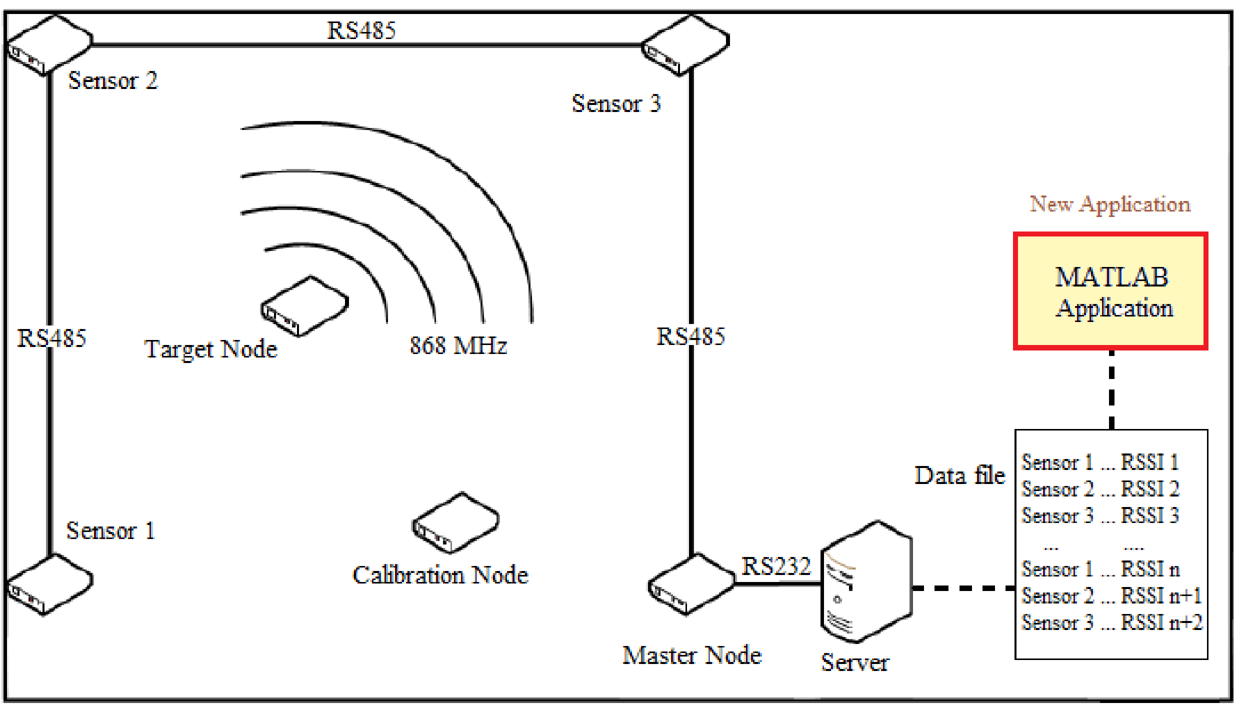


Figure 25: Topology of the network – the red part of the figure (Matlab application) was added to (Shahnewaz & Tabibi, 2012) figure. This part (Matlab application) was implemented in this research.

Most of the experiments have been done in an indoor condition (some of experiment cover the outdoor conditions) in a laboratory, different offices and corridors in Polo Territoriale di Como (Politecnico di Milano). Figure 26 shows some views of the places that wireless sensor networks were deployed for conducting experiments.

Figure 26: Experiments' environments

5.2.1 Hardware

The main hardware for the experiments in this study was Concentrator V1.0 (figure 27). This device is a combination of MRF89XA as a transceiver and PIC18F47J13 as a microcontroller (Shahnewaz & Tabibi, 2012). The applied transceiver is low cost and suitable for very low power consumption and is an interface of data for the microcontroller. The applied microcontroller also has very low power consumption (Shahnewaz & Tabibi, 2012). Concentrator V1.0 has been used as target node, calibration node, anchor node and master node with different specific firmware.

Target Node: is the Concentrator V1.0 with 868 MHz (one significant point to select a suitable frequency is the energy consumption and battery lifetime issue) wireless module and unknown position (Shahnewaz & Tabibi, 2012).

Anchors: we have used three different anchors with known position. Again all of them were Concentrator V1.0 which was used as a receiver of wireless signals transmitted from target node.

Anchors transmit their data to the master through wire RS 485. The master knows the number and ID of the anchors (Shahnewaz & Tabibi, 2012).

Calibration Node: this node is used in the initializing phase to gain the path loss exponent value. This node is used like a target node which we know its distances to the anchors (Shahnewaz & Tabibi, 2012).

Master: is a known position node which receives the anchors' data and send them to the server through RS 232 cable. It sends packet to the anchors repeatedly and give permission to them to send their received RSSI values (Shahnewaz & Tabibi, 2012).

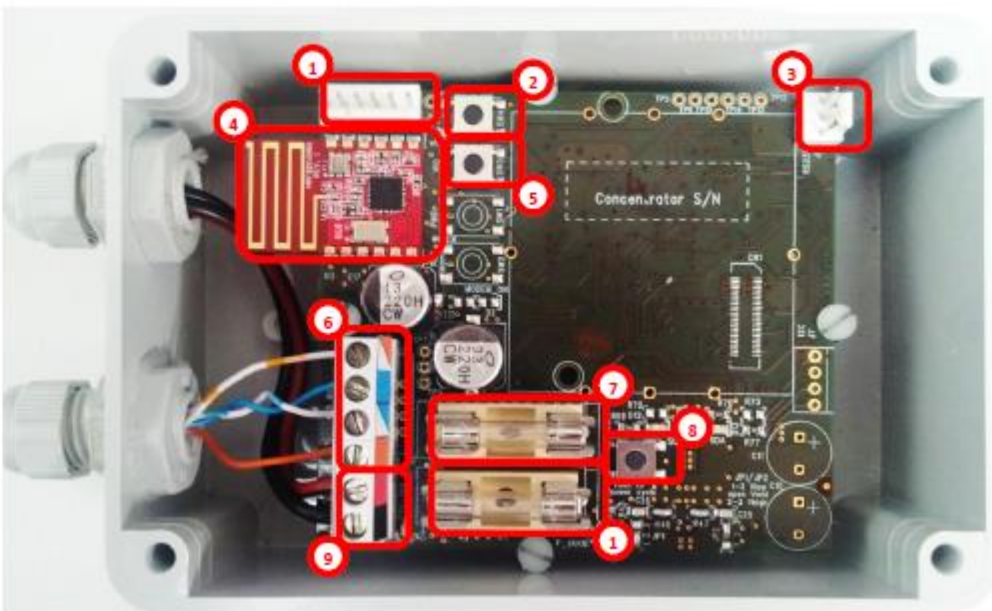


Figure 27: Concentrator V1.0 (Shahnewaz & Tabibi, 2012)

The selected parts are:

1. *"Microcontroller Programming Port (J5)*
2. *Microcontroller Reset Button (SW4)*
3. *RS-232 Interface Port (to Connect to the Server)*
4. *Wireless Module (MRF89XA Transceiver)*
5. *Concentrator Configuration Button (SW5)*
6. *RS-485 Interface Port for Communication to the Sensors (J2)*
7. *Sensor Power Rail Protection Fuse*
8. *Power Cycle Button*
9. *Power Cord Connector (DC voltage between 7V and 20 V)*
10. *Master Power Protection Fuse*" (Shahnewaz & Tabibi, 2012)

5.2.2 Software

When the system starts to work (anchors turn on and receive the target node's transmitted signal) all the anchors' data is demonstrated and stored in the text file by the already developed C# software (figure 28(a)). Then the collected data based on the number of target nodes (calibration node is considered as a target or moving node) is separated in different text file (figure 28(b)) and row data file (RSSI values, anchor' ID and counter) for each target node is prepared (figure 28(c)). These row data files are used by the server application (new application) for further analysis and localization.

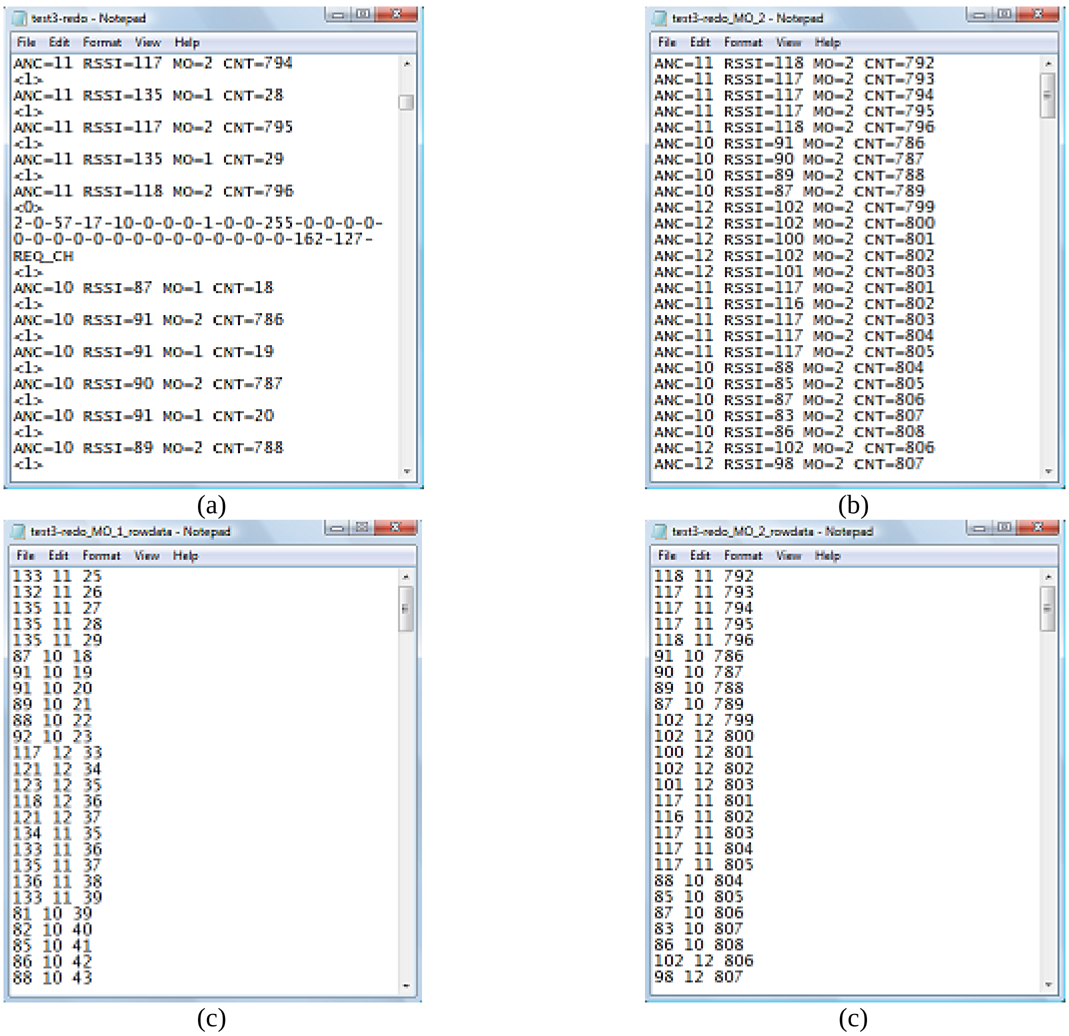


Figure 28: (a) Collected RSSI data from all target nodes, (b) Separated RSSIs, (c) Row data files

5.3 Localization Server Application

As mentioned in chapter 4 there are different steps and algorithms to localize a target node. The server application aims to find the place of the target node based on those steps and received RSSI values. Also it intends to prepare possibility for analyzing different parameters and localization algorithms to improve the location accuracy.

5.3.1 Functional Requirement Analysis and Main Software Features

The focus of this part is to specify only the main functional requirements (some requirements with high priority and not preparing Software Requirement Specification), their relevant motivations and implementation.

System Features:

Functional requirement 1

ID: FR1

TITLE: experiment storage

DESC: the experiments' data should be store in the localization system folder

- The row RSSI data files (as you can see in Fig 28(c)) are included of number anchors and their IDs, RSSI values related to each anchor, number of samples, differences between calibration node (fixed node) and targets nodes and number of target nodes and calibration node in our WSN. Saving these data requires a parser to read, mange and separate an RSSI files into different file with suitable filename for further analysis.
- The real distances for each target nodes and calibration node should be saved separately for each anchors

MOTIVATION: this is important since:

- we can easily manage all the relevant data for each experiments in future and increase the readability of results
- in each experiment we use different analysis approaches and algorithms in which each approaches produce a number of different files such as Beta-file, Distance-file, formulas, address-file and target-location-file. Data storage makes possibility for further information fetch and analysis with the complete history of previous analysis.

DEP: none

Functional requirement 2

ID: FR2

TITLE: possibility of both localization and analysis separately

DESC: the system should give the possibility to users to analyze different experiments in different depth of detail such as path loss exponent, distance algorithms, different RSSI ranges. Also the system should be able to find directly the final location of the target node without passing any analytical steps.

MOTIVATION: this functionality increase the usability the system since the history of the previous experiments can help the user to find and optimize the further algorithms and find shortcut solutions for the high location accuracy.

