Analysis on the Effects of Materials on Propagation Path in an Indoor Office Environment at 60 GHz

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Abstract. Recently, 60 GHz have been logged as a virtuous choice for high data rate indoor communications. This paper presents a millimeter-wave propagation analysis at 60 GHz and measurements in an indoor office environment of a multi-storied building. The main factors for multipath propagation in millimeter waves are delay spread, path loss, and received power. Being an indoor environment, building materials and frequency sensitivity materials (permittivity, conductivity, roughness) plays a significant role in propagation analysis. The model is compared with the International Telecommunication Union's recommendations (ITU), including material attenuation. 20 dBi horn antenna as transmitter and 20 dBi omnidirectional antenna as the receiver, an office environment is modeled in Wireless Insite, and the effects are studied.

Keywords: millimeter-wave, 60 GHz, Indoor propagation, path loss, Wireless Insite.

1. Introduction
The applications used in indoor environments, 2.4 GHz and 5 GHz frequencies, were essential for buildings [1]. For millimeter-wave communication, particularly when high frequencies are used, the propagation characteristics will have substantial effects because of even small changes in the radio path’s environment [2]. Mm-Wave's proportion characteristic, with free-space proportion & losses, has bounded the benefit of using the mm-Wave in communication applications [3-4]. Radio propagation in an indoor space is mostly influenced by the type and layout of the building, materials used for construction, and other electronic equipment is used in the vicinity[5]. The materials used in the indoor environment have substantial impacts on wave propagation, which is defined in terms of the function of the wave frequency [6]. The major impact on the indoor environment's propagation[7] paths is diffraction, reflection, and the most important is the scattering of building materials. The global organization (ITU) recommendations have stated many points relative[8] to material properties. Dielectric constant or relative permittivity is found to be almost constant concerning frequency. At the same time, the conductivity varies concerning variation in frequency [9].

In indoor environments, for both Line-Of-Sight (LOS) and Non-Line-Of-Sight (NLOS), typically measured path loss exponents (PLEs) were found as follow: First, for LOS, in a laboratory is 1.7, in corridors is 1.3 [10], and in an office is 2.2. Second, for NLOS in typical office environments, greater PLEs were recorded, ranging from 3.0 to 3.8 [10]. Average RMS delay spreads, being an important
parameter in indoor propagation, was 12.3 ns in LOS environments and 14.6 ns in NLOS environments at 60 GHz [11]. The propagation effects in the indoor environment at millimeter-wave frequencies[12] are important to industry and researchers due to its wide scope of use[13].

This paper presents simulations and modeling of the channel at 60 GHz for two different indoor scenarios. Scenario 1 uses a horn antenna for transmitter placed at 2.9 m, and scenario 2 uses the same antenna placed at 1.5 m height. A receiver, an omnidirectional antenna, is kept at 0.9 m height for both scenarios[15]. Also, the work concentrated on a single floor building environment considering internal layered drywalls, external walls made of concrete, windows made of glass, doors, and desks made of wood. All material parameters are adopted from the ITU recommendation for 60 GHz.

2. Indoor Environment and Simulations
The paper focuses on radio propagation analysis of two indoor scenarios, considering a typical office building at 60 GHz. The office room selected for analysis is of dimension 15 m x 6 m x 3 m with common office partitions like concrete walls, layered drywall, glass windows, wood doors, wood desks, wood main conference table, two small sofas made of cotton, and a big sofa made of leather.

The evaluation uses five different locations for receivers inside the office. The study also incorporated an XY grid for all office points to know each point's received power. Figure 1 and 2 shows the 2D and 3D view of the office plan with receivers and transmitter location. The floor plan is designed by assigning all the properties of the materials used for constructing walls, doors, floors, and windows. The simulation is carried out using wireless InSite software. The transmitter Tx1 is located in the same room at 2.9 m above the floor for scenario-1 and 1.5 m above aground for scenario-2.

Similarly, a grid of receivers is distributed within the main area room, with 143 receivers points with a length of a 0.5 m gap between each receiver point. A total of five separate receivers is placed, each one in a different location. The effective bandwidth selected is 100 MHz for our case study.

