Localization of Wireless Sensor Networks for Industrial Applications

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ABSRTACT

In new generation manufacturing systems, Wireless Sensor Networks have become an important technology because of the various ameliorations in comparison with common sensors, such as power consumption, connection to base station, data processing and etc. In order to obtain all these capabilities in sensor nodes, some difficulties may be encountered such as power resource, data transmission and localization for each sensor node. The objective of this study is to investigate a localization of the distributed wireless sensor networks in the manufacturing domain with utilizing Trilateration algorithm and received signal strength Indicator (RSSI) as distance based measurement.

In experimental part of this study, an Assumption Based Coordinates (ABC) algorithm is proposed to define the location of a node with unknown position through utilizing the Trilateration method. This part is composed of two different methods. Both of these methods are distance based, and Received Signal Strength Indicator (RSSI) is used as a measurement factor. Friss transmission equation is the base of the theoretical part of this study and the results obtained by experimental methods are compared with the theoretical results related to this equation.

The first experimental part was done in a simple environment without any manufacturing machines and equipments. Sensors were deployed in that area and RSSI was measured in different distance for several times. Because the simulation of Terilateration method is the aim of this experiment, the graph that shows the relationship between the measured RSSI and distance was obtained to use as data resource to calculating the distance for one hundred random RSSI. Nevill algorithm is a mathematical solution to change this graph to be data recourse for the distances those related to one node to use as input data for Trilateration method.

In the second experimental method some unknown nodes are assumed in a coordinate system and their distances to each reference node was calculated. By utilizing the Friis equation the related RSSI for each distance was measured. The theoretical RSSI was changed by adding 40 percent white Gaussian noise (AWGN) and then imported again to the Friis equation to obtain the distances related to each RSSI. Finally, the locations of unknown nodes were obtained with the Trilateration method.

The proposed localization methods were considered on two different manufacturing environments as industrial application of WSN. The first one is EMU mechanical engineering workshop which houses different types of machines and manufacturing equipments and the second one in gas distillation columns used in oil and gas refineries.

Comparison of the theoretical location of unknown node with the location obtained by experimental methods shows the errors and deviations are depend on many factors. These factors are environmental condition, available machines or equipments in sensor field, computational errors of the written program for Trilateration or Nevill algorithm and etc.

Keywords: Wireless sensor network, Manufacturing, Localization, Trilateration, RSSI, Distance

ÖZ

Yeni nesil üretim sistemlerinde, kablosuz algılayıcı ağlar sıradan algılayıcılar ile kıyaslandığında güç tüketimi, ana istasyonlarına bağlanabirliliği ve bilgi işlenebirliliği gibi alanlardaki gelişmelerden dolayı teknoloji yönünden önemli bir konumundadır.Algılayıcı devre düğümlerin tüm bu özelliklerin faydalanabilmek için güç kaynağı, veri aktarımı ve her bir algılayıcı devre düğümün "lokalizasyonu" gibi bazı zorluklarlar karşı karşıya gelmek olasıdır. Bu tezin amacı "Trilateration" algoritma ve gelen sinyal gücünü mesafe tabanlı öiçümü kullanarak üretim alanında dağıtılan kablosuz ağların "lokalizasyonunu" araştırmaktır.

Bu araştırmanın deney bölümünde, "Trilateration" yöntemi ile bilinmeyen bir devre düğümün konumunu belirlemek için "Assumption Based Coordinates (ABC)" algoritma önerilmektedir.Bu kısım iki farklı yöntemden oluşmaktadır. Her iki yöntem mesafe esaslıdır ve Gelen Sinyal Güç Gösterge ölçüm etmeni olarak kullanılmıştır. Friss aktarım denklemi bu araştırmanın teorik yapısını oluşturmaktadır ve ilgili grafiği RSSI ve mesafe arasındaki bağlantıyı göstermek için kullanılacaktır.

Birinci deney, üretim makinaların ve herhangi bir donanımın olmadığı bir ortamda gerçekleştirildi. Bir araba park yerinde algılayıcılar yerleştirildi ve "RSSI" farklı mesafelerde birkaç kez ölçüldü. Ölçülen RSSI ve mesafe arasındaki bağlantıyı gösteren grafik bulundu. Bu grafikle Nevill algoritması kullanılarak, yüz gelişigüzel RRSI in mesafeleri ölçüldü.

İkinci deneysel yöntem birincisinden tamamıyla farklı. Bu yöntemde koordinat sistemde varsayılan bilinmeyen birim devresi ve bilinen her bir algılayıcı birim devresine olan mesafeleri hesaplandı. Friis denklemi kullanılarak her bir mesafe için ilgili RSSI hesaplandı. Teorik “RSSI” 40% beyaz Gaussian parazit (AWGN) eklenerek değiştirildi. Ardından tekrar Friis denklemi kullanılarak her bir mesafe için ilgili RSSI hesaplandı.

Tasarlanan “lokalizasyon” yöntemleri üretim alanında iki farklı deney alanlarında uygulandı. İlki, DAÜ makina mühendisliği atölyesinde bulunan makinalarda ve donanımlarda ikincisi ise gaz ve yağ arıtma tesislerinde kullanılan gaz damıtma haznelerinde.

Bilinmeyen birim devresinin teorik konumu ile deneysel yöntemlerle elde edilen bilinmeyen birim devresinin konumu karşılaştırıldığında RSSI hesaplamaları ve “Trilateration” yöntemi ile elde edilen uzaktan “lokalizasyon” hataların ve sapmaların birçok algılayıcı alanda bulunan makınaların ve donanımların varlığı, hesaplamaya dayalı hatalar gibi birçok çevresel etemenlere bağlıdı olduğunu gösterecektir.

Anahtar Kelimereler: Kablosuz algılayıcı ağı, Üretim, “Lokalizasyon”, “Trilateration”, RSSI, Mesafe

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My final words go to my family. Without my family members, especially my wife, Setare, and my brother Sina supporting and their encouragement, that was not possible to finish this thesis easily.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

Manufacturing enterprises are enabled to move from environments based on data to a more cooperative environment based of information or knowledge with the technologies related to commutation or information. Most of the manufacturing applications have integrated emerging information technologies to improve their performance. The role of sensors or sensor networks in manufacturing applications is providing real-time data collection and control. However, with wired connection is not possible to achieve the real time data and also it cause more installation and maintenance costs.

1.1 Wireless Technology

Around a century ago wireless technology was invented to send telegrams, use in radio, and to develop digital communications today. Comparison between the wireless sensors system with the common sensors shows that the cost of operation, upgrading, and etc in the system with wireless connection is less than the system with wired connection.Therefore, wireless technology has evolved into key technologies for developing next generation manufacturing systems.

1.2 Wireless Sensor Networks

Wireless sensor network (WSN) is a subset of wireless technology systems that contain large numbers of heterogeneous sensor nodes which are dense distributed across a large field of interest and they are connected wirelessly to each other. [2]. There are various applications which the WSNs are extensively used, and their development in other applications is still growing. Industries are using the wireless sensor instead of wired sensors to improve their networks to WSN. In the manufacturing fields, WSNs can sense light, temperature, sound, acceleration, etc. For example, WSN technology has been used to track a part or product in the manufacturing process and make inspections and corrections of the product information to feedback to a quality control server or support for assembly processes. Nowadays, WSNs are going to play a more and more important role in applications of next generation manufacturing systems.

1.3 Wireless Sensor Networks Applications

It is facile to move or deploy Wireless sensor devices without cables and, they are really appropriate for utilizing in most of the industrial applications, controlling and monitoring the environment, assembly, warehousing, measurement, and etc. it can shows that utilizing the wireless sensor networks in manufacturing is increasing [3]. Outdoor localization applications are widespread today like Global Positioning System (GPS), on the other hand indoor applications can also benefit from location determination knowledge. It is possible to have all this application but they should be feasible. To make such applications feasible, the device costs should be low and the network should be organized without significant human involvement.

Adding a GPS device to all the sensor nodes in a network is not feasible for many reasons. GPS devices cannot work indoors, they are so big, and they are not reasonable about cost and are power consumption, while wireless sensor nodes are required to be small, and low priced and low powered [4].

1.4 Wireless Sensor networks Localization

In some applications for example, indoor navigation, objects tracking, remote diagnostics, etc position of the unknown sensor nodes [1] could be calculated by making reference to anchor sensor nodes [2]. So, anchor sensor nodes should be recognized about the location. Many wireless sensor network localization methods have been proposed to obtain the exact location for an unknown node. Generally, unknown nodes obtain their geographical location by estimating the distance to their neighbors.

1.5 Received Signal Strength Indication

Received-Signal-Strength Indication (RSSI) is one of the common methods for calculating the distance between nodes within their mutual transmission range [5]. received signal strength is used as an indicator to measure the distance between two sensor nodes. Since the original signal strength is a known value at the start, it is comparable with the received strength of the signal. In this way lost signal will be achieved and distance will be calculated. This technique does not require extra data is needed to make the distance measurements. The RSSI values are sent in the normal packets. Synchronization is not required between unknown nodes and anchor nodes because it does not need time to measure the distances. Any changes in the environment will alter the RSSI values will be affect by any changes in environment and this one of the disadvantages of this method.

1.6 Trilateration Method

In this research Trilateration method is used to obtain the position of an unknown sensor with using the defined distances by measuring the RSSI. To provide a position estimate in *n* dimensions, a minimum of n-1 nodes are needed, i.e. three anchor nodes are required for a 2D position estimate. When three anchor nodes are used, the method is called Trilateration. By utilizing this method this method accuracy of the information will be increased and exact answer will be obtained. Sometimes there is a point in the intersection of the circles and it is the exact answer of the Trilateration method. Sometimes there is not any common intersection between all the circles in this case the point with minimum distances to all the circles should be estimated and some mathematical techniques can be used such as Least Square Estimation (LSE).

The information of this thesis is organized as follows. In Chapter 2, history and background for sensors and wireless sensors is explained. In Chapter 3 some of the most important general application of WSNs and manufacturing applications are written. Chapter 4 contains the localization of WSNs, different types of localization algorithms, application of localization in manufacturing. In Chapter 5 contains the brief explanation about Trilateration method. Chapter 6 is about the data collecting technique, methodology and two different industrial applications. Chapter 7 consists of discussion and the future works sections

1.7 Motivation

The aim of this thesis is to simulate the efficient wireless sensor network localization via combination of various algorithms and methods and integration of previous proposed methods. Moreover, the algorithm must provide solutions for localization problem in manufacturing applications.

The localization algorithms for manufacturing application of wireless senor networks is not allowed to take up too much hardware and software resources in sensor nodes. The cost of the nodes and also the energy consumption for each of them is considerable in manufacturing applications. For this reason RSSI has been selected as a measurement method to obtain the location for each node.

Trilateration algorithm is used to calculate the absolute position of an unknown node by using the minimum three known node location in the sensor field. Although it is an appropriate algorithm for WSNs localization but some default complicate calculation is needed to obtain the node's location.

The experimental part of this thesis is composed of two different methods. For the first method, because the measurement technique is base on RSSI, we have to convert it to the distance somehow. For this reason we measured some RSSI in some specific distance (1 to10 meter) and then draw the diagram based on RSSI and Distance in which x-axis is related to distance and y-axis is for RSSI.

For the next step, by the aid of Neville algorithm the equation of the drawn diagram is defined and we are able to import some random RSSI (around 100) to this equation and obtain the related distance for each of them. To utilizing the Trilateration method it is necessary to have unknown distances to each basis node with known location (at least four node). But the problem in this method is recognizing these distances those are related to one unknown node between one hundred distances. The selected RSSI by Matlab software for unknown node will be import to the Friis transmission equation to obtain the theoretical distance and finally by Trilateration method the location will be obtain.

In second method for experimental part some random unknown nodes assumed in the 2D senor field which is the square with the size$10m \times 10m$. Four known node are located on intersection of each two edges. The unknown node distances to each of these known nodes are measured by Matlab software and then import to the Friis transmission equation to calculate the theoretical RSSI. The measured RSSI will be affected by additive white **Gaussian noise** (AWGN) to change the RSSI from theoretical mode to experimental as random RSSI. Again random RSSI will be import to Friis transmission equation to calculate the distances and by utilizing the Trilatration method the unknown node location will be obtain.

Chapter 2

WIRELESS SENSOR NETWORKS HISTORY AND BACKGROUNDS

A Wireless sensor Network is defined as a network of devices, named as sensor nodes, which can sense the environment and communicate the information gathered from the monitored physical world (e.g., temperature, volume or light) through wireless connection [4](Figure 1).

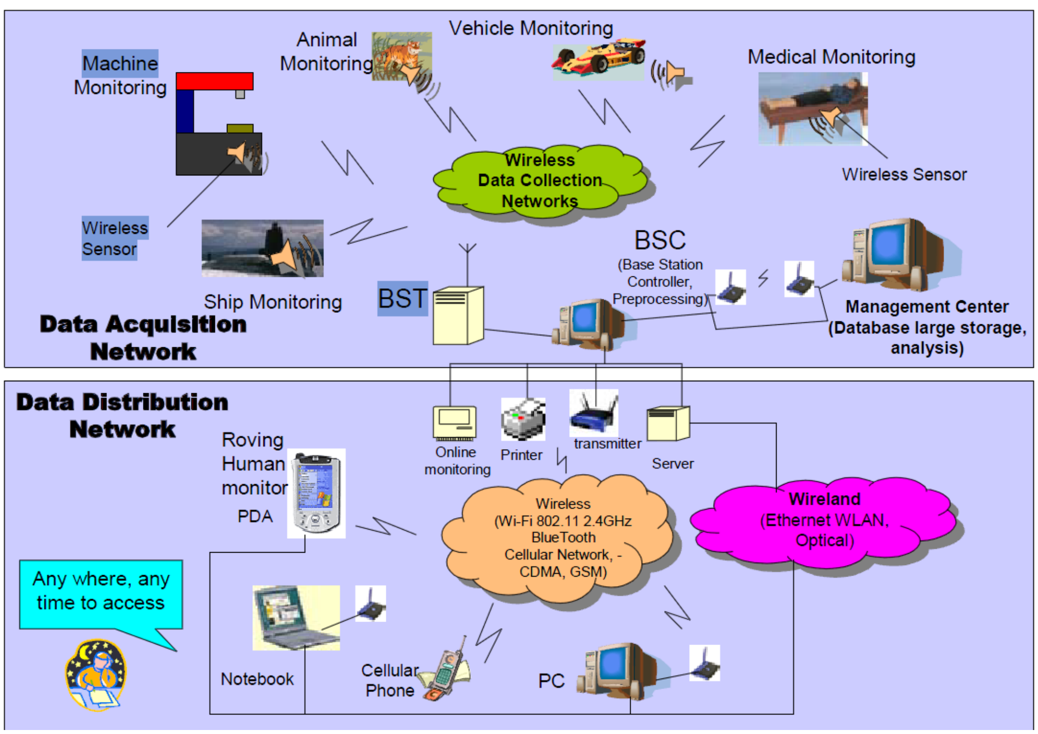


Figure 1: A Wireless Senor Network [4]

2.1 History

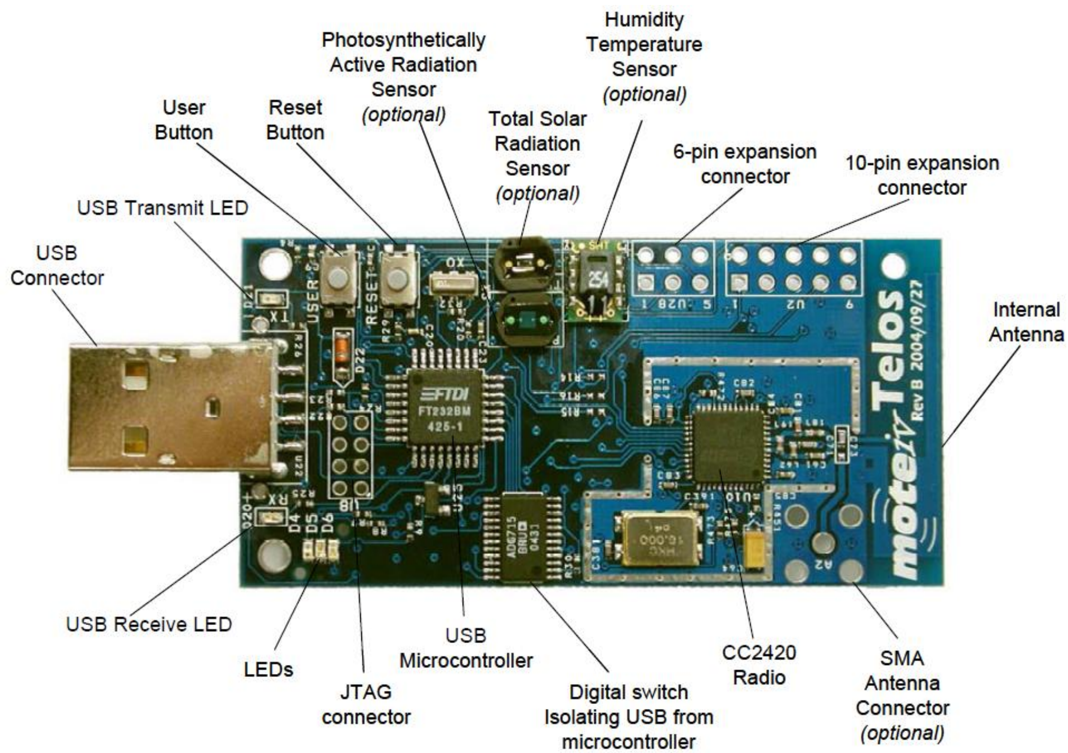
The Distributed Sensor Networks (DSN) program started at the Defense Advanced Research Projects Agency (DARPA) in 1980 and it was the beginning of the researches about the wireless sensor networks (WSNs). By this time, the Advanced Research Projects Agency Network (ARPANET) manages cooperation between universities and research institute for a long time [6]. Distributed Sensor network was proposed to have lots of nodes which are distributed spatially with the minimum cost for sensing and these nodes should collaborated with each other and the operation should be automatically and finally the collected information by each node should be transferred in the best route to basic station. Because of the low level of the computing technology that was near to impossible program in that time. Needed Technology components for a DSN were identified in a Distributed Sensor Nets workshop in 1978 [7].

The DSN technology was limited about the potential application and the size of sensors was not appropriate. Further, the earliest DSNs were not able to connect wirelessly. After the Recent advances in computing, communication and microelectromechanical technology a new significant research have been started and shift DNS technology to WSN research. The next level of the researches about the wireless sensor technology was started in 1998 and these researches attract more researchers and their attention and subsequently this technology has become an international technology. In the new level of WSNs research, the techniques of the networking and processing its information are appropriate for all the ad hoc environments those are highly dynamic [7].

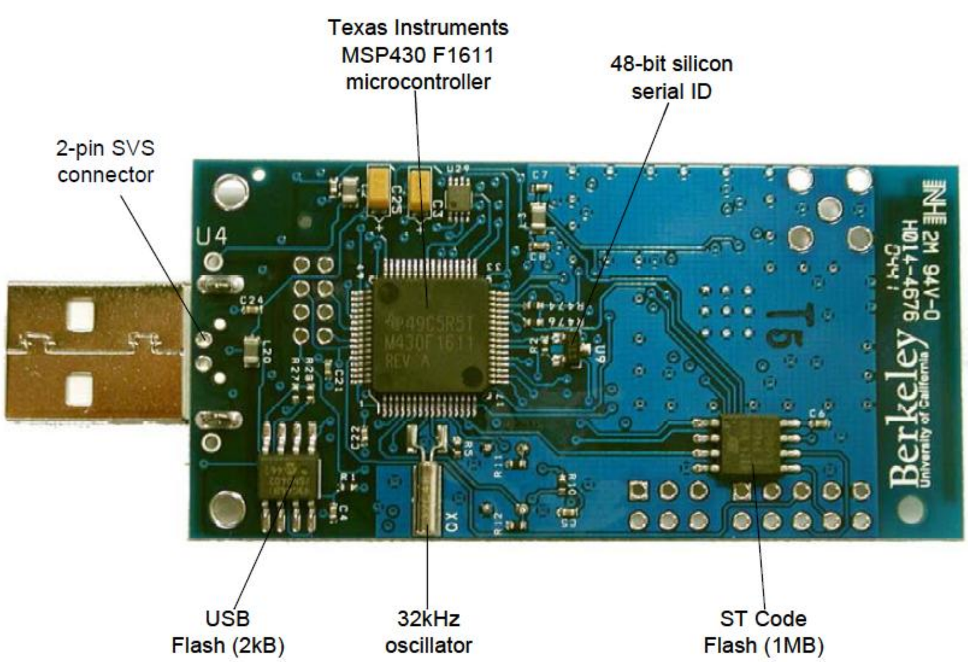
2.2 Hardware Platform

Spatially distributed sensor nodes create a wireless senor network. In a WSN, each sensor node is able sense and processes the sensed data independently. Sensor nodes communicate with each other in order to transfer their sensed data to a central processing unit (gateway) or conduct some local coordination. One of the well-known sensor node platforms is the “Telos rev (B)” developed by Crossbow Technology (Figure 2) [8]. The usual hardware components of a sensor node are:

- Transceiver;
- Embedded processor;
- Internal and external memories;
- Power source;
- Sensors;



a: Front view



b: Back view

Figure 2: Back & Front view of Telos rev (B) sensor node [11]

2.2.1 Transceiver

Wireless communication of a sensor node is under the transceiver responsibility. In most of the WSNs applications, information will be transmitted via Radio Frequency (RF) or Laser and infrared. The operational states of a transceiver are Transmit, Receive, Idle and Sleep. “Telos rev (B)” uses two kinds of RF radios: “RFM TR1000 and Chipcon CC1000”. The outdoor transmission range of “Telos rev (B)” is about 150 meters [7].

