Formulation and Experimental Verification of Distance vs RSSI for Localization in Wireless Sensor Network

By

Md. Dewan Perves Alam

A thesis submitted in partial fulfillment of the requirements for the degree of
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Declaration

This is to certify that the project work entitled "**Formulation and Experimental Verification of Distance vs RSSI for Localization in Wireless Sensor Network**" has been carried by Md. Dewan Perves Alam in the department of Electrical and Electronic Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above research or any part of the work has not been submitted anywhere for the award of any degree or diploma.

03.12.10

Signature of the Supervisor

(Mohd. Noor Islam)

03.12.10

Signature of the Candidate

(Md. Dewan Perves Alam)

Approval

This is to certify that the project work submitted by Md. Dewan Perves Alam entitled **"Formulation and Experimental Verification of Distance vs RSSI for Localization in Wireless Sensor Network"** has been approved by the Board of Examiners for the partial fulfillment of the requirements for the degree of Master of Science in Engineering in the Department of Electrical and Electronic Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh in November 2010.

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Abstract

Wireless Sensor Networks (WSN) is getting interest for its remarkable application in different sectors like in defense for target tracking, monitoring environmental and animal activities, medical treatment etc. In WSN nodes collect data from deployed area and then send it to the center node for further processing. So localization is an important issue in sensor network to locate the position from where the data is receiving to central node. Distance to sensors estimated through several techniques. Among those techniques, Received Signal Strength Indicator (RSSI) method is simple, inexpensive, required no extra hardware like Global Positioning System (GPS).

In RSSI technique, the distance between nodes is determined using RSSI value. So path loss model is necessary to establish a relation between RSSI and distance. However radio wave propagation can be affected by different factors like floor, wall, ground, external interference due to WLAN, human body, temperature etc. in the real environment. To get the exact RSSI vs distance curve the accurate propagation model considering different factors exists in the real environment is needed.

In this project work, different factors which have the effect on radio wave propagation both in indoor and outdoor environment has been tested experimentally. The experimental data is compared with the theoretical model data and it is observed that the basic propagation model does not cover all the factors. So a new factor is added to the basic path loss model to compensate the losses due to different factors exist in real environment in where sensors are deployed. After addition of new factor which consider the other attenuation factors in real environment with the basic propagation model it is shown that the proposed propagation model yields the result near to the practical data.

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Nomenclature

WSN	Wireless Sensor Network
WLAN	Wireless Local Area network
RSSI	Received Signal Strength Indication
TDOA	Time Difference of Arrival
MAC	Media Access Protocol
GPS	Global Positioning System
DSP	Digital Signal Processing
DVS	Dynamic Voltage Scaling
DPM	Dynamic Power Management
PL	Path Loss
P_t	Transmitted power
P_r	Received power
G_t	Gain of transmitting antenna
G_r	Gain of receiving antenna
n	Path loss exponent
T-R	Transmitter-Receiver
dB	decibel
h_1	Transmitting antenna height
h_2	Receiving antenna height
X_σ	Zero-mean Gaussian Random variable
σ	Standard deviation

CHAPTER I

Introduction

1.1 Motivation

Wireless sensor network consists of small, self-configuring, low processing power, battery powered sensor nodes that cooperatively monitor the field of operation. In recent years, wireless sensor networks (WSN) have been widely used in a wide range of applications such as military operations for target tracking, medical treatments, and for monitoring of animal activity and environment in the forest.

Sensor nodes collect data from the deployment area. This data is then forwarded to a central node for further processing and decision purposes. Since individual sensor data is processed together it becomes crucial to know where the data has been collected. The location of a sensor node is essential for data tagging. Moreover, location specific applications such as target tracking require a location service. Localization is also the key element for location-based routing protocols. There are various techniques used for localization in wireless sensor networks [1]. A localization algorithm may use anchor nodes, which are also known as reference or beacon nodes. Anchors are special nodes that already know their location. The coordinates of the anchor node may be embedded during deployment or may be derived from the Global Positioning System (GPS). Localization method may use the coordinates of the several anchor nodes and distance estimates to those anchors to determine the location of a node by triangulation or rigidity [2, 3].

Distance to anchors can be estimated via several ranging techniques [4] such as: Received Signal Strength Indicator (RSSI), the angle of arrival (AOA), the time of arrival (TOA), and the time difference of arrival (TDOA). Recently, localization based on a combination of AOA and TDOA techniques have been proposed, that guarantee a high accuracy location but it requires a specific and complex hardware. On the other hand RSSI-based localization that does not require any special or a sophisticated hardware, and it is available in most of the standard wireless devices. Moreover, RSSI-based localization does not have a significant impact on local power consumption, sensor size and cost, and for this reason it has received considerable interest

In theory, the energy of a radio signal diminishes with the square of the distance from the signal's source. As a result, a node listening to a radio transmission should be able to use the strength of the received signal to calculate its distance from the transmitter. RSSI suggests an elegant solution to the hardware ranging problem as all sensor nodes are likely to have radio frequency that can be advantageous to compute ranges for localization.

In practice, however, RSSI ranging measurements contain noise on the order of several meters [5]. This noise occurs because radio propagation tends to be highly non-uniform in real environments. For instance, radio propagates differently over asphalt than over grass. Physical obstacles such as walls, furniture, etc. reflect and absorb radio waves. In addition, WLAN (802.11 b/g/n) uses the same frequency as wireless sensor network and the uses of WLAN is getting interest day by day. So, interference due to WLAN is another factor which has a great effect on radio wave propagation. As a result, distance predictions using signal strength have been unable to demonstrate the precision obtained by other ranging methods such as time difference of arrival. However, RSSI has got new interest recently. There are many algorithms for localization based on RSSI [6], [7], [8]. Even environments GPS does not work properly, so RSSI is the main metrics there to localize in indoor the sensor in sensor network [9]. Therefore, it is most important to inspect the correct formulation in both indoor and outdoor considering the factors that may arise to have an affect on radio propagation.

Ambili Thottam Parameswaran et. al. [10] showed that experimentally RSSI is not a good metric for localization. However, it is simple and inexpensive. When the cost is important than accuracy RSSI methods is useful [11]. More careful physical analysis of radio propagation may allow better use of RSSI data, as might better calibration of sensor radios.

1.2 Research Objective and Contribution

This project work mainly focused on radio wave propagation model at indoor and outdoor environment. For that reason by doing some experiment this project is tried to find out practically how different types of obstacles (e.g. Walls, floor, furniture, roofs etc), interference, human body (due to WLAN), environmental condition like temperature, humidity etc affect the wave propagation. Lastly a modification is proposed to the theoretical basic radio wave propagation model.

In this project a vast experiments have been performed with telosb sensor mote (MSP 430+ CC2420) for determining and cauterizing the impact on propagation path by the different factors such as floor attenuation, wall attenuation, temperature, interface, human body effect etc. With the experimental result a RSSI vs distance curve and with the theoretical path loss formula same like curve has been generated. Both curves are exponential but their positions are not same. This result indicates that there is some mismatch. This deviation is due to the different factors affect the radio channel which doesn't include in the wave propagation model.

Comparing with theoretical to experimental result it is to be proposed to add new factors with the existing propagation model that will represent all other factors in the equation. The proposed equation shows the result near to the experimental data.

1.3 Outline of Dissertation

This project report consists of total nine chapters. The remainder of the thesis paper is organized as follows:

Chapter II discusses some preliminaries of sensor motes, sensor network, its application. This chapter introduces sensor model that is used for sensing coverage analysis. It also introduces some other short range networks which are using the same ISM band and which have an impact on the performance of wireless sensor network due to have interference among them. Channels those are available for the sensor motes to use are also described in this chapter.

Chapter III discusses the different well known wave propagation models for indoor and outdoor environment. This chapter also describes the properties of some different kind of factors that can have an impact on the radio wave propagation model.

Chapter IV discusses the problems that is dealt in my project and tried to solve as well as the related works. This chapter explains the problems related to propagation model of 2.4 GHz channel.

Chapter V contains the proposed wave propagation model for both indoor and outdoor environment and its discussion.

Chapter VI describes the experimental set up to acquire data. This chapter describe about the mote, Laptop, software, frequency channel used for experiment purpose.

Chapter VII contains detail of the experimental place, experiment procedure, acquired data, data analysis, and comparison in different conditional data and describes its observation. This chapter is fully related to practically gathered data and their analysis.

Chapter VIII contains the research results of experimental data, comparison between theoretical and practical RSSI data, proposed propagation model verification, discussion and suggestion to compensate the deviation between practical and theoretical data at indoor and outdoor environment.

Chapter IX represents the conclusion of the research work and recommendation for further expansion of the project work.

The references are added at the end of the project report.

CHAPTER II

Sensor and Sensor Networks

2.1 Introduction

Wireless Sensor Network (WSN) is a wireless network consisting of spatially distributed autonomous devices using sensor to cooperatively monitor physical or environmental conditions such as temperature, sound, vibration, pressure, motion or pollutant at different locations. Each node is a sensor network is typically equipped with a radio transceiver or other communication device, a small microcontroller, and energy source, usually a battery. The envisaged size of a single sensor node can vary from shoebox sized nodes down to devices the size of grain of dust, although functioning 'motes' of genuine microscopic dimensions have yet to be created.

The cost of sensor nodes is similarly variable, ranging from hundreds of pound to a few pence, depending on the size of the sensor network and the complexity required of individual sensor nodes. Size and cost constrains on sensor nodes result in corresponding constrains on resources such as energy, money, computational speed and bandwidth.

2.2 Sensors Node

A sensor node, also known as a 'mote', is a node in a wireless sensor network that is capable of performing some processing, gathering sensory information and communicating with other connected nodes in the network.

2.2.1 Construction of Sensor Motes

A sensor mote is made of with a micro-controller, sensors, a power source and a transceiver. The typical architecture of the sensor node is shown in Fig 2.1.

i) Micro-controller

Micro-controller performs tasks, processes data and controls the functionality of other components in sensor node. Microcontrollers are the best choices instead of micro-processor, DSP or FPGA because of their flexibility to connect to other devices, which is also programmable and less power consumption. These devices can go to sleep state and part of controller can be active. MSP430, ATMEGA 128, and ARM 920T are mainly used as microcontroller.

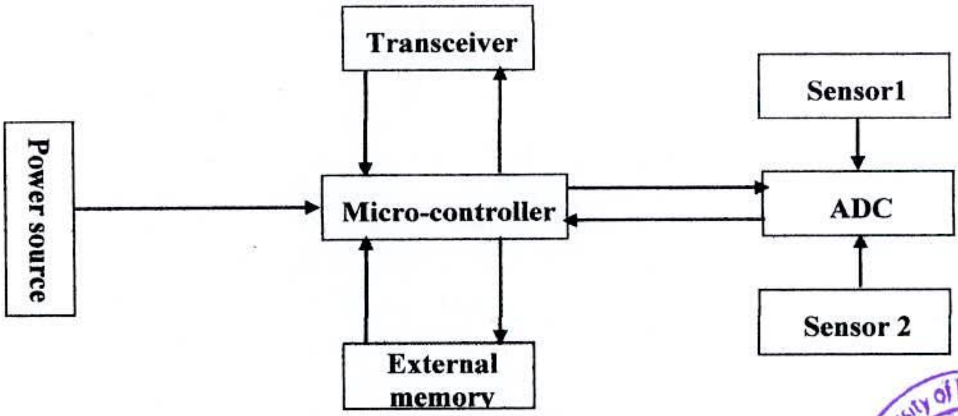

Figure 2.1: The architecture of a sensor

ii) Transceiver

The functionality of both transmitter and receiver are combined into a single device known as transceivers are used in sensor nodes. Radios used in transceivers operate in four different modes. Transmit, receive, idle and sleep. WSN's use the communication frequencies between about 433 MHz and 2.4 GHz.

iii) External Memory

From an energy perspective, the most relevant kinds of memory are on-chip memory of a microcontroller and FLASH memory - off-chip RAM is rarely if ever used. Flash memories are used due to its cost and storage capacity. Two categories of memory based on the purpose of storage a) User memory used for storing application b) Program memory used for programming the device.

iv) Power Source

Power consumption in the sensor node is for the Sensing, Communication and Data Processing. More energy is required for data communication in sensor node. Batteries are the main source of power supply for sensor nodes. Namely two types of batteries used are chargeable and non-rechargeable. Current sensors are developed which are able to renew their energy from solar, thermo-generator, or vibration energy. Two major power saving policies used are Dynamic Power Management (DPM) and Dynamic Voltage Scaling (DVS). DPM takes care of shutting down parts of sensor node which are not currently used or active. DVS scheme varies the power levels depending on the non-deterministic workload.

v) Sensors

Sensors are hardware devices that produce measurable response to a change in a physical condition like temperature and pressure. Sensor senses or measures physical data in the area to be monitored. The continual analog signal sensed by the sensors is digitized by an Analog-to-digital converter (ADC) and sent to controllers for further processing. As wireless sensor nodes are micro-electronic sensor device, can only be equipped with a limited power source of less than 0.5Ah and 1.2V. Sensors are classified into three categories:

- Passive, Omni Directional Sensors: Passive sensors sense the data without actually manipulating the environment by active probing.
- Passive, narrow-beam sensors: These sensors are passive but they have well-defined notion of direction of measurement. Typical example is 'camera'.
- Active Sensors: This group of sensors actively probes the environment, for example, a sonar or radar sensor or some type of seismic sensor, which generate shock waves by small explosions.

The overall theoretical work on WSN's considers Passive, Omni directional sensors. Each sensor node has a certain area of coverage for which it can reliably and accurately report the particular quantity that it is observing.