Figure 1: 2D plan of a small office environment
Figure 2: Placement of Transmitter and Receivers Antenna in the office

Table 1 shows the antenna properties for transmitters and receivers that are used in this work. Table 2 shows the properties of buildings materials such as thickness, permittivity, and conductivity in this work concerning a recommendation from ITU for 60 GHz.

**Table 1**: Properties of Transmitter-Antenna and Receiver-Antenna

| Antenna parameters       | Transmitter Antenna | Receiver Antenna |
|--------------------------|---------------------|------------------|
| Antenna type             | Horn                | Omnidirectional |
| Gain (dBi)               | 15                  | -                |
| Input Power (dBm)        | 0                   | -                |
| Waveform                 | Sinusoid            | Sinusoid         |
| Temperature (K)          | 293                 | 293              |
| Polarization             | V                   | V                |
| Received Threshold (dBm)| -250                | -250             |

**Table 2**: Characteristics of the building material: Thickness, Permittivity, and conductivity [4]

| Materials          | Thickness | Permittivity | Conductivity |
|--------------------|-----------|--------------|--------------|
| Concrete[4]        | 0.30[4]   | 5.31[4]      | 0.896[4]     |
| Wood[4]            | 0.045[4]  | 1.99[4]      | 0.378[4]     |
| Glass[4]           | 0.003[4]  | 6.27[4]      | 0.567[4]     |
| Brick[4]           | 0.28[4]   | 3.75[4]      | 0.038[4]     |
| Ceiling Board[4]   | 0.009[4]  | 3.66[4]      | 0.058[4]     |
| Drywall[4]         | 0.009[4]  | 2.94[4]      | 0.210[4]     |
| Floor Board[4]     | 0.022[4]  | 1.5[4]       | 1.113[4]     |
3. Results and Discussions

a) Scenario-1 (Transmitter at 2.9 m above the floor level)

Propagation paths are studied for scenario 1, and here, the highest power is considered to be selected to show how different building materials impact radio propagation. During the study, it is observed that the penetration through brick walls decreases with an increase in the wall thickness at some points. This study also showed that the concrete walls would prevent the signal from penetration, whereas the signal with the highest power was penetrating through glass and drywall with no loss in the signal power. Figure 3 shows the structure materials' effect on the propagation paths for both LOS and NLOS conditions from the transmitter (2.9 m height) to different receiver points[14].

Figure 4 shows the performance of delay spread based on different Transmitter-to-Receiver separation distances. The delay spread indicates the average excess delay produced by the channel. As reflections are stronger, delay spread increases[15]. We can compare the effect of leather and cotton sofas in one hand and free space in another hand on propagation paths. There are variations in values during the distance between 1m and 4m, the peak ones related to sofa' effects. Figure 5 shows the direct correlation between the path loss and the Tx-to-Rx Separation Distance. When the receiver is near the transmitter, the path loss is low, and the path gain is high considering the room's furniture. Figure 6 depicts the received power for varied Tx-to-Rx separation distances.

Figure 3: Scenario 1 - Propagation paths from the transmitter (2.9 height) to different received points

Figure 4: Scenario 1 - Shows the Delay Spread for different Distances of Tx-Rx
Figure 5(a): Scenario 1 - Path Loss

Figure 5(b): Scenario 1: Path loss and Path gain for Scenario 1

Figure 6: Scenario 1 - Received power.
Figure 7 shows the propagation paths of 60GHz waves inside the office reflecting and diffracting through the walls. The strong paths seen in the diagram penetrated the wooden doors, reinforcing the material effect for LOS and NLOS situations.

![Figure 7. Scenario 1 - Received Power for Rx5](image)

b) **Scenario 2 (transmitter at 1.5 m from the floor)**

In scenario 2, the horn antenna transmitter has the same configuration as scenario 1 but is placed at a different height. Figure 8 shows the propagation paths from the transmitter (2.9 m height) to the different receiver points above the conference table. Figure 9 shows the performance of delay spread against Tx-Rx distance for scenario 2.

In Figure 10, the received power of scenario 2 is better than scenario-1, especially the points which are nearer to the transmitter. But other points which are far from the transmitter have low received power than scenario 1. The propagation path illustrated in Figure 11 shows how the paths are weak at the receiver end. It also shows the existence of few strong paths that penetrate the wood doors.

