Simulation and Characterization of WLAN Indoor Channels at 60 GHz

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***Abstract*—This paper simulates and characterizes the 60 GHz band wireless channels for typical indoor. The Radio wave Propagation Simulator (RPS) is used to simulate the model characteristics. Simulations performed on the three rooms at Telematics Laboratory of Bandung Institute of Technology (ITB) those are Residency room, Computer Laboratory (size 1013 cm x 589.5 cm x 289.8 cm), and Undergraduate/Final Project room (size 900 cm x 1013 cm x 289.8 cm). The rooms were built with concrete walls in the left and right side with a thickness 14 cm, 0.5 cm for ceiling thickness, and the combination of walls and glasses at the front and backside of the rooms. The model characteristics were measured based on three classifications of distance between transmitter and receiver, i.e., CM1 (0 - 4 m), CM2 (4 - 10 m), and CM3 (> 10 m). We then obtain the model characteristics in terms of RDS value at 0.26 to 7.74 ns for the receivers at Residency room, 1.02 to 8.76 ns at Computer Lab and 2.07 to 15.65 ns at Final Project room. The system performances shown the coherence bandwidth is 1.2778 to 76.9492 MHz for frequency correlation above 90% and therefore the maximum bit rate that can be achieved with 1.25 spectrum efficiency is 60 Mbps.**

***Keywords*—60 GHz, RPS, rms delay spread, coherence bandwidth.**

I. Introduction

Wireless network is no longer an exclusive technology. The utilization of this wireless network can served as an alternative for computer network communication system whether in large scale or small scale that can be choose by someone who preferred practical non-wire-communication. This service can be found for private area (WPAN-Wireless Personal Area Network), local area (WLAN-Wireless Local Area Network), and public area (WMAN-Wireless Metropolitan Area Network), i.e., office buildings, school or campus, supermarket and residential home.

In wireless network realization, problems will occur that consist of data rates, coverage area, network size and power consumption, however, this can be fixed using WPAN (Bluetooth) or WLAN (Wi-Fi) which has different data rates. WPAN has lower data rate characteristics compared to WLAN, therefore WLAN application is more developed. Bandwidth which being used at present is 2.4 GHz (ISM-Industrial, Scientific and Medical), unfortunately, this bandwidth is jam-packed with many applications that runs in short and long distance transmission, while the demand on higher data rates are increasing. Therefore, frequency around 60 GHz (millimeter waveband), which is unlicensed frequency, is becoming more interesting. The new technologies are designed to develop the gigabyte wireless connection although there are many challenges ahead [5][7].

The most important issue in this frequency applications are the channel modeling and characteristics. Reference [2] shows measure and characterization of wireless channel using S-V Model. However, this analytical research is not sufficient enough, not to mention the frequency integration of 2.4/5 GHz to 60 GHz [7].

Concerned with the model that being used and to respond with the future challenges, this research are based on the wireless indoor channel characterization at 60 GHz through computer simulation so that we can identify the channel behavior.

To limit the scope of this work, we focus our research on the delay spread value including mean excess and rms delay to obtain the main wireless indoor parameters. The rest of the paper is organized as follows. Section 2 reviews the wireless channel, propagation and channel modeling. Section 3 describes the simulation procedure and the model. Section 4 shows simulation results in terms of the main parameters. We draw conclusions in Section 5.

II. Channel Modeling

In wireless communication systems, the propagation characteristics are having influence on the system design, both for outdoor or indoor. For 60 GHz, characteristics indoor system have significant differences (very unique) compared to outdoor system, are mainly caused by obstacles, i.e., walls, floor, ceilings and many objects which cause the radio signals will experience the reflection, diffraction and scattering effect. In addition to the basic mechanisms of propagation that associated with the fading and multipath, there is also attenuation due to absorption of oxygen in the amount of 10-15 dB/km which makes the frequency is not suitable for long distance (> 2 km). Therefore, applications for 60 GHz dedicated to indoor, so that characteristic of indoor communication systems should be considered especially the delay spread as multipath effects.

