

Propagation Characteristics of Millimeter-Wave Band for 5G Mobile Communications

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Abstract

Background: Millimeter wave band has been identified as a potential frequency band to meet out the high data traffic targeted in 5G Mobile Communications. At this band, the losses during its propagation pose greater challenges in its use for communication. **Methods:** Propagation characteristics of millimeter wave band have been analyzed through simulation considering the MIMO-OFDM system in Matlab. The propagation characteristics in terms of losses, bit-error rate, cell edge performance and cell throughput are analyzed. **Findings:** The MIMO-OFDM using millimeter wave band is capable of delivering an average cell throughput and cell-edge throughput performances better than the current LTE Advanced Systems. **Application:** Higher throughput performance of the MIMO-OFDM in millimeter wave band necessitates its use in 5G Mobile Communication Systems.

Keywords: 5G System, Millimeter Wave, Propagation, Mobile Communication

1. Introduction

5G should make an important difference and add more services for benefit to the real world over 4G and 5G should be more intelligent in our technology that interconnects the entire world without limits. In this paper, the Millimeter Band (MMB) system using MIMO-OFDM has been considered to study 5G. In this study, we have analyzed the propagation loss and path loss in the 5G system. The propagation characteristics at higher frequencies such as higher penetration and precipitation are reasonable, even though the actual amount of additional propagation losses vary depending on the material of the building^{1,2}. The possibility to increase the capacity in a given area is to increase the frequency reuse by deploying smaller cells in a mobile network³. Simulating wideband fading channels, Multiple Input Multiple Output (MIMO) channels and diversity combined fading channels often demand the generation of multiple uncorrelated Rayleigh fading waveforms⁴. One of the biggest challenges is the continuous growth in energy consumption by cellular infrastructure equipment, Base Stations (BSs) especially, which make up to about 80% in the total energy consumption of cellular infrastructure⁵.

Simulation results indicate that joint Relay Stations (RS) decoding outperforms independent Relay Station decoding, but cooperative link with a bit rate of an order of magnitude greater than that achievable by the relay network is required⁶. Multiple-Input Multiple-Output (MIMO) and Orthogonal Frequency Division Multiple access (OFDM) antenna technology can provide significant improvements in capacity and error performance over conventional single-antenna technology, without requiring an extra power or bandwidth⁷. The blocking probability of streaming users can be calculated by using the Kaufman-Roberts algorithm. For an elastic user, explicit expressions of the throughputs are obtained by using a meticulous processor sharing model⁸.

2. Millimeter Wave and Propagation Characteristics

2.1 Millimeter Wave (3-300ghz) Range

Millimeter (mm) wave wireless communications can be considered as one of the best constructive candidates for future systems, especially the bands of 60 GHz, which is available but unlicensed in the most of the countries.

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Figure 1 shows the spectrum of millimeter wave, whose range between 57 GHz to 64 GHz occur oxygen Absorption Band and 164 GHz to 200 GHz occur water vapor (H₂O) Absorption Band¹¹. Exactly all the commercial radio communications, such as FM radio, TV, mobile phone, space communications, GPS and Bluetooth have been using the Ultra High Frequency (UHF) band with frequencies about 300 MHz – 3 GHz.

2.2 Propagation Loss

In microwave systems, the transmission loss is mainly due to the free space loss. Transmission loss of millimeter waves due to the free space loss is given by:

$$L_{FSL} = 49 + 40\log_{10} D + 30\log_{10} f_c \quad (1)$$

Where L_{FSL} is the free-space loss in dB, f_c is the carrier frequency in GHz and D is the distance between the transmitter and receiver in meters. The formula in Equation 1 is applicable for frequencies in the range of 300 MHz – 75 GHz as shown in Figure 2.

2.3 Penetration Loss

Foliage losses at Millimeter wave frequencies are significant. In fact, the foliage losses may be limiting the propagation impairment in some cases. While signals at lower frequencies can penetrate more easily through buildings,

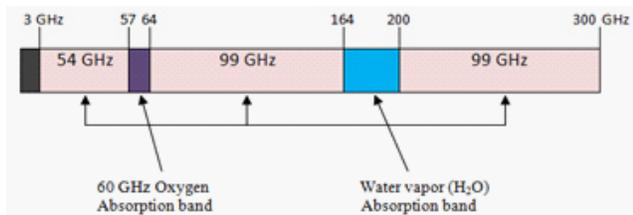


Figure 1. Future 60 GHz bandwidth system.

