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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 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 recommendations of International Telecommunication Union (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.

I. INTRODUCTION

The applications that use in indoor environments, 2.4 GHz and 5 GHz frequencies were essential have been used inside 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 environment of the radio path [2]. The propagation characteristics of mm-Wave, including the free-space propagation and penetration losses have bounded the benefit of using the mm-Wave in communication applications [3]. Radio propagation in an indoor environment is mostly influenced by the type and layout of the building, materials used for construction, and other electronic equipment is used in the vicinity. The materials used in the indoor environment has substantial impacts on wave propagation, which is defined in terms of the function of the wave frequency [6]. The major impact on the propagation paths in indoor environment are diffraction, reflection, and the most important is the scattering of building materials. Also, the global organization (ITU) recommendations have stated many points relative to material properties, dielectric constant or relative permittivity is found to be almost constant with respect to frequency, while the conductivity varies with respect to variation in frequency [7].

In indoor environments, for both Line-Of-Sight (LOS) and Non-Line-Of-Sight (NLOS), typical measured path loss exponents (PLEs) were found as follow: First, for LOS, in a laboratory is 1.7 [4], in corridors is 1.3 [8], and in an office is 2.2 [5]. Second, for NLOS in typical office environments, greater PLEs were recorded, ranging from 3.0 to 3.8 [5]. Average RMS delay spreads being an important parameter in indoor propagation were found to be 12.3 ns in LOS environments and 14.6 ns in NLOS environments at 60 GHz [5]. The propagation effects at the indoor environment at millimeter-wave frequencies are of importance to industry and researchers due to its wide scope of use.

This paper presents simulations and modeling of 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 same antenna placed at 1.5 m height. Receiver which is an omnidirectional antenna are kept at 0.9 m height for both scenarios. 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, and all material parameters is adopted from ITU recommendation for 60 GHz [2].

II. 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 XY grid for all office points to know the received power for each point. 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, floor and windows and the simulation is carried out using wireless InSite software. The transmitter Tx1 is located at the same room at a height of 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 numbers of receiver points with a distance of 0.5 m spacing 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.

