ISTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF INFORMATICS

NODE IDENTIFICATION IN IR BAND IMAGES : LOCALIZATION WITH WIRELESS SENSOR NETWORKS

M.Sc. Thesis by
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Programme : **Satellite Com. & Remote Sensing**

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ BİLİŞİM ENSTİTÜSÜ

KIZILÖTESİ BANT GÖRÜNTÜLERİNDE DÜĞÜM KİMLİKLENDİRME : TELSİZ SENSOR AĞLARINDA KONUM BULMA

YÜKSEK LİSANS TEZİ
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FOREWORD

I would like to express my deep appreciation and thanks for my advisor. This work is supported by ITU Institute of Informatics.

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Deniz SÜMBÜLLÜ
Satellite Com. & Remote Sensing

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ABBREVIATIONS

WSN **:** Wireless Sensor Network
RSSI **:** Received Signal Strength Indicator
App **:** Appendix
TDOA **:** Time Difference of Arrival
AOA **:** Angle of Arrival
WLANs **:** Wireless Local Area Networks
WPANs **:** Wireless Personal Area Networks
IEEE **:** The Institute of Electrical and Electronics Engineers
AARS **:** Army-Amateur Radio System
ARRL **:** American Radio Relay League
RF **:** Radio Frequency
ARPANet : Advanced Research Projects Agency
DARPA **:** Defense Advanced Research Projects Agency
PRNet **:** Packet Radio Network
CRC : Cyclic Redundancy Checksum
TNC : Terminal Node Controler
FCC : Federal Communications Commission
FSK : Frequency Shift Keying
SURAN : Survivable Radio Networks
CSMA : Carrier Sense Multiple Access
LMSC : LAN/MAN Standard Commitee
OFDM : Orthogonal Frequency Division Multiplex
DSSS : Direct Sequence Spread Spectrum
SWAP : Shared Wireless Access Protocol
DECT : Digital European Cordless Telephony
ETSI : European Telecommunication Standards Institute
FH/TDD : Frequency Hopping/Time Division Duplex
HVAC : Heating, Ventilation, and Air-Conditioning
MAS : Multi-Agent Systems
PDA : Personal Digital Assistant
RFID : Radio Frequency Identification
RKE : Remote Keyless Entry
DCTC : Dynamic Convoy Tree-Based Collaboration
ATMS : Authenticated Tracking and Monitoring System
GPS : Global Positioning System
INMARSAT : International Maritime Satellite
BSN : Basic Sensor Nodes
CRN : Communication Relay Node
DDN : Data Discharge Nodes
NCC : Network Control Center
HSP : Hop and Skip Protocol

MEMS : Micro Electro Mechanical Sensor
CMOS : Complementary Metal Oxide Semiconductor
SMVM : Statistical Mean Value Model
DBFM : Distance Between the Fixed-nodes-based Model
GM : Gaussian Model
NLOS : Non-Line-of-sight
VOR : VHS Omni-directional Range

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NODE IDENTIFICATION IN IR BAND IMAGES : LOCALIZATION WITH WIRELESS SENSOR NETWORKS

SUMMARY

Localization of sensor nodes is the main aspect of wireless sensor networks. Measurements of sensory systems are meaningless without location information. Location of a sensory measurement is a must have information in most of the systems. Current localization techniques depend on data like radio signal strength attenuation or speed of sound which are indirectly related to distance and location. These measurement's disadvantage, which is not being a function of distance alone, is the main source for erroneous location estimations. An image based system would include direct location information but it is hard to distinguish desired sensor nodes from irrelevant entities. A series of operations are used to tackle this problem.

A new approach for localization at wireless sensor networks is proposed in this thesis. The proposed method depends on addition of new change dimensions and filters applied to those dimensions that result in identification of unique sensor nodes. In that matter, IR band images and existence of sensor nodes at those images as a function of time are used. Sensor nodes are instructed to toggle emitting infrared signals at a specific period in order to distinguish themselves from other infrared signal sources while irrelevant signal sources are eliminated from the list of possible candidates.

KIZILÖTESİ BANT GÖRÜNTÜLERİNDE DÜĞÜM KİMLİKLENDİRME : TELSİZ SENSOR AĞLARINDA KONUM BULMA

ÖZET

Telsiz sensor ağlarındaki temel ihtiyaç sahip olduğu sensör düğümlerinin konumlandırılmasıdır. Sensörler tarafından yapılan ölçümler çoğu zaman konum bilgileriyle anlam kazanırlar. Hatta bazı sensor ağlarında konum bilgisi bir gereklilik durumundadır. Kullanımda olan konumlandırma teknikleri radyo sinyalinin sönümlenmesi ya da sesin hızı gibi uzaklık ve konum ile dolaylı olarak bağlantılı olan verilere dayanmaktadır. Bu nedenle bu konumlandırma tekniklerinin direkt olarak uzaklığın bir fonksiyonu şeklinde olmamaları hatalı yapılan ölçümler için başlıca bir hata kaynağı olmaktadır. Görüntü temelli sistemler ise doğrudan konum ile bağlantılı olmalarına rağmen bu sistemlerde arzu edilen sensör düğümlerinin ilgisiz bileşenlerden ayrılması çok zordur. Ancak birçok işlemin ardarda gerçeklenmesiyle bu başarılabilmektedir ve buda sistem için fazla bir yük olduğundan tercih edilmemektedir.

Bu tezde telsiz sensor ağlarının konumlandırılması konusunda yeni bir yaklaşım önerilmektedir. Bu yaklaşım temel olarak çeşitli değişken boyutların eklenebilirliği ve bu değişken boyutlara uygulanan filtreleme işlemleriyle farklı sensör düğümlerinin belirlenebilirliği üzerine dayanmaktadır. Bu amaçla, IR bandı resimleri ve bu resimler içerisinde sensor düğümlerinin zamanın bir fonksiyonu şeklindeki varlıkları kullanılır. Sensör düğümlerine de, kendilerini diğer kızılötesi sinyal kaynaklarından ayırt edilebilir hale getirmeleri amacı ile belirli bir period ile kızıl ötesi sinyal yayınımı yaptırtılır. Bu sayede hatalı konum bilgisi yaratabilecek diğer ilgisiz kaynaklar elenmiş olur ve periyodu bilinen bir kızılötesi yayınım yapan sensor düğümü ayrıştırılarak konum bilgisi belirlenir.

1. INTRODUCTION

Localization of the sensor nodes is a critically important issue for wireless sensor networks and for most of its applications. So far, some different localization methods have been proposed and they are still developed for the same purposes such as, localization information of the nodes must be more accurate and should be obtained with less power consumption.

1.1 Purpose of the Thesis

The main objective of this thesis is to propose a new method for localization in wireless sensor networks which provides high precision information. It is aimed to make this method to be more selective method for localization through all the other existing localization methods. Proposed method aims to achieve this with the advantages like reduced power consumption, decreased environmental dependence and high precision.

1.2 Background

Existing localization methods depend on radio signal strength attenuation or speed of sound which are indirectly related to distance and location. For example in TDOA method, distance between two nodes is calculated by using elapsed time between transmitting and receiving ultrasonic signals. Likewise attenuation of radio signal is used to calculate distance between nodes in RSSI method.

The problem with these methods is that they rely on measurements which are not pure functions of distance between nodes. TDOA’s fundamental element, speed of sound, depends on various parameters like temperature, pressure, humidity etc. . RSSI’s key measurement unit, radio signal attenuation, is also affected by topology of the environment. However the biggest issue with RSSI is that measured attenuation values usually do not respond to distance changes in a sensitive manner.

Furthermore, these approximate distances yield to higher error rates at multi dimensional location calculations.

1.3 Hypothesis

This thesis is formed with the aim of overcoming the limitations that apply to current localization techniques. The main source of localization error on current methods is the indirect relationship between measured entities and location information.

Image based system is an option for direct data relation between location and measured entity. Desired information is provided by the very nature of imagery data. The measured entity, an image, has location information embedded into its pixels. As a result image based method solves the problem with indirect data.

Although using imagery data for location purposes provides more accurate information, it comes with its own burdens. Extracting the desired entities from an image is the main obstacle in this approach. This thesis will provide methods in order to tackle that problem.

First thing to do is moving from visible portion of electromagnetic spectrum to another frequency band. Motive behind this moving action is to have a clearer image which does not have intentional human interference. Visible band is spoiled by all the objects humans use or create in their daily lives.

Although moving from visible band to another portion of electromagnetic spectrum provides clearer images it does not identify desired entities in the imagery when used by itself. There are still going to be intruding electromagnetic signals in received images. Another additional dimension is needed to be considered for applying a filter. Amplitude of the emitted electromagnetic signals from trackable objects is controllable so an amplitude filter can be applied to eliminate irrelevant signal sources. In order to further increase contrast, trackable objects will be required to emit electromagnetic signals that have an amplitude higher than a certain limit. That contrast between desired entities and others which are present at image will be used to apply an amplitude filter. Applying a high pass amplitude filter to a raw image will cause most of the signals to vanish. Further enhancement of the image is achieved with this filter.

After applying an amplitude filter the resulting image is not guaranteed to have a single entity. Last and most important component of the proposed method is addition of another dimension to be filtered, that dimension is dedefined with existence as a function of time. That filter is applied to an entity’s existence function over time. First step in order to achieve singularity is to instruct trackable objects to toggle emitting electromagnetic signals at a specific period. After that the image stream is provided to a frequecy filter as input. Finally output of the filter, signal source that passes the frequency filter, is determined to be the desired one.

2. WIRELESS SENSOR NETWORKS

2.1 Introduction to Wireless Sensor Networks

“Recent advances in sensor and wireless communication technologies in conjunction with developments in microelectronics have made available a new type of communication network made of battery-powered integrated wireless sensor devices. Wireless Sensor Networks (WSNs), as they are named, are self-configured and infrastructureless wireless networks made of small devices equipped with specialized sensors and wireless transceivers. The main goal of a WSN is to collect data from the environment and send it to a reporting site where the data can be observed and analyzed.” [1].

“At present time, due to economic and technological reasons, most available wireless sensor devices are very constrained in terms of computational, memory, power, and communication capabilities. This is the main reason why most of the research on WSNs has concentrated on the design of energy- and computationally efficient algorithms and protocols, and the application domain has been restricted to simple data-oriented monitoring and reporting applications. However, all this is changing very rapidly, as WSNs capable of performing more advanced functions and handling multimedia data are being introduced. New network architectures with heterogeneous devices and expected advances in technology are eliminating current limitations and expanding the spectrum of possible applications for WSNs considerably.” [1].

2.1.1 Early Wireless Networks [2]

“Wireless communication networks have a long history. In 1921, for example, the U.S. Army Signal Corps received authorization to establish the War Department Radio Net[3], a nationwide radiotelegraphic network that, by 1925, numbered 164 stations, stretched to Alaska, and was called “the largest and most comprehensive radio net of its kind in the world today.”[4]. It carried more than 3.8 million words of message traffic its first year and, by 1933, more than 26 million words were carried annually[3]. Another early example is the Army-Amateur Radio System (AARS), established in 1925 by the Signal Corps and the American Radio Relay League (ARRL), an organization of amateur radio operators, to pass wireless message traffic between Army, National Guard, and Reserve units nationwide[5][4][6]” [2].

2.1.1.1 The ALOHA System[2]

“The ALOHA system [7] is generally recognized as being the first successful wireless data communication network… The ALOHA system provided a 24 kBaud interactive link between a University of Hawaii mainframe computer and computer users on four of the Hawaiian Islands, using two radio frequency (RF) channels (one for transmission, one for reception) in the 400 MHz band. Although sometimes considered a “packet” radio system, a message was not broken up into multiple packets—each packet corresponded to a single message. Packets had a fixed length of 640 payload bits (80 bytes), plus 32 identification and control information bits and 32 parity bits (for a total of 704 bits in each packet) [7]” [2]**.**

2.1.1.2 The PRNET System [2]

“Based at least partially on the success of the ALOHA system, plus the developing technology of the Advanced Research Projects Agency (ARPANet),[8] the U.S. Defense Advanced Research Projects Agency (DARPA) began a series of packet radio development programs, beginning with the DARPA Packet Radio Network (PRNET) project in 1972… The data rate was 100 or 400 kb/s, switchable based on link conditions; interleaving, convolutional coding—at three rates, 7/8, 3/4, and 1/2—and a 32-bit cyclic redundancy checksum (CRC) were used [9]. Beacons were transmitted by each packet radio every 7.5 seconds to announce its existence and inform its neighbors of its understanding of the network topology.

The PRNET system was not without its weaknesses. These weaknesses included the limitation to relatively small networks, the size and power consumption of PRNET nodes, and a susceptibility to certain forms of electronic attack, and were addressed in a follow-on DARPA project, the Surviv able Radio Networks (SURAN) program, initiated in 1983 [10]” [2]**.**

2.1.1.3 Amateur Packet Radio Networks[2]

“The first amateur packet radio communications controller, called a Terminal Node Controller (TNC), was built before 1980 [11]. Following a change in Federal Communications Commission (FCC) rules to permit it, the first U.S. amateur data packet repeater station was built in 1980. Operating on a single channel at 146 MHz, it transmitted an identification beacon once every five minutes, using 1200 Baud frequency shift keying (2-FSK); the rest of the time was a contention period during which it would retransmit any errorfree packet received in a simplex fashion[12]. Packet collision avoidance was performed by a Carrier Sense Multiple Access (CSMA) method as follows:

…the TNC performs a carrier-*sense check (to see if anyone is using the channel). Just to reduce the possibility of two TNC boards hearing nothing and bursting packets at exactly the same time, a variable time delay is built in. Because the time delay at each TNC (user) is changing, repeated collisions between the same pair of users should not occur* [13]. *(Published with the permission of the ARRL. Copyright 1981, ARRL)*" [2]

2.1.2 Wireless Local Area Networks (WLANs) [2]

"In 1990, the Institute of Electrical and Electronics Engineers (IEEE) 802 LAN/MAN Standards Committee (LMSC) established the 802.11 Working Group to create a WLAN standard. The first standard was released in 1997. The standard has been revised and amended several times since its initial publication, and now includes five physical layers: [14]

- Infrared at 1 and, optionally, 2 Mb/s
- Frequency hopping spread spectrum at 1 and, optionally, 2 Mb/s at 2.4 GHz
- Direct sequence spread spectrum from 1 to 11 Mb/s at 2.4 GHz [15]
- Orthogonal Frequency Division Multiplex (OFDM) up to 54 Mb/s at 5 GHz [16] [17]
- A choice between DSSS and OFDM up to 54 Mb/s at 2.4 Ghz.

The 802.11 standard specifies the carrier sense multiple access with collision avoidance (CSMA/CA) channel access method, which is a refinement of the MACA protocol that employs a binary exponential random backoff mechanism [18]" [2]**.**

2.1.3 Wireless Personal Area Networks (WPANs) [2]

"The development of WPANs began in 1997, with the formation of the Home RF Working Group, [19] and in 1998, with the formation of the Bluetooth Special Interest Group [20]. Revision 1.0 of both specifications was released in 1999 and, while the Home RF Working Group dishanded in January 2003, development of Bluetooth continues today. Both of these WPANs operate in the 2.4 GHz ISM band, employing frequency hopping spread spectrum.

HomeRF had a raw data rate of 800 kb/s using 2-level frequency-shift keying (2-FSK), and optionally 1.6 Mb/s using 4-level FSK (4-FSK); a data throughput on a lightly loaded system of near 1 Mb/s was claimed, using 4-FSK [19]. Bluetooth has a raw data rate of 1 Mb/s, also using 2-FSK, and claims a maximum data throughput of 721 kb/s.

HomeRF systems used the Shared Wireless Access Protocol-Cordless Access (SWAP-CA) protocol, which incorporates features of the Digital European Cordless Telephony (DECT) standard from the European Telecommunication Standards Institute (ETSI) for isochronous traffic, and the IEEE 802.11 WLAN standard for conventional data transfer. The standard considered four types of devices—connection points (gateways), isochronous nodes (voice-centric), asynchronous nodes (data-centric), and combined isochronous and asynchronous nodes—thereby enabling heterogeneous networks [21].

In contrast, Bluetooth employs a frequency hopping/time division duplex (FH/TDD) access method. All devices are physically identical (i.e., the network is homogeneous). The channel is divided into 625 μs slots, during which a network node may alternately transmit or receive a single packet; the channel frequency is changed for each slot. There is no provision in the Bluetooth specification itself for the creation of networks larger than a single piconet (so-called “scatternets”); however, this is an active area of research [22]” [2].

2.2 Wireless Sensor Networks – System Overview

“A wireless sensor network (WSN) in its simplest form can be defined as a network of (possibly low-size and low-complex) devices denoted as *nodes* that can sense the environment and communicate the information gathered from the monitored field (e.g., an area or volume) through wireless links; the data is forwarded, possibly via multiple hops relaying, to a *sink* (sometimes denoted as *controller* or *monitor*) that can use it locally, or is connected to other networks (e.g., Internet) through a gateway. The nodes can be stationary or moving. They can be aware of their location or not. They can be homogeneous or not” [23].

“Unlike a centralized system, a WSN is subject to a unique set of resource constraints such as finite on-board battery power and limited network communication bandwidth. In a typical sensor network, each sensor node operates untethered and has a microprocessor and a small amount of memory for signal processing and task scheduling. Each node is also equipped with one or more sensing devices such as acoustic microphone arrays, video or still cameras, infrared (IR), seismic, or magnetic sensors. Each sensor node communicates wirelessly with a few other local nodes within its radio communication range" [24].

