Study of propagation path loss for OFDM mobile systems

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Abstract
In recent years, by the rapid growth of mobile communication services and emerging broadband mobile Internet access services; the optimization of the wireless communication system has become critical. In fact, the understanding of wireless channels propagation will lay the foundation for the development of high performance and bandwidth-efficient wireless transmission technology. In wireless communication, path loss is the mean power loss that occurs between the transmitter antenna and receiver antenna. In another word, the performance of wireless communication systems is mainly governed by the wireless channel environment, therefore understanding the characterization of the mobile wireless channel can clarify why OFDM is becoming a common technology and a good choice in broadband mobile system. Depend on the environment for predicting and calculating the path loss, various models have been used by now. Some of these models are empirical and the others are analytical. In this paper, a number of the common models are reviewed and then we propose an extended model that can cover the outdoor and indoor populated environments.

Key words:
Path loss, Radio propagation, Indoor radio propagation, Outdoor radio propagation, Orthogonal Frequency Division Multiplexing (OFDM), Propagation prediction for OFDM

1. Introduction

In wireless communication, the radio propagation investigates the behavior of radio waves when they are transmitted from one point to another point. Radio propagation can be affected by numerous factors which understanding them has several practical benefits. When propagation is considered in outdoor environment, one is primarily interested in three types of areas: urban, suburban, and rural areas. Of course, the presence of trees, buildings, moving cars, and other obstacles are needed to be considered too. The presence of objects in a channel can cause the channel to lose its free space classification. When this happens, various methods of propagation occur, which is classified to four main propagation mechanisms: direct propagation, reflection, diffraction and scattering. Generally speaking, radio waves can usually be affected by reflection, diffraction and scattering whose intensity depends to the environments. Direct propagation is the Line Of Sight (LOS) signals components therefore it can be considered as the free space propagation. The phenomena of reflection and scattering are functions of the wavelength and object dimensions. If the wave length is smaller than the dimension of the object, the phenomena of reflection take places and if the dimensions of the object are smaller than the wavelength the phenomena of scattering happens. Reflection and scattering are the source of multipath in a channel which they can change the signal amplitudes, signal phases and times of arrival signals at the receiver antenna. Some other terms that describe the multipath characteristics of a channel are: delay spread, angle spread and power delay.
The change of signal amplitude over the time and frequency is called fading. Signal fading can be produced by the various signal components (LOS and/or multipath propagation) or it can be caused by shadowing from an obstacle. In the first case it is called multipath fading and in the second case it is called shadow fading. Basically fading categorized into two major kinds which are: Small Scale Fading (SSF) and Large Scale Fading (LSF).
Small scale fading (SSF) happens when there is a rapid change in the signal levels. In a short distance, these changes in the signal level occur while the mobile station is in motion. In this case the interference of the multiple signal paths is the factor that causes the rapid variation in the signal level. On the other hand the large scale fading (LSF) refers to the average path loss and shadowing.
Channel environments can be classified and described as in table 1.

Category	Objects in Channel	LOS / NLOS	Fading
Free space	No	LOS	Flat fading
LOS Multipath Environment	Yes	LOS + NLOS	Flat fading / Frequency selective
LOS Multipath + LOS interference	Yes	LOS + NLOS	Flat fading / Frequency selective
NLOS Multipath	Yes	NLOS	Flat fading / Frequency selective

Table 1: Classification of the channel environments

The radio channel is known by the amount of the Inter Symbol Interference (ISI). The movement of the transmitter, receiver, the presence and the type of the objects and changing the weather conditions can cause the channel varies over the time. All of the above mentioned issues and some other issues are the factors that consider in wireless system design and development. Figure 1 illustrates the LOS, and Multipath channel environment.

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What makes difficult the exact analysis of the wireless channel; is the dynamic environment between the transmitter antenna and receiver antenna. Optimization of the wireless communication systems due to the growth of the broad band mobile communication is getting more and more critical. Propagation models have usually used to predict the received signal strength at a certain distance from the transmitter. Propagation models are very useful for estimating the coverage area of the transmitter that can help radio service provider for planning efficient radio coverage. Moreover Propagation models are useful for predicting signal attenuation or path loss [1].