2.2.2 Memory

The required storage or program memory for the sensor nodes is so much. Data will be stored for a short time for analyzing and transmitting to the base station. For this reason high capacity of memory is not needed. “In general, modern flash-based microcontrollers contain between 1 and 128 KB of on-chip program storage”. This capacity will be use for the program memory and temporary data storage. In addition for the program execution the data ram between 128 and 32KB is available [9].

2.2.3 Power source

One of the most critical modules in sensor node is power source. In order to have low power consumption network, consumption characteristics and source should be considered together .In most of the cases the power source of a sensor node is a battery and plays an important role in sensor lifetime. The methods for recharging batteries are not applicable for the sensor nodes because most of the time sensors are deployed in harsh or remote environments. In some of the sensor application it is possible for sensors to use the external power source like sun light and wind power and it will increase the sensor node operational time. Some sensor nodes now include multiple power sources to replenish the charge over time like sensors with solar panels. For instance, “Zebranet”, a mobile wireless sensor network, contains a solar array that generates up to 5W, in addition to 14 Sony Li-ion polymer cells [10].

2.2.4 Sensors

“A sensor is a hardware device that produces a measurable response signal to a change in a physical condition such as temperature, pressure and humidity”. The sensed signal by the sensor is in analog mode and by the Analog to Digital (A to D) convertor on the sensor board will be changed to the Digital mode. As next step data will be sent to the embedded processor. Because a sensor node is a micro-electronic device powered by a limited power source, the attached sensors should also be small in size and consume extremely low energy. A sensor node can have one or several types of sensors integrated in or connected to the node [7].

Table 1: The characteristics of common micro-sensors [9]

	Current (mA)	**Discrete Sample (uS)**	**Voltage Requirement (V)**	**Manufacturer**
Photo	1.9 mA	330 uS	2.7-5.5V	Taos
Temperature	1 mA	400 mS	2.5-5.5V	Semiconductor
Humidity	550 uA	300 mS	2.4-5.5V	Sensirion
Pressure	1 mA	35 mS	2.2V-3.6V	Intersema
Magnetic Fields	4 mA	30 uS	Any	Honeywell
Acceleration	2 mA	10 mS	2.5-3.3V	Analog Devices
Acoustic	5 mA	1 mS	2-10 V	Panasonic
Smoke	5 uA		6-12 V	Motorola
Passive IR (Motion)	0 mA	1 mS	Any	Melixis
Photosynthetic Light	0 mA	1 mS	Any	Li-Cor
Soil Moisture	2 mA	10 mS	2-5 V	Ech2o

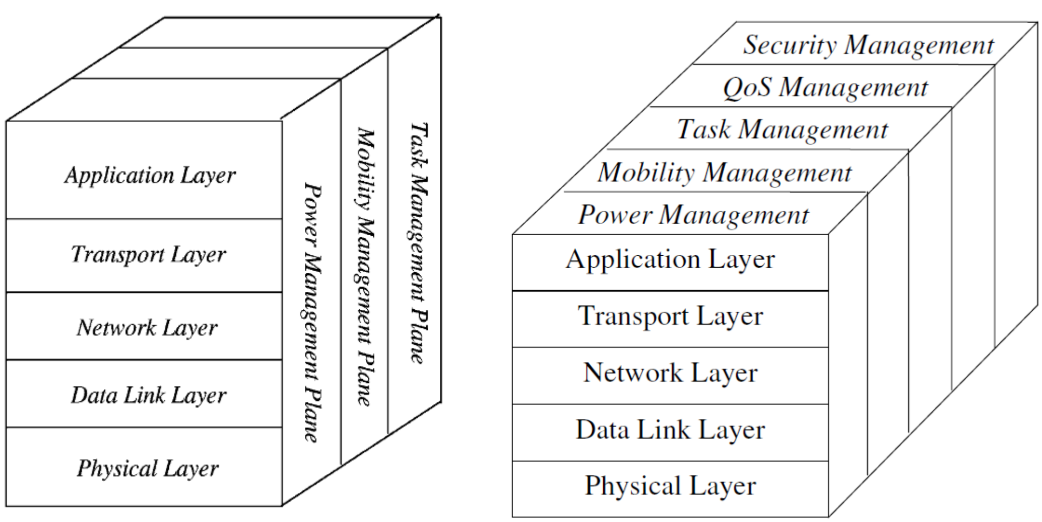
2.3 Tiny Operating System (TinyOS)

Tiny attribute on the tiny operation system is because of that this system is fewer than 400 Bytes but it is so flexible operating system that is built from a "set of reusable components that are assembled into an application-specific system". "TinyOS supports an event-driven concurrency model based on split phase interfaces, asynchronous events, and deferred computation called tasks". TinyOS is implemented in the NesC language [13], which supports the TinyOS component and concurrency model as well as extensive cross-component optimizations and compile-time race detection. TinyOS has caused innovations in sensor network systems and various applications [12].

2.4 Networking

2.4.1 Protocol Stack of WSNs

The senor network protocol stack layers are very similar to the traditional protocol stack (Figure 3):



a: Traditional sensor protocol stack [14]   **b**: WSN protocol stacks [7]

Figure 3: Traditional Sensor and WSN Protocol stacks

The management of Power, Mobility, Task, Quality of System and Security should be considered in order to function efficiently in WSN [15].

2.4.1.1 Power Management

The Power Management Plane is provided for less power consumption and sometimes minimum functionality to save energy.

2.4.1.2 Mobility Management

The Mobility Plane detects and registers movement of node so a data route to the sink is always maintained.

2.4.1.3 Task Management

The sensing tasks will be assigned to the necessary sensor in the sensor field by balancing and scheduling of the task plane and the other sensors can focus their energy on routing and data aggregation.

These management planes monitor the power, movement, and task distribution among sensor nodes. They also help coordinate sensing tasks and routing in order to lower the overall power consumption. Protocols developed for wireless sensor networks must address all three of these planes.

2.4.1.4 QoS Management

Quality of Service (QoS) supports the applications of wireless senor networks. Some of the application have specific QoS requirements but most of them usualy used QoS metrics used to measure network performance are delay, throughput, bandwidth and efficiency of the protocol in use [16].

2.4.1.5 Security Management

Security management in WSNs has become a noteworthy issue because the more dependency on the information provided by the WSN has been increased and also the risk of secure transmission of information over the networks has increased. For the secure transmission of various types of information over networks, several "cryptographic", "steganographic" and other techniques are used [17].

2.4.2 Network architecture

Because of the ascending development in WSNs researches, many applications have been proposed to make use of this technology. With consideration to various applications of WSNs the different requirements from underlying sensor network will be appeared. To address these varying needs, many different network models have been proposed, around which protocols for different layers of the network stack have been designed. The following list named some of the fundamental differences in sensor networks that affect on protocol design and in this way we can classify different WSNs architecture [18].

- Network sinks
- Sensor mobility
- Sensor resources
- Traffic patterns

2.4.2.1 Network sink

The data is transferred, via multiple hops, to a sink, controller or monitor that is possible to use it locally or is connected to other networks (e.g., the Internet) through a gateway. The nodes can be mobile or stationary. They can be aware of their location or not. They can be homogeneous or not.

A traditional single-sink WSN is shown in the Figure 4 left part. In this single-sink the lack of scalability is evident. The Capacity of this sink is limited; by increasing the sensor nodes, the amount of collected data by the sink increases and the sink capacity will be reached. Moreover, for reasons related to Medium Access Control (MAC) and routing protocols, network performance cannot be considered independent from the network size. [4]

In the Figure 4, left side shows multiple sinks as more general sinks in the network. In high level of node density, it is facile to decrease the probability of isolated clusters of nodes that cannot deliver their data owing to unfortunate signal propagation conditions by increasing the number of sinks. In principle, a multiple-sink WSN can be scalable; for instance the same performance can be achieved even by increasing the number of nodes, while this is not possible for a single-sink network.

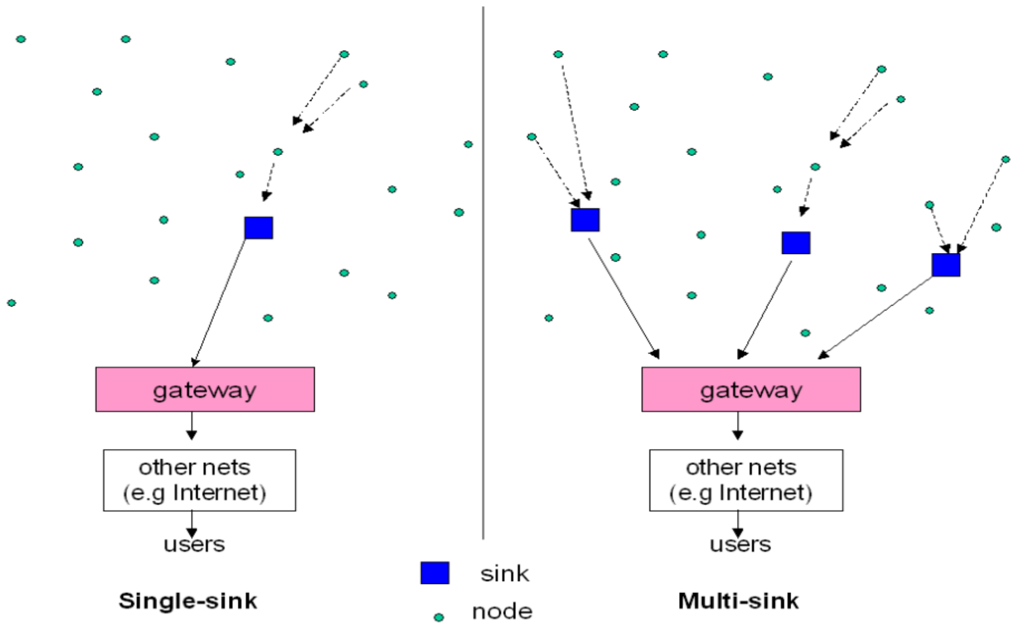


Figure 4: Different types of WSN sink [4]

In most of the cases nodes send the collected data to one of the sinks by selecting one among many, which transferred the data to the gateway, to the end user (Figure 4, right side). This means that a selection can be done, based on a suitable condition that could be, for example, minimum delay and number of hops, maximum throughput, etc. Therefore, the presence of multiple sinks guarantees better network performance with respect to the single-sink case, but the communication protocols are more complex and should be designed according to suitable criteria [4].

2.4.2.2 Network Mobility

In recent years, mobility for data collection has been proposed as approaches exploiting in WSNs .These approaches can be categorized with respect to the properties of sink mobility as well as the wireless communication methods for data transfer [19]:

2.4.2.2.1 Solutions based on mobile base station

“An MBS is a mobile sink that changes its position during operation time. Data generated by sensors are relayed to MBS without long term buffering.”

2.4.2.2.2 Solutions based on mobile data collector

“An MDC is a mobile sink that visits sensors. Data are buffered at source sensors until the MDC visits the sensors and downloads the information over a single-hop wireless transmission.”

2.4.2.2.3 Solution based on Rendezvous

“Rendezvous based solutions are hybrid solutions where sensor data is sent to rendezvous points close to the path of mobile devices. Data are buffered at rendezvous points until they are downloaded by mobile devices”.

2.4.2.3 Sensor resources

Sensor nodes in the computing resources are often different .It is clear that memory and processing limitation should influence protocol design at each level.

2.4.2.4 Traffic patterns

Another considerable parameter is the traffic generated on the network. In most of the “evenr-driven” application sensors may operate in specific time and generate data traffic will be generated when an event of interest detected. In other applications such as environmental monitoring, data should be continuously generated.

Chapter 3

APPLICATION OF WIRELESS SENSOR NETWORKS

3.1 General applications of Wireless Sensor Networks

Different types of sensors such as seismic, low sampling rate magnetic, thermal, visual, infrared, acoustic and radar, are available to monitor a wide variety of data that include the following [5]:

- Temperature,
- Humidity,
- Vehicle motion,
- Lightning condition,
- Pressure,
- Soil makeup,
- Level of noise,
- Object monitoring.
- Objects mechanical stress testing,
- Speed, direction, and size of an object and etc.

Nowadays sensor nodes are using for continuous sensing, event detection and event ID, location sensing, and local control of actuators. Many new application areas will be create by using micro-sensing and wireless connection. In this thesis applications of WSN are categorized into military, environment, health, home and other areas. [14]

3.1.1 Military applications

The most popular applications of wireless sensor networks in military are target detection, classification, identification and tracking. The launch of missiles detection and other weapons by an enemy is of great interest. [20]

3.1.1.1 Battle-damage assessment

Effectiveness determination of weapons employed by the military is Battle-damage assessment. Unmanned aerial vehicles can carry on Imagers and other wireless sensors and they are especially useful for the military.

3.1.1.2 Battlefield surveillance

All militaries services are interested in force protection, battlefield surveillance, and command and control. Local WSN and networks are expected to play a role in improving all of these functions.

3.1.1.3 Communications

Navies are interested in underwater communications between ships and submarines and between instrumentation and facilities on shore. Wireless Sensor information can be transmitted by underwater phones and data links that are in routine use. While in comparison of Radio Frequency (RF) in air the bit-transmission rates are low, a great deal of data can be transmitted over time.

3.1.1.4 Monitoring

Remote Readiness Asset Prognostic and Diagnostic System are developed by U.S Army, to monitor the conditions within missile and munitions canisters. Temperature, humidity, shock, vibration, and, possibly, other factors will be monitored by a “wireless hand-held interrogator”. It has also the ability to monitor the conditions of rail cars, trucks, and shipping containers.

The Armies are going to developing a “War fighter Physiological” Status Monitoring System to report on the condition of soldiers in the field with WSN. It has much similarity with medical monitors, but will be concerned with performance as well as health matters. Maximize operational effectiveness while reducing casualties and Keeping track of things are the system goals. Identification and sensing systems, which report the locations and conditions of military goods and vehicles automatically to a field or other headquarters command, are under development.

3.1.2 Environmental applications

Applications of wireless sensor networks in Environment include: [20]

• Monitoring the behavior of organisms,

• Monitoring environmental conditions,

• Irrigation of farm lands

• Earth monitoring,

• Chemical/ biological detection,

• Accuracy in agriculture,

•Under water earth, and environmental monitoring,

• Soil, and atmospheric fields,

• Forest fire detection,

• Meteorological or geophysical research,

• Flood detection;

• Bio-complexity mapping of the environment;

• Pollution study.

3.1.2.1 Monitoring the behavior of organisms

It is difficult to achieve practical and reliable animal monitoring with current conventional technologies due to challenges such as large grazing areas of organisms (Figure. 5), long time periods of data sampling, and constantly varying physical environments. WSN increase the possibilities of this area with the potential for greatly increased spatial and temporal resolution of measurement data. “Commonwealth Scientific and Industrial Research Organization” (CSIRO) has created a wireless sensor node for animal behavior monitoring where we are able to collect all kinds of information of animals without any significant harm for them. With this node monitored information, we are able to identify each animal’s behavior and activities successfully. [21]

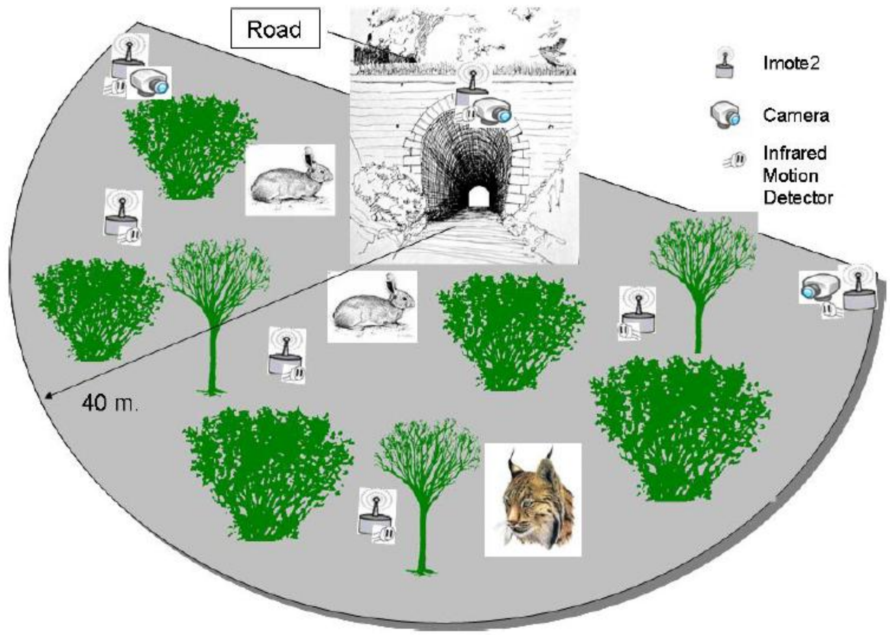


Figure 5: Grazing area to analyze the behavior of animals [22]

3.1.2.2 Forest fire detection

Forest fires, or wild fires, are fires without any control in wild areas and cause significant damage to natural and human resources. Forest fires destroy forests, burn the infrastructure, and cause human death near urban areas. Lightning, human fire, not enough isolation for fuel tanks against heating and aridity are most of the famous forest fire reasons . Some of the causes of fire are inevitable and they are parts of the forest ecosystem and they are important to the life cycle of indigenous habitats.

Forest fire detection system (Figure 6) should have immediate response in order to minimize the scale of the disaster. This requires permanent surveillance of the forest. Current fire surveillance systems are not able to detect fire on time and they have low resolution and long period of scan. Therefore, there is a need for scalable solutions that can provide “real time fire detection” with high accuracy. WSNs can potentially provide such solution. Recent advances in WSNs support this idea that they make a promising framework for real-time forest fire detection systems. Current sensor nodes can sense a variety of phenomena including temperature, relative humidity, and smoke which are all helpful for fire detection systems. [23]

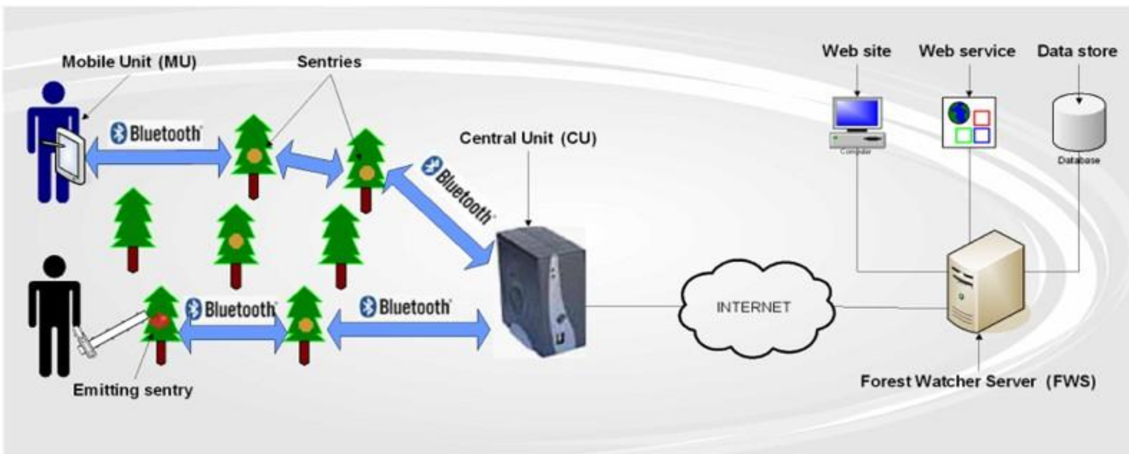


Figure 6: Forest fire detection system [24]

3.1.2.3 Mapping of the environment

3.1.2.3.1 Contour mapping

Contour mapping is a general method to visualize sensor fields. “A contour map of an attribute (e.g., height) shows a topographic map that displays the layered distribution of the attribute value over the field” (Figure 7) [25].

Background information for the sink is provided by contour mapping to detect and analyze the events of environment in a global view of the features in the field. Such a view is often difficult to achieve by individual sensor nodes with constrained resources and insufficient knowledge.

