INTRUDER LOCALIZATION WIRELESS SENSOR NETWORK RADAR
DESIGN WITH VIRTUAL REFERENCE TAGS

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ABSTRACT

This research designs a WSN (Wireless Sensor Network) algorithm for human intruder localization and path detection. There are two commonly used position estimation techniques in WSN, ToA (Time of Arrival) and RSSI (Received Signal Strength Indicator). In ToA the difference between arrivals of signal is estimated and based on this information position of target is calculated. This technique produces better results but in real time the cost of nodes used increases due to synchronization requirement. On the other hand RSSI technique requires no synchronization and can be considered as most simple and low cost technique but its accuracy is very low. To increase the accuracy of RSSI this research introduces VRTs (Virtual Reference Tags). VRTs are previously used in RFID (Radio Frequency Identification) system to provide reference to the system. Four reference nodes are used such that one acts as transmitting while three as receiving nodes. These nodes are placed at the edges of surveillance area. NS2 (Network Simulator 2) is used to design the WSN. The surveillance area of system is taken as 80X80 meters. Nine scenarios are checked with varying number of VRTs mapped over surveillance area. From the results it is observed that as the number of VRT is increased, accuracy of WSN radar also increases. But in actual implementation greater number of VRT can result in greater hardware requirement in terms of processor and high speed data storage. Since the proposed WSN radar is designed for human intruder localization, the WSN accuracy is kept to 0.2 meters. In simulation for a surveillance area of 80X80 meters to locate and track human intruder with 0.2 meter accuracy, 1721 VRTs are required to be virtually mapped over surveillance area. This research also presents a proposed design of WSN which can be used in vehicles as road safety feature providing assistance to driver. The WSN consists of three receivers, one on each side and one in front and the surveillance area around the vehicle is divided into levels which determine whether it is safe for driver to move towards that side. Driver alerting method is also presented using vehicle's steering wheel.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

P -   Power transmitted in watts (W).

B -   Bandwidth of the signal in hertz (Hz).

P_r -   Received signal strength

P_t -   Transmitted signal strength

G_r -   Receiver antenna gain

G_t -   Transmitter antenna gain

λ -   Wavelength of transmitted signal

d -   Distance between nodes

L -   System loss

h_t^2 -   Height of transmitter antenna

h_r^2 -   Height of receiver antenna

t_1 -   Time of departure of signal

P_{r-UWB}^{LOS} -   Line of sight received signal strength in UWB

$P_{r-UWB}^{t\,\arg et}$ -   Target reflected received signal strength in UWB

t_2 -   Time of arrival of signal

s_r -   Signal propagation speed (speed of light)

d	-	Distance between transmitting and receiving node
s_s	-	Slower propagation speed signal (ultrasound signal)
x, y	-	Coordinates of unknown node
x_1, y_1, x_2 y_2, x_3, y_3	-	Locations of the reference nodes
d_1, d_2, d_3	-	Distance of unknown node from reference nodes
S_t	-	Total surveillance area
S_r	-	Surveillance region of each VRT
$\sum_{i=1}^{n} VRTs$	-	Total number of VRTs used
f_L	-	Lower frequency
γ	-	The minimum delay between direct and reflected signal
c	-	Speed of light
AoA	-	Angle of Arrival
APS	-	Ad Hoc Positioning System
BB	-	Bounding box
CLS	-	Cricket Localization System
DA	-	Design Accuracy
DPE	-	Directed Position Estimation
GPS	-	Global Positioning System
ID	-	Indoor
LMB	-	Localization Mobile Beacon
ML	-	Multilateration
OD	-	Outdoor
P	-	Probabilistic
PC	-	Position computation

RE	-	Range estimation
RN	-	Reference Nodes
RT	-	Reference Tags
RRT	-	Real reference tags
RSSI	-	Received Signal Strength Indicator
RPE	-	Recursive Position Estimation
RFID	-	Radio Frequency Identification
SA	-	Surveillance area
TL	-	Trilateration
TA	-	Triangulation
TDoA	-	Time Difference of Arrival
ToA	-	Time of Arrival
UWB	-	Ultra Wide Band
VRT	-	Virtual reference tags
WSN	-	Wireless Sensor Network

LIST OF APPENDICES

LIST OF PUBLICATIONS

Journals:

(i)   Hadi Abdullah, Ijaz Khan, Mohd Shamian Bin Zainal (2013), "Improved UWB wireless sensor network algorithm for human intruder localization." Research Journal of Applied Sciences, Engineering and Technology. © Maxwell Scientific Organization.

(ii)   Hadi Abdullah, Ijaz Khan, Mohd Shamian Bin Zainal (2012) "Ultra Wide Band localization and tracking hybrid technique using VRTs." International Journal of Integrated Engineering, UTHM, Vol. 4 No. 3 (2012).

(iii)   Hadi Abdullah, Ijaz Khan, Mohd Shamian Bin Zainal (2013) "Low cost Ultra Wide Band hybrid radar design using virtual reference tags as road safety feature in vehicles", Journal of Information and Communication Technologies, Vol. 3, No. 4, April (2013).

(iv)   Hadi Abdullah, Ijaz Khan, Mohd Shamian Bin Zainal (2013) "Clutter removal technique using virtual reference tags for intruder localization in ultra wide band radar network.", International Journal of Engineering and Applied Sciences, EAAS, Vol 3, No. 3, (2013).

(v)   Ijaz Khan, Hadi Abdullah, Mohd Shamian Bin Zainal (2013) "Efficient fatigue detection system as road safety feature for vehicle" Research Journal of Applied Sciences, Engineering and Technology . © Maxwell Scientific Organization.

(vi)   Ijaz Khan, Hadi abdullah, Mohd Shamian Bin Zainal (2013) "Efficient eyes
         and mouth detection algorithm using combination of Viola Jones and skin
         color pixel detection." International Journal of Engineering and Applied
         Sciences, EAAS, Vol 3, No. 3, (2013).