2.2.2 A comparison of Sensor Motes

There are many sensor motes available commercially. Most of the sensor motes are constructed with micro-controller produced by TI, Atmel, MSP430, ATMEGA 128 and ARM 920T are mainly used as microcontroller. Among all and their features are shown in Table 2.1

Table 2.1: A simple comparison of different sensor motes

Sensor mote name	Micro controller	Transceiver	Program + Data Memory	External memory	Program-ming	Supporting OS
TelosB	TI MSP430	250 Kbit/s, 2.4Ghz,Chipcon CC2420	10K RAM	48K flash	C and nesC	TinyOS SOS
KMote	TI MSP430	250 Kbit/s, 2.4Ghz,Chipcon CC2420	10K RAM	48K flash	C and nesC	TinyOS SOS
KPIC Mote	TI MSP430	250 Kbit/s, 2.4Ghz,Chipcon CC2420	10K RAM	48K flash	C and nesC	TinyOS
Sensenode	MSP430 F1611	250 Kbit/s, 2.4Ghz,Chipcon CC2420	10K RAM	48K flash	C and nesC	GenOS, TinyOS
Micaz	ATMEG A 128	TI CC2420 802.15.4/Zigbee	4K RAM	128K flash	nesC	Tinyos, SOS MantisOS and Nano-RK
Mica2	ATMEG A 128L	Chipcon 868/916 MHz	4K RAM	128K flash	C and nesC	Tinyos, SOS and MantisOS
Mica	Atmel ATMEG A103 4MHz 8bit CPU	RFM TR1000 radio 50 kbit/s	129+4k RAM	512K flash	nesC	TinyOS
Rene	ATMEL 8535	916 MHz radio with bandwidth of 10 kbit/s	512 bytes RAM	8K flash	nesC	TinyOS
Iris	Atmega 1281	Atmel AT86RF230 802.15.4/Zigbee compliant radio	8K RAM	128 K flash	nesC	Tiny OS, Moteworks
SunSPOT	ARM 920T	IEEE 802.15.4	512K RAM	4 MB flash	Java	Squawk J2ME Virtual Machine

2.3 Sensing Models

Deployment and sensing coverage depends on the sensing range and sensor characteristics. A proper sensor model is essential to analyze the propagation loss for region of interest. A sensor transforms environmental stimuli into electrical signal, the quality of resulting signal depends, among other factors, on the distance between the sensor and actual event. For an example, the amplitude of sound wave decreases quadratically (more general according to a power law) with increasing distance to the location to the sound producing event. When an acoustic sensor node has a very large distance to the sound event, the sensor reading becomes indistinguishable from the case of no sound event occurring at all. A second aspect of sensing quality is directionality. In an idealized scenario, a sensor has the same sensitivity in all direction; however in practice, often certain directions are preferred. This can be either by construction (for an example, video camera) or as a result of sensor development, when for example, a node's acoustic sensor is obstructed by other node components. A third aspect is constituted by possibility that the same sensor can generate different out put for the same environment stimulate at different times, for example, due to temperature variations the sensing circuitry is exposed to. Generalizing this observation, the signal delivered by sensor for an external event at a certain distance is not fixed, but a distance dependent random variable. One simple assumption here would be to model such a random variable as a constant plus some zero mean Gaussian noise with either constant or distance dependent variable. The area coverage of the region of interest is analyzed using different sensing models such as Boolean sensing model, general sensing model, shadow fading sensing model, Elfes sensor model [12], [13]. Some sensors are called point sensor which detect a phenomenon only upon having the direct contact with it. For example, chemical sensors that can sense toxic only by direct measurements.

2.4 Application of Wireless Sensor Network

Due to recent advancement in wireless communication and embedded micro sensing technologies like Microelectromechanical System (MEMS), inexpensive wireless nodes capable of sensing, storing, processing and communicating data are becoming increasingly common and readily available. Wireless sensor network is getting interest from small scale to large scale applications. The development of Wireless sensor network was originally motivated by military application such as battle field surveillance. However, Wireless Sensor networks are now used in many industrial and civilian applications areas, including industrial process monitoring and control, machine health monitoring, environment and machine health monitoring, environment and habitat monitoring, healthcare application, home automation and traffic control.

2.5 Wireless Standards for Sensor Application

IEEE 802.15.4 is a low power, low data rate standardization that is used for sensor network. It has very low complexity. It is operating in an unlicensed, international frequency band. IEEE 802.15.4 Working Group is upgrading the IEEE 802.15.4 for different applications. The features of IEEE 802.15.TG4 are given below:

IEEE 802.15.TG4 FEATURES

- Data rate of 250 kbps, 40 kbps, and 20 kbps.
- Two addressing modes; 16-bit short and 64-bit IEEE addressing.
- Support for critical latency devices, such as joysticks.
- CSMA-CA channel access.
- Automatic network establishment by the coordinator.
- Fully handshake protocol for transfer reliability.
- Power management to ensure low power consumption.
- 16 channels in the 2.4 GHz ISM band, 10 channels in the 915 MHz and one channel in the 868 MHz band.

2.6 Other Short Range Wireless Technologies

There are some other short range technologies. Among which some technologies, like IEEE 802.11b/g, RFID, Bluetooth, are using same non licensed band as wireless sensor network. The different short range technologies are shown in Table 2.2

Table 2.2: Different short range wireless technologies

Standard	User data rate	Frequency band	Range
UWB	>100 Mbps	3.1-10.6 GHz	5-10 m
WLAN IEEE 802.11 a/b/g	5-30 Mbps	5 GHz / 2.4 GHz	100 m
DECT	500 kbps	1880-1900 MHz	100 m
RFID	1-200 kbps	125-134 KHz /13.56 GHz / 2.4 GHz / 5.8 GHz UHF (400-960 MHz)	0.1-10 m
Bluetooth	700 kbps	2.45 GHz	10 m

2.7 Available Channels for Wireless Sensor Network

For wireless sensor network free ISM band is used. IEEE 802.15.4 specifies and CC2420 radio chip provides 16 non-overlapping channels within the 2.4 GHz band, in 5 MHz steps, numbered 11 through 26 shown in figure 2.2. The RF frequency of channel *l* in given by [14].

$$F_c = 2405 + 5\,(l\text{-}11)\ \text{MHz},\ l = 11, 12, \ldots\ldots 26$$

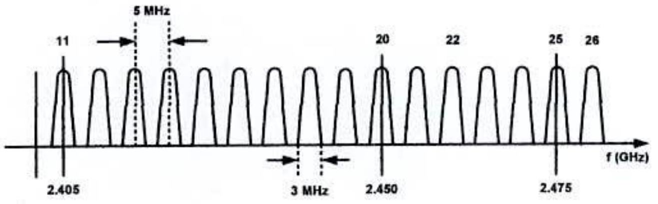

Figure 2.2: Frequency ranges specified by IEEE 802.15.4

2.8 Summary

Sensor networks are making the world informative and it is opening the door of future wireless automation and monitoring. Nowadays many sensor notes are commercially used. As sensor network and other short range networks are using the same frequency band by managing the proper channel assignment to avoid the interference and man can be more benefited from wireless sensor network.

CHAPTER III

Propagation Models

3.1 Introduction

A propagation model is a set of mathematical expressions, diagrams, and algorithms used to represent the radio characteristics of a given environment. Generally, the prediction models can be either empirical or theoretical, or a combination of these two. For radio propagation some well established models are given below:

3.2 Propagation Models

Path-Loss (PL) large-scale propagation models represent a way to predict the behavior of signal propagation over large distances variations. Typically they estimate the attenuation imposed to the transmitted signal (P_t), in decibel (dB), as a function of distance (d) and considering some parameters with values fixed or established from measured data.

3.2.1 Indoor Environment

The performance of the wireless alarm system depends heavily on the characteristics of the indoor radio channel. Excessive path loss within the home can prevent units from communicating with one another. Thus, it is useful to attempt to predict path loss as a function of distance within the home.

The indoor mobile radio channel can be especially difficult to model because the channel varies significantly with the environment. The indoor radio channel depends heavily on factors which include building structure, layout of rooms, and the type of construction materials used. Different type of home and office furniture also behaved as obstacles to the radio wave propagation at indoor. In order to understand the effects of these factors on electromagnetic wave propagation, it is necessary to recall the three basic mechanisms of electromagnetic wave propagation reflection, diffraction, and scattering. Important wave propagation models for indoor are describe below:

3.2.1.1 Log-Distance Path Loss Model

One of the most important parameters in any prediction model is the path loss. It is a relationship between attenuation, often in decibels (dB), and the distance between transmitter and receiver. The simplest path loss model occurs when there is no obstacle between transmitter and receiver, a line of sight (LOS) case. Equation (3.1) reveals the relationship between the attenuation and the distance between transmitter and receiver in mathematical form [15].

$$PL(d) = PL(d_o) + 10\, n \log (d / d_o) \quad \text{………………………} \quad (3.1)$$

Where *n* is the path loss exponent, *d* is the T-R separation in meters, and d_0 is the close-in reference distance in 1 meter. *PL* (d_0) is computed using the free space path loss equation. The value d_0 should be selected such that it is in the far-field of the transmitting antenna. The value of the path loss exponent *n* varies depending upon the environment. In free space, *n* is equal to 2. In practice, the value of *n* is estimated using empirical data.

3.2.1.2 Log-Normal Shadowing Model

Random shadowing effects occurring over a large number of measurement locations which have the same T-R separation, but different levels of clutter on the propagation path is referred to as Log-Normal Distribution. This phenomenon is referred to as log-normal shadowing. Variations in environmental clutter at different locations having the same T-R separation is not accounted for by the log distance path loss model alone. This leads to measured signals which are vastly different than the average value predicted by using the log-distance path loss model. To account for these variations, the average path loss PL (d) for a transmitter and receiver with separation d thus becomes [15]:

$$PL(d) = PL(d_o) + 10\, n \log (d / d_o) + X_\sigma \quad \text{………………………} \quad (3.2)$$

Where $X_\sigma = \frac{1}{\sigma \sqrt{2\pi}} e^{\frac{d^2}{2\sigma^2}}$ is a zero-mean Gaussian random variable with standard deviation σ. Both X_σ and σ are given in dB. The random variable X_σ attempts to compensate for random shadowing effects that can result from clutter. The values *n* and σ are determined from empirical data.

3.2.1.3 Two-Ray Model

The ray-tracing approach approximates the scattering of electromagnetic waves by simple reflection and refraction. The degree of transmission and reflection of a signal through and off an obstacle is related to the complex permittivity of the obstacle. One of the propagation models based on ray-optic theory is the Two-Ray model. Two-Ray model is used in this study because all the scenarios considered in this study have one reflecting surface, i.e., it have a direct path and reflected path. It is used for modeling of Line of Sight radio channel as shown in Figure 3.1. The transmitting antenna of height h_1 and the receiving antenna of height h_2 are placed at distance d from each other.

The received signal P_r for isotropic antennas, obtained by summing the contribution from each ray, can be expressed as [15]:

$$P_r = P_t\,(\lambda / 4\pi)\,[\,1 / r_1\, e^{(-jk_1)} + \Gamma(\alpha)\, 1 / r_2\, e^{(-jkr_2)}\,]^2 \quad ....(3.3)$$

Where, r_1 and r_2 represent the length of direct and reflection path respectively. $\Gamma(\alpha)$ is the reflection coefficient which depends on the angle of incidence and the polarization. For the low antenna heights compared to long distance d ($d >> h_1, h_2$), the $\Gamma(\alpha)$ can be simply put as -1.

The tow-ray model is more practical than the free-space model because it take the reflection path and the ground characteristics into account. However, it is still a theoretical model which is almost independent with environment.

3.2.1.4 1-Slope and 2-Slope model

These two propagation model are empirical models. The 1-Slope model [16] is frequently used in an in-door environment, especially for LOS path, and its path loss in dB at distance d can be expressed as [15]:

$$PL_{1\text{-}Slope}(d) = PL(d_o) + 10\, n \log(d/d_o) + X_\sigma \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.4)$$

The explicit value of n and σ are usually computed through a linear regression in least square (LS) sense for the measured data.