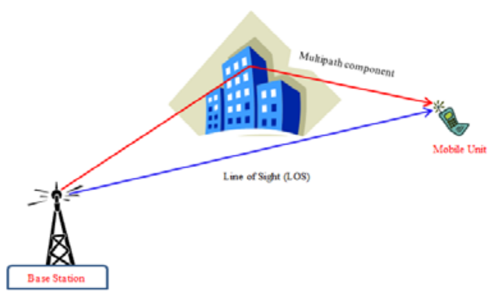


Fig.1 LOS, Multipath channel environment

2. General Path Loss Models

2.1 Free –Space model

This model is an analytical model which the electromagnetic signals that radiated from transmitter antenna, is a function of the inverse square of the distance(i.e. $1/d^2$) . This model is generally good for the satellite communication in where the signals actually travel through the free space. For mobile communication systems which there are additional losses such as terrestrial obstacle, reflections and etc. this model is not an adequate model for precisely predicting the path loss, therefore to construct a more generalized model we need to consider the parameter in actual environments. The Friis equation [2] is the equation that is used for free-space propagation model, this model is applied for predicting the strength of the received signal where there is no obstacle between the transmitter antenna and receiver antenna and the transmitter and receiver antenna are in line-of-sight (LOS). Figure 2 illustrates the free space model.

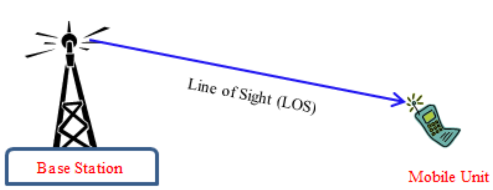


Fig.2 Free space model

The Friis equation is as follows:

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \quad (1)$$

In where P_r is received power, P_t is transmitted power, G_t is transmitted gain, G_r is received gain, λ^2 is wavelength of the radiation, d is distance and L is hardware system loss factor. Equation (1) shows the received power has an exponentially relationship with the distance d, which it means it exponentially decreases by increasing the distance and it increases by increasing the antenna gains.

The free space path loss,$PL_F(d)$, in dB can be stated as:

$$PL_F(d) = 10log\left(\frac{P_t}{P_r}\right) \quad (2)$$

$$PL_F(d) = -10log\left(\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2 L}\right) \quad (3)$$

Since the actual environments has a direct effects on received signal, therefore to construct a more generalized model for path loss we need to consider it, so the Log distance path loss model $PL_{LD}(d)$ is:

$$PL_{LD}(d) = PL_F(d_0) + 10log\left(\frac{d}{d_0}\right)^n \quad (4)$$

$$PL_{LD}(d) = PL_F(d_0) + 10nlog\left(\frac{d}{d_0}\right) \quad (5)$$

In where d_0 is the reference distance and its value depends to the propagation environments, n is called path loss exponent and its value also depends to the propagation environments. (For free space $n = 2$)
Since the surrounding environments depend to the location of the receiver and can vary; therefore every path can have different path loss. To consider such a condition, a model which is called log normal shadowing is used; this model lets the receiver to have different path loss at the same distance from receiver. This model is stated as follows:

$$PL(d) = \overline{PL}(d) + X_\sigma \quad (6)$$

$$PL(d) = PL_F(d_0) + 10log\left(\frac{d}{d_0}\right)^n + X_\sigma \quad (7)$$

Here X_σ is a Gaussian random variable with standard deviation of σ.

2.2 Plane-Earth Model

In this model the path loss is more than the free space. In this model the received signals to the receiver antenna is a combination of the signals that comes from the direct path and indirect path. The direct path is considered as the Line of Sight (LOS) signals and the signals that come from the reflection form objects are considered as No Line of Sight (NLOS). This model is called the Plane-Earth model since it considers the reflection from the ground that is flat, not curved. The equation that is used for this analytical model is:

$$L_p = a\frac{h_r^2 h_t^2}{d^4} \quad (8)$$

Or

$$L_p = 10\log a + 20\log h_t + 20\log h_r - 40\log d \quad (9)$$

In where a is called correction factor and its value depends on the carrier frequency, h_r and h_t are the height of the receiver antenna and transmitter antenna, d is the distance between transmitter antenna and receiver antenna with this assumption that $d \gg h_t$ and $d \gg h_r$.