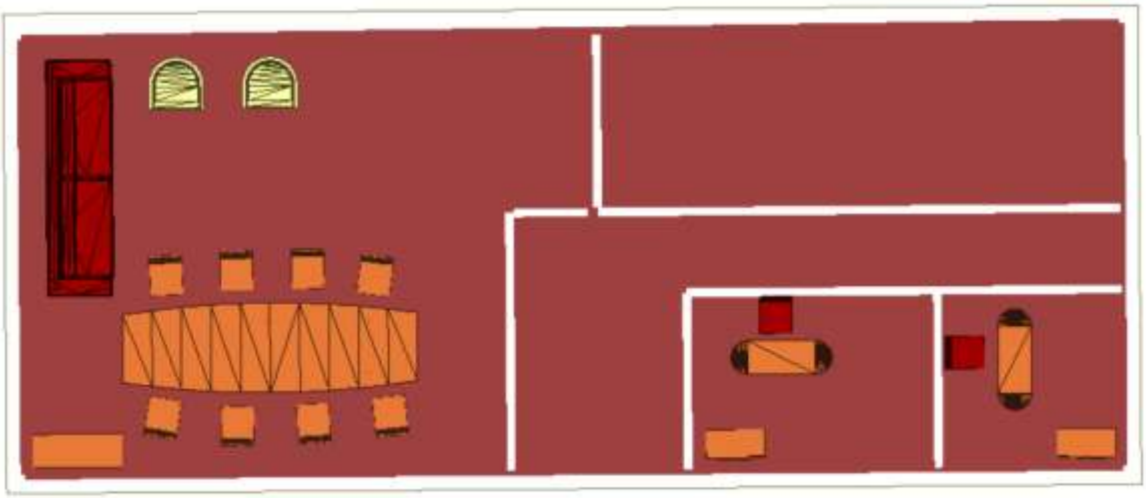

Figure 1. 2D plan of a small office environment

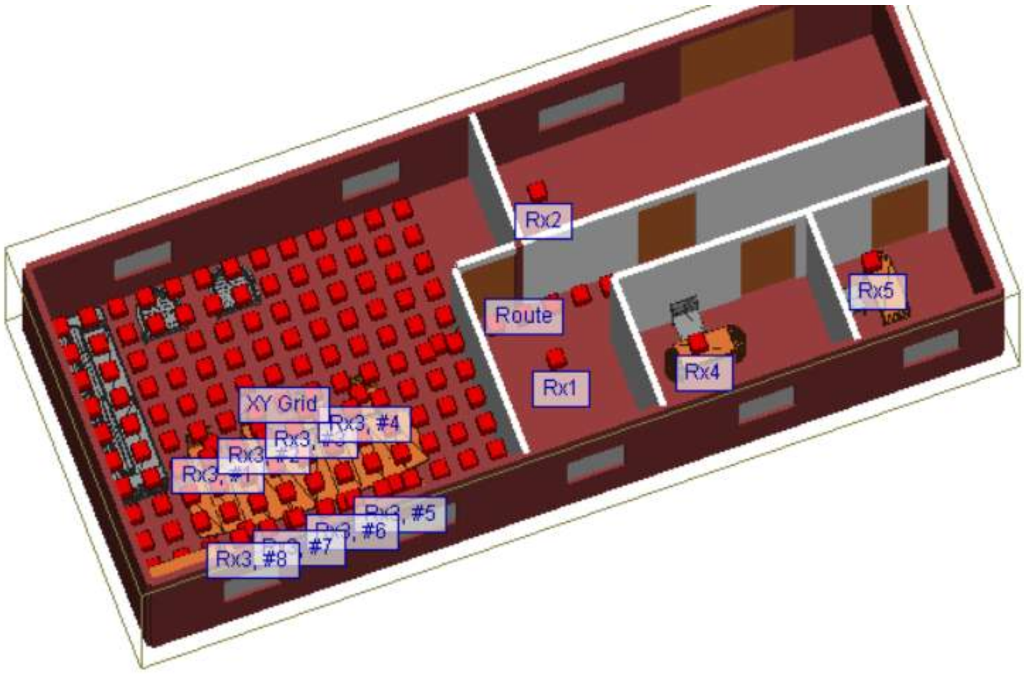

Figure 2. Placement of Transmitter and Receivers Antenna in the office

Table 1 shows the antenna properties for transmitter and receivers that are used in this work. Table 2 shows the properties of buildings materials such as thickness, permittivity, and conductivity that are used in this work with reference to recommendation form ITU for 60 GHz.

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

Antenna parameters	**Transmitter Antenna**	**Receiver Antenna**
Antenna type [1]	Horn	Omnidirectional
Gain (dBi) [1]	15	-
Input Power (dBm) [1]	0	-
Waveform [1]	Sinusoid	Sinusoid
Temperature (K) [1]	293	293
Polarization [1]	V	V
Received Threshold (dBm) [1]	-250	-250

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

Materials	**60 GHz**		
	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]

III. 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 have an impact on radio propagation. During the study, it is observed that at some points the penetration through brick walls decreases with increase in the wall thickness. This study also showed that the walls which made from concrete will prevent the signal from penetration whereas the signal with the highest power was found to be penetrating through glass as well as drywall with no loss in the signal power. Figure 3 shows the effect of the structure materials on the propagation paths for both LOS and NLOS conditions from the transmitter (2.9 m height) to different receiver points.

