MIMO Antenna Selections using CSI from Reciprocal Channel

P. Uthansakul, K. Attakitmongkol, N. Promsuvana and M. Uthansakul

Abstract—It is well known that the channel capacity of Multiple-Input-Multiple-Output (MIMO) system increases as the number of antenna pairs between transmitter and receiver increases but it suffers from multiple expensive RF chains. To reduce the cost of RF chains, Antenna Selection (AS) method can offer a good tradeoff between expense and performance. In a transmitting AS system, Channel State Information (CSI) feedback is necessarily required to choose the best subset of antennas in which the effects of delays and errors occurred in feedback channels are the most dominant factors degrading the performance of the AS method. This paper presents the concept of AS method using CSI from channel reciprocity instead of feedback method. Reciprocity technique can easily archive CSI by utilizing a reverse channel where the forward and reverse channels are symmetrically considered in time, frequency and location. In this work, the capacity performance of MIMO system when using AS method at transmitter with reciprocity channels is investigated by own developing Testbed. The obtained results show that reciprocity technique offers capacity close to a system with a perfect CSI and gains a higher capacity than a system without AS method from 0.9 to 2.2 bps/Hz at SNR 10 dB.

Keywords—Antenna Selection, Capacity, Channel, Measurement, MIMO, Reciprocity.

I. INTRODUCTION

A Multiple-Input-Multiple-Output (MIMO) system recently becomes one of the most attractive techniques for the future use because it proposes an extensive improvement over conventional smart antenna systems in both Quality of Service (QoS) and the transfer rate [1-4]. However, using multiple antennas require multiple radio frequency (RF) chains which consist of amplifiers, up and down converters, digital to analog converters, etc., that are typically very expensive. A promising approach for reducing cost while retaining a reasonably large fraction of the high potential data rate of a MIMO approach appears to be to employ some form of Antenna Selection (AS) [5-8]. The AS method employs a reduced number of RF chains at the receiver (or transmitter) and attempt to optimally allocate each chain to one of a larger number of receiving (transmitting) antennas which are usually cheaper elements. In this way, only the best set of antennas is used, while the remaining antennas are not employed, thus reducing the number of required RF chains.

In literatures [9-17], the developments of AS method are classified into two main topics. At first, the algorithms to select the best subset of antennas are on focus. These algorithms may apply to either transmitter [9] or receiver [10]. The fast and precise selections are the required demand in practice. However, the success of these algorithms depends on the knowledge of CSI especially for the transmitting AS system that Channel State Information (CSI) feedback is necessarily required to be used for choosing the best subset of antennas [11-14]. Although the work presented in [15] tries to perform AS method without knowing CSI at transmitter for transmitting AS system, but the expense of many iterations degrades its attraction. For second topic, researchers pay attentions to the methods of Channel State Information (CSI) acquisitions. This is because the more exact CSI is realized, the more enhanced performance of AS method is obtained. Unfortunately, the CSI is usually not available at the transmitter so the method to realize CSI is still of important. In literatures, there are two approaches in order for the transmitter to obtain the CSI. The first approach utilizes CSI from feedback channel and the second approach is based on the reciprocity principle. In the first method, the forward channel is estimated at receiver and then it is sent back to the transmitter through the reverse channel. This method does not function properly if the channel is rapidly changed. In order to realize the correct CSI at transmitter, more frequent estimations and feedbacks are required. As a result, the overheads for the reverse channel become prohibitive. In turn, the second approach based on reciprocity does not have such a problem. Due to the reciprocity principle, it is well known that the radio propagation channel is reciprocal between two antennas. Ideally, the forward and reverse channels are assumed to be the same. Therefore, the transmitter can realize the forward CSI by estimating the reverse CSI instead. In Time-Division-Duplex (TDD) mode, the same carrier frequency is alternately used in forward and reverse channels. The propagation surrounding is not rapidly changed by time so the channel coefficients are able to be considered as similar for both directions. Based on TDD mode, the reciprocity approach is superior to any explicit feedbacks.

Recently there have been many researches concerning on channel reciprocity of a MIMO system which are based on the non-reciprocal effects between forward and reverse channel caused by any mismatches among RF components and

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interferences between transmitter and receiver [16-17]. However, from all works described in literatures [16-17], the system model is based on the assumption of that the forward and reverse channels are identical. This assumption is not practical because of the fact that fadings due to surroundings of transmitter and receiver are totally different. They cause the deviation of CSI between forward and reverse channel and it is wondered whether this deviation of non-reciprocal CSI would degrade the AS performance.

In this paper, the performances of adaptive MIMO system with AS method at transmitter based on channel reciprocity are investigated. The measured data are measured and tested by own developing Testbed based on FPGA board. In recent times, most researches move their experiments from simulations into real measurements. MIMO Testbed [18-23] is one the most comfortable platforms to realize the true performance of a proposed system under a real circumstance. For the work presented in [18-20], the performance investigations of MIMO system under indoor and outdoor have been reported through the Testbed. In [23], a transmitting AS system with an eigenbeam for MIMO-OFDM system is employed. This work achieves CSI via feedback technique and uses it to compute eigenvectors for selecting the best subset of transmitting antennas. In summary, all MIMO Testbeds presented in literatures utilize CSI from feedback channels. Moreover, some works [21-22] use a direct link to perform feedback channels which exclude any errors due to wireless operations. As far as the best survey of the authors, the issue of channel reciprocity for MIMO Testbed has never been reported in any publications. Hence, the contributions of this paper mainly fall into two issues. Firstly, the use of channel reciprocity for AS method in a MIMO system is originally demonstrated. The second contribution is on a proposed MIMO Testbed working by FPGA processors which is ready to be launched as commercial products. More importantly, it is interesting to delete the need of feedback channels by replacing reciprocity technique because this can save costs of system complexity and make the system more reliable.

