Energy Efficient Localization in Wireless Sensor Networks With Noisy Measurements

MS Research Dissertation

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Final Approval

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Declaration

I hereby declare that this work, neither as a whole nor as a part has been copied out from any source. It is further declared that I have accomplished this thesis entirely on the basis of my personal efforts and under the sincere guidance of my supervisor Dr. Sadaf Tanvir and Co-Supervisor Prof. Dr. Muhammad Sher and all my family members and colleagues. If any part of this project is proved to be copied out from any source or found to be reproduction of some other project, I shall stand by the consequences. No portion of the work presented in his dissertation has been submitted in support of any application for any other degree or qualification of this or any other university or institute of learning.

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Project in Brief

Project Title:	**Energy Efficient Localization in Wireless Sensor Networks with Noisy Measurements**
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Supervised By:	**Dr.Sadaf Tanvir**
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System used:	**Pentium 4, 2.6 GHz**

Abbreviations Used

Abbreviations	**Meanings**
SNL	**Sensor network localization**
OBP	**Optimized Beacon Protocol**
DV	**Distance vector**
SDP	**Semi Definite Programming**
GPS	**Global positioning system**
AOA	**Angle of Arrival**
RSSI	**Received Signal Strength Indicator**
TDOA	**Time Difference of Arrival**
TOA	**Time of Arrival**
APIT	**Approximate point in Triangulation**
MDS	**Multidimensional scaling**
RF TOF	**Radio Frequency Time of Flight**
TWR	**Two Way Ranging**
UNs	**Unlocalized nodes**
RMs	**Range Messages**

Abstract

Sensor Network Localization (SNL) is subject that has attracted the interest of researchers. It is the process of finding or computing the location of randomly deployed sensor nodes in sensor network. SNL protocols find the location of unknown nodes by using prior knowledge of known nodes. One of such approach is the Optimized Beacon Protocol (OBP). It reduces the energy consumption in terms of Communication cost in the localization process. However, it does not incorporate errors during distance and position estimates of sensor nodes. The scope of this thesis is to study and evaluate the performance of OBP in terms of communication cost vs. accuracy tradeoffs.

Table of Contents

List of Figures

Chapter 1

Introduction

Micro-Electro-Mechanical Systems(MEMS) technology and wireless communication enabled the development of low cost, multifunctional tiny sensor nodes that communicate over short distances. Sensor network is composed of thousands of tiny sensor nodes act as source and one or more base stations called as sink [1]. Sensor nodes possess limited processing power, memory, communication and energy capabilities. Power saving techniques tends nodes to sleep most of the time to increase their life. While sink is a resource enriched computer. WSNs can be structured and unstructured in nature. An unstructured WSN contains a collection of sensor nodes arranged in an ad hoc manner in the field i.e. they are randomly deployed in sensor field. In a structured WSN, sensor nodes are placed according to some specific pattern at fixed locations. Sensor nodes use broadcast communication and they do not have global identification as they are large in number. They are deployed where climate and environmental constraints hinder the deployment and setting up of regular networks [2].

1.1 Sensor Network Applications

WSN applications are broadly classified into monitoring and tracking.

- Monitoring applications includes:

- Indoor/outdoor environmental monitoring.
- Health and wellness monitoring
- Power monitoring
- Location monitoring
- Factory and process automation, and
- Seismic and structural monitoring.

Tracking applications includes:

- Tracking objects, animals, humans, and vehicles.

For performing specific tasks, sensor nodes should know their locations to enable themselves to communicate with their neighboring nodes.

> The process of finding node's location (i.e. position) is known as localization.

It helps to remove uncertainty in the exact location of some fixed or mobile devices. For example to calculate the temperature and humidity in a forest where sensor nodes are randomly deployed through an aero plane. In such situation it is difficult for human being to find the exact location of nodes so a well defined localization protocol can use available information from sensor nodes to compute the position of sensor nodes.

1.2 Localization Methods

[2]Describes existing localization methods:

- Satellite based Global positioning system (GPS) localization
- Beacon (or anchor) nodes based localization, and
- Proximity-based localization

Nodes equipped with GPS receiver can directly obtain their location by communicating with a GPS satellite.GPS are not favourable for indoor localization of nodes as it requires line of sight communication. Delay in Satellite communication is not favorable for real time tracking moving sensor nodes.
GPS location technology is not suitable in some situations due to:

1. Huge cost
2. Large size
3. Extensive infrastructure
4. LOS (line of sight) communication
5. Reasonable power consumption of receiver

The Beacon Method uses beacon (anchor) nodes with known location and help to localize other unlocalized nodes (UNs) or non-anchor nodes. Beacon nodes are also called Anchor nodes (ANs). This method is not effective for large networks due to environmental conditions. Proximity based localization uses neighboring anchor nodes to get their position and then act as beacons (anchors) for other nodes to localize them.

1.3 Motivation and Objectives

Position awareness ability of sensor nodes along with the desired data enables themselves to work efficiently during various applications such as Geographic routing or Target movement monitoring. The process of localization should be distributed by the nodes and start automatically after network being deployed. As sensor nodes are energy constraint, should use minimum amount of energy during localization resulting position estimates should of be of desired accuracy.
Sensor nodes normally use radio frequency transmission as it is affordable for sensor node. Radio Frequency (RF) has long range and does not require additional hardware .Nodes transceiver performs communication during localization. Computation aspect of nodes consumes less energy than communication among nodes. So communication should

be minimized among sensor nodes.
One way time of flight of radio signal requires tight synchronization among transmitter and receiver clocks making this approach less appealing for sensor networks. Radio signals two way time of flight enable sensor nodes to communicate with each other without clock synchronization. In this dissertation, localization in WSNs based on the use of two way time of flight of radio signal for calculating internode distances. Radio communication helps in reducing energy consumed by nodes during the process of localization.

1.4 Thesis Organization

The rest of thesis is organized as follows. Chapter 2 describes the structure of sensor node, localization process in WSN, taxonomy of localization process. Chapter 3 gives overview of related work done in localization. Chapter 4 explains the actual identified problem briefly. Chapter 5 provides the proposed solution of the identified problem. Chapter 6 describes the implementation and simulation details of the proposed solution with results. Chapter 7 contains the conclusion and future work.

Chapter 2

Localization in WSNs

2.1 A Sensor Node

WSN is composed of numerous tiny devices called as sensor nodes or motes. These nodes are randomly deployed having self-organizing capability to make a senor network. A typical sensor node consists of hardware and software components. Hardware components consist of sensing unit, a processing unit, a transceiver unit and a power unit [1]. Figure 2.1 shows the structure of typical sensor node.

2.1.1 Sensing unit (Sensor Node Hardware)

Sensing unit further composed of sensor and analog to digital converters (ADCs). Analog signals produced from some event are converted into digital signals by this converter and then these readings are transferred to processor.

2.1.2 Processing unit

Processing unit is concerned with storage that contains two types of memory i.e. Random Access Memory (RAM) and Read Only Memory (ROM). RAM stores data before sending it and store communication packets received from other nodes.ROM also called flash memory stores the programs and operating system of sensor nodes.

2.1.3 Transceiver unit

This unit uses radio frequency as communication medium that connects sensor nodes to other sensor nodes or base station/sink. Maximum

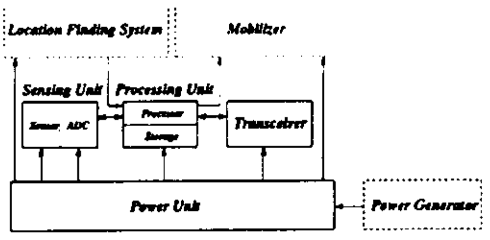

Figure 2.1: Components of sensor node [1]

distance of sensor node communication is 100 meters. It works between the frequency range of 433MHz and 2.4GHz. It has four operational modes. It can sleep, remain idle, transmit and receive.

2.1.4 Power unit

Power unit is the backbone of the sensor node. All other units of sensor node cannot work even for one second without this power unit. If sensor node has large energy resource it means sensor node will live for long time. Long time means more sensing, more computation and more communication. The life of the sensor is directly proportional to the energy budget. Among all components of sensor transceiver takes more energy than all because it has to communicate with other senor nodes for transmitting and receiving data. The processing unit takes very less energy for its computation. Location knowledge is required by sensor network for routing and sensing tasks and it is provided by location finding system of sensor node. A mobilizer moves the sensor node to perform designated tasks.