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

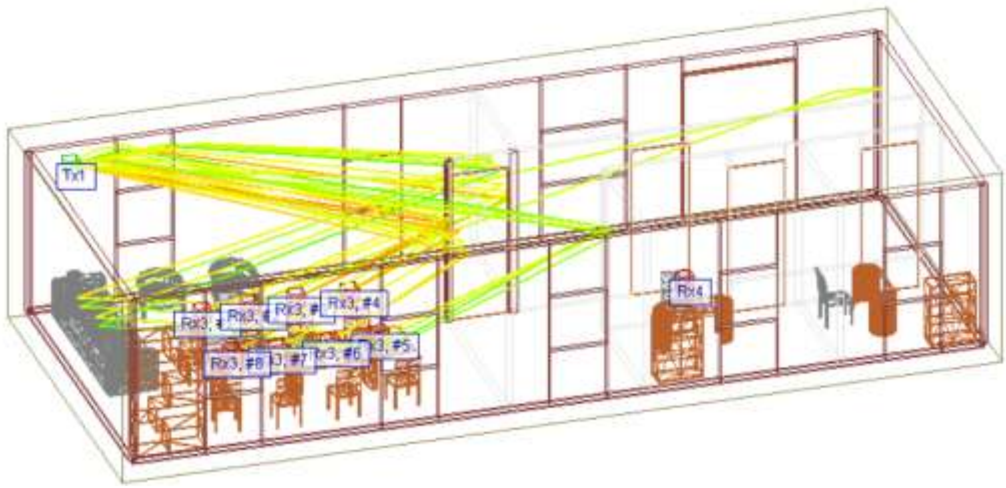

Figure 3. Scenario 1 - Propagation paths from the transmitter (2.9 height) to different received points