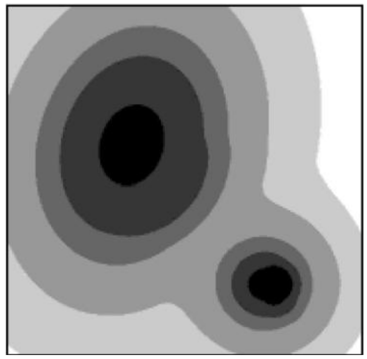


Figure 7: Contour mapping by WSN. A section of underwater depth measurement [25]

3.1.2.3.2 Biocomplexity mapping

Complex methods are required to integrate information across temporal and spatial scales and finally obtain “Biocomplexity” mapping of the environment (Figure 8). By utilizing the WSNs technology and remote sensing and automated data collection the cost of biocomplexity mapping with higher spatial, spectral, and temporal resolution for per unit area will be decrease. It is facile to connect the sensor nodes to internet, which allows remote users to control, monitor and observe the biocomplexity of the environment. [14]

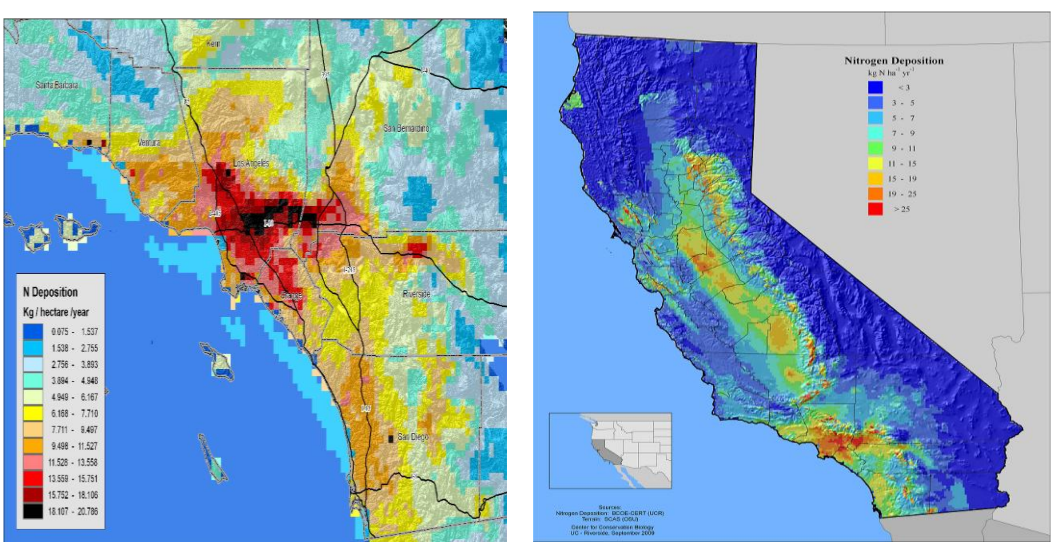


Figure 8: Nitrogen deposition map for Southern California in 2002. Data collected by chemical WSN [26]

3.1.2.4 Flood detection

The flood "ALERT system" has been deployed in several US states since two last decades [27]. There are different types of sensor nodes in a typical flood ALERT installation field such as rainfall sensors, water level sensors, weather sensors, etc. A predefined set of data is collected by each sensor node, transferred to a central site and stored in a database station. Results will be available graphically by database system. [58]

3.1.2.5 Precision Agriculture

Monitoring is one of the most important applications of WSNs in agriculture. Because of the global climate changing, not only a wide range of research and study of the crop growth is needed, the small scale environment for the growth of crops needs to be understood. Monitoring the environmental parameters of crop growth provides scientific guidance and countermeasures for agricultural production. An environmental parameter model of different regions of crop growth pattern of different environments can be established to improve the overall efficiency of agriculture [28].

The monitoring system contains two types of nodes those collects meteorological and soil information such as temperature, humidity, wind, air, rainfall, soil ph and so on. The image capture platform obtains crop growth images. The growth of crops and growing conditions can be observed directly. A large number of nodes form the agricultural condition monitoring sensor network, and then access to the internet.

3.1.3 Health applications

Wireless senor networks play an important role in human health. The quality of health care across a wide variety of settings and for different parts of the population will improve by utilizing the WSNs. For instance tracking and monitoring doctors and patients inside a hospital, Drug administration and detect elderly people's behavior [14] are just some of several famous applications of WSNs in health. [17]

3.1.3.1 Hospital staff and patients tracking and monitoring

Sensor nodes should attach to each patient (Figure 9) or doctor and the sensor task for the doctors and patients are different. For example, one sensor node may be sense the heart rate while the other one is detecting the blood pressure. WSNs localization determines doctor's coordination for the other doctors within the hospital. [14]

3.1.3.2 Drug administration in hospitals

By attaching the sensor nodes to the medicines, error in prescribing the wrong medication to patients will decrease and can be minimized, because, patients will have sensor nodes that identify their allergies and required medications. [14]

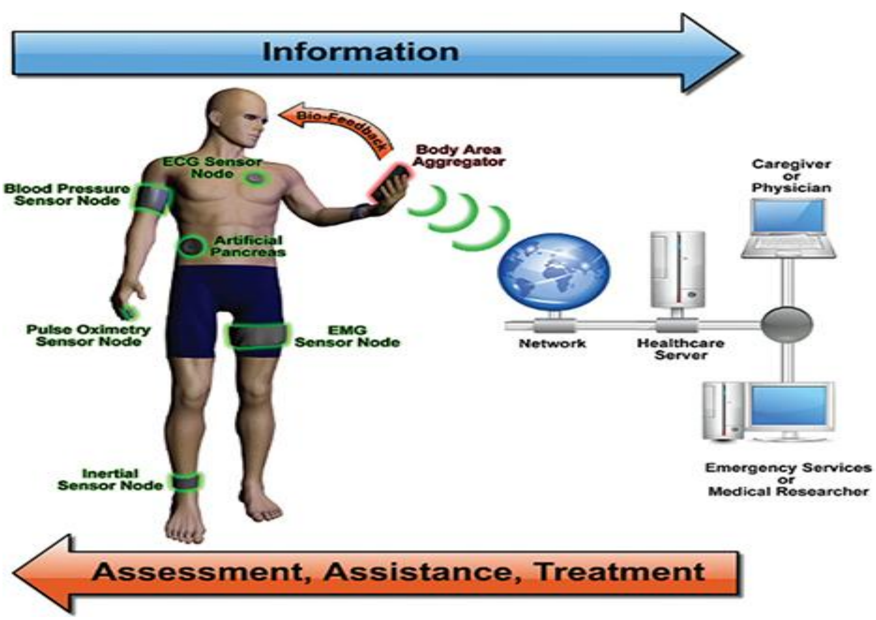


Figure 9: WSN for a patient or doctor to monitor the physiological condition or coordination. [30]

3.1.4 Home applications (Home automation)

The Home Automation system provides connection between various electronic, electrical, and power devices to have interoperability as well as human being to control their operation by each other. These system effects on the energy consumption and it is so helpful to saved energy and make more money. By implementing this system in home, people’s life become so easy, especially for elderly persons and persons with disabilities [31](Figure 10).

Figure 10: A Smart Home wireless sensor network system [32]

3.1.5 Other applications

Some of the commercial applications are [14]:

• Monitoring material fatigue;

• Virtual keyboards;

• Inventory management;

• Quality control;

• Smart offices;

• Environmental control in office buildings;

• Robot control and guidance in automatic manufacturing environments;

• Healthy toys;

• Interactive museums;

• Factory process control and automation;

• Smart structures;

• Machine diagnosis;

• Transportation;

• Factory instrumentation;

• Local control of actuators;

• Detecting and monitoring car thefts;

• Vehicle tracking and detection;

• Instrumentation of semiconductor processing chambers,

3.2 Application of Wireless Sensor Networks In manufacturing

WSNs are utilizable for two main applications in manufacturing; event detection or data collection. In event detection, sensors can detect rare, random, and ephemeral events, such as alarms and faults when an important change happens in machine, process, system security, operator actions, or instruments. On the other hand, data collection is required for operations such as tracking of the material, parts and machines, health monitoring of equipment, process or labors. Such monitoring and control applications reduce the cost, human errors and prevent costly manufacturing downtime [2].

Wireless senor network nowadays is one of the most noteworthy cases in manufacturing because this technology makes the engineers able to acquire and control the real-time data of the factory at anytime in anywhere. Figure 11, shows the importance of WSNs in the environment with multiple networks.

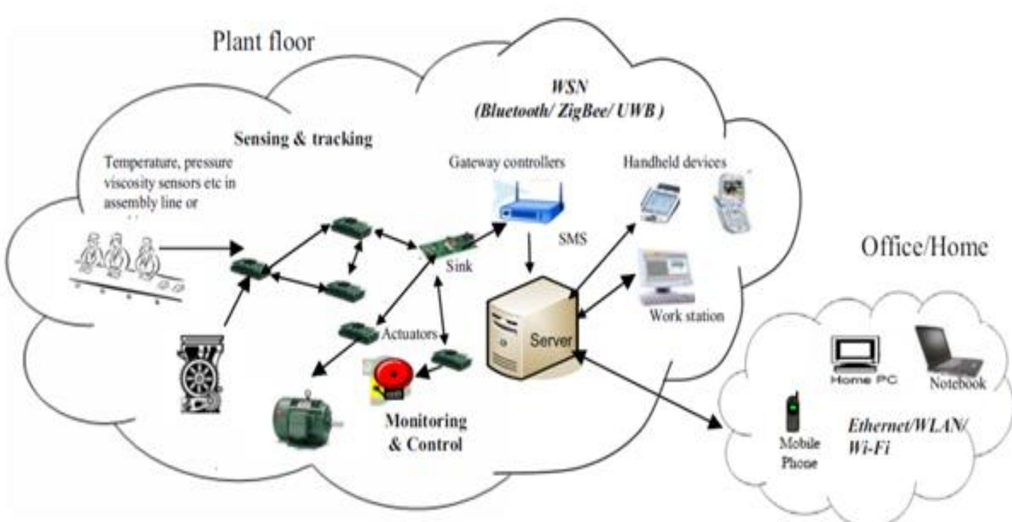


Figure 11: Wireless senor networks in manufacturing [2]

By using the wireless sensor networks, process control and maintenance systems are able to send real-time data to the server and this server can be connected to the internet and sent data via SMS or emails to the responsible person in the office or remote location. Combining some short range communication technologies like Zigbee or Bluetooth into the automation system will enable the engineers to collect and control real time sensors or actuators data from the shop floor, and by internet some mobile devices such as mobile phones, PADs or laptops are able to connect with the outside of the factory [2].

3.2.1 Industrial robots

Recent improvement in robotic technology has increased the usage of mobile robots. However, mobile robots have still problem in detecting the physical world and environment perception because of the dynamic change of workspace and lack of information. It is not possible to recognize the physical world that is contained human labors and other moving objects, just by using collected data from a sensors embedded to robot. Utilizing wireless senor networks in workspace will improve the robot environment perception ability and self-localization [33].

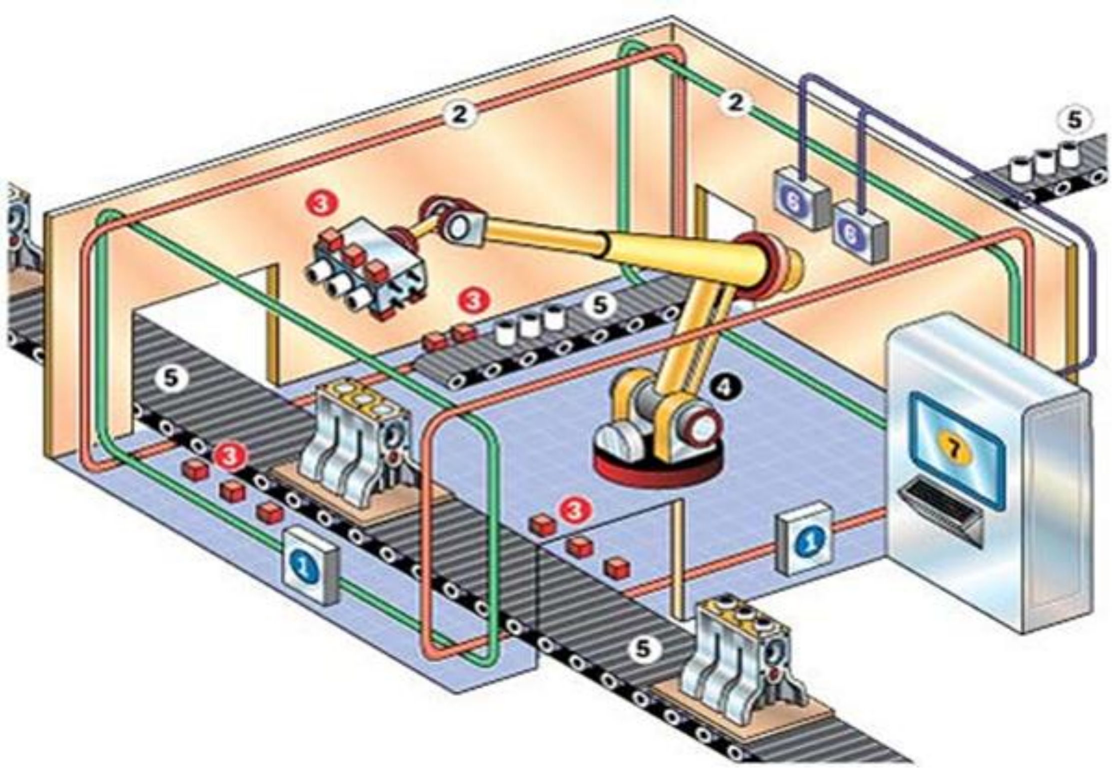


Figure 12: Robot in engine assembly line with wireless sensor network [34]

This engine assembly manufacturing cell is an example for application of wireless sensor networks for industrial robots (Figure 12). The system has four primary loops (2) installed around the manufacturing cell (two green and two orange). Two power supplies (1) connect to these loops to produce magnetic field throughout the manufacturing cell. Wireless senor nodes (wireless proximity switches) (3) within the small coils that gain the energy from the magnetic field and convert it to electric power. The sensors also have small radio transceivers and low-power supply that produce the wireless communication link. The sensors send data to an input module (7) via antennas (6) installed in the cell. This input module is look like a traditional wired input module. It can handle up to 60 wireless proximity switches simultaneously and is connected to the control system [34].

3.2.2 Real-time inventory management

The old fashioned manual inventory management systems may cause different problems such as "out-of-stocks", "expedited shipments", "production slowdowns", "excess buffer inventory", and "billing delays situations". By equipping the manual process inventory management system with wireless sensor network technology, it is possible to monitor the inventory in real time and all the information such as the arrival of the raw materials could be collected across a distant to the gateway or control system for management decision and control [2].

Inventory management for packaged gases is one of the applications of WSNs in inventory management. Gas cylinders have different application with different situation, such as in research, in industry, in healthcare, and even in the home. Because of the variety of circumstances, it is really serious for gas factories to improve the efficiency of their business. One of the most important cases to improve the efficiency in such factories is tracking system to this end, a tracking system .Wireless senor network is the best solution to installed on gas factories tracking system and improve its efficiency. This system is contained different key components; ID tags and relay nodes, a Graphical User Interface (GUI) with an associated base station, and a Hand Held Unit (HHU).As it shown in Figure 13 Each gas cylinder requires identification and so should be tagged; the tags in this system are Mica2 motes [35].

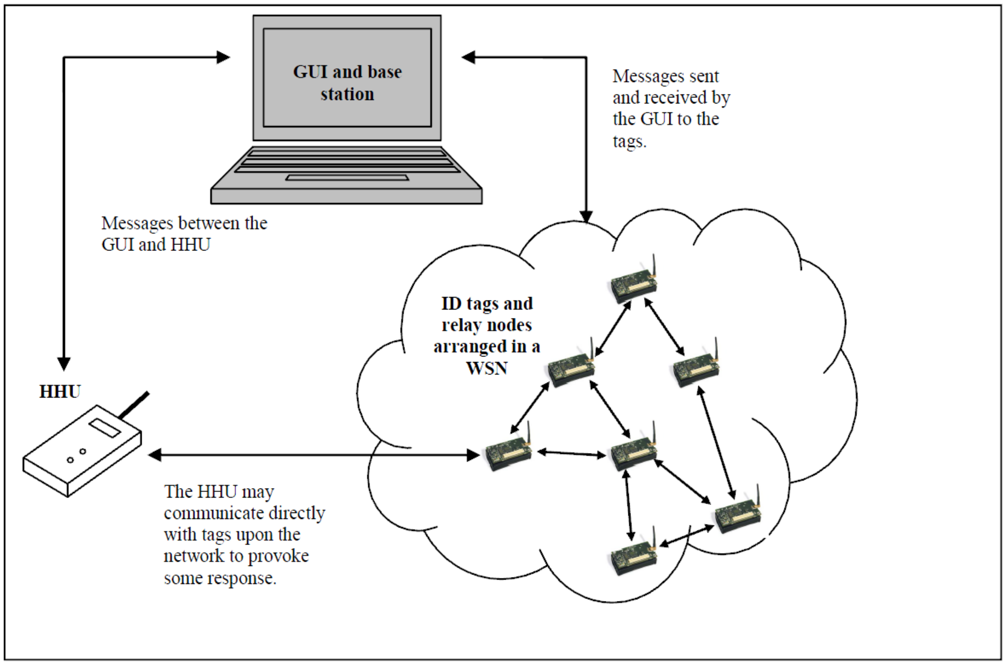


Figure 13: Inventory management system for packaged gases [35]

General Motors is another well known factory which implements a real-time inventory tracking system by utilizing the WSNs. First step for inventory tracking process is starting from the suppliers of the components, second step is in the factory and in the assembly and the last step is the company to the costumer. Real time inventory tracking with help of wireless senor network improves the visibility and location of material and also reduce the cost and theft and makes it possible to find the equipment immediately and increase the efficiencies of supply chain ultimately [36].

3.2.3 Process and equipment monitoring

One of the applications of WSNs in manufacturing is remote monitoring the process, tools and equipments to have the healthy machinery. The cost of the failures, maintenance because of the inappropriate machinery will be reduced by monitoring the necessary items such as temperature, pressure, vibrations and power usage etc continuously [2].Figure 14 shows the schematic of the WSN monitoring system.

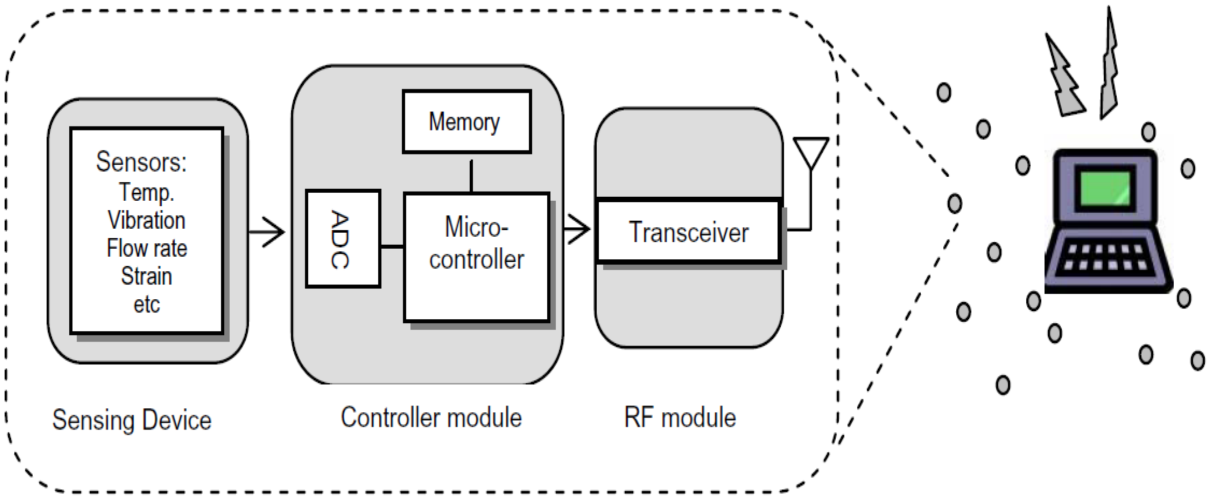


Figure 14: Schematic of the monitoring system based on WSN [2]

General Motor utilized the monitoring system which is integrated by wireless sensor network technology to monitor the manufacturing equipment like the conveyer belts. Vibration, temperature and some other necessary factors will measure by the WSN and then transmitted to the computer. By real time collecting data and information from the equipments, the engineers could forecast machine's failure, mean time to failure and perform "pre-emptive" maintenance. The collected data also facilitates future improvement and faster repair of equipment from the data collected [36].

Intel Company also uses this technology to monitor some equipment. "Eco Sense" is the name of project that is deploying smart maintenance system that uses wireless sensor network to monitor the health of semiconductor fabrication equipment. By utilizing this system it is facile to monitor the vibration signature of water purification equipment real time [37].

3.2.4 Environment monitoring

Wireless sensor network can be useful to detect leakage, radiation and intrusion in industry. The collected data could be sent to the operating managers as emergency alerts to request immediate preventive actions. Toxic, biological, radioactive gas or substance will be tracked throughout the facility by wireless sensor networks [2].

Leakage of danger gases and liquids such as flammable liquids ammonia gas, chlorine gas etc in the oil and gas refineries can cause heavy loss, risks for public and hazardous emissions to the environment (Figure 15). Most of the oil and gas companies are now utilize WSNs and plan to deploy widely in near future [38].

