RAY TRACING ALGORITHM FOR SPECIFIC INDOOR PROPAGATION MODELING

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Abstract

A large number of indoor wireless channel models has been described in the literature. Some of them are based on geometrical optics while other models are based on geometric probabilistic theory and field measurements. The use of field measurements, although necessary to validate analytical methods, is expensive and difficult to implement for a large number of environments. On the other hand, analytical models provide an alternative and efficient way to predict the mean received power strength for a given wireless environment. In this way, a computer-based tool can be designed and used to allow for an efficient design of a propagation model. This tool can be used to optimize the specific propagation model by allowing the network designer to modify a variety of parameters, example the distance, and type of material used in the environment.

Keywords: *specific indoor propagation, geometrical optics, received power, different materials.*

I. INTRODUCTION

Upon mentioning wireless technology, the first thing that comes to mind is its capability in minimizing the need for cabling and wired connections. The transmitter will launch the rays and propagate through the air to the receiver in many ways. By realizing it or not, this condition contributes a little towards the decrease in received signal strength since the signal transmitted is propagated through many obstacles. Ray tracing propagation technique is the best method to be used to trace the best ray to be transmitted to the receiver in order to obtain the best coverage prediction for the best signal power received [1]. Ray tracing technique has been used widely to predict radio propagation in the outdoor and also indoor environment. It is used to identify all possible ray paths between transmitter and receiver in wireless network. This technique has been enhanced in order to account for the propagation of the electromagnetic waves through wireless environment, including the absorption and reflection phenomenon at obstacles.

Ray tracing produces deterministic channel models that operate by processing user-defined environments. As cell sizes reduce, the need to accurately plan base stations locations will become critical due to a need to minimize infrastructure costs. Site-specific propagation model are based on electromagnetic-wave propagation theory to characterize indoor propagation. Site-specific model does not depend on extensive measurement, but it needs a greater detail of indoor environment in order to obtain an accurate prediction of signal propagation inside the building.

The main weakness in wireless network is the lower quality of signal received to the client/customer. Since the data or signal is transmitted through the air, there is a high probability for the ray signal to propagate and emerge with any obstacles that exist in the environment. When the transmitter launches the ray, it will be reflected, refracted or diffracted to any kind of surface such as concrete wall, wooden surface, floor, glass and many more. That process indeed will decrease the signal strength received by the client at the receiver. Let's take one environmental condition, for instance, a single storey house, there are several types of obstacles that exist such as edge, internal structure shape of the building, and the most important thing that needs to be considered is the type of material used for that building. The different types of material used such as wood, glass and concrete can result in the variation of power performance in the receiver. Relative permittivity, ε is the dielectric constant of the material used in the building. In other words, the ratio of the amount of energy stored in that material is relative to the energy stored in the vacuum. Different material will have different relative permittivity value, ε and this consequently leads to power loss performance.

II. RADIO WAVE PROPAGATION MECHANISM

The mechanism which governs radio propagation is complex and it can be recognized by the three basic propagation mechanisms of reflection, diffraction and scattering. Reflection happens when the propagating electromagnetic wave hits an obstruction with very large dimensions compared to the wavelength of the radio wave itself. Reflection may produce reflected wave that will interfere at the receiver. For diffraction, it occurs when the radio waves that travel between transmitter and receiver hits the edge or sharp corner of any obstacle or corner of the building. Besides, diffraction can also be called as 'shadowing' phenomenon because the diffracted field still can be reached by the receiver even if it is shadowed by the obstacles [2]. Scattering can cause the energy from the transmitter to be radiated in many different directions. Scattering happens when a radio channel contains object with dimension of the order of wavelength or less than the propagating wave.

Free space loss (FSL) is the loss exists in the signal strength that occurs when electromagnetic wave travels from transmitter to the receiver in the line of sight path in free space. In this condition, there is not any obstacle that exist, that might cause the signal to be reflected, refracted or diffracted which can contribute to the attention.

FSL is used in many areas to predict the signal strength in radio system. It is requirement basic parameters that need to be considered in radio frequency (RF) calculations. It can be used as a first approximation for a number of areas where there are numerous obstacles. In free space loss propagation, a signal is spreading out from a transmitter and then it will move away from the source out in the form of a sphere. Consequently, the surface area of the sphere is increased and thus causing the intensity of the signal strength to be decreased [3].

III. INDOOR RADIO WAVE PROPAGATION

It is important to characterize the indoor radio propagation channel in order to obtain satisfactory performance of a wireless communication system. Indoor radio channel do not suffer from the environmental effect of snow, rain, hail, clouds or temperature inversion as outdoor does. In any indoor setting, due to variations such as building size, shape and structure, layout of rooms and most importantly the type of construction material, electromagnetic wave propagation inside a building is a more complex multipath structure than that of terrestrial radio channel. The layout of the building and material used for the building construction strongly influenced the propagation of wave in the building.

