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Analyses of Virtual MIMO Multi-User System Performance with Linear Precoding Schemes Using Indoor Measurements at 5 GHz

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Abstract

In this paper, based on 5 GHz indoor multi-user measurements, linear precoding schemes such as zero-forcing (ZF), minimum mean square error (MMSE) and successive interference cancelation (SIC) are applied in the base station in order to investigate the performance of virtual multi-input multi-output (MIMO) over single-user MIMO system. However, to form a virtual MIMO multi-user system, the resources of two users are brought together. In order to achieve a low spatial correlation, two spaced antennas in the MS have been chosen and four spaced antennas elements in BS have been selected. Therefore, the resources of two users (U1 and U2) are brought together to form a 4 × 4 virtual MIMO multi-user system with the BS. The properties of the user_1 (U1) and user_2 (U2) will be analyzed and compared to those properties of virtual MIMO multi-user system formed by U1 and U2. In most cases, the maximum achievable rate is seen with virtual MIMO multi-user compared to single-user MIMO. So virtual MIMO multi-user is desirable for boosting system capacity than single-user MIMO.

Keywords

Virtual MIMO, Capacity, ZF, MMSE, SIC

1. Introduction

In wireless communication, the radio channel is affected by many distortions such as channel fading and signal-to-noise ratio variation [1] [2]. The signals will propagate by way of multipath before they reach the destination in different directions, which is an undesirable phenomenon. To deal with this problem multi-antenna elements are adapted in the base station (BS) and mobile station (MS). The process of using multi-antenna elements in both of the BS and MS is called single-user multi-input multi-output (SU-MIMO). To achieve maximum capacity, SU-MIMO is used with a special post-precoding signal processing [3]. The goal of post-precoding signal processing techniques is to produce among of the multiple signals arrived at the receiver, one signal that has been originally transmitted by the transmitter. The signal processing technique used in this paper is the receiver diversity [4] such as zero-forcing (ZF), minimum mean square error (MMSE) and successive interference cancelation (SIC). The SU-MIMO exploits space dimension to improve wireless system capacity. It offers significant increases in data throughput and link range without additional bandwidth or increased transmit power. With the SU-MIMO the capacity is increased as the number of antenna is increased. However, if the antennas are much closer from each other's, the radio channel will be correlated which causes the capacity degradation. Because, if the radio channels are full correlated, the SU-MIMO system will become like traditional single-input single-output (SISO) system. For that reason, the antennas must be paired in a suitable way between the users and the BS site in order to benefit from low correlation. That is to say, we need to put more space between antenna elements. For the proper set of antennas number in MS and BS terminal, it is better to use antennas selection techniques as indicated in [5] [6]. To exploit wider space between antenna elements, one approach is to use cooperative or virtual MIMO (VMIMO) multi-user [7]. With VMIMO multi-user system, it can benefit wider space between antenna elements from users.

The main focus of this paper is the evaluation of VMIMO system performance in multi-user compared to SU-MIMO system. Is it possible for two users to cooperate? The answer of the question is yes, two users can cooperate and share their resources. The cooperative MIMO has been incorporated in some wireless standards, such as Wireless sensor networks [8] [9].

In this paper the performance of the VMIMO multi-user over SU-MIMO is investigated by the linear precoding schemes in the BS using real indoor data measurements performed in Helsinki, Finland.

The paper is structured as follows. Section 2 shows measurement system and campaigns. Section 3 is the System model. Section 4 shows virtual MIMO system construction. Section 5 introduces the linear precoding schemes. Section 6 is the performance analysis. Section 7 presents numerical results and comparisons with measurements, and Section 8 draws the conclusions.

2. Measurement System and Campaigns

The measurement campaign took place in the building of the Nokia Research Center (NRC) in Ruoholahti, Helsinki, Finland. The environments covered the following propagation scenarios: wide indoor areas, open office environments, office rooms connected by a corridor, and meeting rooms, see **Figure 1**. The measurements were performed using 5.25 GHz carrier frequency with 100 MHz bandwidth. The BS consists of the radio channel sounder receiver unit, which was connected to a planar array with 32 dual-polarized elements, but for measurement only 12 dual polarized (vertical and horizontal polarizations) antenna elements was activated as shown in Figure 2(a). The user or the MS antenna prototype having four different dipole antennas was connected to the transmitter as shown in Figure 2(b). So the total number of the BS (Rx-receiver) was 24 and the total number of the MS (Tx-transmitter) was four. This results in 4 × 24 = 96 measured radio channels. In addition, the Tx-switching requires four additional channel guards to be present, therefore resulting in a channel number of 100 measured channels.