2.2 Sensor Node Software

Hardware components of sensor node are useless without software that runs these components. TinyOS [70], Contiki [11] and Nano-RK [69] are common operating systems for sensor nodes. TinyOS is the first operating system developed for sensor nodes. It is a joint project of University of California, Berkeley and Intel Research but later on became a great success for most other sensor nodes as well. TinyOS has component based architecture. Contiki is another open source operating system for sensor nodes. It typical configuration uses 2K of RAM and 40K of ROM. It has an event-driven kernel which dynamically loads and unloads the application programs on runtime .Nano-Rk is a real-time operating system developed at Carnegie Mellon University. The term 'Nano' implies that it consumes a very small amount of memory i.e. 2K of RAM and 18K of flash.'RK' stands for Resource Kernel. Its resource kernel provides a mechanism for managing sensor node's energy by creating a virtual budget for node's resources [3].

2.3 The Process of Localization

Localization is the process of finding the position of an object. Localization history traced back to prehistoric times when human beings were fascinated in finding the location of their ships/crafts in oceans. They called this process as Navigation.Polynesians used direction of ocean winds and tides and positions of sun, planets, constellations and stars to navigate. Vikings are reported to use coastal lines and a tool called sun compass to know their direction. Ancient Greeks were the first ones to use maps with latitudes and longitudes to calculate position. These advancements led the Arabs and Europeans sailors know how to navigate using a magnetic compass and clock. Developments in this area continued and at present navigation have been revolutionized by the development of Global Positioning System (GPS).

2.4 Taxonomy of Localization Process

WSN localization Literature can be classified in two main categories:

1. Exogenous Approach
2. Endogenous Approach

2.4.1 Exogenous Approach

Exogenous approach is based on an external infrastructure which estimates the positions of nodes and maintains them. Initial works on localization uses exogenous approaches. Famous approach includes: RADAR

RADAR

[3]RADAR is a system developed by Microsoft Research group in 2000. It is based on IEEE 802.11 technology that is used in homes these days. It uses wireless LANs infrastructure and base stations to measure received Signal Strength (RSS) and signal to noise ratio (SNR) to get location information. It can localize objects based on lateration. The system gives an accuracy of 4.3m 50 percent of time with lateration. These initially proposed exogenous schemes were used to localize objects and people. They did not match well for localizing WSNs because of WSN's distinctive characteristics specially the decentralized nature where every node is capable of estimating its position by itself.

2.4.2 Endogenous Approach

In Endogenous approach, the nodes may make use of external infrastructure like the gathering of GPS satellites but they calculate and maintain position by themselves. Most of the WSN localization techniques belong to this class.

2.5 The Localization Process

Endogenous approach of localization in WSN is carried out in several steps. Existing literature has a large number of independent localization approaches sharing resemblance.

According to [13] Localization in WSN is performed in three steps:

1. Estimate distance beotween anchor nodes and unlocalized nodes
2. Derive position of each unlocalized node using estimated anchor distance.
3. Inter node collaboration refines estimated node position.

Three steps mentioned above are carried out during sensor nodes localization. In [3] author proposed a refined localization model shown in figure 2.2. The first phase in this process can be considered as the 1-hop measurement / communication phase. During this phase an unlocalized node (UN) 'a' wants to get distance estimates from anchor

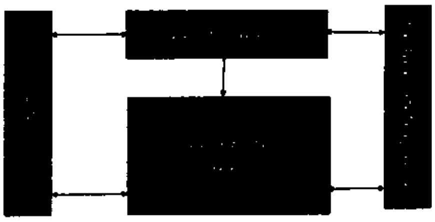

Figure 2.2: Localization Block Diagram [3]

node (AN) which is placed at several hops away from it. In such situation an unlocalized node 'a' will communicate its 1-hop neighbors', in this way 'a's' message will be delivered to anchor node through multiple hops. We saw that 1-hop measurement / communication is energy efficient for WSN and does not cause network congestion. After this phase UN 'a' got its distance estimates from anchor node.After getting raw estimates of distance from anchor node, "Local process" is second phase in figure 2.2. It uses raw data to calculate its distance within sensor node itself and then estimates its position. After getting initial position estimates, Global process phase helps neighboring nodes to localize remaining nodes through Internodes' communication. 1-hop measurement/communication phase and global process phase perform message exchange using wireless Medium Access Control (MAC) layer.

Chapter 3

literature survy

Literature Review No boundaries and constraints in research field, truth-seeker and ingenious can actively contribute in this field. Pioneers work cannot be ignored and neglected by the emergence of new researches. Similarly before conducting our this research we have studied books, thesis, different articles, research publications and other related material to determine what has been done in this domain earlier and to find out the gaps that are present in this specific area from which we have drawn our problem.
Sensor Network Localization (SNL) increased interest of people in recent years. Typical sensor network is composed of thousands of sensor nodes deployed in a physical area to monitor environmental data. Sensor data from these nodes is appropriate only if their location (or position) is known. Position finding techniques are based on distance measurement between neighboring nodes. Position finding of all nodes using few anchor nodes and distance information is called as position estimation or localization problem. Various efficient methods have been proposed in literature for getting distance estimation between neighboring nodes. They are divided into Range free and Range based methods.

3.1 Range-Free Method

It uses hop-count and topology information for position estimates and gives approximate node positions. It has no assumptions about the availability of distance or range estimates. In following section few range free methods are described.

3.1.1 DV (Distance Vector) Hop

Adhoc positioning system (APS) uses distance based on hop-by-hop fashion between unlocalized nodes and anchor nodes.It gives DV-hop and DV-distance methods.In DV-hop technique, anchor nodes broadcast their location (i.e. position information) including their node IDs and hop count field (initially set to 0) across the network [4].The relaying nodes forwards this information to its neighbors and maintains this information in a table.When the distance between two anchor nodes is found then average size for one hop is calculated and used as correction factor across the entire network.

$$cor_i = \frac{\sum \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum h_j}, i \neq j \tag{3.1}$$

Upon receiving such information,the relaying nodes increment hop count field by one, in this way every node can determine how many hops it is away from certain (Anchor) node and vice versa. Using this information average hop-distance between two nodes is calculated by using formula: distance between two nodes/ number of hops. This average distance is broadcast across the network to compare with already known hop distances. Triangulation method is used to find the position of unlocalized nodes using these distances. In figure 3.1 unlocalized node Nj is 4 hops (shown with thin line), 2 hops (shown with thick line), 1 hop (shown with solid line) away from anchor nodes A1, A2, A3 respectively.

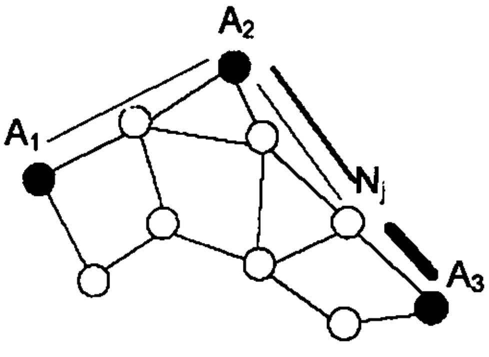

Figure 3.1: The DV-Hop localization scheme [5]

3.1.2 HOP-TERRAIN

Similar approach is adopted for finding distance between anchor nodes and unlocalized nodes as DV-Hop. It works in two stages: First stage is startup stage in which unlocalized nodes get average distance from anchor nodes using formula: distance between two nodes/ number of hops and get initial position estimates. 2nd stage for refinement, one-hop message exchange with neighboring nodes is performed to refine initial position estimates. Here position estimates of node is broadcast. neighboring node receives these estimates and distance information between itself and neighboring node. Then using least square method (LSM), a node refines its position iteratively until to get final position [6].

