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Break Point Distance Path Loss Model for Indoor Wireless Communications with Equivalent Floor

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***Abstract*—This paper presents break point distance path loss models with equivalence floor for 5G millimeter wave (mmWave). The proposed model consists of dual slope path losses which are in distances before and after breakpoint together with additional wall attenuation loss. In case of non-line-of-sight (NLOS), shadowing caused by obstacles will appear with equivalent floor and raise ground reflection caused by furniture and exiting multi-wall attenuation loss. Comparison between two types of buildings show that the equivalence floor and total wall attenuation provide a characteristic of the buildings which influence on wave propagation as well.**

Keywords— equivalent floor, millimeter wave, path loss

I. Introduction

Indoor wireless communication 5G challenges daily life to new normal especially in work from home, healthcare, IOT, building and industrial automations. Therefore indoor propagation path loss models for millimeter wave or high band frequencies (6-100 GHz) are important things for connecting the communication. Indoor path loss model has been an active area of research in recent years. Various measurement campaigns have been executed to determine propagation characteristics of electromagnetic waves in office [1-3]. These measurements resulted in propagation models which support the coverage prediction of wireless networks operating in these environments. For office [1], mmWave measurement and channel are presented and discussed. NLOS Path loss model with break point distance are proposed for office and shopping mall [2]. However these models are empirical models that include the wall attenuations. Our break point model predicts LOS path loss in office and parking at only a frequency of 1800 MHz [3] and Factory at a frequency of 2400 MHz [4]. The effects of path loss for large conference room are investigated at frequencies of 2.4/5 GHz [5]. However the above models do not classify the difference type of the building in term of path loss parameters. This propose new equivalence ground floor which occurs from the furniture and walls which are a building characteristic. Although the equivalent ground floor is proposed in [6], but it is used only for outdoor communication. The proposed model is used both LOS and NLOS in frequency ranges of 6-100 GHz.

Section II presents path loss models Section III presents path loss data. Section IV presents proposed model. Finally, section V presents conclusion.

II. Path Loss Models

The empirical path loss model for indoor environment was used to predict path loss by using map of buildings. Propagation path routes are mainly classified into line of sight (LOS) and non-line of sight (NLOS).

A. LOS

The path loss of LOS generally consists of 3 terms including 2 arbitrary constants.

$$PL_{FI}(d) = 32.4 + 20\log f_G + 10 n_1 \log d_{3D} \quad (1)$$

where d_{3D} is the mobile device 3D Euclidean distance from transmitter (m) and f_G is frequency in GHz. The path loss exponent n_1 is less than 2 in case of indoor communication. Because of the first Frenel zone region, PL has two distinct regions. The first region is (1) in distance before break point (d_{BP}), while the second one is in (2).

$$PL_{after\ BP}(d) = PL(d_{BP}) + 10 n_2 log_{10}\left(\frac{d}{d_{BP}}\right) \quad (2)$$

where $PL(d_{BP})$ is the path loss as the brake point distance, n_2 is path loss exponent after d_{BP}.

$$PL(d_{bp}) = 20 log_{10}\left(\frac{\lambda^2}{8\pi(H-h_2)/h_2}\right) \quad (3)$$

and

$$d_{BP} = 4[H - (h_2 - h_0)](h_2 - h_0)/\lambda \quad (4)$$

where H is the ceiling height (m) and h_2 is the receiving height (m). λ is wavelength (m) and h_0 is the equivalence floor height (m) as shown in Fig. 1. Note that path loss before the break point is the same as (1) and $n_2 = 2.5$ [3].

B. NLOS

Because of walls between the transmitter and the receiver, propagation loss as a function of distance and wall attenuations can be calculated.

$$PL_1(d) = PL_{FI}(d) + \sum_{i=1}^{k} WA_i$$

$$PL_2(d) = PL(d_{BP}) + 10 n_2 log_{10}\left(\frac{d}{d_{BP}}\right) + \sum_{i=1}^{k} WA_i \quad (5)$$

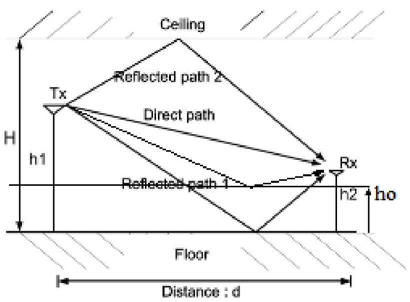

Fig. 1. Three ray model with equivalence floor h_0.