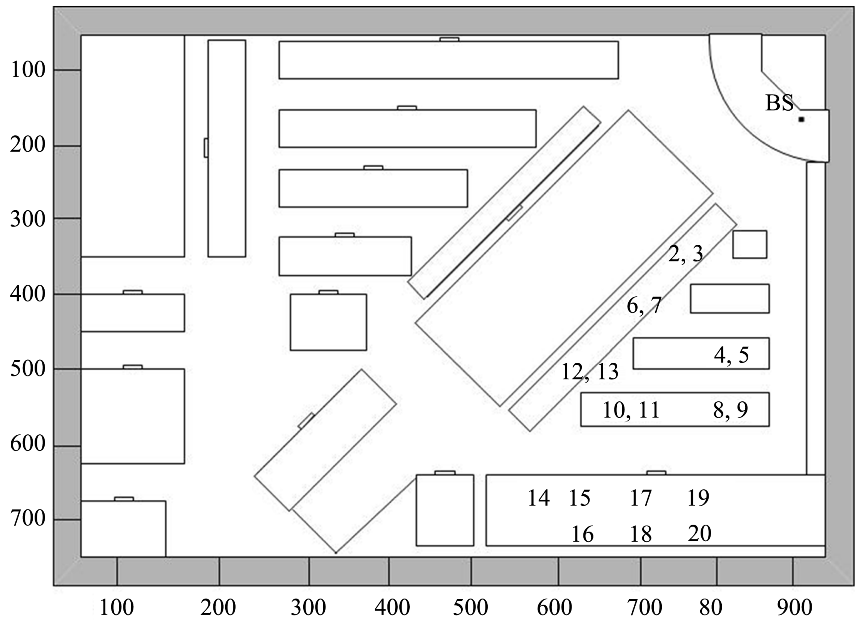

Figure 1. Measurement locations in NRC, Helsinki, Finland. The numbers on figure show the mobile station locations (users).

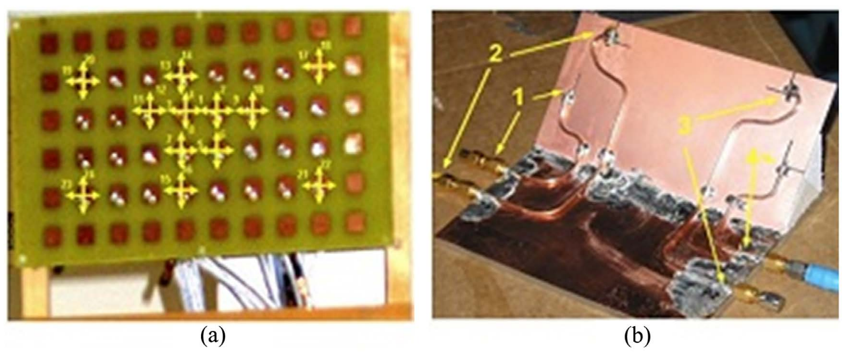

Figure 2. Antennas elements. (a) The base station antenna array connected antenna elements are marked and shown with the corresponding Rx-antenna numbers. Each odd channel number (1, 3 …) was designated for a horizontally polarized input and each even channel number (2, 4 …) for a horizontally polarized input, respectively; (b) the mobile terminal antenna prototype used in the measurements. The antennas and the connectors are shown with the corresponding Tx-antenna numbers.

3. System Model

In this paper, assume the receiver signal at the BS is given by:

$$y = h_k x_k + \sum_{i \neq k} h_i x_i + n \quad (1)$$

where h_k is channel, x_k is a transmit signal, n is a noise.

Our purpose is to decode packet k from receiver signal. Therefore the receiver is to be decomposed to isolate the contribution packet k.

The term $\sum_{i \neq k} h_i x_i$ acts as an interference and is referred to us as inter-symbol interference (ISI).The system will becomes like a SIMO system with input x_k, channel h_k and an additive white Gaussian noise n if the ISI is suppressed. However the precoding techniques are used to suppress that inter-symbol interference (ISI) from receiver signal. And we consider ZF, MMSE and SIC precoding schemes in this paper.

4. Virtual MIMO Construction

In order to form a VMIMO multi-user, resources of two users are brought together. As described above, in order to achieve a low spatial correlation, two spaced antennas in the MS have been chosen and four spaced antennas elements in BS have been selected. Therefore, the resources of two users (U1 and U2) are brought together to form 4 × 4 VMIMO multi-user system with the BS. For users U1 and U2, the two spaced antennas correspond to the antennas 1 and 3 or the antennas 2 and 4. In our calculation, we consider the two spaced antennas 2 and 4 for each user that correspond to the dashed column matrix 2 and 4 of the user channel matrices as shown in Figure 3. Then the two dashed column matrix of the two users channel matrices are brought together to set up a VMIMO multi-user channel matrices. The properties of the user_1 (U1) and user_2 (U2) will be analyzed and compared to those properties of VMIMO multi-user system formed by U1 and U2.