To predict the delay spread, modeling based on deterministic propagation model that is ray tracing model with a computational model (optical ray technique). Propagation described by the wave propagation of different signals from transmitter to receiver antenna with respect to reflection, diffraction, and scattering objects in buildings and other obstructions. For computational process, is based on the general theory of diffraction, that is the Universal Geometrical Theory of Diffraction (UTD). In this computational process, is required much time, especially in determining where the relevant point between transmitter and receiver. However, the accuracy level is higher because of obstructions or objects are taken into account during the propagation. Figure 1 shows a computing propagation model with the ray tracing algorithm.

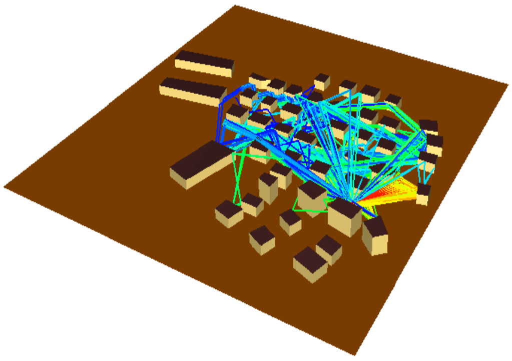
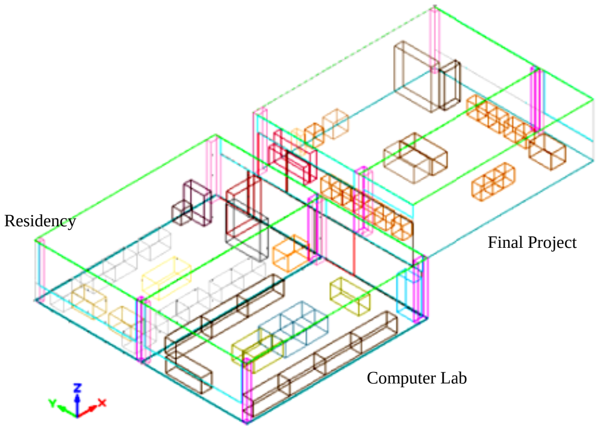


Figure 1. *Ray tracing*.

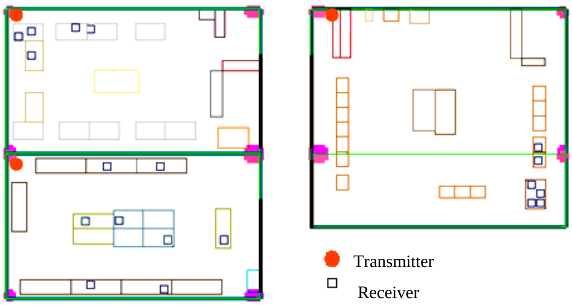
III. SIMULATION MODEL

The simulation will be performed using RPS software to obtain delay spread value within simulation areas wherein the 3D database of that area will be required. In this work we must considering the space area, shape, size and position of every objects within the area, included the material of all objects. The simulation area in Telematics Lab at ITB, that is S2/S3 Residency Room, Computer Lab, and Final Project Room.

Based on the database mentioned earlier, we create the 3D area image using IDE and arrange the system configuration both on transmitter and receiver. Transmitter antenna using horn antenna with 20 dB gain positioned at the corner of the area with 2.5 m height and transmit power of 10 dBm. At the receiver we employ dipole antenna with different heights and positioned in entire of area correspond to the data that will be taken which based on the distance between transmitter and receiver. We divide the distance into three groups, i.e., CM1 (0 – 4 m), CM2 (4 – 10 m) and CM3 (more than 10 m). In Residency Room we had 5 receivers for CM1 while for CM2 and CM3 we put 6 and 8 receiver, respectively. For the Computer Lab and Final Project Room, the receivers for CM1, CM2, and CM3 are (6, 8, 4) and (2, 8, 6), respectively. After configuring the systems we start the simulation using 3D ray tracing algorithm with total two reflection and penetration each and one diffraction. Fig. 2 shows the simulation area and system configuration.



