Study on indoor RF Propagation Model with Doppler Effect

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Abstract- Radio wave propagation models are recently important for wireless network designer while designing the specific network design in definite regions, building and infrastructure. There may be some problems when using and designing indoor wireless network. It causes signal attenuation because of complex structure and infrastructure of building and other unwanted effect of carrier frequencies. To overcome these problems, nowadays the estimation of path losses becomes the main challenge. Moreover, while moving mobile objects move around the building and campus, the estimation of path loss values become more complex and hard to define. This paper presents the studies of indoor radio wave propagation models with Doppler frequency shift effect. The common Free Space and Log Distance propagation models are used to analyze these problems in indoor environment. As the various speed of moving object can affect the path loess level at the receiver side, the estimation of carrier frequency at the receiver becomes main issue in correct form. The purpose of this paper is to estimate the path loss values of moving object with constant speed by considering Doppler Shift Effect. The necessary experiments are conducted on different days and in different time to get more stable received signal strength values (RSSI). The estimations of path loss values with Free Space model, with Log Distance model and RSSI values according to those propagation models with Doppler Effect are presented with different points of view. Although Doppler shift effect can mainly cause in outdoor environment, but according to the analytical result, this effect can also cause in indoor wireless communication system.

Index Terms- Radio Wave Propagation, Doppler Effect, indoor propagation models, path loss

I. INTRODUCTION

The demand of wireless communication consistently increases in high-speed mobile environment due to the development of moving object. It is important to provide better link quality which is caused by moving objects' speed up and data rate increase [1]. Indoor coverage is gaining its importance as time is going on because most of the users use cell phone indoor as compared to outdoor users according to a rough estimates more or less 80% of the people use cell phone indoor. Path loss models describe the signal attenuation between a transmitter and receiver antenna as a function of propagation distance and other parameters which is caused by the dissipation of the power radiated by the transmitter as well as effects of the propagation channel. Shadowing is caused by obstruction between the transmitter and the receiver that attenuate the signal power through absorption, reflection, scattering, and diffraction. There are many models of analyzing the path loss model nevertheless any path loss model can not apply to comprehensive. There have been studies on path loss between transmitter and receivers at urban and suburban environment, and also in indoor environment [1]. In this research work, to provide the better communication link, not only the correct estimation of path loss, but also the Doppler Effect for moving object will be analyzed.

II. INDOOR RADIO WAVE PROPAGATION MODELS

Radio waves (electromagnetic radiation) propagate from the transmitting antenna to the receiving antenna utilizing the propagation medium between them [5]. RF signals generally propagate between the transmitting antenna and the receiving antenna in one of the following most common methods: line-of-sight (LOS), refraction, or reflection. Dominant propagation characteristics vary with the frequency (or wavelength) of the transmitted signal involved. There are different models to calculate the path loss especially for indoor environments. Some of them have been modified to be used for monitoring indoor propagation also. But none of them have been accepted as standard; it depends on the types of scenario where we are calculating and also depends upon the reading that we get from the calculation. Many of the papers have adopted the hit and trial rule to figure out the best model that meets their requirements. The performance of indoor high frequency capacity wireless communication is restricted by propagation and wireless channel characteristics due to the fact that transmitter and the receiver either with direct line-of-sight or non-line-of-sight (NLOS) are surrounded by different kinds of objects which have adverse effect on the propagation characteristics of radio medium. Indoor channels are dependent on the physical attribute of buildings, construction materials and other structures [[7]. The main characteristics of wireless communication channel are Path loss, Fading and shadowing, Interference, Doppler shift and so on.

In this study, the path loss and Doppler shift effect are studied and analyzed. Path loss is an electromagnetic wave that propagates through the space between the transmitting antenna and the receiving antenna in communication system. This brings about undesirable dwindling of radio signals due to effects of wireless channel characteristics. These effects are influenced by the condition of the environment, frequency of operation, distance between the transmitter and receiver [[7].