"The advancement in technology has made it possible to have a network of 100s or even thousands of extremely small, low powered devices equipped with programmable computing, multiple parameter sensing and wireless communication capability, enhancing the reliability, accuracy of data and the coverage area. In short, some of the advantages of WSN (Wireless Sensor Network) over wired ones are as follows:

- Ease of deployment – These wireless sensors can be deployed (dropped from a plane or placed in a factory) at the site of interest without any prior organization, thus reducing the installation cost and time, and also increasing the flexibility of deployment;
- Extended range – One huge wired sensor (macro-sensor) can be replaced by many smaller wireless sensors for the same cost. Such a macro sensor can sense only a limited region whereas a network of smaller sensors can be distributed over a wider range;
- Fault tolerant – With macro-sensors, the failure of one node makes that area completely unmonitored till it is replaced. With wireless sensors, failure of one node does node affect the network operation substantially as there are other adjacent nodes collecting similar data. At most, the accuracy of data collected may be somewhat reduced;
- Mobility – Since these wireless sensors are equipped with battery, they can possess limited mobility (e.g. if placed on robots), Thus, if a region becomes unmonitored we can have the nodes rearrange themselves to distribute evenly, i.e., these nodes can be made to move towards area of interest but having lower mobility as compared to ad hoc networks.

The wireless medium does have a few inherent limitations such as low bandwidth, error prone transmissions, and potential collisions in channel access, etc. It is clear that the available bandwidth for sensor data is low and is of the order of 1-100 kb/s. Since the wireless nodes are not connected in any way to a constant power supply, they derive energy from batteries which limit the amount of energy available to the nodes. In addition, since these sensor nodes are deployed in places where it is difficult to either replace the nodes or their batteries, it is desirable to increase the longevity of the network and, preferably, all the nodes should die together so that new nodes could be replenished simultaneously in the whole area. Finding individual dead nodes and then replacing those nodes selectively would require dynamic deployment and eliminates major advantages of these networks. Thus, the protocols designed for these networks must strategically distribute the dissipation of energy, which also enhances the average life of the overall system. In addition, as we mentioned before, environments in which these nodes are expected to operate and respond are very dynamic in nature, with fast changing physical parameters” [25].

“An ideal sensor network should have the following additional features:

- *Attribute-based addressing.* This is typically employed in sensor networks where addresses are composed of a group of attribute-value pairs which specify certain physical parameters to be sensed. For example, an attribute address may be (temperature > 35˚C, location= “Recife”). So, all sensor nodes located in “Recife” which sense a temperature greater than 35˚C should respond;
- *Location awareness* is another important issue. Since most data collection is based on location, it is desirable that the nodes know their position whenever needed;
- Another important requirement in some cases is that the sensors should react immediately to drastic changes in their environment, for example, in *time-critical applications.* The end user should be made aware of any drastic deviation in the situation with minimum delay, while making efficient use of the limited wireless channel bandwidth and sensor energy;
- *Query Handling* is another important feature. Users should be able to request data from the network through some base station (also known as sink) or through any of the nodes, whichever is closer. So there should be a reliable mechanism to transmit the query to appropriate nodes which can respond to the query. The answer should then be re-routed back to the user as quickly as possible.” [25].

2.3 Key Definitions [24]

- ***Sensor :*** A transducer that converts a physical phenomenon such as heat, light, sound, or motion into electrical or other signals that may be further manipulated by other apparatus.
- ***Sensor node:*** A basic unit in a sensor network, with on-board sensors, processor, memory, wireless modem, and power supply. It is often abbreviated as *node*. When a node has only a single sensor on board, the node is sometimes also referred to as a *sensor*, creating some confusion.
- ***Network Topology:*** A connectivity graph where nodes are sensor nodes and edges are communication links. In a wireless network, the link represents a one-hop connection, and the neighbors of a node are those within the radio range of the node.

- ***Routing:*** The process of determining a network path from a packet source node to its destination.
- ***Date-centric:*** Approaches that name, route, or access a piece of data via properties, such as physical location, that are external to a communication network. This is to be contrasted with address-centric approaches which use logical properties of nodes related to the network structure.
- ***Geographic routing:*** Routing of data based on geographical attributes such as locations or regions. This is an example of date-centric networking.
- ***In-network:*** A style of processing in which the data is processed and combined near where the data is generated.
- ***Collaborative processing:*** Sensors cooperatively processing data from multiple sources in order to serve a high-level task. This typically requires communication among a set of nodes.
- ***State:*** A snapshot about a physical environment (e.g., the number of signal sources, their locations or spatial extent, speed of movement), or a snapshot of the system itself (e.g., the network state).
- ***Uncertainty:*** A condition of the information caused by noise in sensor measurements, or lack of knowledge in models. The uncertainty affects the system's ability to estimate the state accurately and must be carefully modeled. Because of the ubiquity of uncertainty in the data, many sensor network estimation problems are cast in a statistical framework. For example, one may use a covariance matrix to characterize the uncertainty in a Gaussian-like process or more general probability distributions for non-Gaussian processes.
- ***Task:*** Either high-level system tasks which may include sensing, communication, processing, and resource allocation, or application tasks which may include detection, classification, localization, or tracking.
- ***Detection:*** The process of discovering the existence of a physical phenomenon. A threshold-based detector may flag a detection whenever the signature of a physical phenomenon is determined to be significant enough compared with the threshold.
- ***Classification:*** The assignment of class labels to a set of physical phenomena being observed.
- ***Localization and tracking:*** The estimation of the state of a physical entity such as a physical phenomenon or a sensor node from a set of measurements. Tracking produces a series of estimates ever time.

- ***Value of information or information utility:*** A mapping of data to a scalar number, in the context of the overall system task and knowledge. For example, information utility of a piece of sensor data may be characterized by its relevance to an estimation task at hand and computed by a mutual information function.
- ***Resource:*** Resources include sensors, communication links, processors, on-board memory, and node energy reserves. Resource allocation assigns resources to tasks, typically optimizing some performance objective.
- ***Sensor tasking:*** The assignment of sensors to a particular task and the control of sensor state (e.g., on/off, pan/tilt) for accomplishing the task.
- ***Node services:*** Services such as time synchronization and node localization that enable applications to discover properties of a node and the nodes to organize themselves into a useful network.
- ***Data storage:*** Sensor information is stored, indexed, and accessed by applications. Storage may be local to the node where the data is generated, load-balanced across a network, or anchored at a few points (warehouses).
- ***Embedded operating system (OS):*** The run-time system support for sensor network applications. An embedded OS typically provides an abstraction of system resources and a set of utilities.
- ***System performance goal:*** The abstract characterization of system properties. Examples include scalability, robustness, and network longevity, each of which may be measured by a set of evaluation metrics.
- ***Evaluation metric:*** A measurable quantity that describes how well the system is performing on some absolute scale. Examples include packet loss (system), network dwell time (system), track loss (application), false alarm rate (application), probability of correct association (application), location error (application), or processing latency (application/system). An evaluation method is a process for comparing the value of applying the metrics. On an experimental system with that of some other benchmark system [24].

2.4 Research Directions for Wireless Sensor Networks [26]

2.4.1 Tiered Architectures

“Although Moore’s law predicts that hardware for sensor networks will inexorably become smaller, cheaper, and more powerful, technological advances will never prevent the need to make tradeoffs. Even as our notions of metrics such as “fast” and “slow” evolve, there will always be compromises: nodes will need to be faster or more energy-efficient, smaller or more capable, cheaper or more durable.

The choice of any *single* hardware platform will make compromises. The diverse needs of a sensor network can be satisfied only through a tiered architecture, a design that is a composition of platforms selected from a continuum of design points along axes of capability, energy requirements, size, and price." [26].

2.4.2 Routing and In-Network Processing

"Routing is a topic that arises almost immediately in any network as soon as it is large enough to require multiple hops—that is, if there is a pair of nodes that are not directly interconnected. In sensor networks, as in the Internet, this is of course the case. However there is an important difference in the routing used by sensor networks. The Internet, and much of earlier research in ad-hoc wireless networks, was focused on building the network as a *transport mechanism*—that is, a way to route packets to a particular endpoint. In a sensor network, efficiency demands that we do as much in-network processing (e.g., data reduction) as possible. Instead of blindly routing packets to a far-away endpoint, many applications do processing at *each top* inside the network aggregating similar data, filtering redundant information, and so forth." [26].

2.4.3 Distributed Signal Processing

"For decades, the signal processing community has devoted much research attention to seamless integration of signals from multiple sources, and sources with heterogeneous sensing modalities. The signal processing literature sometimes refers to this as *array processing*; with heterogeneous sensors, it is often called *data fusion*. There are many applications, such as signal enhancement (noise reduction), source localization, process control, and source coding. It would seem to be a natural match to implement such algorithms in distributed sensor networks, and there has been great interest in doing so. However, much of the extensive prior art in the field assumes *centralized sensor fusion*. That is, even if the sensors gathering data are physically distributed, they are often assumed to be wired into a single processor." [26].

2.4.4 Storage, Search and Retrieval

"Sensor networks can produce a large volume of raw data—a continuous time-series of observations over all points in space covered by the network. In wired sensor networks, that mass of data is typically aggregated in a large, centralized database, where it later processed, queried and searched. The easiest path toward the adoption of new wireless sensor networks might be to provide users with a familiar model. For example, we might conceive a sensor network with a well-known declarative query interface such as SQL, allowing them to exploit traditional data mining techniques to extract interesting features or event information from the data. However standard database assumptions about resource constraints, characteristics of data sources, reliability and availability no longer hold in a sensor network context, requiring significant modifications to existing techniques." [26].

2.4.5 Actuation

"In many cases, a sensor network is entirely passive system, capable of detecting the state of the environment, but unable to change it or the network's relationship to it. *Actuation* can dramatically extend the capabilities of a network in two ways. First, actuation can enhance the sensing task, by pointing cameras, aiming antennae, or repositioning sensors. Second, actuation can *affect* the environment—opening valves, emitting sounds, or strengthening beams [27]" [26].

2.4.6 Simulation, Monitoring, and Debugging

"Simulation and debugging environments are important in any large-scale software development project. In sensor networks, a number of factors make the use of innovative development models particularly important." [26].

2.4.7 Security and Privacy

"In sensor networks, many unique challenges arise in ensuring the security of sensor nodes and the data they generate [28] [29] [30]. For example, the fact that sensors are embedded in the environment presents a problem: the physical security of the nodes making up the network can not be assured. This can make security significantly different than in Internet servers. In sensor networks, attackers may modify node hardware, replace it with malicious counterparts, or fool sensors into making observations that do not accurately reflect the environment. To a single temperature sensor, a small match may look no different than a forest fire. Algorithms for ensuring network-wide agreement are crucial to detecting attacks because we can no longer assume the security of individual nodes, or the data they generate." [26].

2.4.8 Automatic Localization and Time Synchronization

"Some of the most powerful benefits of a distributed network are due to the integration of information gleaned from multiple sensors into a larger worldview not detectable by any single sensor alone. For example, consider a sensor network whose goal is to detect a stationary phenomenon P. P might be a region of the water table that has been polluted, within a field of chemical sensors. Each individual sensor might be very simple, capable only of measuring chemical concentration and thereby detecting whether or not it is within P. However, by fusing the data from all sensors, *combined with knowledge about the sensors' positions,* the complete network can describe more than just a set of locations covered by P: it can also compute P's size, shape, speed, and so forth. The whole of information has become greater than the sum of the parts: the network can deduce the size and shape of P even though it does not have a "size" or "shape" sensor.

Nearly every sensor network does this type of data fusion, but it is only possible if the sensors have known positions. Positions may be absolute (latitude and longitude), relative (20 meters away from the other node), or logical (inside the barn vs. on the pasture). But, in any of these cases, sensor networks need *automatic localization*. That is, nodes require the capability of localizing themselves after they have been deployed. This is necessary both due to the large scale of deployments, making manual surveys impractical, and due to dynamics that can change a node's position estimates into a velocity estimate.

For any phenomenon that is time-varying or mobile, time synchronization is also a crucial service necessary to combine the observations of multiple sensors with each other. For example, synchronized time is needed to integrate multiple position estimates into a velocity estimate." [26].

2.5 Application Domains And Examples For WSN

"Wireless sensor networks have gained considerable popularity given their flexibility to solve problems in different application domains. Wireless sensor devices can be equipped with single or multiple sensors according to the application at hand. WSNs have been applied in a myriad of applications and have the potential to change our lives in many different ways.WSNs have been successfully applied in the following application domains:

- **Agriculture:** WSNs have been used to control irrigation systems according to the humidity of the terrain.
- **Military:** Intrusion detection systems based on WSNs have been used by the military.
- **Manufacturing:** WSNs have been used to monitor the presence of lethal gases in refineries.
- **Transportation:** Real-time traffic information is being collected by WSNs to later feed transportation models and alert drivers of congestion and traffic problems.
- **Environmental:** WSNs have been installed to monitor water deposits in mountains to detect mudslides. WSNs have been utilized in intelligent buildings to automatically control the temperature.
- **Engineering:** Civil engineers have used WSNs technology to monitor the condition of civil structures, such as bridges.

Additional advantages of WSNs are the possibility of monitoring these applications from remote places and having a system that can provide large amounts of data about those applications for longer periods of time. This large amount of data availability usually allows for new discoveries and further improvements." [1].

2.5.1 Industrial Control and Monitoring [2]

"A large, industrial facility typically has a relatively small control room, surrounded by a relatively large physical plant. The control room has indicators and displays that describe the state of the plant (the state of valves, the condition of equipment, the temperature and pressure of stored materials, etc.), as well as input devices that control actuators in the physical plant (valves, heaters, etc.) that affect the observed state of the plant. The sensors describing the state of the physical plant, their displays in the control room, the control input devices, and the actuators in the plant are often all relatively inexpensive when compared with the cost of the armored cable that must be used to communicate between them in a wired installation. Significant cost savings may be achieved if an inexpensive wireless means were available to provide this communication. Because the information being communicated is state information, it often changes slowly. Thus, in normal operation, the required data throughput of the network is relatively low, but the required reliability of the network is very high. A wireless sensor network of many nodes, providing multiple message routing paths of multihop communication, can meet these requirements.

An example of wireless industrial control is the control of commercial lighting. Much of the expense in the installation of lights in a large building concerns the control of the lights—

where the wired switches will be, which lights will be turned on and off together, dimming of the lights, etc. A flexible wireless system can employ a handheld controller that can be programmed to control a large number of lights in a nearly infinite variety of ways, while still providing the security needed by a commercial installation.**”** [2]**.**

Sandhu et al. gave an introduction for this kind of applications. They explain like: “The application of wireless sensor networks to commercial lighting control provides a practical application that can benefit directly from artificial intelligence techniques. This application requires decision making in the face of uncertainty, with needs for system self-configuration and learning. Such a system is particularly well-suited to the evaluation of multi-agent techniques involving distributed learning.

Two-thirds of electricity generated in the US is for commercial buildings, and lighting consumes 40% of this. An additional 45% energy savings are possible through the use of occupant and light sensors[31]. The goal in this domain is to leverage wireless sensor networks (WSN) to create an intelligent, economical solution for reducing energy costs - and overall societal energy usage - while improving individual lighting comfort levels. Much of the prior work in intelligent lighting control involves building control systems that focus on HVAC (heating, ventilation, and air-conditioning), security or other aspects of building management. Several groups have examined the use of multi-agent systems (MAS) for building control; however, this prior work varies significantly from the presented WSN problem.” [32].

“A further example is the use of wireless sensor networks for industrial safety applications. Wireless sensor networks may employ sensors to detect the presence of noxious, poisonous, or otherwise dangerous materials, providing early detection and identification of leaks or spills of chemicals or biological agents before serious damage can result (and before the material can reach the public). Because the wireless networks may employ distributed routing algorithms, have multiple routing paths, and can be self-healing and self-maintaining, they can be resilient in the face of an explosion or other damage to the industrial plant, providing officials with critical plant status information under very difficult conditions.

The monitoring and control of rotating or otherwise moving machinery is another area suitable for wireless sensor networks. In such applications, wired sensor and actuators are often impractical, yet it may be important to monitor the temperature, vibration, lubrication flow, etc. of the rotating components of the machine to optimize the time between maintenance periods, when the machine must be taken off-line. To do this, it is important that the wireless sensor system be capable of operating for the full interval between maintenance periods; to do otherwise defeats the purpose of the sensors. This, in turn, requires the use of a wireless sensor network with very low energy requirements. The sensor node often must be physically small and inexpensive as well. Wireless sensor networks may be of particular use in the prediction of component failure for aircraft, where these attributes may be used to particular advantage.

Still another application in this area for wireless sensor networks is the heating, ventilating, and air conditioning (HVAC) of buildings. HVAC systems are typically controlled by a small number of strategically located thermostats and humidistats. The number of these thermostats and humidistats is limited, however, by the costs associated with their wired connection to the rest of the HVAC system. In addition, the air handlers and dampers that directly control the room environment are also wired; for the same reasons, their numbers are also limited.