(a)



(b)

Figure 2. Simulation area : (a) 3D *database* and (b) system configuration.

We evaluate the system performance (based on the simulation results of area modeling) in terms of BER vs Eb/No which correspond to multipath fading condition that is flat and frequency selective fading. We use BPSK modulation with Rayleigh channel fading model and spectrum efficiency of 1.25 where bitrate as an analysis parameter.

IV. SIMULATION RESULTS

In this section, we analyze the data and the simulation results. Our target is the model characteristics and system performance (BER vs Eb/No) based on bit rate capacity (R_b).

For CM1 condition at Residence Room, we found that the RDS value for each receiver with minimum of 0.26 ns at Rx1 and maximum of 1.85 ns at Rx2. RDS value based on range (on average at CM1) is 1.18 ns. The color differences show the different experienced delay. In Fig. 3(a), the blue color indicates that the delay period is quite small because the distance between transmitter and receiver not to remote and also have not too many reflector objects. Ray propagation in 2D and 3D can be seen in Fig. 3(b) and 3(c).

Fig. 4 shows CM2 condition. The results indicate that if we increase the distance and the receiver for different position, it will also increase the reflection resulting in longer time for ray to arrive at the receiver. This can be shown from the color variation (Fig. 4(a)) that indicates larger delay compared to that in CM1. The minimum RDS for this condition is 1.94 ns at Rx2 and maximum 7.74 ns at Rx5. Averaging RDS is 4.05 ns.

Simulation results for CM3 can be seen in Fig.5. The minimum RDS is 1.10 ns at Rx1 and maximum 2.11 ns at Rx2 with 1.52 ns on average. The RDS value is quite small although the distance between transmitter and receiver are quite remote. This is caused by the fact that the longer distance the smaller the signal power is therefore the ability to reflect also reduced. Table 1 shown the complete results of this first category.

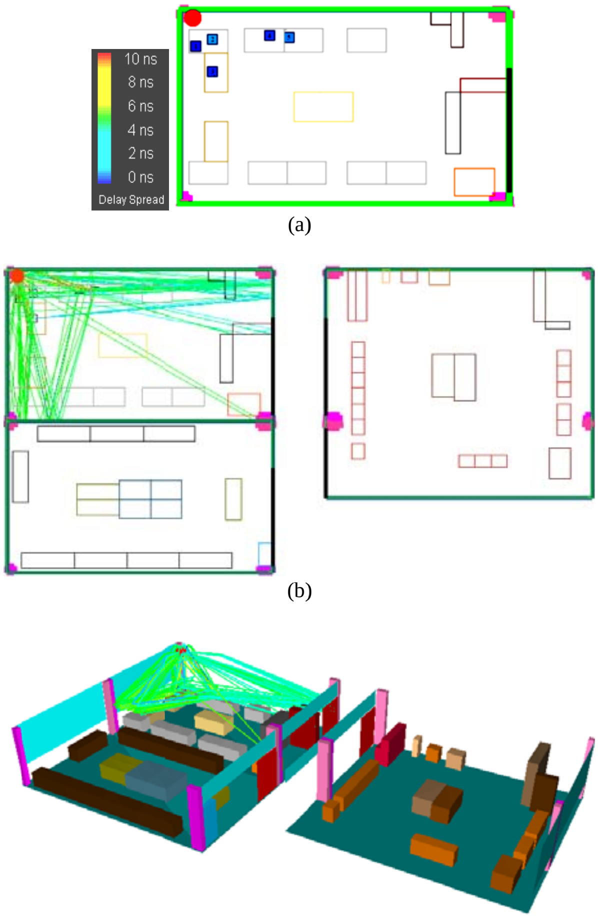
The measurements based on the receiver distance and position at identical area, for CM1 at Residence Room, position of Rx1 near with the transmitter and having 1.85 ns RDS while Rx4 at the farthest position having a 1.79 ns RDS. The minimum RDS at Rx3 with 1.03 ns and maximum at Rx4 with 1.85 ns.

