An Overview of Actual SU- and MU-MIMO Performances in a Measured Indoor Channel

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Abstract

The performance of a multiple-input and multiple-output (MIMO) system highly depends on the hardware characteristics and MIMO channel statistics. The authors conducted MIMO channel measurement campaigns for a specific indoor site and have shown several potential problems in actual situations. In the paper, these results are summarized as an overview.

Keywords: MIMO Measurement MU-MIMO SU-MIMO E-SDM

1. Introduction

Multiple-input multiple-output (MIMO) systems, where both TX and RX sides are equipped with multiple antennas, are absolutely essential for achieving high link throughput and have been already incorporated in several standards such as WiFi, WiMAX, and 3GPP LTE. The research on MIMO systems starts from a single-user (SU) scenario and is now extended to multi-user (MU) systems, cooperative MIMO communications, and so on.

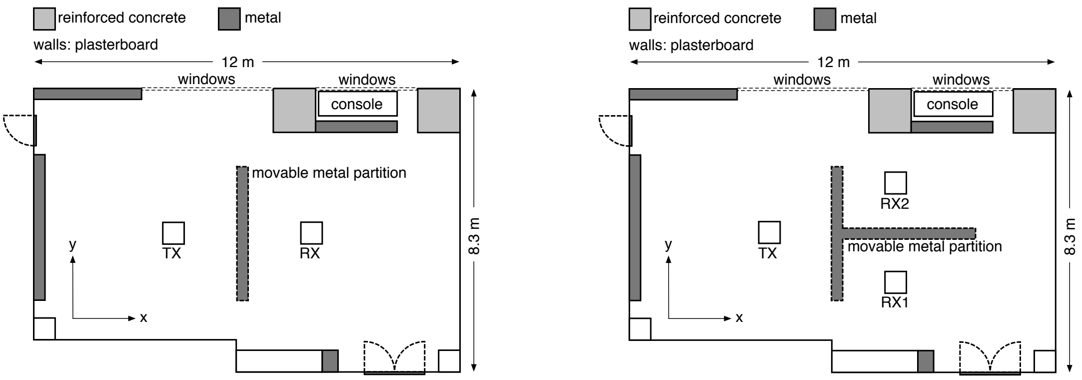
Through these works, it has been well-discussed that the MIMO channel characteristics (transmit/receive correlation in specific) affect the performance of spatial multiplexing transmission. In general, line-of-sight (LOS) environments increase the MIMO channel correlation (i.e., reduce rank of the channel matrix) but provide higher SNR. Thus, the total performance cannot be simply predicted in terms of LOS or non-LOS (NLOS).

The hardware-originated problems: RX/TX calibration and IQ-imbalance are also important factors. Although these impairments might be possible to be calibrated, mutual coupling among antenna elements is inevitable. The mutual coupling changes the element antenna pattern from the original one (omni-directional in usual) [1]. Thus, the MIMO channel characteristics observed by use of such antennas depend on not only propagation environments but also array configuration.

There have been several measurement campaigns on indoor/outdoor MIMO channels to investigate the actual channel property and its impact on MIMO capacity [1–4]. The authors also conducted the measurements focusing on LOS/NLOS difference and channel change behavior [5–7]. In the paper, the results which have not been focused well by others are summarized, and the important characteristics are topically described.

2. Measurement Setup

The indoor measurement campaigns were carried out at a conference room (about 12 m $\times$ 8 m in size) in an 11-story building as shown in Fig. 1. We examined both 4 $\times$ 4 SU-MIMO (Fig. 1(a)) and 4 $\times$ 2 two-user-MIMO (Fig. 1(b)) configurations. The adjacent antenna spacing was 3 cm (half wavelength at 5 GHz), and two linear array orientations (TX-x/RX-x: endfire alignment), TX-y/RX-y: broadside alignment) along the x- and y-axes were considered. LOS/NLOS environments were switched by removing/placing metal partitions shown in Fig. 1. Narrow band MIMO channel matrices were measured by sweeping the frequency from 5.15 GHz to 5.4 GHz (1,601 points by 156.25 kHz interval) with a vector network analyser and switching antenna pairs. At the receive side, an antenna



(a) SU-MIMO setup (b) MU-MIMO setup

Figure 1: Measurement site of SU- and MU- MIMO channels.

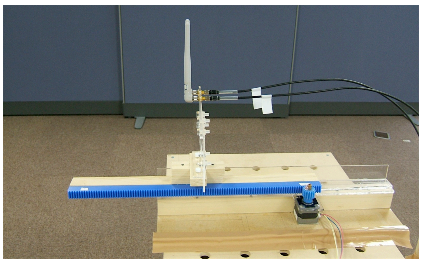
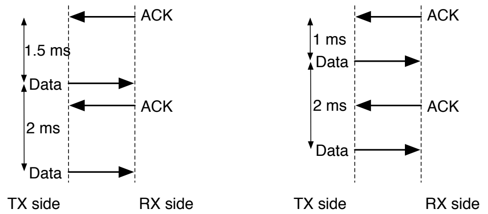


Figure 2: Linear step scanner.