DEP: FR1

Functional requirement 3
ID: FR3
TITLE: define mathematical formula
DESC: the user should be able to define different formula. Since the path loss exponent, distance measurement and localization algorithms are all mathematical formulas.
MOTIVATION: as mentioned in the previous chapters, each algorithm for distance measurement or calculating path loss exponent has different parameters which will define in the calibration phase and these parameters are dependent on environmental conditions which differ from one place to another. Also, with respect to algorithm complexity, we can consider or neglect the random Gaussian variable. Each of these conditions emphasizes the necessity of defining new formula for analysis the RSSI samples.
DEP: none

Functional requirement 4
ID: FR4
TITLE: define filter
DESC: use should be able to define filter on the RSSI samples
MOTIVATION: based on characteristics of RSSI values defining a threshold or boundary for both RSSI values and path loss exponent improve the accuracy. Also the other filters such as Gaussian filter have considerable effect on RSSI optimization.
DEP: FR1

Functional requirement 5
ID: FR5
TITLE: comparing analysis results
DESC: user should be able to add different plots of the samples to his analysis panel based on different filters of formula.
MOTIVATION: this feature gives possibility to compare the different results, plots, mid and median in one page to better analysis.
DEP: FR1, FR3

Figure 29 demonstrates implementation of some of high priority requirements which mentioned in this section:

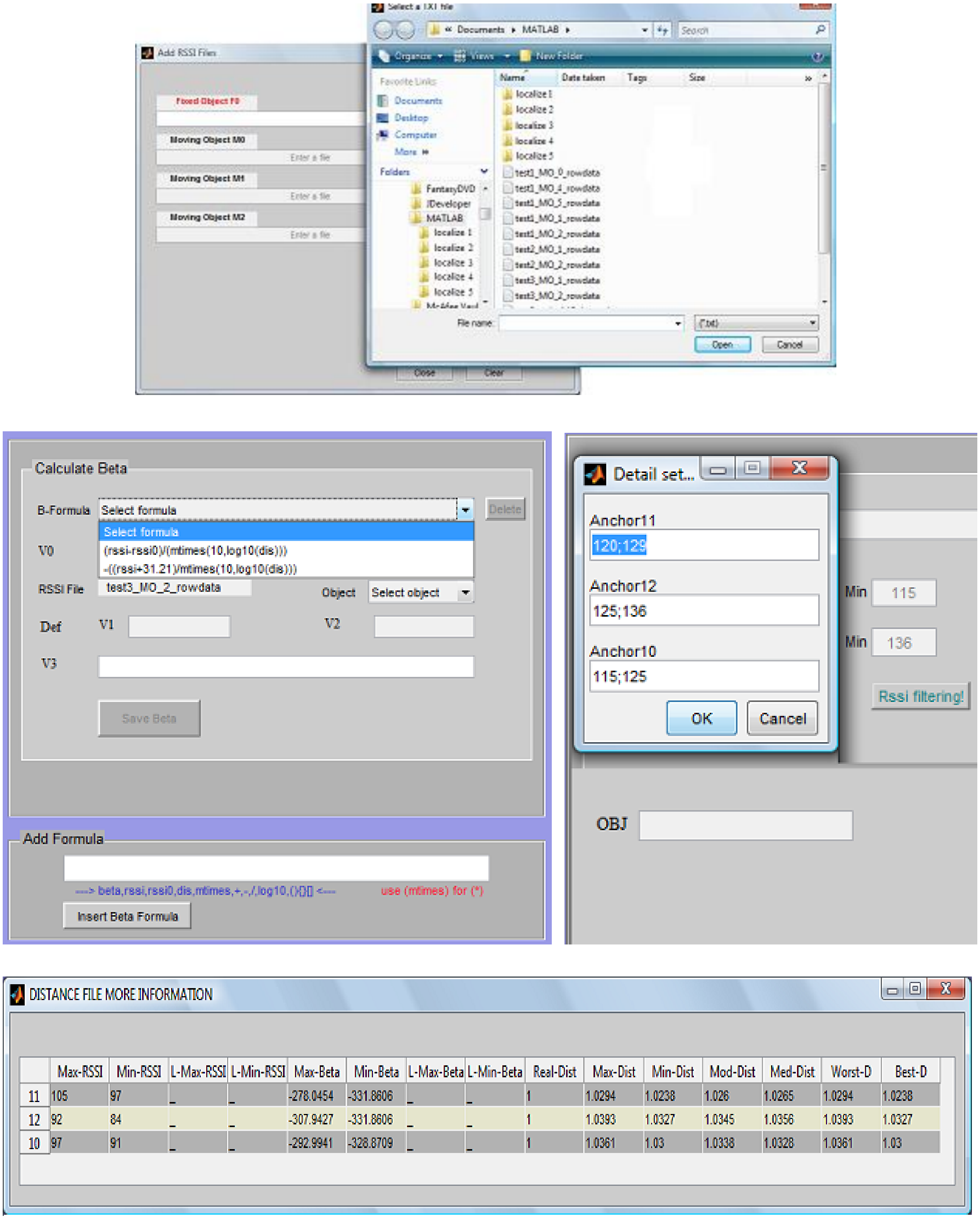


Figure 29: Some of system's features

Chapter 6

Experiments' Results

6.1 Design of Experiments

This chapter focuses on different experiments and their results. Since the experiments have been conducted in different conditions (e.g. indoor or outdoor places) the results of the experiments with the same situation grouped together to make a better possibility for comparison and analysis. Figure 30 illustrates the relation of independent variables, experiments' groups and dependent variable for these experiments. The results were achieved by a MATLAB application which considered in the chapter 5 and the applied frequency for all experiments is 868 MHz. Also the number of anchors (sensor nodes with known position) is 3. All the maps of the experiments are available in the appendix A.

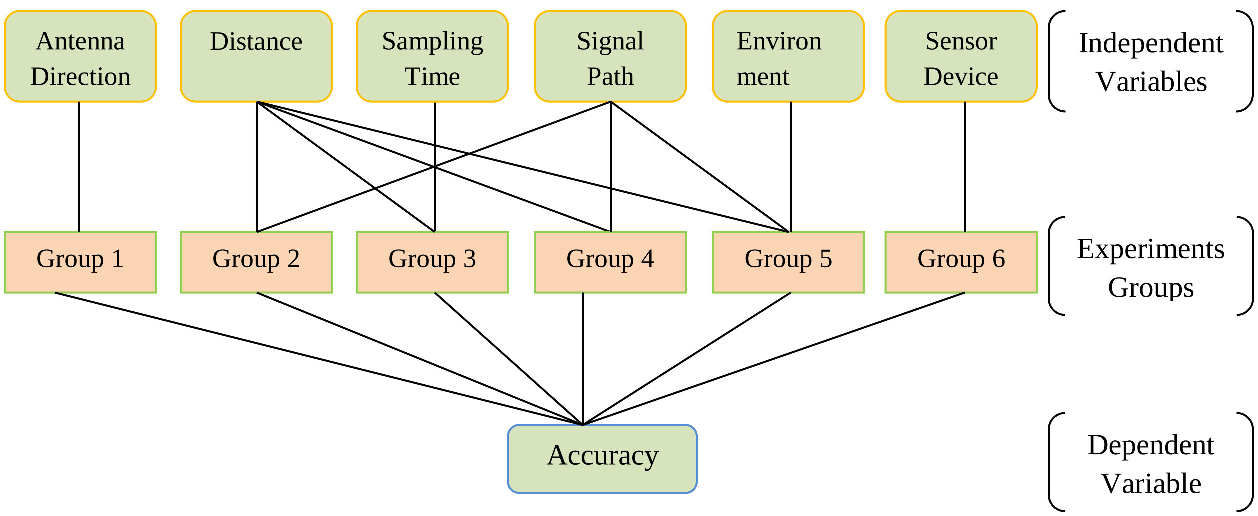


Figure 30: Relationship of independent variables, experiments' groups and dependent variable in our experiments

Experiments group one

This group includes three experiments in an indoor environment. In these three experiments all the environmental and network parameters (the place of calibration node, the place of all anchor nodes, and the place of experiments) are the same and fixed. The only change is in the direction of the target node's antenna. The reason of designing these experiments is to evaluate the effect of antenna's direction in localization accuracy. As mentioned in chapter 4, the influence of antenna has considered in some literature. In each of the experiments, the direction of the target node's antenna is toward one anchor.

Experiments group two

This group again includes three experiments in an indoor environment. Every conditions are the same and fixed during these experiments and similar to the group one (place of anchors and calibration node are the same as group one). The only change is in the place of the target node and people movement in the laboratory. The reason of these experiments is to evaluate the effect of different barriers between target node and anchors in localization accuracy. As mentioned in chapter 2 and 4, the barriers have considerable effect on the RSSI signals and the signal will be NLOS. In the first experiment (test1 of group two) the target node is completely behind a wall and in the last experiment it is in front of the anchors.

Experiments group three

The group three includes five pairs of indoor experiments' results. In fact, each experiment has been done two times with different duration in the same situation. In the first time of the experiments the RSSI values collected for one minute and in the second time they collected for three minutes. In all pair of the experiments, the place of the anchors and calibration node were the same and only the place of the target node became closer to the anchors' network. The aim of doing the experiments in two different times span was to assess if the number of RSSI samples can affect the accuracy or not. In other words, if we leave the system for a long time, the collected samples can improve the localization accuracy. The sensor network in these experiments was deployed in two places (corridor and office) and two meter above the floor. The reason of moving the target node towards the anchors (decreasing the distance) in each experiment was to see how the distance factor affects the accuracy. As mentioned in chapter 2, we applied a model (path-loss normal shadowing model) that works based on the relationship between distance and signal strength.

Experiments group four

This group has again conducted in an indoor situation and comprises nine experiments. In these experiments the target node placed in nine different areas in a grid pattern room. Again, all conditions and anchors' places were the same and the RSSI samples measured for each area. The main aim was to see and characterize the target node signals in different areas of one place.

Experiments group five

This group includes three pairs of experiments which conducted in a mixture of indoor and outdoor situation. The main aim of these experiments was to see and analyze the results of outdoor conditions. All the anchors and calibration node were in the office (indoor situation and in the fixed situation during the experiments) and the target node placed in the yard in different places. As mentioned in chapter 2, the environmental conditions (especially temperature, humidity and people movement in this case) have high effects on RSSI signals. Again, each experiment has been done two times to make a comparison between the gained results.

Experiments group six
This group has two experiments in an indoor condition. The aim of these experiments was to see the effects of the anchor nodes on the received RSSI signals and also accuracy of the localization. Therefore, the only change in these experiments was replacing two sensor anchors; the other nodes as well as the target node remained at their same situation. We wanted to see if the sensors receive almost the same data or not and how much the position of a specific sensor can affect the RSSI values.

6.2 Results

In this part the results of the experiments have been illustrated. Since some groups have lots of experiments so the worst case, best case or important results in these groups have been presented. Moreover, some relevant information about the achieved samples (such as mid, median, maximum, mode, minimum values) has been prepared and used in the analysis and discussion parts. For each experiment the RSSI values, relevant calculated beta values (path loss exponent) and calculated distances diagram have been presented.

Experiments group one
Since the result's plots are various (RSSI samples for different anchors, beta value for different anchors and calculated distances for different anchors) for each experiment and each group of experiments encompasses of different number of experiments, we put all plots of the group one in the report and for the other groups only some sample results are illustrated.

Test1

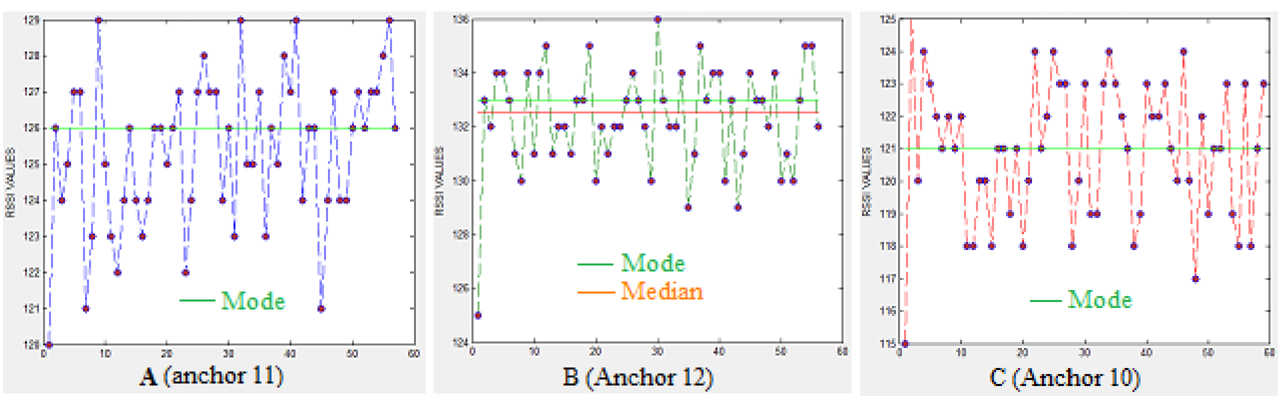


Figure 31: The figures show the RSSI samples of test 1, experiments of group one for 3 anchors. The horizontal axis represents samples' numbers and the vertical axis represents the values of the RSSI samples. The figures illustrate the RSSI values (data points) fluctuation during the sampling period. The green line shows mode of RSSI values and the red line shows the median of RSSI value.

In test 1 (the first experiment of group one (figure 31)) the direction of the target node's antenna is towards anchor 12 (in the appendix A all the experiments' maps are available). Figures depict the RSSI values fluctuation during our experiment.

	Median value	Maximum	Minimum	No. samples	Unique samples
Anchor11(blue)	126	129	120	57	10
Anchor12(green)	133	136	125	56	9
Anchor10(red)	121	125	115	59	10

Table 6: The significant RSSI values (median, maximum, minimum, No. samples and unique samples) shown in figure 31 for 3 anchors (11, 12, and 10).

The unit of the median, maximum and minimum RSSI values is in dBm.

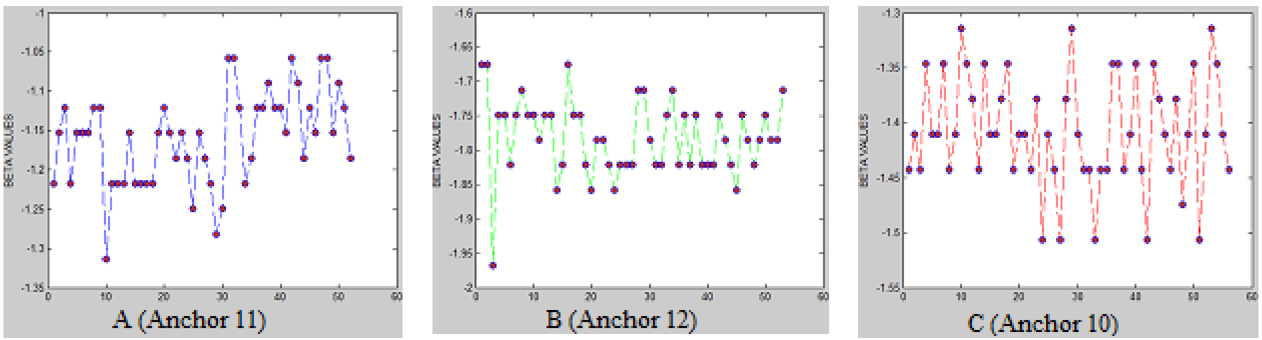


Figure 32: The figures show calculated beta values (path loss exponent) based on the RSSI values in figure 31for the experiments of group one. The horizontal axis represents samples' numbers and the vertical axis represents the values of path loss exponent. The figures illustrate the path loss exponent values (data points) fluctuation during the sampling period.