We can see that at the Computer Lab, the min RDS is 0.65ns at Rx2 and maximum at Rx3 with 3.23ns. It indicates that although the receiver is located in equal position and distance, we still obtain different RDS value. This shown that distance and position is not a suitable parameters to obtain the maximum and minimum of RDS value. The RDS value for this category can be seen at Table 2.

We also perform the simulation at 2.4 GHz frequency. The most significant difference is in terms of coverage and ability to mitigate the reflection, diffraction and scattering. Fig. 6 and Table 3 shown the differences of the two frequencies.

For system performance we considered only the maximum and minimum RDS value at Residency Room. From Fig. 7 with flat condition, the BER performance of 10^{-3} is feasible up to 15 Mbps bitrate and move toward selective condition after 60 Mbps (BER > 10^{-3}). Theoritically this can be obtain through equation (1) for frequency correlation function above 90%.

At RDS of 0.26 ns, the coherence bandwidth with 0.9 frequency correlation is 76.92 MHz. The channel bandwidth must be smaller than coherence bandwidth in order to achieve flat fading condition. We choose 76 MHz so that the maximum bitrate is 60 MBps under flat fading. However this maximum condition still influenced with another factors so that the maximum bitrate value still vary.



(a)

(b)

(c)

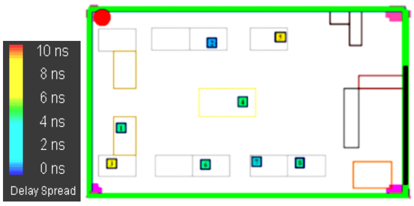
Figure 3. Simulation results for CM1 : (a) *delay*, (b) 2D, and (c) 3D.

TABLE I. RMS DELAY SPREAD AT 60 GHZ.

Condition	Rx Position	Residency RMS (ns)	Residency average RMS
CM1	1	0.26	1.18
	2	1.85	
	3	1.04	
	4	1.14	
	5	1.59	
CM2	1	3.27	4.05
	2	1.94	
	3	7.51	
	4	3.46	
	5	7.74	
	6	3.28	
	7	2.07	
	8	3.13	
CM3	1	1.1	1.52
	2	2.11	
	3	1.23	
	4	1.58	
	5	1.22	
	6	1.85	

Condition	Rx Position	Computer Lab. RMS (ns)	Computer Lab. average RMS
CM1	1	1.43	3.39
	2	1.02	
	3	4.21	
	4	4.57	
	5	3.86	
	6	5.25	
CM2	1	1.12	4.01
	2	3.75	
	3	4.12	
	4	8.76	
	5	1.97	
	6	6.54	
	7	2.04	
	8	3.75	
CM3	1	2.76	2.90
	2	3.45	
	3	3.28	
	4	2.10	

Condition	Rx Position	Final Project RMS (ns)	Final Project average RMS
CM1	1	4.04	6.17
	2	8.30	
CM2	1	7.57	7.31
	2	6.90	
	3	2.07	
	4	3.45	
	5	9.08	
	6	15.65	
	7	9.75	
	8	3.94	
CM3	1	5.41	4.01
	2	3.68	
	3	4.26	
	4	4.45	
	5	3.03	
	6	3.26	