3.1.3 Centroid System

N.Bulusu and J.Heidemann [7] proposed a range-free, proximity-based, coarse grained localization algorithm that uses multiple anchor nodes with overlapping regions of coverage. Their placement is non-uniform and they get their coordinates using GPS receiver equipped with them. They transmit their synchronized beacon signals in order to avoid collisions among them. Neighboring anchor nodes use randomized scheme to avoid collisions. In this scheme time interval T is further subdivided into several smaller time slots. Each anchor nodes chooses slot randomly with uniform distribution to transmit their beacon signals. A node Nk localizes itself in the centre of quadrilateral A1 A2 A3 A4 shown in figure 3.2.

Figure 3.2: Centroid localization[5]

Anchor nodes have ranges labeled from A1 to AN with known locations (X1,Y1) to (XN,YN). A node after receiving beacon signals from anchor nodes, uses following formula to find its location:

$$(X_{est}, Y_{est}) = [\frac{X_1+,\ldots,+X_n}{N}, \frac{Y_1+,\ldots,+Y_n}{N}] \quad (3.2)$$

Where

$$X_{est}, Y_{est}$$

are the estimated locations of unlocalized nodes in x,y coordinates.

3.1.4 APIT

APIT (Approximate point in Triangulation)[8] is another range free area-based localization scheme. It gets location information by dividing the area into overlapping triangles shown in figure 3.3. Anchor nodes have a priori location knowledge via GPS.

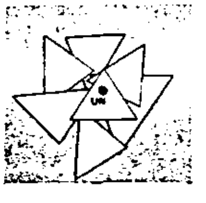

Figure 3.3: APIT overview: An area-based scheme

APIT Works in Following Steps:

1. After hearing beacon message from ANs, UNs maintains a table with these fields (Anchor ID, Anchor location, and Signal Strength) for each anchor node.
2. Table is exchanged by UNs with its 1-hop neighbour to show the state of neighboring nodes.
3. UN chooses three anchor nodes that have beacons and test whether it is in triangle formed by these anchor nodes. This test is called as Point-In-Triangulation Test (PIT).
4. PIT test is repeated with other anchor nodes combination to get the required accuracy.

5. Centre of gravity (COG) at the intersection of all triangles is determined where a node (i.e. UN) resides to find node's estimated position.

3.1.5 Gradient Algorithm

[5] Proposed the Gradient algorithm, a gradient begin by anchor nodes that helps a sensor node to get its distance from the anchor node. After estimating distances from three anchors a sensor node gets its own location through multilateration. It uses hop count value between a sensor node and anchor node. This algorithm works in the following steps:

1. An anchor node Ai broadcast beacons that contain coordinates and hop count value initially set to one in sensor network.

2. Each sensor node Nj stores shortest path (in terms of hop count hj,Ai) to anchor node Ai from which it received beacons. Following formula is used to get distance between sensor node and anchor node:
$$d_{ji} = h_j, A_i, d_{hop} \tag{3.3}$$
Where dhop is the estimated Euclidian distance covered by one radio hop.

3. Each node Nj computes its coordinates(i.e. position) by using multilateration so that to get minimum total error:
$$E_j = \sum_{i=1}^{n}(d_{ji} - d_{ji}) \tag{3.4}$$
where
$$d_{ji} = \sqrt{(x_i - x_j)^2 - (y_i - y_j)^2)}$$

Based on distance estimation approach, localization algorithms are classified into two categories: centralized algorithms and distr buted algorithms. In centralized approach there exists centralized information system such as road traffic monitoring and control, environmental monitoring, health monitoring [10]. All distances between sensor nodes are sent to a centralized processing unit for determining the position of nodes by creating the map of entire network. It includes Multidimensional scaling (MDS) based approaches [10, 11] and Semi Definite

Programming (SDP)[12] based algorithms. In MDS whole sensor network is divided into smaller groups. Each group has at least three anchor nodes which find the relative position of sensor nodes in each group and builds up local maps. Several local maps are combined to make estimated global map by using common sensor in each group. The position of anchor nodes in global map is used iteratively along with true location of anchor nodes to get final estimated global map [10]. MDS is based on robust quadraterials scheme to estimate the position of unknown nodes. Quadraterials are appropriate for localization as they are considered sub graphs for localization.Figure 3.4 shows robust quadraterials with four vertices, knowing the location of any three vertices we can find the location of fourth vertices using trilateration.

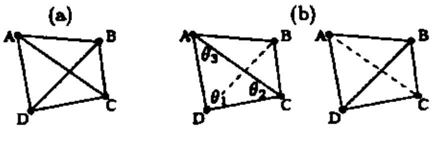

Figure 3.4: MDS robust quadrilateral [11]

Limitations: The drawback of this approach is that under conditions of low node connectivity or high measurement noise, the algorithm may be unable to localize a useful number of nodes.

SDP (Semi definite Programming) [12] handles error in position estimation problem. Node position estimation techniques rely on distance measurement between neighboring nodes. It uses few anchor nodes to find the accurate position of unknown nodes. It uses convex optimization to handle position estimation problem. A polynomial-time algorithm solves SDP and it is generalized form of a linear program. General form of SDP is: Minimize

$$c^T x \tag{3.5}$$

subject to:

$$F(x) = F_0 + x_1 F_1 +, \ldots, +x_n F_n \tag{3.6}$$

$$Ax < b \tag{3.7}$$

$$F_i = F_i^T \tag{3.8}$$

where

$$x = [x_1, x_2, \ldots, x_n]^T$$

and x represents the coordinate vector of node.The quantities A, b, c and Fi are all known. The inequality 3.7 is known as a linear matrix inequality (LMI). A connection between node i and j can be represented by a 'radial constraint' on the node locations

$$\|x_i - x_j\| \leq R$$

where R is the transmission range. Centralized algorithms give accurate results than distributed approach but they are not scalable hence they are not suitable for implementing large sensor network. They have higher computational complexity and gives unreliable results due to accumulated inaccuracy caused by multihop transmission in WSN [10].

3.2 Range-Based Method

It uses distance measurements (i.e. range) or angle estimates between anchor nodes and unlocalized nodes to find location estimates. In literature various Distance estimating techniques exist. Some of them are explained below.

3.2.1 Angle of Arrival (AOA)

Angle of arrival is distance-estimation technique between ANs and UNs by using signal's angle between line of sight of UN and at least two anchor nodes [3]. Angle information helps to find the location of UNs. In figure 3.6 UN gets two angles 1, 2 from two anchor nodes AN1 ,AN2 and estimates its internal angle . Such angles information is then used to find location of UN using triangulation method.AOA method for distance estimation is expensive due to directional antennas [13].

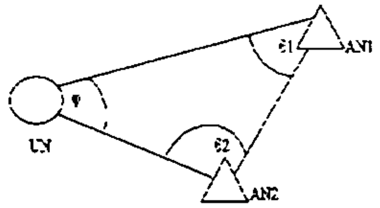

Figure 3.5: AOA distance measurement method

3.2.2 Time of Arrival (TOA)

This technology is commonly used as a means of obtaining range information via signal propagation time. The most basic localization system to use TOA techniques is GPS. GPS and other TOA technology present a costly solution for localization in wireless sensor networks [7]. This technique is also called as Time of Flight (ToF) technique.

3.2.3 Time Difference of Arrival (TDOA)

It broadcast two different signals, calculates their time difference of arrival at destination. This difference is then converted into distance based on signal propagation speed to obtain distance between UN and AN. In figure there is transmitter rt that transmits signals and various receivers (with known positions) like r1, r2, r3 and r4. They receive transmitted signals at different times [9].

$$\Delta t_{ij} t_i - t_j = 1/c(\|r_i - r_t\| - \|r_j - r_t\|), i \neq j \tag{3.9}$$

Where: ti is time when receiver ri receives, tj is time when receiver rj receives,and c the propagation speed of the signal,

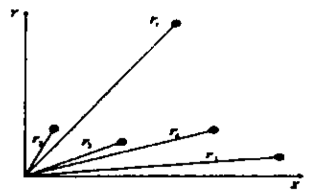

Figure 3.6: TDOA-Distance Estimation Technique

3.2.4 Received Signal Strength Indicator (RSSI)

References [9, 13] present a scheme proposed for finding the distance between transmitter and receiver. It finds out distance between neighboring nodes by received signal strength of the radio signal at the receiver. Packets received from transmitter by receiver, receiver gets RSS value in the form of Inverse Square of distances between transmitter and receiver. Received power Pr(d) is related to distance'd' is given by Friis equation [14]:

$$P_r(d) = P_t G_t G_r \lambda^2/(4\Pi)^2 d^2 \qquad (3.10)$$

3.2.5 Radio Frequency Time of Flight (RF TOF)

Range estimations can be obtained by measuring the radio frequency time of flight of travelling message from one node to another. This time of flight is measured at the physical layer. It is suitable for WSN due to high speed, multipath propagation (MP). less hardware requirements and lack of highly synchronized clocks. Radio signals can penetrate wall's obstruction and give meter level location accuracy. Mechanism of using RF TOF with two messages is known as the Two Way Ranging (TWR) technique [3]. In RF TOF TWR clock synchronization of both transmitter and receiver is not necessary as they have their own reference clocks. Optimized Beacon Protocol (OBP) proposed by [3] used RF TOF TWR for energy efficient localization. In this protocol ANs broadcast beacon message (BM) to show their presence. A starter node starts the localization process by sending query message or range message (RM) in response to beacon messages. UNs overhear RM from neighboring UNs and start sending their RM. This process is shown in figure 3.7.