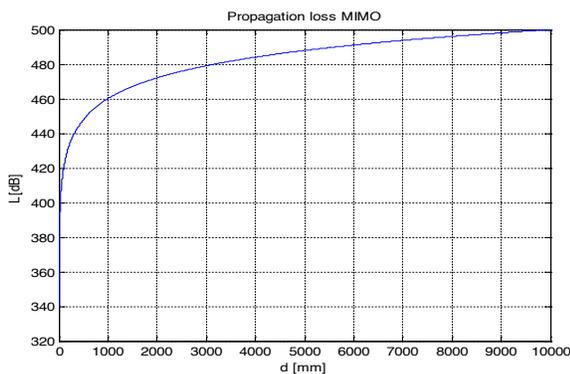


Figure 2. Propagation loss of MIMO.

Millimeter waves do not penetrate most hard materials. Propagation loss through Foliage L_{fol} is given by

$$L_{fol} = \frac{f^{0.3} R^{0.6}}{5} \quad (2)$$

Where f is the carrier frequency in MHz and R is the depth of foliage traversed, in meters and $R < 450m$. The above Equation 2 is applicable for frequencies in the range of 300 MHz – 90 GHz. In Figure 3, we plot penetration losses for foliage depth of 5, 10, 20 and 40 meters. We note, for example, that at 60 GHz frequency and 5 meters foliage penetration, the loss can be about 10 dB higher than the loss at 3 GHz frequency. We can consequently expect that the millimeter-wave signals will be strictly attenuated by great foliage depths.

3. System Description

The proposed work is based on the MMB system with MIMO-OFDM combination with the 5G network. The basic structure of the MIMO system can be designed for the frequency range of the 3-300 GHz in the Millimeter range¹⁰. At the end of the design the propagation and path loss can be analyzed. The propagation losses can be reduced as much as possible through proper channel designed in the MIMO-OFDM system as shown in Figure 4.

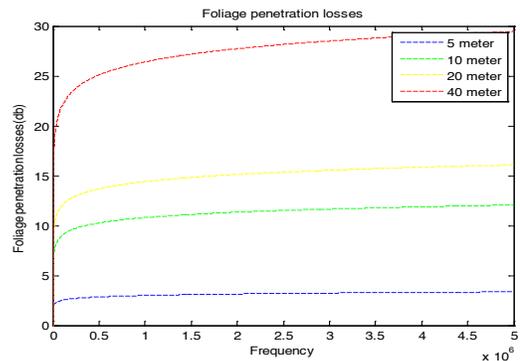


Figure 3. Foliage penetration losses.

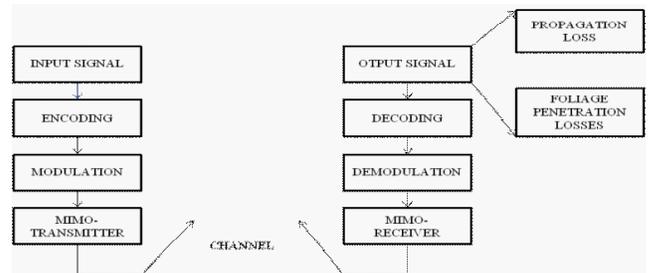


Figure 4. Architecture diagram of MMB system design.

Microwave and millimeter wave have been widely used for long-range (e.g., a few kilometers) point-to-point communication for many years. However, the antennas and electronic components are used in the systems, including the mixers, oscillators, low noise amplifiers, synthesizers and power amplifiers are too big in size and consume too much power to be applied in mobile communication. Notwithstanding the foregoing, efforts have been made in the recent years to utilize mm waves for high data rate communication and the flow diagram of MMB system design as shown in Figure 5.