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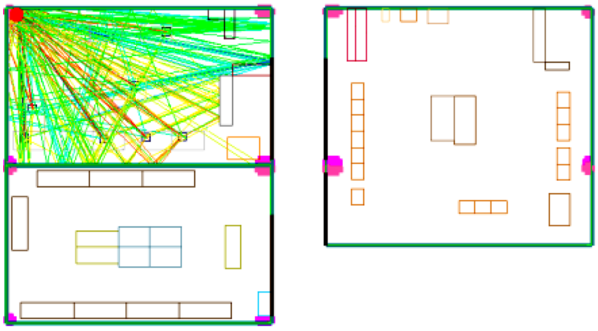
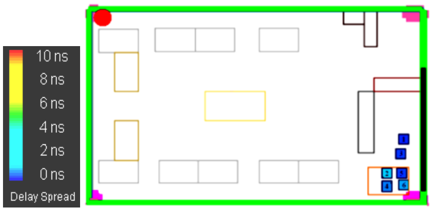
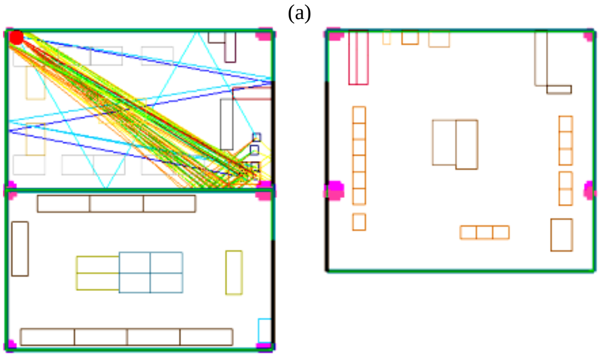


(b)

Figure 4. Simulation results for CM2 : (a) *delay* and (b) 2D.



(a)



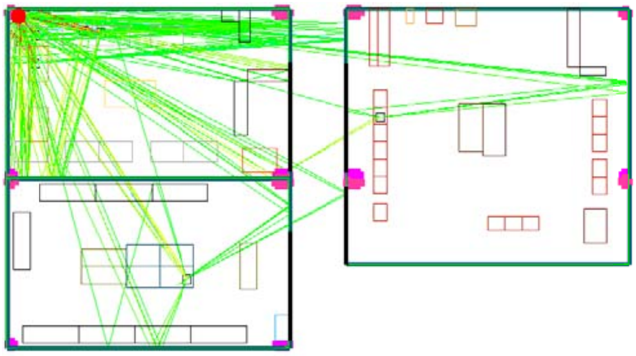
(b)

Figure 5. Simulation results for CM3 : (a) *delay* and (b) 2D.

TABLE II. RMS DELAY SPREAD AT IDENTICAL POSITION AND DISTANCE OF RECEIVER.

Condition	Rx Position	Residency		Computer Lab.	
		RMS (ns)	Average RMS	RMS (ns)	Average RMS
CM1	1	1.85	1,41	1.52	2,15
	2	1.04		0.65	
	3	1.03		3.23	
	4	1.79		3.19	
CM2	5	2.94	5,06	2.95	3,47
	6	7.47		3.45	
	7	11.1		3.83	
	8	8.37		6.75	
	9	2.91		3.86	
	10	3.24		1.57	
	11	2.56		1.69	
	12	2.97		2.91	
	13	4.04		4.22	
CM3	14	1.06	1,43	3.39	2,96
	15	1.58		2.69	
	16	1.22		3.04	
	17	1.85		2.74	

(a)



(b)

Figure 6. Comparison for 60 GHz and 2,4 GHz : (a) *ray* at 2.4 GHz and (b) *ray* at 60 GHz.

TABLE III. RMS DELAY SPREAD COMPARISON FOR 60 GHZ AND 2.4 GHZ.

Room	Condition	Rx Position	60 GHz		2.4 GHz	
			RMS (ns)	Average RMS	RMS (ns)	Average RMS
Residency	CM1	1	0.26	0.87	0.55	3.71
		2	1.86		2.18	
		3	1.05		2.09	
		4	1.24		1.95	
		5	1.70		2.10	
Computer	CM2	6	0.00		3.15	
Final Project		1	0.00		13.98	