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where WA_i is wall attenuation of i^{th} wall. Because of influence of mmWave, the d_{BP} of LOS is very far from the transmitter and out of the coverage area. The break point model for NLOS is proposed [2].

$$PL_1(d) = PL(d_0) + 10n_1\left(1 + b_1\frac{(f_c - f_0)}{f_0}\right)log_{10}(d) \quad ; \; 1 < d < d_{BP}$$
$$PL_2(d) = PL(d_0) + 10n_1\left(1 + b_1\frac{(f_c - f_0)}{f_0}\right)log_{10}(d_{BP}) + 10n_2\left(1 + b_1\frac{(f_c - f_0)}{f_0}\right)log_{10}\left(\frac{(d)}{d_{BP}}\right) \quad ; \; d > d_{BP} \qquad (6)$$

where in case of office, d is the mobile distance from transmitter (m), f_G is the frequency (6-100 GHz), n_1 =2.51, b_1=0.12, f_0 = 24.1 GHz, n_2=4.25, b_2=0.04, and d_{BP} = 7.2 m. In case of shopping mall, n_1 =2.43, b_1=0.01, f_0 = 39.5 GHz, n_2=8.26, b_2=0.39, and d_{BP} = 110 m. Fig. 2 shows d_{BP} over frequencies 6-100 GHz of office and shopping mall. It found that d_{BP} are very large values without h_0 (LOS), while the d_{BP} with h_0 (NLOS) are small values and in the building area.

III. COMPARISON OF MODELS

In order to obtain h_0 and analyze the proposed model, the empirical model (dual slope) 5GCM office and shopping mall [2] are used. It found that the proposed models without wall attenuation (WA) are large difference from 5GCM especially for the distance after break point as shown in Fig. 3. The differences are static WA as shown in Fig. 4. The WA of the office is the large values comparing with the shopping for the distance after break point. This is because there are many hard walls in the office, while the shopping mall has almost soft partitions and tables. The equivalence floor heights, h_0 are 0.68m and 1.7m for office and shopping mall buildings respectively. These values depend on furniture and table including other obstructions.

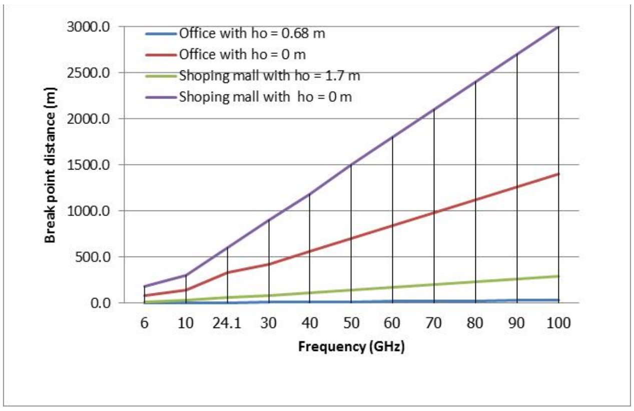

Fig. 2. d_{BP} and h_0 over frequencies 6-100 GHz.

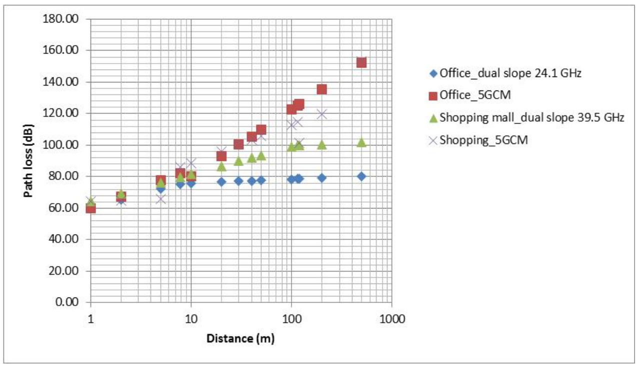

Fig. 3. NLOS dual slope model without WA.