The heat load generated by people in a building is quite dynamic, however. Diurnal, hebdomadal, seasonal, and annual variations occur. These variations are associated with the distribution of people in the building throughout the day, week, season, and year; important changes also affect the heat load of the building at more irregular intervals. For example, when organizations reorganize and remodel, space previously used for offices may be used by heat-generating laboratory or manufacturing equipment. Changes to the building itself must also be considered: interior walls may be inserted, moved, or removed; windows, curtains, and awnings may be added or removed, etc. Due to all these possible variations and, as nearly anyone who works in an office building can attest, improvement is needed.

The root cause of such unsatisfactory HVAC function is that the control system lacks sufficient information about the environment in the building to maintain a comfortable environment for all. Because they do not require the expense of wired sensors and actuators, wireless sensor networks may be employed to greatly increase the information about the building environment available to the HVAC control system, and to greatly decrease the granularity of its response. Wireless thermostats and humidistats may be placed in several places around each room to provide detailed information to the control system. Similarly, wireless bypass dampers and volume dampers can be used in great number to fine-tune the response of the HVAC system to any situation. Should everyone in an office area move to the conference room for a meeting, for example, the system can respond by closing the volume dampers in the office area, while opening the volume dampers in the conference room. Should the group leave the building, the HVAC system may instruct the wireless bypass dampers to respond to the change in total building heat load. Should the group return during a driving rainstorm, the humidistat in the umbrella and coat closet could detect the increased humidity in that closet. The HVAC system could then place especially dry air there, without affecting the occupants elsewhere in the building.

The wireless HVAC system can also solve one of the great problems facing the HVAC engineer: balancing heating and air conditioning. It is often the case that heat sources are not uniformly distributed throughout a building. In the home, for example, kitchens tend to be warm, due to the heat of cooking, while bedrooms tend to be cool. In winter, more heated air needs to be sent to the bedroom, where it is cooler, and less heated air needs to be sent to the kitchen, where it is warmer. In summer, however, just the opposite is true—more cooled air needs to be sent to the kitchen, where it is warmer, and less cooled air needs to be sent to the bedroom, where it is cooler. This difference between the air distribution of heating and air conditioning is a difficult and expensive problem to solve with wired control systems, because a volume damper to each room in the house must be independently controlled. Often, the dampers are placed in a single, fixed position, leaving some areas perpetually cold and others perpetually warm. With wireless sensors and actuators in the HVAC system, however, the problem becomes trivial; the damper(s) to each room can be controlled by the sensor(s) in each room, leading to perfect system balance at any time of the year.

Such a wireless HVAC system has other advantages. Close monitoring of system performance enables problems to be identified and corrected before occupant complaints arise. In addition to the living-area sensors, wireless sensors may be placed inside air ducts (to monitor the performance of heat exchange apparatus, for example) without requiring maintenance personnel to make manual measurements atop ladders. In addition, sensors may be placed in attics and crawlspaces that contain ductwork; anomalous temperatures in such areas may indicate costly leaks of heated or cooled air. For these reasons, total building HVAC costs should drop, while occupant comfort would increase when wireless sensors and actuators are employed.” [2]**.**

2.5.2 Home Automation and Consumer Electronics [2]

“The home is a very large application space for wireless sensor networks. Many of the industrial applications just described have parallels in the home. For example, a home HVAC system equipped with wireless thermo-stats and dampers can keep the rooms on the sunny side of the house comfortable—without chilling the occupants on the shady side of the house—more effectively than a home equipped with only a single, wired thermo stat. However, many other opportunities are available.

One application is the “universal” remote control, a personal digital assistant (PDA)-type device that can control not only the television, DVD player, stereo, and other home electronic equipment, but the lights, curtains, and locks that are also equipped with a wireless sensor network connection. With the universal remote control, one may control the house from the comfort of one’s armchair. Its most intriguing potential, however, comes from the combination of multiple services, such as having the curtains close automatically when the television is turned on, or perhaps automatically muting the home entertainment system when a call is received on the telephone or the doorbell rings. With the scale and personal computer both connected via a wireless sensor network, one’s weight may be automatically recorded without the need for manual intervention (and the possibility of stretching the truth “just this once”). ” [2].

Suh et al. introduce the home applications as: **“**In order to provide more intelligent home services, the physical environments sensing information is demanded. Recently, as the part of ubiquitous networks, wireless sensor networks is populated and issued to perceive physical sensing information [33]. The wireless sensor networks is the collection of smart sensors or RFID, which can self-organize and co-ordinate among each other to gather and transmit sensed data such as temperature, pressure, humidity and photo etc. This technology can be combined into home network areas for making the home services more advances. For example, light sensing information can help to develop the automatic movement of curtain according to amount of light in the home. Temperature and humidity sensor can provide the intelligent air condition system and helps the development of the smart music players [34].

In this paper [35], we introduce the new smart sensor devices with processing and networking as well as various sensing abilities for the ubiquitous home networks. The sensor nodes establish the wireless networks and can be controlled by remote embedded systems. By using these devices, we implement a real ubiquitous model house where the intelligent services are operated based on the wireless sensor networks.

The main purposes of the model house are:

- The wireless home network is established by the smart devices that are equipped to electronic households.
- These equipments are centrally controlled by the remote embedded system

- The control system is easily used by inhabitant
- Defining control packet formats between control system and smart sensors.
- Providing intelligent house operations based on the wireless sensor networks
- Movement detecting sensor manages the door-lock systems.
- Gas sensor prevents the explosion.
- Actuator sensors control the TV, refrigerator and electronic lamp.
- Weather information affects the curtain movements.
- Magnetic sensor detects the window’s open/close states.
- RFID system is combined into home networks

Our paper addresses not only the new smart sensor device and additional modules but also the intelligent home operation. The contributions of our works are as follows: First, we suggest the new paradigm as the ubiquitous house based on wireless sensor networks. Second, we show various intelligent home services with physical sensing information. Third, we implement the new smart device, a real ubiquitous house models and easy home controller system.” [35].

“Toys represent another large market for wireless sensor networks. The list of toys that can be enhanced or enabled by wireless sensor networks is limited only by one’s imagination, and range from conventional radio-controlled cars and boats to computer games employing wireless joysticks and controllers. A particularly intriguing field is personal computer (PC)enhanced toys, which employ the computing power of a nearby computer to enrich the behavior of the toy itself. For example, speech recognition and synthesis may be performed by placing the microphone and speaker in the toy, along with the appropriate analog-to-digital and digital-to-analog converters, but employing a wireless connection to the computer, which performs the recognition and synthesis functions. By not placing the relatively expensive yet limited speech recognition and synthesis circuits in the toy, and using the (much more powerful) computing power already present in the computer, the cost of the toy may be significantly reduced, while greatly improving the capabilities and performance of the toy. It is also possible to give the toy complex behavior that is not practical to implement in other technologies.

Another major home application is an extension of the Remote Keyless Entry (RKE) feature found on many automobiles. With wireless sensor networks, wireless locks, door and window sensors, and wireless light controls, the homeowner may have a device similar to a key fob with a button. When this button is pressed, the device locks all the doors and windows in the home, turns off most indoor lights (save a few night lights), turns on outdoor security lights, and sets the home's HVAC system to nighttime (sleeping) mode. The user receives a reassuring "beep" once this is all done successfully, and sleeps soundly, knowing that the home is secure. Should a door be left open, or some other problem exists, a small display on the device indicates the source of the trouble. The network may even employ a full home security system to detect a broken window or other trouble.

Outside of the home, the location-aware capabilities of wireless sensor networks are suitable for a diverse collection of consumer-related activities, including tourism and shopping. In these applications, location can be used to provide context-specific information to the consumer. In the case of the tourism guide, the user is provided only information relevant to his present view; in the case of the shopping guide, the user is provided information relevant to the products before him, including sale items and special discounts and offers." [2]**.**

2.5.3 Security and Military Sensing [2]

"The wireless security system described above for the home can be augmented for use in industrial security applications. Such systems, employing proprietary communication protocols, have existed for several years. They can support multiple sensors relevant to industrial security, including passive infrared, magnetic door opening, smoke, and broken glass sensors, and sensors for direct human intervention (the "panic button" sensor requesting immediate assistance).

As with many technologies, some of the earliest proposed uses of wireless sensor networks were for military applications. One of the great benefits of using wireless sensor networks is that they can be used to replace guards and sentries around defensive perimeters, keeping soldiers out of harm's way. In this way, they can serve the same function as antipersonnel mines, without the attendant hazard mines represent to allied personnel during the battle (or the civilian population afterward). In addition to such defensive applications, deployed wireless sensor networks can be used to locate and identify targets for potential attack, and to support the attack by locating friendly troops and unmanned vehicles. They may be equipped with acoustic microphones, seismic vibration sensors, magnetic sensors, ultrawideband radar, and other sensors.

Wireless sensor networks can be small, unobtrusive, and camouflaged to resemble native rock, trees, or even roadside litter. By their nature, multihop networks are redundant. These networks have distributed control and routing algorithms (i.e., without a single point of failure), a feature that makes them difficult to destroy in battle. The use of spread spectrum techniques, combined with the bursty transmission format common to many wireless sensor networks (to optimize battery life), can give them a low probability of detection by electronic means. The relative location determination capability of many ad hoc wireless sensor networks can enable the network nodes to be used as elements of a retrodirective array of randomly distributed radiating elements; such an array can be used to provide exfiltration of the sensor network data. The relative location information is used to align the relative carrier phase of the signals transmitted by each node; with this information, the exfiltrated data may be transmitted not just in the direction of the incoming signal, but in any desired direction. Beamforming techniques can also be applied to the sensors themselves, to enhance their sensitivity and improve detection probabilities." [2]**.**

According to Culler and his colleagues, "Wireless sensor networks could advance many scientific pursuits while providing a vehicle for enhancing various forms of productivity, including manufacturing, agriculture, construction, and transportation. On one of their researches, they explain about the issues of self-organized networks. Culler told about the principle as Wireless communication and instrumentation have long been associated with remote sensing from satellites and missile telemetry-prime examples of wireless links. A network consists of many nodes, each with multiple links connecting to other nodes. Information moves hop by hop along a route from the point of production to the point of use. In a wired network like the Internet, each router connects to a specific set of other routers, forming a routing graph. In WSNs, each node has a radio that provides a set of communication links to nearby nodes. By exchanging information, nodes can discover their neighbours and perform a distributed algorithm to determine how to route data according to the application's needs. Although physical placement primarily determines connectivity, variables such as obstructions, interference, environmental factors, antenna orientation, and mobility make determining connectivity a priori difficult. Instead, the network discovers and adapts to whatever connectivity is present [36].

Another military application is about target tracking. Dynamic Convoy Tree-Based Collaboration (DCTC) is a way to target tracking in sensor network. Zhang and Cao did researches about this issue and published their researches. In their research paper, Zhang and Cao explain the DCTC for target tracking in sensor network. They point out that" Most existing work on sensor networks concentrates on finding efficient ways to forward data from the information source to the data centres, and not much work has been done on collecting local data and generating the data report. This paper studies this issue by proposing techniques to detect and track a mobile target. We introduce the concept of dynamic convoy tree-based collaboration (DCTC), and formalize it as a multiple objective optimization problem which needs to find a convoy tree sequence with high tree coverage and low energy consumption. We propose an optimal solution which achieves 100% coverage and minimizes the energy consumption under certain ideal situations. Considering the real constraints of a sensor network, we propose several practical implementations: the conservative scheme and the prediction-based scheme for tree expansion and pruning; the sequential and the localized reconfiguration schemes for tree reconfiguration. Extensive experiments are conducted to compare the practical implementations and the optimal solution. The results show that the prediction-based scheme outperforms the conservative scheme and it can achieve similar coverage and energy consumption to the optimal solution. The experiments also show that the localized reconfiguration scheme outperforms the sequential reconfiguration scheme when the node density is high, and the trend is reversed when the node density is low." [37].

"Wireless sensor networks can also be effective in the monitoring and control of civilian populations with the use of optical, audio, chemical, biological, and radiological sensors to track individuals and groups. The control of wireless sensor networks and the data they produce in a free society, while an important public policy discussion, is outside the scope of this text." [2]**.**

2.5.4 Asset Tracking and Supply Chain Management [2]

"A very large unit volume application of wireless sensor networks is expected to be asset tracking and supply chain management.

Asset tracking can take many forms. One example is the tracking of shipping containers in a large port. Such port facilities may have tens of thousands of containers, some of which are empty and in storage, while others are bound for many different destinations. The containers are stacked, both on land and on ship. An important factor in the shipper's productivity (and profitability) is how efficiently the containers can be organized so that they can be handled the fewest number of times and with the fewest errors. For example, it is important that the containers next needed be on top of a nearby stack instead of at the bottom of a stack 1 km away. An error in the location record of any container can be disastrous; a “lost” container can be found only by an exhaustive search of a very large facility Wireless sensor networks can be used to advantage in such a situation; by placing sensors on each container, its location can always be determined.” [2]**.**

The most famous application is supply chain management. Kim et al. made a research about Intelligent Network Containers. They produce their system as:

“A mesh network delivers the network *scalability* into our hierarchical architecture because it can be easily expanded as needed. In addition, a hierarchical architecture is suitable for *flexibility* and *scalability*. Containers are moved together in a ship, and then into ports, container yards trucks, or onto another ship. Therefore, containers need to form and participate in networks with their new neighbours *dynamically*.

The network inside a container is designed to remain isolated from the dynamic networks outside a container. Any changes inside a container should not affect other networks in our hierarchical architecture as well. In mesh networking, multiple nodes are interconnected through the network. Because this creates redundant network paths, the mesh network enhances the network *reliability*. Besides, the distributed database system in our hierarchical architecture improves the overall reliability of the system. To support *better connectivity,* the hierarchy includes a gateway supporting multiple network protocols (e.g. 802.15.4, 802.11, 802.16, satellite, cellular, etc) for transmission of the mesh networks’ information. These protocols can be dynamically selected based on current transmission requirements (e.g. alerts, data push, instructions, etc), and the current availability or efficiency of communication.

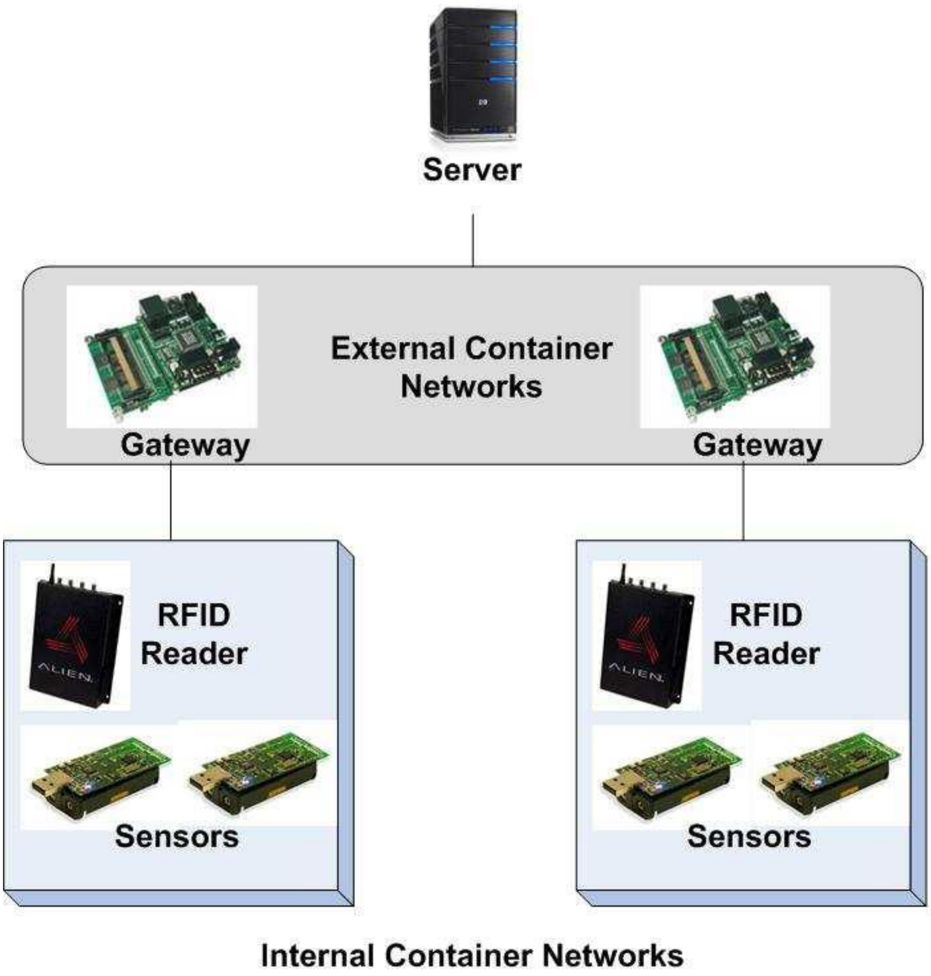


Figure 1: Hierarchical Network Structure for Intelligent Containers

Figure 1 shows the proposed hierarchical structure which consists of the *Server/Data Center*, *External Container Network*, and *Internal Container Network* and Figure 2 shows *External Container Network* and *Internal Container Network* in detail.

Server/Data Center: resides at a shipper's control center or a DHS facility. It receives information (e.g. the environmental condition, containers' status, alert, etc) from gateways via the External Container Network.

External Container Network: provides communication between gateways in a ship/truck/trail. The External Container Network also supports the communication interface between the Server/Data Center and Internal Container Network.

Internal Container Network: supports the communication between devices within a container.