With 1.85 ns RDS and same bitrate, the near-selective condition achieved at 10 Mbps whereas theoritically at 8 Mbps. This simulation result approaching the theoretical results however is not too noticeable at this condition since we do not perform the simulation for 8 Mbps bitrate. The max bitrate that can be achieved at min RDS is larger than maximum RDS and applied at all simulation results. The simulation results can be compared with theoretical estimation as shown in Table 4, while the compared results between 2.4 GHz and 60 GHz frequency can be seen in Table 5.

$$B_c = \frac{1}{50\sigma_s} \quad (1)$$

From this work we can proves that the simulation results correspond to the estimation results and we can identify the correlation between RDS, coherence bandwidth and bit rate. With the greater RDS value, the coherence bandwidth will be increasingly narrow therefore the achieveable maximum bitrate will be smaller.

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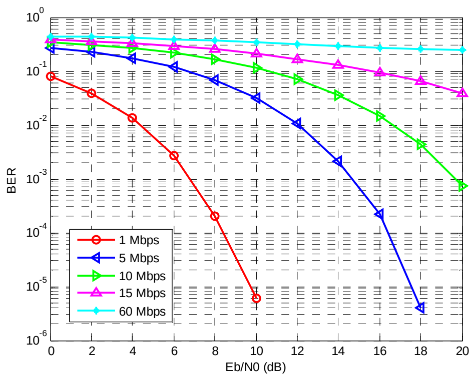
TABLE IV. COHERENCE BANDWIDTH AND BITRATE OBTAINED FROM MINIMUM AND MAXIMUM DELAY SPREAD.

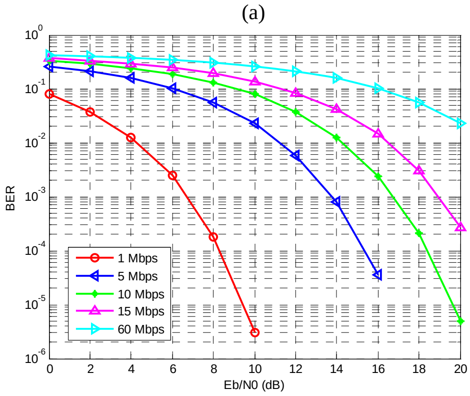
Room	Condition	RMS (ns)	Bc (MHz)	Rb (Mbps)
Residency	CM1	1.18	16.94915	12
	CM2	4.05	4.93827	3
	CM3	1.52	13.15789	10
Computer	CM1	3.39	5.89971	4
	CM2	4.01	4.98753	3
	CM3	2.90	6.89655	4
Final Project Room	CM1	6.17	3.24149	2
	CM2	7.31	2.73598	1
	CM3	4.01	4.98753	3

TABLE V. COHERENCE BANDWIDTH AND BITRATE AT 2.4 GHZ.

Room	Condition	RMS (ns)	Bc (MHz)	Rb (Mbps)
2.4 GHz	Min.	0.55	36.36364	28
	Max.	13.98	1.43062	1
	Area	3.71	5.39084	4
60 GHz	Min.	0.26	76.92308	60
	Max.	1.86	10.75269	8
	Area	0.87	22.98851	17



(a)



(b)

Figure 7. Performance for CM1 with RDS : (a) minimum 0.26 ns and (b) maximum 1.85 ns.

V. CONCLUSION AND FUTURE WORK

Based on simulation results and analysis at three simulation area we can conclude that the indoor channel characteristics are influenced by the objects and the object materials inside the area itself. The wavelength will affecting the reflection, if the frequency higher therefore the reflection effect will be larger. The model characteristics for 60 GHz, maximum RDS value achieved at 15.65 ns in Final Project room while minimum value achieved at 0.26 ns in Residency room. Using frequency correlation function above 90%, the coherence bandwidth is 1.2778 – 76.9492 MHz therefore the maximum bitrate that can be achieved with 1.25 spectrum efficiency is 60 Mbps.

This contribution is limited to an experimental ray-tracing simulation for indoor 60 GHz transmission. The measurement is required to validate the simulated channel model. Our future work will be focused to validate the model by using experimental measurement.

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