(vii)   Ijaz Khan, Hadi Abdullah, Mohd Shamian Bin Zainal (2013) "A Robust
         Hybrid Design for Driver Fatigue Detection", Journal of Information and
         Communication Technologies, Vol. 3, No. 4, April (2013).
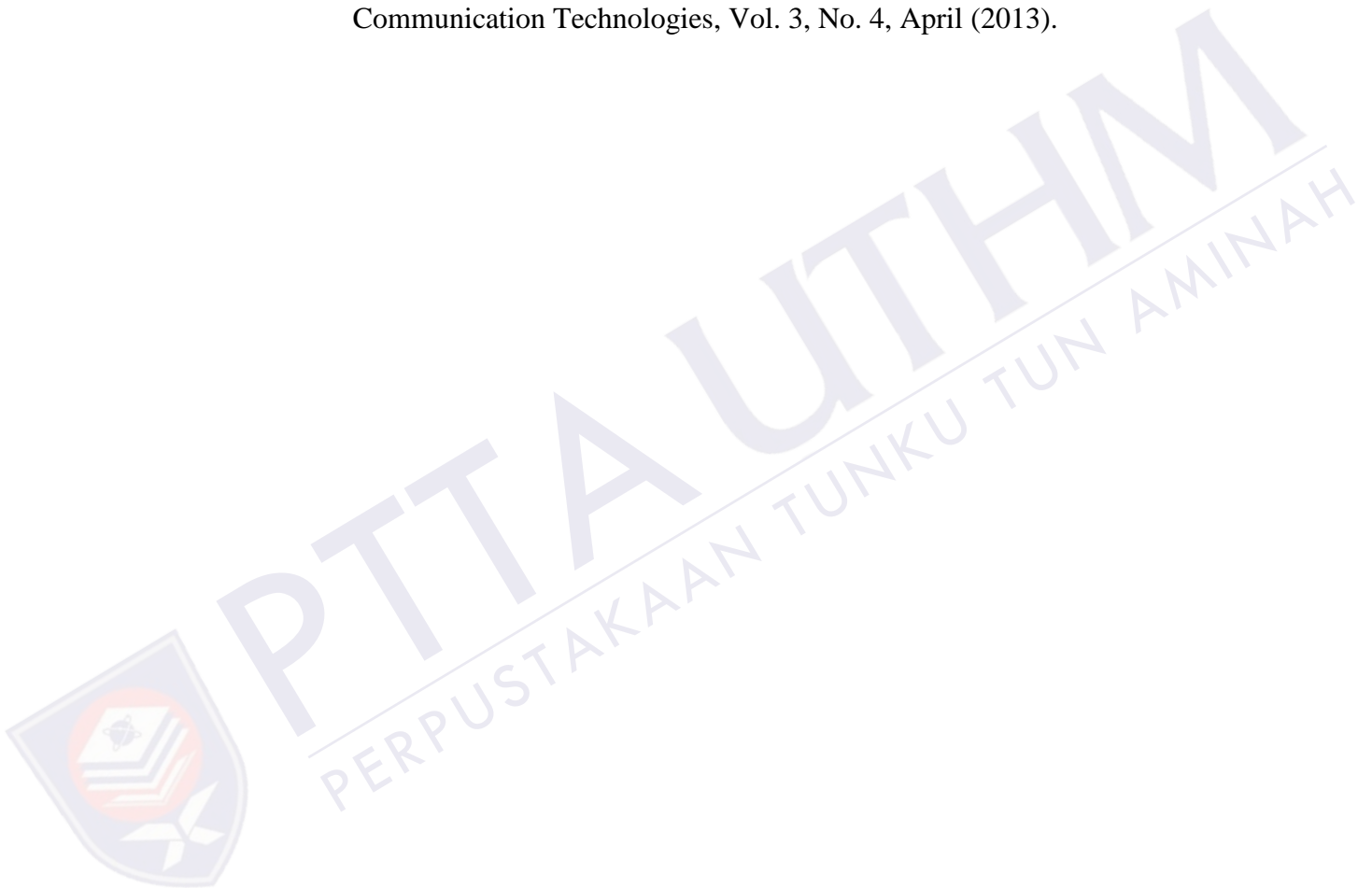
Proceedings:

(i)   Hadi Abdullah, Ijaz Khan, Mohd Shamian Bin Zainal "Proposed Wireless Sensor Network in vehicles for road surveillance", IEEE conference on system, process and control (ICSPC 2013), 13-15 December 2013, Kuala Lumpur, Malaysia.

(ii)   Hadi Abdullah, Ijaz Khan, Mohd Shamian Bin Zainal "Improved range estimation method in WSN for human intruder localization" 10th IEEE colloquium on signal processing and its applications (CSPA 2014), 7-9 March 2014, Kuala Lumpur, Malaysia.

(iii) Hadi Abdullah, Ijaz Khan, Mohd Shamian Bin Zainal "Wireless sensor network algorithm for localization based on ToA and RSSI" Malaysian Technical Universities Conference on Engineering & Technology (MUCET 2013), 2-4 December 2013, Kuantan, Malaysia.

(iv)   Hadi Abdullah, Ijaz Khan, Mohd Shamian Bin Zainal "Improved Received Signal Strength Indicator localization algorithm with Virtual Reference Tags", Prosiding Seminar Kebangsaan Aplikasi Sains dan Matematik 2013 (SKASM2013) Batu Pahat, Johor, 29 – 30 October 2013.

(v)   Ijaz Khan, Hadi Abdullah, Mohd Shamian Bin Zainal "Vision based composite approach for lethargy detection" 10th IEEE colloquium on signal processing and its applications (CSPA 2014), 7-9 March 2014, Kuala Lumpur, Malaysia.

(vi)   Ijaz Khan, Hadi Abdullah, Mohd Shamian Bin Zainal "Efficient fatigue detection system as road safety feature for vehicle" Malaysian Technical Universities Conference on Engineering & Technology (MUCET 2013), 2-4 December 2013, Kuantan, Malaysia.

(vii)   Ijaz Khan, Hadi Abdullah, Mohd Shamian Bin Zainal "Non intrusive alerting system for drowsy drivers", Prosiding Seminar Kebangsaan Aplikasi Sains dan Matematik 2013 (SKASM2013) Batu Pahat, Johor, 29 – 30 October 2013.

CHAPTER 1

INTRODUCTION

1.1   Overview

Radio detection and ranging, abbreviated as RADAR was first patented in Germany in 1904 by Christain Hulsemeyer (Pritchard, 1989). The first used of radar systems was to detect other ships and prevent from collision in fog. The technology was refined over the years and its military importance was recognized. In the intercourse of Second World War both Germany and United Kingdom used radars to detect enemy's aircrafts and radar technology developed quite rapidly and resulting in radar systems small enough to carry along in naval vessels and aircrafts. Most radar systems that we use today are not fundamentally different for those which were used in 1940s (Swords, 1996; Galati, 1993). Our recent technologies such as computers have changed the way we process and display radar information but the basic technology is same. Radar is technically defined as a system which sends out electromagnetic energy in form of pulses, these pulses travel unhindered unless any object comes in their path. Three basic phenomena occurs when these pulses interact with object, first some portion of energy is reflected back, secondly the object absorbs a portion and thirdly some just pass through the object. Since transmitted energy is divided after collision with object, the reflected energy is very weak. Appropriate receivers are used in radar systems which can detect these weak reflections and use their information in object identification and localization (Tait, 2005). With increase in technology radar systems are designed to detect targets in with more precision and accuracy on ground and on water. Their range can be designed for inside as well as outside earth's atmosphere. The nature of targets also varies for different designs like aircrafts, ships, vehicles, human being, missiles,

tanks etc. Smaller and high speed targets are able to be detected using more advance hardware and algorithmic techniques (Farina, 1987).