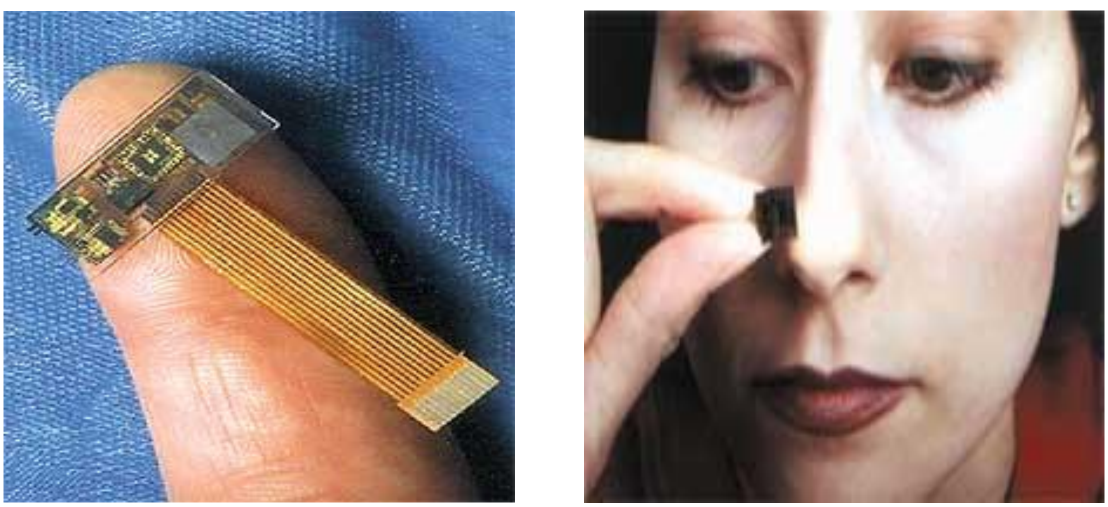


Figure 15: “Nose-on-a-chip” is a gas detector senor and it can detect more than 400 kinds of gases and send signal to a basic station [39]

Chapter 4

LOCALIZATION OF WIRELESS SENSOR NETWORKS

Localization or location estimation ability is one of the most important cases in the wireless sensor network applications. In environmental applications such as animal habitat monitoring, forest fire detection, water quality control and precision agriculture, the measurement data are meaningless without an accurate knowledge of the location from where the data are obtained. In addition, the availability of location information may enable lots of applications such as smart home management, flood detection, road traffic monitoring, health monitoring, reconnaissance and military.

Coordination of an unknown sensor in Wireless sensor networks will be estimated by using localization techniques. Some specific sensor with defined location (anchor) will be used to measuring different items such as distance, time difference of arrival, angle of arrival, connectivity and received signal strength (RSSI) between unknown sensor and anchors. Localization techniques for WSNs are not similar to traditional techniques like GPS or radar-based geolocation techniques. They cover more challenges in different applications [40]:

(1) A variety of measurements;
(2) Complicated WSN fields, involving urban environments, indoor environments and non-line-of-sight conditions;

(3) Limitation in wireless senor networks capability.

(4) For implementing localization techniques of WSN, minimum hardware investments are needed and available measurement methods should be utilized.

(5) These techniques should be able to deploying in the multi-hop network and in large scale.

(6) Cost, size and localization accuracy are often considerable in localization techniques to make the WSN suitable for different application requirements.

4.1 Measurement techniques

Localization of wireless sensor networks depends on measurements. The localization algorithm to be used for a specific application, , the network architecture, node degree ,accuracy of the estimated, network area geographic shape, will be affected by many factors. “However, it is the type of measurements employed and the corresponding precision that fundamentally determine the estimation accuracy of a localization system and the localization algorithm being implemented by this system”. Measurements also determine the type of algorithm that can be used by a particular localization system [40].

4.1.1 Angle-of-arrival measurements

In angle-of-arrival (AOA) measurement, the angle between the reference direction which is named as orientation and the distribution direction of a wave is measured. The direction of the orientation is fixed during the measurement and it is represented as degree and in clockwise direction from the North. To obtain the angle-of-arrival there are many approaches but the most famous one is using the array of an antenna on each node. By using the explained method unknown nodes without any information about their orientation can obtain the angle-of-arrival between the other nodes in neighboring. [40].

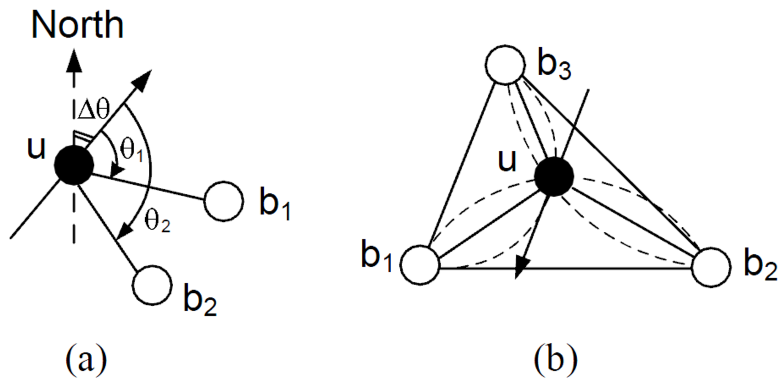


Figure 16: (a) Localization with orientation (b) Localization without orientation

Sometimes orientation of unknown node is not known when they are distributing. First we imagine orientation of the unknowns is known. In Figure 16(a), θ1 and θ2 are angles related to unknown node named as u, and each of them are related to the angle-of-arrival of the sent signal by known node b1 and b2. The angle of arrival from b1 and b2 is obtained by adding the orientation of unknown node (Δθ) to its angle from each of b1 and b2 (θ_i). The location of the unknown node is restricted by each absolute AOA measurement corresponding to an anchor along a ray starting at the anchor. Finally the unknown node u location will be defined where all the rays intersect each other in same point with existing two or more anchor in non-collinear design[41].

When the orientation of the unknown nodes is not available, the different AOA can be use instead of the absolute AOA. In Figure 16 (b), by using the AOAs those are related to the angles *b*1*ub*2, *b*1*ub*3 and *b*2*ub*3 it is possible to compute all of the angles. The other angles are ignored. Because of the same chord between them they are equal together. For example in Figure 16 (b) position of u is restricted on the arc passing through the b1, b2 and u by the angle between the b1and b2 and also the chord between them. The location of an unknown node is on the intersection of all the chords since they are non-collinear anchors and each of the chords determine on the arc[41].

4.1.2 Distance related measurements

All the Distance related measurements are based on propagation time measurements and they are categorized to:

1- Measurements based on the time for one-way propagation;

2- Measurements based on the time for Roundtrip propagation;

3- Measurements based on time difference-of-arrival (TDOA);

4- Measurements based on receive signal strength (RSS) ;

4.1.2.1 One-way propagation time measurements

One-way propagation time measurements compute the elapsed time between sending the signal by transmitter and receiving the signal by receiver and convert it to distance. It is important that the local time for the transmitter and receiver should be same and accurately synchronized. One of the disadvantages of this method which makes it a less attractive than the other methods is cost of sensor with accurate clock or a sophisticated synchronization mechanism [42].

4.1.2.2 Roundtrip propagation time measurements

Roundtrip propagation time measurements measure the time for sending the signal by transmitter of anchor node to the receiver of unknown node and again sending the signal by transmitter of unknown node to the receiver of anchor node and by converting this time the distance will be defined. In this measurement if a same clock is used for measuring the time for roundtrip propagation the synchronization problem won't be happen. The most important error in this measurement is the delay time related to handeling the signal in another sensor [42].

4.1.2.3 Time difference-of-arrival (TDOA) measurement

The time-difference of arrival measurement considers the difference of the arriving time between the anchor nodes without any synchronization problem. However, in order to get the TDOA measurement, one TOA measurement is subtracted from another, which makes the noise signals corrupting different TDOA measurements correlated [42].

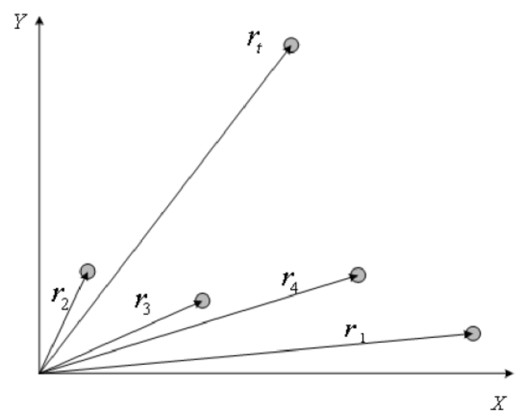


Figure 17: Localization using time-difference-of-arrival measurements [42]

Figure 17 shows a TDOA localization scenario. In this figure four receiver at different locations r_1; r_2; r_3; r_4 receive signal from the transmitter at r_t .The TDOA between a pair of receivers i and j is given by:

$$\Delta t_{ij} = t_i - t_j = 1/c\,(\lVert r_i - r_t \rVert - \lVert r_j - r_t \rVert),\ i \neq j \quad (1)$$

4.1.2.4 RSS measurements

RSS measurements measure the received signal strength between neighboring sensors and convert it to the distance. Received signal strength indicator (RSSI) is the base of RSS measurement techniques that is the available standard feature in most of the wireless devices. It means to define the location of an unknown node, the RSS of that sensor node to an anchor node should be measured and then it is facile to calculate the distance between them. This technique is really considerable because it requires no additional hardware, and no needing more local power consumption, sensor size and thus cost [40].

According to the Friis equation receiver power is depends on distance and in the free space the other varies related to the RSS are not considered and just the inverse square of the distance between the transmitter and the receiver is [43]:

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2\, d^2} \qquad (2)$$

Where the transmitted power is P_t, the transmitter antenna gain is G_t, the receiver antenna gain is G_r and the wavelength of the transmitter signal in meters isλ.

In real world free space model is not a true model and is a ideal model because in the real space the propagation of a signal is affected by many items like reflection, diffraction and scattering and all these affects are depend on environmental factors i.e. indoors, outdoors, rain, buildings, etc.

$$P_r(d)[dBm] = P_0(d_0)[dBm] - 10n_p\log_{10}\left(\frac{d}{d_0}\right) + x_\sigma \qquad (3)$$

Where P_0 (d_0)[dBm] is the known power value as a reference with dB unit in milliwatts and d_0 is the distance to transmitter as reference, n_p is the path loss exponent and measures decreasing of the RSS rate along the distance. This value highly depends on environment; X_σ is a zero mean Gaussian distributed random variable with standard deviation σ [43].

4.2 Categorization of network localization algorithms

Generally, localization algorithms are utilizable for sensor network which contain a large number of densely distributed nodes. Most of the time , in the network whit a few distributed nodes these algorithms are not utilizable. Localization algorithms can be classified into the following four categories [44]:

1- Algorithms based on presence or absence of nodes with pre-configured coordinates

2- Algorithms based on the way node locations "propagate" in the network

3- Algorithms based on the "granularity" of information acquired by the sensors during communication.

4- Algorithms based on computational distribution

5- Other algorithms

4.2.1 Algorithms depends on nodes with configured coordination

4.2.1.1 Anchor- based algorithms

Anchor nodes are sensor node with known position either through manual configuration or using GPS in the network and anchor-based algorithms operate on an ad-hoc network with a few anchor nodes. In these kinds of algorithms the goal is to define the position of many unknown nodes by using the position of anchor nodes. In the algorithms based on anchor nodes the accurate location system will be obtained where accurate node position is available, for example, latitude, longitude, and altitude. The accuracy in this algorithms is depends on the distribution of anchor nodes and their numbers in the sensor field [45].

4.2.1.2 Anchor- free algorithms

In anchor free algorithms the assumptions are regarding to relative positioning instead of the positioning in the coordinate system which is based on reference nodes. Sometimes the relative positions of the nodes are enough for comparison with each other. In 2D systems three separate “non-colinear” nodes with known coordinates and for 3D systems four nodes are needed to transform a relative coordinates system to absolute coordinates system. In these algorithms the position of the fix node should be recomputed when the reference node moves. When the sensor nodes are fixed in the network, the moving reference node will be the most considered problem [45].

4.2.2 Algorithms based on propagation of way node in the network

4.2.2.1 Incremental algorithms

In these algorithms nodes are distributed in the same time so that each node will use the collected information by the previous node to obtain its own location [46]. These algorithms start with three or more node with known coordinate as reference node. Other nodes in the network can use the information of the reference nodes and determine their own coordinates. When the unknown node determines its own position it can become a reference node for the other unknown nodes. In order to obtain the position for all the nodes in the networks this process will be continued incrementally [44]. The aim of this algorithm is covering the whole network and also each node should be visible for minimum one node in the network and this algorithm should ensure that this visibility is satisfied

4.2.2.2 Concurrent algorithms

Achieving the location for all the sensors in concurrent algorithm is based on communication of many pairs of sensors and shares the measurements. Besides defining the position for each sensor node all sensor positions are simultaneously estimated in the same time. In this localization system a sensor node with unknown location is not allowed to make measurement with a node with known location as reference point and they can make measurement just with the other unknown nodes [44].

4.2.3 Algorithms based on granulation of information obtained by the sensors during communication.

4.2.3.1 Fine-grained algorithms

Most of the fine-grained algorithms estimate the location of unknown node by using some detailed information such as distance or angle between them. Trilateration and triangulation are two approaches for the location estimation of an unknown node with presence of three sensor nodes with known location. In order to gain fine-grained localization, a sensor node typically should contained special hardware and often “extensive computational resources”. The most famous fine-grained approaches are given below [47]:

1- Angle of Arrival (AoA)

2- Time Difference on Arrival (TDoA):

3- Radio Signal Strength (RSS):

4.2.3.2 Coarse-grained algorithms

These algorithms are less accurate than fine-grained algorithms and they utilize information, such as “proximity” to a given reference point with minimum accuracy. Coarse-grained algorithms estimate the distances between the nodes in the network by using some unusual techniques such as “hop-count”. In a WSN, the number of hops is equal to the number of edges between the source node and destination node to have the shortest way to transfer the signal. For example, in Figure 18 the number of hops between nodes j and n is 2 [44].

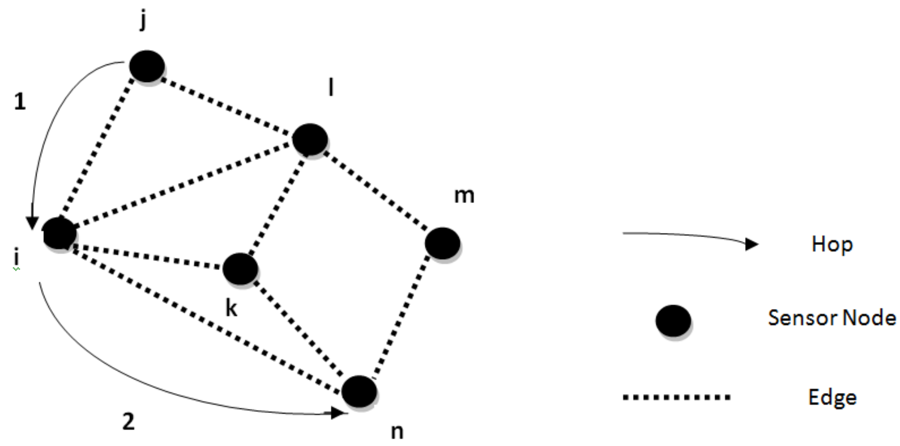


Figure 18: Scheme of 'hop-count' in a sensor network

4.2.4 Algorithms based on computational distribution

4.2.4.1 Centralized algorithms

Sensor nodes collect data from environment and transfer it to a base station for analyzing, after computing the position in base station, information will transfer again into the network. In these algorithms computing is performed by a centralized nodes or network device. All the other nodes broadcast information to a single computer to define the location [44][48].

Centralization algorithms are able to do more complex mathematics than is possible in a distributed algorithm. The most important difference between centralized algorithms is the type of processing they do at the base station [48].

4.2.4.2 Distributed algorithms

In this algorithms computing distributed between the nodes in the network equally. Each node receives information about the estimated location from the other nodes in its neighboring, performs computation and transmits the obtained results to them.

4.2.5 Other algorithms

4.2.5.1 Assumption based coordination (ABC) algorithms

The Assumption Based Coordinates (ABC) algorithms are incremental and anchor-free algorithms and determine the locations of all unknown nodes one at a time if they establish communication, making assumptions, and correcting the errors and redundant calculations as more information becomes available. In these algorithms in 2D, two and in 3D, three nodes with assigned coordinate are needed to determined the inter-node distance with a node that is located at the origin of local coordinate system. Figure 19 shows the necessary assumption to have such a local coordinate system.

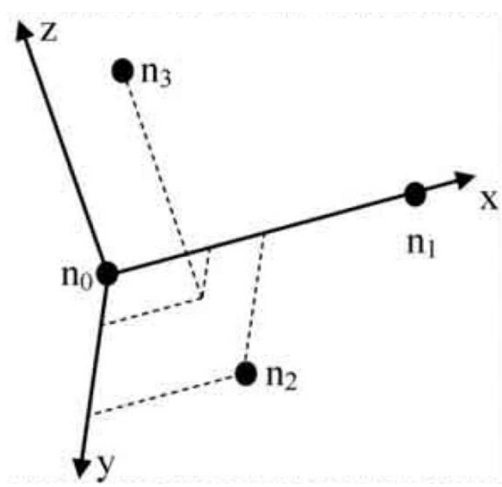


Figure 19: local coordinated system around node n0

Where we assume:

1- n_0 is located at the origin of local coordinate system

2- n_1 is located along the x-axis

3- n_2 is located on positive direction of y-axis

4- n_3 is located on positive direction of z-axis

For any new node with unknown location it is facile to calculate its coordinate by using the distances to $n_{0,}$ $n_{1,}$ $n_{2,}$ n_3 with already known coordinates. Trilateration problem is the most accurate solution to defining the position for an unknown node according to the distances to the reference nodes [49][44].

Chapter 5

TRILATERATION LOCALIZATION METHOD

One of the most basic methods in localization of WSNs is Trilateration. This method estimates the position of unknown nodes by using the intersection of minimum three circles (Figure 20). To utilizing this method three nodes with known position are required and the distance to unknown node for each of them should be measured. Imagine 3 circles which the center of each is one of the known nodes and the radius of each is the distance to the unknown node. So the intersection of the circles is the location of unknown node [50].

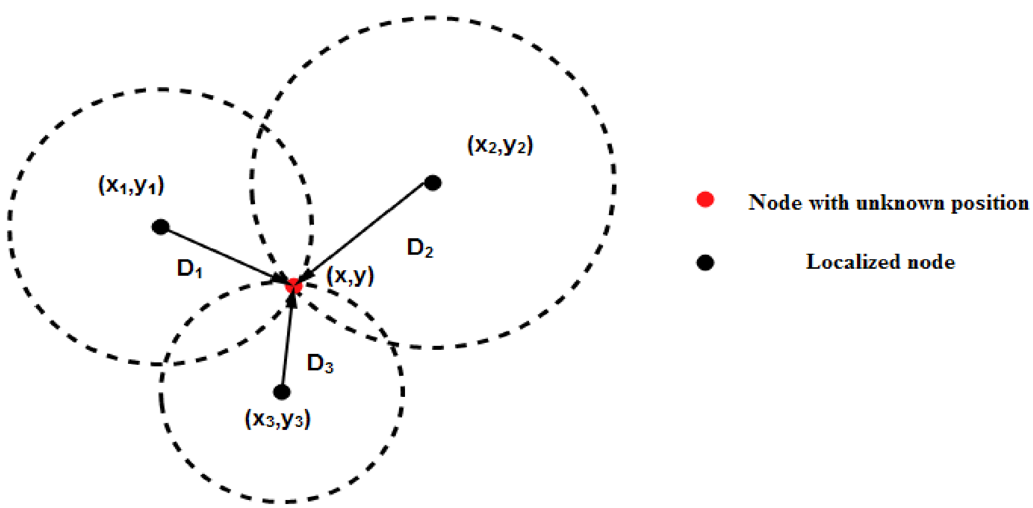


Figure 20: Trilateration in 2D sensor fields

The circles those are related to the position and distance to each of the known node can be shown by this formula:

$$(X - X_i)^2 + (Y - Y_i)^2 = D_i^2 \qquad (4)$$

Where X and Y are the X-position and Y-position of unknown node and it should be compute, X_i and Y_i are the coordination of the ith known node, and D_i is the distance between the ith node with known position and the node with unknown position. Here three equations should be solved by two unknowns (X,Y) [44].

$$\begin{bmatrix} (x - x_1)^2 + (y - y_1)^2 = d_1^2 \\ (x - x_2)^2 + (y - y_2)^2 = d_2^2 \\ (x - x_3)^2 + (y - y_3)^2 = d_3^2 \end{bmatrix} \; after\ solving \rightarrow (x, y) \qquad (5)$$

In real-world it is not possible to always have accurate distance estimation or measuring the position for the reference nodes so in this case obtaining the position of unknown node will be difficult. As the Figure 21 shows, the intersections of the circles do not cause the single point [50].