	Mode value	Median value	No. samples	Unique samples
Anchor11(blue)	-1.15	-1.15	53	9
Anchor12(green)	-1.82	-1.79	54	7
Anchor10(red)	-1.44	-1.41	57	7

Table 7: The significant beta values (mode, median, No. samples and unique samples) shown in figure 32 for 3 anchors (11, 12, and 10).

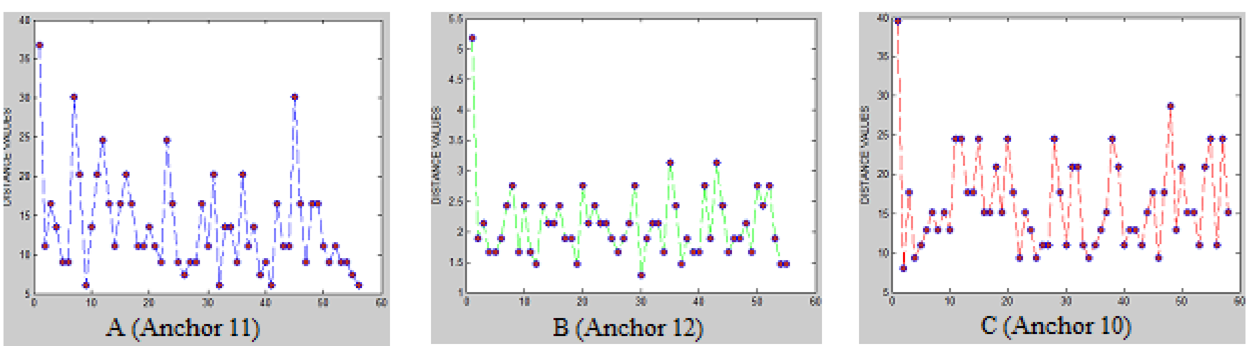


Figure 33: The figures show the calculated distances of test 1, experiments of group one for 3 anchors. The horizontal axis represents samples' numbers and the vertical axis represents the calculated distances. The figures illustrate the distance values (data points) fluctuation during the sampling period. The distances calculated by the unique mode of beta values for each anchor.

Figure 33 demonstrates the calculated distances based on mode of beta values for each anchor (11, 12, and 10).

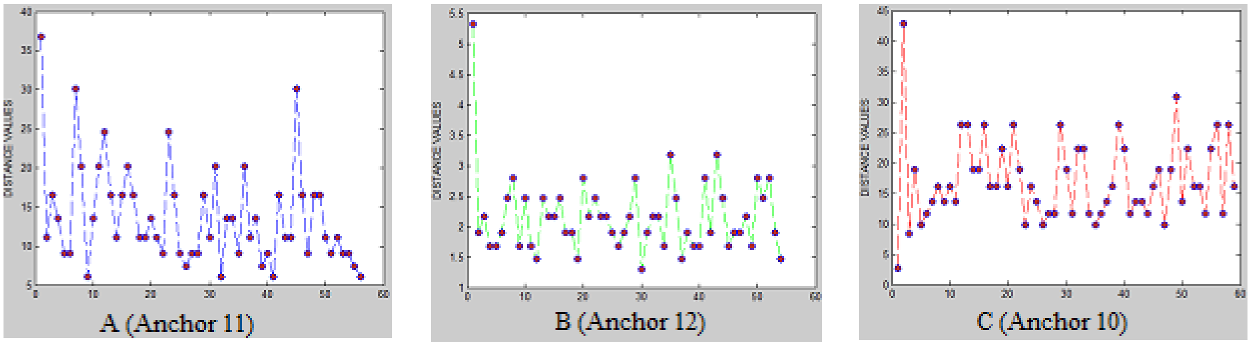


Figure 34: The figures show the calculated distances of test 1, experiments of group one based on a "median" beta values for each anchor. The horizontal axis represents samples' numbers and the vertical axis represents the calculated distances. The figures illustrate the distance values (data points) fluctuation during the sampling period.

Figure 34 demonstrates the calculated distances based on median value of calculated beta values array and the RSSI values array. It means that in this method of distance calculation we used a median beta value for each anchor node (in the previous figure we used the median value of the beta array for each anchor node).

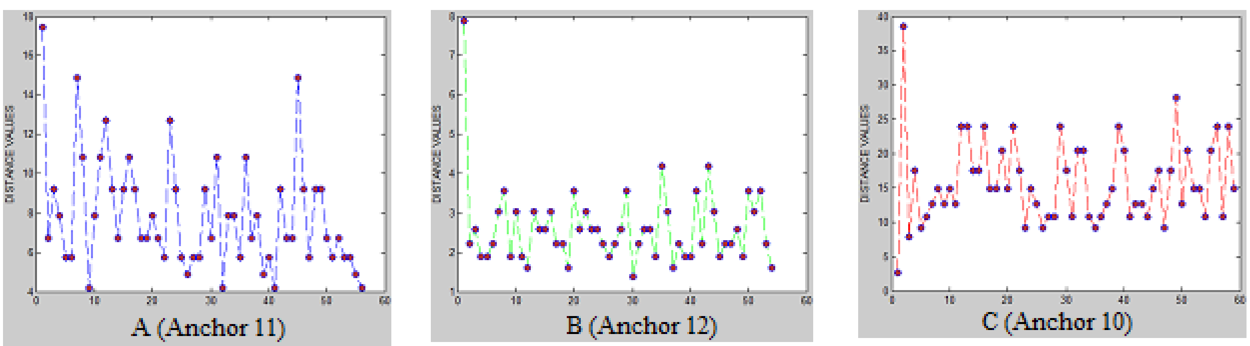


Figure 35: The figures show the calculated distances of test 1, experiments of group one based on a unique median beta (for whole environment) and filtered RSSI values. The horizontal axis represents samples' numbers and the vertical axis represents the calculated distances. The figures illustrate the distance values (data points) fluctuation during the sampling period.

Figure 35 presents the calculated distances based on putting filter (upper bound, lower bound) on RSSI values and applying a unique beta value for all anchors. This beta value is a median value of the entire beta values' vector.

Test2

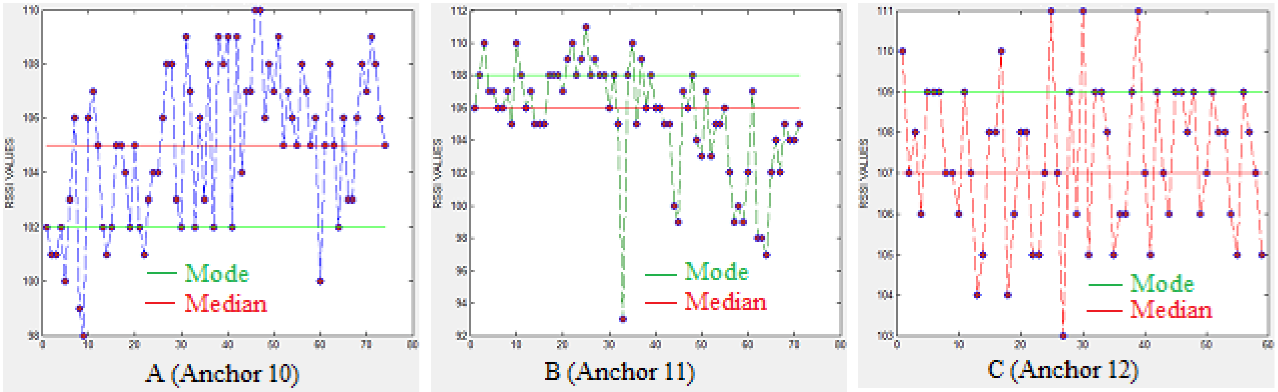


Figure 36: The figures show the RSSI samples of test 2, experiments of group one for 3 anchors. The horizontal axis represents samples' numbers and the vertical axis represents the values of the RSSI samples. The figures illustrate the RSSI values (data points) fluctuation during the sampling period. The green line shows mode of RSSI values and the red line shows the median of RSSI value.

In the test2, the direction of the target node's antenna is towards anchor 10.

	Median value	Maximum	Minimum	No. samples	Unique samples
Anchor10(blue)	105	110	98	74	13
Anchor11(green)	106	111	93	71	15
Anchor12(red)	108	111	103	59	9

Table 8: The significant RSSI values for each anchor (based on figure 36)

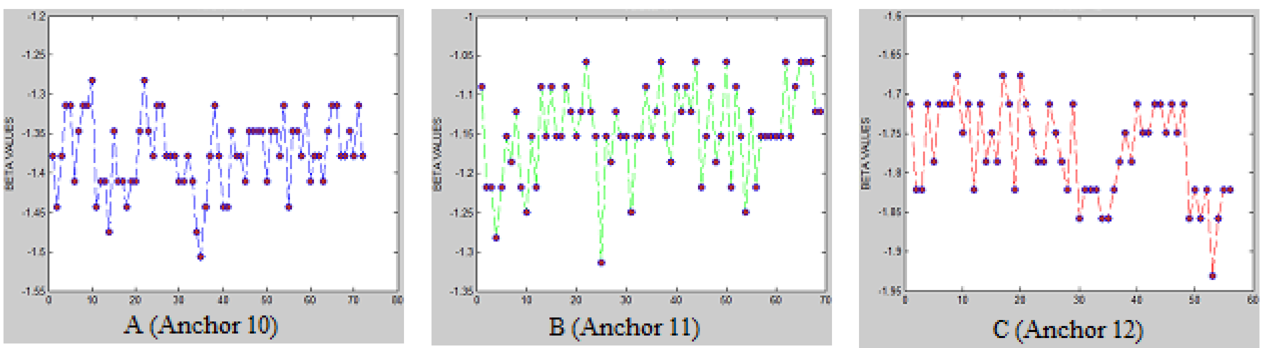


Figure 37: The figures show calculated beta values (path loss exponent) based on the RSSI values in figure 36 for the experiments of group one. The horizontal axis represents samples' numbers and the vertical axis represents the values of path loss exponent. The figures illustrate the path loss exponent values (data points) fluctuation during the sampling period.

	Mode value	Median value	No. samples	Unique samples
Anchor10(blue)	-1.38	-1.38	73	8
Anchor11(green)	-1.15	-1.15	69	9
Anchor12(red)	-1.71	-1.77	58	7

Table 9: The significant beta values (path loss exponent) for each anchor (based on figure 37)

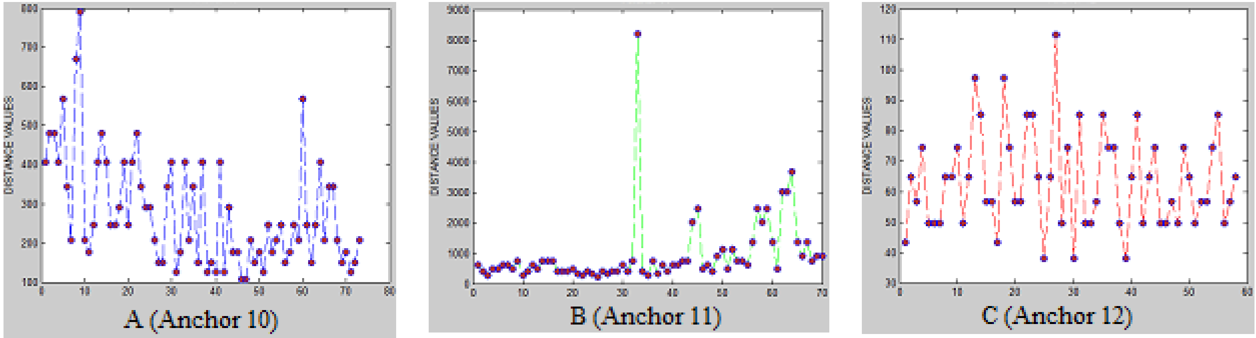


Figure 38: The figures show the calculated distances of test 2, experiments of group one based on the "mode" of beta values (figure 37). The horizontal axis represents samples' numbers and the vertical axis represents the calculated distances. The figures illustrate the distance values (data points) fluctuation during the sampling period.

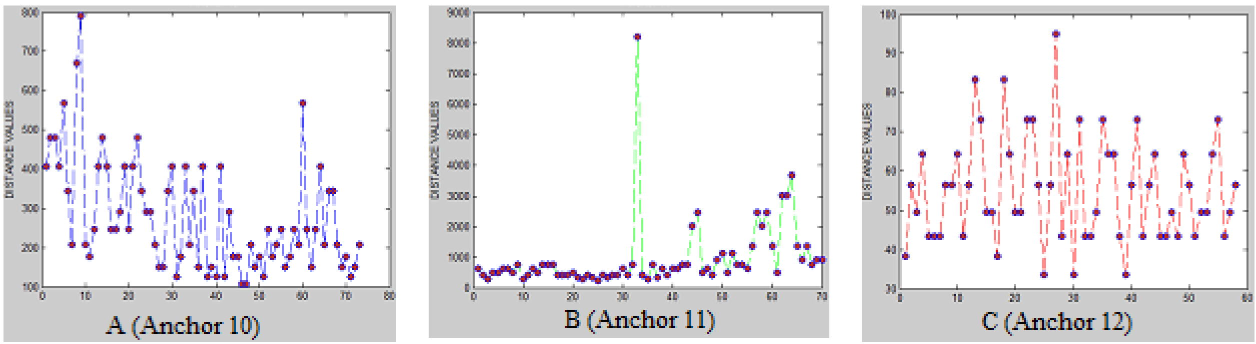


Figure 39: The figures show the calculated distances of test 2, experiments of group one based on the "median" of beta values (figure 37). The horizontal axis represents samples' numbers and the vertical axis represents the calculated distances. The figures illustrate the distance values (data points) fluctuation during the sampling period.