In this work, the effect from the mismatches of RF components can be assumed to be neglected by using the exact same components at both transmitter and receiver. The CSI information between transmitter and receiver for using in AS method is acquired by channel emulator in which forward and reverse CSIs are measured from real propagation environments. The 2x4 MIMO channels are considered as 2x2 by AS method and then the channel capacity is calculated by computer to find the optimal subset of antennas. In addition, the comparison between feedback approach and reciprocity approach are also undertaken to provide the fair judgment with measured data. The results in this paper are helpful to realize the use of channel reciprocity in practice and its impact on channel capacity due to non-identical CSI between forward and reverse channels. The remainder of this paper is organized as follows. In Section II, the MIMO system model and two approaches estimating CSI are presented. Section III describes the channel measurement and then the testing implementation is detailed in section IV. The MIMO channel capacities are presented in Section V. Finally, the paper conclusion is given in Section VI.

II. MIMO SYSTEM MODEL

A. MIMO Channel Capacity

Considering the MIMO system which has N_T transmitting antennas and N_R receiving antennas, the formula of MIMO channel capacity is given in (1) [4]. This expression presents the averaging capacity in bps/Hz by assuming the ergodic process for channel matrix $\mathbf{H}$.

$$C = E_H \left\{ \log_2 \det \left(\mathbf{I}_{N_R} + \frac{P_T}{P_N N_T} \mathbf{H} \mathbf{H}^* \right) \right\} \tag{1}$$

where $\mathbf{I}_N$ is the $N_R \times N_R$ identity matrix, P_T is the total transmit power, P_N is the noise power, N_T is the number of transmitting antennas, N_R is the number of receiving antennas, $E_H\{\}$ is the expectation over $\mathbf{H}$ and * denotes the conjugate and transpose operation.

When AS method is employed at the transmitter or the receiver, a subset of transmitting or receiving antenna elements is chosen. The channel seen by the subset is the sub-matrix, $\mathbf{H}_{sub}$ that is obtained by selecting only the rows and columns of $\mathbf{H}$ that correspond to the selected receiving and transmitting antenna elements. The optimal subset is one that leads to the largest mutual information between the antenna elements. The capacity of MIMO system with AS is given by

$$C_{sel} = \max_{S(\mathbf{H})} \log_2 \det(\mathbf{I}_{L_R} + \frac{P_T}{P_N L_T} \mathbf{H}_{sub} \mathbf{H}_{sub}^H) \tag{2}$$

where $\mathbf{I}_{L_R}$ is the $L_R \times L_R$ identity matrix, $\mathbf{H}_{sub}$ is an $L_R \times L_T$ matrix obtained by removing $N_R - L_R$ rows and $N_T - L_T$ columns from $\mathbf{H}$ and S($\mathbf{H}$) denotes the set of all possible $L_R \times L_T$ sub-matrices of $\mathbf{H}$ that can be chosen. L_R and L_T represent the number of receiver RF chains and transmitter RF chains respectively. Please submit your manuscript electronically for review as e-mail attachments. When you submit your initial full paper version, prepare it in two-column format, including figures and tables.

B. CSI at Transmitter

As seen in Section A, the system achieves the optimal capacity when the transmitter has knowledge of the forward channel. To obtain the CSI at transmitter, there are two approaches explained as follows.

1. Feedback approach

For this approach, the receiver realizes a current CSI by channel estimation and then feeds it back to the transmitter through reverse channel. The configuration of feedback approach is shown in Figure 1.

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In Figure 1, the receiver uses the estimated channel to extract the data and to generate the feedback CSI. The feedback CSI is sent back to the transmitter using the feedback control channel. It is assumed that CSI is perfectly known at the transmitter. The transmitter, in turn, uses this information to customize the transmitted signal for the channel.

In practice, errors from feedback link which influence to channel knowledge cannot be neglected. This effect can degrade the capacity performance and it is more pronounced when feedback link contain errors excessively, under this assumption the available CSI at transmitter can be expressed as

$$\mathbf{H}_T = \mathbf{H} + \boldsymbol{\varepsilon}_E + \boldsymbol{\varepsilon}_F \tag{3}$$

Or

$$\mathbf{H}_T = \mathbf{H}_{ES} + \boldsymbol{\varepsilon}_F \tag{4}$$

where $\mathbf{H}$ is the forward channel, $\mathbf{H}_T$ is the available CSI at transmitter, ε_E and ε_F are $N_R \times N_T$ errors matrix from estimation and error matrix from feedback link, respectively and $\mathbf{H}_{ES}$ is the channel matrix which is achieved by channel estimation.

2. Reciprocity Approach

According to the principle of reciprocity, the forward and reverse channels are identical when the time, frequency and antenna locations are the same. Based on the principle, the transmitter may use the CSI obtained by the reverse link for the forward link. In practice, the forward and reverse channels are not truly identical because of the effect of channel fading, noises and environments. The CSI known at transmitter can be given by

$$\mathbf{H}_T = \mathbf{H} + \boldsymbol{\varepsilon}_E + \boldsymbol{\varepsilon}_R \tag{5}$$

where ε_R is the $N_R \times N_T$ channel reciprocity error matrix realized by measurements.

