Simulation and Analysis of 37 GHz Millimeter Wave Propagation Characteristics in Indoor Office Environment

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ABSTRACT

In this paper, the method of shooting and bounding ray tracing/image (SBR/IM) is used in the simulation of indoor office environment, with which the study on millimeter-wave propagation characteristics can be processed well. Through simulation parameters such as path loss, received power and root mean square (RMS) delay spread is obtained and analyzed. All the results of this paper could be used as a reference when setting the position of transmitter and selecting parameters in indoor office environments.

KEYWORDS

Path Loss, Wave Propagation, Indoor Office Environment, Millimeter Wave.

INTRODUCTION

As mobile communication is developing rapidly, satellite communication and space-borne electronics, the requirement of system capacity is getting higher and higher. Because of the abundant spectrum resources in the high frequency microwave band, modern communication systems are developing towards the high frequency microwave band. Compared with traditional radio wave, ultrashort wave and microwave communication, millimeter wave communication has many unique features. The wavelength of millimeter wave is between microwave and light wave, so it has some advantages of both microwave and light wave. In addition, the communication equipment of millimeter wave is small in size, and can obtain high directivity by using small size antenna, which is convenient for concealment and confidentiality of communication. The millimeter wave is less affected by clutter and has strong penetration ability to dust and other particles, so its communication is relatively stable [1-2].

As early as the 1940s, scientists began to study millimeter-wave communication. However, millimeter-wave communication has not been applied in practice. Until the 1970s, the successful development and mass production of millimeter-wave integrated circuits and solid-state devices made the production cost decreasing quickly. It can be predicted that with development of technology, millimeter-wave communication will have broad application prospects.

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With the rapid development of economy in recent years, the proportion of global urbanization is increasing, and the main places where people live and work are more and more concentrated in indoor environments [3]. Statistics show that for the time people spend, 80% to 90% is indoors, 70% is on mobile phone use, for data transmission, 80% of them is occurred indoors. Nowadays, indoor short-range wireless interconnection (Wireless Local Area Network, WLAN for short) technology is developing rapidly [4], and people are in urgent need of high-quality indoor communication [5].

The most outstanding feature of millimeter wave is that the bandwidth it can provide reach up to hundreds of megabytes. However, due to the serious attenuation cause by obstacles, the apply of millimeter wave may be limited in indoor environment. Therefore, it is necessary to analyze millimeter-wave channel propagation characteristics in indoor radio environment [6-7]

In this paper, millimeter-wave propagation of 37 GHz are simulated in indoor office environment.

SIMULATION ENVIRONMENT

The material for study of indoor office environment is from literature [8]. The office space modeled for measurement and the simulation is showed in Figure 1. The measurement environment is a office which width is much larger than depth (49.8m × 16m) and its height is 2.7m. The height of partition and desk is 1.0m and 0.7m respectively. There are two transmitter antennas Tx1 and Tx2, for position of the two transmitters in the room, Tx1 is placed in the center and Tx2 is on the left side, which is marked in Figure 1. Both two transmitters are set at the height of 2.6m. The receiver antenna are set at the height of 1.5m, which is just above the desk and the partition.

Table I is the properties of the materials in the environment.
TABLE I. MATERIAL PROPERTIES IN THE SIMULATION.

| Parameters       | Glass | Wood | Concrete |
|------------------|-------|------|----------|
| Relative permittivity | 6     | 5.0  | 5        |
| Conductivity (s/m) | 0.01  | 0.01 | 0.7      |

SIMULATION RESULT AND ANALYSIS

Path Loss

Path loss, or propagation loss, refers to the loss caused by the propagation of radio waves in space. It is caused by the radiation diffusion of transmitting power and the propagation characteristics of channels. It reflects the change of the average received signal power in macro scope. In theory, the path loss is the same for the same transceiver distance. But in practice, it is often found that the receiving power at different receiving points of the same receiving distance varies greatly, and even the receiving power at the same receiving point fluctuates greatly at different time points. The path loss function for indoor scenario is defined by the difference value between transmitter and receiver, which function can be shown as following.

\[ PL \left( d \right) = PL \left( d_0 \right) + 10n \log_{10} \left( \frac{d}{d_0} \right) + S \]  

(1)

PL \left( d_0 \right) is the path loss determined by measurement. The value of \( d_0 \) is 1m in indoor environment commonly. \( d \) is the distance between transmitter and receiver, \( n \) is the path loss exponent and \( S \) is the shadow fading. The following two figure is result obtained from simulation. It shows that the path loss become bigger while the distance become longer, and in the scenario of indoor office, path loss is smaller than that of free space under the same condition. For office the path loss exponent is 1.95 and for free space it is 2.