2.3 Multipath Fading

There are short periods that there is no line of sight signal (NLOS) path between the transmitter antenna and receiver antenna, in this incident, the received signal in the receiver comes from the reflections from the different objects (see figure 3), therefore these reflected received signals have different amplitude, different phase and to some extent different times. These occurrences can cause the received power to the receiver goes up and down. This effect which occurs over a short distances is called fast fading. Since the Rayleigh distribution refers to the variations on the received power in the absence of the existence of the line of sight (LOS) between the transmitter antenna and receiver antenna; the fast fading is called Rayleigh fading too. This is verified both experimentally and theoretically that it is a Rayleigh distributed [3]. The received signal envelope in complex form can be stated as Eq. 10.

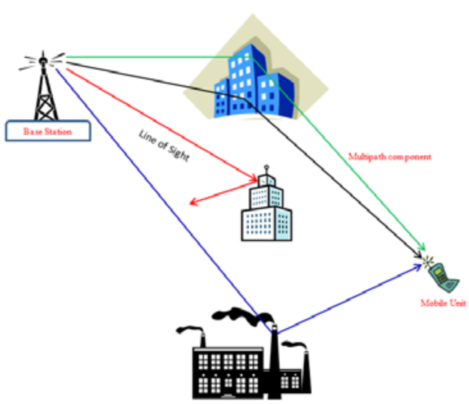


Fig.3 No LOS channel

$$S = \sum_{n=1}^{N} S_n e^{j\theta_n} \quad (10)$$

Here θ_n is the phase and S_n is the amplitude and $S = S_r + jS_i$.

Where the amplitude is:

$$S = \sqrt{S_r^2 + S_i^2} \quad (11)$$

It is necessary to mention that, the term of Fast Fading does not always refer to the movement for the transmitter, receiver or both of them; it only implies that the distance between continuous fades are to some extent small. Undeniably it is obvious that if the transmitter, receiver or both of them are in motion, at that time the chance of occurrence of successive fades will increase.

2.4 Delay spread

In multipath there is different path lengths from transmitter antenna to receiver antenna, therefore different signals from different path hit the receiver antenna at different time. Comparing with symbol period, when the maximum time difference (τ_{MAX}) between the first arriving signal and last one is big enough; the receiver experiences the Inter Symbol Interference (ISI). In time domain, delay spread is directly related to coherence bandwidth W_c in frequency domain. The relation between delay spread and coherence bandwidth is [4]:

$$W_c \approx \frac{1}{\tau_{MAX}} \quad (12)$$

If $W\tau_{MAX} \geq 0.1$ then the channel is considered as frequency selective and if $W\tau_{MAX} < 0.1$ then the channel is considered as frequency flat [5,6]. To show the channel is not flat, let's consider figure 4 with two signal paths and with the equal amplitude A, which one of them hit the receiver antenna with delay.

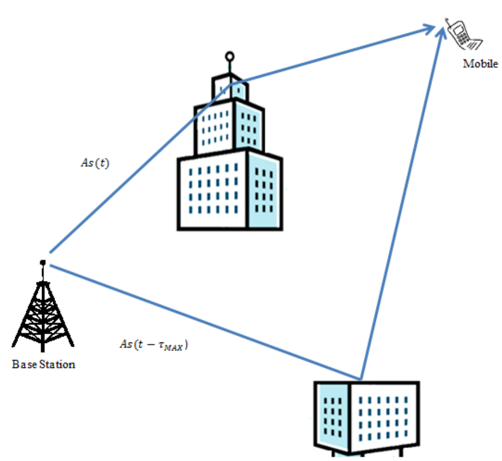


Fig.4 Two multipath components

In this model, the received signal can be written as:

$$r(t) = As(t) + As(t - \tau_{MAX}) \quad (13)$$

Let's take the Fourier transform

$$R(f) = AS(f) + AS(f)e^{-j2\pi f \tau_{MAX}} \quad (14)$$

$$R(f) = AS(f)[1 + e^{-j2\pi f \tau_{MAX}}] = AS(f)H(f) \quad (15)$$

In where the transfers function $H(f)$ and its magnitude $|H(f)|$ can be stated as follows:

$$H(f) = 2e^{-j2\pi f\left(\frac{\tau_{MAX}}{2}\right)} cos\left[2\pi f\left(\frac{\tau_{MAX}}{2}\right)\right] \quad (16)$$

$$|H(f)| = cos\left[2\pi f\left(\frac{\tau_{MAX}}{2}\right)\right] \quad (17)$$

3. Okumura/Hata Model

Okumura/Hata is the most common model that is applied for path loss. Okumura model is the model that has been gained after doing numerous experiments [7]. It is one kind of the models that is used for predicting the path loss in urban area for mobile communication system. Okumura model is:

$$PL_{ok}(d) = PL_F + A_{MU}(f,d) - G_{Rx} - G_{Tx} + G_{AREA} \quad (18)$$

In where PL stands for path loss, G_{Rx} and G_{Tx} are the receiver antenna gain and transmitter antenna gain; these two parameters are only and only the function of the antenna height. $A_{MU}(f,d)$ is the medium attenuation factor at the distance d and frequency f, G_{AREA} is the gain for propagation environment in the desired area.
Gain for the propagation environment (G_{AREA}) such as plain area, urban area, suburban area and mountain area can be covered by Okumura/Hata model. The urban area in Hata model is using the Eq. (19) [8]:

$$PL_{H,U}(d) = 69.55 + 26.16log f_c - 13.82log h_{TX} - C_{RX} + (44.9 - 6.55log h_{TX}) \log d \quad (19)$$

In where f_c is carrier frequency, h_{TX} is the height of transmitter antenna. C_{RX} which is called the correlation coefficient for receiver antenna, is determined by the size of area, the carrier frequency and the height of antenna. The path loss in Hata model for a suburban zone can be obtained from the following equation:

$$PL_{H,SU}(d) = PL_{H,U}(d) - 2\left(log\frac{f_c}{28}\right)^2 - 5.4 \quad (20)$$

Figure 5 shows the path loss in urban zone versus a plain zone for this model.

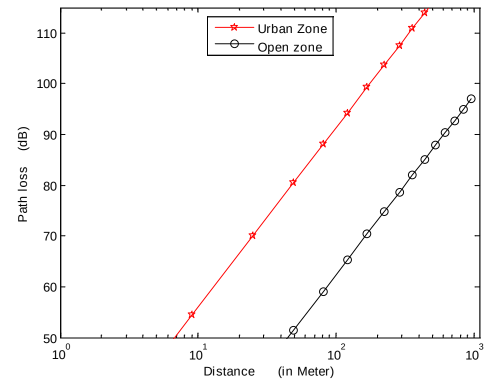


Fig.5 The path loss in urban zone versus open zone

The Fig. 5 implies that due to the obstructions that can be found in urban zone, the path loss is much bigger than the open zone.

4. Indoor path loss

Due to the increasing usage of the Personal Communication Systems (PCS), there is a high demand of interest in characterizing radio propagation inside the buildings. Because of the refractions, reflections and diffraction by the objects inside the malls or buildings; the signals that reaches the receiver comes from different path. Generally speaking, the indoor propagation is influenced by the layout of the building. Path loss between the transmitter and receiver is the amount of average attenuation that the Radio Frequency (RF) experiences. This amount depends to whatever is between transmitter antenna and receiver antenna. This path loss in dB is defined by [11]:

$$PL(dB) = 10log\frac{P_t}{P_r} \quad (21)$$

P_r is received power and P_t is transmitted power.

4.1 Indoors Propagation

Considering the growing of the OFDM mobile communication system, the size of a cell is getting smaller and smaller; i.e. from Macro-cell to the Pico-cell. Therefore the services should include both indoor and outdoor environments.
The differences of indoor mobile channel with outdoor mobile channel can be summarized as follows:

i. The distance covered in indoor environment is considerably smaller
ii. The indoor environment has more variability

iii. Due to the nature of the structures of the buildings, malls and the materials that have been used for constructing them, the indoor propagation inside the malls and building has a more complex multipath structure.

4.2 Building propagation

The propagation of waves inside the malls and buildings has a complex mechanisms which governs by some detailed parameters, these parameters depend to the following criteria: building layouts, structures of the building, type of the walls and windows (which specifies the wave penetration), and propagation inside the building and between the interior walls and roofs.

4.3 Wall Penetration

The amount of path loss during the penetration of the waves inside the buildings depends on:

(i) The wall dielectric coefficient
(ii) The thickness of the wall
(iii) The direction of the wave incident
(iv) The polarization of the waves

There is another loss for the waves that passes through the walls. This loss is called Ohmic loss. The amount of Ohmic loss depends to the type of the material that is used for building the wall and its wetness.