(a) SU-MIMO time chart (b) MU-MIMO time chart

Figure 3: TDD time charts.

scanner (500 points by 0.88 mm step) was used to move the receive antennas along the x- or y-axis during the experiments. Thus, we had $1,601 \times 500 = 800,500$ channel matrices for each case of the SU/MU configuration, the array orientation, LOS/NLOS condition, and direction of the receiver motion. Note that the measurement equipment was automatically controlled to keep out anyone for statistical stationarity of propagation.

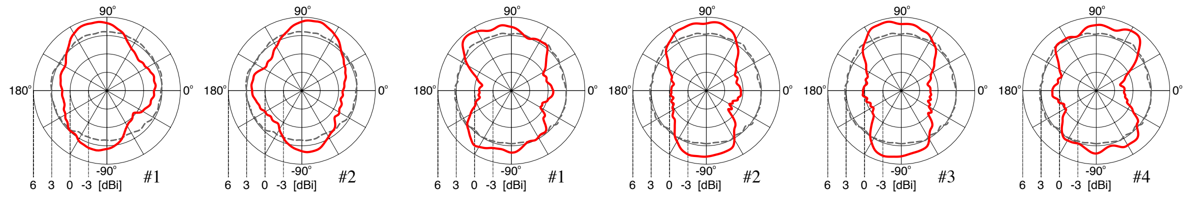
For the performance evaluation of MIMO spatial multiplexing, we considered eigenbeam-space division multiplexing (E-SDM) as an upper bound. Since E-SDM requires the channel information at the transmitter side, we assumed a TDD mode as defined in WiMAX and LTE. The simple frame configuration is shown in Fig. 3. The transmission interval is 2 ms, and the transmission delay from channel feedback (assumed to use ACK) is 1.5 ms for SU-MIMO case (Fig. 3(a)) and 1 ms for MU-MIMO case (Fig. 3(b)), respectively[1]. If we suppose 4-step antenna motion (3.52 mm) during the single frame interval (2 ms), the emulated maximum Doppler frequency (f_D) corresponds to 30.9 Hz. Note that the channel is assumed to be time-invariant in the data packet for the sake of simplicity.

3. Topical MIMO Characteristics

3.1. Array Pattern

Antenna patterns of the linear arrays for antenna spacing of 0.5λ are shown in Fig. 4 (solid curves). The pattern of a single antenna is also shown with a dashed curve for comparison. It is clearly indicated that the mutual coupling changes the element antenna pattern from the quasi omnidirectional one observed for the single isolated element. In the case shown in Fig. 4, the gain in broadside direction becomes higher by about 5 dB compared to the one in endfire direction. This means that the total SNR gain of the direct path (in the LOS case) in broadside alignment (TX-y/RX-y) reaches about 10 dB higher than that in endfire one (TX-x/RX-x). As a result, the array orientation considerably affects the MIMO performance as will be shown later. Note that the non-uniform element pattern due to mutual coupling is not constant but changes with the antenna spacing [1].

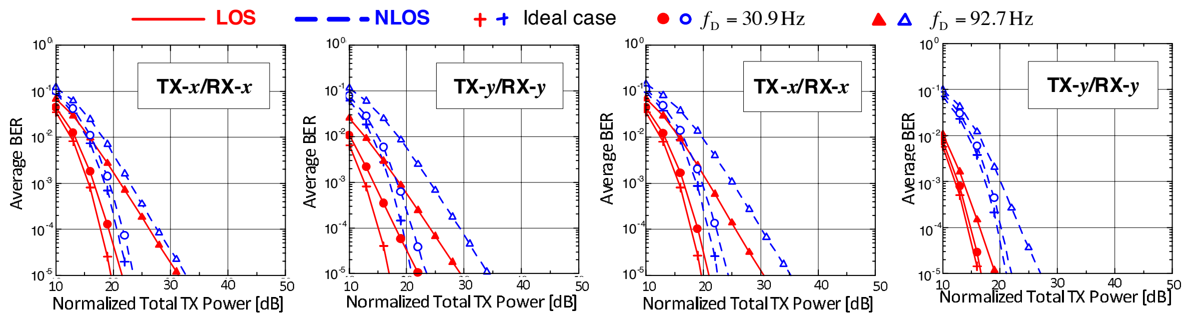
[1] As shown later, MU-MIMO is more sensitive to channel change. Thus, a shorter delay was used.



(a) two-element array (RX in MU-MIMO case)

(b) four-element array (TX in SU-MIMO case and TX/RX in MU-MIMO case)

Figure 4: Antenna patterns of linear arrays with mutual coupling (solid curve) and isolated element (dashed curve). Reprinted from [6] with permission (©2010 IEEE).



(a) RX motion along x-axis

(b) RX motion along y-axis

Figure 5: BER performance of 4×4 SU-MIMO E-SDM system. Reprinted from [5] with permission (©2007 IEEE).