Ultra Wide band (UWB) have evolved in wireless communication systems due to its vast applications while co-existing with other licensed and unlicensed narrow band systems. To overcome its interference with other narrow band systems the transmitted power of UWB systems are controlled by regularities such as Federal Communication Commission (FCC) in United States. Due to its wide band, systems using UWB provides more information than other short range narrow band counter parts. UWB in modern world is defined as a wireless communication technology that uses signal bandwidth greater than 500 MHz or fractional bandwidth greater than 0.2(Huseyin Arslan, 2012). System using UWB have several advantages over ones using narrow band in short range communication. Firstly, it provides a wide range of unlicensed spectrum, which not only increases the performance but also increases its scope of application. Exemplary time resolution is another key benefit of UWB. Low power transmission increases UWB system applications to portable design. UWB has several applications from wireless communication to radar imaging and localization systems. Its unique properties have allowed its implementation in short range radars, providing excellent accuracy and precision of targets. High resolution imaging is obtained in UWB systems which has vast medical applications. Accurate time estimation and precise ranging has opened doors for UWB systems in luxury vehicles for road monitoring, auto parking, collision avoidance, auto breaking systems etc. Target localization is one of the great applications of UWB systems which have recently gained attraction. Despite of its high advantages UWB also have some challenging features in its designs. Some of them are:

(i)   System design which can handle strong narrow band interference.

(ii)   Low power transmitter and receiver design.

(iii)   Accurate synchronization.

(iv)   Powerful processing capabilities.

(v)   Wide band antenna designs.

(vi)   High sampling rate for digital implementations.

(vii)   Complex algorithm designs.

Radar localization systems use different algorithm to extract information from reflected signals. The constituents of localization systems can be divided in following main parts.

(i)   Range estimation: Angle and distance is calculated between nodes which help in estimating targets location.

(ii)   Position Computation: Bases on calculated distance and angle this part calculates position of nodes.

(iii)   Localization Algorithm: This is the main component of a localization system. In this part different algorithms are used to extract information and estimate location of unknown nodes or targets.

In case of Wireless Sensor Network (WSN) there are many localization algorithms having different hardware requirements and varying accuracies (discussed in detail in chapter 2). Table 1.1 shows a comparison of precision, surveillance area range, extra hardware required and challenges in designing of different present localization methods (Boukerche, 2009).

Table 1.1: Comparison existing methods used for distance/angle estimation

Method	Precision	Maximum Distance	Extra Hardware	Challenges
RSSI	Meters (2-4 m)	Communication range	None	Variation of the RSSI, interferences
ToA	Centimeters (2-3 cm)	Communication range	None	Nodes synchronization
TDoA	Centimeters (2-3 cm)	Few meters (2-10m)	Ultrasound transmitter	Maximum distance of work
AoA	Degrees (5)	Communication range	Set of receivers	Work on small sensor nodes

Reference tags are used in some narrow band tracking systems providing reference to track intruder or object. These systems use a number of sensor nodes. Reference tags are symmetrically placed over the surveillance area and a tag is given to the intruder while entering in surveillance area (Ni *et al.*, 2011). There are number of limitations to these kind of systems. For example for an unknown intruder with no tag they cannot be localized, positioning of actual reference tags symmetrically over

surveillance area makes the system complicated, greater number of sensor nodes are used making these system suitable only in the case of limited surveillance area. In this research we have given an improved radar algorithm design which virtualizes reference tags and their information is kept in receiving nodes. Secondly number of sensor nodes are reduced to four (having one transmitting node and three receiving nodes), and Received Signal Strength Indicator (RSSI) tracking techniques are used in which there is no need for the intruder to carry a tag. Whenever intruder arrives in surveillance area it is monitored with RSSI localization technique and Virtual Reference Tags (VRTs) provide reference point closest to actual intruder location. This algorithm design has no synchronization problem (like in ToA) and has greater accuracy than RSSI.

1.2   Problem statement

WSN human intruder localization system are small in size and require less system resources compared to other localization radar systems. But there are also limitations in application and localization of WSN. Combination of different range estimation techniques with position estimation methods and localization algorithms gives us WSN designs with varying system properties and area of application. For human intruder localization WSN radar design previously presented (discussed in chapter 2, section 2.8) have a number of limitation in terms of less accuracy, hardware requirement, area of application, surveillance area range and additional tags requirement for localization.

For places which have large surveillance area like nuclear reactors, airports, hospitals, military bases etc require a system which can provide surveillance in longer ranges and have good accuracy. In previously presented system range of the systems differs with range estimation technique applied. In this research we have introduced VRTs which when virtually mapped over surveillance area increases WSN range (discussed in chapter 3, section 3.4).

For human intruder localization WSN system previously ToA technique is used. This technique gives radar design accuracy of up to 2 cm (Enrico Paolini, 2008) . But in actual implementation ToA technique requires high level nodes synchronization which increases system hardware requirement and cost of each node.

On the other hand RSSI range estimation technique gives less accuracy but requires very no additional hardware assistance in actual implementation. In this research we have used RSSI range estimation technique and improved its performance with VRTs in terms of accuracy, cost and surveillance range.

Previously VRTs are used in RFID systems which used them to locate target carrying a reference tag. These systems have low surveillance are due to design of actual tags with virtual tags. This makes these systems application limited to indoor localization of known targets which carry tag. To overcome these limitations in our design we have virtualized all reference tags and their information is kept at each receiver or at fusion center connecting three receivers (discussed in chapter 3, section 3.1).

Increasing technology in vehicles makes them faster, comfortable and easy to drive. But on the same time it makes drivers too comfortable and unaware of the ground situation on which they are driving. The National Highway Traffic Safety Administration (NHTSA) of USA estimates that 100,000 police-reported crashes each year (NHTSA., [On- line]. Available: http://www.nhtsa.dot.gov/). This results in an estimated 1550 deaths, 71,000 injuries, and $12.5 billion in monetary losses. Many systems are presented that detect drowsiness and assist driver by alerting. These systems use monitoring eyes, facial expression detection, yawning state detection, heart rate variability and other physical approaches (Ijaz Khan, 2013). The main drawback of these systems is that they lack in accuracy in many cases. For example, if driver wears sun glasses eyes monitoring fails. In yawning detection if driver puts hand in front of his mouth while driving, yawning state cannot be detected and every person has his own facial features so having system suitable to extract all types of features is difficult (Omidyeganeh *et al.*, 2011; Weiwei *et al.*, 2010; Abtahi *et al.*, 2011; Hariri *et al.*, 2011).