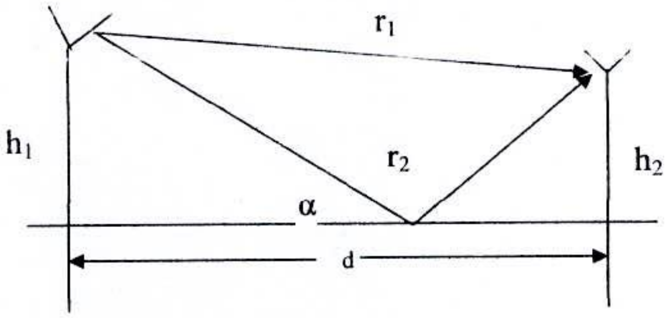

Figure 3.1: The path of Two-Ray model

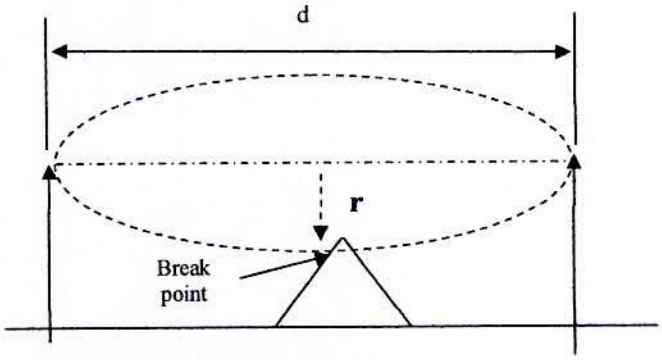

Figure 3.2: The first Fresnel zone is obstructed by obstacle

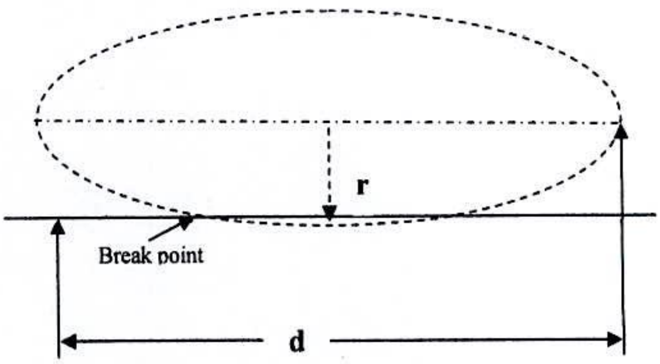

Figure 3.3: The first Fresnel zone is obstructed by ground

This model is simple, efficient and suitable for computer implementation and more accurately predicts path loss when the parameter n and σ are determined as a function of the general surroundings. The 2-Slope model [17] is widely used in outdoor environment when the first Fresnel Zone is obstructed as depicted in Fig. 3.2 and Fig.3.3. In Fig.3.2 and Figure 3.3, r is the Fresnel radius and $r = \sqrt{(\lambda\, d / 4)}$, where λ is the wavelength and d is the distance between the transmitter and receiver. Breakpoint is just the place where the obstacle or ground impinges into the first Fresnel Zone.
Path loss for this model can be expressed as:

$$PL_{2\text{-}Slope}(d) = PL(d_o) + 10\, n_1 \log(d / d_o) + X_{\sigma 1} \ldots\ldots (3.5) \qquad \text{When } d \leq d_b$$

$$Or \qquad = PL(d_b) + 10\, n_2 \log(d / d_b) + X_{\sigma 2} \ldots\ldots (3.6) \qquad \text{When } d > d_b$$

$$\text{And } d_b = 1/\lambda \sqrt{\{(\Sigma^2 - \Delta^2)^2 - 2(\Sigma^2 + \Delta^2)(\lambda/2)^2 + (\lambda/2)^4\}}$$

Where, n_1 and n_2 are the path loss exponents before breakpoint and after breakpoint, respectively. And $X_{\sigma 1}$, $X_{\sigma 2}$ are zero mean log-normally distributed random variables representing uncertainty of the model caused by shadow fading before breakpoint and after m breakpoint, respectively. And *db* denote the distance between transmitter and breakpoint, $\Sigma = h_T + h_R$, $\Delta = h_T - h_R$, where h_T and h_R represent the antenna height of transmitter and receiver, respectively. For Fig.3.2, the position of breakpoint for flat ground can be determined by (3.5), while for Fig.3.3, the position of breakpoint, besides the antenna height, is also related to the obstacle. The parameter of (3.6) can also be obtained by linear regression.

3.2.1.5 Direct Ray Model

The Direct Ray model [17] is similar to 1-Slope model. However it adopts the attenuation factor of obstacle which makes it suitable for NLOS channel. The path loss of Direct Ray model at distance d is given in equation (3.7).

$$PL_{Direct\text{-}Ray}(d) = PL(d_o) + 10\, n \log(d / d_o) + \sum (OBS_i \cdot AF_i) \ldots\ldots\ldots (3.7)$$

Where, OBSi is the number of obstructions of type i that intersect the direct-ray path from the transmitter and the receiver, and the AFi is the attenuation factor of signal loss incurred per intersecting obstacle of type i. Before measurement, the obstacle should be simply classified into a few types as in [16]. Then, the parameters in equation 3.7 can be obtained from a LS regression analysis of measurement data taken in the propagation environment. This model yields satisfactory results in both outdoor environment [16] and indoor environment [18] when the antenna height is above 1m, but the result of near ground antenna is not included in [16] and [18].

3.2.2 Outdoor Environment

In out door environment factors affect the propagation loss are the distance from the receiver and obstacles that are strewn on the path transmission. If the WSN is placed in an urban area then the multipath characteristics of the signal have to be considered. Normally Log-shadow propagation model is used to represent the path loss characteristics at outdoor environment, but there are also other two popular models.

3.2.2.1 Free Space Path Loss Model

In an ideal environment the power radiated by an antenna is spread uniformly over the surface of an imaginary sphere surrounding the antenna. Therefore, the power density at a point on the sphere decreases as the distance from the antenna increase [17].The power received at a distance, d from the transmitting antenna is given by equation (3.8) and the path loss in dB is given by equation (3.9).

$$P_r = P_t\,^2\, G_t\, G_r \,/\, (16\,\pi^2 d^2) \qquad (3.8)$$

$$PL_{FS} = 20 \log d + 20 \log 4\pi - 20 \log \lambda - 10 \log G_t - 10 \log G_r \qquad (3.9)$$

Where P_r and P_t are the received and transmitted power, G_t and G_r are the gain of the transmitter and receiver antennas respectively. From the equation (3.9) it is found that the free space PL model is a pure theoretical model only determined by the distance and frequency.

3.2.2.2 Foliage Model

It is very common for the WSN signal propagation over a distance of foliage, especially for those WSN applied in wild environment. Some of empirical propagation model over foliage and vegetation are:

a) The Weissberger model [19]

$$PL_{wei}(d) = 1.33 f^{0.284} d_f^{0.588} \ldots\ldots\ldots\ldots(3.10) \qquad 14 < d_f \le 400$$

$$Or \qquad = 0.45 f^{0.284} d_f \ldots\ldots\ldots\ldots\ldots(3.11) \qquad 0 \le d_f \le 14$$

b) ITU Recommendation [20]

$$PL_{ITU}(d) = 0.2 f^{0.3} d_f^{0.6} \ldots\ldots\ldots\ldots\ldots\ldots(3.12)$$

Where f is the frequency in GHz Weissberger and MHz for ITU model, and d_f is the propagation distance through the foliage in meters. In this section, we summarize some commonly used propagation models for different transmission environment. In the following sections, the actual measurements will be taken and comparison between models and measured data will be made.

3.3 Factors Affect The Radio Channel

The performance of the wireless system depends heavily on the characteristics of the indoor radio channel. Excessive path loss within the home can prevent units from communicating with one another. Thus, it is useful to attempt to predict path loss as a function of distance within the home.

The indoor mobile radio channel can be especially difficult to model because the channel varies significantly with the environment. The indoor radio channel depends heavily on factors which include building structure, layout of rooms, and the type of construction materials used. In order to understand the effects of these factors on electromagnetic wave propagation, it is necessary to recall the five basic mechanisms of electromagnetic wave propagation reflection, diffraction, abortion, interference and scattering. With those mechanisms there are some other factors which also have effect on radio channel. All those are describing below:

i) Reflection

Reflection occurs when a wave impacts an object having larger dimensions than the wavelength. During reflection, part of the wave may be transmitted into the object with which the wave has collided. The remainder of the wave may be reflected back into the medium through which the wave was originally traveling. In an indoor environment, objects such as walls and floors can cause reflection.

ii) Diffraction

When the path between transmitter and receiver is obstructed by a surface with sharp irregularities, the transmitted waves undergo diffraction. Diffraction allows waves to bend around the obstacle even when there is no line-of-sight (LOS) path between the transmitter and receiver. Objects in an indoor environment which can cause diffraction include furniture and large appliances.

iii) Scattering

The fifth mechanism which contributes to electromagnetic wave propagation is scattering. Scattering occurs when the wave propagates through a medium in which there are a large number of objects with dimensions smaller than the wavelength. In an indoor environment, objects such as plants and small appliances can cause scattering.

iv) Absorption

In physics, absorption of electromagnetic radiation is the way by which the energy of a photon is taken up by matter, typically the electrons of an atom. Thus, the electromagnetic energy is transformed to other forms of energy for example, to heat. As the radio wave passes through a material, a portion of its energy is absorbed. The amount of absorption depends on the characteristics of the material.

v) Interference

In physics, interference is the addition (superposition) of two or more waves that results in a new wave pattern. Interference usually refers to the interaction of waves that are correlated or coherent with each other, either because they come from the same source or because they have the same or nearly the same frequency. Interference in physics corresponds to what in wireless communications is called multi-path propagation and fading, while the term interference has a different meaning in wireless communications.

Because of low cost and non-licensed frequency band the interest on wireless sensor network application are increasing. Sensor networks are overlapping as well as another short range networks, mainly IEEE 802.11b/g is also overlapping with the sensor network.

vi) Noise

In any transmission event, a received signal will consist of the transmitted signal, modified by various distortions imposed by the transmission medium, plus additional unwanted signals that are inserted by the medium. These unwanted signals are referred to as noise or interference. Noise is the major limiting factor in any communications system performance.

vii) Atmospheric Absorption

Atmospheric absorption is an additional loss due to the presence of different atmospheric elements such as water vapor and oxygen etc. Peak attenuation occurs in the vicinity of 22 GHz due to water vapor. At frequencies below 15 GHz, the attenuation is less.

viii) Human body

It is inevitable effect of human mobility on radio propagation in the indoor environment for moving bodies will cause radio attenuation and shadowing. While a great deal efforts have been taken in studying the fading effects caused by human body in wireless local area networks (WLANs) or cellular systems [21] because these effects become particularly important to characterize the propagation model, the comprehensive effects of the human activity on WSNs radio propagation for indoor environment remain unexplored widely.

3.4 Summary

The combined effects of above cause multipath signal reception that the transmitted signal arrives at the receiver by more than one path. The multipath signal components combine at the receiver to form a distorted version of the transmitted waveform. The multipath components can combine constructively or destructively depending on phase variations of the component signals. The destructive combination of the multipath components can result in a severely attenuated received signal.

CHAPTER IV

Problem Statement and Related Work

4.1 Introduction

In WSN network, sensors communicate with each other to create an ad hoc information collection networks. An ad hoc network is created on the spur of the moment to send information to a base station, or to raise an alarm. These networks are usually short-lived and created in time to respond to a change in stimuli in the area under observation. Historically, wireless sensor networks have mainly addressed for military applications. However, in recent years, many civilian applications, such as managing inventory, monitoring product quality and monitoring disaster zones have emerged. In military applications, the sensing devices are very sophisticated and therefore costly. However for industrial and environmental monitoring, cost is of more of a concern. As such, it is very important for these latter applications to know how much of an area is effectively being covered by the given number of sensors deployed and obviously coverage area mostly depends on the path loss model of the network. For example, heavy signal loss due to harsh environmental conditions or large distance from the receiver will imply unreliable information transmission or ineffective spatial-temporal resolution. So it necessary to develop a proper path loss model in which all kind of harsh will be considered those effects the propagation path in both indoor and outdoor environment.

4.2 Propagation Model Problems

The most basic model of radio wave propagation involves so called "free space" radio wave propagation. In this model, radio waves emanate from a point source of radio energy, traveling in all directions in a straight line, filling the entire spherical volume of space with radio energy that varies in strength by inversely square to range (or 20 dB per decade increase in range). In real world radio propagation rarely follows this simple model. The three basic mechanisms of radio propagation are attributed to reflection, diffraction and scattering. All of these three phenomenon cause radio signal distortion and give rise to signal fades, as well as additional signal propagation losses. At outdoors, with mobile units, movements over very small distances give rise to signal strength fluctuations. This is because the composite signal which is made up of a number of components from the various sources of reflections (called "multi-path signals") from different directions as well as scattered and diffracted signal components. These signal strength variations amount to as much as 30 to 40 dB in frequency ranges useful for mobile communications and account for some of the difficulty presented to the designer of reliable radio communications systems. The basic signal attenuation with range noticed in the real world gives rise to what are termed "large scale" effects, while the signal strength fluctuations with motion are termed "small scale" effects.

4.2.1 Indoor Environment

The situation in indoors is even worse. It is very difficult to design an "RF friendly" building that is free from multipath reflections, diffraction around sharp corners or scattering from wall, ceiling, or floor surfaces. The closest one could probably get to an "RF friendly" building would be an all wooden or all fiberglass structure but even this must have a structurally solid floor of some kind and this more ideal RF building will still have reflections, multipath and other radio propagation disturbances which will prove to be less than ideal. Indoors then, the simple free space model fails to account for the small and large scale fading that is observed in real world radio links.

Indoor channels are highly dependent upon the placement of walls, partitions, furniture and different types of appliances within the building. Signal is attenuated by the floor also. As placement of these walls and partitions dictate the signal path inside a building. Excessive path loss within the home can prevent units from communicating with one another. Thus, it is useful to attempt to predict path loss as a function of distance within the home.

4.2.2 Outdoor Environment

Factors that affect the propagation loss are the distance from the receiver and obstacles that are strewn on the path of transmission. As is the case in outdoor systems, there are several important propagation parameters to be predicted. The path loss and the statistical characteristics of the received signal envelope are the most important for coverage planning applications. In outdoor environment channels are heavily suffer from environmental effect like obstacles, temperature and humidity.

4.3 Related Works For Propagation Model

Over the years, a number of models have been developed for the prediction of radio wave propagation. These propagation models are used in the network planning and deployment process. They can be categorized into two main approaches: empirical and deterministic. Empirical models are based on vast amounts of actual measurements, while deterministic models utilize the laws of electromagnetic waves to determine a number of parameters, including the phase and signal strength of the wave at a particular domain of interest or area. Deterministic models often require extensive knowledge about the terrain in the form of three dimensional maps, aerial photography or satellite pictures. Ray tracing is an example of a deterministic model. Researchers have been trying to find out a relation considering different factors affecting on propagation model.

4.3.1 Related Works For Indoor Propagation Model

The author in [22] suggest that algorithms estimating distances between two wireless devices based on their reciprocal RSSI are unable to capture the myriad of effects on signal propagation in an indoor environment. Paolo Barsocchi et.al. [4] proposed a localization algorithm of mobile sensor based on WSN providing RSSI measurements between the mobile and the fixed sensors in the network, in where they consider two parameter wall attenuation and floor attenuation as parameter for path loss model. In [23] work presents a channel model based on measurements conducted in commonly found scenarios in buildings include closed corridor, open corridor, classroom, and computer lab, where path loss equations are determined using log-distance path loss model and lognormal shadowing. In [24] quantitative models are presented that predict the effects of walls, office partitions, floors, and building layout on the loss at 914 MHz. The site specific models have been developed based on the no of floors, partitions and concrete walls between the transmitter and receiver, and provide simple prediction rules which relate signal strength to the log of distance.