B. Internal Container Networks

There are two types of internal sensing and communication networks. The first provides a unique identifier capability through the use of a small form factor RFID reader connected to a WSN sensor device. The second network provides a wide variety of sensing capabilities participating in their own mesh network inside the container.

The *Identifier Internal Container Network* contains an RFID reader and motes placed within a container. Each container also has a low-power mobile gateway, (in this case a CrossBow StarGate device [38]) which provides the external communication interface between the internal network and the external infrastructure. A gateway is located on a container door and wirelessly communicates with motes and the RFID reader. The gateway can send commands to those devices participating in this container's identifier internal mesh network and gather information from them. To ensure a more reliable and efficient architecture, all sensor network data collected by the gateway can also be saved into its local database and then sent to the remote Server/Data Center periodically or upon request.

In summary, an RFID reader placed inside a container door provides visibility into the physical cargo IDs moving in and out of the container. RFID tagging on a container's doors enables location tracking of that particular container. Therefore, RFID technology applied in different manners can support tracking contents through the hierarchy of cases, boxes, containers, ships, etc.

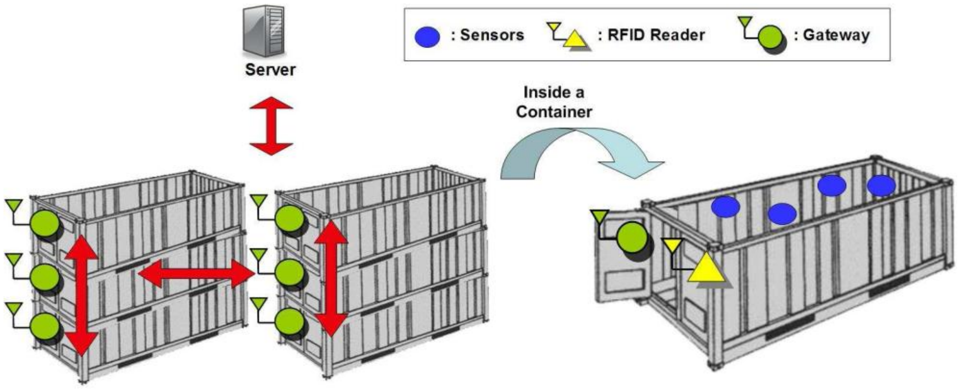


Figure 2: Internal and External Container Networks

The *Sensing Internal Container Network* can contain a wide variety of motes providing continuous or event-triggered condition monitoring capabilities in the container. This mesh network also requires access to external communication infrastructure via a multi-protocol gateway device.

C. External Container Networks

External Container Networks are created via the dynamic interaction of externally mounted gateways. These networks form and change due to proximity as well as to the current physical environment conditions. The ability to interact and create networks among containers leads to enhanced security. In addition, by using the container stacks to communicate up and out of the ship via the mesh network, a container can compensate for a lack of clear line of sight for GPS sensing. The ad-hoc external mesh networks between containers provide an efficient mechanism for sharing information from outside and moving information through the mesh up and out of the ship." [39].

"Similar situations involving large numbers of items that must be tracked occur in rail yards, where thousands of railroad cars of all types must be organized, and in the manufacture of durable goods, such as cars and trucks, that may sit in large lots or warehouses after manufacture, but before delivery to a retailer.

A related application is that of supply chain management. An item in a large warehouse, but with its precise location unknown, is practically lost because it is unavailable to be used or sold. This represents inventory shrinkage, even though the item is physically on the premises, and is therefore a business expense. In a manner similar to that of the asset tracking application described previously, wireless sensor networks can be used to reduce this cost; however, additional benefits may be obtained. In a large distribution chain, one of the most vexing problems facing the distributor is to quickly and accurately identify the location of material to be sold. Knowing where a product is can mean the difference between making or not making a sale, but knowing the status of the entire supply chain—from raw materials through components to final product—can help a business operate more efficiently. For example, transferring excess product from Division X (where it is selling slowly) to Division Y (where it is selling briskly) can help a company avoid the purchase of component parts to manufacture more product for Division Y. Wireless sensor networks placed along the supply chain enable everyone in the business to make better decisions because more information about product in the supply chain is available.

This information can also be used as a competitive advantage; by being able to tell a customer exactly where his product is (or even where the component parts of his product are) in the supply chain, the customer's confidence of on-time delivery (and opinion of the seller's competence) rises. This has already been used extensively in the package shipping industry, so much so that customers expect this service as a matter of course—a shipper that cannot tell a customer where his package is at any given time is rarely reused.

The use of wireless sensor networks for the tracking of nuclear materials has already been demonstrated in the Authenticated Tracking and Monitoring System (ATMS). The ATMS employs wireless sensors (including the state of the door seal, as well as infrared, smoke, radiation, and temperature sensors) within a shipping container (e.g., a railroad car) to monitor the state of its contents. Notification of sensor events are wirelessly transmitted within the shipping container to a mobile processing unit, connected to both a Global Positioning System (GPS) receiver and an International Maritime Satellite (INMARSAT) transceiver. Through the INMARSAT system, the location and status of each shipment may be monitored anywhere in the world." [2]**.**

2.5.5 Intelligent Agriculture and Environmental Sensing [2]

"A textbook example of the use of wireless sensor networks in agriculture is the rain gauge. Large farms and ranches may cover several square miles, and they may receive rain only sporadically and only on some portions of the farm. Irrigation is expensive, so it is important to know which fields have received rain, so that irrigation may be omitted, and which fields have not and must be irrigated. Such an application is ideal for wireless sensor networks. The amount of data sent over the network can be very low (as low as one bit—"yes or no"—in response to the "Did it rain today?" query), and the message latency can be on the order of minutes. Yet, costs must be low, and power consumption must be low enough for the entire network to last an entire growing season.

The wireless sensor network is capable of much more than just soil moisture measurements, however, because the network can be fitted with a near-infinite variety of chemical and biological sensors. The data that is provided by such a network is capable of providing the farmer with a graphical view of soil moisture; temperature; the need for pesticides, herbicides, and fertilizers; received sunshine; and many other quantities. This type of application is especially important in vineyards, where subtle environmental changes may have large effects on the value of the crop and how it is processed.

The location determination features of many wireless sensor networks also may be used in advanced control systems to enable more automation of farming equipment.

Many applications of wireless sensor networks are also used on ranches. Ranchers may use wireless sensor networks in the location determination of animals within the ranch and, with sensors placed on each animal, determine the need for treatments to prevent parasites. Dairy farmers may use wireless sensors to determine the onset of estrus in cattle, a laborintensive manual process at present. Hog and chicken farmers typically have many animals in cooled, ventilated barns. Should the temperature rise excessively, many thousands of animals may be lost. Wireless sensor networks can be used to monitor the temperature throughout the barn, keeping the animals safe.

Wireless sensor networks may also be used for low-power sensing of environmental contaminants such as mercury. Integrated microcantilever sensors sensitive to particular contaminants can achieve parts-per-trillion sensitivities. These microelectromechanical (MEMS) sensors may be integrated with a wireless transceiver in a standard complementary metal oxide semiconductor (CMOS) process, providing a very low-cost solution to the monitoring of chemical and biological agents." [2]**.**

2.5.6 Health Monitoring [2]

"A market for wireless sensor networks that is expected to grow quickly is the field of health monitoring. "Health monitoring" is usually defined as "monitoring of non-life-critical health information," to differentiate it from medical telemetry, although the definition is broad and nonspecific, and some medical telemetry applications can be considered for wireless sensor networks.

Two general classes of health monitoring applications are available for wireless sensor networks. One class is athletic performance monitoring, for example, tracking one's pulse and respiration rate via wearable sensors and sending the information to a personal computer for later analysis. The other class is at-home health monitoring, for example, personal weight management. The patient's weight may be wirelessly sent to a personal computer for storage. Other examples are daily blood sugar monitoring and recording by a diabetic, and remote monitoring of patients with chronic disorders.

The use of wireless sensor networks in health monitoring is expected to accelerate due to the development of biological sensors compatible with conventional CMOS integrated circuit processes. These sensors, which can detect enzymes, nucleic acids, and other biologically important materials, can be very small and inexpensive, leading to many applications in pharmaceuticals and medical care.

A developing field in the health monitoring market is that of implanted medical devices. In the United States, the Federal Communications Commission (FCC) established regulations governing the Medical Implant Communications Service, in January 2000, "for transmitting data in support of diagnostic or therapeutic functions associated with implanted medical devices.” These types of systems can be used for a number of purposes, from monitoring cardiac pacemakers to specialized drug delivery systems.

A developing field related to both health monitoring and security is that of disaster relief. For example, the wireless sensors of the HVAC system in a collapsed multistory building (perhaps the result of an earthquake) can provide victim location information to rescue workers if acoustic sensors, activated automatically by accelerometers or manually by emergency personnel, are included. Water and gas sensors also could be used to give rescuers an understanding of the conditions beneath them in the rubble. Even if no additional sensors were included, the identities and pre- and post-collapse locations of the surviving network nodes can be used to help workers understand how the building collapsed, where air pockets or other survivable areas may be, and can be used by forensic investigators to make future buildings safer.

Wireless disaster relief systems, in the form of avalanche rescue beacons, are already on the market. Avalanche rescue beacons, which continuously transmit signals that rescuers can use to locate the wearer in time of emergency, are used by skiers and other mountaineers in avalancheprone areas. The present systems have their limitations, however; principal among these is that they provide only location information, and give no information about the health of the victim. In a large avalanche, when emergency personnel can detect several beacons, they have no way to decide who should be assisted first. It was recently proposed that these systems be enhanced by the addition of health sensors, including oximeters and thermometers, so that would-be rescuers would be able to perform triage in a large avalanche, identifying those still alive under the snow [40]” [2].

3. EXISTING LOCALIZATION TECHNIQUES

3.1.1 Introduction

The design of accurate localization algorithms in the realization of wireless sensor networks is a challenging task. Localization in wireless sensor networks is becoming more important, because many applications need to locate the source of incoming measurement as precise as possible. In many applications of wireless sensor networks, sensing data is meaningless without predictable location. Also, self configuration and self organization are key mechanisms for robustness and can easily be supported by position information. Even the position itself would be the information of interest. Therefore, the calculation of positions of the sensor nodes is so important. In this paper three main localization techniques which are RSSI (Receiving Signal Strength Indicator), TDOA (Time Difference of Arrival) and AOA (Angle of Arrival), will be examined.

3.2 Receiving Signal Strength Indicator (RSSI)

One of the most suitable and practically tested approaches in location management or Real Time Locating System is Receiving Signal Strength Indicator (RSSI) based distance calculation algorithm. There are many other methods that use ultrasound or lasers can success high accuracy, but each device adds to the size, cost, and energy requirements. Especially GPS provides proper location data as a popular location estimation system; it may not satisfy all the purposes by considering the issues of the indoor reliability, high expenditures, installment and power consumption. This system requires line of sight to some satellites consumes additional energy and is too expensive to get integrated on hundreds of sensor nodes. For these reasons, such methods are not suitable for common sensor networks. Additionally, “an inexpensive RF-based approach the received signal strength indicator (RSSI) has a larger variation because it is subject to the deleterious effects of fading or shadowing.” [41].

3.2.1 Analysis of Received Signal Strength Indicator

The idea behind RSS is that the configured transmission power at the transmitting device directly affects the receiving power at the receiving device. According to Friis’ free space transmission equation, the detected signal strength decreases quadratically with the distance to the sender [42]. Radio propagation path loss has great effects on localization precision of the RSSI localization algorithm. The free space radio propagation path loss model is shown as follows in Eq.1:

(1)

In this equitation, d is distance from signal source, km; f is frequency, MHz; k is path attenuation factor. As indicated in the article of Su "In actual applications, the radio propagation path loss makes some difference from that of theoretical values due to the effects such as multipath, diffraction and obstacles, etc. The following log-distance distribution model will be more reasonable. Eq.2 can be used to calculate path losses as nodes receive beaconing information." [43].

— **(2)**

"Where, *PL*(*d*) is path loss of distance d, dB; is random variable in Gaussian distribution with an average value 0 and standard deviation range 4~10. k value in the formula ranges between 2 and 5. d = 1m is substituted into Eq.1 and Loss as well as value of can be obtained. Signal strength as each unknown node receives beaconing node signal can be obtained as shown in Eq.3 according to Eq.2." [43].

(3)

"Where, P is emission power, G is antenna gain. On the other hand, there are lots of influencing effects such as reflections of metallic objects, superposition of electro-magnetic fields, diffraction at edges, refraction by media with different propagation velocity that interfere the radio signals. That causes the ideal distribution of receiver power applicable." [44].

3.2.2 IEEE 802.15.4 Standard

Receiving Signal Strength Indicator can be used in an IEEE Standard that set up properly for the common purposes. It is significant to decrease energy consumption in wireless sensor networks, so some spread-wide using IEEE protocols is not suitable for wireless sensor networks and RSSI applications such as IEEE 802.11 [41]. The IEEE 802.15.4 standard that has been adopted by the ZigBee Alliance has appeared for low-rate wireless personal area networks. As mentioned in the article of Srbinovska, Gavroski and Dimcev , "The reference model shows the various layers of the ZigBee wireless technology architecture the relationship of the IEEE 802.15.4 standard to the ZigBee alliance MAC layer protocol model. These layers facilitate the features that make ZigBee very attractive: low cost, very low power consumption, reliable data transfer, and easy implementation. Using the IEEE 802.15.4 specifications, the alliance focuses on the design issues related to the network, security and applications layers." [44]. Layers of this standart are shown below by Figure.3

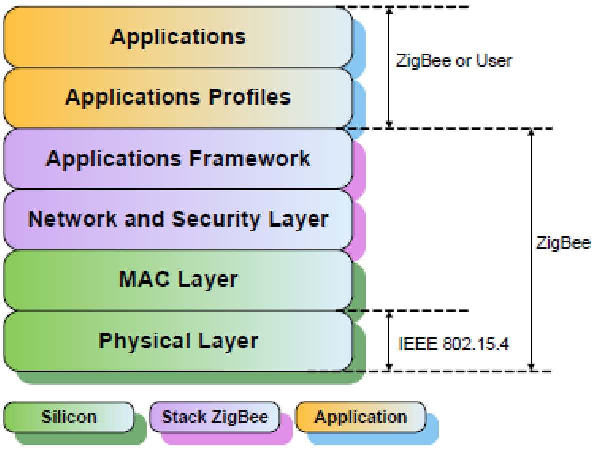


Figure 3: ZigBee Alliance Layer Protocol Model [44]

The ZigBee technology oparates three possible frequncy bands: 868.0-868.6MHz with 20 -40kbits/s transfer rate which can be used in Europe ,902-928MHz with 20-40kbits/s transfer rate which can be used in North America and 2400-2483.5MHz with 250kbits/s transfer rate which is available worldwide use [45].

3.2.3 Signal Strength Evaluating Methods

When determining distance based on RSSI, the instability of RSSI should be eliminated by using some algorithms. In order to obtain meaningful RSSI data's, three major data processing methods will be examined such as statistical mean value model (SMVM), distance between the fixed-nodes-based model (DBFM) and Gaussian model (GM).

A. *Statistical Mean Value Model (SMVM)* [46]

In this model, the mean value of the receiving RSSI values is computed and associated with the distance. This basic method is commonly used to evaluate the RSSI data in many networks. The formula is shown below as Eq.4.

– **(4)**

Here, *m* is the number of the RSSI values which the unknown node receives. By adjusting the value of m, this model can balance timeliness and accuracy. When m is very big, this model can avoid instability of RSSI but communication overhead will correspondingly be high [46].

B. Distance Between the Fixed-nodes based Model(DBFM) [46]

There is another model to reduce instability of RSSI called Distance Between the Fixed-nodes based Model. This model is more complex than the previous one. Firstly two fixed nodes are set to identify the distance-RSSI relation properly, then this relation applies to find out the unknown nodes RSSI values. As indicated in article of Jianwu and Lu “When we compute the distance from unknown node to fixed node, we take the distance and signal strength information between fixed nodes as the reference, so that the localization accuracy will be improved. Assuming the nodes and are put in known locations , we assume is the mean value of RSSI which unknown node A receives from the fixed datum node , is the mean value of RSSI which the fixed datum node B1 receives from the fixed datum node , is the mean value of signal strength which unknown node A receives from the fixed datum node , is the mean value of signal strength which the fixed datum node B1 receives from the fixed datum node B2, the formula is shown as Eq.5.” [46].

(5)

is the distance from the fixed datum node to the fixed datum node . is the distance from the unknown node A to fixed datum node [46].

—— – **(6)**

— — —

C. Gauss Model (GM) [46]

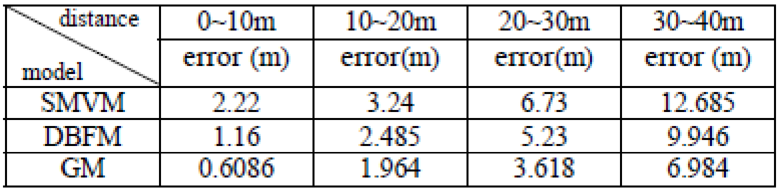
There could be some minor portability events in a sequence of RSSI values as the unknown node receives the RSSI signals from beacons. In order to get more proper RSSI values, these small events should be eliminated by using Gauss Model as emphasized in the article of Jianwu and Lu. The implementation of the study shown as follows; “First, we save the RSSI values which the unknown node receives in identical position to the array named Beacon_val[]. Second, we use Gaussian distribution functions which are shown in 7.th Equations Lines to deal with the RSSI values.” [46].