Indoor propagation phenomenon is the same as outdoor propagation phenomenon, which will have those three propagation of reflection, refraction and diffraction. Dealing with indoor wireless coverage is necessary to add the capability of diffraction. The diffraction of the building's corner is significant compared to the path loss of a signal through an entire building. The signal travelling through entire building needs to go through the large external walls which have layers of bricks and aluminums vapor barrier. These materials will attenuate the signal much more than an internal wall. Diffraction is caused when a radio signal hits the corner of the building. This causes the wave to split into a cone of waves.

There are three main regions of a diffracted signal. The first region is in the illuminated signal. This region is not blocked by the corner/wall and the received signal follows the path loss of free space with a negligible amount of power added by the diffracted wave. The second region is the shadow region which is the transition region between illuminated and shadow region. The received power comes from the diffracted signal and also some from the incident plane wave. The third zone is when the receiver is below the shadow boundary (shadow region). Diffracted rays will not have the same strength as the original ray because it is being split into a finite number of other rays [4].

IV. BRUTE-FORCE RAY TRACING TECHNIQUE

Ray-tracing technique has been widely used to predict the radio propagation in different environments. It is a technique that works based on Geometrical Optics (GO) that can easily be used as a prediction in estimating the levels of high-frequency electromagnetic fields. In GO, energy can be considered to be radiated through small tubes, called as rays. These rays are normal to the surface of equal signal power. They lie along the direction of propagation and travel in a straight line. After that, they provide relative constant refractive index of the medium. Signal propagation can be modeled through ray propagation [5]. There are two types of ray-tracing methods, one is called the image method and the other one called as ''brute force'' ray tracing method.

Brute-Force Ray Tracing methods consider a bundle of transmitted rays that may or may not be reached by the receiver. The number of rays considered and the distance from the transmitter to the receiver location determines the available spatial resolution and also the accuracy of the model.

A ray is launched for each such direction, if a ray hits an object, then a reflecting ray and refracting ray will be generated. If a ray hits a wedge, then a bundle of diffracting rays is generated. The key part of the ray-tracing method is the generation and description of the rays. In 2D, all rays or ray tubes are ray sectors. At the source, rays are launched along different directions with the same sector angle, phi, in a plane. The angle of phi (π) is chosen based on the accuracy required and also the computation time. If the angle is small, it will provide high accuracy and will take a lot of time to compute. This method accounts for all possible propagation paths. The transmitter and receiver are modeled as point at discrete location in three-dimensional space. All the possible angle of departure and arrival at the transmitter and receiver respectively are considered to determine all possible rays that may leave the transmitter and arrive at receiver [6].

V. MODELING APPROACH

In a wireless communications system, the signal arriving at the receiver consists of several multipath components, each of which is the result of the interaction of the transmitted waves with the surrounding environment. Reflected and transmitted rays are evaluated through the use of geometrical optics while diffracted rays are calculated using the geometrical theory of diffraction. According to the objects encountered by the propagating ray, the received power can be calculated by [7]

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2} \left[\pi_j R_j\right]^2 \left[\pi_k T_k\right]^2 \left[h\sqrt{\frac{2(d_1+d_2)}{\lambda(d_1+d_2)}}\right] \quad (1)$$

where Pt represents the transmitter power, d is the total length of the ray path, λ is the wavelength, Gt and Gr are the transmitting and the receiving antennas gains in the direction of the ray, R_j is the reflection coefficient for the j_{th} reflector, T_k is the wall transmission coefficient for the k^{th} transmission and last part is the diffraction coefficient where h is the height of the obstacle, d_1 is the distance between transmitter to the obstacle, and d_2 is the distance between the receiver and the obstacle.

Reflection coefficient part consists of parallel and perpendicular as calculated by [7]

$$R\perp(\theta) = \frac{\cos(\theta) - \sqrt{\varepsilon - \sin^2(\theta)}}{\cos(\theta) + \sqrt{\varepsilon - \sin^2(\theta)}} \quad (2)$$

$$Rll(\theta) = \frac{\varepsilon\cos(\theta) - \sqrt{\varepsilon - \sin^2(\theta)}}{\varepsilon\cos(\theta) + \sqrt{\varepsilon - \sin^2(\theta)}} \quad (3)$$

Equation (2) for the perpendicular reflection while for equation (3) shows the parallel reflection. Parallel reflection coefficient is for incident radiation in which the E field is oriented parallel to the plane of incidence, but not the plane of reflecting surface. Perpendicular reflection coefficient is for E field polarization perpendicular to the plane of incidence. With vertical building wall reflections, horizontal polarization is parallel to the plane of incidence, while vertical polarization is perpendicular to the plane of incidence [8]. The theta (θ) in the equation means the how much degrees the rays hits and bend towards the surface. The θ value being used in this model is from 0˚ – 90˚. Relative permittivity, ε is the dielectric constant of the material used in the building. In other words, the ratio amount of energy stored in that material is relative to the energy stored in the vacuum. Although this equation represents the instantaneous received power, in the propagation model all rays are stored as complex field vectors which are then multiplied by the complex reflection, transmission and diffraction coefficients.