III. CHANNEL MEASUREMENT

The configuration of 2x4 MIMO system is shown in Figure 2, which network analyzer, power amplifier (PA) module, low-noise-amplifier module (LNA) and monopole antennas with 5 dBi gain are used. As seen in Figure 2, the PA module is used at transmitter to provide more transmitted power. As same as transmitter, the LNA module is used to increase the received signal level. The channel coefficients in both magnitude and phase are measured by network analyzer. The data was measured by 5 times per location. In each time, the 100 samples of channel data were recorded continuously within 1.5 seconds. However, we did not continue recording all 5 times in one round. The sequence of recording starts from Location 1 (100 samples) and then moves to Location 2 (100 samples) until Location 5 (100 samples). This sequence is called as one set. In the first day, we did two sets of measurements and the other three sets were done on the
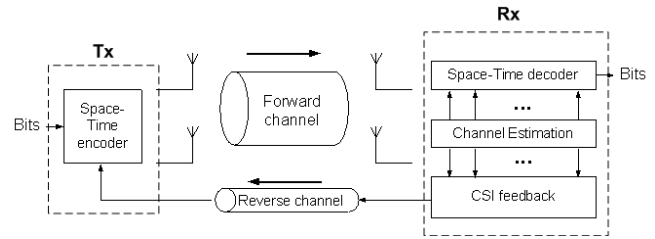

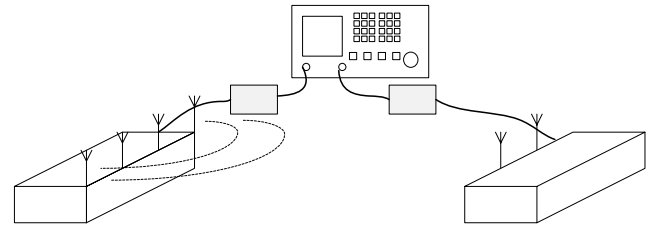Fig. 1 MIMO model with a feedback channel.

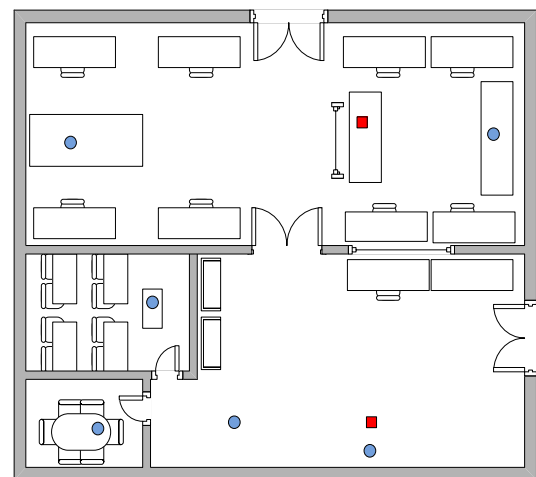

Fig. 2 Measurement set up.

Fig. 3 Map of a measured area.

second day. In summary, 500 samples per location were collected over two days. In order to mitigate the effect of measurement noises, the function of network analyzer, called as smoothing command, is used to average the measured data over specific time. In this work, the specific time is the default operation at 10 ms. It means that each recorded sample is an averaging result over 10 ms.

For the measured area, we choose the large office room to provide many cases of study. Figure 3 shows the map of office room. The circular markers are referred to the locations where the measurement is undertaken. There are five measured locations. In each location transmitter and receiver are switched in order to measure the forward and reverse channel. Although, it is easier to measure both forward and reverse channels by switching transmitted port in network analyzer but the effect of non similarity of PA and LNA including feeding cables might differ the measured channel from the real

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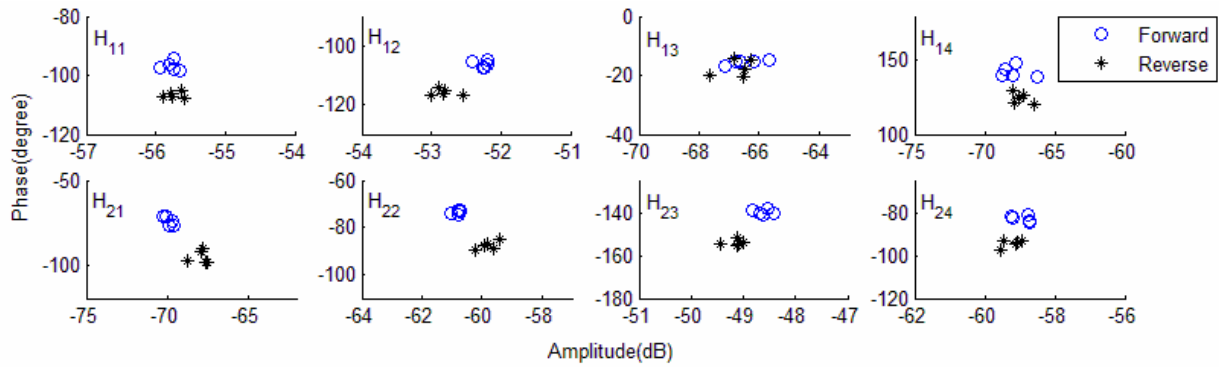Vol:4, No:8, 2010

Fig. 4 Example of forward and reverse channels, measured at Location 4.

results. Therefore, we choose to switch all parts of transmitter and receiver in order to avoid any false outcomes. The switching time between transmitter and receiver is at least 20-30 seconds. In [24], the coherence time, which is the minimum interval that two signals are uncorrelated, is 21.2 ms. It means that the time interval between Tx frame and Rx frame of TDD mode must be longer than this coherence time. Hence, the measured forward and reverse channels are acceptably considered under the same criteria for TDD mode.