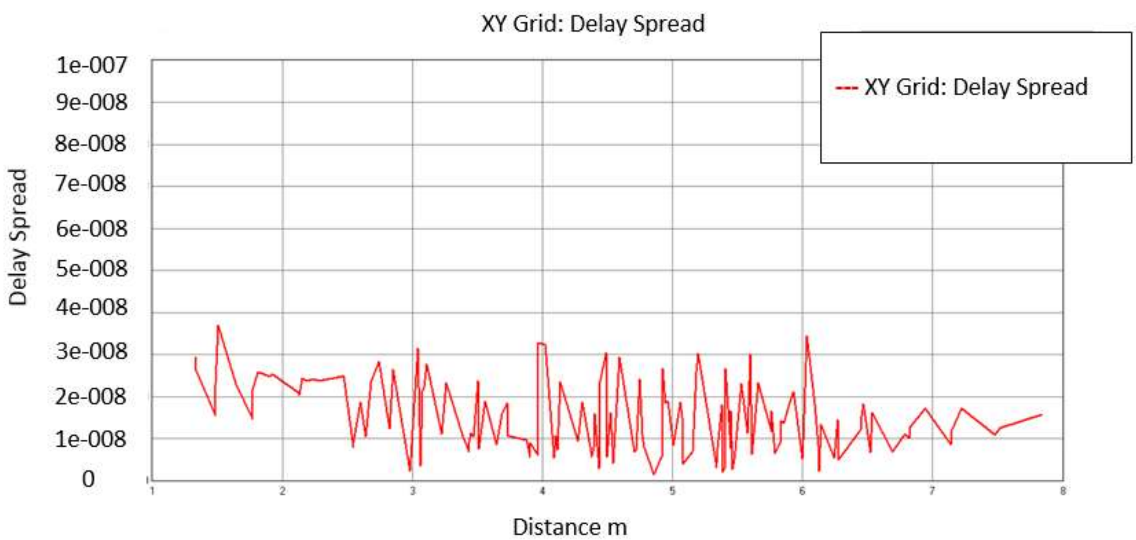

Figure 4. Scenario 1 - Shows the Delay Spread for different Distances of Tx-Rx

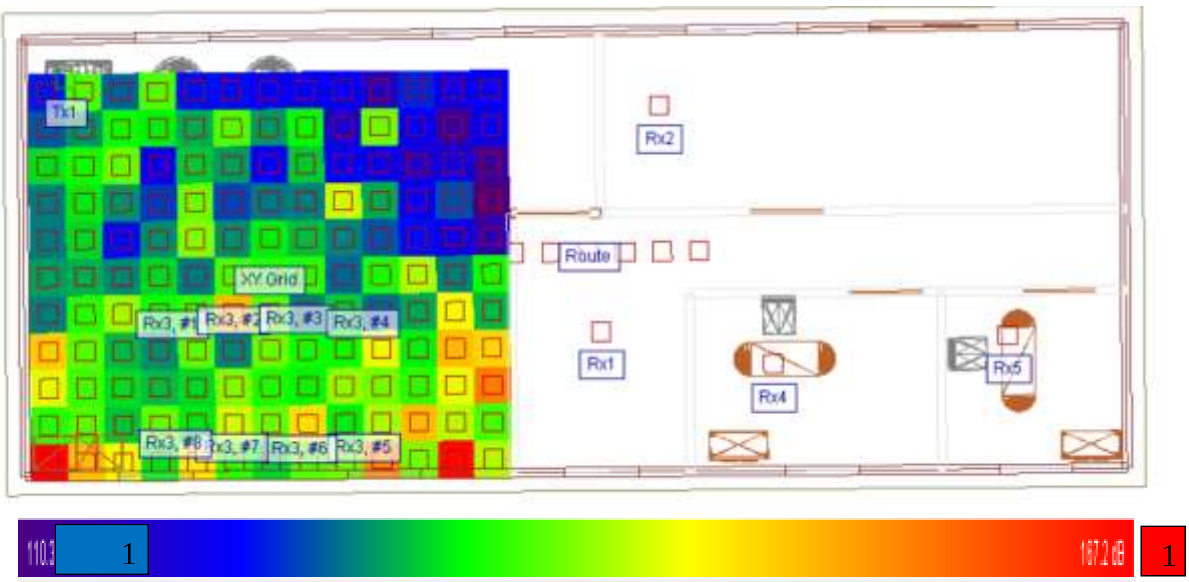

Figure 5(a). Scenario 1 - Path Loss

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

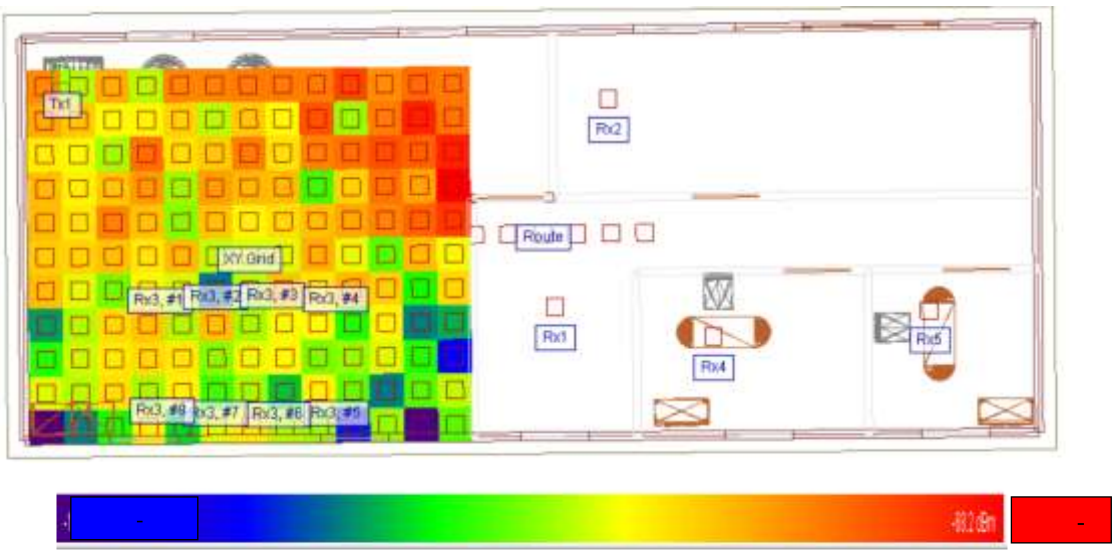

Figure 6. Scenario 1 - Received power.

Figure 7 shows the propagation paths of 60GHz wave inside the office reflecting and diffracting through the walls. The strong paths seen in the diagram penetrated the wooden doors reinforcing the concept of the material effect for LOS and NLOS situations.