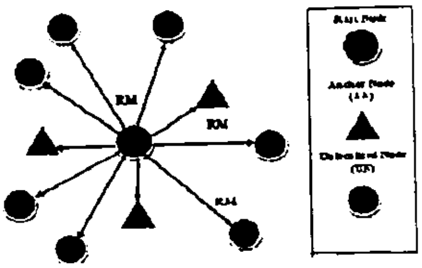

Figure 3.7: OBP working

Sending RM in response to BM constitutes first step of TWR. ANs after receiving RM unicast response messages or acknowledgement messages (AM) makes second step of TWR.AM contains AN's coordinates and distance between UN and AN. Using this information, UN use trilateration method to find its position. Currently, the protocol has been implemented considering an ideal MAC, ideal node communication model and a perfect radio propagation model. Hence, the distance estimates obtained through ranging process are accurate and as a result location of UNs is also accurate. In fact ranging process when done in a wireless medium does give errors in distance that result in false node positions. Such errors and their management are not handled in this protocol.The mechanism of OBP is shown in fig 3.8.

MAIN STEPS: 1. AN1, AN2, AN3 sends hello message to their 1 hop neighbors. This message includes x, y coordinates of anchors/source.
2. UN1 receives all hello messages from all of its anchors. But UN2 receives hello messages only from AN1, AN2.
3. UN1 sends/broadcasts REQUEST message to all of their 1-hop neighbors. In the mean time, UN2 receives this request from UN1 and its size of the number of received messages becomes 3.Now it waits for a predefined delay to send its request message.
But remember UN1 does not include its x, y coordinates in the request message. 4. UN1 receives ACK messages from their ANCHORS. These unicast messages include the x, y coordinates of the source.
5. When UN1 becomes LOCALISED node, it will include its x, y co-

ordinates in the ACK messages.
6. UN2 sends a REQUEST message to its 1-hop neighbors. Once AN1, AN2 and UN1 receive this message, they will reply in the form of ACK messages in which x, y coordinates of the sources are included.
It means that anchors not only know the location of other anchor but also the unlocalized nodes.
It is only the unlocalized node that knows the location of localized/anchor nodes and its own.

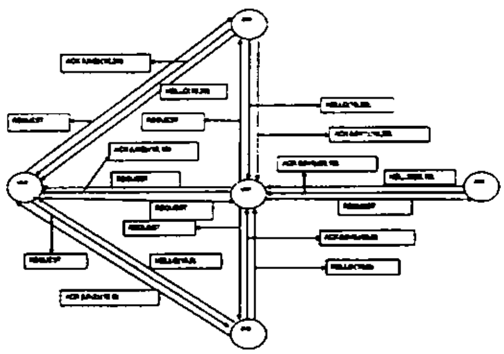

Figure 3.8: OBP Steps

Chapter 4

Problem Statement

Problem Statement In reference [3] Proposed Optimized Beacon Protocol (OBP) used RF TOF TWR for energy efficient localization. In this protocol a starter node in the middle of three anchor nodes broadcasts range message (RM) also called range packets (RPs) to start the localization process across the network. UNs overhear these RPs sent by starter node and wait for certain delay. This delay assures that starter node will become anchor node in future. After this delay, neighboring UNs broadcast their RPs to start their ranging operation. ANs after receiving RPs unicast response messages or acknowledgement messages (AM) .AM contains ANs coordinates and distance between UN and AN. Using this information, UN use trilateration method to find its position and change their state from UN to AN. The concept of Overhearing is energy efficient method in which UNs start their ranging process without waiting for beacon messages from ANs.This process is shown in figure 3.7.Figure 4.1 shows the TWR process being carried out among two unlocalized nodes.

Currently, the protocol has been implemented considering an ideal MAC, ideal node communication model and a perfect radio propagation model. Hence, the distance estimates obtained through ranging process are accurate and as a result location of LNs is also accurate. In fact ranging process when done in a wireless medium does give errors in distance that result in false node positions. Such errors and their management are not handled in this protocol. When UNs broadcast RMs to ANs then distance calculation is done on different time stamps of transmission/reception moments. Figure 4.2 shows these time stamps.

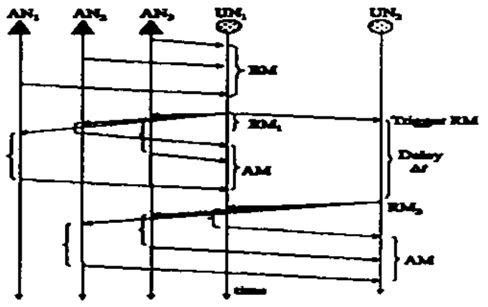

Figure 4.1: OBP Timing Diagram [3]

Distance estimation of UNs for indoor localization is suffered by the physical phenomena such as obstructions, interferences, multipath and changes in the signal propagation speed due to changes in the surrounding environment. Such interferences generate delay in signal's arrival at transmitter and receiver. These unwanted delays give erroneous distance estimation between ANs and UNs. Upon receiving RMs, ANs unicast AMs that contains ANs's coordinates and erroneous distance information. Trilateration (form of Lateration) is a technique used to calculate the position of UN using the estimated distance and known positions of ANs. Error characterization Neighbouring nodes make a Sensing Network Graph (SNG).In SNG; vertices are sensor nodes and edges represents distance b/w pair of nodes as shown in figure 4.3.

In [15] Localization errors come from two sources as:

1. Edge error This is the error in distance measurements between ANs and UNs.

2. Vertex error Error in non-anchor node's position as they don't know their location.

For Anchor nodes this error is equal to zero. Edge errors between neighbour and free node eventually become vertex error in free node. These errors are shown in following figure.

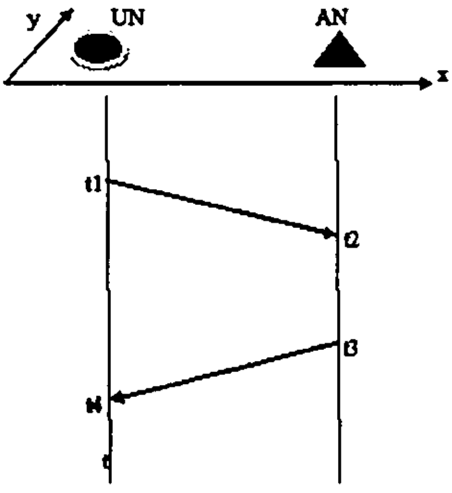

Figure 4.2: Time Stamps

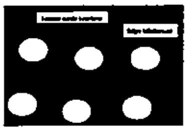

Figure 4.3: Sensing Network Graph

Figure 4.4: Errors in distance and position of nodes

Chapter 5

Proposed Solution

5.1 Least Square Multilateration

Measurement between each Anchor node and an unlocalized node is given by following equation,

$$z_i = \|x - x_i\|/c + \epsilon_i \tag{5.1}$$

Where: zi is the measurement of any sensor node i. i is error in measurement. Taking x to be a location vector containing both x and y coordinate values of nodes, the above equation can be written as:

$$x - x_i = cz_i \tag{5.2}$$

Where: c = speed of light, zi is the estimated distance between two nodes let f(zi) denote r.