Figure 4 shows an example of each element of 2×4 channel matrix at Location 4, where H_{ij} refers to the channel coefficient of ith receiving antenna and jth transmitting antenna. It can be observed that both forward and reverse channels are similar but not the same. The amplitude deviation is about ±2 dB and the phase deviation is about $\pm15^{o}$. These deviations were ignored in all works presented in literatures [16-17]. The result is important to realize how these deviations influence to the practical performance. As seen in Figure 4, the variation of measured data is very small because the environments seem to be a static channel. Hence, the results are grouped into two clusters, forward and reverse channels. However, the forward and reverse channels are not identical as expected because the surroundings of transmitter and receiver are different. For other locations, the deviations of amplitude and phase are similar to Location 4.

In addition, the correlation coefficients evaluated from measurements are 0.62, 0.325, 0.9, 0.52 and 0.73 for Location 1, Location 2, Location 3, Location 4 and Location 5, respectively. These values conclude that Location 2 is the most suitable area for MIMO operation because it has the lowest correlation coefficient in comparison with other locations. Then it is expected that Location 2 should offer more capacity than other locations as well. In turn, the capacity performance of Location 3 is expected to be poor due to its high correlation.

IV. TESTBED IMPLEMENTATION

A. Antenna Selection (AS) Technique

The capacity of MIMO system employing AS technique is described in (2), however this work concerns only the case of AS known at the transmitter. In order to find the optimal subset from knowing of only CSI at transmitter modeled in (3)

and (5) for feedback and reciprocity approaches respectively, the conventional technique is applied by searching all possible subsets of antennas and then select the best subset providing the highest capacity. As a result, the formula of MIMO channel capacity with AS technique at transmitter can be given by

$$C_{sel} = \max_{S(\mathbf{H}_T)} \log_2 \left[\det\left(I_{L_R} + \frac{p}{L_T} \mathbf{H}_{T,sub}\mathbf{H}_{T,sub}^{H} \right) \right] \quad (6)$$

Where $\mathbf{H}_{T,sub}$ is the $N_R \times L_T$ sub-matrix (AS at transmitter) of CSI ($\mathbf{H}_T$) obtained by feedback or reciprocity approaches.

It must be noticed that by using CSI in (6) to find the optimal subset of antenna, the differences between $\mathbf{H}_T$ and $\mathbf{H}$ ($\mathbf{H}_T \neq \mathbf{H}$) cause directly to the capacity performance in (2) due to implementing errors from either feedback or reciprocity channels. In this work, the exhaustive search is applied to find the best antenna subset from all possible cases. Although there are many algorithms proposed in literature to select the antenna subset but the best solution is still the same as exhaustive search. Only fast processing and low complexity are the benefits of other algorithms. The purpose in this work is to investigate the performance of reciprocity channels in comparison with feedback channels so the same conclusion should be found for any AS methods.

B. Design of Developing Testbed

This work chooses Field Programmable Gate Array (FPGA) technology to implement 2x4 MIMO Testbed because FPGAs processing were introduced as promising alternative to custom ICs for implementing entire system on one chip and to provide flexibility of re-program ability to the user. All functions are constructed inside FPGA boards including the AS method at transmitter where 2 transmitting antennas are selected. Hence, the system requires only 2 transmit and 2 receive components such as Analog to Digital Converter (ADC), Digital to Analog Converter (DAC). The block diagram of FPGA boards can be shown in Figure 5. As seen in Figure 5, RF components of transmitter and receiver have been replaced by using channel emulator. The concept of channel emulator has been adopted in many publications [21-22] in order to simulate the various

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conditions of channel collected by real measurements. Another point of using channel emulator is to save cost of RF components because the boards can be functionally tested before passing through the production line.

In this work, we use Spartan 3An starter kit boards from Xilinx Company to implement transmitter and receiver which is explained as follows. Note that both transmitter and receiver boards shown in Figure 5 have the same components of transmitter and receiver to perform full duplex communication. However, we name the direction from transmitter board to receiver board as forward channel and the other direction as reverse channel.
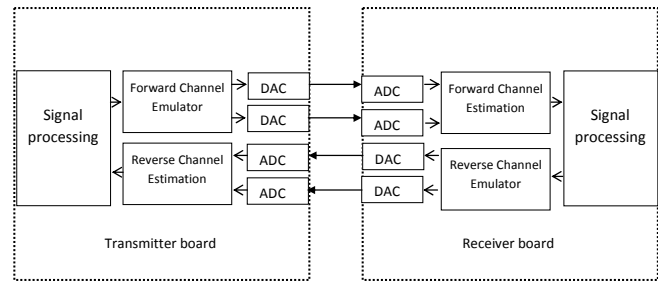
1. Transmitter

The configuration of transmit system is shown in Figure 6. The series of bit information are generated and then it is fed to the de-multiplexer to convert from series to parallel bit information. After that it is modulated by BPSK modulation with frequency 12.5 kHz, bit 1 and bit 0 are represented by phase 0° and 180° respectively. The BPSK signal is fed to the channel emulator which acts as wireless communication channel. Finally, the signals from channel emulator are converted to analog signals which are sent to receiver board.
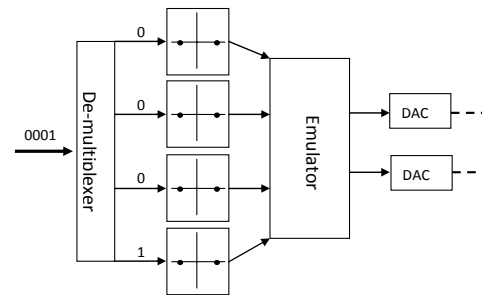
2. Receiver