(A) Free Space Path Loss Propagation Model

Path loss can be expressed as the ratio of power of transmitted signal to the power of the same signal received by the receiver on a given path. It is a function of the propagation distance. Estimation of path loss is very important for designing and deploying wireless communication networks. Path loss between transmitter and receiver plays a vital role when we are doing link budget calculation [6]. The free space propagation model is the simplest path loss model in which there is a direct-path signal between the transmitter and the receiver with no atmosphere attenuation or multipath components. Assuming that the total transmits power at the source is P_t, whose gain in a particular direction is G_t, the radiated power density ρ at given distance d will be given by

$$\rho = \frac{PtGt}{4\pi d^2}.\frac{Watt}{m^2} \quad (1)$$

If the receive antenna is located at a distance *d* and gain is G_r and the effective area is *A*

$$A = G_t \frac{\lambda 2}{4\pi} \quad (2)$$

The received power Pr at the terminal of the receive antenna is given as

$$P_r = \rho.A = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 \quad (3)$$

Therefore Free Space path loss L_P is given by the ratio of the received power to transmit power

$$L_p = \frac{P_r}{P_t G_r G_r} \quad (4)$$

By combining equation 3 and 4, it becomes

$$L_p = \left(\frac{\lambda}{4\pi d}\right)^2$$

In decibel, L_p becomes

$$L_{p(dB)} = 32.45 + 2 - \log(f) + 20\log(d) \quad (5)$$

Where frequency (f) is measured in MHz and distance (d) is measured in km [[7].

(B) Log-Distance Path Loss Propagation Model

In both outdoor and indoor environments, the average large scale path loss for a random transmitter to receiver separation is expressed as a function of distance by the use of path loss exponent *n*. The value of *n* depends on the accurate propagation environment. However, reducing the value of *n* lowers the signal loss, ranging from 1.2 to 8 [[7]. The average path loss *PL(d)* for transmitter and receiver separated at distance *d* is given as

$$PL(d) \propto \left(\frac{d}{d_0}\right)^n \quad (6)$$

$$PL(dB) = PL(d_0) + 10n\log\left(\frac{d}{d_0}\right) \quad (7)$$

Path loss exponent *n* indicates the rate at which path loss increases with distance *d* while the close reference distance d_o is determined from taking measurement which close to the transmitter. $PL(d_o)$ is calculated by using the free space path loss equation mentioned above. In this work, the path loss exponent *n* value of 4 is used to implement.

(c) Doppler Shift Effect

Doppler shift occurs when the transmitter of a signal is moving in relation to the receiver. The relative movement shifts the frequency of the signal, making it different at the receiver than at the transmitter. The waves travel at a speed *v* and are emitted at a frequency *f* (cycles/seconds). In this case, the emitter has moved a distance of *d* towards the receiver between the emissions of two succeeding cycles. The cycles thus arrive at the observer with a frequency higher than the emission frequency. The opposite applies when the transmitter is moving away; the distance between each peak (or cycles) increases, and since the wave is moving at the same *v* speed, the perception of the observer is that the frequency has diminished. The analysis is different because electromagnetic waves do not propagate in a substrate and their speed does not depend on a frame of reference. However, the base concept is the same: a frequency shift is caused by the speed of the transmitter in relation to the receiver. A lot of research is going on in the field of algorithms to enable the prediction and correction of waveforms. To do the correct prediction of wireless coverage area, the basic radio wave propagation models can be used in effective ways. In this paper the error between the estimation of path losses and Tx-Rx with and without Doppler Effect is analyzed with various speeds of moving object. The following equations show the mathematical expression of Doppler Shift Effect.

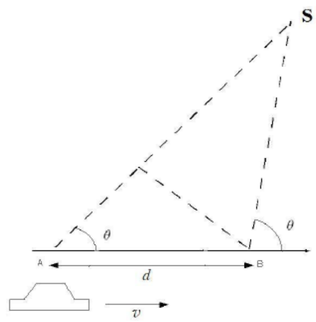

Figure 1. Illustration of Doppler Effect

$$f = \left[\frac{v \pm v_r}{v \pm v_s}\right] f_0 \qquad (8)$$

where f is the observed frequency, f_0 is the emitted frequency; v is the velocity of waves in the medium, v_s is the velocity of the source relative to the medium and v_r is the velocity of the receiver relative to the medium. Consider a mobile moving at a constant velocity v, along a path segment length d between points A and B, while it receives signals from a remote base station to source S shown in figure 1. The difference in path lengths traveled by the wave from source S to the mobile at points A and B is $\Delta l = d \cos\theta = v\Delta t \cos\theta$, where Δt is the time required for the mobile to travel from A to B, and θ is assumed to be the same at points A and B since the source is assumed to be very far away [3]. The phase change in the received signal due to the difference in path lengths is therefore