$$x - x_i = f(z_i) \tag{5.3}$$

Ignoring the edge and vertex errors and square both sides of equation (5.3)

$$x^2 + x_i^2 - 2(x_i * t_x) = f_i^2(z_i) \tag{5.4}$$

These equations can be linearized by subtracting i=0 from rest of equation as follows:

$$-2(x_i - x_0)^t x = f_i^2(z_i) - f_i^2(z_0) - (x_i^2 - x_0^2) \tag{5.5}$$

Where x0 is the reference node i.e. anchor node. Let

$$a_i = -2(x_i - x_0)$$

Let

$$b = f_i^2(z_i) - f_i^2(z_0) - (x_i^2 - x_0^2)$$

Equation (5.5) becomes

$$(a_i)^{TX} = b \tag{5.6}$$

Here

$$a_i$$

is a 2x1 vector and b is a scalar m such equation can be expressed in a matrix form as:

$$Ax = b \tag{5.7}$$

With

$$A = x_1 - x_0, y_1 - y_0, x_2 - x_0, y_2 - y_0, , \ldots, x_m - x_0, y_m - y_0, b = b_1, b_2, , \ldots, b_m,$$

Here matrix A gives us the information regarding node configuration and b tells us about the distance measurement

least squares solution to this system of equations is given by:

$$x^t = (A^T A)^- 1 * A^T b \tag{5.8}$$

Equation (5.8) gives estimated location of free node.

Algorithm for Error Management

A registry is maintained at UN With tuple

$$(AN'scoordinates, x, e^e)_{un}$$

where

$$x_{un}$$

is the sensor measurement(i.e. distance between AN and UN)

$$e^e$$

(edge error) is the uncertainty in measurement x
do
{
for each UN;Examine local neighborhood N where N is the number of nodes with known locations. select neighbors based on edge errors

$$e^e$$

Nodes with edge error below the threshold are selected as best neighbors and nodes above threshold are excluded from the neighborhood. }
whiletermination condition is not met

Termination condition for this algorithm is that compare position error in normal scenario without error control with position error after using error control. If there is small difference in positions then this algorithm will work else stop working. .it will be very computation expensive for sensor nodes limit it to +-20 '

5.2 Proposed Solution

In optimized beacon protocol a starter node in the middle of three anchor nodes broadcasts range packets (RPs) to start the localization process across the network. UNs overhear these RPs sent by starter node and wait for certain delay. This delay assures that starter node will be localized node in future. After this delay, neighboring UNs broadcast their RPs to start their ranging operation. After receiving RPs, ANs unicast response messages or acknowledgement messages (AM). AM contains ANs coordinates and estimated distance between

UN and AN. Using this information, UN use trilateration method to find its position and change their state from UN to LN. Whole network get localized through such repetitive process.The distance estimates obtained through ranging process are accurate and as a result location of LNs is also accurate. OBP uses trilateration for position estimates. Suppose the Anchor nodes are located at (xi, yi) where i= 1, 2, 3. The Euclidean Distance between a UN and the three ANs can be represented by equation as:

$$(x_i - x_{un})^2 + (y_i - y_{un})^2 = r_i^2 \tag{5.9}$$

$$x_{un}, y_{un}$$

are the coordinates of unlocalized node. We will have same equation for any number of anchor nodes. These equations can be solved by writing them in a linear form using linearlization tool. Subtracting equation for i=3 from other two equations for i=1, 2. We get following equations.

$$(x_1 - x_{un})^2 - (x_3 - x_{un})^2 + (y_1 - y_{un})^2 - (y_3 - y_{un})^2 = r_1^2 - r_3^2 \tag{5.10}$$

$$(x_2 - x_{un})^2 - (x_3 - x_{un})^2 + (y_2 - y_{un})^2 - (y_3 - y_{un})^2 = r_2^2 - r_3^2 \tag{5.11}$$

After re-arranging equations we will get matrix form written as:

$$2[x_3 - x_1 y_3 - y_1][x_{un} y_{un}] = [(r_1^2 - r_3^2) - (x_1^2 - x_3^2) - (y_1^2 - y_3^2)]$$

$$2[x_3 - x_2 y_3 - y_2][x_{un} y_{un}] = [(r_2^2 - r_3^2) - (x_2^2 - x_3^2) - (y_2^2) - y_3^2)]$$

From matrix equation we will get coordinates of unlocalized nodes.

As three anchor nodes lies in overlapping range and UN lies nearby them so we can guess its coordinates as well.
Coordinates of anchor nodes when they are deployed:

$$(x_1, y_1) = (10, 10), (x_2, y_2) = (10, 9), (x_3, y_3) = (9, 8)$$

Coordinates of UN that deployed in vicinity of ANs:

$$(x_4, y_4) = (8, 7)$$

Now we calculate the distance between ANs and UN by using Euclidian distance formula:

$$(x_i - x_4)^2 + (y_i - y_4)^2 = r_i^2$$

Distance between AN1 (10,10) and UN (8,7)

$$(r_1)^2 = (x_1-x_4)^2+(y_1-y_4)^2 = (10-8)^2+(10-7)^2 = 2^2+3^2 = 4+9(r_1)^2 = 13$$

Similarly the distance b/w AN2 (10,9) and UN (8,7):

$$(r_2)^2 = (x_2-x_4)^2+(y_2-y_4)^2 = (10-8)^2+(9-7)^2 = 2^2+2^2 = 4+4(r_2)^2 = 8$$

Similarly the distance b/w AN3 (9,8) and UN (8, 7):

$$(r_3)^2 = (x_3-x_4)^2+(y_3-y_4)^2 = (9-8)^2+(8-7)^2 = 1^2+1^2 = 1+1(r_3)^2 = 2$$

After finding the distances now solve the following matrix:

$$2[x_3 - x_1 y_3 - y_1][x_{un} y_{un}] = [(r_1^2 - r_3^2) - (x_1^2 - x_3^2) - (y_1^2 - y_3^2)]$$

$$2[x_3 - x_2 y_3 - y_2][x_{un} y_{un}] = [(r_2^2 - r_3^2) - (x_2^2 - x_3^2) - (y_2^2) - y_3^2)]$$

$$(x_3-x_1) = 9-10 = -1, (y_3-y_1) = 8-10 = -2, (x_3-x_2) = 9-10 = -1, (y_3-y_2) = 8-9 = -1$$

$$(r_1)^2 - (r_3)^2 = 13 - 2 = 11, (x_1)^2 - (x_3)^2 = 19, (y_1)^2 - (y_3)^2 = 36$$

$$(r_2)^2 - (r_3)^2 = 8 - 2 = 6, (x_2)^2 - (x_3)^2 = 19, (y_2)^2 - (y_3)^2 = 17$$

Now put these values in matrix form:

$$[-1 - 2][xun, yun][11 - 19 - 36 = -44][-1 - 1][6 - 19 - 17 = -30]$$

Now we can write equations from this matrix as:

$$2(-x_{un} - 2y_{un}) = -44, 2(-x_{un} - y_{un}) = -30,$$

Dividing 2 on both sides of equation we get:

$$(-x_{un} - 2y_{un}) = -22, (-x_{un} - y_{un}) = -15,$$

Then solve these equations using crammers rule.

$$d = [-1 - 2][-1 - 1]$$

$$d = ((-1) * (-1)) - ((-1) * (-2)), d = 1 - 2 = -1,$$

$$dx = [-22 - 2][-15 - 1]dx = 22 - 30 = -8$$

$$dy = [-1 - 22][-1 - 15]dy = 15 - 22 = -7$$

$$x_{un} = dx/d = -8/-1 = 8, y_{un} = dy/d = -7/-1 = 7,$$

$$(x_{un}, y_{un}) = (8, 7)$$

these coordinates are same as given by GPS.
Distance estimation of UNs for indoor localization is suffered by the physical phenomena such as obstructions, interferences, multipath and changes in the signal propagation speed due to changes in the surrounding environment. Such interferences generate delay in signal's arrival at transmitter and receiver. These unwanted delays give erroneous distance estimation between ANs and UNs. In fact, ranging process when done in a wireless medium does give errors in distance that result in false node positions.Upon receiving RMs, ANs unicast AMs that contains ANs's coordinates and erroneous distance information hence results in position error of UNs.Gaussian Noise is added in the calculated distance and this noise is a randomly generated number. Assume the value of Noise = 5.