The received analog signals from transmitter are fed to the channel estimation block to estimate the CSI which is used to select the optimum subset of antennas in AS method. The estimated CSI is shown via chip scope pro software on PC which is connected to the receiver board.
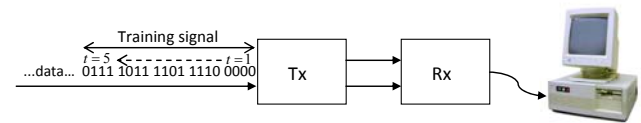
C. Channel Estimation Methods

To obtain CSI at both transmitter and receiver, we develop the simple technique to estimate CSI and it can reduce the complexity of hardware implementation. Considering MIMO system which has 4 transmitting antennas and 2 receiving antennas, the set of training sequence is specified in Figure 7. To understand the principle of channel estimation, first we have to understand the layout of communication in 2x4 MIMO which can be written as

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{1,1} & h_{1,2} & h_{1,3} & h_{1,4} \\ h_{2,1} & h_{2,2} & h_{2,3} & h_{2,4} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} \qquad (7)$$

As seen in Figure 7, then the received signal at each receiving antenna at t time duration can be shown as

$$y_1(t) = h_{1,1}x_1(t) + h_{1,2}x_2(t) + h_{1,3}x_3(t) + h_{1,4}x_4(t)$$

and

$$y_2(t) = h_{2,1}x_1(t) + h_{2,2}x_2(t) + h_{2,3}x_3(t) + h_{2,4}x_4(t)$$

Let S_0 and S_1 are defined by BPSK signals representing 0 and 1 bit modulation respectively, then the channel coefficient can be calculated by

Fig. 5 System diagrams of transmitter and receiver.

Fig. 6 Configuration of a transmitting system.

Fig. 7 Pattern of a training signal.

$$h_{k,t-1} = \frac{y_k(t=1) + y_k(t)}{2|S_0|} \qquad (8)$$

In this work, eq. (8) is used to implement on FPGA and it is help to estimate both forward and reverse CSI. Accordingly, these estimated CSIs are used in AS algorithm mentioned earlier.

D. Test Results

To complete testing system, channel emulators are operated for both forward and reverse channels. These channel information are determined by real measured data and programmed on FPGA boards. The obtained results are collected for the case of AS method, which is employed at only transmitter. Personal computers are connected to the transmitter and receiver to provide programmable interface and capture all concurrence data. Moreover, the oscilloscope is used to capture a real signal coming from any concerned ports in order to compare signal from both forward and reverse channels.

To implement channel emulators for both forward and reverse channels, the measured data described in Section 3 is used. However, channel information matrices from

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measurements have to be multiplied and divided with a constant value in order to adjust a suitable level for ADC and DAC specifications. This is to avoid the unwanted effect due to low sensitivity of ADC or DAC, which it causes a signal error at receiver. Also, by multiplying or dividing channel information matrices with a constant value, it does not change the property of channel characteristics.

Figure 8 shows an example of channel information of forward channel at Location 1 which is obtained by channel estimation and it is shown by Chip scope pro software. As seen in Figure, a_Hij and p_Hij refer to estimated amplitude and phase of channel coefficient of i th row and j th column respectively (Each amplitude are in ADC's based values and theses values must be convert to the actual value before use). The estimated forward and reverse channels have the similar channel responses and there are some phase and amplitude errors between forward and reverse channel for any locations. These errors are occurred by non-identical property of forward and reverse channels. However the other errors due to hardware such as DAC and ADC have been already considered and included in the results. After capturing by both Chip scope pro software as well as real oscilloscope, the channel emulators implemented on FPGA boards properly provide the correct forward and reverse channels realized by measurements. Figure 9 shows an example of comparison in complex form between forward and estimated forward channel matrix by using one sample of channel data at Location 1. The estimated forward and forward channels are similar in terms of real and imaginary parts. Although the deviations are still valid, these are very little in comparison with the errors between forward and reverse channels depicted in Figure 4. Therefore, the channel estimation implemented in the Testbed works very well and ensures the correct achievement of CSI from available sources, either feedback or reciprocity approaches.

V. RESULTS AND DISCUSSION

All capacity results in this section are off-line produced on computer by using real AS outcomes from Testbed selections mentioned in the previous section. Therefore, these capacities can be compared with various system conditions including Rayleigh propagation channel and perfect CSI system which are hardly measured in real scenarios. The MIMO channel capacities are computed by MATLAB programming when AS methods are employed by using (2) and (6). Note that $\mathbf{H}_T$ of forward and reverse channels are obtained by Testbed system. For feedback approach, at first we assume that there is no feedback error in feedback channel and then at the end of this section the effect of this error will be illustrated. The simulations disregard the mismatches of RF circuits in transmit/receive components as well as mutual coupling effects because they are included in one part of channel measurements.