The other parameters that need to be taken into account are power received and power transmit of antenna, transmitter and receiver gain, frequency of 2.4GHz, and also the 100m distance separated between transmitter and receiver. As stated before, wave propagation is affected by the layout and also the type of material used for that building construction. Different type of material used will have different relative permittivity, ε value, thus will contribute to the different power level performance. For indoor environment, the materials to be encountered are wood, floor and concrete. The ε value for all these three materials are 2.07, 5.0 and 5.4 respectively [9]. The simulation and power received calculation can be done based on these three materials. The combination of these materials will give the overall power received. The higher the value of ε will cause the power received to be decreased.

VI. RESULT

The simulation made is based on three major materials that commonly exist in indoor environment especially in the housing area. They are wood, floor and concrete. Figure 1shows the results of the propagation coverage for the free space loss or line of sight environment.

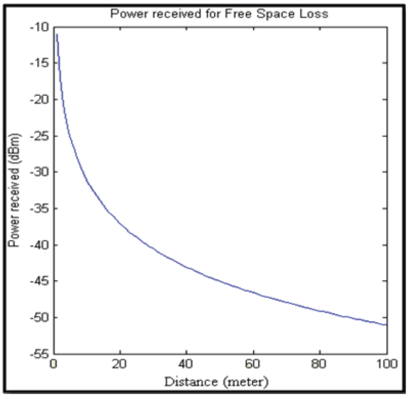

Figure 1: Power Received for Free Space Loss

For free space propagation, the signal traveling from transmitter to the receiver will experience certain loss due to the obstacle that exists in the free space model. As the distance travel until reached 100 meter, the signals gradually lose. Since the free space loss propagate through the air in line-of-sight condition, the signal is interfered by the air intensity and in small ration, the signal will experience a certain loss [10]. The signal starts to drop at -31.05dBm or in watt, 7.85x10^{-7} W, in the range distance of 10 meter and above.

For this model, the simulation is divided into two parts. The first part will just consider the transmission and reflection coefficient whereas for the second part the diffraction coefficient will be included. Therefore it will have multirays result. These two different conditions are analyzed in order to make a comparison of the power performance with the existence and non-existence of diffraction coefficient.

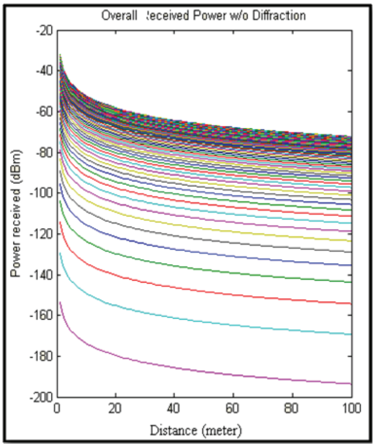

Figure 2: Power Received for Reflection and Transmission Propagation

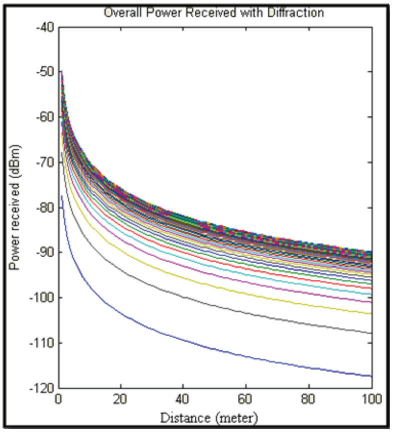

Figure 3: Power Received for Reflection, Transmission and Diffraction Propagation

Figure 2, the signal propagates only include reflection and transmission propagation. It shows that the power starts dropping starting from distance of 10 meter. The power might drop in greater value because of the combination of the material which also the variation parameter of relative permittivity of each material included.

Figure 3 shows the result which includes diffraction propagation. The graph clearly shows that in the event where diffraction propagation is included, the received power for the combination materials will decreased in greater ratio. At a 10 meter distance, the signal is already considered as noise. Diffraction propagation causes a bundle of rays to be transmitted to the receiver until one time the receiver is not able to receive the ray/signal anymore and thus causing the signal to attenuate more than usual propagation.