(a)Tx1  
(b)Tx2  
Figure 2. Simulation results (Tx-Rx distance).
Received Power

The values of received power of 37.1 GHz through simulation are illustrated as shown in Figure 3. Obviously, the power become smaller while Tx-Rx distance become bigger. The received power from two transmitters are both range from -65 dBm to -45 dBm. With Tx2 as the transmitting antenna, the receiving antenna moves on the nine route. Taking three receiving point (P1 to P3 in Figure 1), each point has twenty five paths of received power. For the point P1 the total received power is $9.32 \times 10^{-6}$ mW, for the total twenty five receiving paths there is a path with no reflection, four paths with once time reflection, nine paths with twice reflection and eleven paths with three times of reflection. The received power of the path with no reflection is $7.58 \times 10^{-6}$ mW, accounting for 81.4% of the total power. The received power of the path with once reflection is $1.29 \times 10^{-6}$ mW, accounting for 13.9% of the total power. The received power of the path with twice reflection is $4.12 \times 10^{-7}$ mW, accounting for 4.4% of the total received power. The received power of the path with three reflection is $3.18 \times 10^{-8}$ mW, accounting for 0.3% of the total received power.

![Figure 3. Simulation results of received power (Tx-Rx distance).](image)

The distribution of received power for point P2 and P3 are shown in Table II. It can be seen in the indoor office environment that the received power of the path with no reflection is the largest, followed by the path with once reflection, the path with twice reflection and the path with three times of reflection contribute little to the total power.

| Point | Times of reflection | 0    | 1    | 2    | 3    |
|-------|---------------------|------|------|------|------|
| P1    | 81.4%               | 13.9%| 4.4% | 0.3% |
| P2    | 48.9%               | 38.0%| 12.2%| 1.8% |
| P3    | 62.5%               | 29.4%| 6.9% | 1.2% |
RMS Delay Spread

RMS delay spread is caused by the different arrival time of different path of signal, which is defined as

$$\sigma_{rms} = \sqrt{\frac{\sum_{i=1}^{N_p} p_i t_{i}^2}{p_R}} - t^{-2}$$  \hspace{1cm} (2)

and the definition of the average arrival time is

$$\bar{t} = \frac{\sum_{i=1}^{N_p} p_i t_{i}^2}{p_R}$$  \hspace{1cm} (3)

Where $p_i$ and $t_i$ is parameter of path i, means received power and arrival time. $p_R$ is the received power of all paths. As shown in Figure 4, both result of Tx1 and Tx2 ranges from 1.8 ns to 3.8 ns. There are distinct minimum values in both graphs. They appear at positions of 20 m and 6 m respectively. These two positions are exactly where the transmitter is located, so we can see that the nearest position to the transmitter has the lowest delay. It can be seen in the indoor office environment there is little contact between RMS delay spread and position of transmitter. Notably, the point which has the least delay spread appears at the position near the transmitter.

![Figure 4. RMS delay spread.](image)

CONCLUSION

In this paper, three different parameters are discussed: path loss, receiving power and RMS delay spread. In terms of path loss, it is observed that path loss component is smaller than that of free space with reflections from walls and desks and chairs. Although there is less interference in free space, there is no reflection
wave, so the path loss index is higher than that of office environment. This point is also reflected in the received power. It can be seen that although the contribution of reflected wave becomes less and less as the number of reflections increases, it is the negligible reflected wave that makes the path loss of indoor environment lower. For the part of RMS delay spread, it is observed that the closer the receiving point is to the transmitting point, the smaller the delay spread is. This paper provides a material for channel research of indoor office. The shortcoming is that there is a lack of NLOS environment, in addition, the research objectives are somewhat single. More detailed research is needed on the study of 37 Ghz millimeter wave propagation.

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REFERENCES

1. P. Smulders, “Exploiting the 60GHz band for local wireless multi-media access: prospects and future direction”, IEEE Communication Magazine, vol. 40. pp. 140-147, 2002.
2. C. Doan, S. Emami, D. Sobel, A. Niknejad, and R. W. Brodersen, “Design considerations for 60GHz CMOS radios”, IEEE Communication Magazine, vol. 42. pp. 132-140, 2004.
3. G. Sun, J. Chen, W. Guo, et al, “Signal processing techniques in network-aided positioning: a survey of state-of-the-art positioning designs”, IEEE Signal Processing Magazine, vol. 22. pp. 12-23, 2005.
4. M. Paul, L. Erik, W. Klaus, “UWB for robust indoor tracking: Weighting of multipath components for efficient estimation”, IEEE Communications Letters, vol. 3. pp. 501-504, 2014.
5. S. William, B. Salil, H. Adam, “Using a map of measurement noise to improve UWB indoor position tracking”, IEEE Transaction on Instrumentation and Measurement, vol. 62. pp. 2228-2236, 2013.
6. N. Moraitis, and A. D. Panagopoulos, “Millimeter wave channel measurements and modeling for indoor femtocell application”, 9th European Conference on Antennas and Propagation, pp. 1-6, 2015.
7. Y. Choi, Y. Han, “Modeling and analysis of millimeter/sub-millimeter wave indoor communications for multi-gigabit wireless transmission”, 39th International Conference on Infrared, Millimeter, and Terahertz Waves, pp. 1-2, 2014.
8. M. Sasaki, M. Inomata, W. Yamada, et al, “Path loss characteristics at multiple frequency bands from 0.8 to 37GHz in indoor office”, IEEE European Conference on Antennas and Propagation, 2016.