Previously WSNs have been used in different designs such as targets localization (Sichitiu &Ramadurai, 2004), wild life safety (Viani *et al.*, 2011), vehicle speed and traffic control (Ding *et al.*, 2008) and has many other applications (Boukerche, 2009). The reason why WSNs are preferred over other system is its low cost and small system size. Advances in WSNs provide new designs having greater functionality and accurate results. But on the same time their cost also increases. This makes it difficult to be accessed by mediocre buyers. Same is the case with most of

the radar systems presented as collision prevention assistant in vehicles. Their size and cost contradicts with implementation in compact and low budget vehicles (Dickmann *et al.*, 2012).

This research presents a solution to this problem by presenting a proposed radar design which can provide surveillance around the vehicle to its driver, assisting the driver to drive safely. The design uses UWB technologies over a WSN consisting of four sensor nodes. The localization algorithm of WSN uses ToA, AoA and RSSI information to locate position of other vehicles in surveillance area.

1.3   Objectives of the Study

The objectives of this project are:

(i)   Design a WSN algorithm by using RSSI position estimation technique and modify with VRTs.

(ii)   Design VRTs as clutter removal technique for objects other then target in surveillance area.

(iii)   Propose a WSN radar application in automobiles as road safety feature.

1.4   Scope of the study

Our study is mainly focused on intruder tracking techniques in radar systems. We have combined WSN localization techniques to form a hybrid. Further hybrid design is modified using VRTs which overcomes synchronization problem in transmitter and receiver and received signal distortion. The work is done only on the physical layer WSN system. The WSN transmitter sends UWB pulses which when reflected from the target are observed at three receivers. The intruder in our system is considered to be a human intruder with radar crossection (RCS) to be $1\,m^2$. The information of VRTs is kept at receiver or at fusion center of three receivers. For clutter removal the system can remove clutters of objects other than target whose RCS is previously known. Overall the WSN in this research is designed for human intruder localization with accuracy of 0.2 to 0.4m. The number of VRTs effect

accuracy of WSN radar. Greater number of VRTs result in greater accuracy but on the same time it increases system hardware requirement in actual implementation.

1.5   Aim of the study

The aim of this research is to develop an algorithm of UWB radar localization system that can extract the information from target reflected signal and using that information can locate target location accurately. Also design the algorithm that can remove clutters created by different object other than target in surveillance area. Further, use the same algorithm with some modification to design road surveillance system for vehicles.

1.6   Significance of the Study

As technology drifts towards innovations, so does the security problems in areas that are critical such as airports, hospitals, nuclear reactor, army base etc. For a large area camera monitoring becomes difficult to implement and cost high. Radar designers are now focusing on systems that are long range, free of tags and are easy to implement and reliable. Our research outcome is a hybrid radar design that is easy to implement, low cost, efficient, long range, high accuracy and reliable. This hybrid design is not only limited to target localization and path detection but also with little modification it can be used in scenarios for example in disaster case it can be used to locate trapped people under building rubble or in a mine. Another application of the hybrid radar design is in automobiles. With some design modification this radar design can be used in vehicles to monitor the road up to a specific distance to locate other vehicles. This can give vehicle road surveillance to prevent from accidents and can be used in automatic break system and automatic car parking.

1.7   Novelty

In this research we have introduced reference tagging concept in UWB radar localization algorithms. Reference tags (previously used in RFID) are virtualized to assist in range estimation technique. RSSI range estimation technique is used with VRTs mapped over surveillance area. This has increased accuracy of RSSI from 2-4 m to 0.2-0.4m.

1.8   Project Schedule

The full project schedule is given in APPENDIX A table A.1.

1.9   Outline of the Thesis

The main parts of this thesis presents hybrid intruder localization algorithm for WSN which is discussed, analyzed and compared with other co-existing algorithms.

The remainder of this thesis is structured as follows:

Chapter 2 - Literature Review This chapter shows details about localization systems from multistatic radar designs to complex WSN systems. Further, WSN components which are range estimation techniques, position computation method and localization algorithms are explained and compared. Lastly intruder localization systems presented by different authors closest to our design are given with their system design, accuracy and limitations.

Chapter 3 - Methodology Presents the system design which uses three receivers and one transmitter. Also this chapter shows how VRTs are virtually mapped over surveillance area and what information each VRT has for a particular location. The system design flowchart is also given in this chapter. Chapter 3 also describes proposed WSN application in automobiles.

Chapter 4 - Results And Analysis This chapter presents simulation results of designs which are based on chapter 3 methodology. First single point intruder is

introduced in surveillance area of 10x10m with 100 VRTs. For moving target NS2 simulator is used and nine different cases intruder localization and tracking is simulated with varying number of VRTs.

Chapter 5 - Conclusion And Future Work summarizes and concludes the thesis, while highlighting venues for future research.

CHAPTER 2

LITERATURE REVIEW

This chapter presents detailed description of related terms, methods and algorithms which are either used or are related to this research project. It starts by giving introduction to radar technology and its types namely monostatic, bistatic and multistatic radar. After this, UWB technology is discussed in details with its pros and cons and why UWB frequencies are used in this research project. WSNs being an important part of the research are extensively defined and discussed. With their basic system components and system requirements, their applications in different aspects are also given.

Localization algorithms (a part of WSN component) are the key focus of this research. This chapter gives a detailed review of the commonly used WSN localization algorithms which are ToA, RSSI, TDoA and AoA. Whenever the system nodes have enough information, they need to calculate target's position. To calculate position of target, the system can use one of these methods which are discussed in section 2.6. There are several methods which include trilateration, multilateration, triangulation, probabilistic approaches, bounding box, and the central position.

A list of comparative designs with their system requirement, range and challenges in designing are given in table 2.1. Radio frequency identification RFID systems which have introduced reference tags and VRTs for localization are also part of this chapter. These localization systems have improved their performance by using reference tags but on the same time have some drawbacks which make limits their application. The UWB localization design which this research has improved by introducing VRTs is discussed in detail at the end of this chapter.