4.4 Window Penetration

The windows of the building are considered as receiving apertures, all the plane waves that hit the windows can penetrates through the windows without any attenuation to the depth of $(\frac{S^2}{4\lambda})$. Figure 6 illustrates the passage of wave through the window. Any diffusion inside the building can happen when the wave is diffracted by the objects and bounced from the interior walls. The other diffraction that can be considered is the diffractions form the windows edges, these diffractions can affect the plane wave that goes through the window.

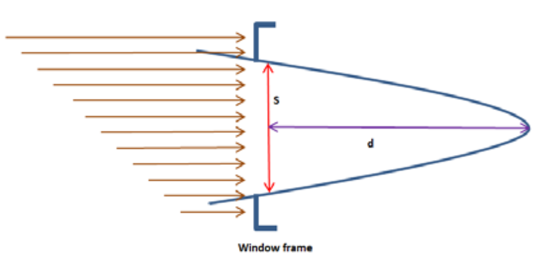


Fig. 6 Passage of wave through the window

4.5 Indoors Propagations

Indoor propagations include floor propagation and interior propagation. Since the floor is usually built with steel grid reinforced, the usual loss can be considered from 10 to 20 dB/F (dB per floor). The interior of the building varies form big open spaces (such as spaces in the malls) to dense spaces (such as crowded offices).

4.6 Indoor model

By increasing the usage of mobile systems inside the malls, buildings, airports and train stations [9], the indoor propagation prediction is getting more and more important for OFDM mobile systems. There are different approaches to model indoor propagation. A good approach can be on the base of combination of empirical propagation model combine with electromagnetic theory such as Uniform Theory of Diffraction (UTD).

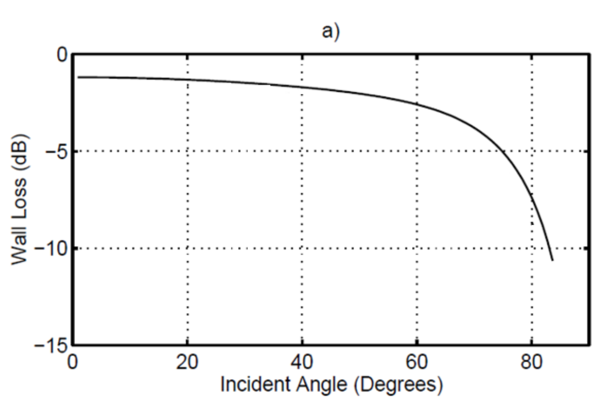
As we have already talked over it, for indoor path loss we need to consider walls and floors. Depends on the type of the walls and floors, each of them has an attenuation factor [10,11]. Wall attenuation is a function of the angle of incident. Wave incident to the wall partially reflects and partially penetrates.

Considering the Snell's law of refraction (Eq. 22), the reflection and transmission between two media depends to the dielectric constant of the media and the incident angle of the wave.

$$\frac{Cos\theta_1}{Cos\theta_2} = \sqrt{\frac{\varepsilon_2}{\varepsilon_1}} \quad (22)$$

In where ε_1, ε_2 are dielectric constant, θ_1, θ_2 are angle of incident and reflation.

Figure 7 illustrates the wall attenuation for two different wall structures [20]. Floor attenuation also depends to floor structure.



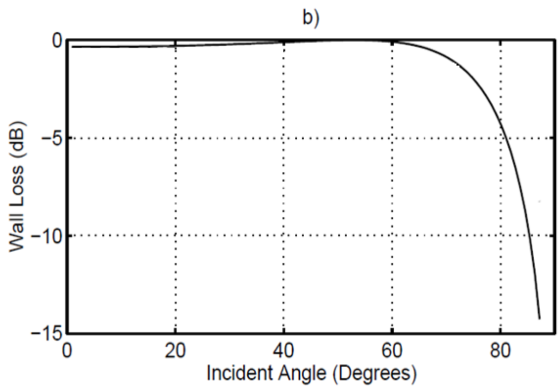


Fig. 7 Wall attenuation for two different wall structures [20]

Table 2 shows the floor attenuation for two different building [21].