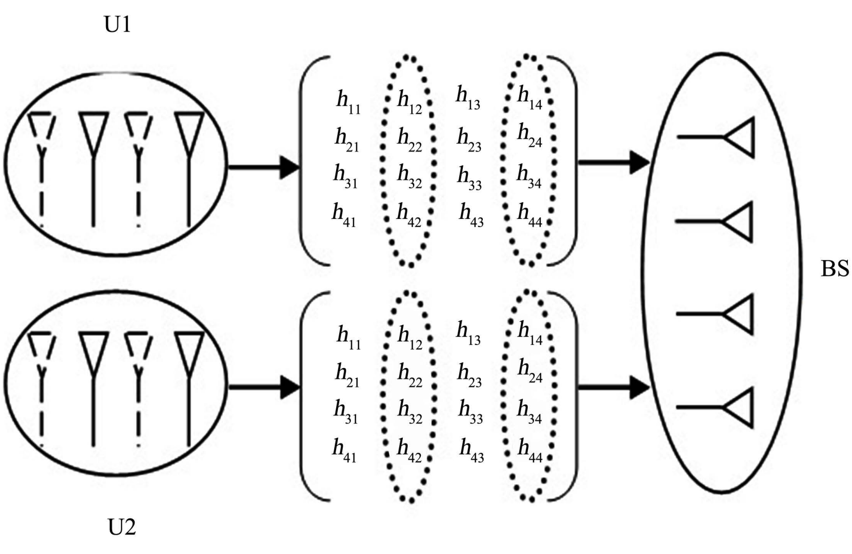

Figure 3. Construction of 4 × 4 virtual MIMO system from standard users.

5. Linear Precoding Schemes

The linear precoding considered here are ZF, MMSE, SIC.

5.1. Zero-Forcing Receivers

Let us denote as W_k a precoding matrix with $Nt-1$ columns equal to $\{h_i, i \neq k\}$:

$$W_k = \left[h_1 \cdots h_{k-1}\ h_{k+1} \cdots h_{Nt}\right] \tag{2}$$

where Nt is a number of transmit antenna.

By multiplying the precoding matrix W_k with the receiver signal y the ISI will be suppressed ($\sum_{i \neq k} W_k h_i x_i = 0$). And after some manipulation [10] the ZF precoding matrix is elaborated and given by:

$$W_{ZF} = \left(H^H H\right)^{-1} H^H \tag{3}$$

And the system signal to noise ratio (SNR) is given by:

$$SNR_{ZF} = \frac{P_x}{\sigma_n^2 \left(H^H H\right)^{-1}} \tag{4}$$

σ_n^2 is a noise variance, P_x is signal power.

5.2. Minimum Mean Square Error Receiver

In ZF precoding, the interfering data is treated as an unknown deterministic quantity. But in MMSE precoding, the interfering data is modelled as a random Gaussian variable.

Considering the received signal in Equation (1), the interference plus noise term $\sum_{i \neq k} h_i x_i + n$ is modelled as a coulored Gaussian noise with covariance matrix:

$$R_k = P_x \sum_{i \neq k} h_i h_i^H + \sigma_n^2 I \tag{5}$$

where P_x is signal power, σ_n^2 is a noise variance, I is unity matrix.

The interference plus noise term is whitened by multiplying the received signal by $R_k^{-1/2}$. And after some manipulation [10] we yield with MMSE precoding matrix and is given by:

$$W_{MMSE} = D^{-1} \left(H^H H + \frac{\sigma_n^2}{P_x} I\right)^{-1} H^H \tag{6}$$

where P_x is signal power, σ_n^2 is a noise variance, I is unity matrix. The matrix D is the diagonal matrix whose diagonal is equal to the diagonal of

$$\left(H^H H + \frac{\sigma_n^2}{P_x} I\right)^{-1} H^H H.$$

The post-processing SNR for stream k is:

$$SNR_{MMSE}(k) = \frac{P_x}{\sigma_n^2 \left[\left(H^H H + \frac{\sigma_n^2}{P_x} I\right)^{-1}\right]} - 1 \tag{7}$$

where P_x is signal power, σ_n^2 is a noise variance, I is unity matrix.