(7)

“According to the practical experience, we choose 0.6 as the critical point. When the value of Gaussian distribution function is bigger than 0.6, we figure that the corresponding RSSI values are high probability events, Otherwise we figure that the corresponding RSSI values are small probability events. By using equations above, the array named Beacon_val_gauss can be obtained. At last RSSI value appears in Eq.8 by using the defined array.” [46].

(8)

The experiment carrying on by Jianwu & Lu shown in their article, comprasion of three models displayed in Figure.4 and Table.1 below. IEEE802.15.4 compatible CC2430 chip used in this experiment and variables are set as n=3.5 and .As the result of this work, the measurement error of Gauss model meets the need of the wireless sensor node localization technology [46].



distance	0~10m	10~20m	20~30m	30~40m
model	error (m)	error(m)	error(m)	error (m)
SMVM	2.22	3.24	6.73	12.685
DBFM	1.16	2.485	5.23	9.946
GM	0.6086	1.964	3.618	6.984

Table 1: Comparision of Three Models

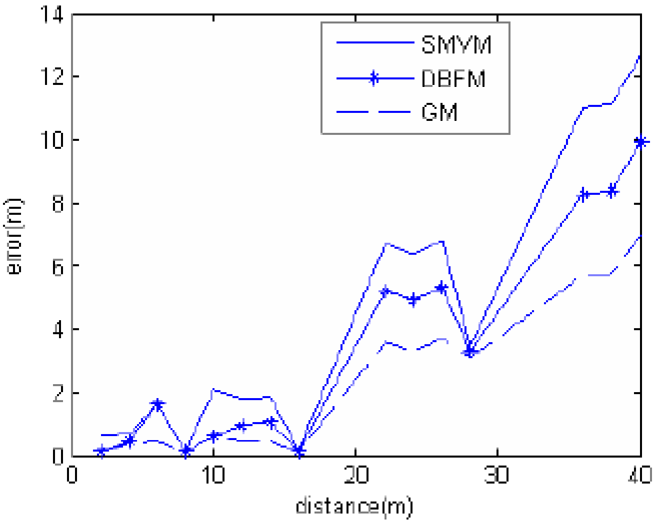


Figure 4: Performances of Three Models

3.2.4 Parameters on RSSI Based Distance Estimation

All signal strength-based localization systems, in particular indoor, must consider some parameters that affect the RSSI value. These parameters could cause some errors as multi-path propagation, reflection, and fading effects. However, there is another usage of these parameters that is improving relation between RSSI value and the distance. By adjusting the parameters improved measurement results can be gathered from the nodes. In this section some of these factors will be examined.

A. *Antenna characteristics and orientation* [47]

As referring the article of Awad, "The used antennas are regarded to forming sources with spherical radiation. Typically, signals are sent in the frequency range between 868 MHz and 915 MHz, thus, the antennas are about 8.3 cm (λ/4) long. Usually, it is assumed that the signals on their way from the transmitter to the receiver spread in all directions equally – otherwise, measurements of the mutual orientation would have to be admitted. Since we cannot determine mutual orientation but we do assume the fact that the orientation directly exerts influence on the RSSI, a method is needed to compensate the orientation effects." [47].

B. *Variation of the transmission power* [47]

As Awad, Frunzke and Dressler mentioned in their article, "The transmission power and the frequency determine the maximum range of the radio waves. While the maximum transmission power might be appropriate for long distance communication (disregarding energy requirements), differences in the RSSI are hardly visible for small distances between transmitters and receivers. However, the measurement of short distances for the localization in closed areas with small dimensions is important. Thus, the transmission power must be well controlled for meaningful RSSI based distance measurements.” [47].

C. *Variation of the Frequency* [47]

As implemented in the work of Awad, Frunzke and Dressler, “Small changes of the wavelength can lead to different developments of the fading effects caused by reflection. Thus, the dispersions caused by inappropriate frequency under the given basic conditions must be considered. Therefore, also the observation of the signal strength under different frequencies is a subject of the accomplished experiments.” [47].

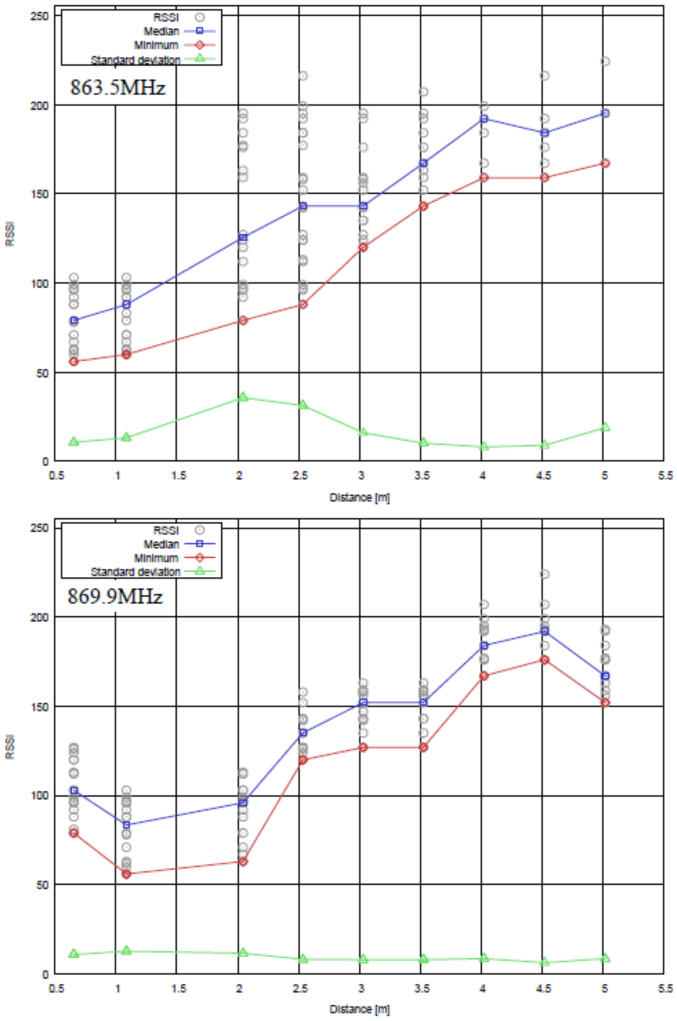


Figure 5: Frequency Dependent RSII Values

The displaying graphics in Figure.5 are the results of the experiment on the effects of different frequencies on RSSI signals. As seen in Figure.5, some frequencies are more vulnerable to disturbances than others especially in some distance intervals. Although these differences might be caused by the environment, it is significant to choose frequency for the localization setup by comparing the measurements of different frequencies to get the best possible result [47].

D. Variation of Sampling Time [47]

As obviously realized in the studies of both Wu, Lee, Tseng, Jan, & Chuang and Awad, Frunzke, & Dressler, there isn't any connection between the RSSI signals and sampling time [48]. The figures and the table shown in below clearly point out that sampling time does not make any considerable affect on RSSI signals. The experiment has been repeated both in 20 seconds and 120 seconds periods without changing anything but the term with Chipcon CC1000 chip at the frequency of 868MHz [47].

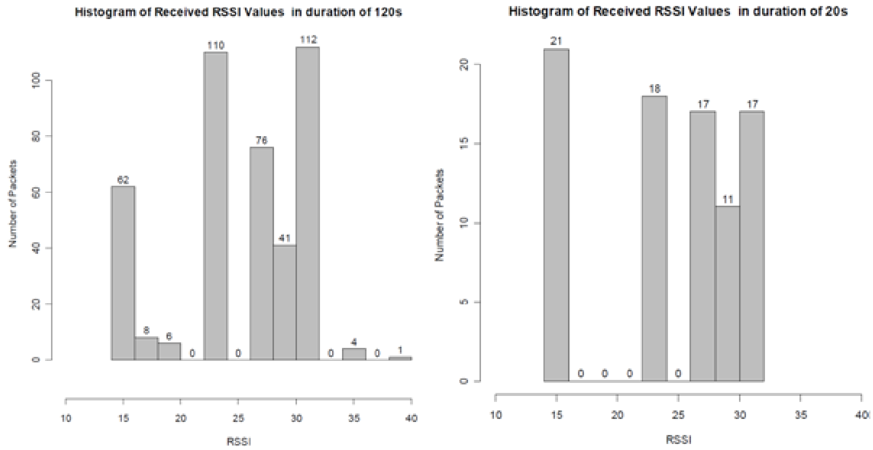
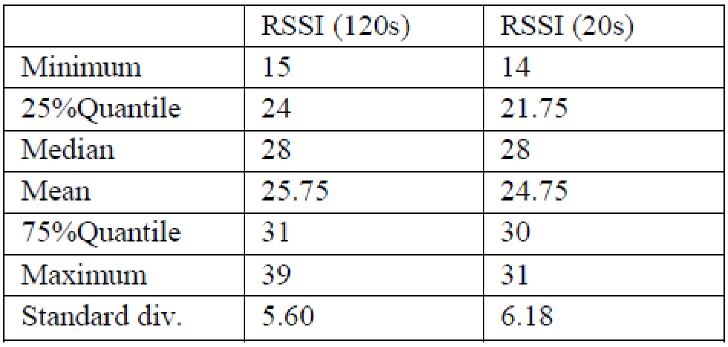


Figure 6: Graphics of RSII Values at Different Sampling Times



	RSSI (120s)	RSSI (20s)
Minimum	15	14
25%Quantile	24	21.75
Median	28	28
Mean	25.75	24.75
75%Quantile	31	30
Maximum	39	31
Standard div.	5.60	6.18

Table 2: Table of RSII Values at Different Sampling Times

3.3 Time Difference of Arrival (TDOA)

Another important localization technique is Time Difference of Arrival (TDOA). "TDOA-based schemes measure the distance between given two points using two signals with different speeds that traverse the same path between the two points. Consider two signals A and B with speeds v_A and v_B sent simultaneously by a transmitter. If $v_A > v_B$, then signal B lags behind signal A as they propagate. Let t denote this time lag at a receiver located at a distance d from the transmitter." [49]. Then,

$$d = \frac{t}{\frac{1}{v_A} - \frac{1}{v_B}}. \tag{9}$$

In TDOA, time difference rather than absolute time is collected and then transformed into distance difference to two base stations. By estimating the difference between the arrival times of the signals the distance can be measured with a simple calculation. It is important to mention that the receivers do not require to know the absolute time at which the signal was transmitted but the time difference.

Most of the localization systems use RF and Ultrasound signals to measure the distance between receivers and transmitters. Since the accuracy is crucial in localization, most important advantage of using RF and ultrasonic signals is the significant speed difference between them. At normal room temperature and humidity, the speed of sound, $v_{us} \approx 344$ m/s, and speed of light, $v_{rf} \approx 3 \times 108$ m/s. Since $v_{RF} >> v_{US}$,

$$d \approx \delta T \cdot v_{us} \tag{10}$$

RF signal, carries a message containing specific information of the signal such as ID or temperature. This message is delivered to receiver after a preamble. It takes a long time for RF receivers to resolve the preamble part before the message. To avoid the miscalculations, receivers estimate the time interval between the start of RF message (instead of arrival of RF signal) and arrival of ultrasound signal.

3.3.1 Possible Error Sources for TDOA

The accuracy of TDOA technique depends on some variables such as environmental effects, line of sight etc...

A. *Environmental Factors*

In sound- based signals like ultrasound, velocity of signal depends on environmental factors such as temperature, humidity, and pressure. "In completely dry air with no humidity, the speed of sound depends only on the absolute temperature T (in Kelvin), and is given by $20.0\sqrt{T}$. In case the measurement takes place indoor, air contains water vapor which affects the speed. The speed of sound is not very sensitive to relative humidity and atmospheric pressure variations. For instance, at 25 ^{0}C and 101.325 kPa (atmospheric pressure at sea level), the speed of sound changes by only about 0.5% as the relative humidity changes from 0% to 100%." [49].

B. Non-Line-of-Sight

TDOA measurements are known to have poor accuracy due to technical limitations of propagation environments. "Many indoor applications require a position accuracy of a few centimeters and an orientation accuracy of a few degrees. The harshness of in- door environments on signal propagation, caused by obstacles, makes it hard to achieve these accuracies." [49]. The major error source of TDOA is the NLOS (Non-Line-of-sight). As see in Figure 7, NLOS propagation error occurs when a direct signal path is blocked by some obstacles. In case there are objects between the transmitter and the receiver, signals can reflect off some of objects. As a result, transmitted signal does not arrive along the shortest path. With NLOS propagation, the signal arriving at the receiver is reflected and diffracted and takes a path that is longer than direct path. So, the line of position computed from such longer estimates of distances will lie far from the true position of the transformers [50].

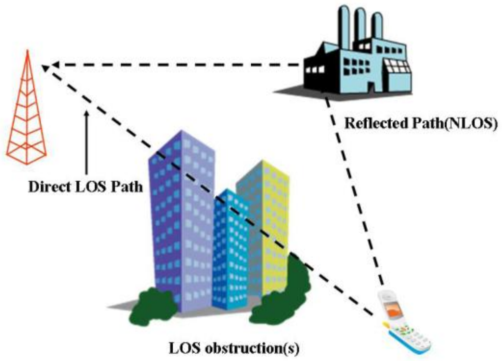


Figure 7: Signal Paths

C. US Detection Threshold

Another problem may occur in detecting US signal. "When the system uses a threshold based approach to detect the arrival of the US signal, receiver detects the arrival of a US signal when the signal amplitude at the output of the US amplifier circuit reaches a preset threshold (65 mV). However, the time taken for the received signal to reach this threshold is dependent on the received signal strength. Hence, there is a received US signal strength dependent error in the distance measurement." [51].

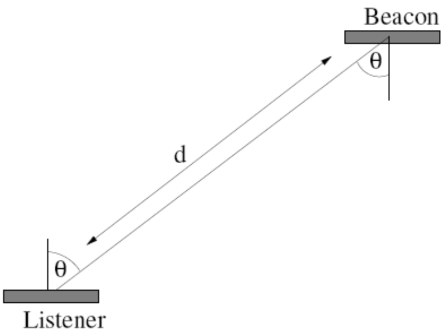


Figure 8: Position of Two Nodes

It is observed that errors in the distance measurement increase as the distance d in the Figure 8 increase. “This increase is to be expected since increasing d causes the received US signal strength at the receiver to drop, causing the detection circuits to take a longer time to detect the signal, resulting in an increased positive error.” [49].

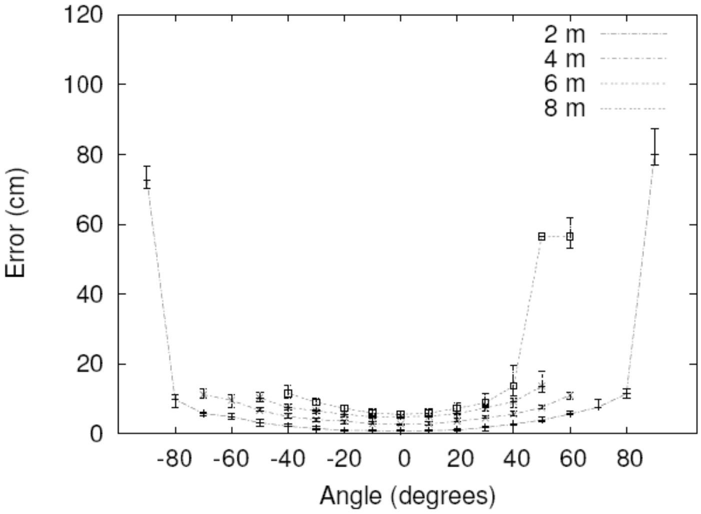


Figure 9: Angle Dependent Estimation Errors

As seen in the Figure 9, when the angle θ (in Figure 8) increases, measurement error increases as well.

D. Signal Interference

Another important error source is interference of transmitted signals. “Since typical indoor applications require accurate location information, receivers must be able to measure these distances accurately. Since beacon transmissions are not centrally coordinated, the distance measurement technique also needs to deal with possible interference among multiple beacon transmissions.” [49]. When there are more than one transmitter that emits RF and US signals, it can cause signals from different transmitter to interfere at a receiver.

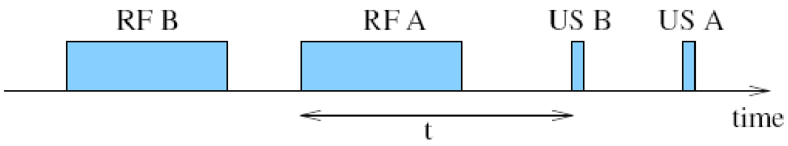


Figure 10: TDOA System With Several Transmitters

3.3.2 Localization Techniques

"If we need to estimate the location of a node based on known node, the position of this node is computed by the solution of a set of equations. The most common localization algorithm is the Multilateration. If the distances are known to at least three reference objects, one can set up a system of circle equations." [47].