The capacity performances are base on Cumulative Distribution Function (CDF) at SNR=10dB by using 500 samples of the collected channel data and they are illustrated into five cases, Rayleigh channel, AS with feedback channel, AS with perfect CSI, AS with reciprocity channel and no use
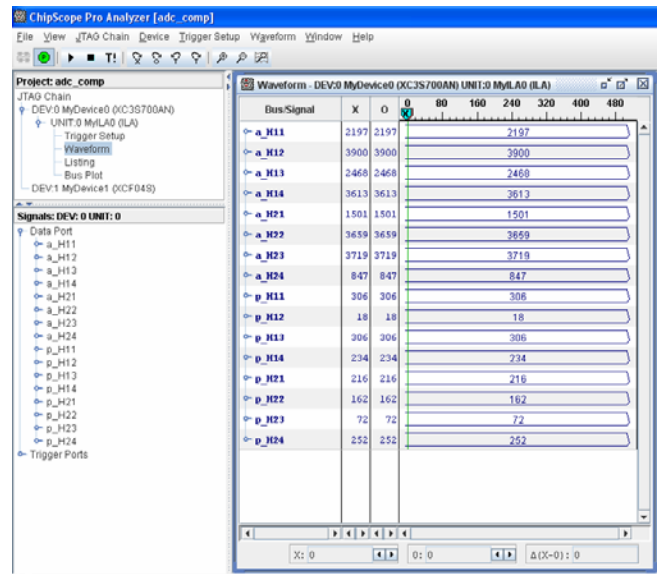

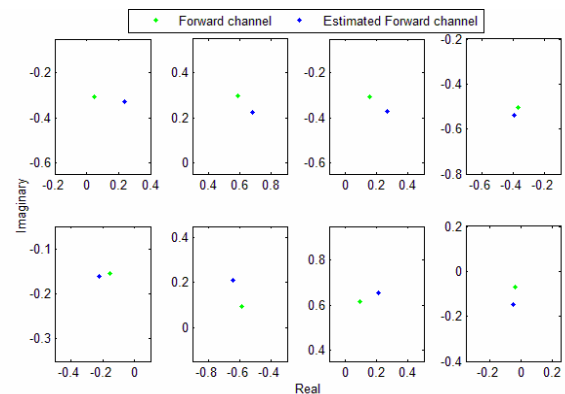Fig. 8 Example of channel information obtained by own developing channel estimation.

Fig. 9 The comparison example between forward and estimated forward channels at Location 1.

of AS method. In case of no antenna selection, the first and second transmitting antennas are used to transmit signals for any locations. For sake of comparison, the channels are normalized to provide a comparable discussion by $\sum|\mathrm{H}_{ij}|^2 = N_T N_R$ which limits total channel energy to one constant value. This normalization is done in order to compare channel properties between various conditions by neglecting the effect of path loss. All details of five cases are explained as follows.

- *Rayleigh channel* : this case represents the capacity of 2x2 MIMO system when wireless channel acts as Rayleigh fading channel which is random channels over 10,000 times.

- *No Antenna Selection :* this case represents capacity of 2x2 MIMO system when there is no selection at transmitter where the first and second antenna elements are used to transmit signals.

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- *AS with Feedback* : this case represents the capacity when the CSI from feedback approach is used to select transmitting antennas in AS technique. Two of four transmitting antennas are optimally chosen to offer the best capacity.
- *AS with perfect CSI* : this case represents the capacity when the CSI is assumed to be perfectly known at transmitter. Hence, the selected transmitting antennas in AS technique are ideally optimal corresponding with the wireless channels. There is no error taken into account so the capacity is computed by using (2).
- *AS with Reciprocity* : this case represents the capacity when the CSI from reciprocity approach is used to select transmitting antennas in AS technique.

As mentioned in Section III, there are five measured locations in which the channels are collected. The surrounding of each location is so different that the capacity results are considerably separated into each location to make a fair judgment on all approaches.

Location 1 As seen in Figure 10, the cumulative distribution function of capacity for AS methods with reciprocity and feedback approaches are close to a perfect CSI case where a feedback case is slightly better than a reciprocity case. The results of reciprocity case provide a performance gain 1 bps/Hz higher than Rayleigh at 50% probability. For this reason, it can be explained that the measured channels at Location 1 might be captured in the area above 50% probability of Rayleigh distribution. However, at 95% probability, the AS methods based either feedback or reciprocity reach the same performance as Rayleigh. In addition, AS method with reciprocity give a performance gain 1.15 bps/Hz higher than a system without AS method at 50% probability.

Location 2 In Figure 11, the cumulative distribution function of capacity for no AS method, AS methods with reciprocity and feedback cases are close to a perfect CSI case and they provide a performance gain up to 1.3 bps/Hz higher than a case of Rayleigh at 50% probability. It is interesting to observe that no AS method provides a performance close to a perfect CSI case at this location. The reason is that no AS method always fixes the first and second transmitting antennas to operate a 2x2 MIMO system which is the best subset of antenna selections.

Location 3 Figure 12 shows the cumulative distribution function of capacity at Location 3. In this location, the interesting point is that a Rayleigh case gives the highest capacity at 50% probability while a Rayleigh case is lower than a perfect CSI case for the other locations. It is also noticed that the performance of a reciprocity case seems to fail on selecting the best subset because the difference of reciprocity and feedback approaches is very large. In this response, the authors generate the other cases with the fixed transmitting antennas to closely investigate this outcome. The presented dot line with (*x,y*) is defined as a system with no AS method which always use *x*th and *y*th transmitting antennas to perform 2x2 MIMO operation. The results indicate that a reciprocity case still offers a higher capacity than all cases of no AS method. It is implied that the AS method still works
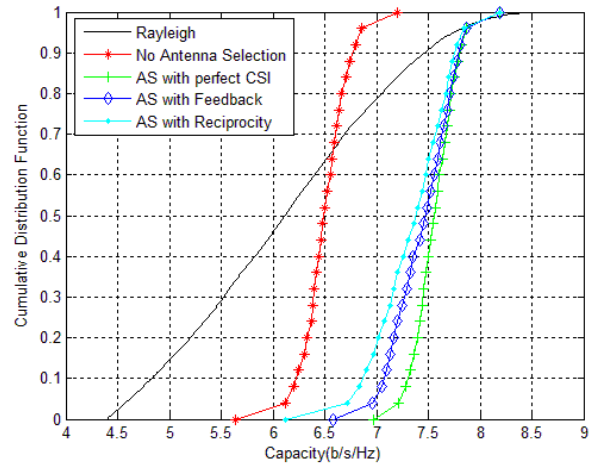