2.1 RADAR

According to Merrill l. Skolnik (Skolnik, 1990) The basic concept of radar is relatively simple even though in many instances its practical implementation is not. Radar operates by radiating electromagnetic energy and detecting the echo returned from reflecting objects (targets). The nature of the echo signal provides information about the target. The range, or distance, to the target is found from the time it takes for the radiated energy to travel to the target and back. Based on the number of transmitter and receiver, radars can be differentiated into three categories which are:

(i)   Monostatic radar

(ii)   Bistatic radar

(iii)   Multistatic radar

2.1.1 Monostatic radar

Monostatic radars are one in which transmitter and receiver is co-located and uses a single antenna to transmit and receive the signal. Merrill l. Skolnik (Skolnik, 1990) explains the basic parts of a monostatic radar system in simple block diagram of figure 2.1. The radar signal, usually a repetitive train of short pulses, is generated by the transmitter and radiated into space by the antenna. The duplexer permits a single antenna to be time-shared for both transmission and reception. Reflecting objects (targets) intercept and reradiate a portion of the radar signal, a small amount of which is returned in the direction of the radar. The returned echo signal is collected by the radar antenna and amplified by the receiver. If the output of the radar receiver is sufficiently large, detection of a target is said to occur. Radar generally determines the location of a target in range and angle, but the echo signal also can provide information about the nature of the target. The output of the receiver may be presented on a display to an operator who makes the decision as to whether or not a target is present, or the receiver output can be processed by electronic means to automatically recognize the presence of a target and to establish a track of the target from detections made over a period of time. With automatic detection and track (ADT) the operator usually is presented with the processed target track rather than the raw radar detections.
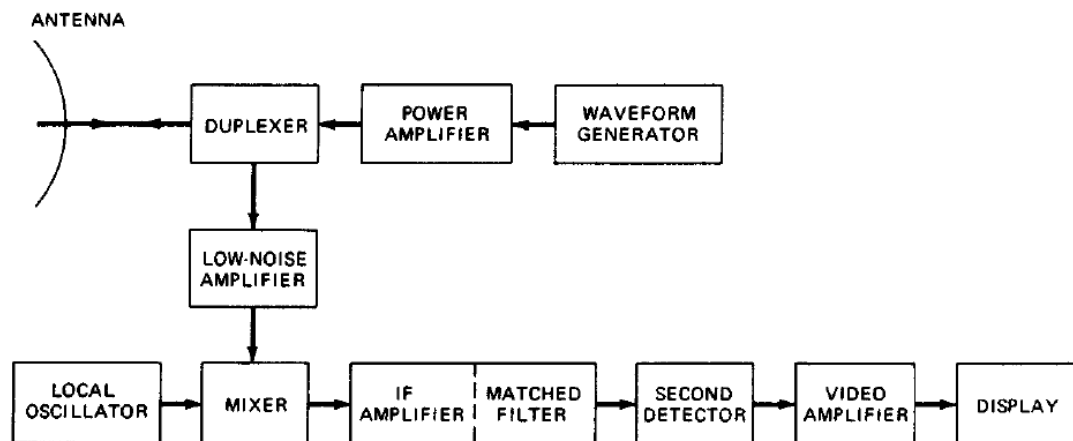
Figure 2.1: Simple block diagram of a monostatic radar system by Merrill l. Skolnik

2.1.2   Bistatic radar

Bistatic radar is defined as a radar that uses antennas at different locations for transmission and reception (IEEE, 1982). Nicholas J. Willis explains the concept of bistatic radar as, a transmitting antenna is placed at one site and a receiving antenna is placed at a second site, separated by a distance L, called the baseline range or simply baseline. The target is located at a third site. Any of the sites can be on the earth, airborne, or in space, and may be stationary or moving with respect to the earth. Figure 2.2 shows Nicholas J. Willis presented bistatic radar geometry and typical requirements for bistatic radar operation.

While the necessary condition in the bistatic radar definition is that the antennas be at different locations, the entire transmitting subsystem is almost always located at one site and the entire receiving subsystem is located at a second site. The IEEE definition (IEEE, 1982) does not clearly state that how much the distance should be between transmitter and receiver. Different people have tried to define the amount of distance. Skolnik in his work (Skolnik, 1980) specified the distance as "a considerable distance." In his previous work (Skolnik, March 1961), he explained considerable distance to be "comparable with the target distance," while providing examples of a few miles to several hundred miles for aircraft targets and hundreds to thousands of miles for satellite targets.
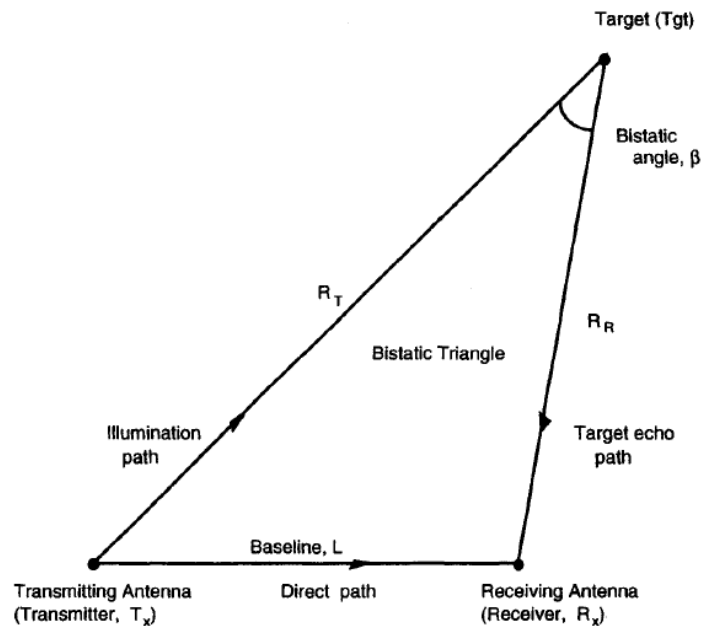
Figure 2.2: Bistatic radar geometry by Nicholas J. Willis

2.1.3   Multistatic radar

Multistatic radars are also referred as 'multisite' or 'netted' radars. These types of radars work on the same principle of radar with some distance between a number of transmitters and/or receivers. These pair of transmitters and receivers may adopt the same geometrical configuration of either monostatic or bistatic radar. The geometry of bistatic radar is considered more closely related to multistatic radar because both have some distance between transmitter and receiver and also require synchronization of nodes. Commonly the sharing of transmitter-receiver pairs for the same surveillance area is known as multistatic radar. This sharing of surveillance area increases the complexity of reflected signal but gives better information about the target hence giving multistatic radar multiple advantages over monostatic and bistatic radars. In multistatic radar it is important to have a system which can interpret the data from the signals and present useful information to its user (Doughty, 2008). Figure 2.3 shows an example of multistatic radar with three transmitters and one receiver.
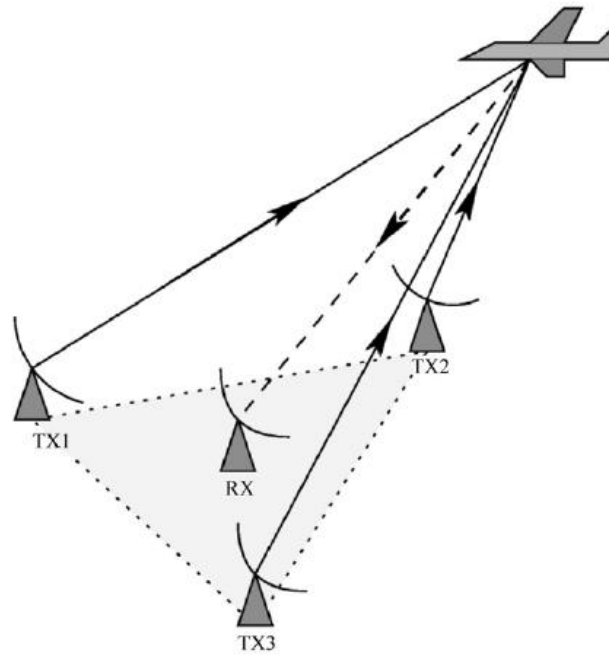
Figure 2.3: Multistatic radar with three transmitters and one receiver (Amanipour &Olfat, 2011)