Office Building #1		
Location	**FAF (dB)**	**PL (dB)**
Through 1 floor	12.9	7
Through 2 floor	18.7	2.8
Through 3 floor	24.4	1.7
Through 4 floor	27	1.5

Office Building #2		
Location	**FAF (dB)**	**PL (dB)**
Through 1 floor	16.2	2.9
Through 2 floor	27.5	5.4
Through 3 floor	31.6	7.2

Table 2: The average floor attenuation for two different building [21]

On the other hand the distance of the building from the transmitter antenna is an important factor. The distance inside the buildings or malls that the considerable attenuation start to occur; is called Break Point (BP) [12]. This break point depends on the locations, structures of the buildings, and their distance from the transmitter antenna. The distance of break point (d_{BP}) can be calculated by using the size of first Fresnel zone [13]. Therefore the model for indoor path loss can be considered as [10,11]:

$$PL_{BP}(d) = 10\log\left(\frac{d}{d_0}\right)^{n1} U(d_{BP} - d) + 10\left[\log\left(\frac{d_{BP}}{d_0}\right)^{n1} + \log\left(\frac{d_0}{d_{BP}}\right)^{n2}\right] U(d - d_{BP}) + \sum_{p=1}^{P} WAF(p) + \sum_{q=1}^{Q} FAF(q) \quad (23)$$

In where WAF is wall attenuation factor, FAF is floor attenuation factor, P and Q are the number of walls and floors, n_1 and n_2 are path loss component, and $U(d_{BP} - d)$ is a step function, when $d < 0$ the value of step function is 0, and when $d \geq 0$ the value of step function is 1.

When electromagnetic radiation is incident on a wall or a floor in an oblique fashion, less power will be transmitted through the wall than would happen at the normal incidence. In this case, the $WAF(P)$ term changes to $WAF(P)/cos\emptyset_p$ and the $FAF(q)$ term changes to $FAF(p)/cos\emptyset_q$ [14]. In where $\emptyset_p$ and $\emptyset_q$ are the angles of incidence of the signal on the walls and floors. Note that inside the malls and building; the received signals to the mobile unit are the summation of the infinite number of the scatters. It is also worth to mention that the indoor propagation like outdoor propagation can be subject to LOS or NLOS. The only difference is that, the LOS environment follows Rician distribution while NLOS environment follows Rayleigh distribution.

5. Proposed algorithm

The objective of channel characterization is its evaluation at any point within the region, and at any time, in terms of its effect on the performance of the wireless communications system.

In order a channel model can be reliable for designing and system research for OFDM based systems; it should consider the following criteria:

i) It should be as close as it possible to the physical propagation phenomena for our desired environment
ii) It should be as simple as it can. (For simulation)
iii) It should be a comprehensive model for different case scenarios (not for a particular condition)

Considering the [15-18], the IEEE is using the Eq. (24) to model the path loss, this model considers for $d > d_0$:

$$PL_{IEEE}(d) = PL_F(d_0) + 10\gamma\log_{10}\left(\frac{d}{d_0}\right) + C_f + C_{RX} \quad (24)$$

In where d_0 is 100 meters, C_{RX} which is related to the receiver antenna is called correlation coefficient for receiver antenna, C_f, and γ are defined as:

$$C_f = 6\log_{10}\left(\frac{f_c}{2000}\right) \quad (25)$$

$$\gamma = a - bH_{TX} - \frac{c}{H_{TX}} \quad (26)$$

Here H_{TX} is the height of transmitter antenna. Depends to the model the parameters a, b, and c can get different values. The following values are the range of values that considered in IEEE for different path loss models, depends to the models these values are: $3.6 \leq a \leq 4.6$, $0.007 \leq b \leq 0.005$, and $12.6 \leq c \leq 20$

For this model, d_0 which is consider as the initial or reference distance causes a discontinuity at $d = 100$ meters, to fix this problem a different reference distance which is called d_{00} should be defined [16, 17], to find d_{00}, in the equation (3) let's consider $G_r = G_t = 1$ and L=1, therefore the equation 3 can be written as:

$$PL_F(d) = -10log\left(\frac{1\times1\times\lambda^2}{(4\pi)^2 d^2\times1}\right) = 10log\left(\frac{\lambda}{4\pi d}\right)^{-2} \quad (27)$$

$$PL_F(d) = 20log\left(\frac{4\pi d}{\lambda}\right) \quad (28)$$

By putting d_{00} for d in Eq. (24) and Eq. (28) and then set it equal to each other we have:

$$PL_F(d_{00}) + 10\gamma\log_{10}\left(\frac{d_{00}}{d_0}\right) + C_f + C_{RX} = 20log\left(\frac{4\pi d_{00}}{\lambda}\right) \quad (29)$$