$$(x_i - x_4)^2 + (y_i - y_4)^2 = r_i^2$$
$$r_i^2 = (x_i - x_4)^2 + (y_i - y_4)^2 + Noise,$$
$$r_1^2 = (10 - 8)^2 + (10 - 7)^2 + Noise,$$
$$r_1^2 = (10 - 8)2 + (10 - 7)2 + 5,$$

Anchor Nodes Coordinates	Distance b/w ANs and UN	Random no added in distance i.e. noise
(12, 8)	r1= 39	6
(10, 11)	r2= 33	4.5
(10, 7)	r3=21	5
(9, 6)	r4=2	1.5
(9, 12)	r5=40	8
(8, 9)	r6=12	2.5
(9, 7)	r7=12	3.5
(10, 12)	r8=43	7.5
(12, 9)	r9=40	6.5

Figure 5.1: Registry information

$$r_1^2 = 13 + 5, r_1^2 = 18, r_1 = 4.2,$$

Later on when this distance is used to calculate the coordinates of UNs they also become erroneous.

Proposed error control mechanism incorporates two elements:

1. Registry Information

Basic idea for error control is that after computing distance estimates between ANs and UN, at this stage a node registry is maintained that contains coordinates of anchor nodes, distance between anchor nodes and unlocalized node and error in distance (i.e. edge error).This registry contains a tuple (anchor location, distance, edge error).Registry information helps to avoid error propagation due to estimated error in distance and select neighbors with less edge error. Registry is shown in following Table1. Where is this registry information kept?

It is kept in every node. This information is helpful to localize other nodes.

Is it distributed over all nodes?

Yes it is distributed and helps during neighbor selection.

How is it calculated in first place?

Once OBP calculates distance estimates then at that stage it is maintained on that node whose position is estimated.

2. Selection of Neighbors

Neighboring nodes are selected on the basis of their measurement errors (i.e. edge error). This step differentiates nodes whose measurements to use and whose discard. For localizing any node x belongs to N (N is number of neighbors in sensing network graph with known locations). Those nodes with lower edge error are selected as neighbors else discarded from neighbor selection and can't be used to localize others.
We arrange neighboring nodes in ascending order on the basis of edge error, then set a threshold value i.e. 3sigma, where sigma is standard deviation of edge error. Nodes with edge error below the threshold are selected as best neighbors and nodes above threshold are excluded from the neighborhood.
Using node registry we perform following computations for neighbor selection. Standard Deviation for Edge Error

$Mean = 6{+}4.5{+}5{+}1.5{+}8{+}2.5{+}3.5{+}7.5{+}6.5/9 = 45/9 = 5, Mean = 5$

Variance = subtract each random number from mean, find its square then take average of result.
Subtract each random number from mean and then square

$$6 - 5 = 1, (1)^2 = 1$$

$$4.5 - 5 = -0.5, (-0.5)^2 = 0.25$$

$$5 - 5 = 0, (0)^2 = 0$$

$$1.5 - 5 = -3.5, (-3.5)^2 = 12.25$$

$$8 - 5 = 3, (3)^2 = 9$$

$$2.5 - 5 = -2.5, (2.5)^2 = 6.25$$

$$Variance = 1 + 0.25 + 0 + 12.25 + 9 + 6.25/6 = 28.75/6 = 4.79$$

Anchor Nodes	Distance	Edge Error
r4	2	1.5
r6	12	2.5
r7	12	3.5
r2	33	4.5
r3	21	5
r1	39	6
r9	40	6.7
r8	43	7.5
r5	40	8

Figure 5.2: Anchor Nodes arranged on the basis of Edge Error

$$StandardDeviationSigma(\sigma) = squarerootofvariance = \sqrt{4.79} = 2.18$$

$$(\sigma) = 2.18, 3 * (\sigma) = 3 * (2.18), = 6.54$$

Now sort the node registry in ascending order by using the edge error and standard deviation.
From all these we choose 6 nodes for multilateration which have less edge error and these 6 nodes lies in the standard deviation.
Selected nodes are: r4, r6, r7, r2, r3,r1. As they have less edge error.
For further calculations of estimated coordinates of UN we use these 6 selected nodes. Now we are using those nodes which have less error.
Finally when we get estimated coordinates those also have less vertex error.

Results

By using this method we are reducing the error in the localization of

Un-localized Node. Means we have integrated an error management system with localization to reduce errors

Chapter 6

OBP Implementation and its Simulation Results

6.1 Simulations and Analysis

6.1.1 NS-2 (Network Simulator 2)

Simulation tools and environment used for this research work will be discussed in this chapter.NS-2 is standard tool for simulations in wired and wireless networks.It is open source and freely distributed event-based simulator that simulates numerous protocols like TCP, UDP, DSR AODV, OLSR etc.NS-2 written in two languages: C++ and OTCL.C++ used as programming language for protocol simulation and implement actual research algorithm. OTCL stands for object TCL.It creates physical structure of network (i.e. topology).it is easy to implement and configure by setting network parameters. Trace files are created after simulating its TCL script. Following figure shows the duality of OTCL and C++ language.

6.1.2 Implementation of Optimized Beacon Protocol

origionally OBP was implemented in OPNET simulator.we implemented our work in NS-2 simulator. Module was written in ns-2 by using C/C++ language and was tested there. After this, simulation files were written by using OTcl language and got results of our implementation in the form of trace files. To extract the required information from the trace files, scripts were written by using perl and awk scripting languages. Graphs were made by using Matlab with extracted values.

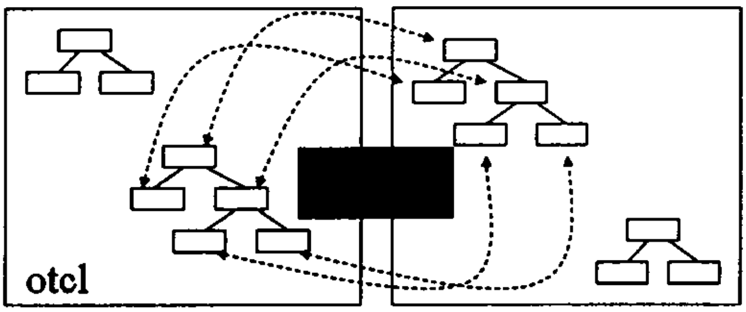

Figure 6.1: OTCL and C++: the duality [16]

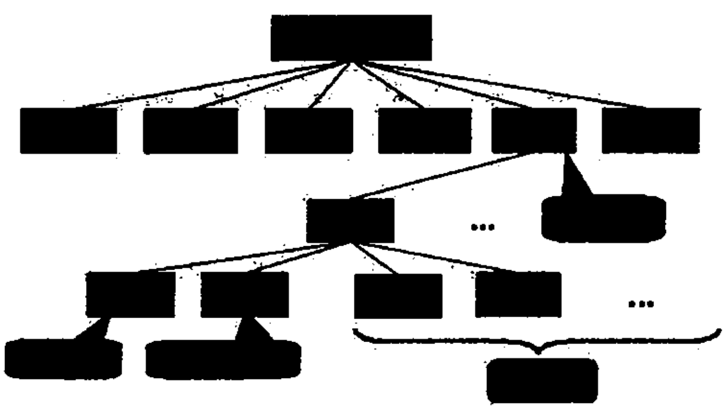

Figure 6.2: NS-2 Directory Structure [17]

The details of important parameters used for OBP implementation are given below:

S.No.	*Description*	*Value*
1	Total number of nodes	1350
2	Topography	300x300
3	Media Access Control	802.11
4	Routing Protocol	DumbAgent
5	Radio Model	Two ray ground
6	Simulation Seed	0
7	Simulation Starting time	30s
8	Simulation Stop Time	1000s

6.1.3 Total Number of Nodes

We used 1350 nodes for OBP simulation and deployed them by using random uniform distribution.

6.1.4 Topography

Topography is the configuration of a surface area where sensor nodes are deployed. In our module, we fixed sensor field of measuring 300x300 meters.