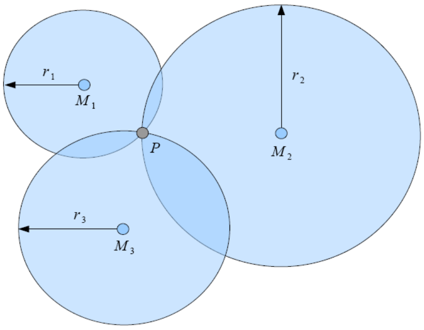


Figure 11: Multilateration with three nodes

"Suppose coordinates of beacon nodes B_1 (x_1, y_1) , B_2 (x_2, y_2) , … , Bn (x_n, y_n) , and coordinates of nodes with position to be determined O(x, y), distances between this node and the beacon nodes are d_2, …, d_n , respectively. A group of non-linear equations can be obtained according to the calculation formula for distance in two-dimensional space, as shown below." [43].

$$\begin{cases} (x-x_1)^2+(y-y_1)^2=d_1^2 \\ (x-x_2)^2+(y-y_2)^2=d_2^2 \\ \quad\vdots \\ (x-x_n)^2+(y-y_n)^2=d_n^2 \end{cases} \tag{11}$$

The last equation was subtracted from the other equations in turns beginning from the first equation.

$$\begin{cases} x_1^2 - x_n^2 - 2(x_1 - x_n)x + y_1^2 \\ \quad - y_n^2 - 2(y_1 - y_n)y = d_1^2 - d_n^2 \\ \quad \vdots \\ x_{n-1}^2 - x_n^2 - 2(x_{n-1} - x_n)x + y_{n-1}^2 \\ \quad - y_n^2 - 2(y_{n-1} - y_n)y = d_{n-1}^2 - d_n^2 \end{cases} \tag{12}$$

Linear equation in Eq. (12) can be shown as $AX = b$, where [43];

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

$$b = \begin{bmatrix} x_1^2 - x_n^2 + y_1^2 - y_n^2 - d_1^2 + d_n^2 \\ \vdots \\ x_{n-1}^2 - x_n^2 + y_{n-1}^2 - y_n^2 - d_{n-1}^2 + d_n^2 \end{bmatrix}, \tag{13}$$

$$X = \begin{bmatrix} x \\ y \end{bmatrix}$$

Coordinate estimation value of Node O can be obtained using estimation method for standard minimum mean square error [43].

3.4 Angle of Arrival

AOA is a localization method to estimate the exact position of any node in a wireless sensor network by using special antenna configurations to estimate the angle of arrival of the received signal from a beacon node. Common approach to obtain AOA measurements is to use an antenna array on each sensor node.

There are two different ways to obtain the exact position of the unknown nodes depend on orientation information. Both of the cases can be solved by using triangulation [52].

Firstly, it is been considering the case when the orientations of the nodes are known. As Peng and Sichitiu mentioned in their article, in the figure shown below, “angles Θ_1 and Θ_2, which are measured at unknown *u*, are the relative AOAs of the signals sent from beacons b_1 and b_2, respectively. Assuming the orientation of the unknown is $\Delta\Theta$, the absolute AOAs from b_1 and b_2 can be calculated as $(\Theta_i + \Delta\Theta)$ (mod 2π), $i = \{1,2\}$. Each absolute AOA measurement corresponding to a beacon restricts the location of the unknown along a ray starting at the beacon. The location of the unknown *u* is located at the intersection of all rays when two or more non-collinear beacons are available.“ [52].

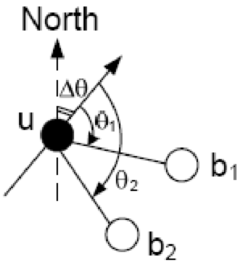


Figure 12: A Sensor Node in An AOA System

Secondly, the orientations of the unknown nodes cannot be available, in other words the absolute AOA cannot be obtained. In the figure below as Peng and Sichiuti point out, “Angles *b*1*ub*2, *b*1*ub*3 and *b*2*ub*3 can be computed using the knowledge of the relative AOAs. All angles subtended by the same chord are equal. Thus, given two points and the chord joining them, a third point from which the chord subtends a fixed angle is constrained to an arc of a circle. That is to say, the angle *b*1*ub*2 and the chord *b*1*b*2 restrict *u*’s position on the arc passing through *b*1, *u* and *b*2. Since each chord determines one arc, the location of an unknown is at the intersection of all arcs when three or more non-collinear beacons are available. “ [52].

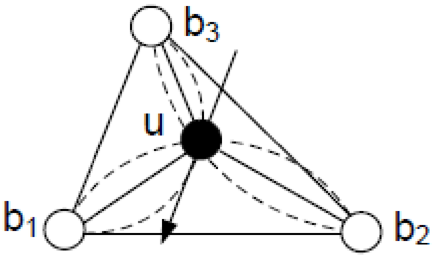


Figure 13: Triletaration in AOA

The same case is discussed in the article of Niculescu and Nath. In the figure 14, for node B, bearing to A is ba, radial from A is ab, and heading is b. The solution of the problem is expressed as same as the previous one “ given imprecise bearing measurements to neighbors in a connected ad hoc network where a small fraction of the nodes have self positioning capability, find headings and positions for all nodes in the network.” [53].

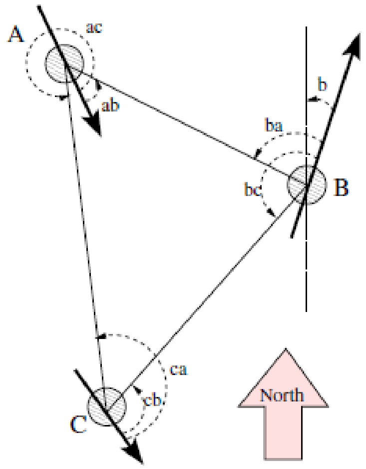


Figure 14: An Example of Three Nodes Angle of Arrival Implemantation

In the same reference, finding the unknown node's position is inferred by using triangulation: "if beside coordinates of *A*, *B* and *C*, node *D* knows distances *DA*, *DB* and *DC*, it can use trilateration to infer its position. On the other hand, if it knows the angles *BDA*, *ADC*, and *CDB* it can find its position using triangulation. This is done by finding the intersection of the three circles determined by the landmarks and the known angles. Information from several landmarks can be used to get a least square error solution." [53].

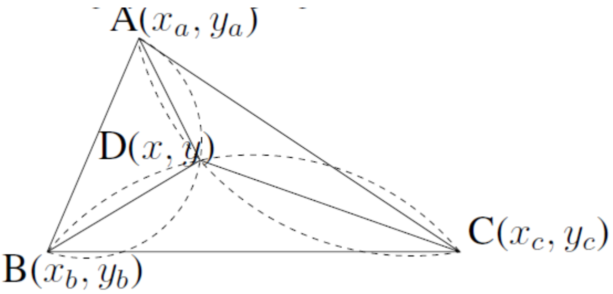


Figure 15: Triletaration in AOA System

As a result, in angle of arrival technique the minimum required non-collinear beacon is described as two if the orientations are obvious. In the other case, at least three anchors are required in order to determine position of the unknown node.

There is an different angle based method, whose name is VOR(VHS Omni-directional Range), mentioned in the article of Niculescu and Nath. "Its principle is very simple: a landmark sends two signals, one that is periodic and omni-directional, while another one is directional and is rotated about the landmark. The equipment receives both signals, and interprets the difference as a radial from the station. The coordinates of the station are known, therefore placing the mobile, anywhere on a given line. A second VOR reading provides a second line to be intersected with the first. Given (*xi*, *yi*, *ri*) the coordinates and the radial to the landmark *i*, a node can build the equation of the line *aix* + *biy* = *ci* on which it places itself…What makes it slightly different form the previous one is the fact that the landmark should be equipped with a compass, so that it reports all radials against a well known direction, such as north. The bearing method, on the other hand does not require any compass at all, but still provides positioning and orientation for the all nodes.” [53].

As similar to previous one, any other directionality based technique has been revealed in the article of Nasipuru and Li. Rotating fixed nodes are used with a stable angular speed and narrow beam. The implemented system is shown below by Figure.16.

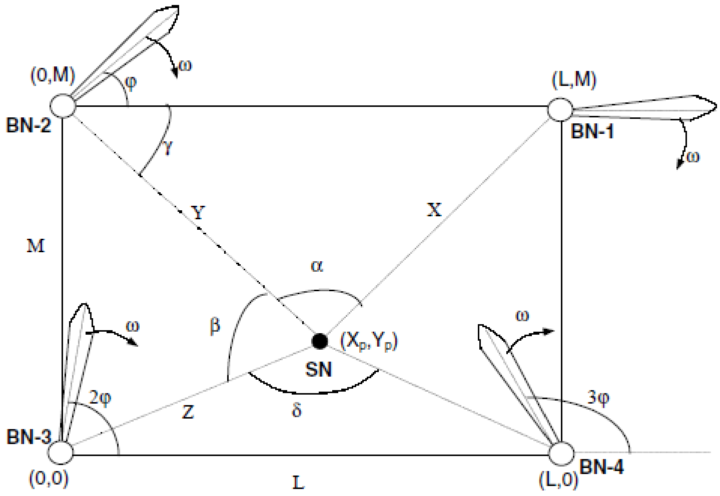


Figure 16: Angle of Arrival Implemantation with Rotating Fixed Nodes

In order to distinguish the beacon nodes, different angular seperations are set arbitrary. Additionally, different carrier frequencies or codes can be implemented to define different beacon signals. As Nasipuru and Li refers, “The localization principle is based on a sensor node noting the times when it receives the different beacon signals, and evaluating its angular bearings and location with respect to the beacon nodes by triangulation. Denote the times at which an SN receives the beacons signals from BN-1, BN-2, BN-3, and BN-4 by *t*1, *t*2, *t*3 and *t*4, respectively. Since the sensor nodes have no time synchronization with the beacon nodes, the absolute values of these times bear no useful information.” [54].

The angles of the unknown node can be expressed in respect to the time as follows:

$$\begin{aligned}\alpha &= \phi - \omega\tau_1 \\ \beta &= \phi - \omega\tau_2 \\ \delta &= \phi - \omega\tau_3\end{aligned} \quad \textbf{(14)}$$

In the equitation, $\tau_1 = t_2 - t_1$, $\tau_2 = t_3 - t_2$, and $\tau_3 = t_4 - t_3$. "Any two angles chosen from α, β, and δ can then be used to solve for the location of the SN using trigonometry."[54]. For example, using the values of α and β, we get:

$$\begin{aligned}\gamma &= arctan\left[\frac{cos(\beta) - Ssin(\alpha)}{Scos(\alpha) - sin(\beta)}\right] \\ Y &= L\frac{sin(\gamma - \alpha)}{sin(\alpha)}\end{aligned} \quad \textbf{(15)}$$

Where,

$$S = \frac{L\ sin(\beta)}{M\ sin(\alpha)}. \quad \textbf{(16)}$$

The location variables of the unknown node are as follows,

$$\begin{aligned}X_p &= Y cos(\gamma) \\ Y_p &= M - Y sin(\gamma)\end{aligned} \quad \textbf{(17)}$$

The methods that use the rotating nodes have major problems such as non-zero bandwidth of the directional beam and multiple signals generated by multipath reflections.

Finite bandwidth of the directional beam causes some problem to determine arrival time of the signal. As indicated in the article, "A directional beam from a wireless antenna has a finite beam width, no matter how small, which will make it difficult for the nodes to estimate the exact time at which the center of the directional beam passes through it. This could be a major concern for estimating the angles of arrival of the beacon signals and lead to an error in location discovery using this technique." Overcoming this problem is also emphasized as center of the beam can be determined when the maximum received signal strength is obtained [54].

Multiple signals generated by multipath reflection are the major noises that obstruct the proper location estimation in angle of arrival method as well. Reflections from surrounding objects can cause the beacon signal to be received at the SN even when the beam is not directed towards it. Reducing beam width is inferred in the article of Nasipuri and Li as a solution of this problem. Therefore, signals reflection possibility can be minimized [54].

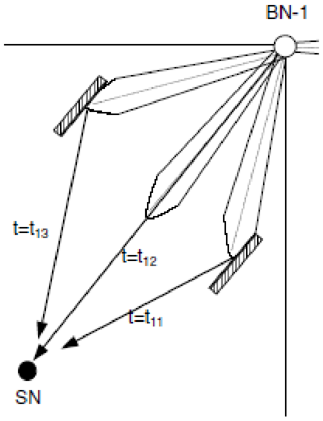


Figure 17: Signal Interference in AOA

3.5 Comparison of Localization Methods

TDOA, RSSI and AOA are existing real time tracking methods that have many applications for wireless sensor networks. As presented in previous sections; TDOA is a method that measure the distance between given two points by using two signals whose speeds are different, RSSI uses the actual strength signal in the determination of distance and lastly AOA uses the signal angles to determine localization despite of giving any distance measurement.

As shown in the experiment displayed in the article “Experimental Performance Comparison of RSSI and TDOA-Based Location Estimation Methods”, location estimation error range of the RSSI based localization is with %100 packet success rate bigger than the TDOA-based localization even with much less packet success rates. In contrast, if the environment consist any moving object, this results would be changed.

Radio wave can reach everywhere in the area and the RSSI-based localization takes into consideration the RSSI variation due to frequent shadowing of the direct wireless links between the target and anchor nodes by the moving objects, on the other hand, the ultrasonic wave cannot reach everywhere due to the sharp beam pattern and the TDOA-based localization measures the distances of the indirect wireless links between the target and anchor nodes reflected by the moving objects [55]. This also shows that the TDOA-based localization has two regions in the location estimation area; in active region, it can give good estimates for locations whereas in inactive region, it cannot estimate locations any more.

Apart from RSSI, TDOA technique requires additional hardware. Therefore it can be said that TDOA is a high-priced localization technique when compared to RSSI. However, it is known that TDOA has better accuracy to RSSI.

An additional approach to localization estimation is Angle of Arrival that has appeared after the other two methods come up. It has some different fearures when comparing the others. Firstly, there is not any additional hardware required in this method but an antenna array. As a superior feature, there are only two fixed nodes enough to estimate any unknown node if the all the orientations are known in the network. On the other hand, it is required direct line of sight like TDOA. There are also additional error sources that come up with this technique such as beam width. Furthermore, AOA is affected by the multipath propagation like others. AOA differs from others in localization technique called triangulation that requires more numerical calculation. Accuracy of the technique is better than RSSI in some environment as soon as direct line of sight provided. The hybrid model of TDOA and AOA is used in some applications as well in order to obtain both better prediction and correlation of any estimation. The general purposes of localization has been satisfied accurately especially in aerial applications by using this method.

RF and US-based TDOA and AOA approaches to determine localization are accurate techniques and also easy to deploy. The TDOA and AOA-based localizations or hybrid applications can work better than the RSSI-based localization only in their active region when empty location estimation areas are used. However, the RSSI-based location always works regardless of whether there are any obstacles in the line of sight. This is because the TDOA-AOA based localizations require clear direct links between a target node and anchor nodes. On the other hand, the RSSI-based localization can take into consideration frequent shadowing of the direct links by the moving objects. Although lack of line-of-sight is still a critical issue, TDOA and AOA have slight accuracies degradation when compared to RSSI.

4. PROPOSED METHOD

Abstract theory behind the proposed method was described at introduction under the hypothesis title. In this section the method will be explained in a more applicable way.

4.1 Infrared Band Images

In order to move out of the visible portion of the electromagnetic spectrum, which is overloaded with human actions, a new band has to be chosen. Although more suitable bands could be found infrared band imagery is suitable for practical purposes because infrared cameras are widely available.

An image captured by an infrared camera is shown below.

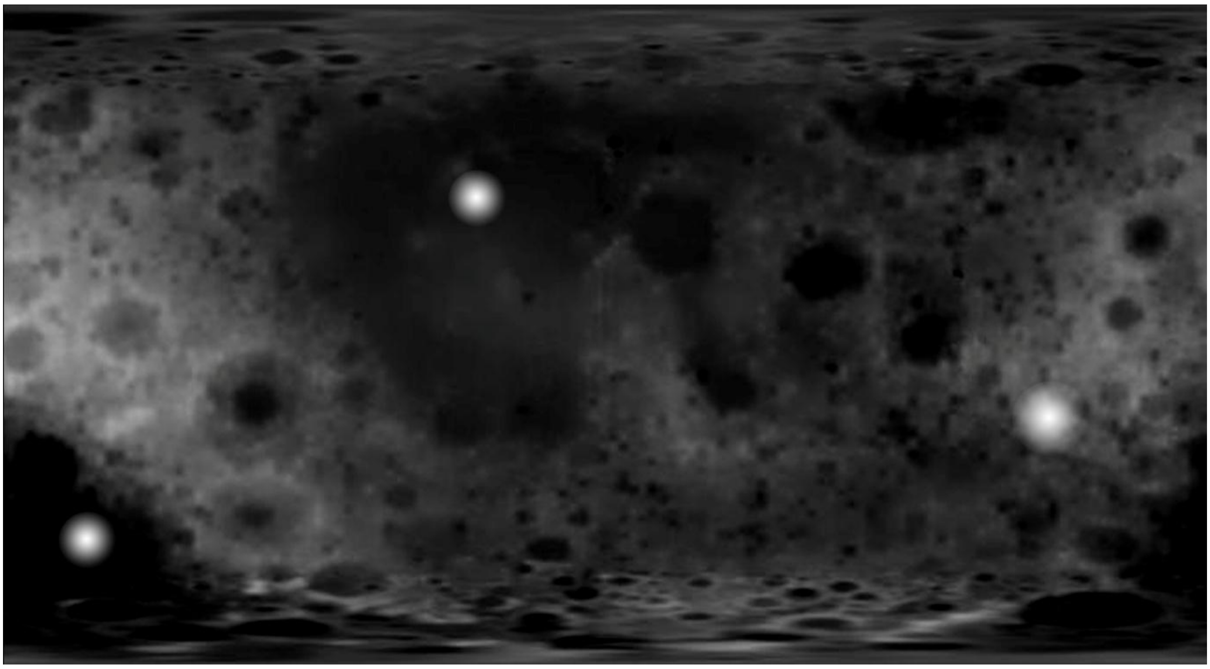


Figure 18: An Example Infrared Image

That gray scale image consists of entities which reflect, scatter or emit infrared signals. Despite moving to IR band, images are still far from providing uniqueness.