The broadside alignment emphasizes the gain of the direct path along the x-axis in the LOS case as described above. Then, the strong and short standing wave along the x-axis is generated due to the forward and backward paths. Thus, the receiver's motion along the x-axis yields the wide-spread Doppler spectrum whereas the motion along the y-axis concentrates the spectrum around 0 Hz [7]. This also affects the tolerance to channel change speed as discussed later.

3.2. LOS/NLOS and Moving Direction Effects

Let us discuss the E-SDM performance in the SU-MIMO case. The average BER performances of 4×4 MIMO E-SDM system versus normalized total TX power with $f_D = 30.9$ and 92.7 Hz are shown in Fig. 5 [5]. The ideal case, where the time delay from ACK to data transmission is forced to zero, shows that BER performance in the LOS environment is better than that in the NLOS one since much higher SNR is given by an existence of the direct path. In addition, the TX-y/RX-y alignment shows about 3 dB better performance in the LOS case as previously expected from the antenna pattern with mutual coupling.

The time delay of a data packet causes a mismatch of eigenbeams to the actual channel matrix generated by the non-zero Doppler frequency. This reduces the orthogonality of the eigen channels and consumes some degrees of freedom for suppression of inter-stream interference (IStI). In addition, the resource assignment per stream is no longer optimum. Thus, the higher the f_D, the worse the BER performance. Note that the case of TX-y/RX-y alignment and RX motion along y-axis is insensitive to the channel change since the Doppler spectrum is concentrated around 0 Hz as described above.

3.3. Sensitivity of Channel Change in MU-MIMO system

Fig. 6 shows the BER performance of a MU-MIMO system where block diagonalization (BD) is employed for user multiplexing [6]. In this case, the mismatch due to the channel change arises in not only eigenbeams but also user-multiplexing beams based on zero-forcing. Thus, the channel change causes severe inter-user interference (IUI). In general, at the receiver side, only the substream detection with spatial filtering, i.e., the IStI reduction, is considered. Therefore, unexpected IUI deteriorates the

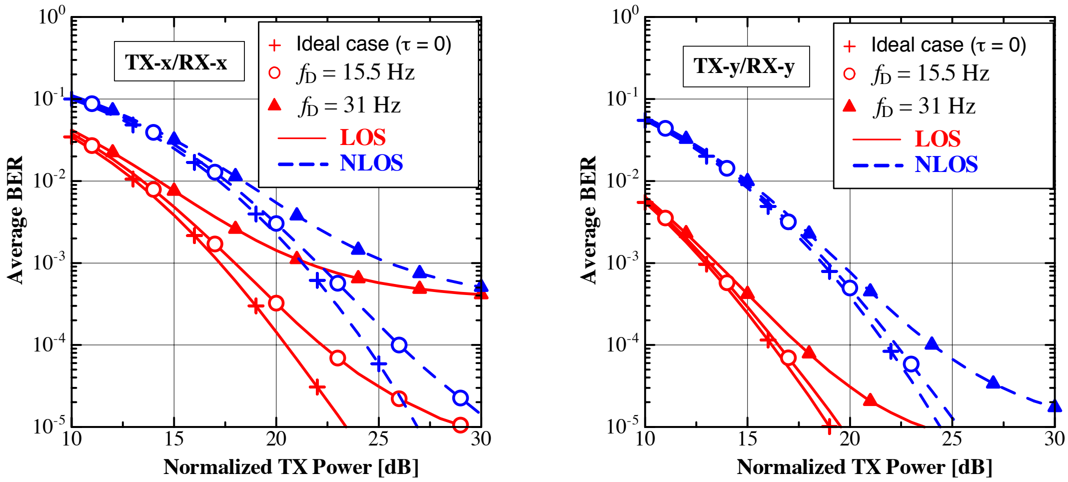


Figure 6: BER performance at RX2 of 4 × 2 two-user MIMO BD/E-SDM system where RXs move along y-axis. Reprinted from [6] with permission (©2010 IEEE).

BER performance dramatically even with the small amount of channel change. The error floor can be seen when $f_D = 15.5$ Hz for the TX-x/RX-x alignment. This corresponds to just a motion of 0.88 mm (1.5% of wavelength in 5 GHz) within 1 ms time delay. We may conclude that particular attention should be paid for such a high sensitivity of the MU-MIMO system on a channel change in an implementation phase. Again, note that the case of TX-y/RX-y alignment is less sensitive to the channel change as in the SU-MIMO case.

4. Conclusions

We have summarized the actual MIMO channel with mutual coupling on the performances of SU- and MU-MIMO systems. In specific, the high sensitivity of MU-MIMO performance on a channel change has been revealed. In order to reduce the IUI, additional degrees of freedom are required at the receiver end. Considering the limit on hardware specification of the receiver, we can say that solutions at the transmitter side are rather attractive. The prediction of BD-based transmit-beams is one of them.

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