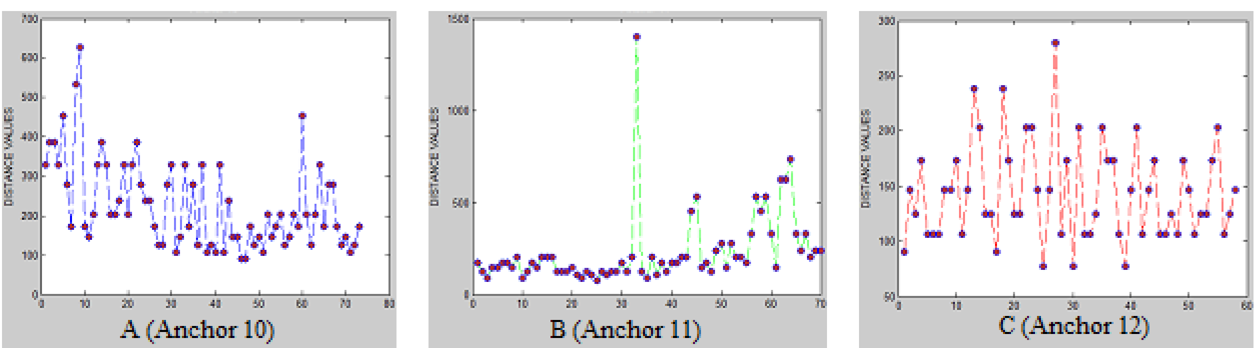


Figure 40: The figures show the calculated distances of test 2, experiments of group one based on a unique "median" of beta values (for whole environment) and filtered RSSI values. The horizontal axis represents samples' numbers and the vertical axis represents the calculated distances. The figures illustrate the distance values (data points) fluctuation during the sampling period.

Test3

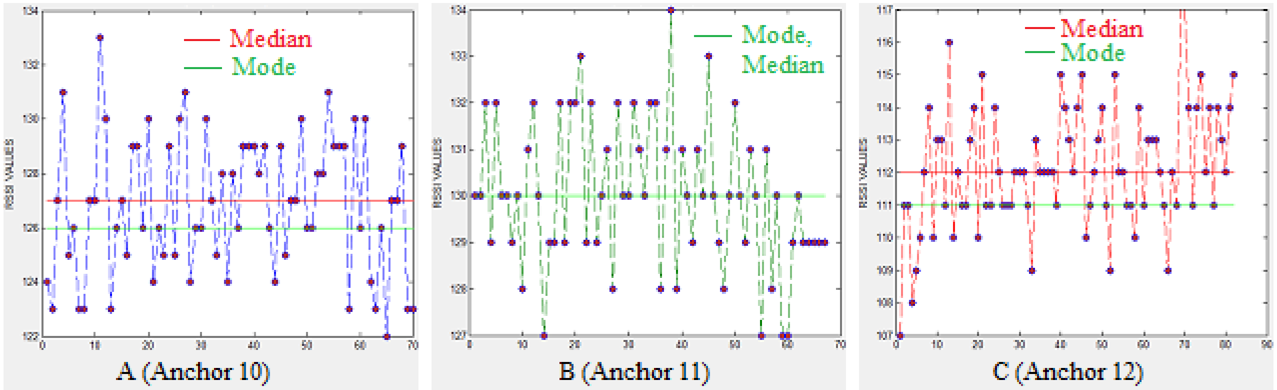


Figure 41: The figures show the RSSI samples of test 3, experiments of group one for 3 anchors. The horizontal axis represents samples' numbers and the vertical axis represents the values of the RSSI samples. The figures illustrate the RSSI values (data points) fluctuation during the sampling period. The green line shows mode of RSSI values and the red line shows the median of RSSI value.

In the test3, the direction of the target node's antenna is towards anchor 11 and the mode and median of RSSI values are the same.

	Median value	Maximum	Minimum	No. samples	Unique samples
Anchor10(blue)	127	133	122	70	11
Anchor11(green)	130	134	127	67	8
Anchor12(red)	112	117	107	82	11

Table 10: The significant RSSI values (median, maximum, minimum, No. samples and unique samples) shown in figure 41 for 3 anchors (10, 11, and 12).

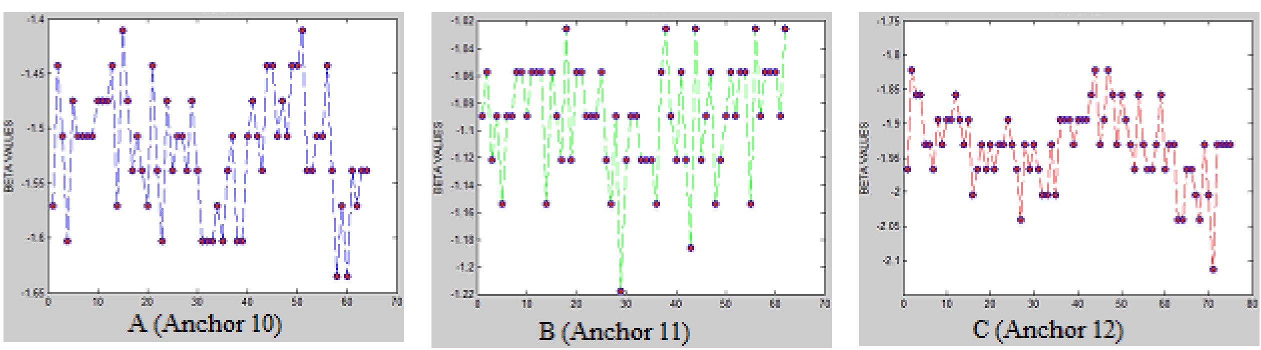


Figure 42: The figures show calculated beta values (path loss exponent) based on the RSSI values in figure 41for the experiments of group one. The horizontal axis represents samples' numbers and the vertical axis represents the values of path loss exponent. The figures illustrate the path loss exponent values (data points) fluctuation during the sampling period.

	Mode value	Median value	No. samples	Unique samples
Anchor10(blue)	-1.51	-1.51	65	8
Anchor11(green)	-1.06	-1.09	63	7
Anchor12(red)	-1.93	-1.93	76	8

Table 11: The significant beta values for each anchor (based on figure 42)

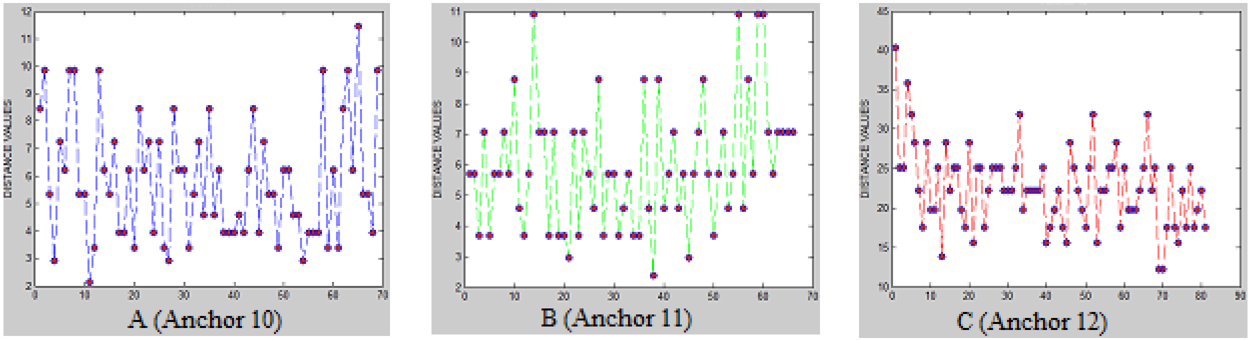


Figure 43: Calculated distances based on “mode” of the beta values

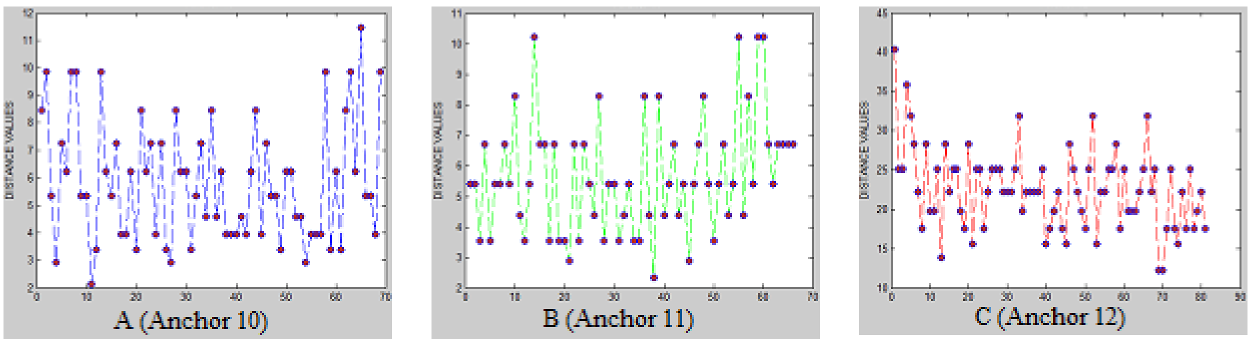


Figure 44: Calculated distances based on “median” of the beta values

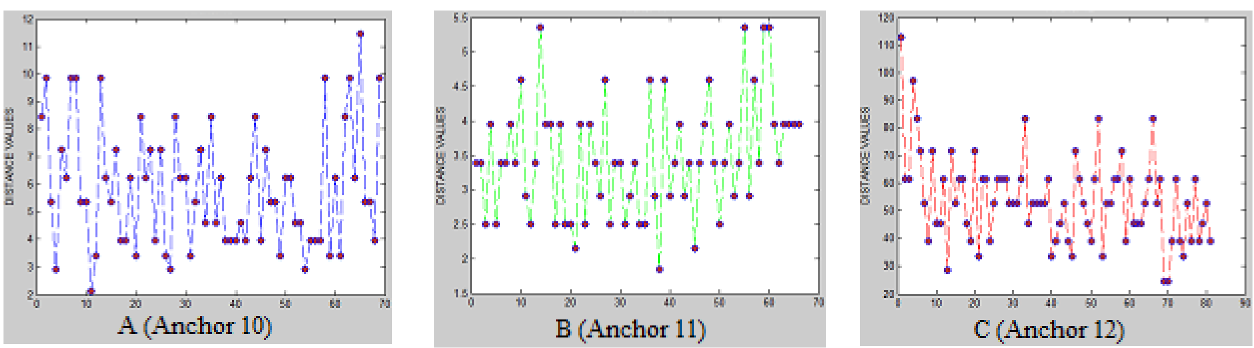


Figure 45: Calculated distances based on a unique median of the beta values (for whole environment)

The figures (43, 44, and 45) show the calculated distances of test 3, experiments of group one based on the “mode”, “median” (separately for each anchor), and a unique median (for whole environment) of beta values (figure 42). The horizontal axes represent samples’ numbers and the vertical axes represent the calculated distances. The figures illustrate the distance values (data points) fluctuation during the sampling period.

Experiments group two

As mentioned before these group of experiments have done in a condition that the target node was behind a wall (in worst case) and there was people movement in the office (people movement can disrupt the signals). In this part, only the distance diagrams of test1 (the first experiment of three) are presented (the RSSI and path loss exponent diagrams for the rest of the groups and experiments are not illustrated). The place of the target node is the farthest corner of the office (the map is available in the appendix one). The illustrated distances are calculated based on the median value of path loss exponent for each anchor and also one unique median value of path loss exponent for the entire environment (the mean value of all the median beta values).

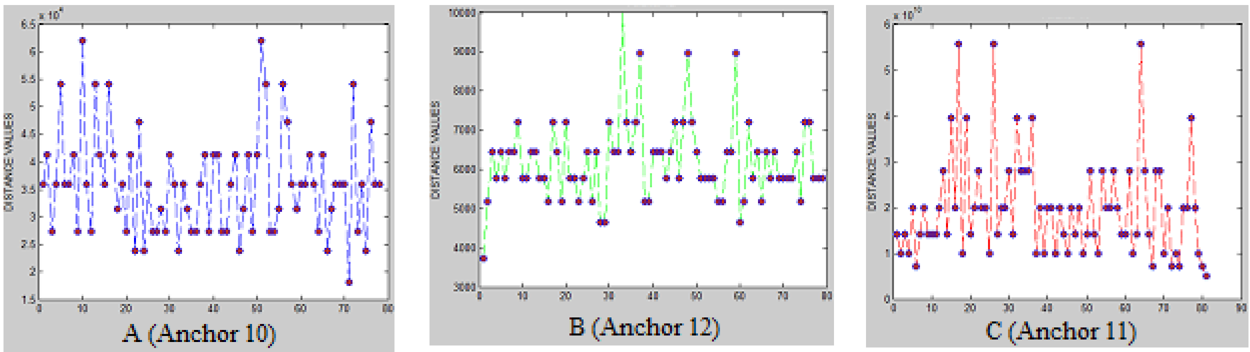


Figure 46: The figures show the calculated distances of the experiments' group two based on the "median" of beta values. The horizontal axis represents samples' numbers and the vertical axis represents the calculated distances. The figures illustrate the distance values (data points) fluctuation during the sampling period.

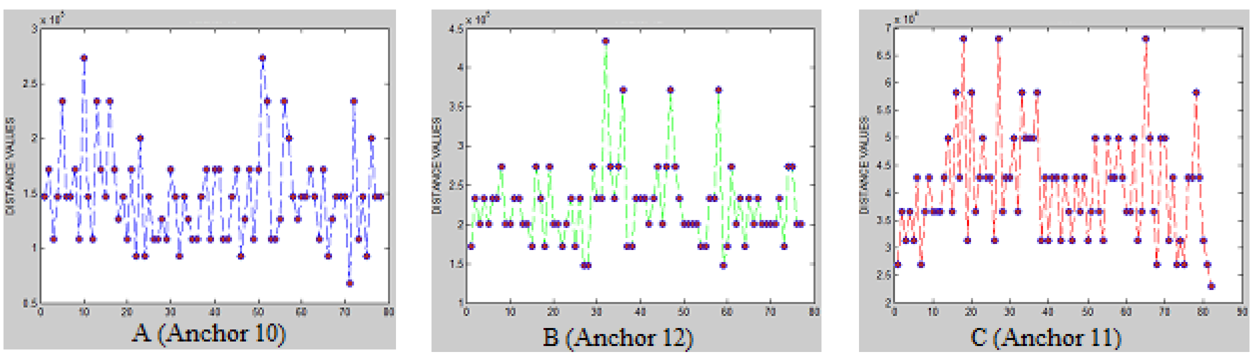


Figure 47: The figures show the calculated distances of the experiments' group two based on the "median" of beta values (for whole environment). The horizontal axis represents samples' numbers and the vertical axis represents the calculated distances. The figures illustrate the distance values (data points) fluctuation during the sampling period.