4.2 Amplitude filter

Amplitude of the emitted infrared signals from trackable objects is controllable so an amplitude filter can be applied to eliminate irrelevant signal sources. Further enhancement towards singular target is gained with application of amplitude filter. Infrared signal emission of deployed sensor nodes are set to be higher than a specific level. A high pass amplitude filter is employed to filter infrared signal sources that have lower brightness values than the specified level. The next image is result of amplitude filter applied to the previous image.

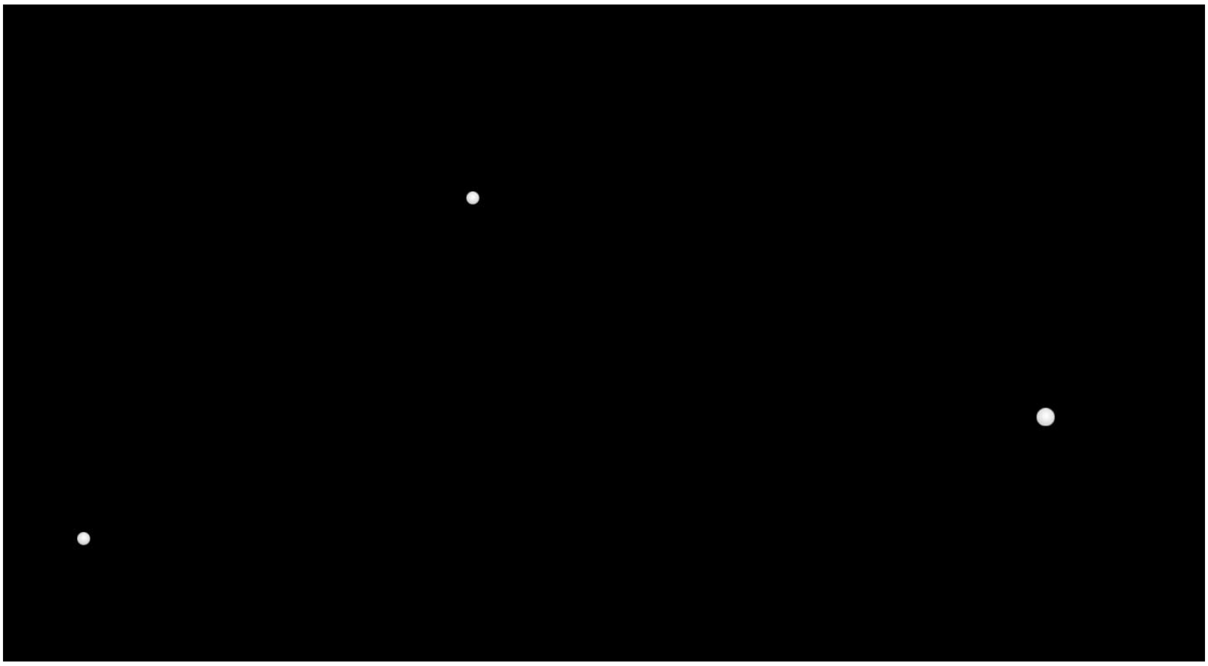


Figure 19: Image After Application of the Amplitude Filter

Although result of the filter is free of many intruding infrared signals it still is not guaranteed to have singular signal source. In a real life topology, infrared signal sources passing the amplitude filter will usually be IR remote controls, other sensor nodes etc. .

4.3 Further Filtering

One last step is proposed in the aim of perfecting the result. That step consists of adding another dimension which is defined with existence as a function of time and application of a filter to this dimension.

In order to create the desired distinction, the tracked node is instructed to toggle its emitting status. A filtered example image shown here is obtained after the toggling.

Figure 20: Image Obtained After Toggling

Implementing a logical XOR operation to Figure.19 and Figue.20 will yield differences between the images. (Note: After applying amplitude filter, pixels passing the filter are set to highest value , in this example 255, and pixels suppressed by filter have the value 0. This transformation gives us the ability to implement logical operations.) Result of the XOR operation contains only the differences between two images (Figure.21). Infact there are two differencing infrared signal sources, which means that the goal is not achieved yet.

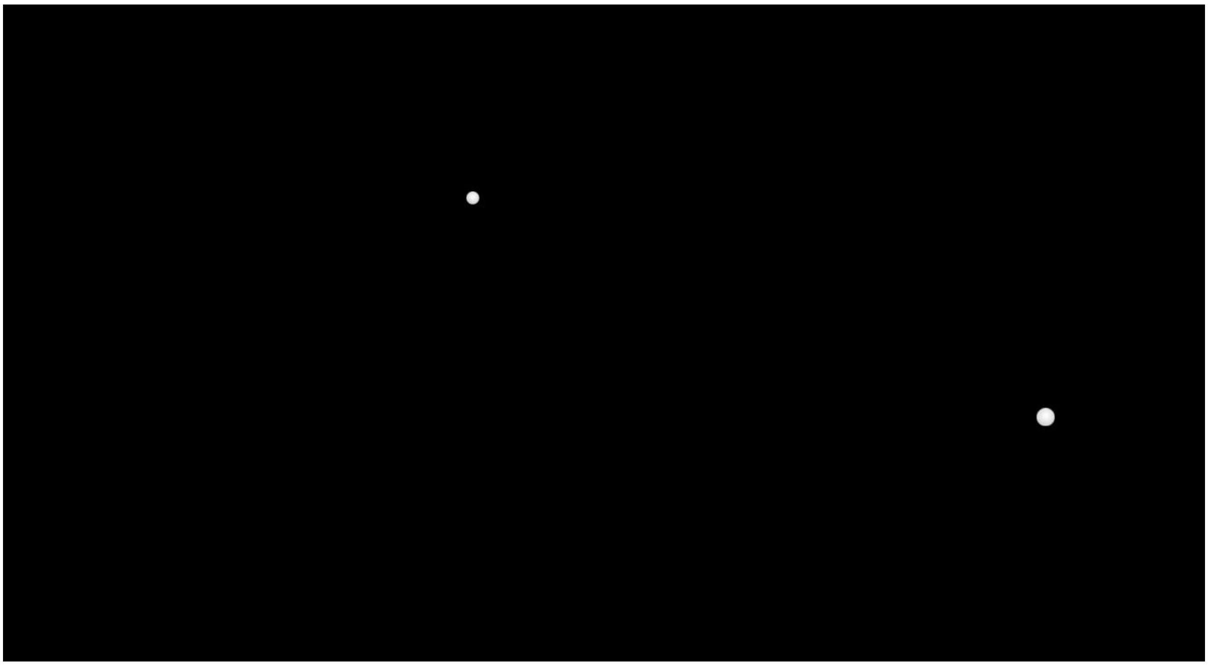


Figure 21: Resulting Image of the XOR Operation

Another round of change detection is needed at this point. A toggling command is sent to the sensor node, in this case a “start emitting signal” instruction. Figure.22 is a filtered image taken after execution of the command.

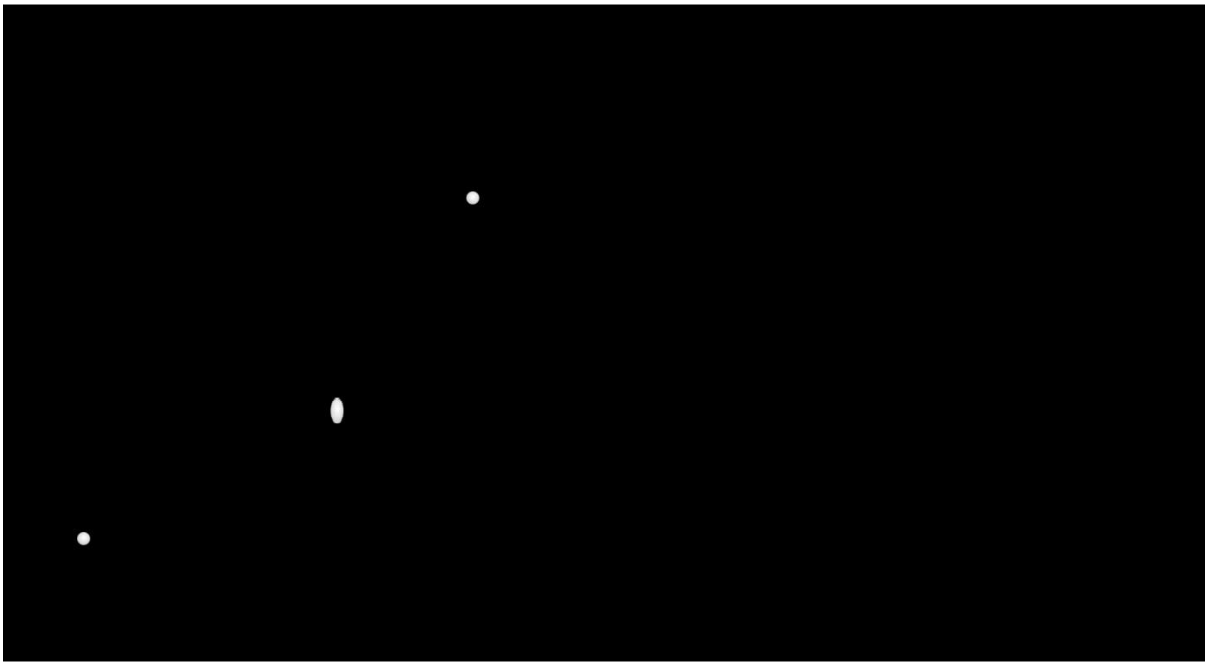


Figure 22: Image Taken After the Toggling Operation

Looking for current chages is done by employing XOR operation to Figure.20 and Figure.22. Resulting image (Figure.23) is the current difference of topology.

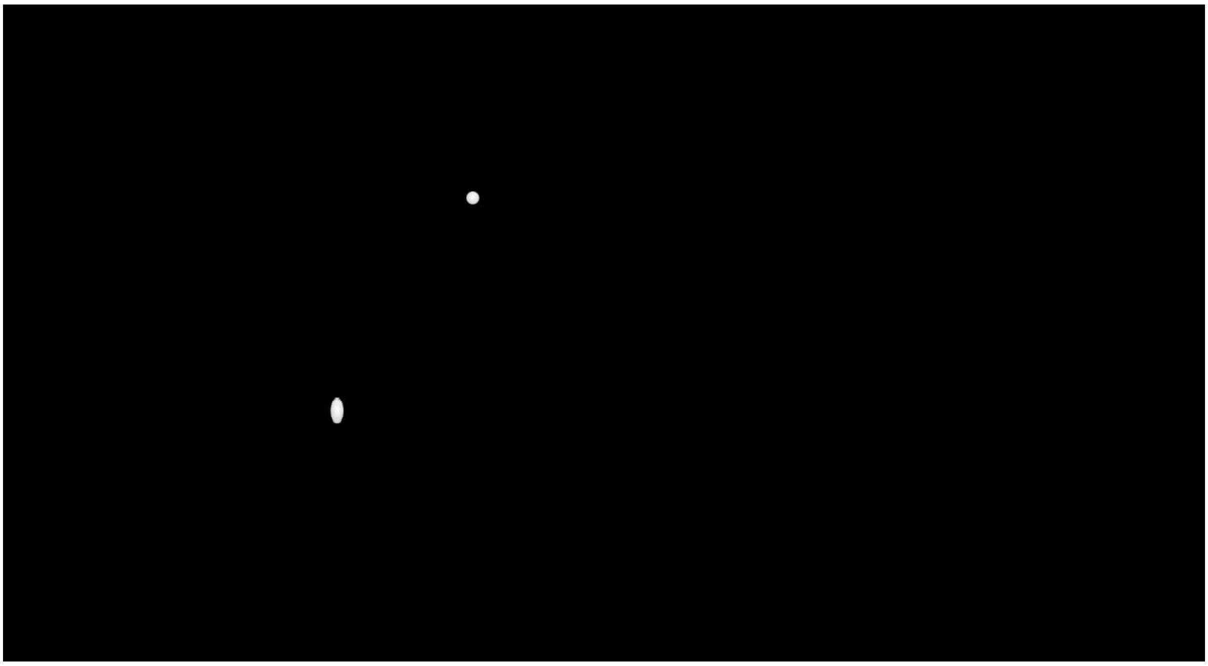


Figure 23: Resulting Image of the XOR Operation Applied to Figure 20 and Figure 22

Applying a logical AND operator to XOR result set (in this example Figure.21 and Figure.23) will give the signal source which changed its state every time the toggling is applied. That very point is the sensor node which is target of the system. The infrared source that has responded to all of toggling instructions is shown in Figure.24.

Figure 24: Infrared Source that has Responded to All of Toggling Instructions

If there is still not a unique signal source then a new sound of toggling and image acquisition flow should be repeated until the singulary of signal is obtained.

Here is a process flow chart of the whole method:

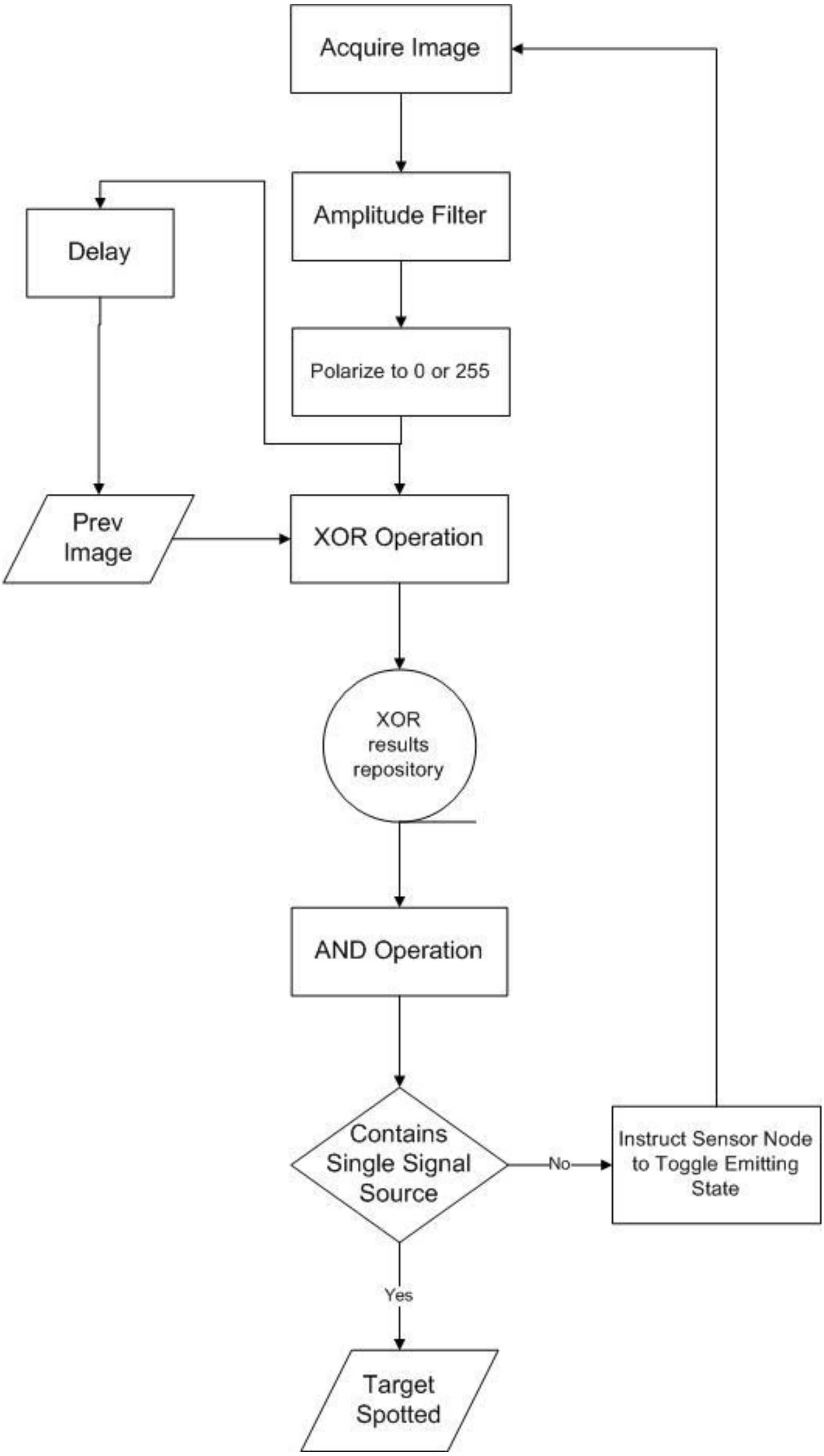


Figure 25: Flow Chart of Whole Method

As a result spotted signal source’s pixel coordinates directly match to sensor node’s location.