Most detailed work done on multistatic radar is by Chernyak in 1998 (Chernyak, 1998). In his work first he defines multistatic radars with some of its characteristic followed by listed pros and cons of the system. Then he describes historical background and military functions and usage. Detection algorithms for target detection are discussed in chapter 2 of his book(Chernyak, 1998). Localization algorithms vary in the context of transmitter-receiver pair's information sharing within a surveillance area. Localziation algorithms, are discussed in chapter 3 of his book(Chernyak, 1998) followed by how they can be used in most efficient way for maximum outcome in different scenarios. This work is inclusive and provides extensive information about multistatic radar to the readers.

2.2   Ultra Wide Band (UWB)

UWB technologies provide a promising solution for accurate target localization and path detection in wireless networks. Federal Communication Commission (FCC) in United States of America (USA) classifies a signal to be UWB if it's bandwidth is greater than 500MHz or it has a fractional bandwidth greater than 0.2 (Commission,

April 2002). Where as in Europe a signal is UWB if its bandwidth is greater than 50MHz (Communities, February 2007).

The power spectral density of UWB systems is generally considered to be extremely low, especially for communication applications. The power spectral density (PSD) is defined as (Ghavami *et al.*, 2004) :

$$PSD = \frac{P}{B} \text{ (W/Hz)} \tag{2.1}$$

where,

P : power transmitted in watts (W).

B : bandwidth of the signal in hertz (Hz).

Previously only narrow band frequencies were used which increased PSD whereas in UWB PSD is kept very low. Table 2.1 shows a comparison transmitted power, bandwidth and PSD of some commonly used wireless broadcast systems.

Table 2.1: A comparison of PSD of commonly used broadcast systems (Ghavami *et al.*, 2004)

System	Transmission power [W]	Bandwidth [Hz]	PSD [W/MHz]	Classification
Radio	50 kW	75 kHz	666,600	Narrowband
Television	100 kW	6 MHz	16,700	Narrowband
2G Cellular	10 mW	8.33 kHz	1.2	Narrowband
802.11a	1 W	20 MHz	0.05	Wideband
UWB	1 mW	7.5 GHz	0.013	Ultra wide band

The energy used to transmit a wireless signal is not infinite and, in general, should be as low as possible, especially for today's consumer electronic devices. If we have a fixed amount of energy we can either transmit a great deal of energy density over a small bandwidth or a very small amount of energy density over a large bandwidth. This comparison is shown for the PSD of two systems in figure 2.4. The total amount of power can be calculated as the area under a frequency-power spectral density graph.
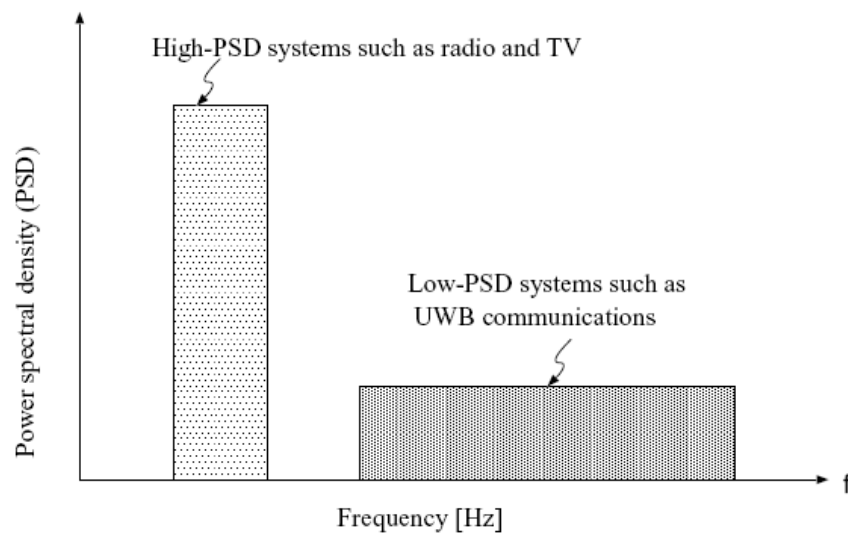
Figure 2.4: Low-energy density and high-energy density systems (Ghavami *et al.*, 2004)

2.2.1 Advantages of using UWB technologies

The advantages of using UWB technologies, but limited to are (Enrico Paolini, 2008):

(i)   Low power consumption.

(ii)   High accuracy (centimeter).

(iii)   Positioning can also be done in indoor environments.

(iv)   Low probability of interception (high security).

(v)   High data rates

(vi)   Low equipment cost

(vii)   Multipath immunity

From above discussion we can see why the use of UWB is preferred in anti-intruder wireless networks. So far intruder detection systems using UWB are presented under different name such as wireless sensor network, UWB multistatic radar and radar sensor networks (Kunz, October 2007; Sakamoto, 2005; Liang, 2007).

2.3   Wireless Sensor Network (WSN)

A wireless sensor network is composed of a number of wireless devices which are able to take environmental measures in a given surveillance area. These wireless sensors transmit their information to an application system where which make decision based on the information they have received. WSN are considered as one of the most technologies for the twenty- first century (Jun Zheng, 2009). Huge development is being made on the design and deployment issues of WSNs and significant advances are done in application and algorithm of WSNs. It is suspected that in coming future WSNs will be a part of most of daily use items and play a significant role in military fields.

2.3.1   Network characteristics

Generally a WSN is composed of a number of sensor nodes which are designed in such a way that they can perform multiple function on the same time while keeping their cost and power consumption low. These nodes are designed with sensors, microprocessors and transceivers giving them the ability to sense the situation, process the information and them communicate the results with system. They accomplish inter-communication by using a wireless channel and share their gathered sensor information to make a system that can monitor environment, light sound, humidity, or intruders with specific sizes and shapes. According to Jun Zheng WSNs have the following uniqueness and limitations when compared with other wireless networks (Jun Zheng, 2009):

(i)   Dense Node Deployment. Sensor nodes are usually densely deployed in a field of interest. The number of sensor nodes in a sensor network can be several orders of magnitude.