Experiments group three

This group has five pairs of experiments. We demonstrate the measured distances in test1 (the farthest distance between anchors and target node) and test5 (the closest distance between anchors and target node) for both RSSI sampling (one and three minutes sampling). The distance measurement is based on one unique beta value (path loss exponent) for whole environment.

Test1

(One minute RSSI sampling)

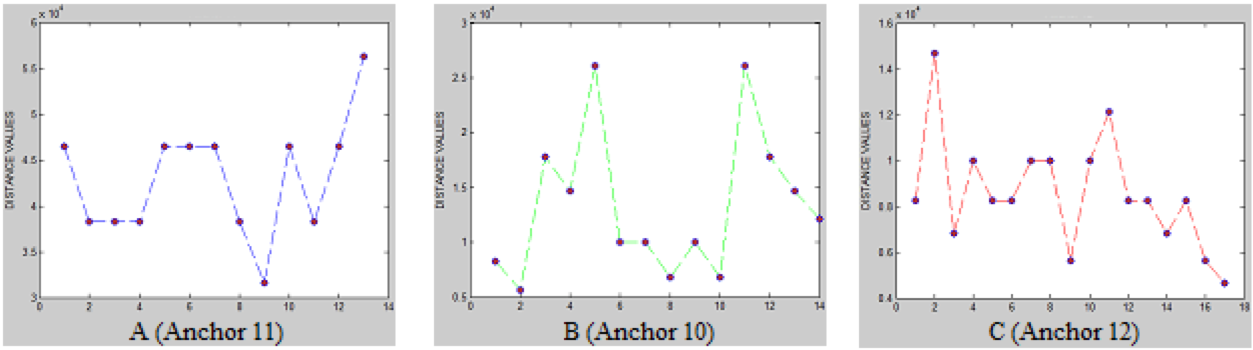


Figure 48: The figures show the calculated distances of the experiments' group three (test 1) based on a unique "median" of beta values (one minute sampling). The horizontal axis represents samples' numbers and the vertical axis represents the calculated distances. The figures illustrate the distance values (data points) fluctuation during the sampling period.

(Three minutes RSSI sampling)

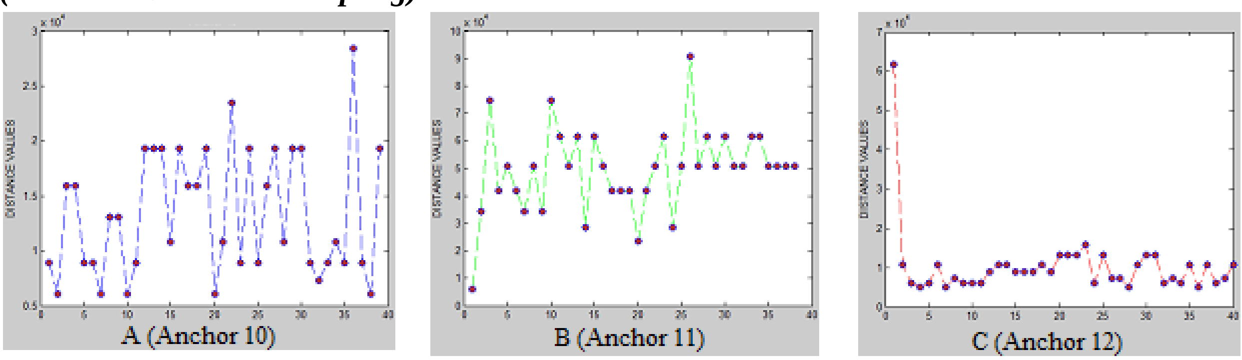


Figure 49: The figures show the calculated distances of the experiments' group three (test 1) based on a unique "median" of beta values (three minutes sampling). The horizontal axis represents samples' numbers and the vertical axis represents the calculated distances. The figures illustrate the distance values (data points) fluctuation during the sampling period.

Test5

(One minute RSSI sampling)

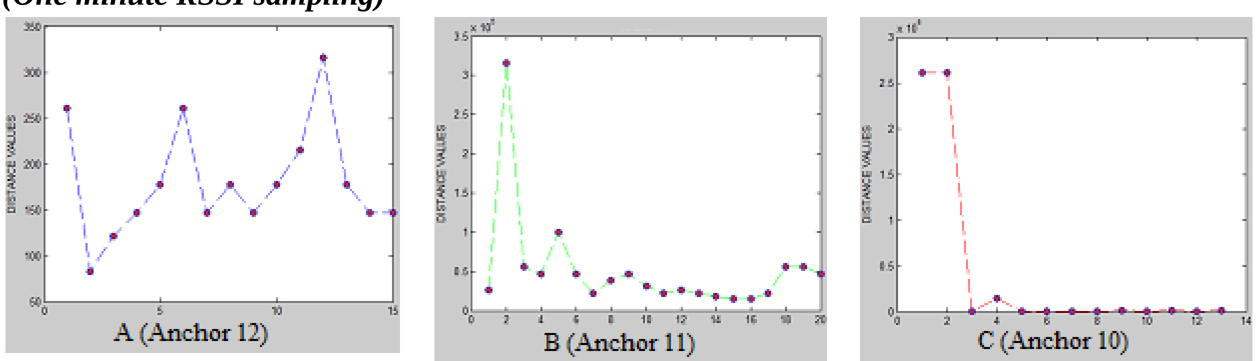


Figure 50: The figures show the calculated distances of the experiments' group three (test 5) based on a unique "median" of beta values (one minute sampling). The horizontal axis represents samples' numbers and the vertical axis represents the calculated distances. The figures illustrate the distance values (data points) fluctuation during the sampling period.

(Three minutes RSSI sampling)

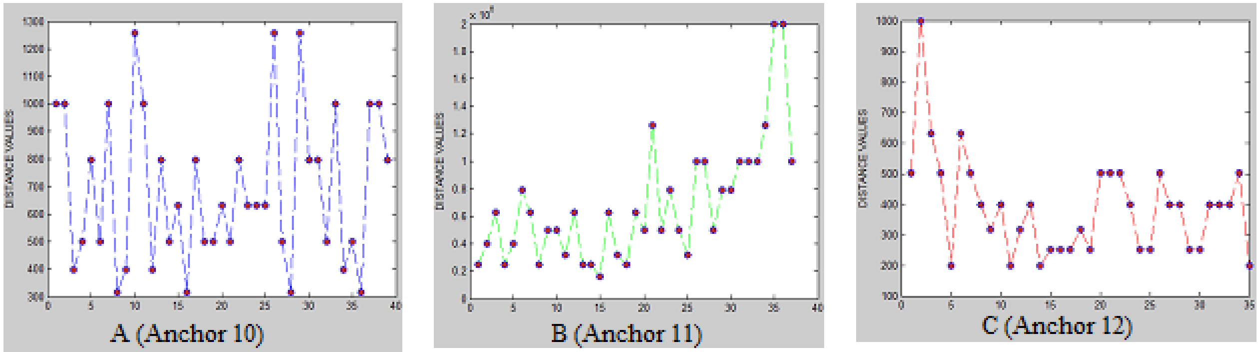


Figure 51: The figures show the calculated distances of the experiments' group three (test 5) based on a unique "median" of beta values (three minutes sampling). The horizontal axis represents samples' numbers and the vertical axis represents the calculated distances. The figures illustrate the distance values (data points) fluctuation during the sampling period.

Experiments group four

To compare the calculated distances in a grid pattern environment, the diagrams of two experiments (of nine) are presented in this part.

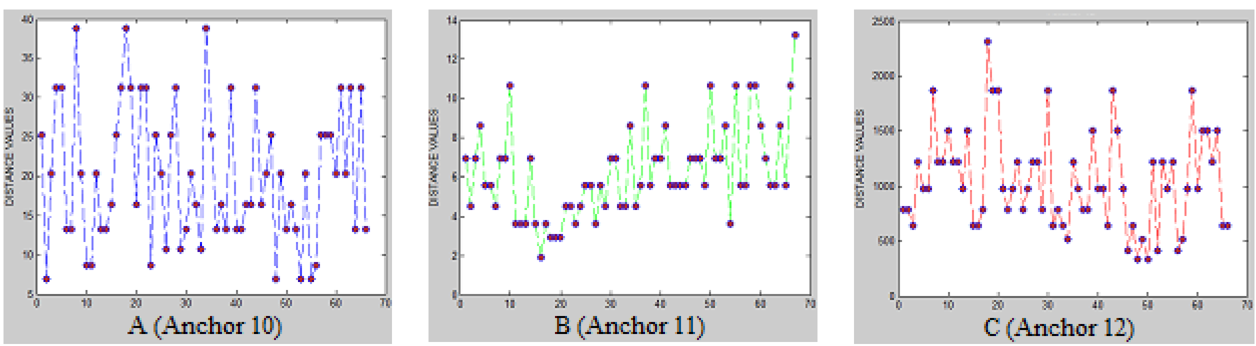


Figure 52: The figures show the calculated distances of the experiments' group four (test 1) based on a unique "median" of beta values. The horizontal axis represents samples' numbers and the vertical axis represents the calculated distances. The figures illustrate the distance values (data points) fluctuation during the sampling period.

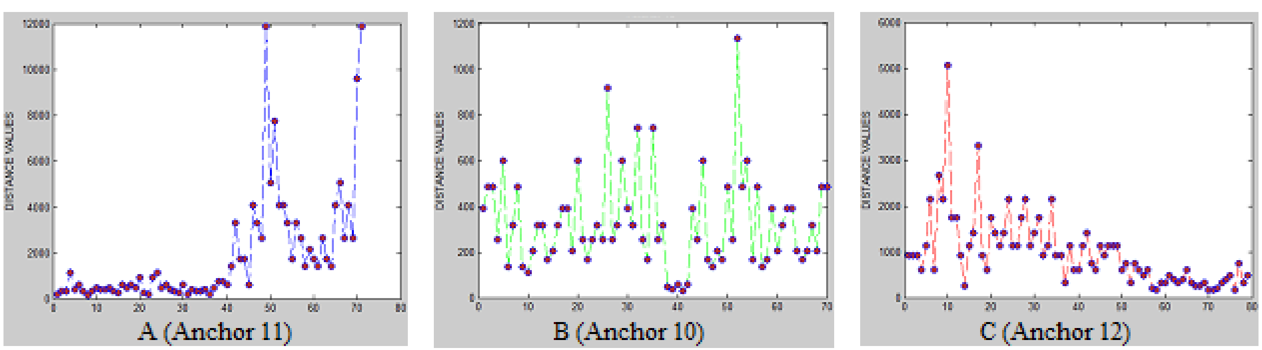


Figure 53: The figures show the calculated distances of the experiments' group four (test 2) based on a unique "median" of beta values. The horizontal axis represents samples' numbers and the vertical axis represents the calculated distances. The figures illustrate the distance values (data points) fluctuation during the sampling period.

Experiments group five

This group has six experiments that the distance diagrams of two experiments with same situation and only a change in the target node location are illustrated. The anchor nodes are inside the office and the target node is placed outside.

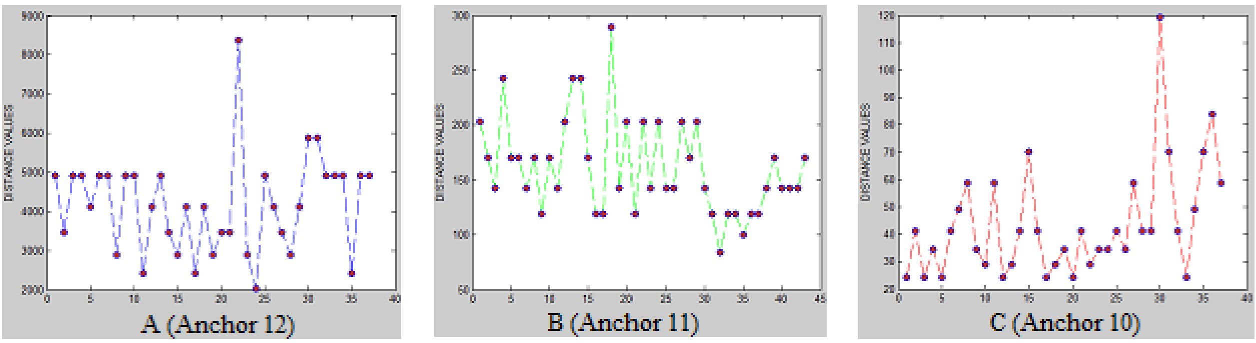


Figure 54: The figures show the calculated distances of the experiments' group five (test 1) based on a unique "median" of beta values. The horizontal axis represents samples' numbers and the vertical axis represents the calculated distances. The figures illustrate the distance values (data points) fluctuation during the sampling period.

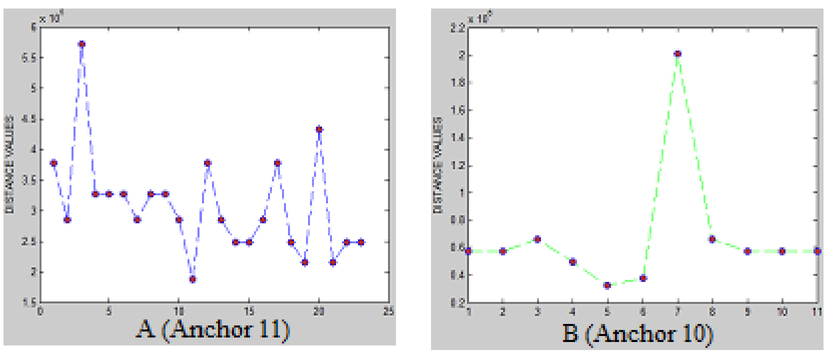


Figure 55: The figures show the calculated distances of the experiments' group five (test 2) based on a unique "median" of beta values. The horizontal axis represents samples' numbers and the vertical axis represents the calculated distances. The figures illustrate the distance values (data points) fluctuation during the sampling period.

In this experiment the anchor 12 did not receive and present any RSSI samples. The anchor 12 was in the farthest place of the target node.

Experiments group six

In this group the distance diagrams of two same experiments are presented. We just replace the position of sensors 10 and 12. The target node is in the same position (same distances) in the both experiments.