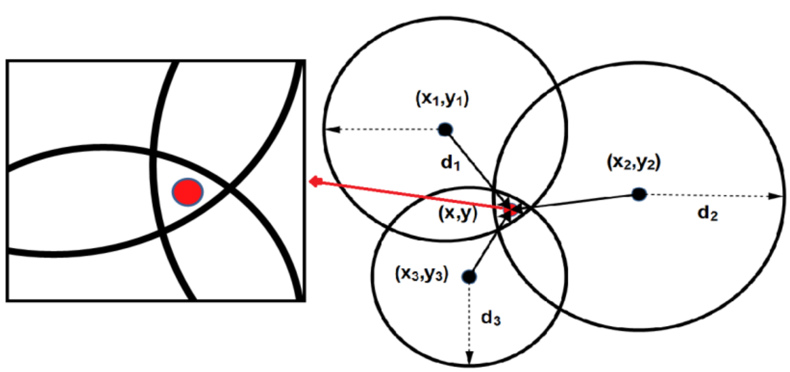


Figure 21: A more realistic model of Trilateration method

Chapter 6

RELATED WORKS AND RESULTS

6.1 Implementing of Trilateration method on Matlab software

For utilizing the Trilateration method for the localization of wireless sensor networks, minimum three nods with known location and one unknown node that we want to determine its location are needed. Although three known node is enough for this method but to improve the accuracy four nodes have been used.

$$\begin{bmatrix} (x - x_1)^2 + (y - y_1)^2 = D_1^2 \\ (x - x_2)^2 + (y - y_2)^2 = D_2^2 \\ (x - x_3)^2 + (y - y_3)^2 = D_3^2 \end{bmatrix} \textit{after solving} \rightarrow (x, y) \quad (6)$$

In Trilateration algorithm we need to identify five different variables, X, Y, $X_{i,}$ Y_i and $D_{i.}$ X and Y are the anonymous values for the location of unknown node and they have to be calculated. X_i and Y_i are related to one of the nodes with known position and D_i is the distance between the unknown nodes to one of the known nodes.

6.2 Defining coordinate system on Matlab software

The coordinated system that is used in this thesis is 2D and the length of X and Y is 10 meter. Four nodes as reference node locate in (0, 0), (0, 10), (10, 0), (10, 10) and all unknown nodes should be in the square that is made by these nodes (figure 22).

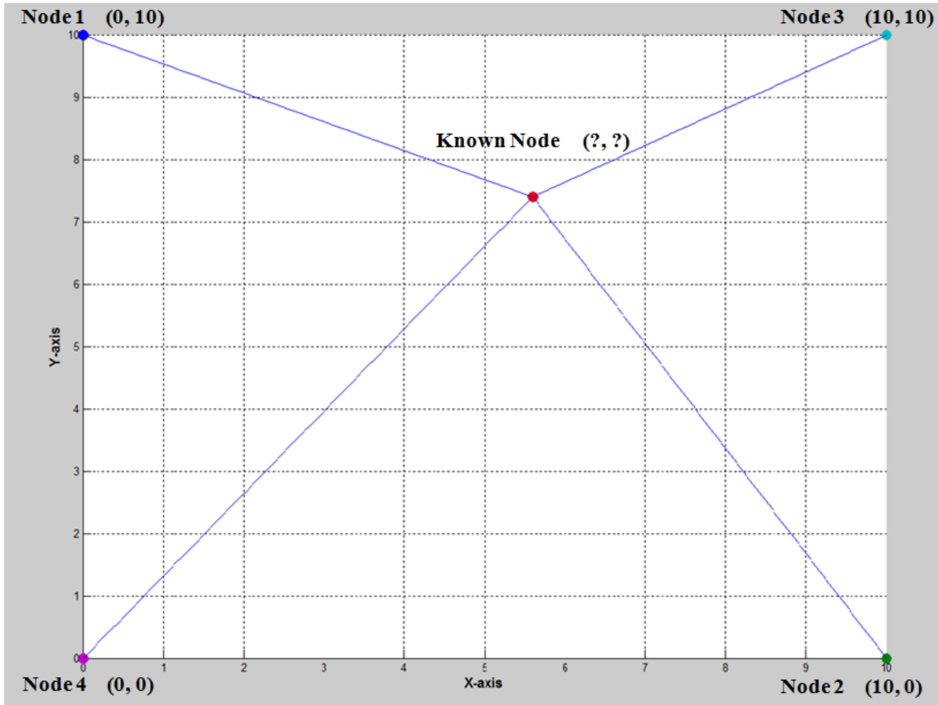


Figure 22: 2D coordinate system for Trilateraion algorithm in Matlab Software

After identifying the reference nodes the Trilateration algorithm will be change to:

$$\begin{bmatrix} (x-0)^2 + (y-10_1)^2 = D_1^2 \\ (x-10)^2 + (y-0)^2 = D_2^2 \\ (x-10)^2 + (y-10)^2 = D_3^2 \\ (x-0)^2 + (y-0)^2 = D_3^2 \end{bmatrix} \rightarrow (x, y) \qquad (7)$$

Now this information should be import to the Matlab software as a function and subsequently this formula is ready to take the distances and solve the problem by Trilateration.

6.3 Theoretical method for localization of WSN by Trilateration

The theoretical part of this thesis is based on Friis transmission equation for RSSI. This equation will calculate the RSSI by using the distance between the transceiver and transmitter with considering environmental condition [51].

$$\mathrm{RSSI[dbm]} = -(10 \times \mathrm{n} \times \log_{10}(\mathrm{d}) + \mathrm{A}) \qquad (8)$$

Where the d is the distance, n is coefficient of signal propagation and empirically its value is 3.25 and A is the initial signal strength or the absolute measured RSSI for 1 meter and empirically its value is 40.

6.4 First experimental method for localization of WSN by Trilatration

6.4.1 Implementing the coordinate system in the real world

In the first experimental method we decide to make an environment without any manufacturing equipments and condition. For this reason we did the experiment in university parking ground without any car and quiet (Figure 23). The coordinate system which is described before was implemented on the ground and RSSI was measured for each meter on x and y axis separately.

Figure 23: Implementing 2D coordinate system in university parking

6.4.2 Optimizing the measured RSSI

After the total average for RSSI was obtained we have to import them to Matlab software to draw the accurate diagram of the measured RSSI based on distance. The diagram for the rest of data is drawn for better comparison with the theoretical part it is done (Figure 24 to 30).

Table 2: Measured RSSI for the first experimental method

	X-axis first (dbm)	X-axis first average (dbm)	X-axis second (dbm)	X-axis second average (dbm)	Y-axis first (dbm)	Y-axis first average (dbm)	Y-axis second (dbm)	Y-axis second average (dbm)	X-axis First & second average (dbm)	Y-axis first & second average (dbm)	Total average (dbm)
1 m	**-43**	**-43**	**-45 to -46**	**-45.5**	**-37**	**-37**	**-37**	**-37**	**-44.25**	**-37**	**-40.2**
2 m	**-58 to -60**	**-59**	**-63 to -64**	**-63.5**	**-49 to -54**	**-51.5**	**-48 to -49**	**-48.5**	**-61.25**	**-50**	**-55.62**
3 m	**-60 to -62**	**-61**	**-61 to -62**	**-61.5**	**-56**	**-56**	**-55 to -57**	**-56**	**-61.25**	**-56**	**-58.62**
4 m	**-68 to -72**	**-70**	**-63 to -67**	**-65**	**-64**	**-64**	**-64**	**-64**	**-67.5**	**-64**	**-65.75**
5 m	**-64 to -66**	**-65**	**-62 to -67**	**-64.5**	**-71**	**-71**	**-63 to -64**	**-63.5**	**-64.75**	**-67.25**	**-66**
6 m	**-65 to -68**	**-66.5**	**-66 to -70**	**-68**	**-75**	**-75**	**-70 to -71**	**-70.5**	**-67.25**	**-72.75**	**-70**
7 m	**-74 to -76**	**-75**	**-75 to -79**	**-77**	**-67**	**-67**	**-67 to -68**	**-67.5**	**-76**	**-67.25**	**-71.62**
8 m	**-78 to -80**	**-79**	**-68 to -73**	**-70**	**-77 to -80**	**-78.5**	**-70 to -73**	**-71.5**	**-74.5**	**-75**	**-74.75**
9 m	**-79 to -80**	**-79.5**	**-73 to -77**	**-75**	**-73 to -75**	**-74**	**-70**	**-70**	**-77.25**	**-72**	**-74.62**
10 m	**-71 to -72**	**-71.5**	**-65 to -67**	**-66**	**-69 to -70**	**-69.5**	**-69 to -70**	**-69.5**	**-68.75**	**-69.5**	**-69.12**

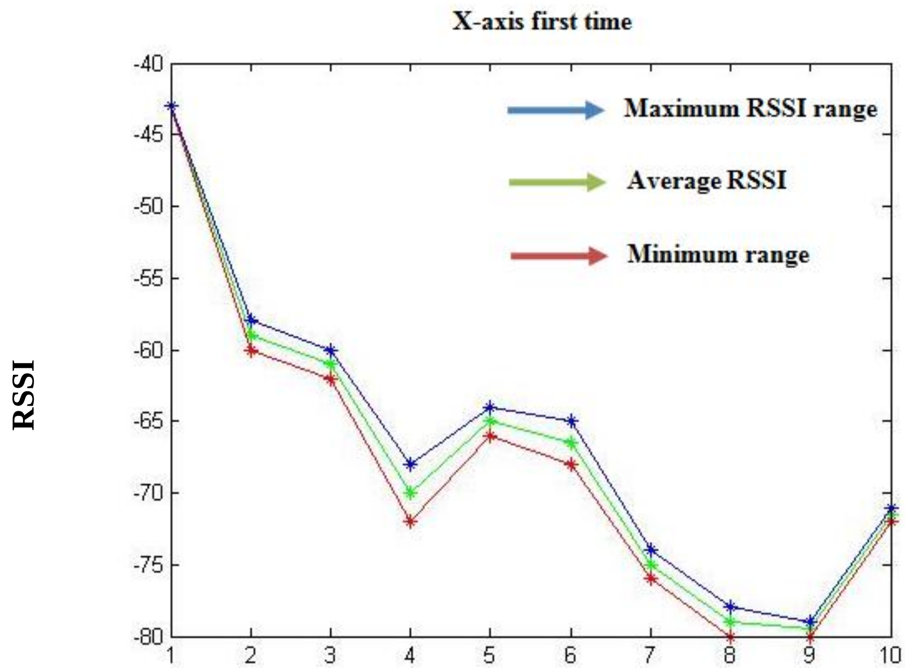


Figure 24: X-axis First time

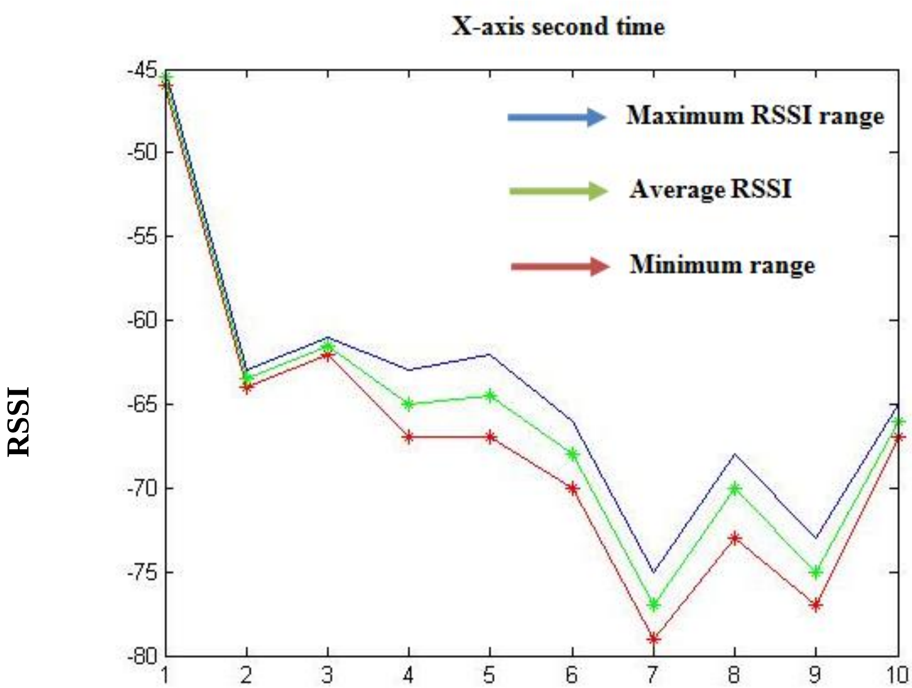


Figure 25: X-axis second time

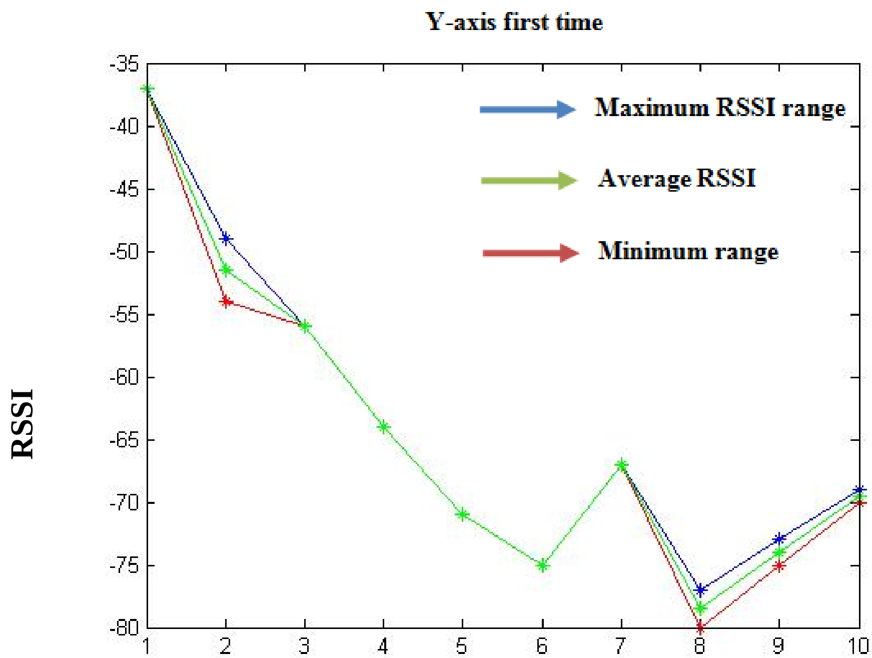


Figure 26: Y-axis First time

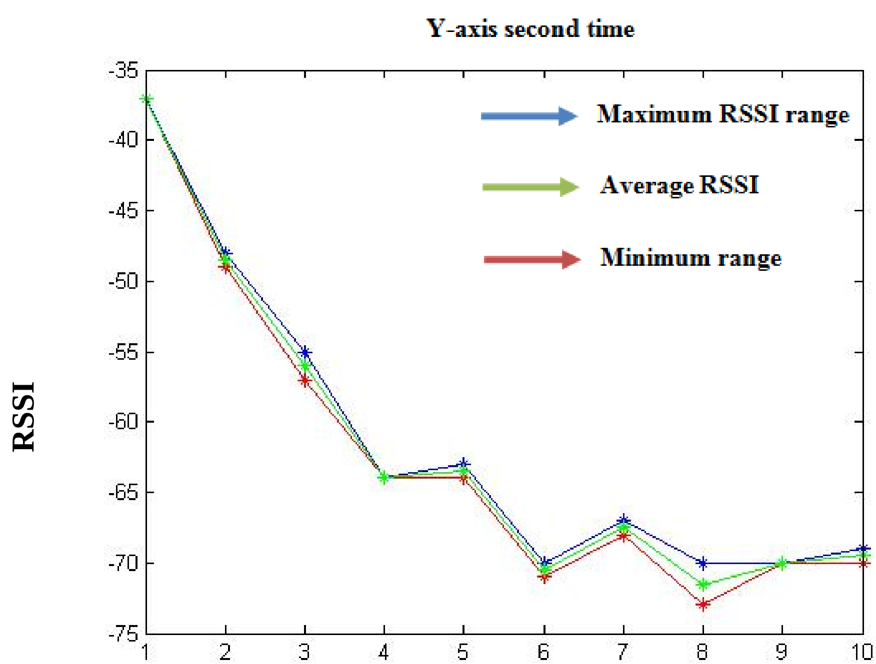


Figure 27: Y-axis second time

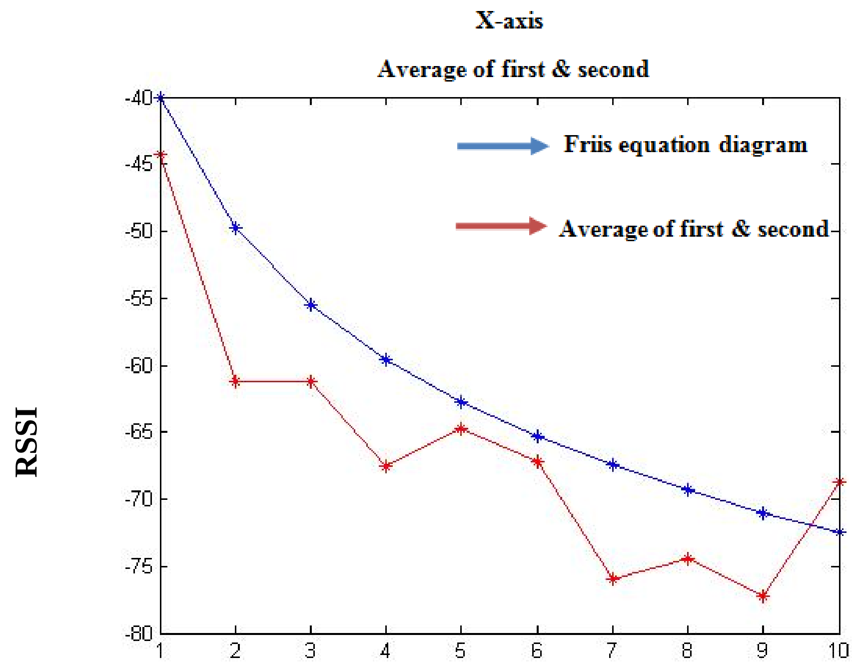


Figure 28 :Average First and Second for X-axis

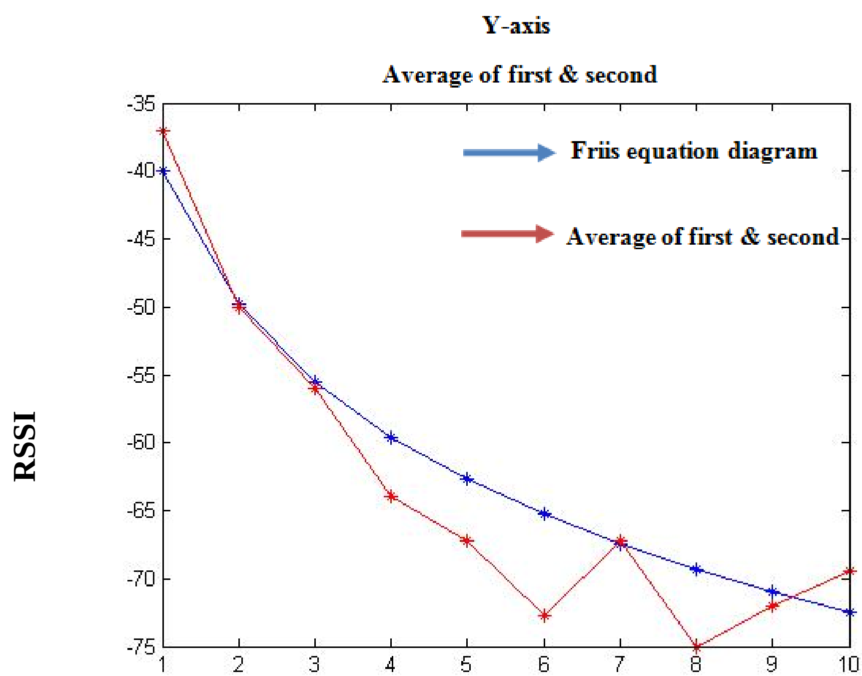


Figure 29: Average of First and Second for Y-axis

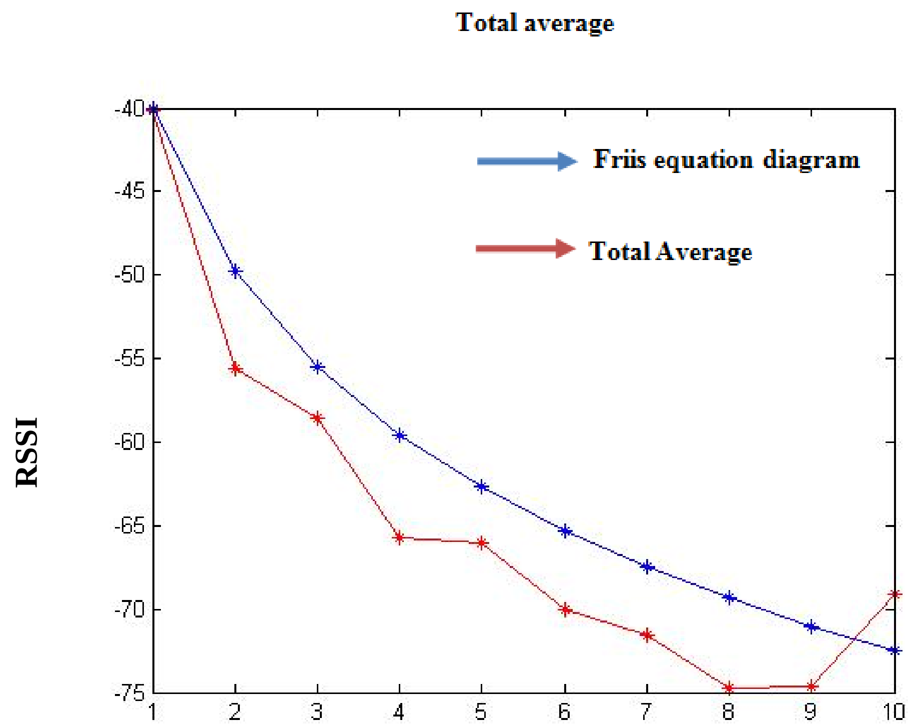


Figure 30: Total Average

6.4.3 Neville algorithm

The diagram for the total average of measured data is so limited about the points in different RSSI values. In this case the related distance calculation for more than one hundred random RSSI is needed and the total average diagram (Figure 30) is the only available data resource in the first experimental method.