4.3.2 Related Works For Outdoor Propagation Model

Wireless Sensor Networks (WSNs) which consist of thousands of sensor nodes has become one of the most popular topics. As the deployment of outdoor wireless sensor networks continues to accelerate, it has been clear that a proper deployment may achieve both the sound networks performance and the low cost. A basic criterion for selecting nodes location is the path loss which has essential impact on the connectivity of the whole network. In addition, a correct path loss model is the prerequisite to obtain valid simulation results. In [15] discusses several popular path loss models and takes measurements in different environment with real WSNs nodes based on MSP430 and CC2420 and shows that the near ground 2.4GHz IEEE802.15.4 signal, the simplistic 1-Slope and 2-Slope can yield satisfactory results both in LOS and NLOS, and the 2-Slope model may achieve better performance if the breakpoint location is predictable. Ms. Abiola Fanimokun et.al. [25] presents new near-ground propagation models at 915 MHz based on field measurement data for three naturally occurring environments (open fields, woods and wooded hills). The effects of the various environments on coverage area are explored for various power transmission levels. They significantly show that wooded environments improve the propagation characteristics due to scattering otherwise lost energy towards the intended receiver. Their result indicates that systems being deployed in wooded terrain can transmit at lower signal levels than those deployed in open areas and yet achieve the same coverage area. Simulations are currently an essential tool to develop and test WSNs protocols and to analyze future WSNs applications performance.

Most of the envisioned applications for WSNs consider the nodes to be at the ground level. However, there is a lack of radio propagation characterization and validation by measurements with nodes at ground level for actual sensor hardware. Alejandro Martinez-Sala et.al. [26] proposed to use a low-computational cost, two slope, log-normal path loss near ground outdoor channel model at 868 MHz in WSN simulations. This model is compared with the well-known one slope path-loss model. They demonstrate that the two slope log-normal model provides more accurate WSN simulations at almost the same computational cost as the single slope one.

In wireless sensor network research, simulation is one of the most important approaches to evaluate system or protocol performance. In existing analysis on wireless sensor network, simple interference models are used in simulations, which only take interference signals from nodes in a particular range into account. These interference models are not accurate enough for practical wireless sensor network applications analysis. ZMAC [27] has considered interference between sensor nodes, it proposes a fixed interference range larger than the reception range in simulation, which ignores potentially interfering nodes in the larger area.

To improve the simulation quality, a full interference model is proposed in [28]. By comparing results, it is shown that the full interference model is able to provide more accurate system evaluation than traditional models.

4.4 Summery

A channel model is useful in determining the mechanisms by which propagation in the indoor or outdoor environment occurs, which in turn is useful in the development of a communication system. By examining the details of how a signal is propagated from the transmitter to the receiver for a number of experimental locations, a generic model may be developed that highlights the important characteristics of a given indoor or outdoor environment. As a result a lot of work already is done to develop a proper path loss model which can assist a WSN designer to predict the loss of signal at indoor or outdoor environment.

CHAPTER V

Proposed Propagation Model

5.1 Introduction

A number of experiments have been done under different environmental conditions and it is found that floor, wall, temperature etc have an effect on the value of RSSI. Obstacles near to the base or sending mote have also an impact on the variation of RSSI.

Wireless communication is one of the most active areas of technology development of this time. This development is being driven primarily by the transformation of what has been largely a medium for supporting voice telephony into a medium for supporting other services, such as the transmission of video, images, text, and data. Thus, similar to the developments in wire line capacity in the 1990s, the demand for new wireless capacity is growing at a very rapid pace.

The impact of wireless technology has been and will continue to be profound. The convergence of different standards that define how wireless devices interact will allow the creation of a global wireless network that will deliver a wide variety of services. WLANs operate in an indoor or outdoor environment. It is very difficult to predict how a RF wave travels in the environment. So there is a need for developing propagation model for indoor and outdoor separately to predict RF wave behavior more accurately. The purpose of this project is to characterize the indoor channel for 802.11b wireless local area networks at 2.4 GHz frequency.

5.2 Proposed Model For Indoor Environment

Several researchers have attempted to modify the log-distance model by including additional attenuation factors based upon measured data. The attenuation factor model incorporates a special path loss exponent, a floor attenuation factor and wall attenuation factor to provide an estimate of indoor path loss.
Including the above effects two another effects are introduced that are the attenuation due to interference and due to human movement. When two sensor networks overlap each

other and use the same channel then it creates inter-channel interference and when sensor network and other network use the same frequency channel then intra-channel interference occurred. This two interferences decrease the throughput and sometimes it block transmission. Sensors used in a human surrounded environment the RSSI is affected by them due to absorption and reflection. So our proposed propagation model for indoor is given in equation (5.1).

$$PL\ (d) = PL\ (d_o) + 10\ n \log (d/d_o) + X_\sigma + \sum WAF + \sum FAF + \sum INTF + \sum HMBD \ldots\ldots (5.1)$$

Where, $PL\ (d_0)$ is the free-space path loss at the reference distance d_0 (usually d_0=1m), n denotes the path loss exponent depending on the propagation environment $X\sigma$ is a zero mean log-normally distributed random variable representing uncertainty of the model caused by shadow fading.

Where,

WAF = Wall attenuation factor

FAF = Floor attenuation factor

INTF = Interference by another signal

HMBD = Human body effect

5.3 Proposed Model for Outdoor Environment

In outdoor environment signal transmission is not as difficult as indoor. Proposed one slope log-distance propagation model is where part of the energy is intercepted by the ground. With basic model we add some other different factors which are normally effect the signal propagation. The proposed propagation model is given in equation (5.2).

$$PL\ (d) = PL\ (d_o) + 10\ n \log (d/d_o) + X_\sigma + \sum FAF + \sum OBST + TEMP \ldots\ldots\ (5.2)$$

Where, OBST = Huge obstacle if present between transmitter and receiver

TEMP = Effect of temperature

5.4 Summary

Though it is not possible to make a perfect and universal equation for RSSI value with distance, the model is proposed in this project after doing a number of experiments. This model could give an idea how the RSSI value is varied with different environment conditions.

CHAPTER VI

Experimental Setup

In this project two sensor motes are used to collect data. All experiments are performed with TelosB (TI MSP430 + CC2420) mote for both transmitter and receiver. As this mote is using CC2420, for radio 16 no different channels can be used. Those 16 channels cover the frequency range from 2.405 GHz to 2.480 GHz band. One mote is programmed for sending data as sending mote (Transmitter) and another mote is programmed for checking the RSSI value of the signal as Base Station mote (Receiver). The Base Station mote was connected with laptop to get data through USB port. The configuration of the laptop was DELL D-90, 1.3 GHz Pentium (iv) processor, 768 MB RAM, operating system is Windows XP. These motes use omnidirectional quarter wave monopole antenna for transmitting and receiving. When mote is turn on it transmit its full transmitting power. The following figures show the arrangement to do the experiment.

The pictures in Figure 6.1 and Figure 6.2 show how motes (Two motes are used as Transmitter and Receiver) and laptop is connected for experimental setup.

Fig 6.1: Mote set as transmitter and receiver.

Fig 6.2: Data is taking in a furnished room

Tinyos 2.0 version software was used for fusing the programs in to the motes. The channel is chosen from the file opt/tinyos2.0/support/make/makefile.

DEFAULT_LOCAL_GROUP = 0x01
PFLAGS + = -DCC2420_DEF_CHANNEL = 12
PFLAGS + = -DCC2420_DEF_RFPOWER =31
PFLAGS + = -DDEFAULT_BAUDRATE = 38400

Here channel flag represents which channel will be used for sensor mote. The channel could be any one form 11 to 26. RFPOPWER flag represents the default transmitting power for sensor mote. For this project 31 was used, which means its transmitting power is 0 dBm or -31 dB. The transmitting power is default as 0dBm and the TelosB can detect the signal strength up to -100 dB. In experimental purposes +45 dB had to add with both transmitting and receiving value. So in calculation transmitting power P_t and receiving sensitivity P_r for the TelosB mote were used +15 dB and -55 dB respectively. Normally transmitter is remained fixed where receiver is moved away from transmitter. Data is taken by keeping the separation between transmitter and receiver normally 01m.

Whenever experiment was performed for interference due to WLAN, channel flag was changed for choosing different channels. WLAN used for this project is using channel no 13, which overlaps with the middle of 23 to middle of 26 of sensor mote's channel.

CHAPTER VII

Experimental Data and Observation

7.1 Introduction

In this project it is tried to establish a new propagation model where different types of attenuation factors will be included. All possible affected factors are described in chapter 03. To observe the effect we divide our experiment place in two, indoor and outdoor environment. Well furnished/empty residential room and class room in university were used as indoor and university grassy ground/residential roof was used as outdoor environment. Experiment was done to get the effect of building wall, floor, interference, temperature and human body on electromagnetic propagation path. More than 30 data was taken for each experiment position. The experimental data, their graphical representation, analysis and observation are presenting sequentially. Figure 7.1 shows the received RSSI data on Laptop screen.

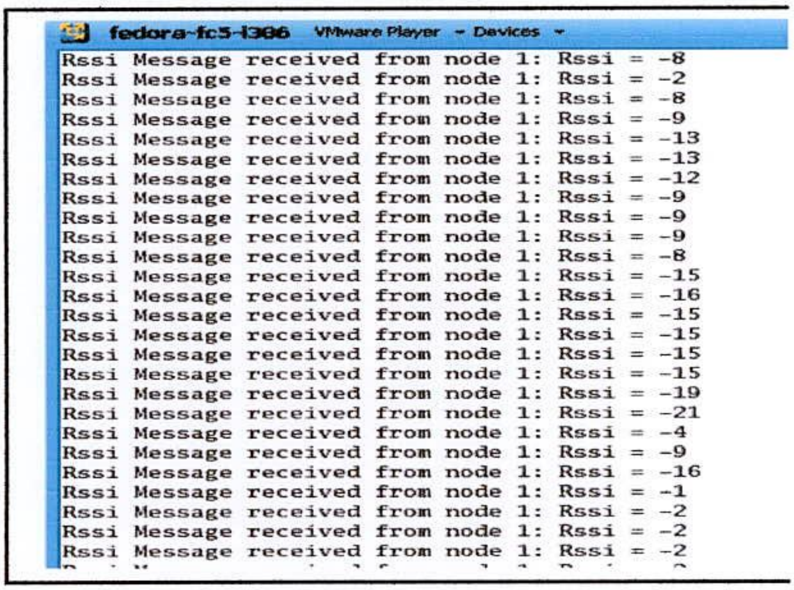

Figure 7.1: Laptop for collecting RSSI value

7.2 Indoor Environment

7.2.1 Floor Attenuation

To observe the wave attenuation characteristics on the floor, the experiment was done at veranda of the 1st floor of EEE department, KUET for 03 different antenna (Both transmitter and receiver) heights. One side of the place had brick wall and other side was open. For all the experiments the height of transmitter and receiver was kept same. All received RSSI data for the antenna height 0.05, 0.45 and 0.9 meters are shown in table 7.1. Here data was taken up to the data break down point (highest coverage) for every antenna height.

Table 7.1: RSSI for different antenna height

T-R antenna height (m)	Receiver position from Transmitter (m)	RSSI (dB)	T-R antenna height (m)	Receiver position from Transmitter (m)	RSSI (dB)	T-R antenna height (m)	Receiver position from Transmitter (m)	RSSI (m)
0.05	0.5	-32.2	0.45	3	-36.3	0.9	1	-17.8
	0.75	-41.5		6	-39.8		3	-27.5
	1	-46.2		9	-44.5		5	-33.75
	1.25	-43.1		12	-49.6		10	-33
	1.5	-44.4		15	-46.6		15	-48.4
	1.75	-46.4		18	-49.9		20	-33.75
	2	-49.3		21	-45.8		25	-43.8
	2.25	-49.4		24	-47.8		30	-43.6
	2.5	-47		26	-49.6		35	-46.67
	3	-48.5					40	-45.2
	3.25	-49					45	-48.4
	3.5	-49.8					50	-48
	3.75	-49.3					52.7	-50.2
	4	-49.4						
	4.5	-49.8						
	4.6	-49.7						

Figure 7.2 is the graphical representation of data in Table 7.1. From the data in Table 7.1 it is clear that the attenuation is increased with the decrease of antenna height. So the coverage is also decreased. This observation is shown in Figure 7.3., which represents the maximum coverage length in m with respect to different transmitter and receiver antenna height.