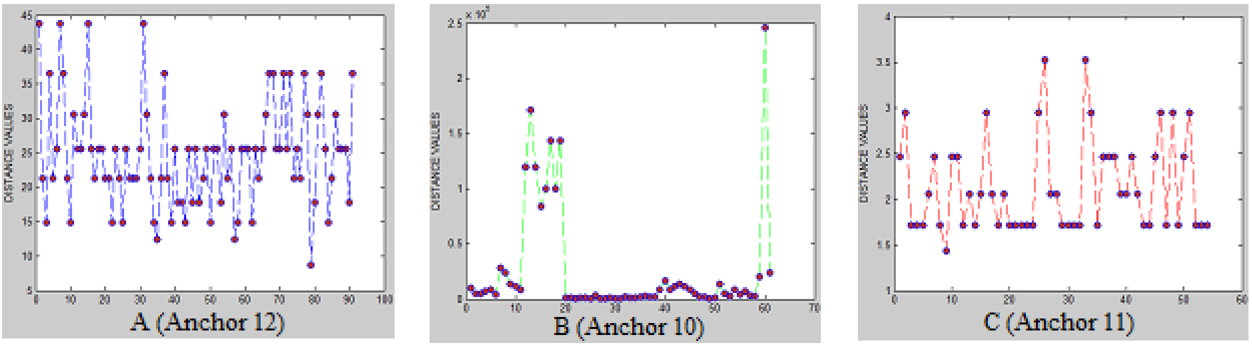


Figure 56: The figures show the calculated distances of the experiments' group six (test 1) based on a unique "median" of beta values. The horizontal axis represents samples' numbers and the vertical axis represents the calculated distances. The figures illustrate the distance values (data points) fluctuation during the sampling period.

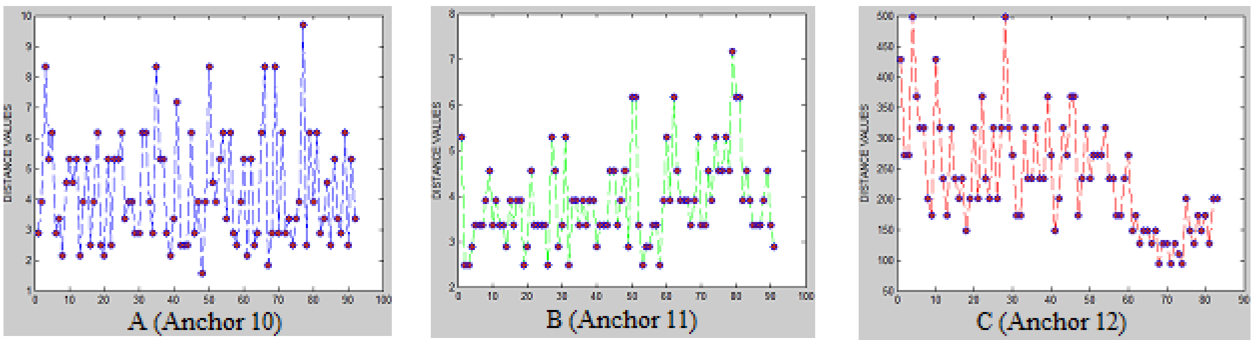


Figure 57: The figures show the calculated distances of the experiments' group six (test 2) based on a unique "median" of beta values. The horizontal axis represents samples' numbers and the vertical axis represents the calculated distances. The figures illustrate the distance values (data points) fluctuation during the sampling period.

6.3 Analysis

This part tries to explain and study the achieved results in each group of experiments. Although the illustrated diagrams can be analyzed with different point of view, we present the significant findings which are in direct relation to distance accuracy and improvement of localization precision. This idea (improvement of localization accuracy and observing the relevant influencing parameters) was the basis of designing each group of experiments that we study in this part. Before considering the analysis of each group, the following graph illustrates the status of accuracy (based on minimum distance error) in the 6 groups (figure 58).

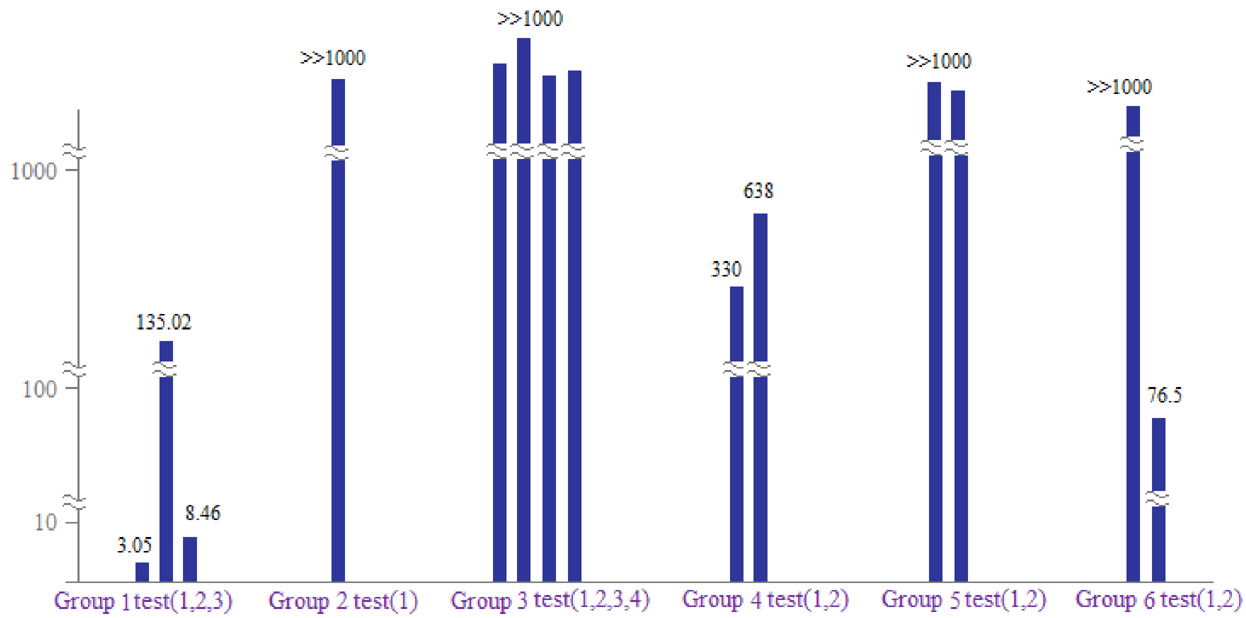


Figure 58: The graph shows the mean value of the calculated minimum distance error for all the anchors in the different tests for each group of experiment. The horizontal axis represents our 6 groups and their tests. The vertical axis represents the distance (meter).

Experiments group one

The experiments in this group consider the direction of target node's antenna. The direction of the antenna in test1, test2 and test3 is respectively towards anchor 12, anchor 10 and anchor 11. Table 12 demonstrate a comparison between different calculated beta values (path loss exponent) and tables 13, table 14, and table 15 present real distances and calculated distances (based on log normal shadowing model) for test1, test2 and test3.

	Anchor 11 (median β)	Anchor 12 (median β)	Anchor 10 (median β)	Mean β for whole environment
Test1	-1.5	-1.79	-1.41	-1.45
Test2	-1.38	-1.15	-1.77	-1.43
Test3	-1.51	-1.09	-1.93	-1.51

Table 12: Calculated median beta values for the experiments group one

	Anchor 11	Anchor 12	Anchor 10
Real distance	8.65m	5m	10.25m
Calculated by (median β)	11.05	2.03	16.06
Calculated by (unique mean β)	**6.72**	**2.4**	**14.87**
Minimum error	-1.93	-2.6	+4.62

Table 13: Calculated and real distances for the experiments group one- test1

	Anchor 11	Anchor 12	Anchor 10
Real distance	8.65m	5m	10.25m
Calculated by (median β)	606.19	**52.98**	246.21
Calculated by (unique mean β)	**172.89**	136.23	**203.09**
Minimum error	+164.24	+47.98	+192.84

Table 14: Calculated and real distances for the experiments group one- test2

	Anchor 11	Anchor 12	Anchor 10
Real distance	8.65m	5m	10.25m
Calculated by (median β)	**5.42**	**22.24**	5.35
Calculated by (unique mean β)	3.39	52.71	**5.35**
Minimum error	-3.23	+17.24	-4.9

Table 15: Calculated and real distances for the experiments group one- test3

Based on the calculated path loss exponent (beta value) we can see in the calibration phase although the differences of the achieved values are not too much, we have three distinct values for beta. It means that although we attempted to have almost the same environmental condition (in the calibration phase), the received RSSI values and as a consequence the beta value have some changes. This can demonstrate that anchor nodes in the calibration phase (with the constant situation) received almost different RSSI values. This situation (not completely the same amount of beta values) occurred in all of the experiments in this report.
In accordance with the results of tables 13, 14 and 15, test1 (the direction of the target node's antenna is towards anchor 12) has the best results with minimum distance error for all anchors and the test2's results are the worst. Anchor 11 has the best results and when the direction of target node's antenna is not towards the anchor 11 the accuracy improved.

Experiments group two
The target node in this experiment is behind a wall (there is not any direct path between anchors and target node). The sensors' results (RSSI values) and calculated distances present a big error. Table 16 demonstrates the median distance values. It seems that in this experiment people movement and other barriers (distraction, diffraction effects) highly effected RSSI signals and the error is very high.

	Anchor 11	Anchor 12	Anchor 10
Real distance	≈23.95m	≈22.11m	≈29.40m
Calculated by (median β)	1.99e+10	5.8e+03	3.6e+04
Calculated by (unique mean β)	4.2e+04	2.3e+05	1.47e+05

Table 16: Calculated and real distances for the experiments group two

Experiments group three
In this group the calculated distances are based on one and three minutes RSSI sampling. When the target node is in the far distance of anchors and come to close distance of them. The RSSI signals are collected by a network of anchors which deployed in two different environments (anchors are in both corridor and office and target node is in corridor).

	Anchor 11	Anchor 12	Anchor 10
Real distance	21.35m	15m	20.95m
Calculated by (unique mean β)	4.6e+04	8.2e+03	1.1e+04
Minimum error	>>1000	>>1000	>>1000

Table 17: Calculated and real distances for the experiments group three (far- one minute)

	Anchor 11	Anchor 12	Anchor 10
Real distance	21.35m	15m	20.95
Calculated by (unique mean β)	5.08e+04	8.9e+03	1.08e+04
Minimum error	>>1000	>>1000	>>1000

Table 18: Calculated and real distances for the experiments group three (far- three minutes)

	Anchor 11	Anchor 12	Anchor 10
Real distance	9.23m	2.3m	8.25
Calculated by (unique mean β)	3.49e+04	177.83	562.34
Minimum error	>>1000	+175.53	+554.09

Table 19: Calculated and real distances for the experiments group three (near- one minute)

	Anchor 11	Anchor 12	Anchor 10
Real distance	9.23m	2.3m	8.25
Calculated by (unique mean β)	6.3e+05	398.11	630
Minimum error	>>1000	395.81	621.75

Table 20: Calculated and real distances for the experiments group three (near- three minute)

	Anchor 11 (median β)	Anchor 12 (median β)	Anchor 10 (median β)	Mean β for whole environment
Test1	-0.64	-2.32	-0.65	-1.2
Test2	-0.57	-2.29	-0.73	-1.19
Test3	-0.64	-2.32	-0.65	-1.2
Test4	-0.21	-2.27	-0.52	-1

Table 21: Calculated median beta values for the experiments group three

Although the results of this group show a great error in the measured distances, we can realize the following points:

- Table 21 explains that calculated beta values for each anchor in different experiments are to an extent equal but these values from one anchor to another one is completely different. For example the distance of anchor 12 and 10 is 5.95m and both of them were placed in the corridor but the minimum difference between their calculated betas is -1.56. It can show if we apply a beta value for each anchor instead of applying one unique beta value (mean of the all anchors beta value) we can improve the accuracy. Also, if we have a wireless sensor network which is deployed in two different environments or one environment with different partitions we separately calculate beta value for each partition or room.

- When the target node's distance decrease the accuracy improve but still we can see a great error because of people movement, obstacles and experimentation in two different environment with indirect signal path (for anchor 11) between anchors and target node.
- Anchor 12 has better results than the anchors 10, 11. Since it had a direct signal path with target node but its results were not accurate enough. It could happen due to signals' interference. Since anchor 12, 10 were placed in one line and almost close to each other.
- The results of the longer sampling experiments were worst than shorter sampling.
- Although the anchor 11 has the worst calculated distances, it can explain that for sure the target node is not in the room which anchor 11 is placed.

Experiments group four

In this group also the experiments have done in two indoor environments (corridor and salon). The focus was on the grid pattern location. In the first illustrated results, the target node was located in the connection of two environments (between salon and corridor). Tables 22, 23 present the calculated distances in two of the experiments in this group.

	Anchor 11	Anchor 12	Anchor 10
Real distance	10.27m	9.82m	3.25m
Calculated by (unique mean β)	5.59	978.71	20.34
Minimum error	-4.41	+968.89	+17.09

Table 22: Calculated and real distances for the experiments group four (test 1)

	Anchor 11	Anchor 12	Anchor 10
Real distance	13.34m	12.99m	6.03
Calculated by (unique mean β)	741.94	918.25	285.87
Minimum error	+728.6	+905.26	+279.84

Table 23: Calculated and real distances for the experiments group four (test 2)

In the test A and for the anchor 11 we achieved the best result. Since the target node was in the opposite direction of that. Although they were in two different environments, there was a direct signal pass between them. The results of table 23 again demonstrate that the target node is not in the environment of anchors' network.

Experiments group five

These experiments have done in two different environments where target node was in outdoor place and anchors network was inside with different height with respect to target node place.

	Anchor 11	Anchor 12	Anchor 10
Real distance	2.3m	8.2m	3.14m
Calculated by (unique mean β)	142.51	4.1e+03	41.25
Minimum error	+140.21	>1000	+38.11

Table 24: Calculated and real distances for the experiments group five (test 1)

	Anchor 11	Anchor 12	Anchor 10
Real distance	12.8m	20.2m	14.45m
Calculated by (unique mean β)	2.8e+05	--	5.7e+05
Minimum error	>>1000	--	>>1000

Table 25: Calculated and real distances for the experiments group five (test 2)

The results achieved in humid cloudy day and none of the anchors received suitable RSSI signals. In the worst case and in the experiment B, anchor 12 did not report any sample. It was the farthest anchor from the outdoor target node.

Experiments group six

In this group we have replaced the position of two anchors to see if each anchor has specific effects of the results.