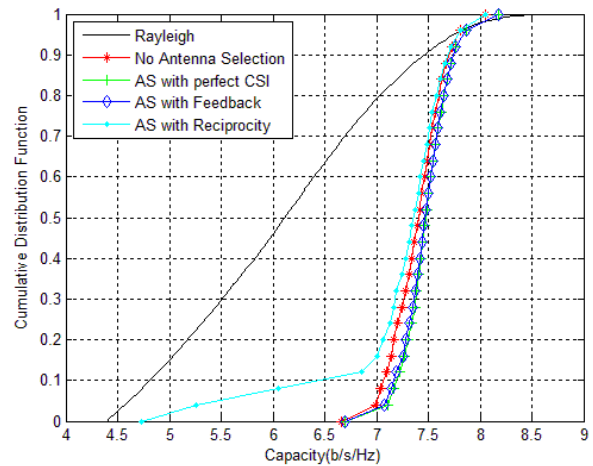Fig. 10 The cumulative distribution function of capacity at Location 1.

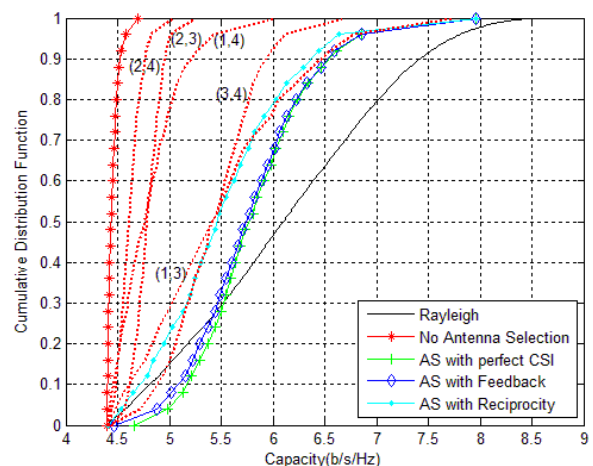Fig. 11 The cumulative distribution function of capacity at Location 2.

Fig. 12 The cumulative distribution function of capacity at Location 3.

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well based on a reciprocity channel. Hence, the poor performance of a reciprocity case in this location is due to only the property of channel which is a direct LOS communication illustrated in Figure 3. The results confirm the well known conclusion that a MIMO capacity in a dominant LOS signal is less than in a Rayleigh channel.

Location 4 The aim of measuring at this location is to investigate the channel property when there are obstructions between transmitter and receiver, in comparison with Location 3. As shown in Figure 13, the cumulative distribution functions of capacity for AS methods with reciprocity and feedback cases are similar and close to a perfect CSI case after 50% probability. The capacity results of AS methods in this location are higher than the results at Location 3 which confirms the conclusion mentioned in Location 3. For Location 4, the use of AS method with reciprocity can provide 2.2 bps/Hz higher than a case of No AS method at 50% probability.

Location 5 As noticed in Figure 14, the results of AS method with reciprocity seem to fail on selecting the best subset of antennas as same as in Location 3. However, the authors did the other cases of fixed transmitting antennas and achieved the same conclusion that AS method with reciprocity still provide a higher capacity than all cases of no AS methods. However, the difference of reciprocity cases between Location 3 and Location 5 is that the capacity of Location 5 is higher than a Rayleigh channel. This can be described by the surrounding around transmitter and receiver are very different and its cause more scattering than Location 3.

In summary, a system using AS method with reciprocity always gives the performance better than a system without AS method while it is slightly less than feedback and perfect CSI cases. However, for AS method with feedback, the presented results are based on the exclusion of any errors in a feedback channel in which these errors are compulsorily occurred in practice due to channel delays and feedback noises. As a result, it is also necessary to examine the effect of feedback errors on capacity performances.

In order to investigate feedback errors included in feedback channel, this work assumes that the model of feedback error (ε_F from (3)) is given by

$$\varepsilon_F = \sigma \mathbf{H}_{i.i.d.} \tag{9}$$

where $\mathbf{H}_{i.i.d.}$ is i.i.d. (Independent Identically Distributed) channel matrix with zero mean and unit variance, σ^2 is the variance of feedback errors ε_F.