TABLE I. COMPARISON OF INDOOR PATH LOSS MODELS [2]

Name	Path loss models	d_{BP} (m)	h_o(m)
5GCM InH Indoor office LOS	PL= 32.4+20$log(f)$+17$lod(d_{3D})$	295	0
5GCM InH Indoor office NLOS Single slope	PL = 17.3+24.9log(f) +38.3$log(d_{3D})$	-	0
5GCM InH Indoor office NLOS Dual slope	$PL_1(d) = PL(d_0) + 10n_1\left(1 + b_1\frac{(f_c-f_0)}{f_0}\right)log_{10}(d)$,$1 < d < d_{BP}$ $PL_2(d) = PL(d_0) + 10n_1\left(1 + b_1\frac{(f_c-f_0)}{f_0}\right)log_{10}(d_{BP})$ $+10n_2\left(1 + b_1\frac{(f_c-f_0)}{f_0}\right)log_{10}\left(\frac{(d)}{d_{BP}}\right)$, $d > d_{BP}$	7.8	0
5GCM InH Shopping mall LOS	PL = 32.4+20$log(f)$+17.3$log(d_{3D})$	506	0
5GCM InH Shopping mall NLOS Single slope	PL = 18.09+22.4log(f) +32.1$log(d_{3D})$	-	0
5GCM InH Shopping mall NLOS Dual slope	$PL_1(d) = PL(d_0) + 10n_1\left(1 + b_1\frac{(f_c-f_0)}{f_0}\right)log_{10}(d)$,$1 < d < d_{BP}$ $PL_2(d) = PL(d_0) + 10n_1\left(1 + b_1\frac{(f_c-f_0)}{f_0}\right)log_{10}(d_{BP})$ $+10n_2\left(1 + b_1\frac{(f_c-f_0)}{f_0}\right)log_{10}\left(\frac{(d)}{d_{BP}}\right)$, $d > d_{BP}$	110	0
Proposed NLOS Indoor office Dual slope	$PL_1(d) = PL_{FI}(d) + \sum_{i=1}^{k} WA_i$ $PL_2(d) = PL(d_{BP}) + 10n_2 log_{10}\left(\frac{d}{d_{BP}}\right) + \sum_{i=1}^{k} WA_i$ where $PL_{FI}(d) = 32.4 + 20\log f_G + 17.3\log d_{3D}$	7.7	0.68
Proposed NLOS Shopping mall Dual slope	$PL_1(d) = PL_{FI}(d) + \sum_{i=1}^{k} WA_i$ $PL_2(d) = PL(d_{BP}) + 10n_2 log_{10}\left(\frac{d}{d_{BP}}\right) + \sum_{i=1}^{k} WA_i$ where $PL_{FI}(d) = 32.4 + 20\log f_G + 17.3\log d_{3D}$	116	1.7

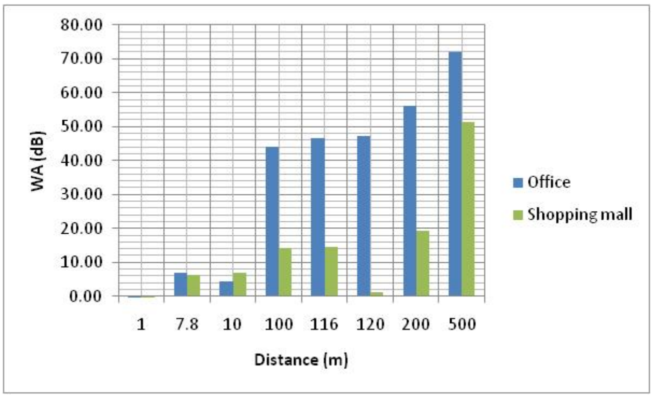

Fig. 4. Static WA for proposed model.

IV. Conclusion

The researchers propose break point distance path loss models with equivalence floor for 5G millimeter wave (mmWave). The proposed model consists of free space loss and multi-wall attenuation loss. The free space loss consists of dual slope path losses which are in distances before and after breakpoint, while the second term is multi-wall attenuation loss including furniture. The shadowing caused by obstacles will appear with equivalent floor and raise ground reflection caused by furniture and exiting multi-wall attenuation loss. We used data from the empirical model 5GCM office and shopping mall for modeling. The result found that the equivalence floor and total wall attenuation provide a characteristic of the buildings which influence on wave propagation as well. The model can predicts both LOS and NLOS with a single formula.

V. Future Work

The WA must be classified and separated especially in case of distance after break point because the path loss will change very fast. The equivalence floor h_0 is a characteristic of the building for communication planning.

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