	Anchor 11	Anchor 12	Anchor 10
Real distance	8.72m	4.74m	9.8m
Calculated by (unique mean β)	2.05	25.48	4.69e+03
Minimum error	-6.67	+20.74	>>1000

Table 26: Calculated and real distances for the experiments group six (test 1)

	Anchor 11	Anchor 12	Anchor 10
Real distance	8.72m	9.8m	4.74m
Calculated by (unique mean β)	3.9	233.57	3.91
Minimum error	-4.82	+223.77	-0.83

Table 27: Calculated and real distances for the experiments group six (test 2)

In this experiment the positions of anchors 10 and 12 were replaced. As we can see, both of them in a specific position show high distance error. Although calculated distance error for anchor 10 is much more than anchor 12 (4.69e+03 >> 223.77). The other achievement is about anchor 11 which albeit its position is the same in two experiments the minimum error is not equal.

6.4 Answer to the Relevant Research Questions

Two research questions have been considered in the experiment's part of this study:

- RQ8: what effect does environmental condition have on the precision of localization?
- RQ9: to what extent do environmental conditions influence the localization accuracy of the RSSI-based algorithms?

The results present that it is important to consider environmental conditions in both the calibration and measurement phases. In fact, the RSSI values are highly affected by conditions of the place of experiments. In the calibration phase, we saw it is significant to calculate the calibration parameters separately for each room or partition or even anchor if the network is deployed in different rooms. In addition, although we applied the specific sensor nodes as the anchors with specific antennas which can affect the results, people's movement has serious effects on the RSSI signals. In other words, in the experiments that there was a direct signal path between a target node and anchors, the positioning was more precise. It means that barriers (even temporary: people's movement) in the signal path have considerable effects on accuracy. Finally, the results of experiments in which the target node was placed outdoors (with different humidity, temperature …), or when two anchor nodes were placed completely in one line, calculated distance error was high.

Chapter 7

Systematic Mapping Study Results

7.1 Introduction

This chapter intends to discuss the defined research questions with respect to the conducted mapping study based on the criteria which have been mentioned in chapter 3. Therefore, the aim of the mapping study is to find the answers of the research questions.

Search Strategy: the review protocol of the search is comprised of the defined research questions in the context of the RSSI-based localization and the described search string.
Data source and selection of primary studies: as mentioned in chapter 3, the search string has been used on IEEE Xplore, Engineering Village and Scopus. In the search process, the author considered the papers published from 2004 to December 2014. Table 28 depicts the results of the primary study selection in brief. The study selection was based on firstly, applying the search string to the different databases and achieving the first list of studies. Secondly, the author studied titles, abstracts and keywords of all the above papers. In this phase, inclusion and exclusion requirements have been used (the papers, which did not explicitly tell in their titles or abstracts about the RSSI-based localization, were out of our study area) and all duplicated papers have been eliminated. Then, papers whose abstracts were not clear enough to answer the research questions, made us change the level of our study (sometimes conclusion and introduction parts were studied and rarely entire papers were read). Although the study of entire papers could have improved the validity of our answers in the domain of WSN and localization, it needs more time and effort that influenced the borders of our mapping study.

Number of papers in different phase of research process	IEEE	Engineering Village	Scopus
After applying search string	239	374	691
After first screening and eliminating duplication	159	64	106
After second screening and eliminating papers with unclear abstracts	150	37	52

Table 28: Search process to find relevant papers

7.2 Answers to our Research Questions

The answers are based on a mapping study that has covered 239 papers[1]. The focus of the study was mostly on the titles and abstracts which explicitly considered the answers of the research questions.

Research question1: *What are the most frequently applied research methods in the context of the RSSI-based localization?*
In this context, 1 survey, 1 case study, 25 implementation, 79 simulation and 92 experimentation methods have been found. Some papers applied two or three different research methods. Therefore, experimentation by approximately 38% forms the most frequently applied method and simulation by 33% is the second most frequently applied method. It should be considered that a subset of the selected papers have not stated clearly their research methods in their abstracts.

Research question2: *In which application fields is the RSSI-based localization applied and how many articles are available in these fields?*
31 papers focused on target tracking. The aim of these papers is only to find the location of an object or robot in an environment. 13 papers focused on environment monitoring. The safety of workers in a mine or underground places and monitoring of children in an environment are prevalent. Finally, 6 papers explained their experiments in the healthcare field to find emergency patients, doctors or specific medical devices.

Research question3: *In how many papers in the context of the RSSI-based localization "computational effort" with respect to energy consumption has been considered?*
19 articles considered the computational effort to find a place of a moving object and only 8 papers focused on computational effort with respect to energy consumption (low complexity in computation and its effect on power consumption).

Research question4: *What are the environments (indoor environment or outdoor) considered by experiments and how many studies reported the comparison between the accuracy of the experimental results?*
76 papers explained their experiments or simulations at the indoor environments and 16 papers at the outdoors. 7 papers made a comparison between indoor and outdoor results. Since, the RSSI localization prepares low cost and low power situations for indoor places and applying GPS is suitable for outdoor places. Hence, the focus of the studies is mostly on the indoor localization.

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[1] https://drive.google.com/file/d/0B8r3FiUzK9gCSnZQZ2xSeEJGV0E/view?usp=sharing
https://docs.google.com/spreadsheets/d/1ouPkASeJBtjxW8IqHVkKuCv3ayWDGxuMrQcNLui_c9A/edit?usp=sharing
https://docs.google.com/spreadsheets/d/1i15zQbTjagNP8aYVWnIqlig-dSvWcK8TwDwac6Iggyg/edit?usp=sharing

Research question5: *How many studies pay attention to the effect of the number of anchors (anchor density) on improving accuracy?*
26 articles considered the issue of anchor density and its effect on accuracy and only in 2 papers the number of anchors for experiments was more than 99.

Research question6: *How frequently do the RSSI-based experiments report effect size as an evaluation result?*
The studied articles have not reported effect size in their results.

Research question7: *How prevalent is consideration of environmental conditions (models for the power received form anchors) and their effect on improving accuracy in publications?*
33 papers considered the importance of environmental conditions on the accuracy problem. To see the effect of environment, some of papers studied the calibration phase while the others did experiments in different environment to evaluate the results. Therefore, approximately 14% of the papers clearly underlined this issue in their abstracts.

Research question8: *What effect does environmental condition have on the precision of localization?*
Since the RSSI values are applied to measure the distance and they are affected by the different obstacles and conditions in environments, the articles have studied different algorithms and methods to reduce the localization error caused by environmental conditions. In fact, considering environmental conditions especially in the calibration phase can clearly improve the accuracy of localization.

Chapter 8

Discussion

8.1 Discussion of the Experiments Findings

Localization's accuracy is the significant requirement in the context of the RSSI-based localization in the WSNs (Barsocchi et al., 2009; Papamanthou, 2008; Rasool et al., 2012; Artemenko et al., 2010; Ahn, 2010; Liu et al., 2012). So, considering the RSSI values as input vectors in the different distance measurement algorithms and the parameters which affect these values can be crucial in the RSSI samples' precision and accordingly the final location precision. The accuracy issue formed the most of our research questions in two frameworks, how the environmental conditions impact on localization's accuracy and how frequent was influences of environmental conditions on the previous studies.

Regarding RQ9, we intended to evaluate to what extent the localization accuracy was affected by environmental condition. Experiments enabled us to define different conditions for our RSSI measurements and observed the effect of each situation on the accuracy. The results revealed that although the RSSI samples in two very similar experiments were not completely the same, they are highly correlated environmental conditions. Existence of a direct signal path between a target node and anchors improved the accuracy while any temporary (people's movement) or permanent obstacle increases the location estimation error. The results indicated that when the target node did not have any direct signal path to each of the three anchors we had the highest amount of distance error. In this case (having a direct signal path between sensors) the results indicated when the direction of target node's antenna is not towards a specific anchor, that anchor reported better samples (it is significant that in the experiments related to direction of antenna, there was a limitation and we did not have different types of antenna to evaluate or confirm our results).

Based on (Chuan-Chin Pu et al., 2011), (Shirahama & Ohtsuki, 2008), (Chuku et al., 2013) and (Fink & Beikirch, 2009) there is a mathematical model between RSSI values and distance. This model (shadowing log normal model) was implemented as a server side application to measure the distances and analyze the experiments. However, based on (Zhu Minghui & Zhang Huiqing, 2010) and (Wu et al. 2008) the RSSI signals have a specific characteristic whose values do not necessarily increase in all situations when two sensors come closer or decrease when we increase the distance between sensors. Our results in the experiments group 3 support these findings by showing the calculated distance error when we reduced the distance between anchors and target node in different experiments. Although we observed an improvement in the localization's

accuracy when we moved the target node closer to the anchors, still the rate of error was very high.
For the results of experiments group 3 of there are two interpretations. One interpretation can be that we deployed our sensor networks in two different spaces (corridor and room). It can affect the calculated path loss exponent in the calibration phase and also there is not a direct signal path between the target node and one of anchors. This would imply that environmental conditions have clear effects on the measured distances. The other interpretation could be that the anchors in the corridor were placed in one line and close to each other. This matter caused the RSSI signals' interferences in the anchor nodes and reduced accuracy.
We received unexpected results when we increased the time of the RSSI sampling. Because of the RSSI characteristic (its Gaussian distribution), we supposed that by increasing the time of the RSSI sampling, we would receive more suitable RSSI values and it can improve the accuracy while there was not any considerable effect. The interpretation of these results can be that our sampling time was not long enough to see a reasonable effect. The experiments have been done in two different sampling times (1 and 3 minutes). The number of achieved samples in these two groups of experiments was not radically different to make a desirable situation for evaluation.
Finally, in the experiments conducted in a combination of indoor and outdoor situations, the error rate was high and one of our anchors did not receive any RSSI values. This can again demonstrate the importance of environmental conditions (the target node was placed in an outdoor situation while our anchor nodes were placed inside of our office) and its effect on accuracy.

8.2 Discussion of the Mapping Study Findings

Since the author could not find any mapping study in previous researches, the findings in the mapping study can be new. However, since the number of papers was huge, there was a limitation of time to study the papers in detail and mapping study has been done by one person, there is a threat of classification bias or judgmental error in the categorization.
Our main findings show:
Firstly, (with respect to RQ2) although there is a considerable amount of research in the context of the RSSI-based localization and improvement method, the experiments and studies have mostly been done in a laboratory condition and not in practical situation and real world. There are 19 papers (of 239) which implement and assess this method of localization in the real world condition.
Secondly, (with respect to RQ3) though the RSSI-based method is a low cost approach in localization, the number of papers which studied the relation between mathematical computation (complexity of the algorithms) and energy consumption was 8. It can show a gap in the context of energy saving in the RSSI localization.
Finally, our data presented an in-depth study in the accuracy issue which is a fundamental requirement in the localization context (152 of 239 papers had an explicit consideration to the

issue of accuracy in their abstracts) while a few papers considered the other issues such as reliability, performance and stability in the localization which can imply a need for more empirical investigations. Table 29 presents contribution of previous studies in the other issues.

Reliability	Performance	Stability
2	41	13

Table 29: Number of studies that considered the other requirements in the localization context

In this thesis we studied 8 research questions related to our mapping study.

RQ1 considered the research method which has been used most, i.e., experiment. We also applied this method during our study to achieve required results for the analysis. Therefore, the results of the mapping study guided us to use the frequently applied and suitable method.

Regarding RQ2, we applied the RSSI localization in the target tracking field in the experimental situations.

Based on RQ3, computational effort and energy consumption can have a direct relation. We considered papers (in our literature review) which studied computational effort or energy consumption, however the results of the SMS show that the number of papers which studied computational effort with respect to the amount of used energy in the system is a few.

RQ4 intended to assess the previous papers based on the environment of experiments (indoor or outdoor) and the results demonstrated that the main focus is on indoor situations. According to what we studied in the background (chapter 2), since GPS is applicable for outdoor situations, so this is the reason why the main focus of the studied papers is on the indoor situations. In this thesis we had only one group of experiments for outdoor situations. The comparison between outdoor and indoor results shows that the distance error in outdoor situations is higher than indoor ones.

Our mapping study (based on RQ5) demonstrated that the anchor density is an important factor in the localization precision, however, in our experiments we applied 3 anchor nodes (minimum required anchors for localization) and we will need to increase the number of anchors in our future work.

Regarding RQ6 none of the studied papers reported the effect size as an evaluation result.

RQ7 and RQ8 considered the environmental conditions. We also tried to design some experiments to study the effect of environmental conditions. Based on the characteristics of the RSSI values (we studied in chapter 2), the results of experiments and the results of our mapping study we still need to study the effect of environmental conditions on accuracy.

Chapter 9

Conclusion and Future Work

9.1 Conclusion

This thesis studied different methods, algorithms and techniques of localizing an object in the WSNs and in particular focused on the RSSI values and the RSSI ranged-based algorithm. We have presented 30 designed experiments, their results and analyses. Our overall goals were: firstly, to understand the concept of localization based on RSSI values and specifically implementation of a localization algorithm to apply, analyze and improve. Secondly, to find the answers of our research questions and the frequency of investigations (especially the effects of environmental conditions on the RSSI values and localization's accuracy) in previous studies in the form of mapping study.

The main contributions in this study are:

- Firstly, we realized based on our experimentation's results, which cover different effective parameters in localization precision, the same hardware device (sensors) in the same situation gained different RSSI values.
- Secondly, our systematic mapping results. It seems this mapping is the first mapping study in the context of the RSSI-based localization and demonstrates that there is a lack of studies in the context of localization performance, stability and reliability.
- Finally implementation of a server side software application, which can receive data, prepare relevant databases and analyze the data based on defined filters and mathematical models.

Our experimental results showed that the distance error in the RSSI localization method is considerable and environmental condition especially obstacles and people's movement (the importance of direct signal path between the target node and anchors) affect the RSSI values and as a consequence the distance measurement and localization precision. In addition, we found the hardware device and in particular the antennas of the sensors have clear influence on accuracy. Although it should be considered that our experiments have a limitation in the number of sensors (our experiments have been done by minimum number of anchor nodes which can affect the accuracy) and type of antennas.

Our mapping study results demonstrated that although there were a number of studies in this context and different methods had been used to improve accuracy, there is still a little applicable implementation and a few studies in the real world. Moreover, there is a lack of research on the other RSSI-based localization requirements such as performance, stability and reliability. Also, in the mapping study it should be considered that it has been done by one person in a limited time and in the level of abstracts' studying which increase the risk of classification error.