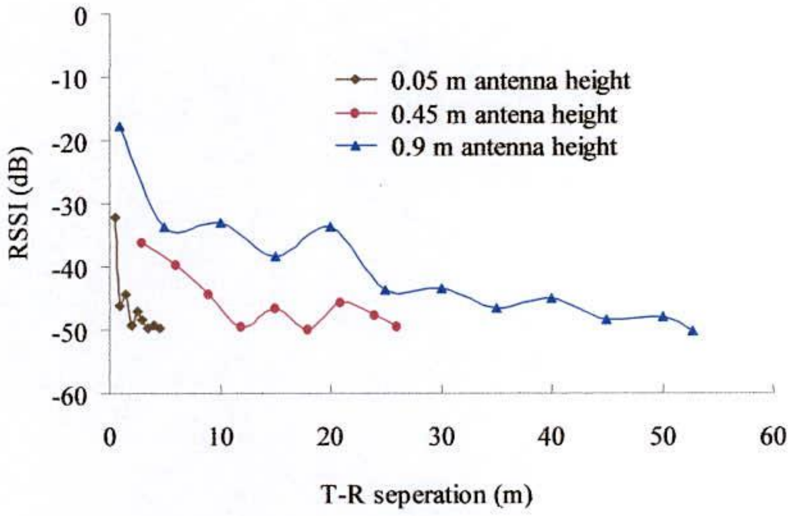

Figure 7.2: RSSI for floor attenuation at indoor

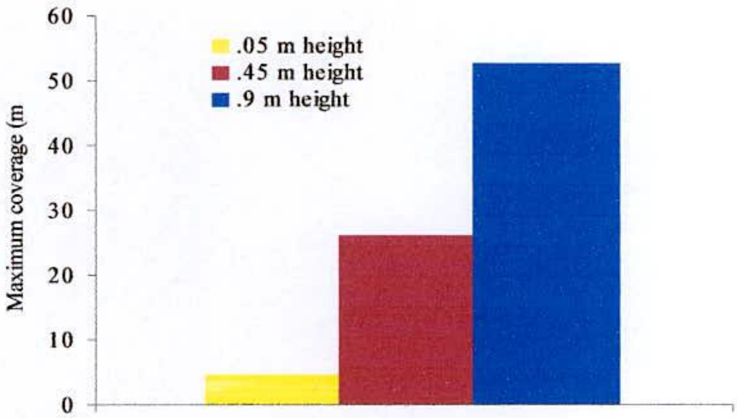

Figure 7.3: Maximum coverage for different T-R height

Observation

From the Figure 7.3 it is observable that floor has huge effect on radio propagation channel. As example (Figure 7.3) for 3 meter T-R seperation point RSSI value for 0.05, .45 and .9 meter heights are -48.5, -36.3 and -27.5 db respectively. So for .45 meter height difference the signal strength is dropped about 10 dB. The reading was taken up to the point in which distance the receiver can response with the signal. The last received RSSI value is -51 to -52 db. From the above graph it can be concluded that when transmitter and receiver both are put on the ground then the floor attenuation is most and decreases if height is increased.

7.2.2 Wall + Floor Attenuation

Radio wave passes through a wall if its dimension is less than the wavelength otherwise it reflected. By experiment it is tried to find out how much attenuation is made by a brick wall. The experiments are performed in three different building rooms.

Experiment 01

To observe how much attenuation is happened by a brick wall, for experiment a room is considered in a building of ground floor. The room area is 4.0 X 4.0 square meter and wall width is 25 cm. Data has been taken to different positions of receiver with respect to wall. Both transmitter and receiver are placed at 0.45 cm height from the floor. Here receiver position remained fixed where transmitter was moved to different position. The experimental set up is shown in Figure 7.3. The data was taken at three different receiver positions which are adjacent, 15 cm away and opposite side of the wall.

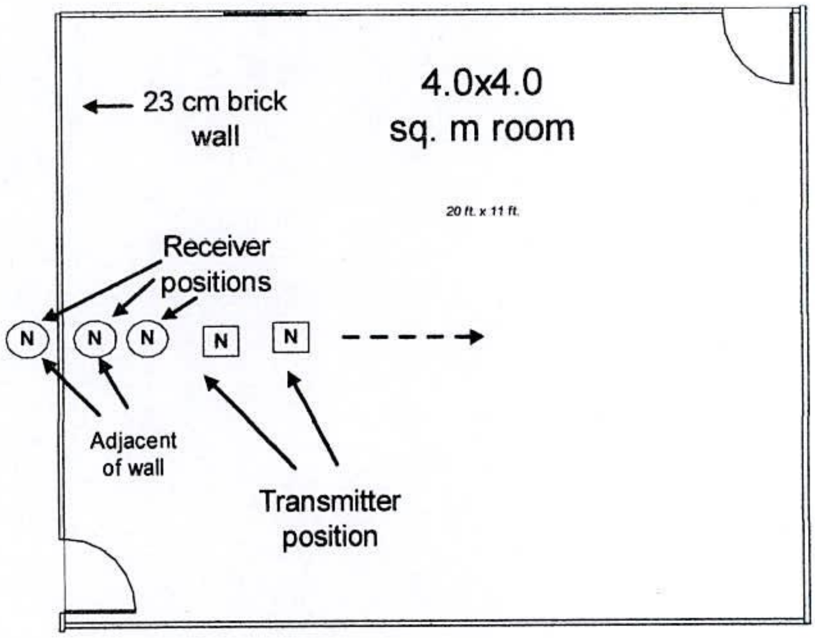

Figure 7.4: Experimental set up at indoor

The experimental data for both transmitter positions are shown in Table 7.2.

Table 7.2: Experimental data for wall attenuation

Receiver Position	Transmitter position from Receiver (m)	RSSI (dB)	Receiver position	Transmitter position from receiver (m)	RSSI (dB)	Receiver position	Transmitter position from receiver (m)	RSSI (dB)
adjacent the wall	1	-23.47	15 cm from the wall	0.5	-24.53	Adjacent opposite side of the wall	0	-29.67
	1.5	-29.6		1	-27.53		0.5	-29.47
	2	-31.6		1.5	-21.2		1	-35
	2.5	-35.53		2	-29.2		1.5	-38
	3	-43.93		2.5	-26		2	-34.8
	3.5	-32.2		3	-34.93		2.5	-42.13
	4	-35		3.5	-40.73		3	-43.4
				4	-25.27		3.5	-43.93
							4	-45.07

Figure 7.4 shows the graphical representation of experimental data in table 7.2

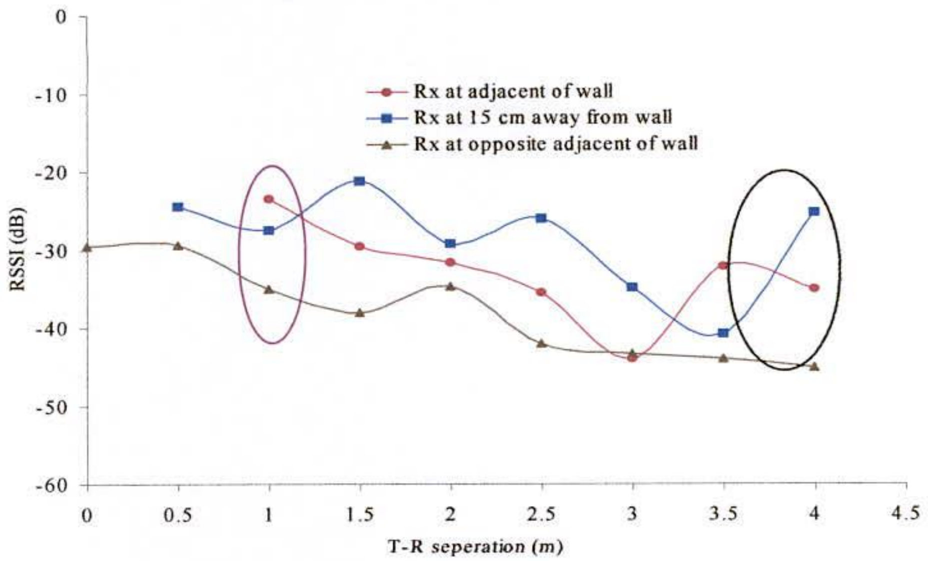

Figure 7.5: RSSI for brick wall attenuation at indoor

Observation

By analyzing the above data in Table 7.2 and in Figure 7.5 it is found that when receiver position is 15 cm away from the wall then receiver received better RSSI value comparing the positions adjacent the wall. And another remarkable feature is that, when receiver is opposite to the wall then the received RSSI value is less than the other positions. In figure 7.5 the violet circle marked the RSSI value for same 1m receiver position where the data is different for same receiver position. The black circle at figure indicate the better RSSI value adjacent the next wall. This amplification is may due to some reflection from the wall.

Experiment 02

This 2^{nd} experiment was performed in a home environment at first floor where all kind of home appliance (like TV, Micro oven, fridge, mobile phone etc) and furniture was present. Area of the room is 6.75 X 6.5 m^2 and wall width is 27 cm. Data was taken by placing transmitter in two fixed positions 1 & 2 m away from the brick wall where receiver was moved away to different position from transmitter. Both transmitter and receiver were placed at 0.45 cm height above the ground. Here all RSSI values are average value for each transmitter position. There are around 30 RSSI data were taken for every receiver position. From those data an average value is taken for further processing. The experimental setup at the room is shown in Figure 7.6. The data was taken for every 1m after the transmitter.

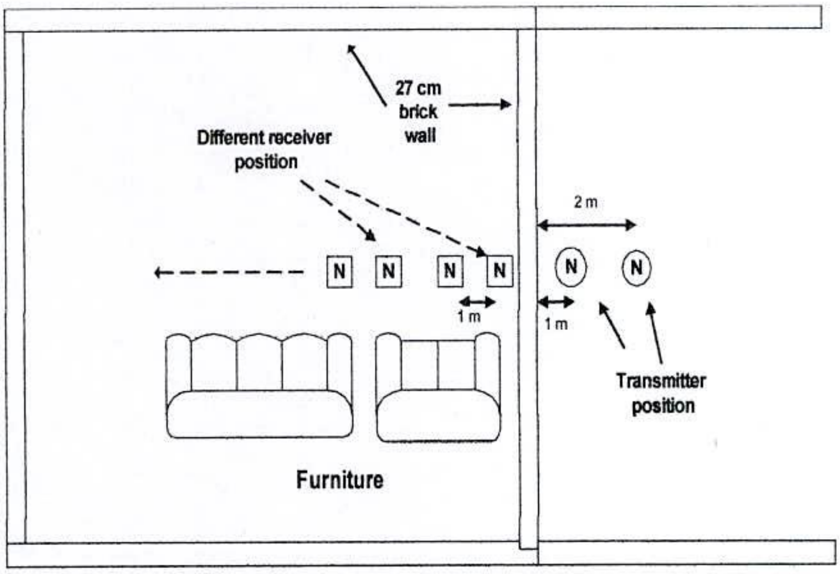

Figure 7.6: Experimental set up for data collection at home

Both experimental data for two transmitter positions (1 and 2 m from away the wall) are given in Table 7.3 and Table 7.4. Data taking was started from the receiver position adjacent opposite to the wall. Here it is remarkable that, data was not found after the next wall.

Table 7.3: Floor + wall attenuation data at 2 m Tx position.

Transmitter position	Receiver position from transmitter (m)	RSSI value(dB)	Comments
2 m away from wall	1	-24.28	
	2	-30.87	Adjacent the wall
	2.27	-33.5	Adjacent after wall
	3.27	-34	
	4.27	-36	
	5.27	-43.14	
	6.27	-47.42	
	6.75	-50.28	Adjacent the next wall.

Table 7.4: Floor + wall attenuation data At 1 m Tx position

Transmitter position	Receiver position from Transmitter (m)	RSSI value (dB)	Comments
1 m away from wall	1	-23.16	Adjacent the wall
	1.27	-27.87	Adjacent after wall
	2.27	-28.83	
	3.27	-41.15	
	4.27	-44.27	
	5.27	-51	
	5.75	-50.86	48 cm away from the next wall.

Graphical representation of data in Table 7.3 and 7.4 is shown in Figure 7.7.

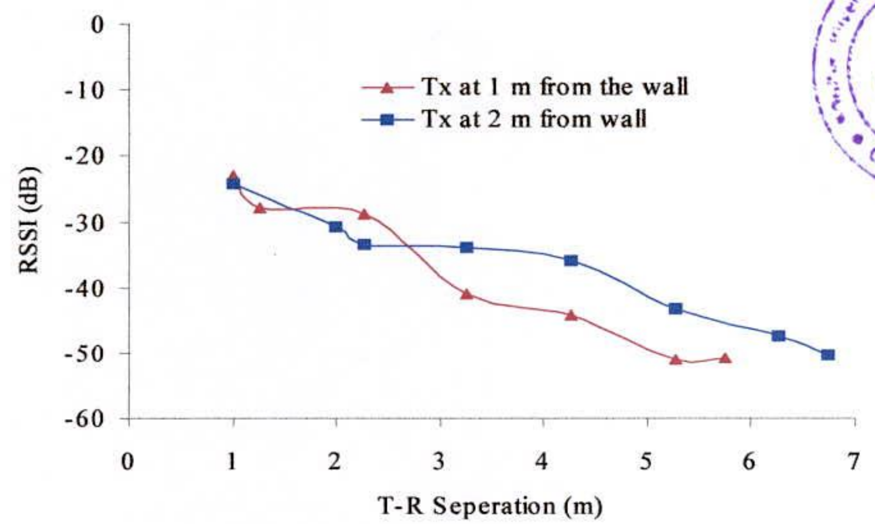

Figure 7.7: Wall and floor attenuation at indoor home

Observation

Analyzing the experimental data in Table 7.3 and 7.4 it can be summarized that if the transmitter is close to the wall then after 2m the attenuation of data by the wall is more than the transmitter away from the wall. So it is clear that the transmitting electromagnetic wave attenuated by the brick wall as a result the receive value is decreased.

Experiment 03

This experiment was done at the 1st floor in empty room at home. The transmitter was placed at the center of the room and both transmitter and receiver were placed at 0.45 m height from the floor. Transmitter position is about 1.67 m from the wall. Width of the brick wall is 20 cm. The experimental set up and respective data are shown in Figure 7.7 and Table 7.5 respectively.

