28 GHz MIMO Channel Characteristics Analysis for 5G Communication Systems

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Abstract. In this paper, 28 GHz MIMO channel capacity and characteristics are analyzed, based on indoor propagation measurements carried out for both LOS and NLOS scenarios. Specifically, MIMO channel link budget, capacity, path loss, K-factor and delay spreads are studied based on experimental data. Results show that Gigabit capacity can be achieved in 28 GHz channel with MIMO (1 × 4) configuration in indoor corridor. RMS delay spread depends on both the size and scenario (LOS and NLOS) of environments. CDF of *K*-factor can be fitted with normal distribution in the LOS corridor. The provided parameters are useful for design of 5G wireless communication systems.

Keywords: Multiple-In Multiple-Out (MIMO) · Channel capacity
Link budget · Path loss · K-factor · Delay spread

1 Introduction

Gigabit millimeter wave indoor M2M (Machine-to-machine) communication technology is rising all over the world [1, 2]. At present, many countries and regions in the world have assigned 26 GHz to 38 GHz frequency band to the wireless broadband application in the local multipoint distribution system (Multipoint Distribution Systems Local, LMDS) [3, 4]. In particular, the FCC is proposing the use of spectrum at Ka-band (28 GHz and 39 GHz bands) for 5G mobile communications. At this frequency, the free space wavelength around 10 mm, enabling phased array antennas that can provide the bandwidth and be small enough to fit into mobile devices such as laptops, tablets and smartphones.

Multiple-in multiple-out (MIMO) technology has become one of the key technologies in the field of wireless communications. With the continuous development in recent years, MIMO technology will be more and more applied to a variety of wireless communication systems. In the wireless broadband access system, IEEE 802.16e, 802.11n and 802.20 which are being developed also adopt MIMO technology. MIMO technology can make full use of space resources and multiple antennas to improve the system capacity several times without increasing the spectrum resources or antenna transmit power.

The 28 GHz outdoor channel modeling has been studied in [5–7]. However, litter information on indoor channel characteristics in open literature. In this paper, the

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28 GHz indoor MIMO channel capacity and characteristics are analyzed based on experimental measurements performed for both LOS and NLOS scenarios, for providing useful information on design of radio systems.

2 Measurement Environment and Campaigns

The 28 GHz indoor channel measurements were performed for both LOS and NLOS corridors in North China Electric power University (NCEPU). In the measurement, MIMO antennas were employed, i.e. antenna elements at transmitter (TX) and receiver (RX) are of 1 and 4 denoted as MIMO (1 × 4). In the measurements, the TX was fixed at certain position at the end of the corridor, and the RX was replaced with different positions along both LOS and NLOS routes. Figure 1 shows the measurement environment and scenarios. Specifically, 11 LOS positions (RX1 to RX11) and 3 NLOS positions (RX12 to RX14) were chosen, the LOS distance separations between TX and RX1 is 2.7 m, RX1 to RX10 is separated by 1.5 m and RX10 to RX11 is separated by 3 m. In NLOS case the TX and RX separations are of 3.4 m, 4.2 m and 5.5 m. The TX antenna was an omni-directional biconical horn (5 dBi gain), and the RX antenna was a 1 × 4 array, which was rotated in the azimuth plane from 0° to 360° (step length is 45°) at each measurement position. This means that 36 data was collected in each measurement position. The bandwidth (B) of system was chosen as 1 GHz in this measurement. Detailed information on measurement parameters and setup are summarized in Table 1.

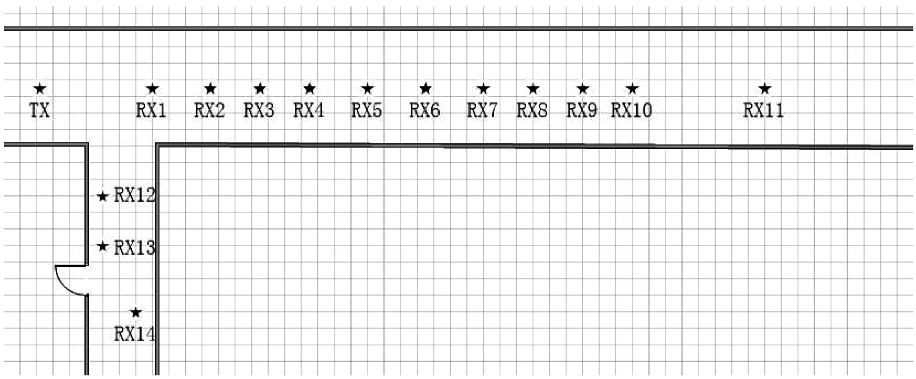

Fig. 1. 28 GHz channel measurements for both LOS (RX2-RX11) and NLOS (RX12-RX14) scenarios

Table 1. The 28 GHz channel measurement parameters

Measurement frequency	28 GHz
Frequency bandwidth	1 GHz
Code length	1024 ns
Delay resolution ratio	1 ns
TX power	18 dBm
TX antenna	Omni-directional biconical horn, 5 dBi gain
RX antenna	4 array antenna, 5 dBi gain
TX/RX antenna height	1.95/1.95 m

3 MIMO Channel Capacity Analysis

MIMO technology can make full use of space resources and use multiple antennas to improve the system capacity several times without increasing the spectrum resources or antenna transmit power. The application of MIMO technology makes the space become a kind of resource that can be used to improve performance and increase the coverage of wireless system.