For this reason the equation of this diagram should be obtain by the mathematical solutions. One of the most famous mathematical algorithms to defining a diagram equation is Neville's algorithms. This is an algorithm based on common interpolation which starts by fitting a polynomial of degree 0 through the point (X_i ,Q_i) for i=1,..., n, i.e., $P_i(X)=Q_i$. A second iteration is then performed in which P_i and P_{i+1} are combined to fit through pairs of points. The procedure is repeated, generating a "pyramid" of approximations until the final result is reached [52].

$$\begin{array}{llllll} x_0 & P_0 = Q_{0,0} & & & & \\ x_1 & P_1 = Q_{1,0} & P_{0,1} = Q_{1,1} & & & \\ x_2 & P_2 = Q_{2,0} & P_{1,2} = Q_{2,1} & P_{0,1,2} = Q_{2,2} & & \\ x_3 & P_3 = Q_{3,0} & P_{2,3} = Q_{3,1} & P_{1,2,3} = Q_{3,2} & P_{0,1,2,3} = Q_{3,3} & \\ x_4 & P_4 = Q_{4,0} & P_{3,4} = Q_{4,1} & P_{2,3,4} = Q_{4,2} & P_{1,2,3,4} = Q_{4,3} & P_{0,1,2,3,4} = Q_{4,4} \end{array} \qquad (9)$$

And the final result is:

$$\begin{aligned} Q_{i,k}(x) &= \frac{(x-x_i)}{(x_{i-k}-x_i)} Q_{i-1,k-1}(x) + \frac{(x-x_{i-k})}{(x_i-x_{i-k})} Q_{i,k-1}(x) \\ &= \frac{(x-x_{i-k})Q_{i,k-1}(x)-(x-x_i)Q_{i-1,k-1}(x)}{(x_i-x_{i-k})} \qquad (10) \\ & k = 1, 2, \cdots; \quad i = k, k+1, \cdots. \end{aligned}$$

After the initial recognition about this algorithm mathematically it should be changed to the Mathlab software language. First of all some initial points with known RSSI and Distance should be defined on desired diagram. After optimizing the measured data in table 1:

$$\text{X (RRSI Values)} =$$

$$\{-40.62, -45.62, -50.62, -55.62, -60.62, -65.62, -70.62, -75.62, \} \qquad (11)$$

$$\text{Y (Distances)} =$$

$$\{-42, -55.62, -58.62, -65.75, -66, -70, 71.62, -74.75, -74.62, -69.12\} \qquad (12)$$

Now by utilizing the written program for Neville algorithm and initial points, it is possible to import one hundred random RSSI to this algorithm and obtain the distance for each of them.

6.4.4 Faced problem and its solution

The aim of this thesis was obtain the location of the unknown node by using the Trilaterarion method but here is the problem about the distances. In last step the distances for one hundred random nodes was obtained but for using the Trilateration method three or four distances related to a specific node is needed and these distances are not detectable between one hundred distance.

To solve the problem a Matlab program is written (appendix). This program will select one of the distances and imagine the distance is related to one of the initial known nodes in the coordinate system and then estimates the other distances to the other nodes. But maybe all necessary distances are not available in measured distances because they are related to random RSSI so it makes us limited about the nodes with available distance to all the initial known nodes. Finally by importing the distance to Trilateration Matlab program the location will be obtained (Table 2).

Random RSSI related to the distances those are selected by the Matlab software will be import to the Friis equation to obtain the new theoretical distances. Then by using the Trilateration Matlab program the location of the estimated node will be obtained (Table 2).

Table 3: Obtained position for the unknown nodes with 100 random RSSI by Trilateration

	Experimental Results			Theoretical Results		
	Random RSSI	**Distance (m)**	**Position**	**Random RSSI**	**Distance (m)**	**Position**
Node 1	-70.0519	5.6786	[5.0113 , 7.3291]	-70.052	8.4076	[5.9620, 9.7462]
	-73.809	8.8658		-73.809	10.9718	
	-70.0244	5.6587		-70.024	8.3913	
	-73.8289	8.8785		-73.829	10.9873	
Node 2	-71.531	6.8942	[3.4970 , 4.0586]	-71.531	9.3365	[4.2693 , 7.1761]
	-72.3636	7.6656		-72.364	9.9038	
	-73.7184	8.8085		-73.718	10.9016	
	-69.5748	5.3573		-69.575	8.1282	
Node 3	-70.8902	6.3321	[2.7593 , 4.3007]	-70.89	8.9221	[3.4515 , 7.2366]
	-73.2127	8.4216		-73.213	10.5179	
	-74.5475	9.2146		-74.548	11.5911	
	-69.1605	5.1098		-69.161	7.8931	
Node 4	-68.484	4.7674	[4.0610, 7.5027]	-68.484	7.5237	[4.6623 , 10.1088]
	-75.0132	9.5689		-75.013	11.9489	
	-71.02	6.4427		-71.02	9.0045	
	-73.3445	8.5312		-73.345	10.6166	
Node 5	-74.8998	9.8912	[6.5041, 2.5480]	-74.9	11.8533	[7.6992 , 5.9872]
	-67.2546	4.3259		-67.255	6.8961	
	-72.9856	8.2313		-72.986	10.35	
	-71.63	6.9854		-71.63	9.4022	
Node 6	-71.1398	6.5462	[4.5646, 5.3077]	-71.14	9.0813	[5.4983 , 8.1205]
	-72.2881	7.5971		-72.288	9.851	
	-71.8415	7.1806		-71.842	9.5442	
	-71.6464	7.0005		-71.646	9.4132	
Node 7	-70.2098	5.7931	[4.3762, 6.2041]	-70.21	8.5022	[5.3383 , 8.7774]
	-73.1521	8.3737		-73.152	10.4728	
	-71.4093	6.785		-71.409	9.2564	
	-72.283	7.5923		-72.283	9.8474	
Node 8	-68.8215	4.9283	[3.2997, 6.3394]	-68.822	7.7058	[4.0375 , 9.1528]
	-74.586	9.224		-74.586	11.5927	
	-72.3289	7.6351		-72.329	9.8795	
	-71.805	7.1467		-71.805	9.5195	

	Experimental Results			Theoretical Results		
	Random RSSI	Distance (m)	Position	Random RSSI	Distance (m)	Position
Node 9	-72.6232	7.9071	[5.3522, 4.1797]	-72.623	10.0877	[6.1935 , 7.3791]
	-70.7925	6.2508		-70.793	8.8606	
	-72.1289	7.4484		-72.129	9.7405	
	-71.4159	6.7909		-71.416	9.2607	
Node 10	-70.5034	6.0173	[5.3087, 7.1671]	-70.503	8.6809	[6.2137 , 9.6464]
	-73.566	8.566		-73.566	10.7845	
	-69.7651	5.4803		-69.765	8.2385	
	-73.889	8.9191		-73.889	11.0341	
Node 11	-71.5324	6.8963	[6.0097, 6.6173]	-71.532	9.3374	[7.4746 , 9.3105]
	-72.4281	7.7273		-72.428	9.9492	
	-69.371	5.2312		-69.371	8.0117	
	-73.922	8.939		-73.922	11.06	
Node 12	-74.9091	9.2726	[6.8922 , 3.7969]	-74.909	11.8611	[7.9186 , 6.8834]
	-68.778	4.9066		-68.778	7.682	
	-71.5783	6.9381		-71.578	9.3679	
	-72.5815	7.8689		-72.582	10.0579	
Node 13	-74.6741	9.3809	[5.3385 , 2.2863]	-74.674	11.6653	[6.2724 , 6.2503]
	-69.3048	5.192		-69.305	7.9742	
	-74.051	9.0128		-74.051	11.1615	
	-70.2292	5.8075		-70.229	8.5139	
Node 14	-71.805	7.4246	[6.3898 , 6.2190]	-71.805	9.5195	[7.2931 , 8.7932]
	-71.8527	7.191		-71.853	9.5518	
	-69.3653	5.2278		-69.365	8.0084	
	-73.922	8.9166		-73.922	11.06	
Node 15	-69.8815	5.559	[2.7100 , 5.1463]	-69.882	8.3067	[3.6215 , 8.0411]
	-73.8662	8.9235		-73.866	11.0163	
	-73.6455	8.758		-73.646	10.8454	
	-70.2098	5.8163		-70.21	8.5022	

Making the comparison between the estimated node location by the theoretical method and experimental method will be defined that and different between the obtained positions in these methods is too much and is not acceptable (Figure 31).

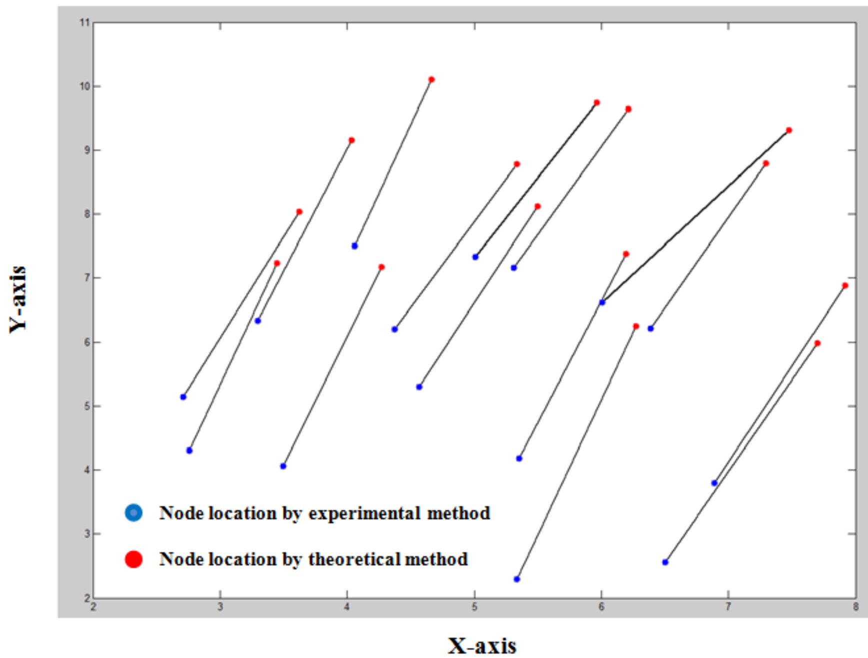


Figure 31: Compassion of the obtained location by experimental and theoretical methods

6.5 Second experimental method for localization of WSN by Trilatration

In second experimental method 85 random unknown nodes are assumed in the initial coordinate system as theoretical nodes location (Figure 32). All the distances to each initial known node will be measured by Matlab software separately. The measured distances will import to the Ferris equation to obtain the related RSSI. This is the theoretical measured RSSI but for comparison the experimental RSSI is needed. For this reason by using the Additive White Gaussian Noise (AWGN) Mathlab software program, RSSI will be change according to the percentage (40 percent) of AWGN and it will be assumed as an experimental RSSI (Table 3).

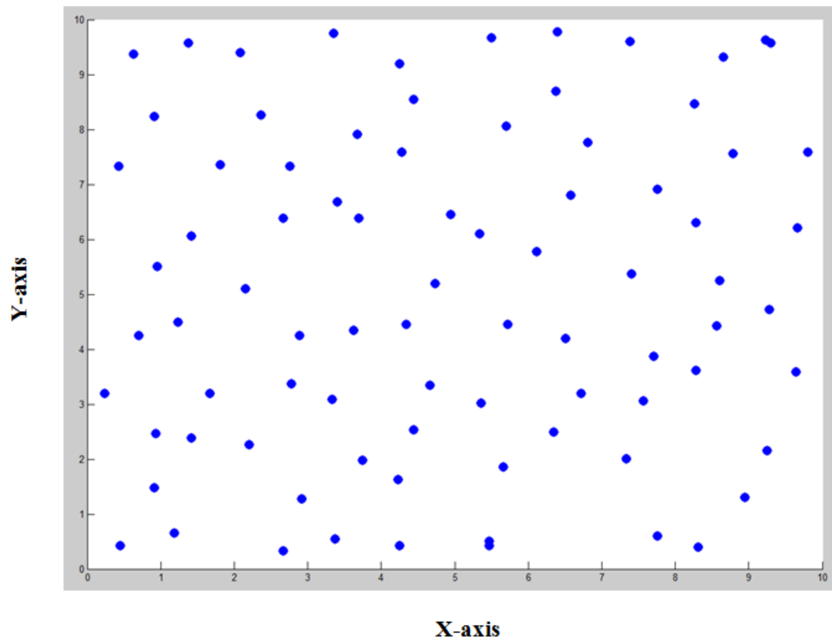


Figure 32: Assumed random unknown node in initial coordinate system

The experimental RSSI will be imported to the Friis equation to obtaining the distances related to each RSSI and by using the Trilateration method and import the distances to this program the position for each method will be obtained and these are the experimental obtained position by Trilateratiomn method (Table 3) (Figure 33). As this Figure 33 shows the error between the nodes locations obtained by second experimental method and theoretical method is obviously less than the first experimental method.

Table 4: Obtained location by theoretical method and experimental method with utilizing Trilateration.

	X-value (OLD)	Y-value (OLD)	Distance (0,10)	Distance (10,0)	Distance (10,10)	Distance (0,0)	X-value (NEW)	Y-value (NEW)
Node 1	**0.6336**	**9.3713**	**0.8926**	**13.2496**	**9.3875**	**9.3927**	**0.9963**	**9.0063**
			-38.3963	-76.4716	-71.6079	-71.6157		
			-38.4426	-75.9163	-71.0826	-71.0874		
			0.8955	12.7385	9.0446	9.0476		
Node 2	**0.9101**	**8.231**	**1.9894**	**12.2628**	**9.2604**	**8.2812**	**1.4085**	**8.0834**
			-49.7085	-75.3792	-72.4158	-69.838		
			-49.7557	-74.813	-71.8802	-69.2993		
			1.9961	11.7806	9.5704	7.9675		
Node 3	**0.4263**	**7.3246**	**2.7092**	**12.0543**	**9.9405**	**7.337**	**0.8955**	**7.688**
			-54.0673	-75.1371	-72.4158	-68.1294		
			-53.8108	-75.5983	-72.1418	-67.5067		
			2.6604	12.4547	9.7494	7.0204		
Node 4	**0.3111**	**6.5351**	**3.4788**	**11.6868**	**10.2898**	**6.5425**	**3.621**	**3.1094**
			-57.5965	-11.6868	-72.9032	-66.5117		
			-57.9417	-11.9482	-73.8541	-66.0472		
			3.5649	0.137	11.0069	6.3307		
Node 5	**0.9562**	**5.5117**	**4.589**	**10.591**	**10.0963**	**5.594**	**1.0634**	**5.9028**
			-61.5058	-73.3105	-72.6353	-64.301		
			-61.3812	-73.5997	-72.1103	-64.9567		
			4.5487	10.8103	9.7277	5.86		

(These are samples just for 5 nodes)

Obtained distance of the assumed nodes (m) (black) — RSSI related to the initial distances (red)

RSSI after 40 percent AWGN (blue) — Obtained distances related to the changed RSSI (green)

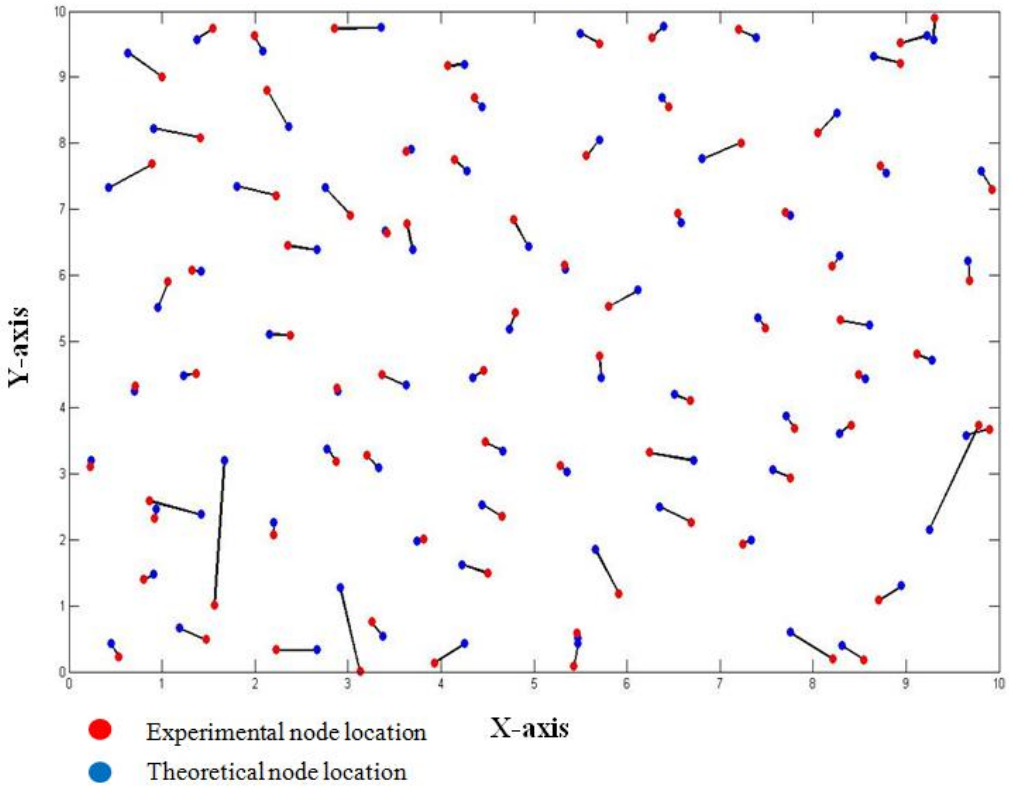


Figure 33: Nodes location by theoretical method and experimental method

6.6 Industrial Application 1

The first test bed that the Trilateration localization method is implemented on is the mechanical engineering department workshop and it could be as industrial application of this thesis in manufacturing field. This work shop contained different kinds of manufacturing equipments and machines such as lathe, surface grinding, milling, and drilling machine (Figure 34).

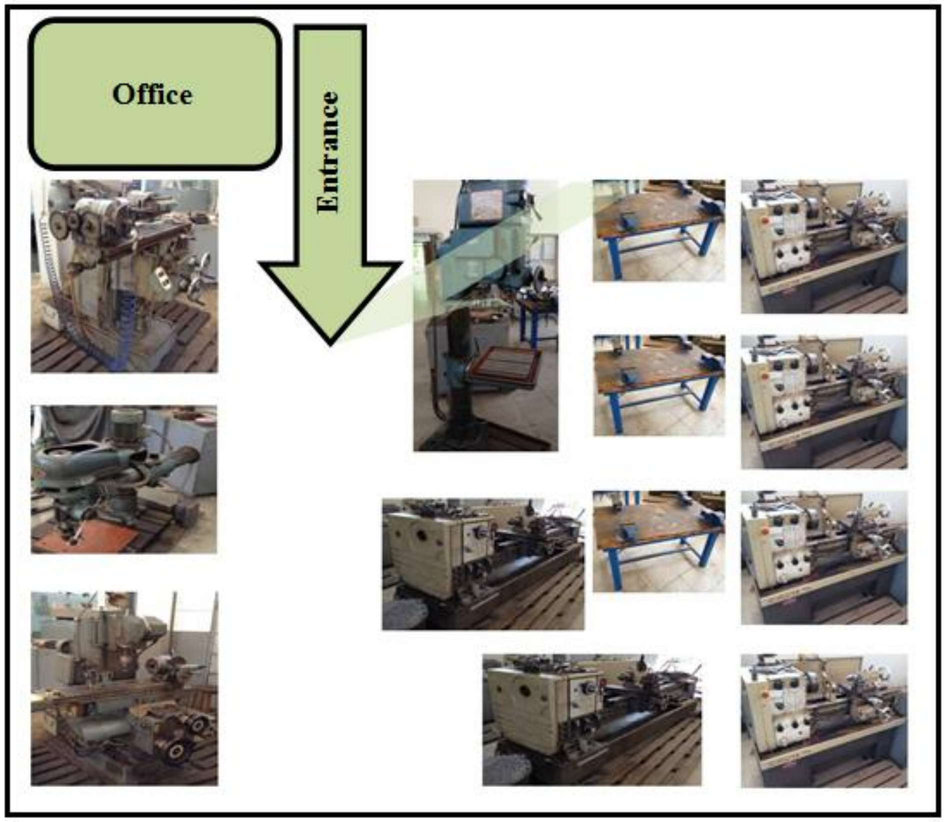


Figure 34: Scheme of mechanical engineering department workshop

The wireless sensor node has been implemented between the workshop machines for measuring the RSSI but different between this area and the previous area in the first experimental method is in the environment condition. In the first environment there was no device or machine and it was so quite silent but in the workshop because of requests all the machines and devices was on and subsequently the environment was too noisy.