$$\Delta\varphi = \frac{2\pi\Delta l}{\lambda} = \frac{2\pi v\Delta t}{\lambda}\cos\theta \qquad (9)$$

and hence the apparent change in frequency, or Doppler shift (f_d) is

$$fd = \frac{1}{2\pi}.\frac{\Delta\varphi}{\Delta t} = \frac{v}{\lambda}\cos\theta \qquad (10)$$

III. Experimental Procedures

The first part of our experiment determines the maximum distance between transmitter and receiver. To conduct all necessary experiments, the TL-WR941ND router is used as a transmitter and Laptop with widows 10 operation and 3 dBi antenna gain with installed inSSIDer software is used as a receiver. According to technical specifications, the TL-WR941ND router has a transmission power of 10 dBm and the omni-directional antennas have a 5 dBi gain. The experiments are carried out at the convocation hall of the University of Computer Studies, Loikaw, Kayah State, the Republic of the Union of Myanmar. To get the stable experimental data, the experiments are carried out in different time and on different days. Figure 2 provides the experimental region and placements of transmitter and receiver. In this experiment, the building is multistoried and with brick wall type of 36.57m x 24.38m. Figure 2 shows experimental environment for estimation model considering Doppler Shift in indoor environment. In this research work, the distance between transmitter and receiver is 15m and the measuring point between two consecutive points is 2m each. The Tx positions were chosen to obtain a line-of-sight condition for all measuring points. The transmitter is placed at the centre of X to Y path and the middle of measuring point and the straight line of transmitter placement is 15m. The carrier frequency for this experiment is 2400MHz. the heights of transmitter and receiver are 0.8m each.

In this research work, the moving mobile object with constant velocity should be actually used to analyze with the experiment. It is difficult to conduct the experiment with moving object in indoor environment. That is why, the estimation of path loss values with free space model and Log distance models are used to analyze.

The path losses value is defined as the difference between the transmitted power level and the receiver sensitivity (in dBm) needed for error free reception according to the following equation (11).