For example, LMD operates at the frequency range from 28–30 GHz was conceived as a Broadband Wireless Access solution. In the United States, 7 GHz of spectrum in the 60 GHz band has been allocated for unlicensed use and about 13 GHz of spectrum has been allocated for high-density fixed wireless services in the 70-80-90 GHz band. The availability of the 60 GHz band as unlicensed spectrum has spurred interest in Gb/s short-range communication. Several industrial standards that include Wireless, IEEE 802.15.3c and IEEE 802.11ad have been developed for the 60 GHz band. Moreover, significant progresses have been made in low-cost, low-power 60 GHz RFIC and antenna9 solutions with the commercial availability of products capable of delivering GB/s data rates for distances up to 20 meters.

3.1 MIMO 1 -Transmitter

Fifth-generation (5G) wireless communications networks should support the data rate of 5 GB/s for low-mobility applications and 100 MB/s for high-mobility applications. To meet these requirements, advanced technologies including a high-level modulation schemes, Multiple Input and Multiple Output (MIMO) and Orthogonal Frequency Division Multiplexing (OFDM) techniques are needed. The channel bandwidth should be at least 100MHz. However, the most existing communications standards

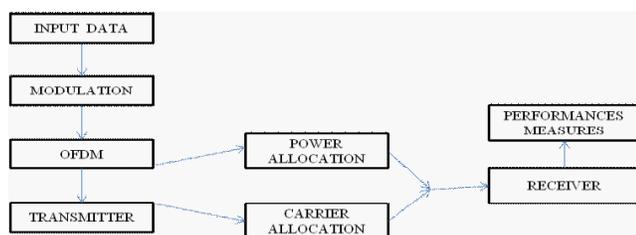


Figure 5. Flow diagram of MMB system design.

employ no more than 20 MHz bandwidth. In this design two transmitters are used to transmit the message signal in the channel with proper modulation enabled.

3.2 MIMO-Receiver

The transmitted signal is received by using two MIMO receivers. The received signal is demodulated using the QAM - demodulation scheme. After that, the encoded message bit is recovered successfully in the decoding process in the receiver side. Then the transmitted signal is received successfully via MIMO-OFDM system. Finally, the received signal is analyzed for the propagation loss and path loss of the MIMO-OFDM system.

4. Results

The performance of MMB system is considered using system level simulations.

The frequency spectrum of original transmitted signal is shown in Figure 6. The magnitude range of 0.6 dB is raised in the corresponding frequency as the middle value of 3.5–4.5 GHz during the half period of time. The received signal at the antenna MIMO design has the large peak magnitude say 0.9 db (0.3 db more than that of transmitted signal) at the frequency range of 3-5 GHz as shown in Figure 8.

The corresponding estimated signal frequency spectrum of MIMO design is presented at the same frequency ranges but small form of peak values are obtained as shown in Figure 7. This is very simple method to achieve small form of transmitted frequency spectrum of estimated value.

Some advantages of the MIMO-OFDM System are low cost, low Loss and expected (Bit Error Rate) BER at the receiver end as shown in Figure 9.

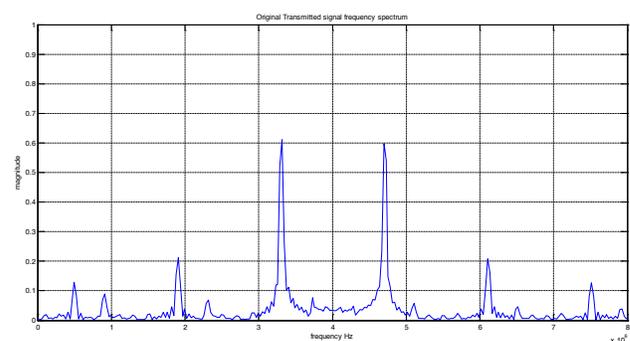


Figure 6. Original transmitted signal frequency spectrum.

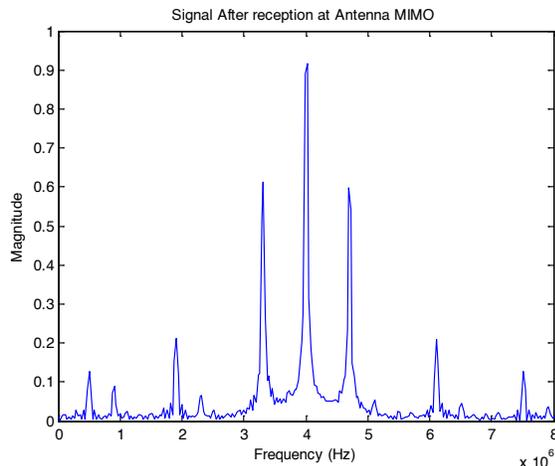


Figure 7. Signal after reception at antenna MIMO.