![Figure 8: Scenario 2 - Strong propagation paths for the transmitter to receivers placed on the table](image)
Figure 9: Scenario 2 - Delay spread versus Tx-to-Rx separation distance.

Figure 10: Scenario 2 - Received power in XY Grid conference room

Figure 11: Scenario 2 - Illustration of Propagation paths for receiver No.5
4. Conclusions
Using EM Simulations, the propagation analysis of mmWaves at 60 GHz for indoor office environments has been interrogated. Lagged spread, path loss & obtained power is dependent on the type of building materials, the height of the antenna (transmitter and receiver) during the propagation. The investigation showed better-received power when the transmitter height of 1.5m from the ground—starting with lagged spread, path loss & obtained power. The values for both delays spread and received power decreased by increasing the distance for LOS and NLOS scenarios. The signal propagation characteristics and their penetration level directly impact materials' properties: permittivity, conductivity, and thickness. Finally, it was found many points for penetration level. First, a measly effect on penetration level for glasses and woods. Second, this effect increased with walls made of drywall, and in the end, it obtained the highest effect with a wall made of concrete due to its impact on preventing the incoming signals. These presented results can add significant knowledge in real building design and mmWave bands' performance in typical small building structures.

References
[1]. G C. Na, J. K. Chaen, & T. S. Rapaport, “Quantified traffic reports and IEEE 802.11 b public WLAN hotspots for 3 separate applications,” IEEE Transactions on Wireless Communications, vol. 5, no. 11, 2006.
[2]. Recommendation ITU-R P.1238-7
[3]. V. W. Wong, R. Schober, D. W. K. Ng, and L. C. Wang, “Key technologies for 5G wireless systems,” Cambridge university press, 2017.
[4]. A. Tharek and J. McGeehan, "Propagation and bit error rate measurements within buildings in the millimeter-wave band about 60 GHz," in European Conference on Electrotechnics, Conference Proceedings on Area Communication, June 1988.
[5]. M. won Jung, J. Kim, and Y.-K. Yoon, “Measurements of path loss in MM-wave for indoor environments,” in Asia Pacific Microwave Conference, Dec. 2009.
[6]. "Wireless InSite, reference manuals, model 2.6.3, romcom including., 315 s. Allen st., suite 416 state college, pa 16801. Nov 2012., January. 2009."
[7]. International Telecommunication Union, "Impact of construction materials & systems on the spread of radio waves over 100 MHz," recommendation itu-r p.2040-1, pp. 22–23, July 2015
[8]. Sreetedi, A. G., Rao, T. R., & Susila, M. (2019). Device-to-Device Radio Link Analysis at 2.4, 3.4, 5.2, 28, and 60 GHz in Indoor Communication Environments, Frequenz, 73(3-4), 131-141.
[9]. Kavita, Sravani, and Bhuvaneswari Balachander. "Drainage Monitoring System Using IoT (DMS)." Indian Journal of Public Health Research & Development 8, no. 4 (2017).
[10]. Seenu Anna Vee EEE: 2.ÖZTÜRK, Yunus Emre, and Zührem Ergün. "The Effect of Business Performance on Market Versatility in Health Institutions."
[11]. Njau, Florence Gathoni, Datche E. Owuor, and Mr. Jacob Juma Oyoo. "Effect of Project Team Management on Implementation of County Government Health Funded Projects In Mombasa County."
[12]. T Alex Stanley Raja, R Senthil Kumar, A. Nandha Kumar, K V Santhosh Kumar, LPG Leakage Detection and Autorefilling Using Arduino, Vol.8, Issue-2S, pp.85, December-2018.
[13]. Suresh Kumar Natrajlan, Parth Deshpande, Pranil Gole, Poonam Bhosale LPG Gas Detector and Prevention, International Journal Of Current Research, Vol.9, Issue-10, pp.60141, oct-2017.
[14]. Rane, Atharv S. "Smart LPG Gas Cylinder Monitoring System using Internet of Things."
[15]. Rohit, Bhavani, and J. Rengamani. "Household Purposes in a Single Touch via Bluetooth Using Smartphones." Indonesian Journal of Electrical Engineering and Computer Science 9, no. 2 (2018):351-353.