On the other hand for finding $PL_F(d_{00})$ we put d= d_{00} in Eq. (28), so we have:

$$PL_F(d_{00}) = 20log\left(\frac{4\pi d_{00}}{\lambda}\right) \quad (30)$$

Let's put this value for $PL_F(d_{00})$ in Eq. (29), therefore:

$$20log\left(\frac{4\pi d_{00}}{\lambda}\right) + 10\gamma\log_{10}\left(\frac{d_{00}}{d_0}\right) + C_f + C_{RX} = 20log\left(\frac{4\pi d_{00}}{\lambda}\right) \quad (31)$$

Solving the Eq. (31) for d_{00} gives:

$$-10\gamma\log_{10}\left(\frac{d_{00}}{d_0}\right) = C_f + C_{RX} \quad (32)$$

$$\log_{10}\left(\frac{d_{00}}{d_0}\right) = -\frac{C_f + C_{RX}}{10\gamma} \quad (33)$$

$$d_{00} = d_0 10^{-\frac{C_f + C_{RX}}{10\gamma}} \quad (34)$$

So the new equations are:

$$PL(d)_{|d>d_{00}} = 20\log_{10}\left(\frac{4\pi d_{00}}{\lambda}\right) + 10\gamma\log_{10}\left(\frac{d}{d_0}\right) + C_f + C_{RX} \quad (35)$$

$$PL(d)_{|d\leq d_{00}} = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right) \quad (36)$$

By recalling Eq. (23) and considering the effect of the angles of incidence of the signal on the walls and floors [9, 14, 19] we get:

$$PL_{BP}(d) = 10\log\left(\frac{d}{d_0}\right)^{n1} U(d_{BP} - d) + 10\left[\log\left(\frac{d_{BP}}{d_0}\right)^{n1} + \log\left(\frac{d_0}{d_{BP}}\right)^{n2} U(d - d_{BP})\right] + \sum_{p=1}^{P}\left(\frac{WAF(p)}{cos\emptyset_p}\right) + \sum_{q=1}^{Q}\left(\frac{FAF(q)}{cos\emptyset_q}\right) \quad (37)$$

By contributing the indoor path loss Eq. (37) with Eq. (35) the total path loss $PL_T(d)$ will be the sum of outdoor plus indoor path loss.

$$PL_T(d) = PL(d)_{|d_{00}} + PL_{BP}(d) \quad (38)$$

If $d < d_{BP}$ therefore $PL_{BP}(d) = 0$ then the total path loss is

$$PL_T(d) = PL(d)_{|d_{00}} \quad (39)$$

Since the surrounding objects, medium and different electromagnetic fields from different sources in desired area have an attenuation impact on received signal to the receiver, we add L_{OA} (in term of dB) to Eq. (38) which is for the impact of these factors. This attenuation impact factor varies for different environments and can only be found by taking a large number of in site measurements.

$$PL_T(d) = PL(d)_{|d_{00}} + PL_{BP}(d) + L_{OA} \quad (40)$$

Conclusion

This paper has presented a short overview of propagation channel characteristic and modeling. We also talk about different types of models for wireless channel systems. Distance dimension is the one that causes path loss. Shadowing and multipath fading is the one that causes delay spread. We also talked about the indoor environments and finally we proposed an equation for modeling outdoor and indoor environment. Indoor environment, due to the presence of different type of obstacles such as walls, furniture and etc. causes the radio wave experience multiple reflections; therefore the waves that hit the receiver antenna come from different paths which lead to fading phenomena. In practical wireless communication system, the indoor propagation is more complex than the outdoor propagation. Objects that are in indoor environments can strictly affect the propagation characteristics of any wireless radio channel. The performance of indoor OFDM wireless systems can be limited by the propagation characteristics. Therefore it is very significant to know how the surrounding objects can impact the propagation. In another word, indoor propagation is complicated; each indoor environment can be different from the other one, for getting the coefficients for any equation that is offered for any model, a large number of measurements are required. These measurements can obtain statistical results that lead to the realistic values for different environments and can provide good estimates for both large-scale and small scale indoor environments. With more measurements, it is likely that the models can be refined and accurately predict the path loss in many more different environments. In another word, any models have its own limitation for prediction the path loss such as accuracy. Their accuracy comparing to the field measurements varies, that's why in industry by taking the field measurements and using the results they do the custom calculation for the model. It is necessary to mention, despite the huge efforts by now, much work remains in understanding and predicting the exact characteristics of mobile communications channels.

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