Table 1: Material Comparison

MATERIAL	POWER RECEIVED (dBm)									
	REFLECTION, TRANSMISSION					REFLECTION, TRANSMISSION, DIFFRACTION				
	Distance (m)					Distance (m)				
	1	5	10	50	100	1	5	10	50	100
Wood	-17.39	-31.37	-37.39	-51.37	-57.39	-35.02	-49.00	-55.02	-69.00	-75.02
Concrete	-19.33	-33.31	-39.33	-53.31	-59.33	-37.16	-51.14	-57.16	-71.14	-77.16
Floor	-18.62	-32.60	-38.62	-52.60	-58.62	-36.13	-50.11	-56.13	-70.11	-76.13
Overall	-32.31	-46.29	-52.31	-66.29	-72.31	-49.86	-63.84	-69.86	-83.84	-89.86

Analysis shows that the strength of power received decreases when the distance is extended. As the distance travels more, the loss seems to be increased because the signal or rays propagate through obstacles and also surface of materials exist between the propagation areas. From the comparison, it can be noted that the received power performance is much better for the propagation of reflection and transmission only, compared to the received power performance that includes diffraction propagation. With diffraction propagation included, the power received generally can be considered as noise from the distance of 10 meter and above. Compared to the propagation without diffraction mechanism, the average power receive be considered as noise start from 50 meter and above.

In addition, power loss also is influenced by the value of relative permittivity value of each material. Concrete give the lowest received power performance, followed by floor and the best result is given by propagation through wood material. Thus, from the result obtained, it is proven that the existence of diffraction propagation mechanism in radio wave propagation contributes more power loss reached by the receiver. Besides, different types of construction material used by a particular building will give different value of power received [11]. Thus, it is relevant to say that the power received performance is affected by the type of material used for a building.

VII. CONCLUSION

For an indoor setting, it is necessary to consider several obstacles, edges that may lead to the phenomenon of reflection and diffraction mainly in propagating the wireless signal [12]. When this happens, it can reduce or weaken the strength of the signal received to the receiver. Diffraction propagation leads to much power loss at the receiver. Besides, the received power value is also affected by the type of material used in building construction, since each different material will have different dielectric constant value [13]. Thus, this analysis is able to predict the coverage for indoor scenarios in terms of maximum distance and obstacles around the environment, by using ray-tracing technique. Furthermore, this analysis also proves that the power received performance will significantly decrease when diffraction mechanism is present in the electromagnetic wave propagation.

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REFERENCES

[1] M.S Zakaria, V.R Gannapathy, M.Muhammad, N.M Salleh, M.K Suaidi, M.S Johal, M.Z.A Abdul Aziz, M.R Ahmad, IEEE Journal P aper, ''Ray Tracing Propagation Prediction for Wireless Mesh Network (WMNs)'', 2007.

[2] W.K. Tam and V.N. Tran, IEEE Journal Paper, ''Propagation Modelling for Indoor Wireless Communication'', 1995.

[3] ''Free Space Path Loss and Formula or Equation'',http://www.radio-electronics.com/info/propagation/path-loss/free-space-formula-equation.php.

[4] Tapan K.Sarkar, Zhong Ji, Kyungjung Kim, Abdellatif Medouri, Magdalena Salazar-Palma, IEEE Journal Paper, ''A Survey of Various Propagation Models for Mobile Communication'', 2002.

[5] Harry R.Anderson, M.Sc, P.Eng, EDX Engineering Inc, IEEE Journal Paper, ''A Ray-Tracing Propagation Model for Digital Broadcast Systems in Urban Areas'', 2003.

[6] Joseph B. Keller, IEEE Journal Paper "Geometrical Theory of Diffraction'', 2000.

[7] Rappaport," Wireless Communications Principles and Practice",Prentice Hall, 2002.

[8] J. Sanchez, C. Castro, L. Villasenor, IEEE Journal Paper, ''Mean Receiver Power Prediction for Indoor 802.11 WLANS using Ray-Tracing Technique'', 2007.

[9] Professor David Jenn, IEEE Journal Paper ,''Geometrical Optics and The Geometrical Theory of Diffraction'', 2002.

[10] Mohd Sharim Zakarian, IEEE Journal Paper ''Ray-Tracing Propagation Modelling'' 2007.

[11] Fernando Aguado Agelet, Ana Fomella, Hernanda Robenos, IEEE Journal Paper ,''Efficient Ray-Tracing. Acceleration Technique for Radio Propagation Modelling'', 2000.

[12] Zhaozhi Gu, Ze Jiang, IEEE Journal Paper, ''A Modified UTD Model for Indoor Propagation Prediction'', 2005.

[13] Larbi Talbi, Gillas Y.Delisle, John Ahern, IEEE Journal Paper ''Characterization of Wireless Indoor Communication'', 2002.