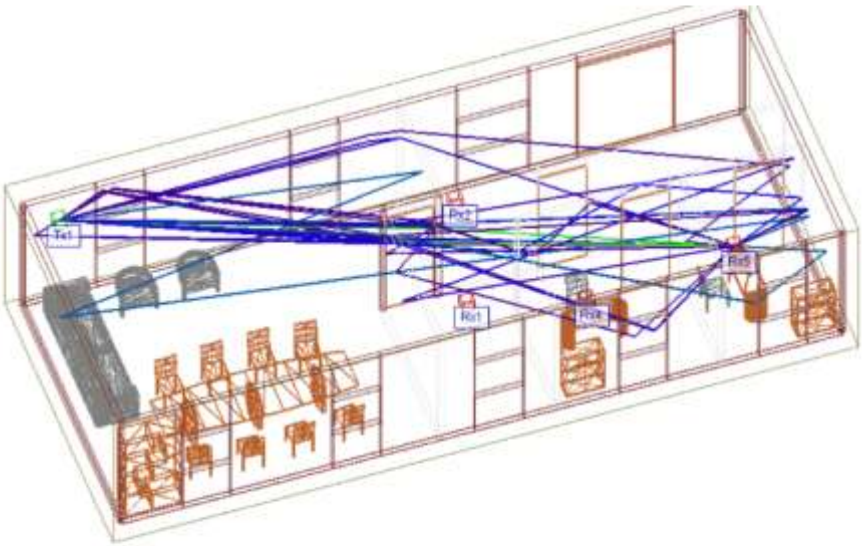

Figure 7. Scenario 1 - Received Power for Rx5

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 has low received power than scenario 1. Also, 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.

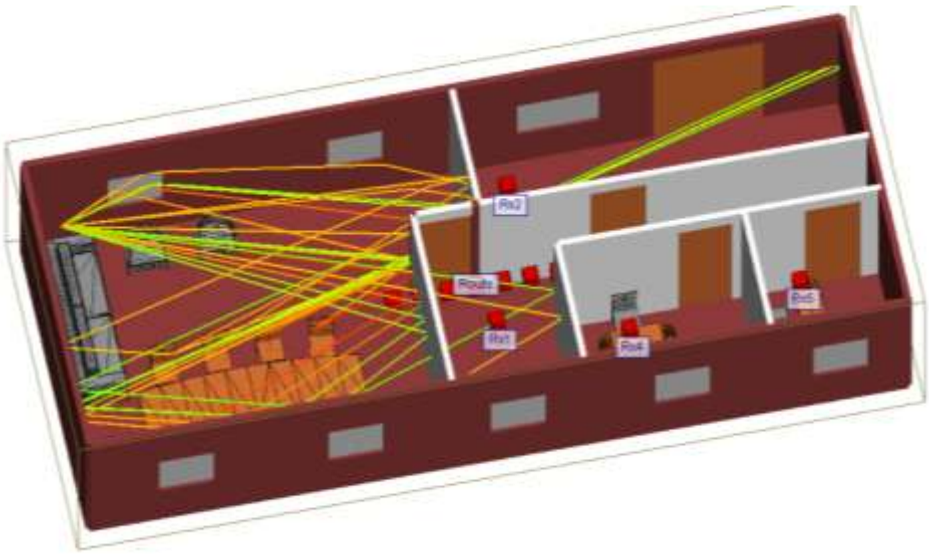

Figure 8. Scenario 2 - Strong propagation paths for transmitter to receivers placed on the table

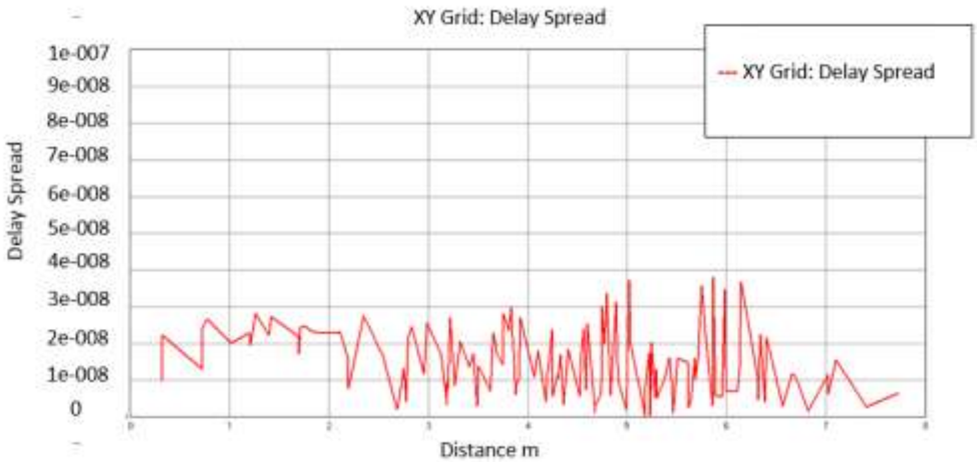

Figure 9. Scenario 2 - Delay spread versus Tx-to-Rx separation distance.