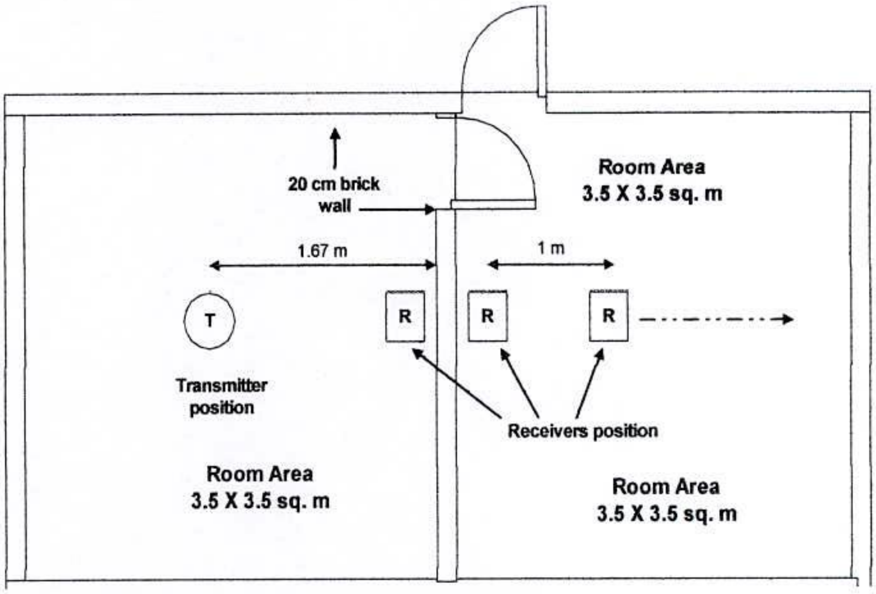

Figure 7.8: Experimental set up at indoor home.

Table 7.5: Experimental data for wall and floor attenuation

Transmitter Position (m)	Receiver position from transmitter (m)	RSSI Data (dB)
At the center (1.67 m away from the wall) of the room.	1	-19
	1.67 (adjacent of wall)	-25.25
	1.87 (Adjacent after wall)	-33.4
	2.87	-38.66
	3.87	-45.75
	4.87	-48.78

Observation

From the above data in Table 7.5 we observe that when receiver is near the brick wall and after the wall about 6 to 8 dB attenuation is happened. So it can be said that there is absorption due to brick wall.

7.2.3 Interference Due to External Source

As sensor network uses free ISM band and other networks (e.g. IEEE802.11b/g) also use the same band, so there is a chance of interference between the networks. And this overlapping has a vital impact on signal strength that may create area block, even link failure. IEEE 802.11b/g networks operate between 2.4 GHz and 2.5 GHz and the frequencies are divided into 14 channels. Where IEEE 802 15.4 network also use 2.405 to 2.480 GHz frequency band and this band is divided into 16 channels.

Figure 7.9 depicts the bandwidth of all 16 channels of IEEE 802.15.4 and bandwidth of all 14 channels of IEEE 802.11b/g. The frequency of each channel is the middle of the bandwidth. Each 802.11 channel is 22 MHz wide and each 802.15.4 channel is 3 MHz wide. Every WSN (IEEE 802.15.4) channel has a probability to interfere with 04 channels of WLAN (IEEE 802.11b/g).

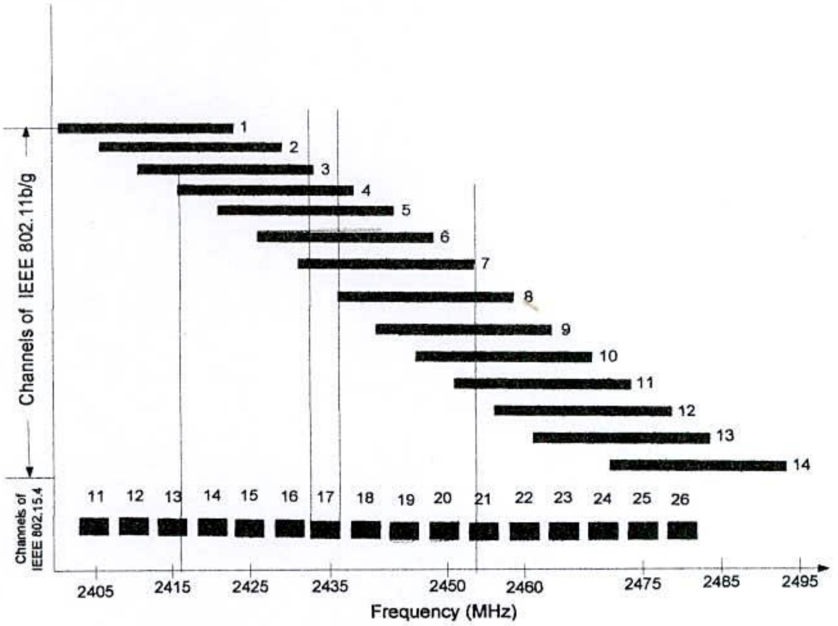

Figure 7.9: Bandwidth of different channels used for IEEE 802.15.4 and IEEE 802.11b/g

To get the interference effect a WLAN (Model of WLAN router is **Ip Time, N604M)** was established which use 13 no channel of IEEE 802.11b/g (Figure 7.9) that covers 22 to 26 no channels of IEEE 802.15.4.

The experimental set up is shown in figure 7.10.

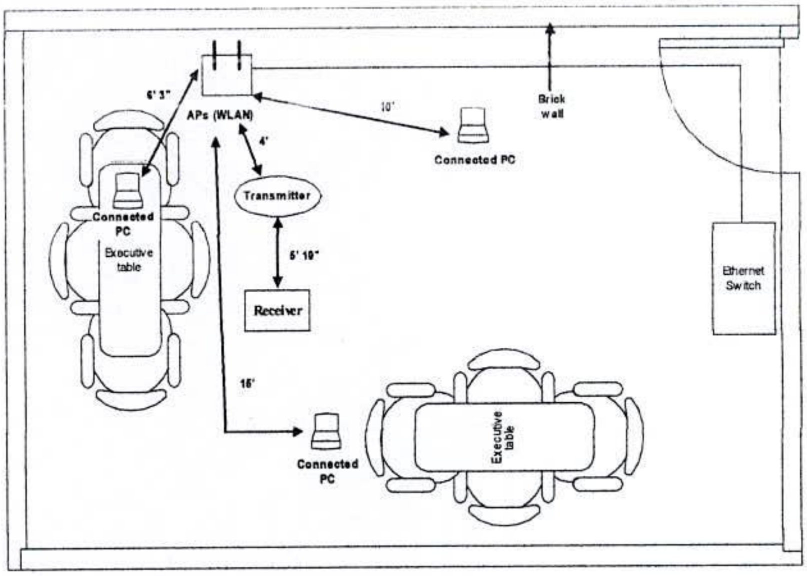

Figure 7.10: Experimental set up for Interference effect measurement

03 (three) laptops were connected to the Internet through WLAN. So experiment was performed by configuring the motes within and out side the 13 no channel of IEEE 802.11b/g. IEEE 802.15.4 channel no 11 and 12 are out side and channel no 23,24,25,26 overlap with 13 no IEEE 802.11b/g channel. The experimental data is shown in Table 7.6.

Table 7.6: RSSI data for interference effect

Average RSSI data (dB)					
Out side the WLAN frequency		Inside the WLAN frequency			
Channel- 11 (2.405 GHz)	Channel- 12 (2.410 GHz)	Channel- 23 (2.465 GHz)	Channel- 24 (2.470 GHz)	Channel- 25 (2.475 GHz)	Channel- 26 (2.480 GHz)
-21.44	-25.62	-33.82	-33.1	-34.5	-37.59
-23.53 (average)		-34.75 (average)			

Observation

From the experimental data in Table 7.6, when wireless motes are operating at the same frequency as WLAN then the average value of RSSI is -34.75 dB and otherwise it is -23.53 dB. So it is remarkable observation is that the received data decrease about 32% when the Wireless Sensors are working in environment where same frequency is already using by another network.

7.2.4 Human Body Effect

Investigation about the effects of human activities on the radio propagation was performed in home environment. In experimental set up both transmitter and receiver antennas were placed on 45 cm height and kept 3 m away from each other in a well furnished room. RSSI data without anybody in the room was taken as reference and calculate the difference between the RSSI with person and without person on two points. Table 7.7 shows the measured data.

Table 7.7: RSSI data for Human effect

Average RSSI data (dB)				
Without human	Human at 1m away from Transmitter	Human at 2m away from Transmitter	Two human at 1m and 2m positions	Human at mobile condition
-29.53	-31.62	-31.22	-33.08	Fluctuation of received RSSI data is about 10 dB

Observation

After analyzing the measured data in Table 7.7 it can be summarized that, when a person stands of LOS of T-R then the attenuation is about 2 dB and if the no of person is increased then attenuation is also increased. Here it is remarkable observation is that if a person cross the LOS then there is a fluctuation in RSSI data and it is about 10 dB.

7.3 Indoor Environment summary

After analysis the above experiments it can be concluded that the electromagnetic signal is attenuated by concrete floor, brick wall, indoor obstacles, human body and has interference effect due to WLAN when it travel in indoor environment. However the exact amount of attenuation or how much impact is happened could not be measured because the characteristics of loss varied with the materials of the element also. This attenuation factors should be considered at the time of propagation model generation. Actually the wave propagation model fully depend upon the real environment in where the sensors are deployed.

7.4 Outdoor Environment

7.4.1 Roof Attenuation

To observe the attenuation characteristics due to concrete roof experiment was performed where both transmitter and receiver were situated at 0.45 cm height from the roof and collected RSSI reading in all around the transmitter. The experimental data is shown in Table 7.8:

Table 7.8: RSSI data for roof attenuation

Position of Rx from Tx (m)	East direction RSSI value (dB)	West direction RSSI value (Db)	North direction RSSI value (dB)	South direction RSSI value (dB)
1.0	-24	-24	-26.5	-25.5
1.5	-28	-26	-29	-26.66
2.0	-36.5	-34	-35.5	-38
2.5	-32	-33	-31.4	-34
3.0	-32	-34	-35	-33.5
3.5	-36	-38	-39	-36
4.0	-42.5	-43.66	-45.5	-44.5
4.5	-47	-46.4	-45.5	-47
5.0	-49.5	-49	-48	-49.33

Figure 7.11 is the graphical representation of data Table 7.8.

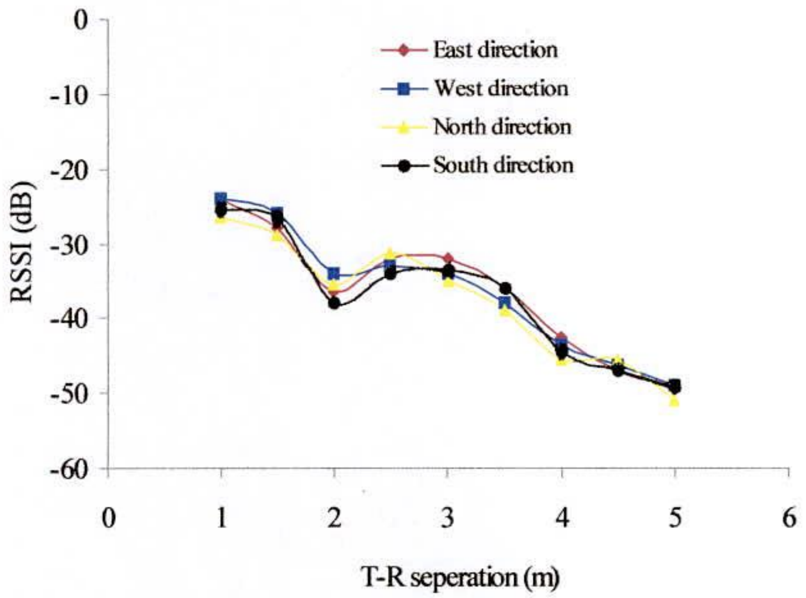

Figure 7.11: Roof attenuation in different direction at outdoor

Observation

By analyzing the data in Table 7.8 and Figure 7.11 it is found that in all direction the signal attenuation characteristic is about to same. Here a mentionable observation is that, the graph has sharp pick of attenuation at 2m receiver position.

7.4.2 Ground attenuation

To observe the attenuation characteristics at outdoor ground, an experiment was performed at KUET grassy play ground. RSSI data was collected for different T-R antenna height from ground. 30 individual RSSI data was taken for every experimental point and then averaged them.

Table 7.9: RSSI for 0.05 m T-R antenna height

T-R antenna height (m)	Receiver position from transmitter (m)	RSSI (dB)
0.05	0.5	-32
	1	-41.77
	1.5	-47.9
	2	-48.57
	2.3	-50

Table 7.10: RSSI for .9 m T-R antenna height

Antenna height (m)	Receiver position from transmitter (m)	RSSI (dB)
0.9	1	-27.9
	2	-36.5
	3	-42.8
	4	-36.33
	5	-43.66
	6	-47.55
	8	-50.375
	9	-51.5

Table 7.11: RSSI for .75 m T-R antenna height

T-R Antenna height (m)	Receiver position from transmitter (m)	RSSI (dB)
0.75	1	-20.5
	2	-27
	3	-29
	4	-35
	5	-36.33
	6	-39.15
	7	-40.77
	8	-43.3
	9	-44.77
	10	-45
	11	-47.75
	12	-47.71
	13	-48.11
	14	-49.75
	15	-49.25
	16	-48.2
	17	-47.75
	18	-49
	19	-50.14
	20	-51
	21	-51.22
	22.4	-51.11

Table 7.12: RSSI for .45 m T-R antenna height

Antenna height (m)	Receiver position from transmitter (m)	RSSI (dB)
0.45	0.5	-28.09
	1	-30.88
	2	-34.6
	3	-42.9
	4	-39.58
	5	-40.45
	6	-37.83
	7	-43.5
	8	-42.91
	9	-44.42
	10	-45.5
	12	-47.66
	14	-49.1
	15	-50.55
	15.3	-50.83

The experimental data for different antenna heights are given in Table 7.9, Table 7.10, Table 7.11 and Table 7.12. Receiver position from transmitter to the minimum RSSI data at each table represents the maximum coverage length for that antenna height.

Figure 7.12 is the comparative graphical representation of the data in Table 7.9, Table7.10, Table 7.11 and Table 7.12.