$$PL(dB) = P_t(dBm) - P_r(dBm) \qquad (11)$$

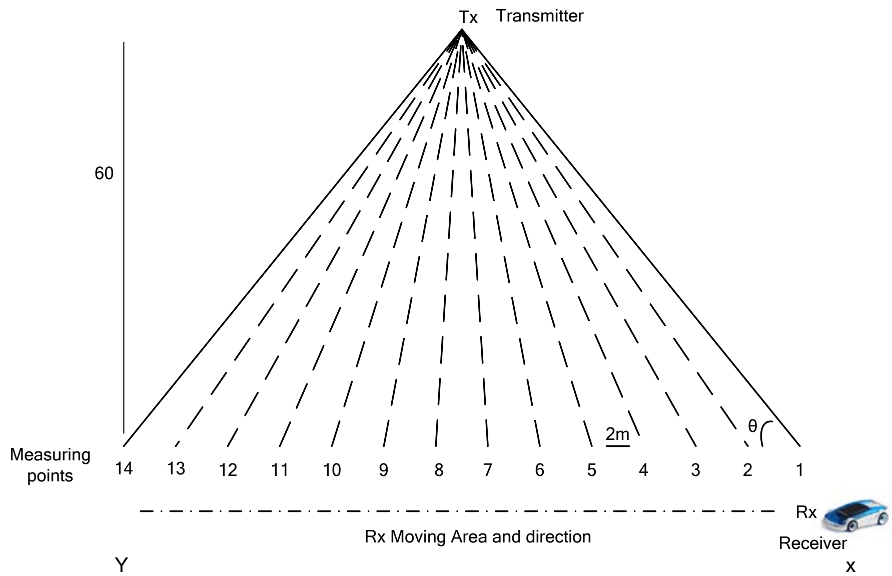

Figure 2. Measuring Points and Direction of Moving Object

While conducting the experiment, there are 14 measuring points for receiving points. In each point, the laptop is placed to get the received signal strength values until the resulting values are stable. The received signal strength (RSSI) is measured at each measuring point with zero velocity in indoor environment. After that, the estimation of path loss using free space propagation model, that of path loss using Log Distance propagation model with Doppler Effect are analyzed. The comparison results of these data are simplified with the help of Matlab programming language.

Figure 3. The Placements of Transmitter and Receiver

IV. Analytical and Experimental Results

Figure 4 and 5 provide the theoretical, experimental and analytical results of the path loss values over different distances between the transmitter and receiver. In this study, the various velocities ranges from 5 to 20 ms^{-1} are used to evaluate. It is clear that the mentioned experiments are carried out in indoor environment; the analytical ranges of velocities should be used in those ranges. The path loss values depend on the velocity of moving object. While analyzing the path loss values with free space propagation model as shown in figure 4, it is clear that the less the speed of moving object, the less the error between the estimation with and without Doppler effect. Some fluctuations are found in some measuring points due to the condition of unwanted indoor wireless characteristics.

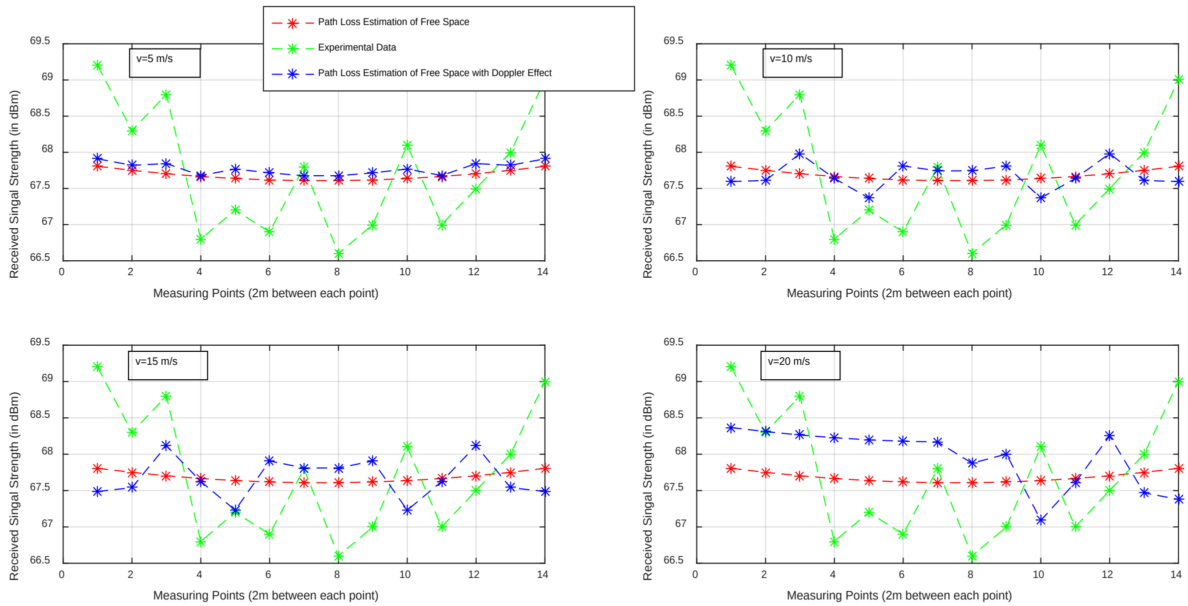

Figure 4. Analysis of Free Space Propagation Model with Doppler Effect (various mobile speed v=5, 10, 15, 20m/s)

The following figure 5 illustrates the path loss estimation of experimental region using mentioned equipments. In this case, the path loss values of log distance show a little more attenuation in such condition. This is because, the path loss exponent value of 4 is used to analyze the proposed system. While analyzing the velocity value of 20 m/s, The fluctuation of path loss values increases obviously because of depending on the path loss exponential value and indoor wireless communication characteristics. In the analytical study of velocity value of 5 m/s, the estimations of path loss value with not only free space propagation model but also log distance propagation model, show that Doppler shift effect can cause a little effect on moving object that can be handled when the network designers implement the network infrastructure.