3.1 MIMO Capacity

In MIMO, N_T and N_R are the number of TX and RX antennas, respectively. Assuming that all antenna signals are spatially uncorrelated, the maximum capacity in MIMO channel with given bandwidth B can be expressed as:

$$C_{MIMO} = B\log_2 \det\left(I + \frac{\rho}{N_T} HH^+\right). \tag{1}$$

where ρ denotes the average *SNR, I* is the identity matrix, and H is the normalized channel matrix, '+' denotes transpose conjugate.

For B = 1 GHz the CDF of MIMO channel capacity is shown in Fig. 2. It is seen that MIMO (4 × 4) capacity is about 2 times in MIMO (2 × 2) channel. MIMO (2 × 2) channel capacity is 1 about Gbps larger than in MIMO (1 × 4) channel at

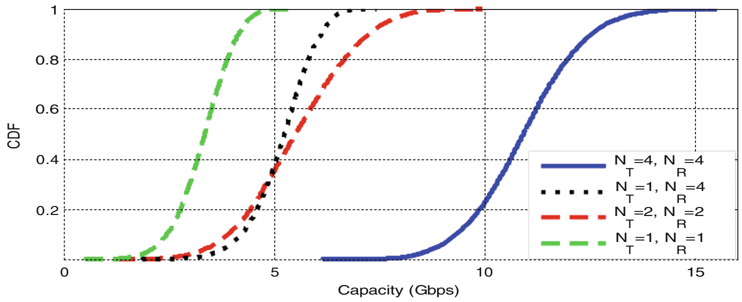

Fig. 2. CDF of MIMO channel capacity

CDF = 0.8. This is because in MIMO (2 × 2) the spatial multiplexing (number of parallel channels) makes information streams transmitted independently in channel.

3.2 MIMO Channel Link Budget Analysis

In wireless system, *SNR* is often determined from radio link budget as:

$$SNR = P_t + G_t + G_r - PL(d) - N_0 - IL. \tag{2}$$

where P_t is the transmitted power, G_t and G_r are the TX and RX antenna gains, PL is channel path loss, N_0 is the total noise power, IL denotes the total implementation loss at the TX and RX. Path loss (PL) can be modeled by mean path loss and fading margin σ [8]:

$$PL(d) = PL_0 + 10\,n\,\log(d/d_0) + \sigma \tag{3}$$

where PL_0 is the free space path loss at $d_0 = 1\,\text{m}$, n is path loss exponent and σ is the standard deviation (STD) of fading margin in multipath channel.

Path loss model in the 28 GHz channel measurement is shown in Fig. 3. It is seen that PL exponent (n = 1.94) in LOS case is lower than free-space value of 2 due to the guided-wave effects in the corridor. The values of PL exponent n and shadowing STD σ are in consistent with the values reported in [1].

In order to estimate 28 GHz MIMO channel capacity, in Eq. (2), parameters $P_t = 18\,\text{dBm}$, G_t and G_r are 5 dB which are chosen as the same values as measurement data. A total of 6 dB *IL* is estimated. The noise power is calculated as: $N_0 = 10\log 10(kTB) + NF$, where k is the Boltzmann's constant, $T = 290K$ (room temperature) and the noise figure *NF* is assumed to be 6 dB at receiver. Note that parameters of *IL* and *NF* are the same values as in [9] for a 60 GHz radio system. Figure 4 shows capacity vs. distance in the LOS corridor. It is seen that at the shortest TX-RX separation d = 2.7 m about 8 Gbps rate can be achieved in channel.

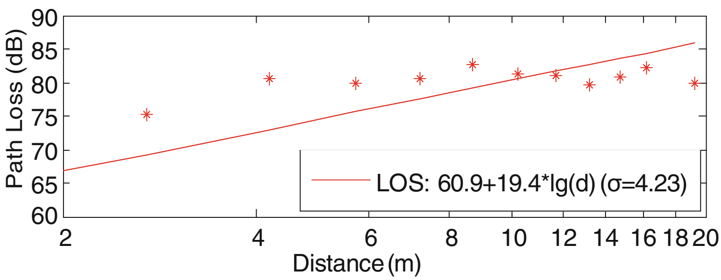

Fig. 3. Path loss model

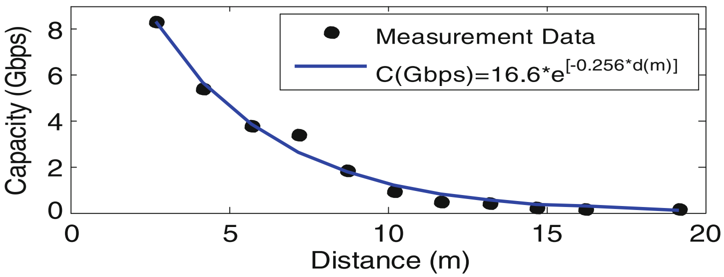

Fig. 4. Capacity vs. distance in the LOS corridor measurements

4 Channel Statistical Parameter Analysis

The statistical parameters and models of the channel are required to describe general channel properties which are useful for system design. Rms delay spread (DS) is very important and a common parameter for comparing different multipath channels in order to develop some general guidelines in system design. Rician *K*-factor is usually used to evaluate the performance of wireless systems.