6.1.5 MAC/802-11

In our simulation, we used ideal MAC IEEE-802 11.

6.1.6 Routing Protocol

Routing protocol is Dumb Agent in our simulation.

6.1.7 Radio Propagation Model

This model is very helpful in predicting the received signal power of each packet. Network Simulator-2 has available three radio models to use i.e. free space model, two ray ground reflection models and Shadowing model[18] However, for OBP implementation, we used two ray ground reflection models. It can deal with both direct (line of sight) and ground reflection path between the transmitter and receiver.

Type Identifier	Time	Source Node	Destination Node	Packet Name	Packet Size	Flags	Flow ID	Source Address	Destination Address	Sequence Number	Packet Unique ID

Figure 6.3: Trace file format [19]

6.1.8 Simulation Seeds

Simulation seeds are used to get slightly variation in simulation during repetition of simulation with same parameters. We set simulation seed value 0 in simulation.

6.1.9 Text- based packet Trace file

This file contains the detail of packets passing in network during simulation. Format of trace file is shown below.

It contains twelve fields:
Type identifier: it defines the type of event that a packet performs i.e. Event: s send, r receive, + enqueue, ? dequeue, d drop, f forward. Time: it tells time when a certain event is experienced. Fields 3,4 tells the source and destination nodes of packets. Fields 5,6 describes packet name and its size. Next field flag shows any abnormal behavior. Dotted line in flag field means no flag. Remaining fields describe flow id, source and destination address in the form of node and port, packet sequence number and last field keeps record of all packets having their IDs.

Trace Example

6.1.10 Network AniMation (NAM) Trace

It shows animated colored packets flow, dropping and dragging nodes means changing their positions, and shaping links among nodes.

```
Fixed_Nodes 0.0 nn 1350 x 300 y 300 rp DumbAgent
Fixed_Node 0.0 sc ./random-deploy.tcl cp ./loc.tcl seed 0
Fixed_Node 0.0 prop Propagation/TwoRayGround ant
Antenna/OmniAntenna
M 0.00000 0 (147.03, 156.75, 0.00), (0.00, 0.00), 0.00
M 0.00000 1 (149.10, 146.79, 0.00), (0.00, 0.00), 0.00
M 0.00000 2 (152.36, 148.69, 0.00), (0.00, 0.00), 0.00
M 0.00000 3 (154.35, 146.60, 0.00), (0.00, 0.00), 0.00
M 0.00000 4 (143.93, 156.02, 0.00), (0.00, 0.00), 0.00
M 0.00000 5 (157.66, 144.87, 0.00), (0.00, 0.00), 0.00
M 0.00000 6 (150.15, 145.35, 0.00), (0.00, 0.00), 0.00
M 0.00000 7 (151.45, 153.73, 0.00), (0.00, 0.00), 0.00
M 0.00000 8 (152.90, 142.65, 0.00), (0.00, 0.00), 0.00
M 0.00000 9 (124.15, 3.54, 0.00),  (0.00, 0.00), 0.00
M 0.00000 10 (158.66, 85.60, 0.00), (0.00, 0.00), 0.00
M 0.00000 11 (65.30, 164.97, 0.00), (0.00, 0.00), 0.00
M 0.00000 12 (84.93, 192.37, 0.00), (0.00, 0.00), 0.00
M 0.00000 13 (208.56, 186.39, 0.00), (0.00, 0.00), 0.00
M 0.00000 14 (15.77, 278.75, 0.00), (0.00, 0.00), 0.00
M 0.00000 15 (41.84, 219.48, 0.00), (0.00, 0.00), 0.00
M 0.00000 16 (62.57, 234.33, 0.00), (0.00, 0.00), 0.00
M 0.00000 17 (78.73, 40.37, 0.00), (0.00, 0.00), 0.00
M 0.00000 18 (213.76, 223.14, 0.00), (0.00, 0.00), 0.00
M 0.00000 19 (189.90, 171.94, 0.00), (0.00, 0.00), 0.00
M 0.00000 20 (109.59, 154.11, 0.00), (0.00, 0.00), 0.00
M 0.00000 21 (189.27, 132.43, 0.00), (0.00, 0.00), 0.00
M 0.00000 22 (105.52, 96.95, 0.00), (0.00, 0.00), 0.00
M 0.00000 23 (213.12, 143.63, 0.00), (0.00, 0.00), 0.00
```

Figure 6.4: OBP trace file

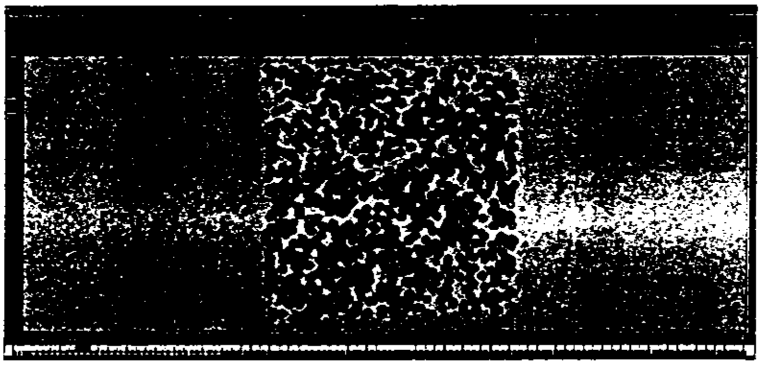

Figure 6.5: NAM trace

6.2 Performance Metrics

6.2.1 Node degree vs. percentage of localized nodes

6.2.2 State-change delay vs. distance from anchor nucleus with trilateration and multilateration

6.2.3 Number of exchanged messages vs. Time with trilateration and multilateration

6.2.4 Position Refinement

Node degree vs. Percentage of localized nodes

We deployed N nodes in square of LL m2 in random uniform distribution fashion using two ray ground radio propagation models. Node degree (also called network degree) is the mean number of neighbours per node. Following figure shows the relationship between node degree and percentage of localized nodes. In trilateration, networks needs three localized neighbours during localization process and then find their position. While in multilateration critical node degree is increased that helps in localizing nodes. Node degree is proportional to the number of localized nodes.

State-change delay vs. distance from anchor nucleus with trilateration and multilateration

In first scenario, we calculated the time when nodes change their states from unlocalized state to become localized with respect to distance from anchor nucleus. Anchor nucleus is the group of ANs placed in such a way that they have overlapping communication range and some UNs lie in this range. In existing scenario, there were three ANs that made anchor nucleus and used trilateration technique to find the location of UN. In proposed scheme, we deployed more than three ANs in anchor nucleus and used multilateration technique to find the location of UNs. We deployed a network of 1350 nodes in 25m range. The UNs wait for 10.0s after overhearing a RP. We saved delay and distance from the ANs' nucleus, in a separate file named "status.dat" with node IDs', their x and y-axis. We plot a graph showing both existing and proposed scheme. Existing scheme assumes no distance error but proposed technique considers error in distance. Delay is measured in seconds and