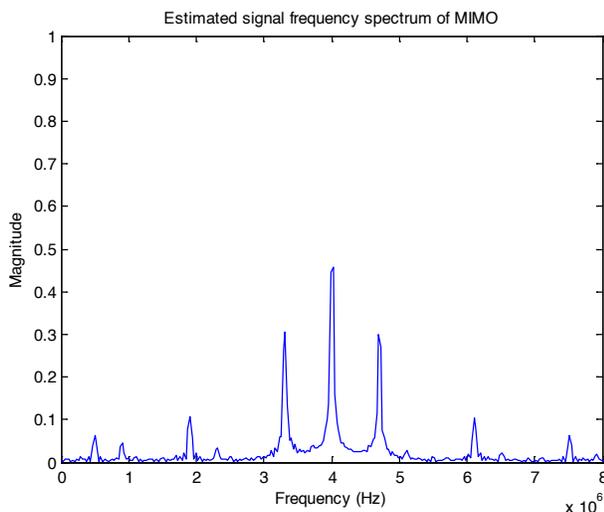


Figure 8. Estimated signal frequency spectrum of MIMO.

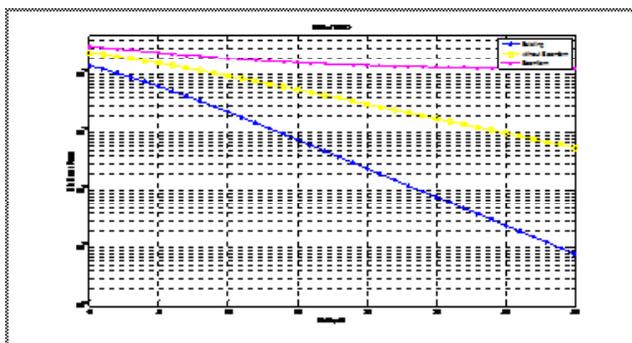


Figure 9. Bit Error Rate of MIMO.

These routine numbers from Figure 10 demonstrate that with millimeter wave communication, it is possible to achieve a 10-100 times development over the current

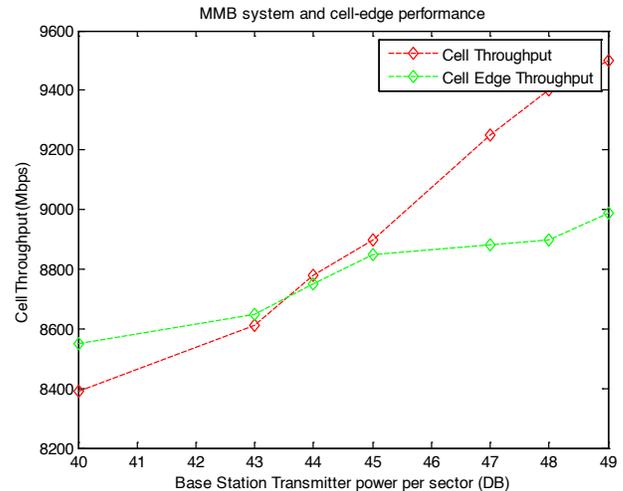


Figure 10. MMB system and cell-edge performance.

4G systems. With more difficult technologies including spatial multiplexing, SDMA, MIMO and channel sensitive scheduling, further works have been made to improve the performance of the MMB system so as to access in 5G mobile communications.

5. Conclusion

In this paper, we analyzed that the Millimeter Wave Mobile Broadband (MMB) system for 5G Mobile Communication provides higher bandwidth. The propagation characteristics of the Millimeter wave has been simulated and analyzed. Through system simulations it is shown that the basic MMB system employing MIMO-OFDM is capable of delivering an average cell throughput and cell-edge throughput performances which are 10 - 100 times better than the current 20- MHz LTE-Advanced systems.

6. References

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