5.3. Successive Interference Cancelation Receivers

5.3.1. MMSE-SIC

The SIC receiver is an iterative receiver where each stream is decoded successively and its contribution removed from the received signal and process is followed.

Stream 1 is decoded considering streams 2 to Nt as an interferers. Once decoded, its contribution is removed from the received signal. When decoding stream k, the interference from streams 1 to $k-1$ has been removed during previous iterations. Decoding is done considering stream $k+1$ to Nt as interferers.

5.3.2. V-Blast

The process of V-Blast is based on the following features:

The streams are coded independently and the receiver is based on SIC.

The maximum achievable can be written as a function of $SNR(L_k)$ as:

$$\mathcal{R}_{\max} = \log_2 \det\left[I + \frac{P_x}{\sigma_n^2} HH^H\right] = \sum_{k=1}^{Nt} \log_2 \det\left[1 + SNR(L_k)\right] \quad (8)$$

where P_x is signal power, σ_n^2 is a noise variance, I is unity matrix, L_k is layer k.

V-Blast achieves capacity for fast fading.

6. Performance Analysis

The maximum achievable rate and outage probability are computed for performance analysis.

6.1. Capacity

The capacity is the maximum achievable rate for which a reliable communication can be achieved [11]. Therefore at given rate R, the communication system is said to be reliable if we design a code that can make the error probability relatively small. The MIMO capacity is:

$$C_{MIMO} = \text{real}\left[\log_2 \det\left[I + \frac{\overline{P}}{Nt\sigma_n^2} HH^H\right]\right] \quad (9)$$

where I is unity matrix, $\overline{P}$ mean power, Nt is a number of transmit antenna, σ_n^2 is a noise variance.

6.2. Outage Probability

The outage probability, Pout is probability that the maximum rate achievable is below a certain threshold value R. The total achievable rate for communication is the sum of maximum achievable rates over all the streams.

$$\mathcal{R}_{\max} = \sum_{i=1}^{M_T} \log_2\left[1 + SNR(k)\right] \quad (10)$$

Hence the outage probability for overall system for selected rate is given as:

$$P_{out} = P_r \left\{ \sum_{i=1}^{M_T} \log_2 \left[1 + SNR(k) \right] < R \right\} \quad (11)$$

where M_T is a number of receiver antenna.

7. Numerical Results and Comparison with Measurements

Figure 4 shows the comparison between the system capacity of Rayleigh i.i.d, SIC virtual MIMO, SIC MIMO, MMSE and ZF. From Figure 4 the maximum capacity is achieved by the SIC. At low SNR, the ZF achieves the lower capacity and at high SNR, the ZF becomes equivalent to MMSE. Also from Figure 4, we saw that VMIMO multi-user achieved capacity over SU-MIMO.

Figure 5 presents the outage probability versus the selected rate R for Rayleigh i.i.d, SIC virtual MIMO, SIC MIMO, MMSE and ZF. From Figure 5, for a selected rate, the outage probability can be easily found. For example for the selected rate R = 15 bits per transmission, the outage probability is 82% for

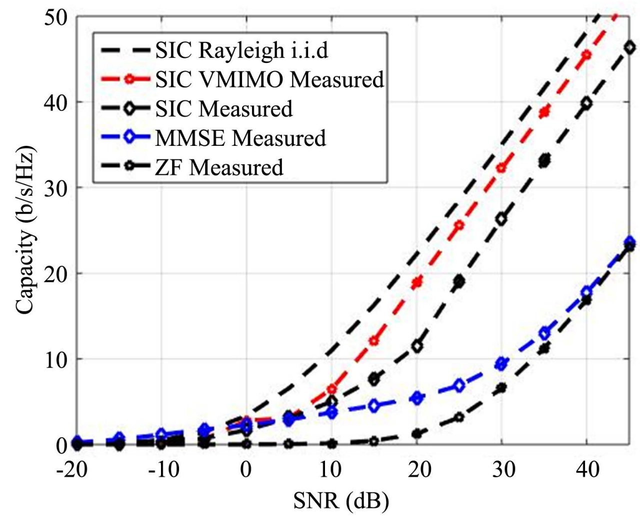

Figure 4. Capacity of MIMO receivers versus signal to ratio.