After implementing the sensor node in workshop (Figure 35) by collecting the RSSI between a sensor node and basic station for each meter to 10 meter the diagram related to these results should be draw and it should be compared with the diagram for Friis equation as theoretical part (Figure 37 to 43).

Figure 35: Schemes of workshop after implementing the sensor node

We are not going to details like last experimental method just the comparison will be done with the previous knowledge about different between the diagrams. As the Figure 43 shows the diagram for the total average of the measured RSSI has the large deviation in some points such as point 8, 9 and 10 in comparison with the Friis equation. It may happen because of different items. One of the most important reasons that could be affecting on the RSSI in workshop in those specific points is concentration of the machines around those points (Figure 36).

Figure 36: Real photo of the workshop and the places of the machines

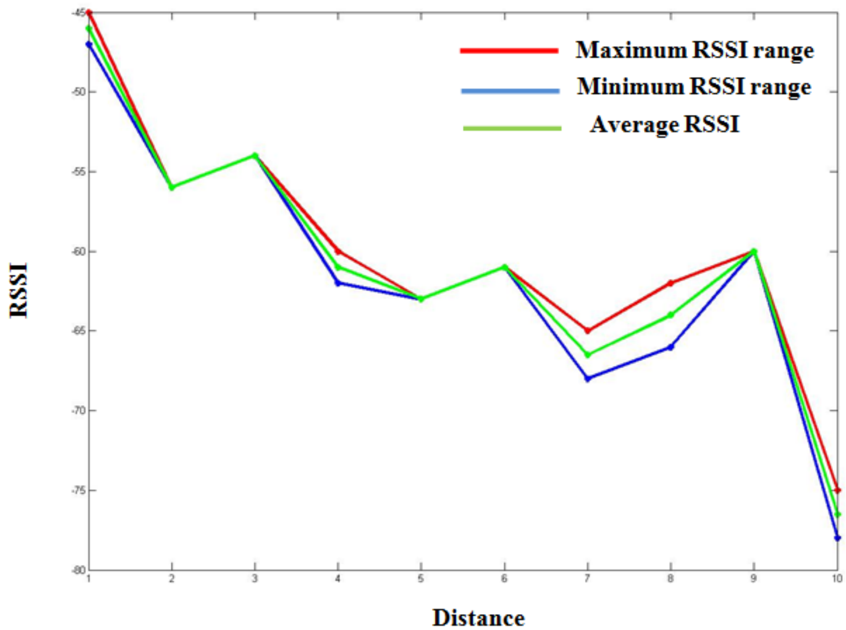


Figure 37: First Measurements

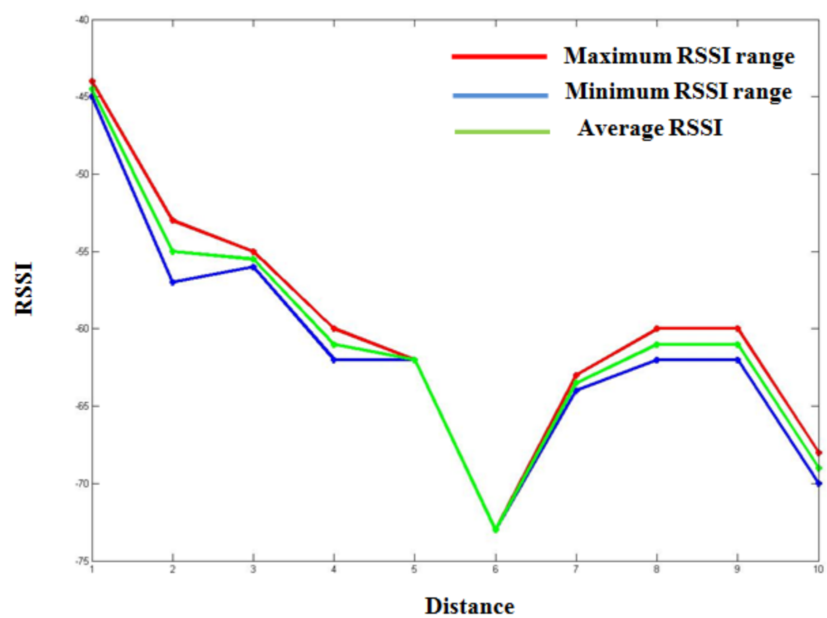


Figure 38: Second measurements

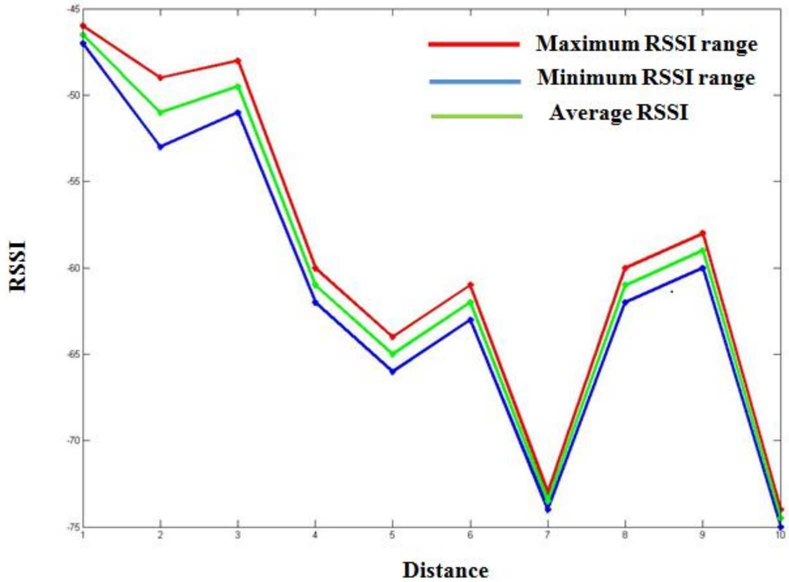


Figure 39: Third measurement

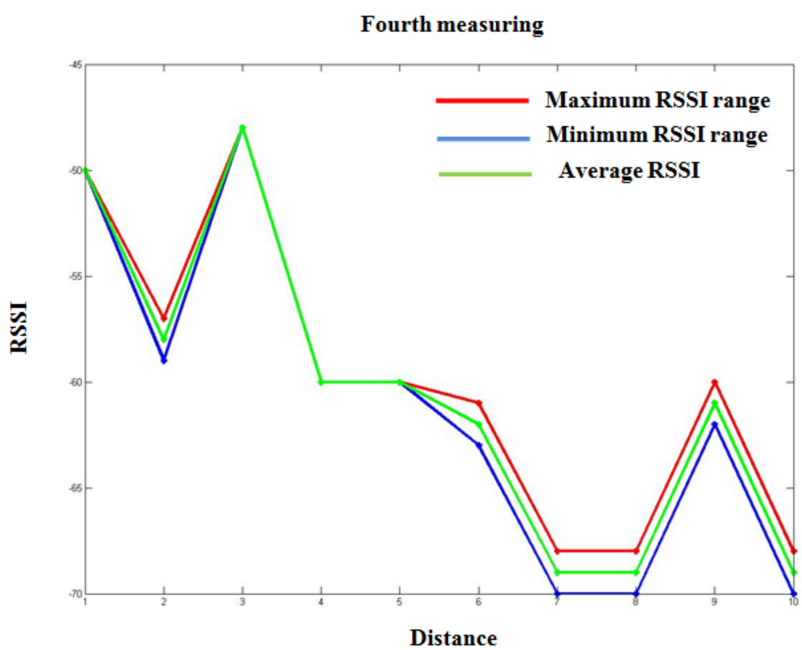


Figure 40: Fourth measurement

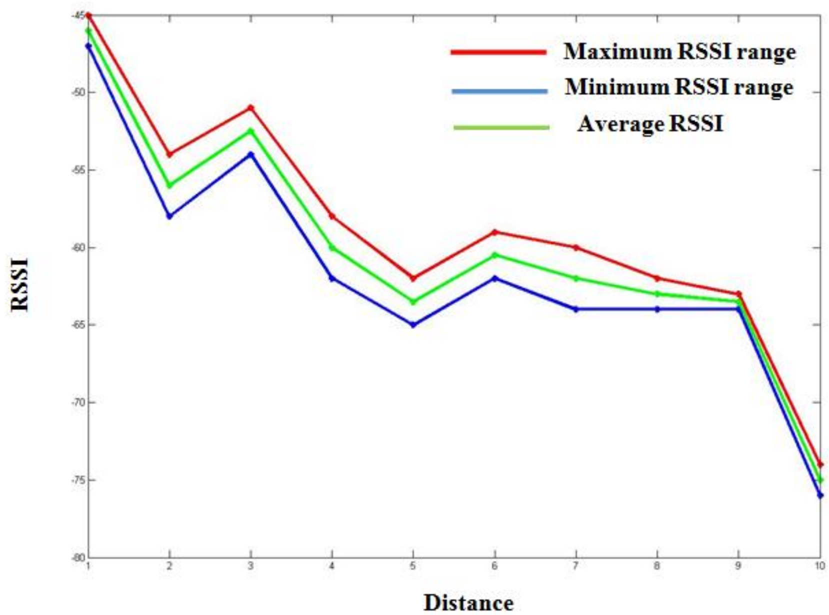


Figure 41: Fifth measurement

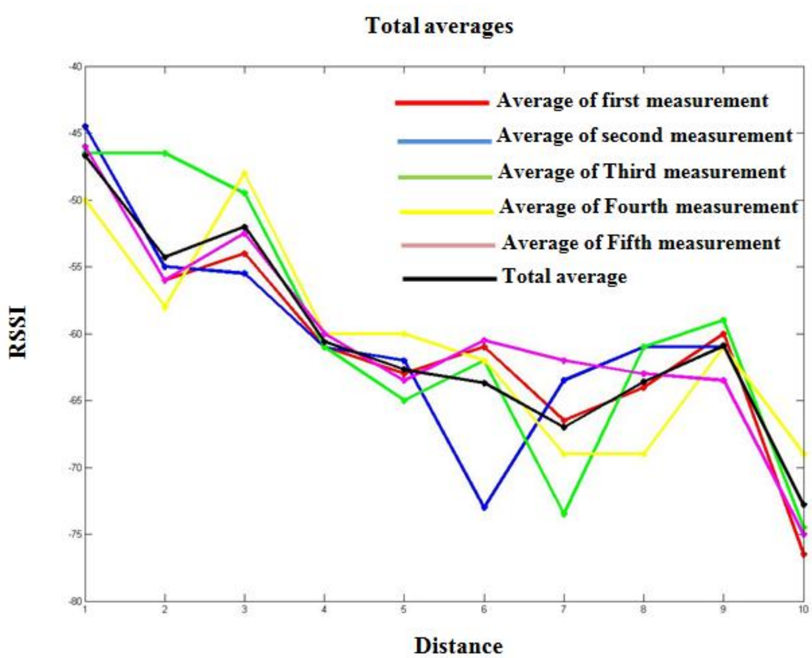


Figure 42: Average of Averages

Table 5: Obtained RSSI in EMU MEchanical Engineering Workshop

	First	Ave	Second	Ave	Third	Ave	Fourth	Ave	Fifth	Ave	Ave
1 m	-45 to -47	-46	-44 to -45	-45	-46 to -47	-46.5	-50	-50	-45 to -47	-46	46.7
2 m	-56	-56	-53 to -57	-55	-49 to -53	51	-57 to -59	-58	-54 to -58	-56	54.3
3 m	-54	-54	-55 to -56	-56	-48 to -51	-49.5	-48	-48	-51 to -54	-52.5	52
4 m	-60 to -62	-61	-60 to -62	61	-60 to -62	-61	-60	-60	-58 to -62	-60	60.6
5 m	-63	-63	-62	-62	-64 to -66	-65	-60	-60	-62 to -65	-63.5	62.7
6 m	-61	-61	-73	-73	-61 to -63	-62	-61 to -63	-62	-59 to -62	-60.5	63.7
7 m	-65 to -68	-66.5	-63 to -64	-64	-73 to -74	-73.5	-68 to -70	-69	-60 to -64	-62	67
8 m	-62 to -66	-64	-60 to -62	-61	-60 to -62	-61	-68 to -70	-69	-62 to -64	-63	63.6
9 m	-60	-60	-60 to -62	-61	-58 to -60	-59	-60 to -62	-61	-63 to -64	-63.5	60.9
10 m	-75 to -78	-76.5	-68 to -70	-69	-74 to -75	-74.5	-68 to -70	-69	-74 to -76	-75	72.8

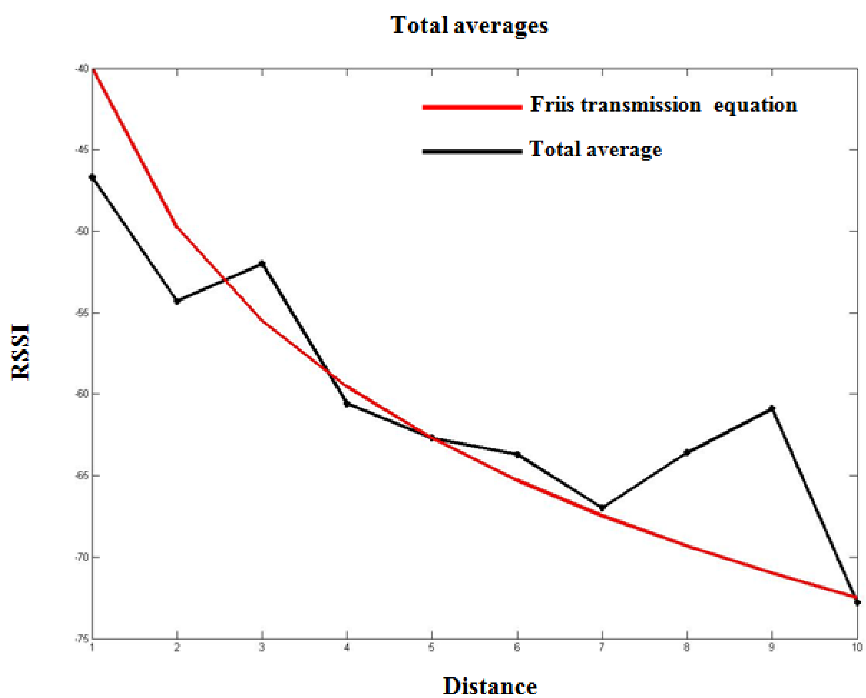
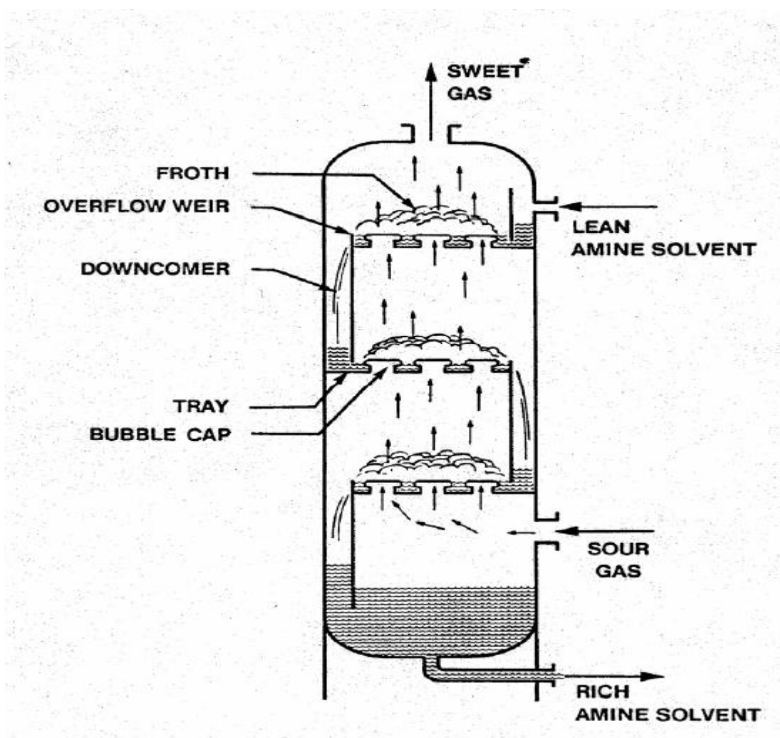


Figure 43: Total average

6.7 Industrial Application 2

In second industrial application of this thesis we are going to discuss about the implementing the wireless sensor networks instead of the traditional sensors and thermocouples on gas distillation columns. These columns have been used to make contact between the sour gases or acid gas and amines.

In different types of raw natural gas there are different ranges of acidic gas with the concentration between 50 % to 70 %. The percentage of acid gas depends on the recourse of natural gas. Sour gas contains H_2S and CO_2 and both of them are toxic gas, harmful for the human and environment and also in the presence of water they will become corrosive substance. For these reasons the entire gas manufacturer makes their gas sweet or with minimum H_2S or CO_2 to prevent any corrosiveness or human damage [53].



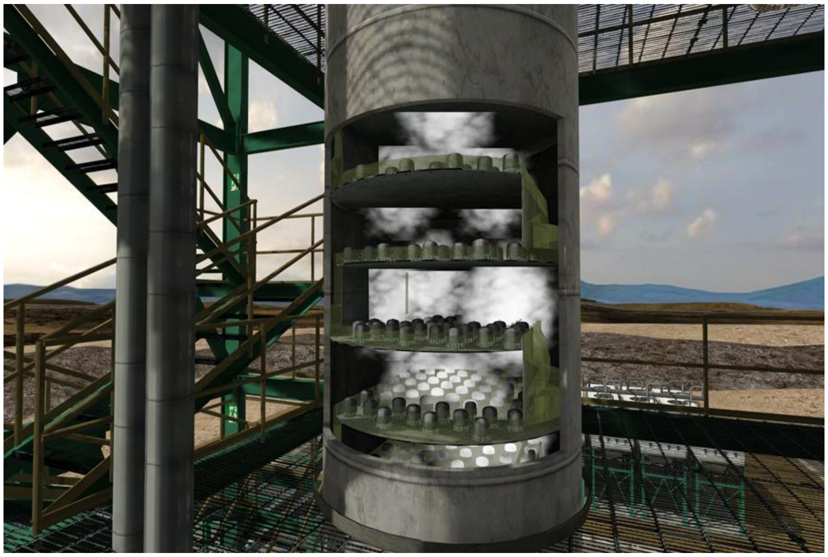


Figure 44: Sour gas sweetening process in distillation column

In order to have more mass transfer between gas and liquid and more acidic gas absorption the column with more contact surface and also increase the liquid retention time the distillation columns have been designed. The distillation column that is considered in this thesis is valve tray type column.The considered distillation column that is utilized in gas purification unit has below properties:

1- Diameter : 2895 mm
2- High: 16460 mm
3- Body thickness: 87.3 mm
4- Number of trays: 20
5- Type of tray: Valve tray
6- Distance between first four tray (Tray spacing): 30 inch
7- Distance between the other trays: 24 inch
8- Type of caps over the trays: Flexitray A type

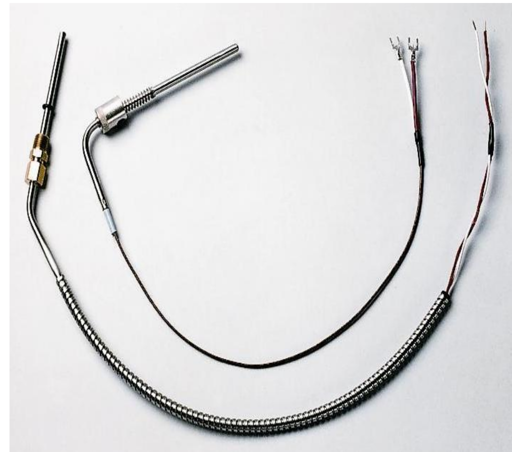
9- Maximum design temperature: 126.7 °C

10- Maximum design pressure:88.84 kg/cm^2

To control the gas distillation column it is necessary to have the real time measurement for temperature and concentration in some of the trays. As the Figure 46 shows this column contain lot of sensors but temperature and concentration sensors are more important than the others.

The temperature sensors are PT 100 (Figure 45-a) and they are placed in tray number 5, 10, and 15 but usually the thermocouple type J (Figure 45-b) has been used instead of the sensors. Both of these equipments have some disadvantages such as wired connection that is so complicate and the time to send collected temperature to controller is so much.