4.1 Delay Spread

Rms delay spread is derived from the square root of the second central moment of a PDP. The formula for rms delay spread can be found in [8]. Figure 5(a) and (b) are the CDFs of RMS delay spreads in the LOS and NLOS corridor measurements, respectively. It is seen that the mean values of RMS delay spread in the LOS and NLOS corridor are of 26.4 ns and 27.6 ns, respectively. As the RMS delay spread depends on

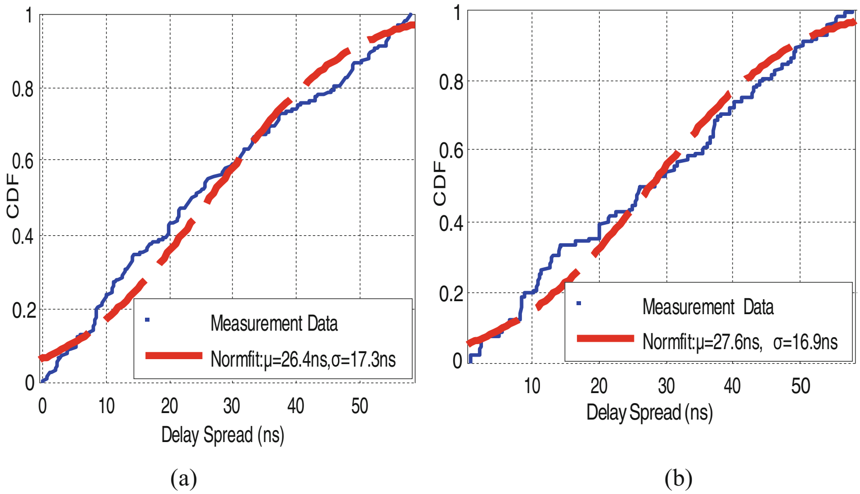

Fig. 5. CDF of RMS delay spread in (a) LOS and (b) NLOS corridors

both the size and scenario (LOS and NLOS) of environments. Note that the LOS corridor measurement route is longer (TX to RX11 is 19 m) comparing with the NLOS corridor measurements (TX to RX14 is 5 m).

4.2 K-factor

K-factor is defined as the ratio between the powers of LOS path and the other random multipaths. The estimation of Ricean K-factor has been widely studied in literature. The moment estimation method [10] of K-factor is used in this work. Figure 6 shows the CDF of K-factor in the LOS corridor measurements. It is seen that normal distribution can fit well with the measurement data. The mean value of K-factor is of 5.5 dB (with STD of 7.1 dB) in the LOS corridor measurements.

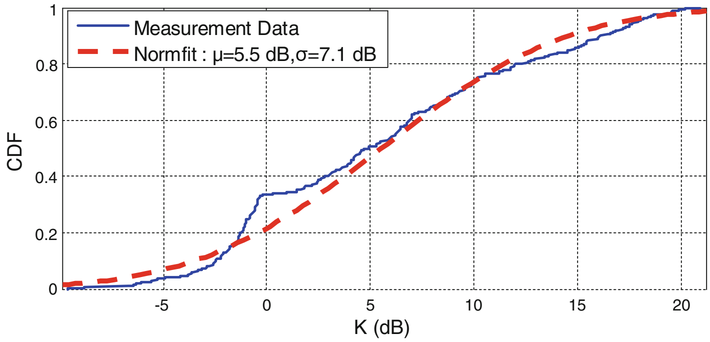

Fig. 6. CDF of K-factor in the LOS corridor measurements

5 Conclusion

This paper presented an investigation of channel characteristics based on experimental measurements performed at 28 GHz for both LOS and NLOS scenarios. Specifically, MIMO channel link budget, capacity, path loss, K-factor and delay spreads are studied based on experimental data. Results show that Gigabit capacity can be achieved in 28 GHz channel with MIMO (1×4) configuration in indoor environment. The mean values of RMS delay spread in the LOS and NLOS corridors are of 26.4 ns and 27.6 ns, respectively. RMS delay spread depends on both the size and scenario (LOS and NLOS) of environments. Normal distribution can fit well with K-factor in the LOS corridor measurements. The mean value of K-factor is of 5.5 dB (with STD of 7.1 dB) in the environment. The presented results are useful for design of 28 GHz high rate wireless communication systems.

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