4.4 Applicational Concerns of the Work

4.4.1 Visible Area

Area covered by the camera depends on three main variables:
1)Distance between camera and visible surface.
2)Angle between camera and the surface.
3)Horizontal and vertical viewing angles of the camera.
In a setup at which the camera is perpendicular to surface the visible area is a rectangle. Calculations about that visible area are as following (Radial distortion is being neglected):

Where:

: Camera’s viewing angle on the x-axis

: Camera’s viewing angle on the y-axis

: Distance of the camera from the surface

: Width of visible area

: Height of visible area

: Area of visible region

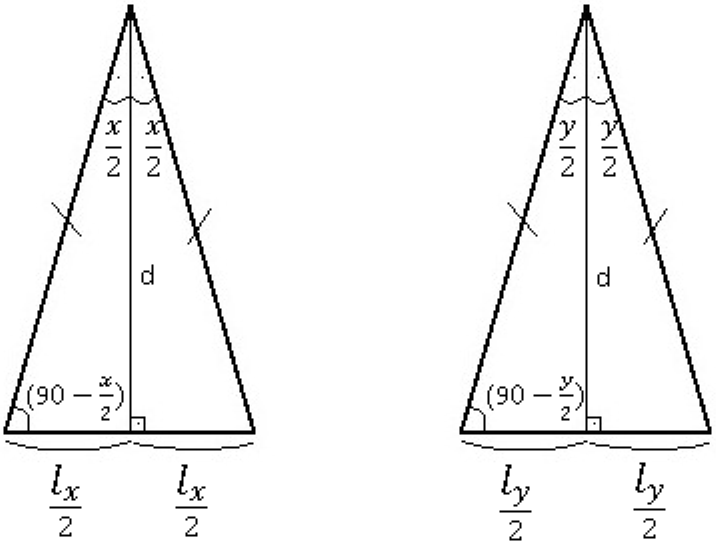


Figure 26: Geometric Representation of Width and Height of the Visible Area

$$\frac{}{-} \qquad \frac{}{-} \qquad \frac{-}{-} \tag{18}$$

$$\frac{}{-} \qquad \frac{}{-} \qquad \frac{-}{-} \tag{19}$$

(20)

The table shows an example of what these calculations mean in numbers, where

	( )	( )	( )
2m	107,2	145,6	15608,32
3m	160,8	218,4	35118,72
5m	267,9	363,9	97488,81
10m	535,9	727,9	390081,61
15m	803,8	1091,9	877669,22
20m	1071,8	1455,9	1560433,62

Table 3: Change of Area as a Response to Distance From the Surface

In a realworld case where camera is attached to a wall with an angle, the visible area is an isosceles trapezoid. Calculations about that visible area are shown below (Radial distortion is being neglected).

Where:

: Angle between vertical axis and the camera

: Camera’s viewing angle on the x-axis

: Camera’s viewing angle on the y-axis

: Height of the camera

: Vertical length covered by the camera

: Narrowest horizontal length covered by the camera

: Broadest horizontal length covered by the camera

: Area covered by the camera

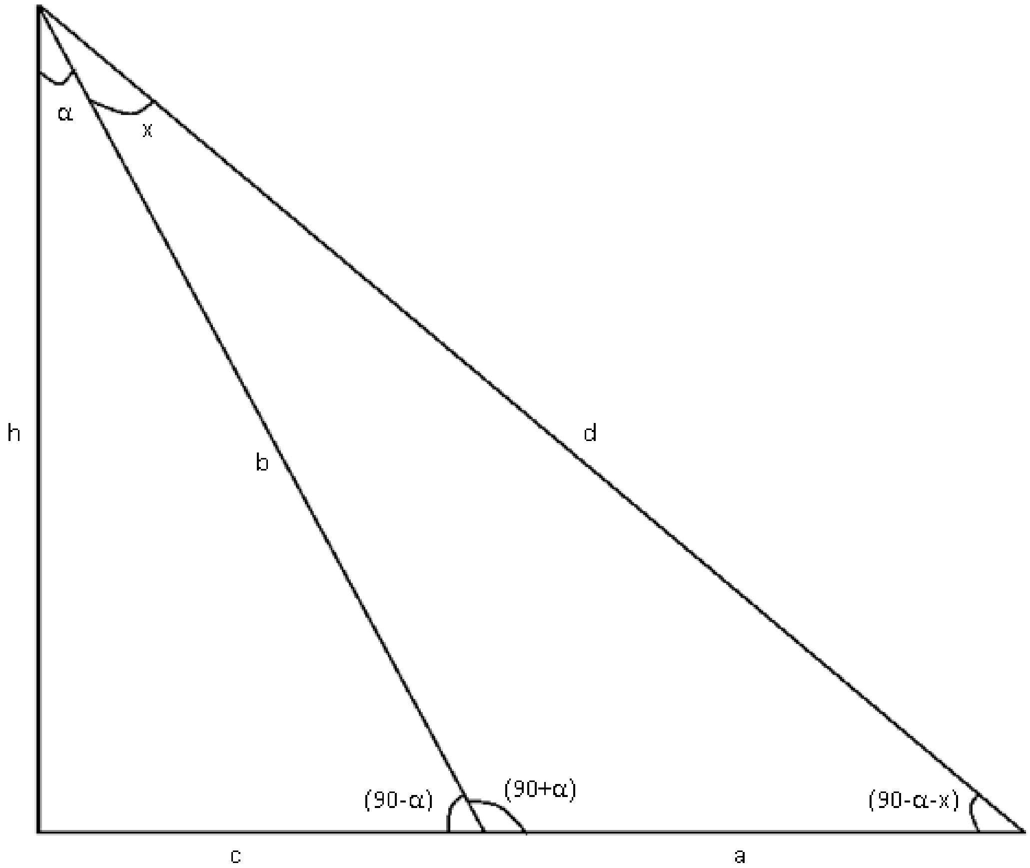


Figure 27: Geometric Representation of Visible Region of a Camera attached to a Wall With an Angle

(21)

(22)

(23)

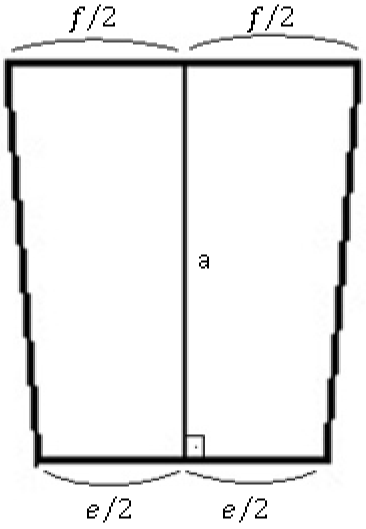


Figure 28: Geometric Representation of Trapezoid Region Covered by the Camera

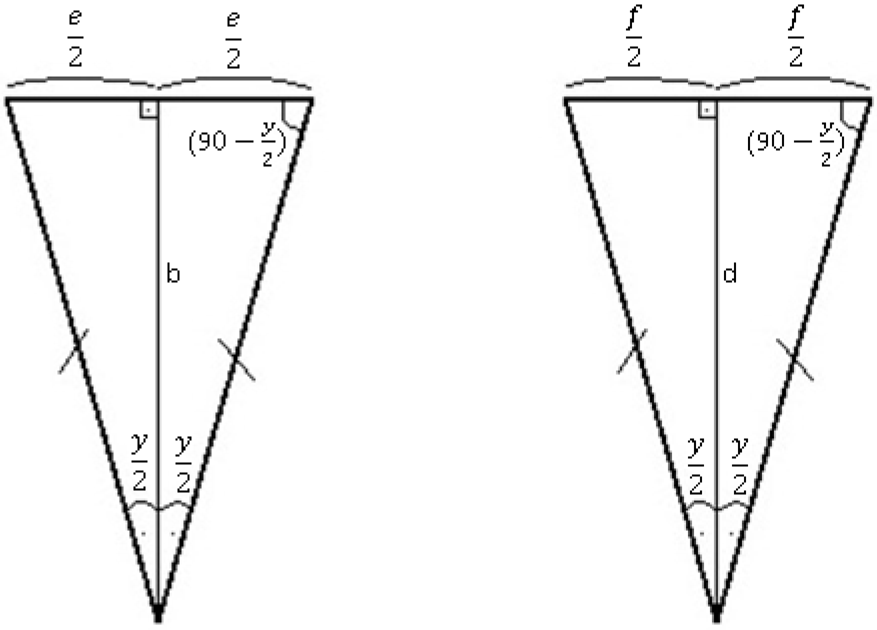


Figure 29: Geometric Representation of Trapezoid's Bases

$$\frac{\quad}{-} \qquad \frac{\quad}{-} \qquad \frac{-}{-} \tag{24}$$

$$\frac{\quad}{-} \qquad \frac{\quad}{-} \qquad \frac{-}{-} \tag{25}$$

$$\frac{\quad}{\quad} \tag{26}$$

The table shows an example of what these calculations mean in numbers, where

	( )	( )	( )	
2m	434,025	123,760	313,372	94863,384
3m	651,038	185,640	470,058	213442,615
5m	1085,063	309,401	783,431	592896,155
10m	2170,127	618,802	1566,862	2371584,620
12m	2604,152	742,562	1880,234	3415081,854
15m	3255,190	928,203	2350,293	5336065,397

Table 4: Change of Area as a Response to Height of the Camera

4.4.2 Identification of Nodes

As explained in the theory, nodes are identified by their change of states over time.There are two main issues of a setup at which patterns of IR LED states are used to identify nodes: selection of synchronization signal and time needed to identify a node.

Where the length of the synchronization signal is equal to length of time slots representing the node id. The synchronization signal should be chosen in a way that its first and last bits don't have the same value in order to eliminate the posibility of vague signal patterns.

For example, where 1 means IR led is on and 0 means off, 1010 can be elected for the synchronization signal whereas 1111 can not be elected because an identity pattern which starts with 1 would make it impossible to determine which id is being sent out of the node.

The time required to identify a node is defined as following.
Where:

: Node count

: Sampling period of the camera (1/frames per second)

: Time span required to identify a node

(27)

For example, in a setup in which there are 15 nodes and the camera is taking 90 frames per second the time span required to identify a node would be 0.088 second.

4.4.3 Window Size for Moving Nodes

Since there is a certain amount of time needed to identify a node, moving objects should be considered in a window so that they could be identified even if they have changed their position.
Required window size for a moving object is calculated as following:
Where:

: Window size required at x-axis

: Speed of the node at x-axis

: Sensitivity in x dimension, width per pixel

: Window size required at y-axis

: Speed of the node at y-axis

: Sensitivity in y dimension, height per pixel

: Required window size

(28)

(29)

(30)

4.4.4 Sensitivity / Error Rate

Sensitivity of a camera is determined by its pixel count representing a specific area..
Where:

: Camera’s viewing angle on the x-axis

: Camera’s viewing angle on the y-axis

: Distance of the camera from the surface

: Width of visible area

: Height of visible area

: Camera’s resolution on the x-axis

: Camera’s resolution on the y-axis

: Sensitivity in x dimension, width per pixel (max error in x)

: Sensitivity in y dimension, height per pixel (max error in y)

: Sensitivity in area, area per pixel (max error in area)

(31)

(32)

(33)

The table shows an example of what these calculations mean in numbers, where

	( )	( )	( )	( )	
2m	1,072	1,456	0,1396	0,1422	0,01984
3m	1,608	2,184	0,2093	0,2133	0,04464
5m	2,679	3,639	0,3489	0,3554	0,12401
10m	5,359	7,279	0,6978	0,7109	0,49604
15m	8,038	10,919	1,0467	1,0663	1,11609
20m	10,718	14,559	1,3956	1,4218	1,98416

Table 5: Sensitivity Values According to Distance Between the Camera and Visible Surface

4.5 Limitations

Multipath is the most challenging task to improve in localization techniques. As indicating, “Multipath interference is a phenomenon in the physics of waves whereby a wave from a source travels to a detector via two or more paths and, under the right condition; the two (or more) components of the wave interfere.”[56]. The measurement technique requires dealing with possible interference among multiple transmissions when transmissions are not properly coordinated. Additionally, the obstructions in the environment can reflect signals from the surfaces that can create multipath affect. There could be any noises that disrupt the actual signal in the area that the measurement occurs, as well. Specifically in RF-based systems, different signals spread from different sources interference each others that cause either signal attenuation or strengthening at the receiver nodes. These kind of affect result in severe distributions on guided data that mislead to obtain actual localization values. Also, being recovered from this error source is required more complicated applications that could bring additional devices or expenditures in the system despite of IR based method.

Multipath affect can be still admitted as a considerable error source that is suffered by IR-based localization as well as other methods due to its misguiding in determination of position of the unknown elements in the network. However, options of recovering multipath affect on IR-based systems are relatively simple to implement by considering additional parameters that are out of favor for the network.

One approach to distinguish actual signal from noises is measuring signal strength at the receivers. The noise signals can lose signal strength while they are being transmitted between the nodes because of being forced to use indirect paths by reflections. Therefore, it can be observed a difference between the real signal and the noise. It is not a subject for an IR signal to affect another one in neither increasing nor decreasing way, so the main consider is reflecting signals appeared on IR band images due to the multipath transmission. Thus, the real signals can be identified from the multipath propagations by determining its signal strength.

Another method to release multipath propagation in IR-based systems is installing two LED with known distance on the sensor nodes to find out the multipath propagation in the environment. These two LEDs transmit two different signals whose distinguishing feature should be chosen their frequencies. These signals reflect from surfaces with different angles because of the distance between them. Therefore, a frequency filter can be used to clarify reflection ratio by separating two sources as known implementations in regular localization practices. Thus, localization algorithm can be improved by considering known multipath affect in the measuring area.

While creating an infrared map in the selected region, foreign noises can cause another significant problem for the accurate localization. IR cameras can perceive any signal which covers equivalent frequency interval with infrared signals. Therefore, there is not any obstruction to receive different signals that is not transmitted from plotted LEDs. This characteristic causes a lot of exterior noises that can be distrup accuracy. In order to overcome from this handicap, different frequency and power strength filters are developed.

Another limitation occurs because of the Sun’s infrared radiation. Infrared radiation from the Sun can saturate the camera. As a result it is limited to indoor applications.

Line of sight is the essential demand for the proposed method. It can be said that IR-based localization method works on two different region as well as the systems of TDOA. The active region, direct line of sight is provided with observing node, so the system can recognize the measuring nodes as the IR images. In the other case, there can be some obstacles existed between the sensor nodes and the IR camera that prevent measurement.

4.6 Advantages

The most outstanding benefit of the proposed method is the ability of reaching extremely high precisions on localization when compared to other techniques. Especially obtaining localization information as an IR image of the environment brings more accuracy and fewer relevancies of exterior disrupted parameters. By using IR cameras and images, localization information is transmitted directly from source to user via infrared signals that are perceived simultaneously without requiring to use any additional numerical algorithm. In this manner, complex calculations and indirect functions of the distances are abandoned by transforming IR signals to visual values with location information on time domain.

The technique proposed in the thesis, primarily departs from the others by using IR bands. Existing methods commonly require RF signal transmissions for determining position of the unknown nodes. Therefore, the sensors are supposed to transmit RF signals for localization in the network. However, IR-based method does not depend on RF signal properties which are much more costly to produce. The location information can be obtained externally by identification of IR band images. In this manner, transmitting consumption can be minimized. Furthermore, determining position by infrared signal provides a straightforward sensing algorithm rather than multifaceted RF signal processing methods.

The method that use ultrasound mentioned before whose name is TDOA. As this method, there are many other techniques that require additional hardware to determine unknown position. Those additional devices need more size, cost and energy consumption. Likewise, the most important device to provide proper position is Global Positioning System used widely for several purposes. It can be used to determine the locations of the sensor nodes by integrating GPS devices in all the nodes. In this way indoor reliability will not be adequate, although the expenditures, installment and power consumption will be high due to GPS receivers exist in every node. In the proposed method, it is enough to install Light Emission Diodes in all the nodes which are exceedingly inexpensive. Furthermore, creating infrared signals is not challenging task that requires considerable power consumptions when evaluating another methods. Also, infrared cameras are required to capture IR images which have low cost as well when comparing with other additional devices. Moreover, limited numbers of IR cameras with wide visual angle can appropriately operate the function of capturing IR images in large indoor areas. Thus, sizing problem can be minimized as well.

IR based localization method does not rely on environmental parameters such as humidity, temperature and pressure. IR signals are less vulnerable to this kind of factors in the environment rather than ultrasound signals. As known from the article of Prythnia, ultrasound signals can be deteriorated by such factors[49].

5. CONCLUSION AND RECOMMENDATIONS

The main purpose of this method is to obtain high precision in location information. Current methods have relatively high error rates due to their use of indirectly related phenomena to calculate location information. The purpose of high precision is achieved by usage of imagery data and additional dimensions of change like differenciation of existence over time.

The proposed method provides serious advantages like high precision and low power consumption at sensor nodes as opposed to its mild disadvantages like that it requires sensor nodes to be in sight like most of other localization methods. On the other hand it has certain limitatiosn like line of sight and limitations regarding infrared radiation.

5.1 Application of The Work

This localization method can be applied to any sensor network that does not have strict line of sight limitations. This is a solution for localization aspects of most wireless sensor networks.

Although this method is explained with sensor networks in mind its applications are not limited to WSN, it can be used for localization purposes at any system.

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