(ii)   Battery - Powered Sensor Nodes. Sensor nodes are usually powered by battery. In most situations, they are deployed in a harsh or hostile environment, where it is very difficult or even impossible to change or recharge the batteries.

(iii)   Severe Energy, Computation, and Storage Constraints. Sensor nodes are highly limited in energy, computation, and storage capacities.

(iv)   Self - Configurable. Sensor nodes are usually randomly deployed without careful planning and engineering. Once deployed, sensor nodes have to autonomously configure themselves into a communication network.

(v)   Application Specific. Sensor networks are application specific. A network is usually designed and deployed for a specific application. The design requirements of a network change with its application.

(vi)   Unreliable Sensor Nodes. Sensor nodes are usually deployed in harsh or hostile environments and operate without attendance. They are prone to physical damages or failures. Frequent Topology Change. Network topology changes frequently due to node failure, damage, addition, energy depletion, or channel fading.

(vii)   No Global Identification. Due to the large number of sensor nodes, it is usually not possible to build a global addressing scheme for a sensor network because it would introduce a high overhead for the identification maintenance.

2.3.2   Wireless sensor network applications

WSN have a vast scope of application that proposed as well as actually implemented. These applications include the fields of military, environmental and medical. Keeping in mind the advantages of WSNs over wired networks this section discusses some application of WSNs in different fields.

(i)   **Military**: Wireless sensor networks play the key role in command, control, communications, computing, intelligence, surveillance, reconnaissance, and targeting (C4ISRT) systems of the military. These systems can be used to track soldiers, monitor weapon transportation, battlefields surveillance and detection of chemical or nuclear attacks. WSN are also used in locating and tracking vehicles and tanks providing an advantage of better strategy of attack and defence. The information of all the army units in different battlefields can be gathered on a single platform. WSNs can also be used to detect and track army troops, vehicles and tanks when deployed in precarious areas. Programmable sensor nodes when deployed in surveillance area can send information whenever they sense any movement and can remain hidden until

they sense some information. For example in figure 2.5 the sensor nodes are deployed over the surveillance area. When enemy tanks arrive their information is passed on through the surveillance area. The soldiers upon receiving information about enemy tanks movement path, can relocate themselves to counter the attack (Jun Zheng, 2009).
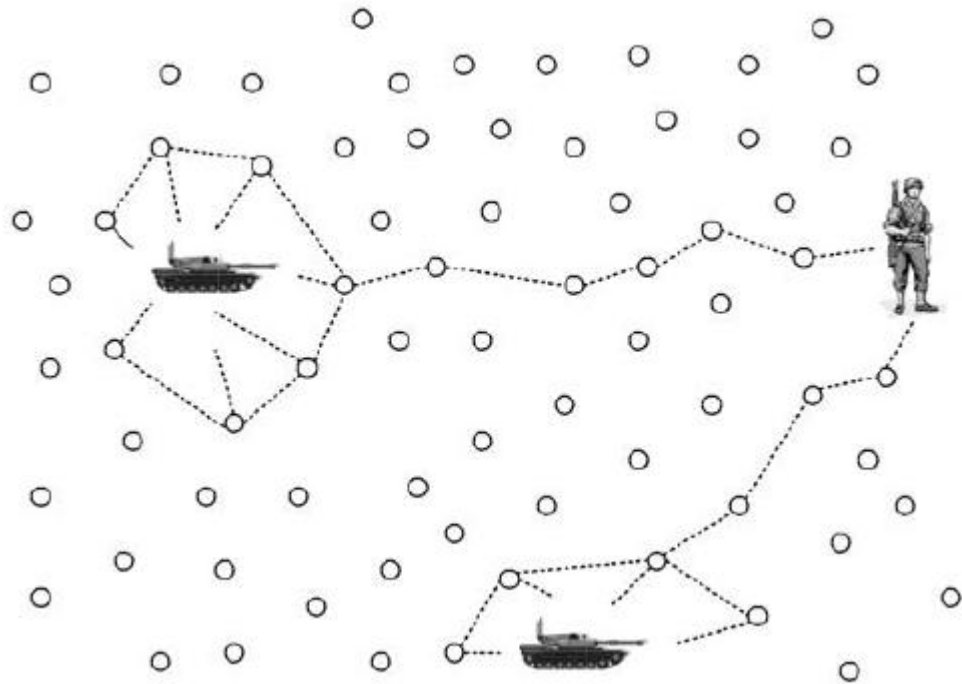
Figure 2.5: WSN in surveillance area for enemy target localization (Stojmenovic, 2005)

(ii) **Environmental monitoring:** Environmental monitoring is one of the earliest applications of sensor networks. In environmental monitoring, sensors are used to monitor a variety of environmental parameters or conditions. WSNs can be used to monitor animals and plants in their natural habitat. These sensors when deployed in water and air can monitor hydro chemical fields and pollution by sending sensed samples to system. These sensors can also be used in hazardous locations for example monitoring the environment surrounding a nuclear plant or a chemical industry. In case of disasters such as forest fires WSN can identify can locate the position of fire. Floods can also be monitored over a specific surveillance area. Figure 2.6 shows a fire monitoring application of WSN. When there is a fire the sensor nodes send

the information of location and severity of fire to the system which guides fire fighters to arrange a team based on severity of fire and send it to the location given by WSN system (Jun Zheng, 2009).
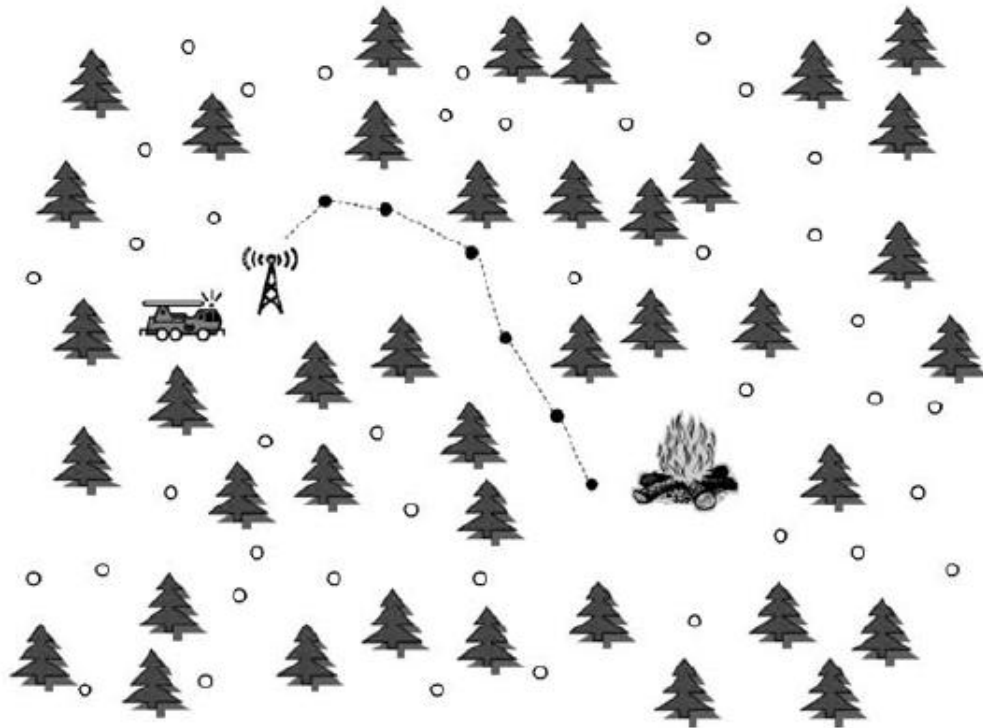
Figure 2.6: WSNs application as disaster monitoring system (Stojmenovic, 2005)