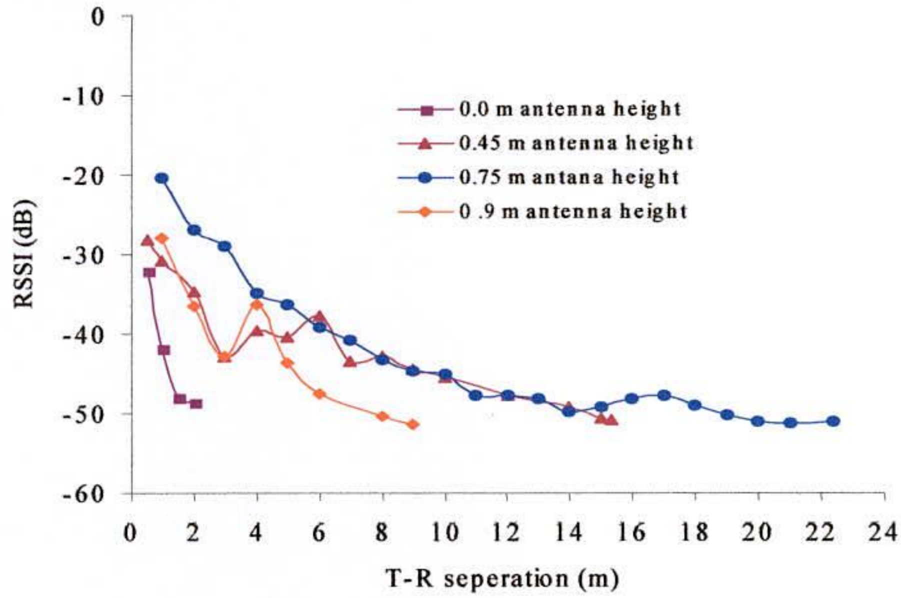

Figure 7.12: Ground attenuation at different antenna height

Observation

Analyzing the experimental data in Table 7.9, Table 7.10, Table 7.11 and Table 7.12, it is observable that, when the coverage length increased from 2.35 m to 22.4 m for 0.05 m and .75 m T-R antenna height. But if the antenna height is increased near .9 m then coverage length decreased abruptly to 9 m.

Excluding the above data some other coverage length for different antenna height was collected that is given in Table 7.13.

Table 7.13: Maximum coverage length for different antenna height

T-R antenna height (m)	Maximum coverage length (m)
0	2.3
0.45	15.3
0.75	22.4
0.9	9
1.15	14.8
1.35	15

The Figure 7.13 and Figure 7.14 are the graphical representation of the data Table 7.13.

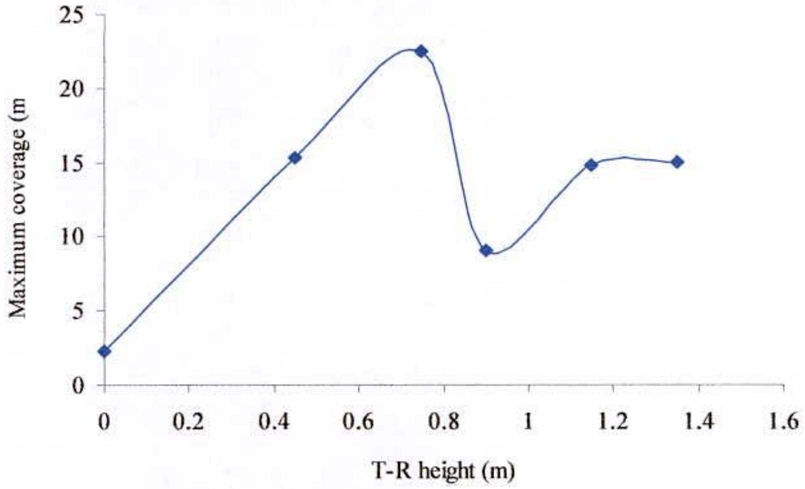

Figure 7.13: Maximum coverage with T-R antenna height

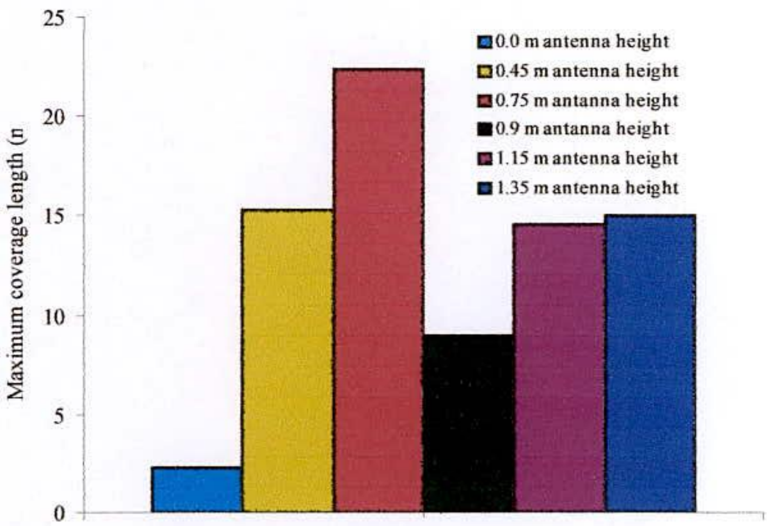

Figure 7.14: Maximum coverage with T-R antenna height

Observation

Table 7.13 contains some wireless sensor node coverage value and their corresponding T-R antenna height. By analyzing the data table and the graph it can be concluded that if the wireless node's height increases then the coverage area also increases except near .9 m height. So it can be summarized that there is an effect on antenna height in radio propagation.

7.4.3 Comparison Between Indoor-Outdoor Data

In the experiments data has been collected in both indoor (in building) and outdoor (at grassy field) environment for the same transmitter and receiver height. If those data is plotted for 0.45 and 0.9 m T-R antenna height then it will show the electromagnetic wave attenuation characteristic at different environment but at same antenna height.

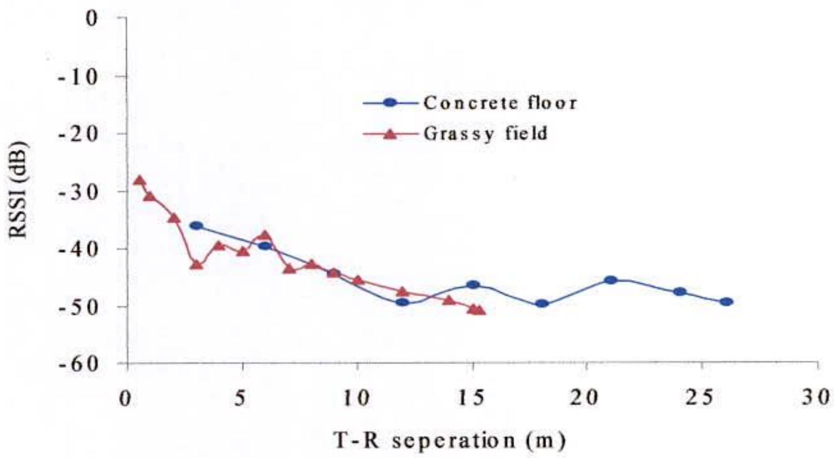

Figure 7.15: RSSI comparison at 45 cm antenna height

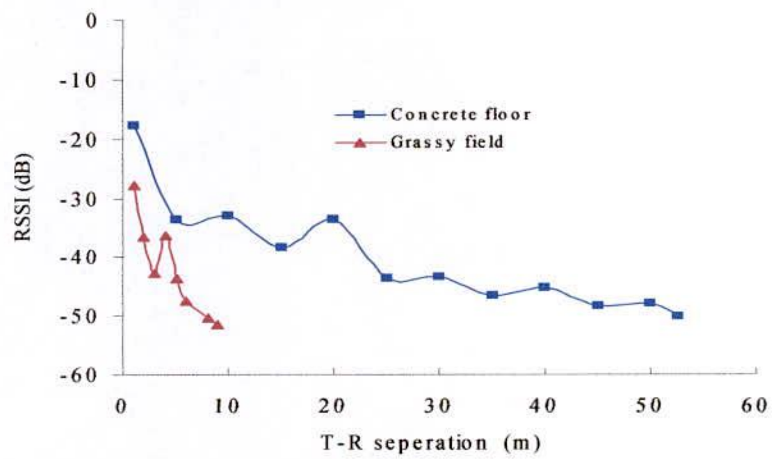

Figure 7.16: RSSI comparison at 90 cm antenna height

Figure 7.15 and Figure 7.16 represent the comparable graph between indoor and outdoor at two different transmitter-receiver antenna heights .45 and .9 m respectively. When antenna height is 45 cm, RSSI value is likely same but coverage length at indoor is more than out door. At .90 m antenna height, outdoor signal coverage is very poor as comparing indoor. Here remarkable observation is that the coverage at indoor is higher than outdoor. So it is observable that floor material affects the radio propagation.

7.4.4 Temperature Effect on RSSI

As all telecommunication equipments are manufactured by semiconductor so it has huge effect on environmental temperature. Some experiment was performed in outdoor at different temperature to observe how RSSI value is affected by temperature.

Experiment 01

To observe if there any effect on RSSI due to different places at same temperature, data was collected from two different places at ground and concrete roof at same 32^0 C temperature and 80% humidity. Both transmitter and receiver were placed at 45 cm height from ground. The recorded data is given in Table 7.14.

Table 7.14: RSSI at 32^0C temperature

Receiver position from Transmitter (m)	RSSI value (dB)	
	At ground	At roof
0.5	-22.00	-22.10
1	-24.33	-23.73
1.5	-34.00	-31.27
2	-31.67	-36.13
2.5	-34.00	-36.93
3	-35.89	-37.13
3.5	-35.50	-45.67
4	-36.20	-43.67
4.5	-37.00	-42.13
5	-37.50	-45.53
5.5	-33.00	-47.00
6	-36.80	-44.73
6.5	-34.00	-45.93
7	-38.27	-47.67
7.5	-40.33	-45.93
8	-46.25	-48.33
9	-48.50	-42.73
10	-38.60	-40.87
11	-46.40	-40.87
12	-41.30	-41.93
13	-44.80	-42.67

Observation

The above experiment is done at same temperature on ground and at concrete roof. As the material of two places is different so we found that from antenna distance 3 m to 8 m data lable is different (marked by circle). Attenuation at roof is higer within that region than the ground.

Comparative graphical representation of data in Table 7.14 is shown in Figure 7.17.

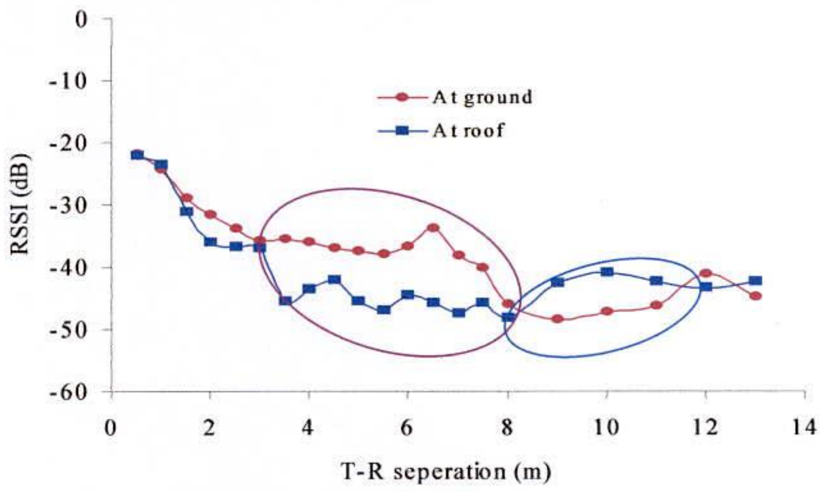

Figure 7.17: Comparison at 32^0 C temperature on ground and roof

Experiment 02

To observe the direct effect of temperature to RSSI, data was collected at two different temperatures for the same place. We recorded RSSI data at 32^0 C and 38^0 C temperatures at the roof of a building. Both transmitter and receiver were placed at 45 cm height from the roof. The humidity of that time was about 80%.

Table 7.15: RSSI at 32^0 C and 38^0 C temperature on concrete roof

Receiver position from Transmitter (m)	RSSI value (dB)	
	At 38^0 C	At 32^0 C
1	-29.13	-22.1
2	-30.53	-23.73
3	-40.13	-31.26
4	-44.4	-36.13
5	-44.4	-36.93
6	-41.8	-37.13
7	-42.6	-45.66
8	-47.46	-43.66
9	-46.18	-42.13
10	-39.46	-45.53
11	-41.64	-47
12	-40	-44.73
13	-45.78	-45.93
14	-47.0909	-47.66
15	-46.71	-45.93
16	-49	-48.33
17	-46.06	-45.8
18	-48.8	-46.7
19	-49	-47.5
20	-50.8	-47.7

Graphical comparison of data in Table 7.15 is presented in figure 7.18.

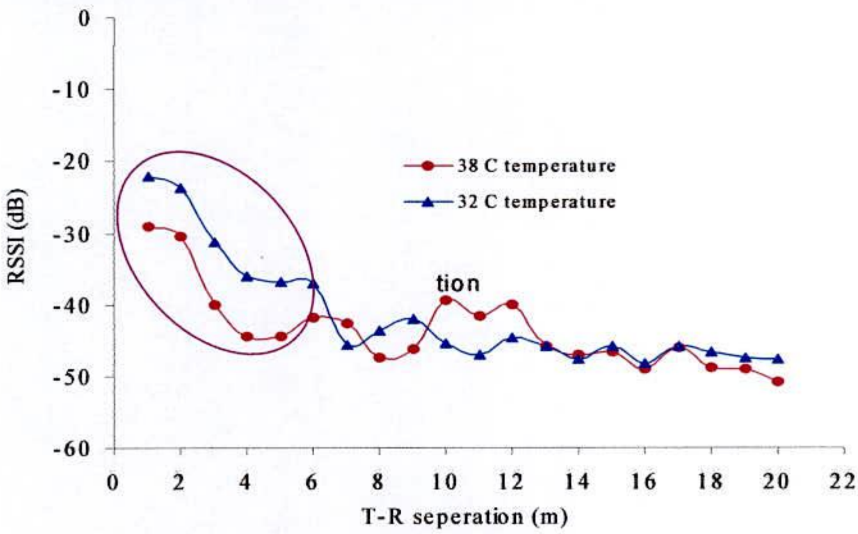

Figure 7.18: Roof attenuation at 38^0 C and 32^0 C temperature

Observation

Analizing the data in Table 7.15 and also from Figure 7.18 it is found that, up to 6.15 m T-R antenna distance the RSSI data is differed (marked by violet circle in figure) but after then it is nearly same. As the temperature differenc is not so high so remarkable deviation on data is not found. But it can say that temperature has an effect on radio signal propagation.