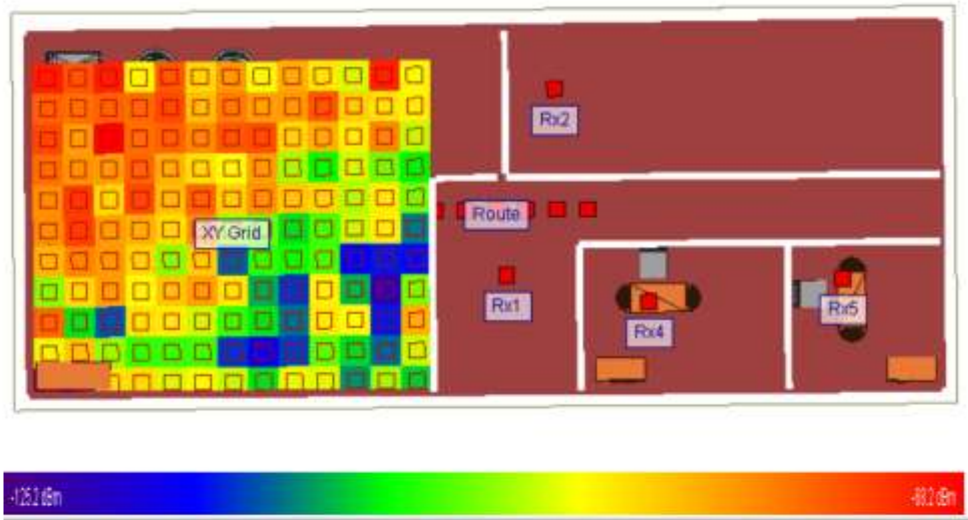

Figure 10. Scenario 2 - Received power in XY Grid conference room

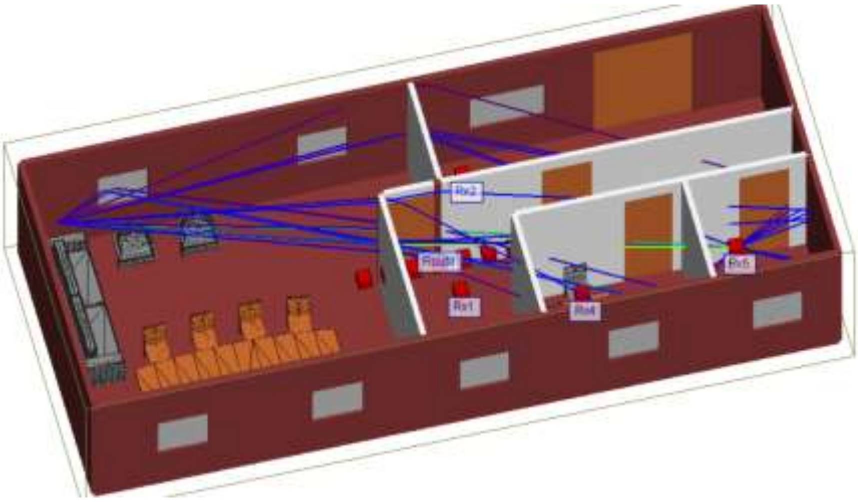
Figure11. Scenario 2 - Illustration of Propagation paths for receiver No.5

IV. CONCLUSIONS

Using EM Simulations, the propagation analysis of mm Waves at 60 GHz for indoor office environments has been investigated. Delay spread, path loss and received power is found to be dependent on 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 ground. Starting with received power and delay spread. It was observed that by increasing the distance for LOS and NLOS scenarios, the values for both delays spread and received power decreased. In addition, the signal propagation characteristics and its penetration level have direct impact from the properties of materials: 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 that made of drywall, and in the end obtained the highest effect with wall that made of concrete due to its impact on preventing the incoming signals. These presented results can add significant knowledge in real building design and the performance of mm Wave bands in typical small building structures.

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