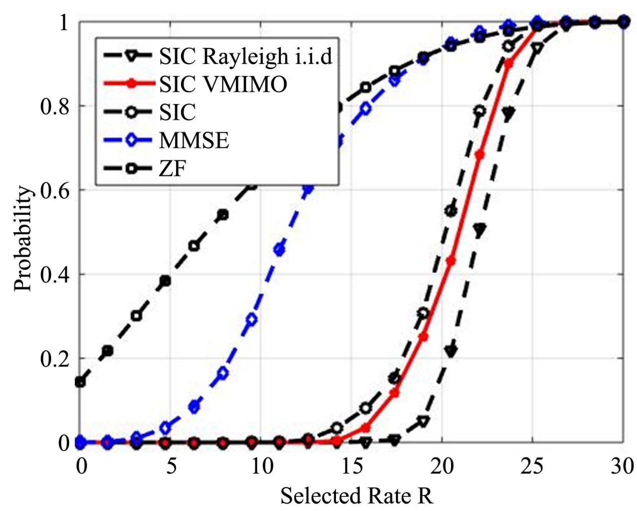

Figure 5. Outage probability versus selected rate R.

ZF, 75% for MMSE, 5,6% for SIC, 1.3% for VMIMO multi-user and almost zero for SIC Rayleigh i.i.d. The capacity with 10% outage probability is equal to 1.2 bits per transmission for ZF, 8.38 bits per transmission for MMSE, 17.96 bits per transmission for SIC, 18.39 bits per transmission for SIC VMIMO multi-user and 20.37 bits per transmission for SIC Rayleigh i.i.d.

Figure 6 and Figure 7 show the outage probability versus signal-to-noise ratio for different selected rates. From Figure 6 the outage probability is calculated for a fixed rate *R* for SIC, SIC VMIMO multi-user, MMSE and ZF. We observe that for the SIC the outage probability is much decreased compare to MMSE and ZF. The performance of VMIMO multi-user is also highlighted versus SU-MIMO. The SIC VMIMO multi-user performs the best outage Probability. Figure 7 shows at high selected rate *R* the ZF becomes equivalent to MMSE.

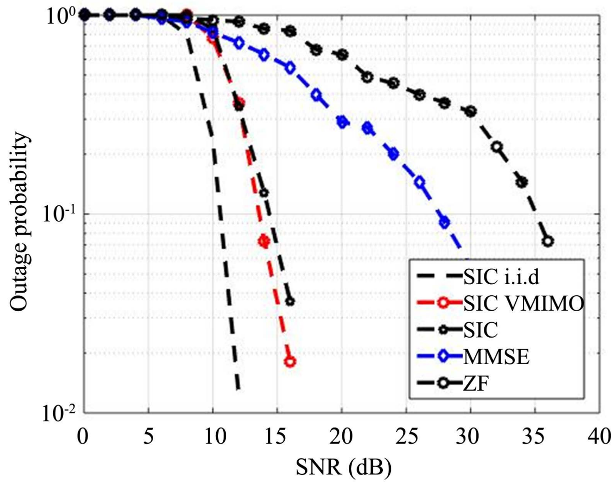

Figure 6. Outage probability versus signal to noise ratio with selected rate = 10 bits per transmission.

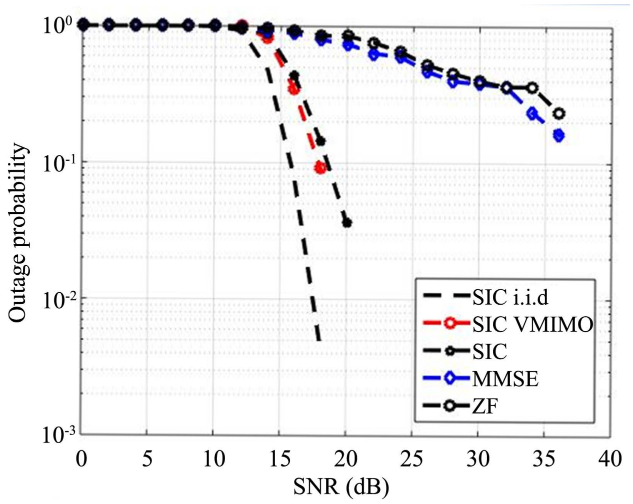

Figure 7. Outage probability versus signal to noise ratio with selected rate = 15 bits per transmission.

8. Conclusion

The performance of VMIMO multi-user is evaluated using linear precoding schemes such as SIC, MMSE and ZF. We found that the SIC achieves capacity compared to MMSE and ZF. Considering SIC linear precoding scheme, the maximum achievable rate is seen with SIC VMIMO multi-user compared to SIC SU-MIMO. We have to keep in mind that VMIMO multi-user does not always provide capacity improvement. Therefore, in many papers [12] [13] [14], it has been proved that VMIMO multi-user achieves capacity in a great proportion compared to SU-MIMO. So VMIMO multi-user is desirable over SU-MIM.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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