Although we studied some challenges about the RSSI-based localization, there might be more issues that we have not considered and there is a requirement for further researches. This thesis suggests more studies in the areas such as localization reliability and RSSI filtering to improve the localization systems.

In spite of the fact that there are many researches and experiments in the context of the RSSI-based localization and distance error improvement, RSSI-based localization is still an interesting context of research.

9.2 Future Work

In accordance with the results of our mapping study and experiments, we intend to conduct the next studies on these issues:

- We found that when the positions of our anchor nodes were replaced, the median value of the received RSSI samples changed dramatically. Since the measurement error can be possible because of our limitation of doing more experiments, we plan to redo our experiment and evaluate the new results.
- To improve the localization accuracy, the shadowing effect (zero-mean Gaussian random variable) plays a decisive role. We plan to design some experiments to assess this factor and consider it as a new requirement in our software.
- One limitation to our experiments was the number of anchor nodes. According to the background of this study, anchor density has a clear effect on accuracy. To improve precision of the localization we will conduct more experiments with more than 3 anchor nodes and study how to select the best anchors.
- Another restriction on our experiments was sampling time. All the experiment had a short RSSI sampling time. Although the sensors produce a lot of data, we need to increase the experiment duration and observe the effect of the number of samples on accuracy.
- Based on the findings of our mapping study, there is a lack of study on other requirements such as performance, stability and reliability. We intend to study these requirements in our RSSI localization system.

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Appendix A

Experiments' Maps

In the figures of this part, we see different maps of the experiments. In our experiments there are 3 anchors (Anc12, Anc10, and Anc11), one calibration node (FO), one moving object or target node in different positions (MO) and one master node (Mas). The corresponding distances have been written on the maps.

A.1 Map of the Experiments of Group One

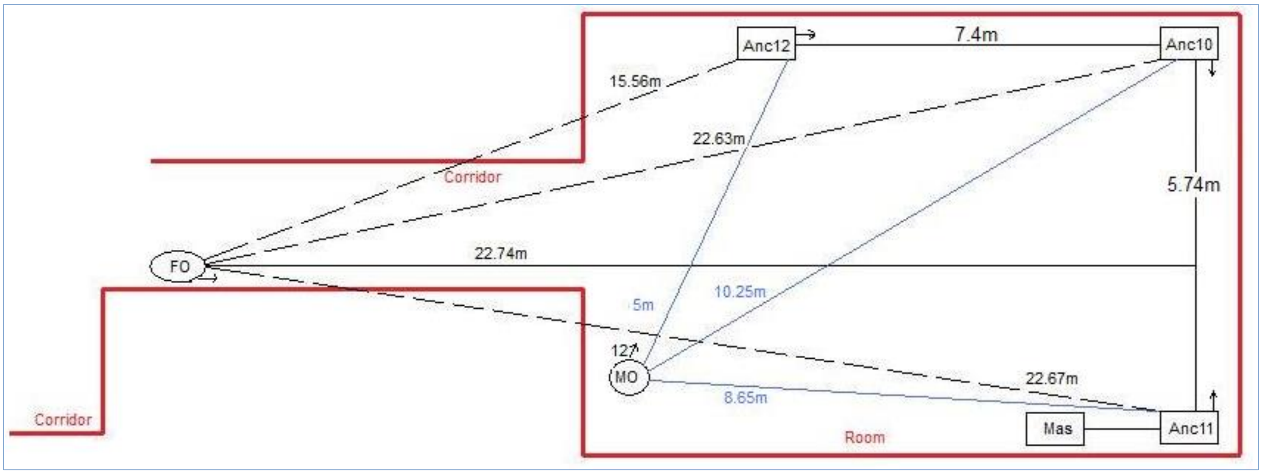

Figure 59: Finding the position of the target node (MO) while direction of the target node's antenna is the independent variable. The map shows that the target node's antenna is toward anchor 12.

A.2 Map of the Experiments of Group Two

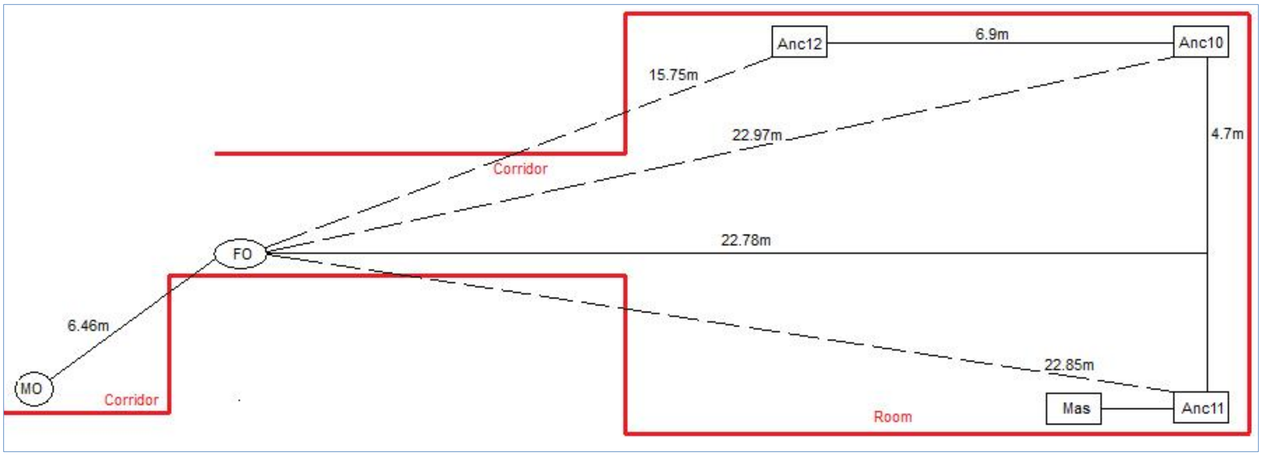

Figure 60: Finding the position of the target node (MO) while the signal path and distance are the independent variables.

A.3 Map of the Experiments of Group Three

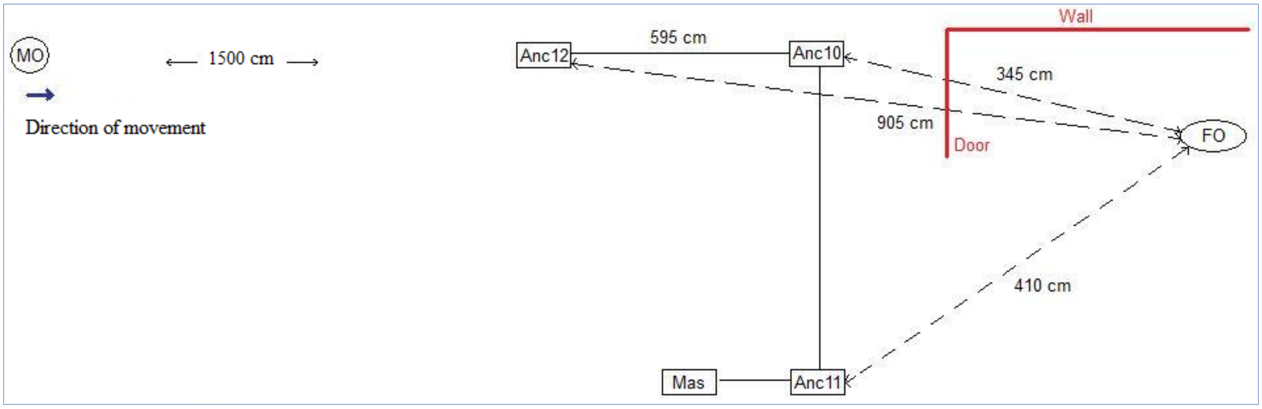

Figure 61: Finding the position of the target node (MO) while the distance and sampling time are the independent variables. The map shows that how the target node moves toward the sensor network.

A.4 Map of the Experiments of Group Four

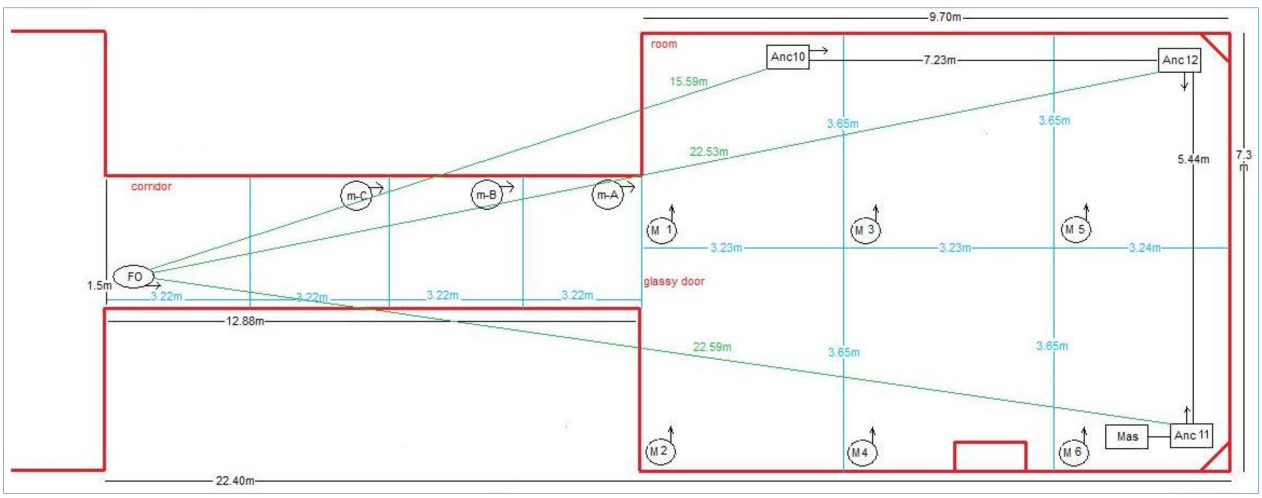

Figure 62: Finding the position of the target node (MO) while the distance and signal path are the independent variables. The map shows that how the target node moves in a grid pattern map.

A.5 Map of the Experiments of Group Five

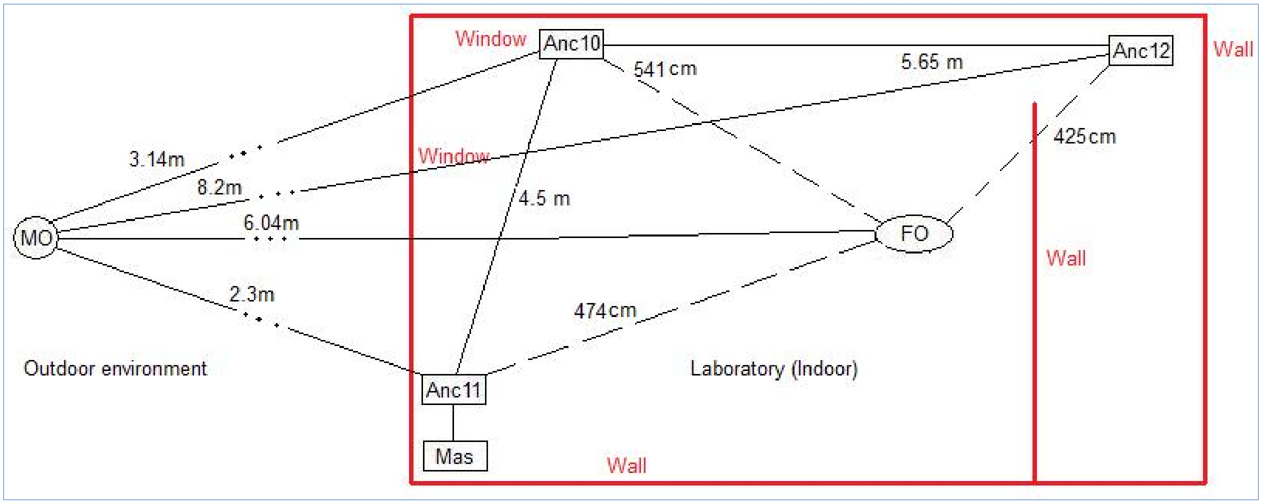

Figure 63: Finding the position of the target node (MO) while the experiments have been done in two indoor and outdoor places. The map shows that the target node is placed in an outdoor situation and the sensor network is inside.

A.6 Map of the Experiments of Group Six

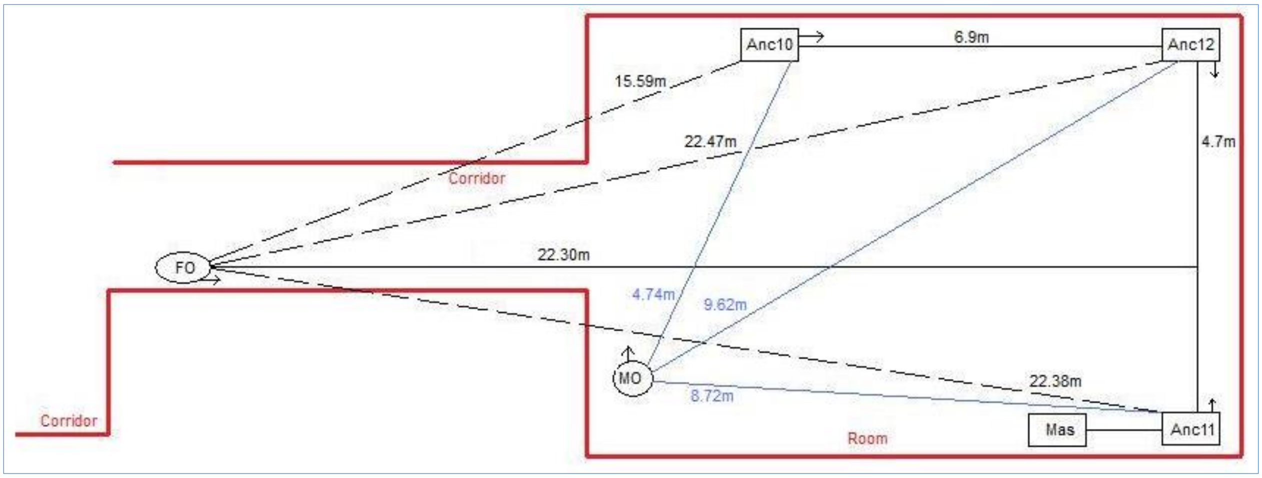

Figure 64: Finding the position of the target node (MO) while anchors 10 and 12 were replaced (in comparison with figure 57).