The use of inexpensive wireless temperature sensors (Figure 45-c) in large quantities along the length of distillation columns will provide a very large amount of real-time data to the operators that they have never been able to get before and that can be used for process bottleneck discovery and process optimization [54].



(a) (b)

(c)

Figure 45: (a) PT 100 temperature sensor [56] (b) thermocouple type J(c) Temperature wireless senor [55]

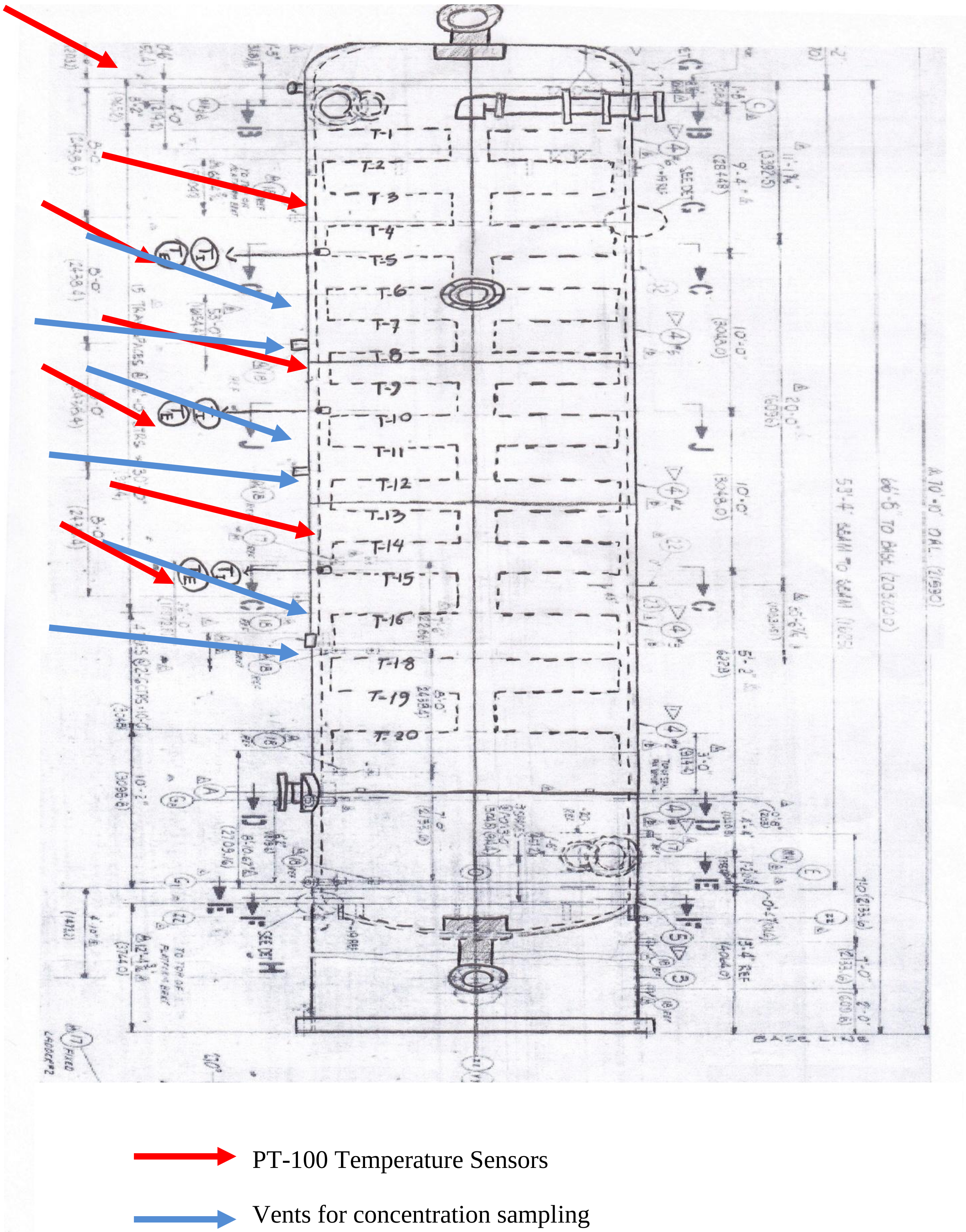


Figure 46: Real schemes of distillation column for one of the gas refinery in Iran

Today in most of the distillation columns to control the concentration some vents are embedded as access point to the gas sampling in some special trays (Figure 46). This method has some disadvantages like the cost of the concentration analyzer and the time to analyzing and in addition sampling for all the trays is not possible. To overcome such problems there are different types of wireless sensors with real-time concentration ability in minimum time to analyzing i.e. iTrans fix point gas monitor wireless senor node (Figure 47).

Figure 47: iTrans gas monitoring sensor node [57]

The location of new wireless sensors could be in the same location with wired sensors or because there is no limitation about the wired connection and number of the sensor nodes it is possible to located more wireless senor node on column i.e. in the explained gas distillation column ha temperature sensors were locate on tray number 5,10and 15 but by utilizing wireless sensors instead of wired sensors,it is feasible to have one sensor for each tray.

The proposed localization method here is Trilateration because like industrial application 1 here again sensors have been deployed in a line (X or Y axis) with length of 12792 mm. Totally 20 sensor node are available (if one sensor for each tray intended). Distances between each sensor are not same. For the first four sensors is 762 mm and for the others is 609 mm. By utilizing the RSSI based measurement system distances will be obtained and with Trilateration method the location for each sensor node will be calculated.

Chapter 7

CONCLUSION AND FUTURE WORKS

Wireless sensor networks play an important role in various applications such as military, healthcare, environment, and especially in industries. The advantages of this technology are more than its probable encountered limitations or problems for the users, but it is not meaning that they are negligible. In order to increase the use of this technology in more applications with less limitation these problems have to be handled, and a solution should be defined. One of the most important difficulties in WSN is localization, because the collected data by wireless sensor node should be meaningful about the geographically position in most of the applications and also embedding GPS as a localization device to obtaining the location of sensor node is not possible because of its hardware limitation.

Trilateration method is the localization technique that is mentioned in this thesis. As it described before Trilateraton is an assumption based technique and all the location computations are depends on the distance between the nodes. Received signal strength indication has been utilized as distance base measurement technique and it has been converted to the distance as impute for Terilateration method. Terilateration is not a flexible method in comparison with the other localization methods because location computation will be affected by many factors such as accuracy of the measured distances related to the reference nodes, measured RSSI, and converting the RSSI to distance. On the other hand if a solution guarantees the accuracy for all these items, the position that is obtained by this method will be position with minimum error.

All the experiments of this study were done in 2D coordinate system and the importance of the computations accuracy was the reason to select this type of coordinate system. Another reason to use 2D coordinate system was the specific applications those are mentioned as industrial application of wireless sensors networks in this thesis. In both of these applications (EMU workshop and Gas distillation column) the environmental condition and physical dimension of the area were the difficulties to do the measurements in 3D coordinate system. It is possible to measuring the RSSI as the distance based measurement in 3D coordinate system but with considering about the measurements accuracy. Although Terilateration method is an appropriate localization technique in the application of WSN in industry but there are different distance base localization technique such as Angle of arrival or time different of Arrival to use instead of Trilateration.

REFERENCES

[1] w. Burke, P. Kulkarni, A. Severinson, S. C. Chen, R. Kyker, D. Sexton and J. Coates, Industrial Wireless Technology for the 21st Century, California: US Department of Energy, 2002.

[2] S. K. Low, N. W. Win and j. M. Er, "Wireless Sensor Networks for Industrial Environments," in *IEEE International Conference on Computational for Modelling,Control and Automation* , 2005.

[3] L. Hanna, K. Koumpis, M. Andersson and M. Johansson, "Wireless Industrial Control and Monitoring beyond Cable Replacement," in *PROFIBUS International Conference*, Warwickshire, 2005.

[4] C. Buratti, A. Conti, D. Dardari and R. Verdone, "An OVerview on Wireless Sensor Networks Technology and Evolution," *Sensors*, pp. 6870-6896, 2009.

[5] D. Estrin, R. Govindan, J. Heidemann and S. Kumar, "Next Century Challenges : Scalable Coordination in Sensor Networks," in *ACM*, Marina del Rey, 1999.

[6] C.-Y. Chong and p. S. Kumar, "Sensor Networks:Evolution,Opportunities,and Challenges," *Proceeding Of IEEE,* vol. 91, no. 8, pp. 1247-1256, 2003.

[7] Q. Wang and I. Balasingham, "Wireless Sensor Networks -An Introduction," Norwegian University of Science and Technology, Norway.

[8] "MOOG Crossbow," The smart Sensor Company, [Online]. Available: http://www.xbow.com/.

[9] J. Lester, "System Architecture for Wireless Sensor Networks," Univresity of Californian, Berkeley, 2003.

[10] B. Gholamzadeh and H. Nabovati, "Concepts for Designing Low Power Wireless Sensor Networks," in *World Academy of Science, Engineering and Technology*, 2008.

[11] "TELOS," Mote iv, [Online]. Available: www.tinyos.net/scoop/special/hardware.

[12] P. Levis, S. Madden, J. Polastre, K. Whitehouse, A. Woo, D. Gay, J. Hill, M. Welsh, E. Brewer and D. Culler, "TinyOS: An operating System for Sensor Networks".

[13] D. Gay, P. Levis, V. R. Behren, M. Welsh, E. Brewer and D. Culler, "The nesC language: A Holistic Approach to Networked Embedded Systems," ACM, San Diego, 2003.

[14] I. Akyildiz, W. Suq, Y. Sankarasubramaniam and E. Cayirci, "Wireless sensor networks: a survey," *ELSEVIER Computer Networks,* vol. 38, pp. 393-422, 2002.

[15] J. E. Goff, "Explorig the Protocol Stack of Wireless Sensor Networks," [Online]. Available: htto://www.thecourse..us/Students/Wireless _Sensor_Networks.htm.

[16] X. H. Tan, "Quality of Service in Wireless Sensor Networks," National University of Singapore, Singapore.

[17] K. A.-S. Pathan, W. H. Lee and S. C. Hong, "Security in Wireless Sensor Networks : Issues and Chalenges," *ICACT,* pp. 1042-1048, 2006.

[18] M. A. Perillo and W. B. Heinzelman, "Wireless Sensor Network Protocols," University of Rochester- Department of Electrical and Computer Engineering, Rochester.

[19] E. Ekici, Y. Gu and D. Bozdag, "Mobility- Based Communication in Wireless Sensor Networks," *IEEE Communications Magazine,* pp. 56-62, 2006.

[20] D. J. Nagel, "Wireless Sensor Systems and Networks:Technologies,Applications,Implication and Impacts," The George Washington University .

[21] Y. Guo, P. Corke, G. Poulton, T. Wark, G. Bishop and D. Swain, "Animal Behavior Understanding using Wireless Sensor Networks," *IEEE,* pp. 607-614, 2006.

[22] A. J. Garcia-Sanchez, F. Garcia-Sanchez, F. Losilla, P. Kulakowski, J. Garcia-Haro, A. Rodriguez, J.-V. Lopez-Bao and F. Palomares, "Wireless Sensor Networks Deployment for Monitoring Wildlife Passages," *Sensors,* vol. 10, pp. 7236-7262, 2010.

[23] M. Hefeeda and M. Bagheri, "Forest Fire Modeling and Early Detection using Wireless Sensor Networks," *Ad Hoc Sensor Wireless Network,* vol. 7, pp. 169-224, 2009.

[24] C. L. Pop, R. L. Bratie, O. Choudary and M. D. Gheorghe, "Windows for Devices," Forest Watcher. [Online].

[25] M. Li and Y. Liu, "Iso-map:Energy Efficient Contour Mapping in Wireless Sensor Networks," *IEEE Transactios on knowledge and Data Enginnering,* vol. 22, no. 5, pp. 699-710, 2010.

[26] "University of California,Riverside," Center for Conservation Biology, 19 April 2012. [Online]. Available: http://ccb.ucr.edu.biocommaps.html.

[27] "Alert system Organization," Alert Users Group, [Online]. Available: http://www.alertsystems.org.

[28] Z. Liqiang, Y. Shouyi, L. Leibo, Z. Zhen and W. Shaojun, "A Corp Monitoring System Based on Wireless Sensor Networks," *ELSEVIER*, pp. 558-568, 2011.

[29] J. Ko, C. Lu, M. B. Srivastava, A. J. Stankovic, A. Terzis and M. Welsh, "Wireless sensor Networks for Healthcare".

[30] R. Frank, "Design World Online," 18 August 2011. [Online]. Available: http://www.designworldonline.com/Sensors-Adavance-Medical-and-Helthcare-Application/.

[31] M. Varchola and M. Drutarovsky, "Zigbee Based Home Automation Wireless Sensor Networks," Slovak, 2007.

[32] "KOMSA Technology," KOMSA, 2010. [Online]. Available: http://www.komsa.com.cn/en/product.asp.

[33] T.-K. Moon and T.-Y. Kuc, "An Integrated Intelligent Control Architecture for Mobile Robot Navigation within Sensor Network Environment," in *IEEE/RSJ International Conference on Intelligent Robots and Systems*, Sendel, 2004.

[34] C. Apneseth, D. Dzung, S. Kjesbu, G. Scheible and W. Zimmermann, "Introducing wireless proximity switches," ABB, 2002.

[35] A. Mason, A. Al-Shamma'a and A. Shaw, "Wireless Sensor Networks for Intelligent Inventory Managment for Packaged Gas," in *IEEE Second International Conference on Developments in eSystems Engineering*, 2009.

[36] P. Hochmuth, "Case Study:GM cuts the cords to cut the costs," 21 June 2005. [Online]. Available: http://howto.techworld.com/mobile-wireless/1530/case-study-gm-cuts-the-cords-to-cut-costs.

[37] A. Schwartz, "3 Ways Intel Is Changing The Energy Landscape," Intel, June 2001. [Online]. Available: http://www.fastcompany.com/1758155/3-ways-intel-changing-energy-landscape.

[38] L.-z. Wang, H.-b. Liu, G. Zhang and T. Hang, "The Network Nodes Design of gas Wireless Sensor Monitor," *IEEE*, pp. 1778-1781, 2011.

[39] R. Walli, "OAK Ridge National Laboratory," Communications and Media Relations, [Online]. Available: http://www.ornl.gov/info/press_releases/get_press_release.cfm?ReleaseNumber=mr19980428-01.

[40] G. Mao and B. Fidan, Localization Algorithms and Strategies for Wireless Sensor Networks, Uinited States: IGI Global, 2009.

[41] R. Peng and L. M. Sichitiu, "Angle of Arival Localization for Wireless senor networks," Depatment of Electrical and Computer Engineering, Raleigh, 2006.

[42] G. Mao, B. Fidan and B. D. Anderson, "Wireless Sensor Networks Localization Techniques," 2009.

[43] G. Mao, B. Fidan and D. B. Anderson, "Senaor Network Localization," 2009.

[44] L. Franceschini, M. Galetto, D. Maisano and L. Mastrogiacomo, "A review of Localization for Distributed Wireless Sensor Networks in Manufacturing," *International journal of Computer Integrated Manufacturing,* pp. 698-716, 2009.

[45] A. Youssef and M. Youssef, "A taxonomy of Localization Schemes for Wireless Sensor Networks," University of Maryland, Maryland, 2004.

[46] A. Howard, J. M. Mataric and S. G. Sukhatme, "An Incremental Self -Deployment Algorithm for Mobile Sensor Networks," *Autonomous Robots,* vol. 2, no. 13, pp. 113-126, 2002.

[47] L. Klingbeil and T. Wark, "AWireless Sensor Network for Real-time Indoor Localisation and Motion Monitoring," in *International Conference on Information Processing in Sensor Networks*, 2008.

[48] J. Bachrach and C. Taylor, "Localization in Wireless Sensor Networks," Massachusetts Institute of Technology, Cambridge.

[49] M. Essoloh, C. Richard, H. Snoussi and P. Honeine, "Distributed Localization In Wireless Sensor Networks As Pre-image Problem in Reproducing Kernel Hilbert Space," in *16th Europian Signal Processing Conference*, Lausanne, 2008.

[50] A. Boukerche, A. H. Oliveira, F. E. Nakamura and A. A. Loureiro, "Localization Systems for Wireless Sensor Networks," *IEEE Wireless Communication,* pp. 6-12, 2007.

[51] X. Wang, O. Bischoff, R. Laur and S. Paul, "Localization in Wireless Ad-hoc Sensor Networks Using Multilateration with RSSI for logistic Applications," *Procedia Chemistry -*

ELSEVIER, vol. 1, pp. 461-464, 2009.

[52] W. E. Weisstein, "Wilfram," MathWorld, [Online]. Available: http://mathworld.wolfarm.com/NevillesAlgorthm.html.

[53] *Gas Sweentening.* [Performance]. The Dow Chemical Company, 1998.

[54] ADVANTECH, "The Internet of Things," 2011.

[55] "Hoskin Scientific," HOBO Temperature Logger, [Online]. Available: http://www.hoskin.ca/catalog/index.php?main_page =index&cPath=2_671_683.

[56] "PICO Technology," PT 100 Platinum Resistance Thermometers, [Online]. Available: http://www.picotech.com/applications/pt100.html.

[57] "ES-SENS Equipments and Sensors," Industrial Scientific (ISC) iTarns Gas Detector, [Online]. Available: http://www.es-sens.com/P_e.asp?id=178.

[58] P. Bonnet, J. Gehrke and P. Seshadri, "Querying the Physical World," Cornell University, Ithaca.

APPENDIX

Matlab code for Trilateration Problem

```
% trilati.m
% define observations
d1=6.7691;
d2=10.4773;
d3=11.9717;
l=[d1;d2;d3];
% define the sigmas and weights
sigd1=0.5;
sigd2=0.2;
sigd3=0.2;
% define a priori sigma-naught squared
sig0=0.5;
W=eye(3);
W(1,1)=sig0^2/sigd1^2;
W(2,2)=sig0^2/sigd2^2;
W(3,3)=sig0^2/sigd3^2;
W
% the points
xa=0;
ya=10;
xb=10;
yb=0;
xc=10;
yc=10;

xf=140;
yf=90;
B=zeros(3,2);
f=zeros(3,1);
max_iter=10;
iter=1;
keep_going=1;
% convergence variables
phi=10;
last_phi=20;
threshold=1.0e-06;
while keep_going == 1
```

```
  d_af=sqrt((xa-xf)^2 + (ya-yf)^2);
  d_bf=sqrt((xb-xf)^2 + (yb-yf)^2);
  d_cf=sqrt((xc-xf)^2 + (yc-yf)^2);
  % make coefficients of the condition equations
  B(1,:)=[(xa-xf)/d_af  (ya-yf)/d_af];
  B(2,:)=[(xb-xf)/d_bf  (yb-yf)/d_bf];
  B(3,:)=[(xc-xf)/d_cf  (yc-yf)/d_cf];

  f(1)=-(d1 - sqrt((xa-xf)^2 + (ya-yf)^2));
  f(2)=-(d2 - sqrt((xb-xf)^2 + (yb-yf)^2));
  f(3)=-(d3 - sqrt((xc-xf)^2 + (yc-yf)^2));

  if iter == 1
    disp('iteration 1 B,f,W');
    B
    f
    W
    end
  % now solve and update and check convergence
  N=B'*W*B;
  t=B'*W*f;
  iter
  del=inv(N)*t
  xf=xf + del(1);
  yf=yf + del(2);
  v=f-B*del;
  phi=v'*W*v;

  if( abs(phi-last_phi)/last_phi < threshold )
    keep_going=0;
    disp('we have converged');
    end
  last_phi=phi;
  if iter > 10
    keep_going=0;
    disp('too many iterations');
    end
  iter=iter+1;
  end;

disp('final coordinates');
[xf yf]
disp('residuals');
v=f - B*del
lhat=l + v
```

Matlab code for Neville algorithm

```
function y = neville ( xi, fi, t )

%NEVILLE     evaluate the Lagrange form of the interpolating polynomial
%            associated with a given set of interpolating points and
%            function values at a single point
%
%    calling sequences:
%            y = neville ( xi, fi, t )
%            neville ( xi, fi, t )
%    inputs:
%            xi      vector containing the interpolating points
%            fi      vector containing function values
%                    the i-th entry in this vector is the function
%                    value associated with the i-th entry in the 'xi'
%                    vector
%            t       value of independent variable at which interpolating
%                    polynomial is to be evaluated
%
%    output:
%            y       value of the interpolating polynomial associated with
%                    the given set of interpolating points and function
%                    values at the indicated value of the indepedent
%                    variable
n = length ( xi );
m = length ( fi );

if ( n ~= m )
  disp ( 'neville error: number of ordinates and number of function values must be equal'
  return
end

temp = fi;
for j = 2:n
   for i = n:-1:j
      temp(i) = ( (t-xi(i-j+1))*temp(i) - (t-xi(i))*temp(i-1) ) / ...
              ( xi(i) - xi(i-j+1) );
   end
end
if ( nargout == 0 )
  disp ( temp(n) )
else
  y = temp(n);
end
```