CHAPTER VIII

Result and Discussion

8.1 Introduction

After a vast investigation with experiment explained in chapter-vii, it is clear that the signal strength could be absorbed or attenuated by floor, ground, wall, human body, temperature and interfered by other devices which use the same channel as wireless sensor network like WLAN. Those effects are not pronounced simultaneously, as a result the collected practical data is not uniformed but there is a fluctuation.

After finishing all experiments a comparison to the experimental data with the theoretical data is performed. To do so, the basic equation for wave propagation model is used to get the theoretical data. The basic wave propagation model (Log normal shadowing model) is:

$$PL\ (d) = PL\ (d_o) + 10\ n \log (d / d_o) + X_\sigma$$

The value of $PL\ (d_o)$ is calculated from the equation 3.8, where d = 1 m, $G_t = G_r = 1$ and $P_t = 15$ dB. And X_σ is found from the experimental data by using the following equation:

$$x_\sigma = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{d^2}{2\sigma^2}}$$

Where, $\sigma = \sqrt{\left[\frac{1}{m-1}\sum_{i=1}^{m}(x_i - \mu)\right]}$, m and μ is the number and mean value of RSSI data.

Here *PL (d)* is the path loss in dB between transmitter and receiver. After getting the PL (d) from the above equation, theoretical received value $[P_r = P_t - PL\ (d)]$ is calculated and these data is then compared with the practical acquired data with respect to T-R antenna distance. In path loss equation $n=1.9$ and $n=2$ [29] are used as path loss exponent (n) for calculation at indoor and outdoor respectively.

8.2 Comparison at Indoor

For the 1st comparison at indoor, experimental data is considered here is the collected data from the veranda of EEE building in first floor for .9 m T-R height. The theoretical value is calculated by the procedure explained in 8.1 the comparison between calculated theoretical received data with the data that actually collected at the point when experiment is performed is shown in Figure 8.1.

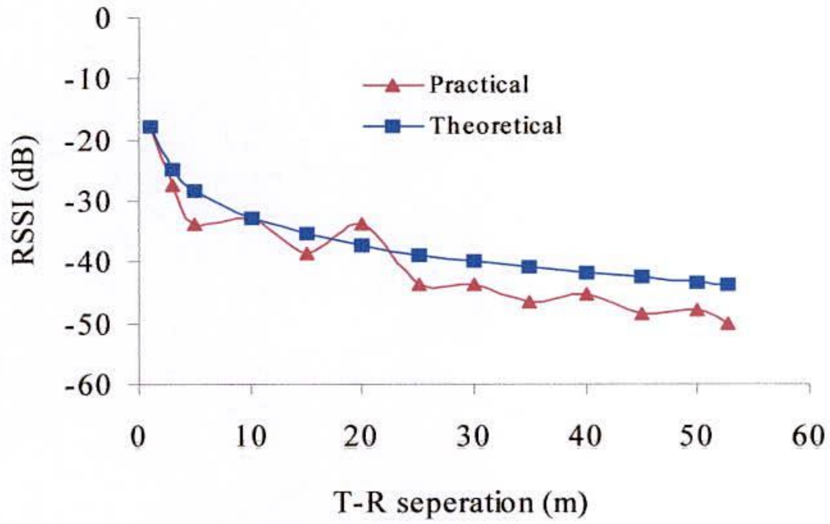

Figure 8.1: Practical and theoretical data comparison at Indoor

From the Figure 8.1, it is observable that the signal strength is decreased with the increase of distance between transmitter and receiver for the both practical and theoretical curve. But there is a mismatch between the two curves, trend to decrease the RSSI value with distance is more to the practical curve than the theoretical. That is, there is a deviation between the two curves. The deviation is maximum at the receiver sensitivity value or last coverage point. This is due to that there is some attenuation by the existing environmental factors which is not considered in the calculation done by basic path loss model.

8.3 Comparison at Outdoor

2^{nd} comparison is performed for the experimental data that was collected from the outside that is the grassy field at KUET campus. Transmitter and receiver height of the data was 0.75 m. The comparison is shown in the figure 8.2.

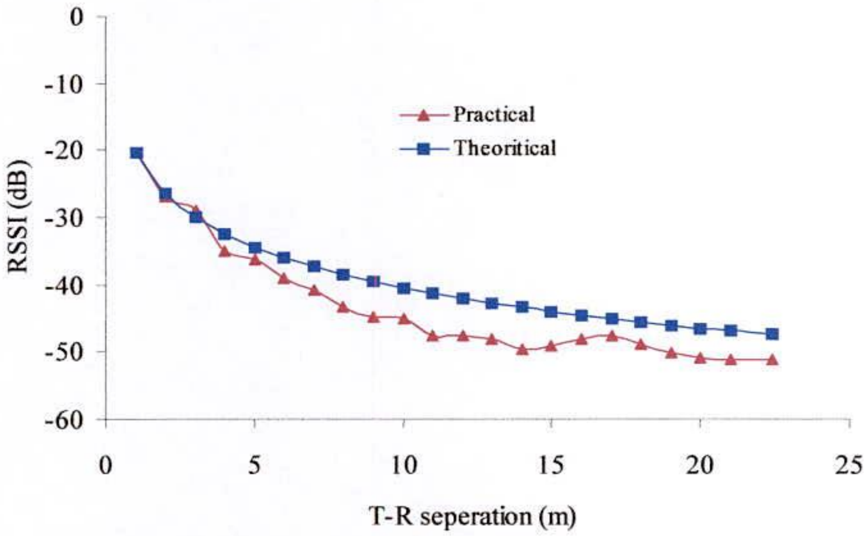

Figure 8.2: Practical and theoretical data comparison at outdoor

From this figure 8.2 it is also clear that the RSSI value is decreasing with the increase of distance. Here it is also observable that the theoretical data is not matched with the practical data. The trend of decreasing the RSSI value with the increase of distance is more than the theoretical value. In out door environment the deviation between the two curve is not so high as compared with the curves in indoor. This is because the factors affect the propagation of radio wave in indoor is more and complicated than in outdoor. In out door attenuation of signal is happened normally by the ground, due to some obstacle and if there some moving body exist. This all effects have to be considered at propagation model generation.

8.4 Proposed Path Loss Model

So, from the two comparisons de scribed above, it is observable that there is some other factors those are not considered in the basic path loss equation. Due to that there is some deviation between theoretical and practical model curve. Actually the basic path loss equation does not consider the signal drop due to different factors existing at real environment where the sensor nodes are deployed. To consider those factors we propose an exponential factor to compensate the difference between the theoretical and practical lacking.

The proposed new path loss model is shown in below where other attenuation factors will be added with the shadowing effect.

$$PL_{proposed}(d) = PL(d) + (d / L) * (A_f) * e^{((d/L)/10)} \dots\dots\dots\dots\dots (8.1)$$

Where, $PL(d) = PL(d_o) + 10\, n \log(d / d_o) + X_{\sigma}$, Basic path loss model

d = Antenna (T-R) distance in m

L = Maximum Coverage length for respective mote in m

A_f (Attenuation factors) = $\sum WAF_i + \sum FAF_j + \sum INTF + \sum HMBD + \sum$other effects...in dB

Actually the factors which will be considered for A_f fully deepened upon the real world where the sensor nodes will be deployed. The network designer will first where will be his sink node and where the sensor nodes will be deployed and what kind information sensors will collect. Then he will fix the maximum coverage length (L) and determine which kinds of factors affect the radio channel. After that he will fix his A_f and calculate the actual path loss by using equation 8.1.

8.5 Proposed Model Verification

8.5.1 Verification at Indoor

If the calculated received data from proposed model curve is plotted in figure 8.1 then the Figure 8.3 shows theoretical, practical and proposed model curve at in door environment.

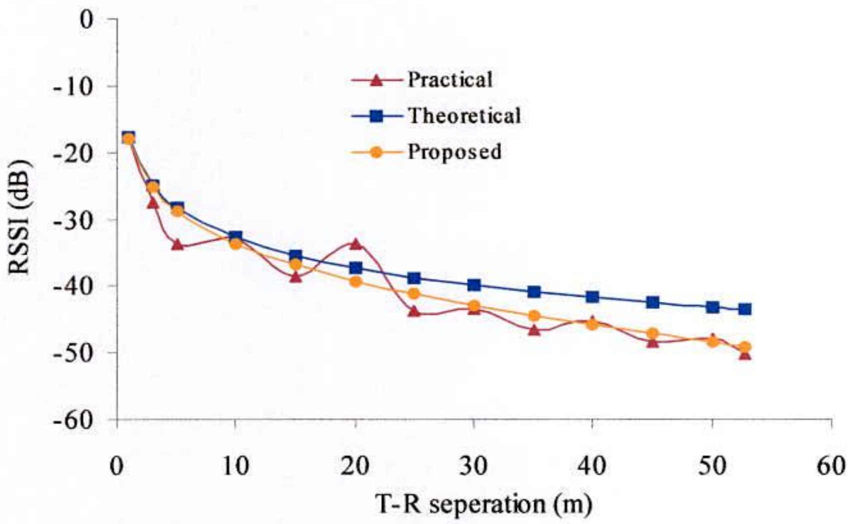

Figure 8.3: Proposed propagation model curve at indoor

In Figure 8.3 it is observed that the proposed model curve tends to merge with the practical model curve after other attenuation factors consideration. But there is some deviation between the practical and proposed model curve. If the factors consideration is perfect and accurate then may have not any deviation between them.

8.5.2 Verification at Outdoor

At outdoor grassy field only ground attenuation and a little bit human effect are exist. So we considered 3 (2+1) dB as A_f (Ground + Human attenuation) in equation 8.1 to calculate the path loss at ground. After calculation new path loss model curve is added with the Figure 8.2 and the three model curves are shown figure 8.4.

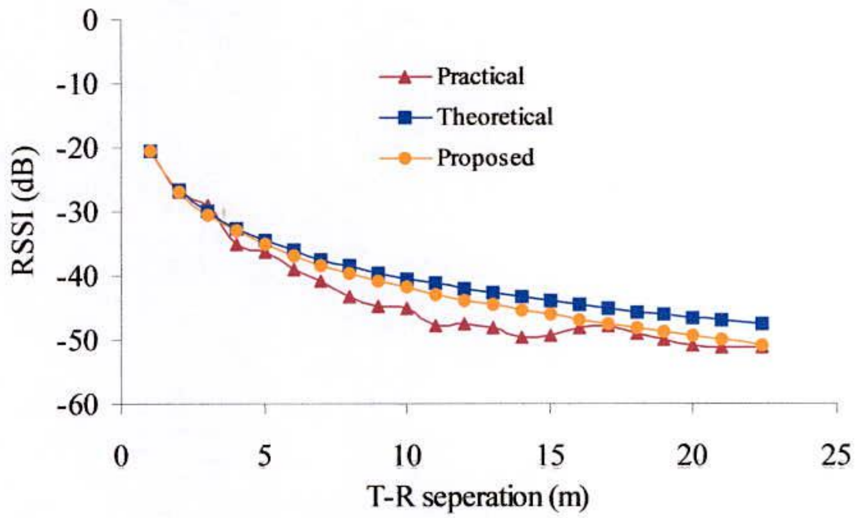

Figure 8.4: Proposed propagation model curve at outdoor

From the Figure 8.4 it can be easily observed that the proposed model curve is tend to be imposed with the practical model curve after two attenuation factors consideration. And it is seemed to that the average value of the practical model curve is the proposed model curve.

CHAPTER IX

Conclusions and Recommendations

9.1 Conclusions

In this project, a huge amount RSSI value at different places in indoor and outdoor was collected, shorted and verified. The characteristics of attenuation which is happened when a radio wave is propagated in real environment is tried to find out. With numerous no of experiment it is proven that wave propagation has an impact with different factors like floor attenuation, Ground attenuation, wall attenuation, human movement, temperature, interference due to external source. At now day's sensors are used in not only as stand still data collection but also as mobile transmitter like sensing and transmitting human heart beat to a center point. But this signal may obstructed by different things which may diminish the strength of the signal. Weak data may translate to wrong information and even may cause communication failure.

The basic path loss equation for wave propagation doesn't cover the whole factors. So, it is necessary to modify the basic wave propagation model that considers some other factors which exists at real environment. It is experimentally observed that the loss increase in an exponential manner. So, an exponential factor is proposed to consider the different factors with the basic log normal propagation model to compensate the variation between experimental and theoretical data.

The proposed model is then verified with two data which were collected at indoor and outdoor in KUET. And it is found that the data calculated from the proposed propagation model is about to the practical data.

So this new proposed propagation model curve may assist a Wireless Sensor Network designer to calculate path loss in a real environment and which will be beneficial to design a suitable Network to that environment.

9.2 Future Works

In this project observation is performed in some of surrounding things in indoor and outdoor that may affect the radio wave propagation. There are also more other lot of things which need to be considered to establish a proper and suitable propagation model that may suit in any environment. The experiment is performed by only one transmitter and receiver mote where more than one mote can be used to collect the data. This observation can be executed within the whole frequency band which allocated for wireless sensor Network. So there is a huge opportunity to further research with radio wave propagation model.

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