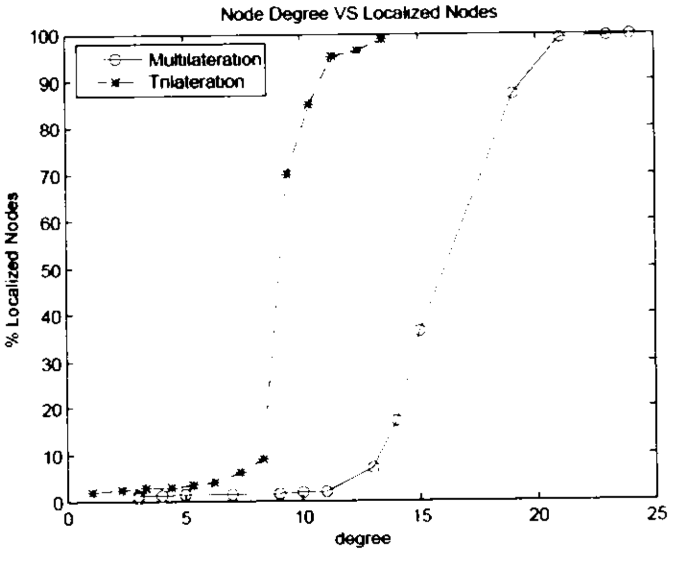

Figure 6.6: Node degree vs.percentage of localized nodes

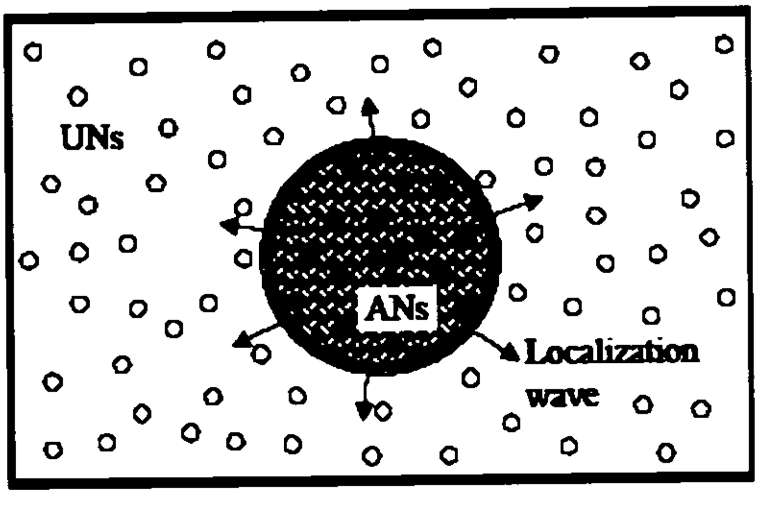

Figure 6.7: Anchor Nucleus [24]

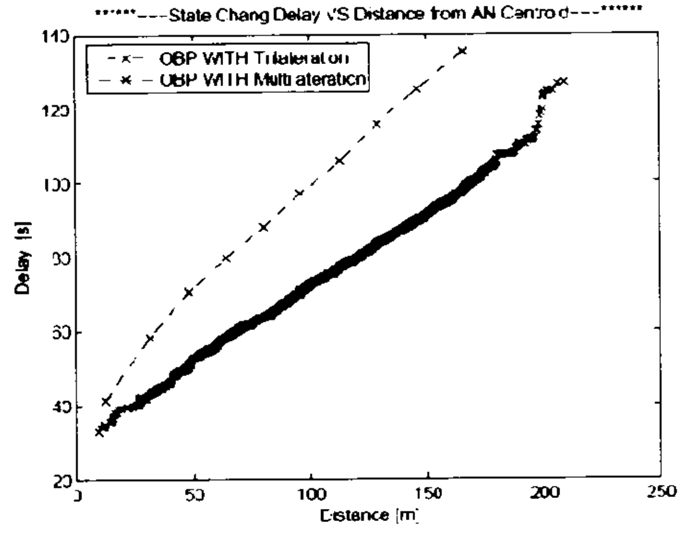

Figure 6.8: State-change delay of nodes across network

distance is measured in meters. State change delay increases linearly as the distance from anchor nucleus increases. Nodes rapidly change their state near anchor nucleus through overhearing.

Number of exchanged messages trilateration and multilateration vs. Time

Like previous parameter, we used 1350 nodes deployed in an area of 25 meters communication range. Here we count the number of transmitted packets with respect to time using both trilateration and multilateration techniques. In OBP anchor nodes transmit hello packets (also called hello messages) and acknowledgement packets while unlocalised nodes transmit range packets for distance estimates. Following table shows each packet transmitted and received to/by each node with respect to time. This table has columns as: node id, state delay(time),packets sent, packets received ,hello sent, hello received, request sent, request received, ack sent.ack received. Request message is also called as range message. The packet inter-arrival time for the two types of packets is set to 5 secs. Each UN transmits 5 RPs and a LN transmits 15 ACKs. The UNs wait for t 10.0s after overhearing a RP. The OBP starts its execution 10sec after starting simulation. Simulation is terminated either when all nodes have changed their state or

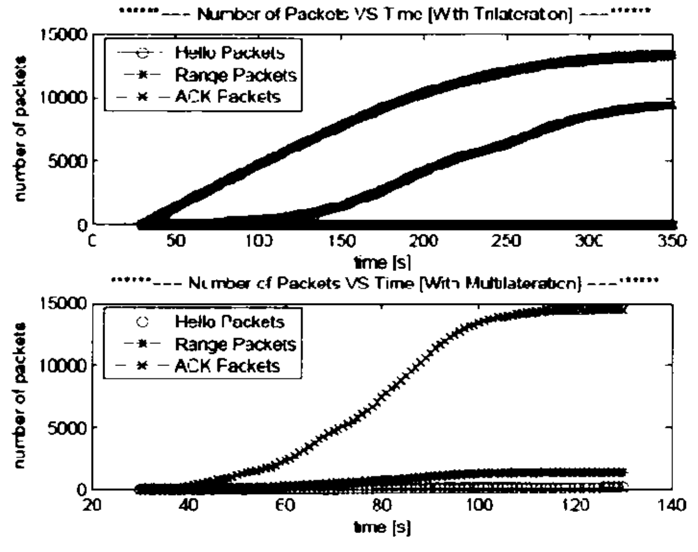

Figure 6.9: Number of exchanged messages across network

the maximum simulation duration is reached.

Ground truth position of nodes, and their estimated positions based on multilateration

Ground truth node positions obtained through GPS are marked as circles and estimated position obtained through multilateration is marked as cross. We can see the deviation in estimates caused by applying error control mechanism. The scheme with error control actively selects from its neighborhood which measurements to use and which to reject, using the registry information. Estimated node positions are calculated using range measurements. When range error becomes greater than threshold value then no neighbors are selected. Performing repetitive simulations, we get best neighbors (that should be more than 3) whose range error is less than pre-defined threshold value. Then we solve linear equations for calculating estimated node positions.

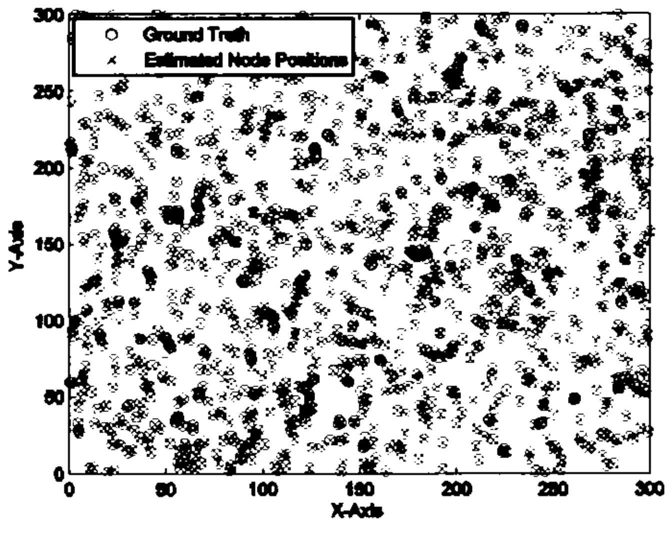

Figure 6.10: Position Refinement

Chapter 7

Chapter 7 Conclusion and Future work

7.1 Conclusion

Sensor nodes possess limited energy during their deployment. Sensor network localization being an active research area suffers from this constraint. This thesis handles localization, error in localization and evaluates the performance of OBP in terms of communication cost vs. accuracy tradeoffs by introducing error management scheme. Proposed error handling scheme filters out outliers ("the bad seeds") that may contaminate the entire network. In order to get reliable location information, several iterations are performed. Simulation results have shown that the active selection strategy significantly mitigates the effect of error propagation. Fewer nodes are localized in early little iterations due to larger error. After 6-7 iterations, almost all nodes are localized using error control mechanism. Error control strategy improved node localization. Position refinement of nodes is done through Least Square Multilateration (LSM) technique.

7.1.1 Future Directions and Perspectives

Our research work has opened many new directions for future work. Computations during position estimates using tri- multilateration bear cost/accuracy trade-offs. We have simulated our scheme using NS2. In future we planned to have testbed implementation. Our present work can be enhanced for the purpose of geographic routing and study the communication cost/accuracy trade-offs for this particular application. We also have planned to compare present scheme with genetic algorithm for neighbour selection.

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