(iii)   **Health applications:** WSN provide a great application in medical for elderly and patients in case of health care monitoring. This helps in reducing the shortage health care working in this field (Jafari *et al.*, 2005). WSNs can be deployed over a patient's house which monitor the movement of patient while he moves around the house and guide him whenever doctors suspect any this wrong. This also helps in emergency cases like patients accidently fells down or has a heart attack etc. WSNs can also be integrated with wearable sensors and can send information about patient's physical conditions. This helps in making a record of the patient's body signatures over a specific medical treatment and can alert doctors if they sense something out of order (Trossen &Pavel, 2007).

(iv)   **Security and surveillance:** WSNs can be used for security and surveillance in critical regions such as hospitals, nuclear power plants and airports etc. WSNs can provide surveillance over large areas in which other methods like

video surveillance are difficult to install and cost more than WSN systems. WSNs can also provide surveillance in regions having fog of dust storms where video surveillance fails (Feng Zhao).

(v)   **Industrial applications:** WSNs can be used in industries to monitor manufacturing equipment, process and products. The sensor network can identify if any equipment is broken or there is a faulty product. Also WSNs can be used to monitor workers giving information of their location and the work they are doing.

(vi)   **Intelligent housing:** WSNs can provide a more comforting, convenient and time saving lifestyle to its users. These systems can monitor house temperature according to the user requirement and send its information to user through internet. Water level and temperature of a swimming pool, cooking stove temperature, quantity of food items in refrigerator and microwave oven can also be controlled using WSNs (Herring &Kaplan, 2000). TV, DVD and CD players can also be monitored and controlled based on the requirement of all the family members.

2.3.3   Wireless sensor network design objectives

Different application makes diversity in designs of WSNs based on the ground situation for which they are being designed. This makes WSNs complicated to propose and general design objectives. But some aspects of all WSNs are common can we can say they are the key focus in a general WSN. These design objectives are (Jun Zheng, 2009):

(i)   Node size.

(ii)   Node cost.

(iii)   Power consumption.

(iv)   Configuration in a network.

(v)   Scalable number of nodes.

(vi)   Adaptive to changes.

(vii)   Reliable information delivery.

(viii) Secure.

(ix)   Utilization of network resources.

2.4   Localization system in wireless sensor networks

The locations of nodes are not predesigned, which can cause huge amount of error in information the sensors pass back to the system. In order to remove this error location of node needs to be calculated. This is done by using localization systems. In WSNs sensor node monitor a given surveillance area and send their information back to system where the information of these sensor nodes are merged to calculate the findings and it becomes important to find out from which node this information has arrived. Since WSNs have vast applications and their design vary from each other so having localization system requires some properties which it need to fulfill. Some of these properties are:

(i)   The localization system should fit in all type of infrastructures and automatically organize itself within the WSN.

(ii)   The system should be fast and robustly process the information which is gathered by sensor nodes.

(iii)   The system must be designed to tackle any amount of sensor nodes.

(iv)   System efficiency should be high such that it utilize all the available resources

The localization systems can be divided into three major components namely range estimation, position computation and localization algorithms (briefly described in chapter 1).

2.5   Range estimation

Range estimation is done by calculating angle or distance between nodes. Range estimation is one of the most important aspects of localization system because its information is then used by localization algorithm to locate the target. There are different methods that can be used to calculate angle or distance between nodes. They differ in accuracy, cost, hardware, power consumption and processing time. The commonly used methods are:

(v)   Received Signal Strength Indicator (RSSI)

(vi)   Time/Difference of Arrival (ToA/TDoA)

(vii)   Angle of Arrival (AoA)

2.5.1   Received Signal Strength Indicator (RSSI)

The strength of signal received by the node is used to measure its distance from signal source in RSSI. The main disadvantage is in actual environment the signal gets interrupted by noise, clutters and antenna type, causing high inaccuracy in localization. The strength of signal received by the node is used to measure its distance from signal source. Greater the distance, lower the signal strength when it arrives to node. The signal strength weakens as the inverse of square distance, theoretically. The disadvantage is that in actual environment the signal gets interrupted by noise, clutters and antenna type, causing high inaccuracy in localization. An error of 2 to 3 meters is shown in surveillance area communication range of 10 meters through experimentation (Savvides *et al.*, 2001). Figure 2.7 shows a transmitting node which is transmitting a signal which gradually loses its signal strength.

Communication Range

Figure 2.7: Decreasing signal transmitted by a transmitting node. The signal is send with specific signal strength which decreases as the square of distance. In real world different other factors also contribute in decreasing signal strength (Boukerche, 2009)

In case of controlled environment and simulation RSSI show conceivable results but in actual scenario their design is still doubtable(Chengdu *et al.*, 2003). But considering the low cost surveillance systems offered by RSSI it becomes impossible to completely ignore RSSI method.

In 1946 Friis presented signal propagation formula in ideal condition without obstacle or any interference, providing a way to calculate received signal for any

system with known parameters (Friis, 1946). Equation 2.2 represents Friis formula to calculate received signal strength in ideal condition.

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

(2.2)

Where,

P_r : Received signal strength

P_t : Transmitted signal strength

G_r : Receiver antenna gain

G_t : Transmitter antenna gain

λ : Wavelength of transmitted signal

d : Distance between nodes

L : System loss

In 1996 Theodore extended equation 2.2 while considering signal reflection from ground (Rappaport, 1996). Equation 2.3 represents Theodore's equation which can be used to calculate received signal strength while considering signal reflections from the ground.

$$P_r(d)_b = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4 L}$$

(2.3)

Where,

h_t^2 : Height of transmitter antenna

h_r^2 : Height of receiver antenna

2.5.2 Time/Difference of Arrival (ToA/TDoA)

In ToA the distance between two nodes is calculated by measuring the difference of time at which signal was send by one node and received by the other. The distance between two sensor nodes placed at a measurable distance is directly proportional to

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