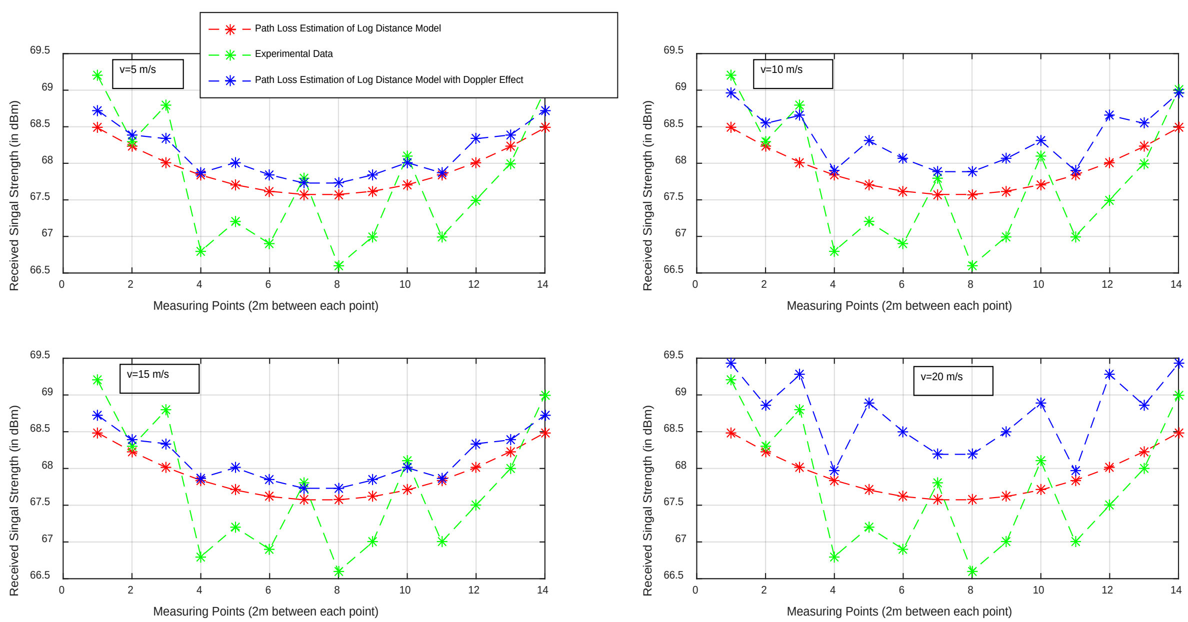

Figure 5. Analysis of Log Distance Propagation Model with Doppler Effect (various mobile speed v=5, 10, 15, 20m/s)

V. Discussion and Conclusion

The basic theoretical background of Doppler Shift Effect on moving object is presented. In this paper, estimation of path loss values for mobile object using free space and log distance models taking into consideration of Doppler Effect with respect to the constant speed is analyzed. The indoor propagation models considering Doppler Effect by using measured data of moving object around the convocation room was investigated. The path loss values which are fading with Doppler Effect and with various motion velocities are also simulated. The experiment presented here provides nice additions to the standard study of the Doppler Effect in a straight-line movement. To avoid signal attenuation with Doppler spread, path loss value should be predicted correctly with the help of empirical data. The main idea is to estimate the Doppler spread by free space and log distance path loss models with respect to the experimental data in indoor environment in which the motion of receiver is along the straight line such as LOS condition.

As the further work, these results should be compared with outdoor propagation model with and without Doppler Effect. The different types of transmitter and receiver should be used. Theoretical and empirical experiments should be conducted with different high speed velocity and with different frequency ranges.

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