Figure 15 shows the effect of feedback errors on capacity performance of AS method at Location 5. It is obviously seen that errors degrade the capacity performance as a function of error variance. Also seen in the figure, the capacity performance of AS method with feedback is worse than a reciprocity case when the error variance in a feedback channel is more than 0.4. The results indicate the tradeoffs between using reciprocity and feedback approaches. If the variance of
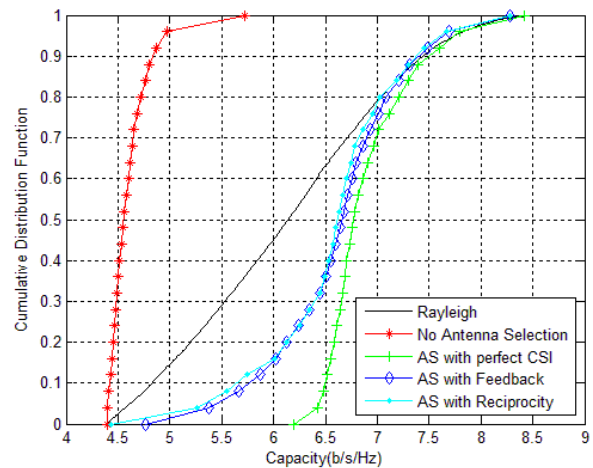

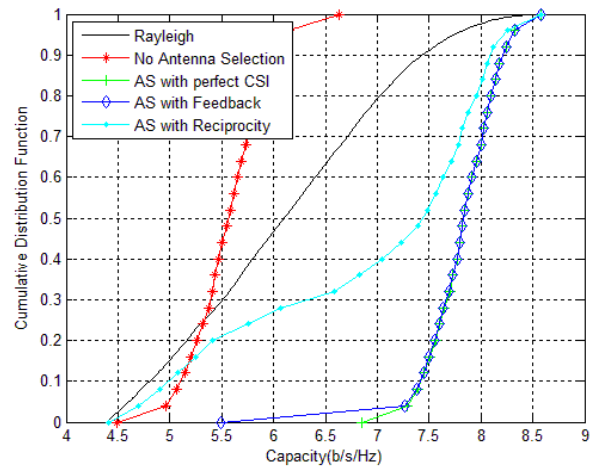Fig. 13 The cumulative distribution function of capacity at Location 4.

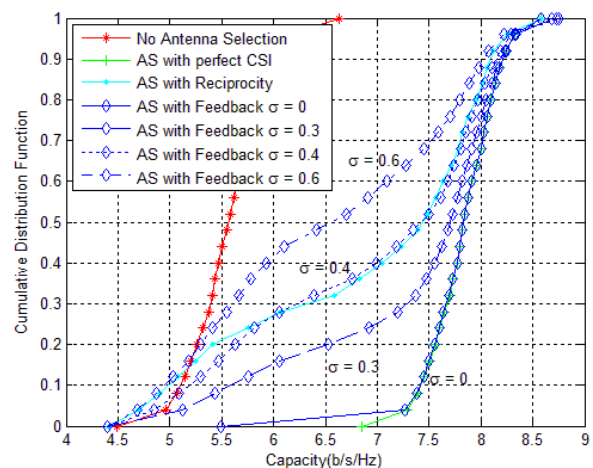Fig. 14 The cumulative distribution function of capacity at Location 5.

Fig. 15 The cumulative distribution function of capacity with the present of feedback error at Location 5.

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feedback errors is higher than 0.4, the reciprocity approach might be more attractive than feedback with the benefit of low complexity.

VI. CONCLUSION

This paper presents the performance of adaptive 2x4 MIMO system when AS technique is employed at transmitter using channel reciprocity realized by the measured data. The experimental results reveal that antenna selection using channel reciprocity provides the capacity performance slightly less than perfectly knowing CSI at transmitter. In addition, the system using AS method with reciprocity approach offers higher capacity than system without antenna selection for all locations. Instead of feedback approach, the reciprocity does not require any information sent back to the other side. Therefore, the proposed system can properly be an attractive choice to replace the feedback system with the less complexity.

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REFERENCES

[1] Murch R.D., Letaief K.B., Antenna systems for broadband wireless access, *IEEE Communications Magazine* 2002; 40(4) : 76-83.
[2] Wong K.K., Murch R.D., Letaief K.B., Performance enhancement of multiuser MIMO wireless communications systems, *IEEE Transactions on Communications* 2002; 50(12) : 1960-1970.
[3] Foschini G.J., Gans M.J., On limits of wireless communications in a fading environment when using multiple antennas, *Wireless Personal Communications* 1998; 6(3) : 311-335.
[4] Telatar I.E., Capacity of multiantenna Gaussian channels, *AT&T Bell Laboratories*, Tech. Memo. 1995.
[5] Kong N., Milstein L.B., Combined average SNR of a generalized diversity selection combining scheme, *IEEE International Conference on Communications* 1998; 3 : 1556-1560.
[6] Win M.Z., Winters J.H., Analysis of hybrid selection/maximalratio combining in Rayleigh fading, *IEEE Transactions on Communications* 1999; 47 : 1773-1776.
[7] Win M.Z., Winters J.H., Analysis of hybrid selection/maximal-ratio combing of diversity branches with unequal SNR in Rayleigh fading, *IEEE Vehicular Technology Conference Proceedings* 1999; 215-220.
[8] Win M. Z., Beaulieu N. C., Shepp L. A., Logan B. F., Winters J. H., On the SNR penalty of MPSK with hybrid selection/maximal ratio combining over IID Rayleigh fading channels, *IEEE Transactions on Communications* 2003; 51(6) : 1012-1023.
[9] Molisch A., Win M.Z., Winters J.H., Capacity of MIMO systems with antenna selection, *IEEE International Conference on Communications* 2001: 570-574.
[10] Nabar R., Gore D., Paulrai A., Optimal selection and use of transmit antennas in wireless systems, *IEEE International Conference on Telecommunications* 2000.
[11] Blum R.S., Winters J.H., On optimum MIMO with antenna selection, *Communications Letters* 2002; 6(8) : 322-324.
[12] Dai L., Sfar S., Letaief K.B., Optimal antenna selection based on capacity maximization for MIMO systems in correlated channels, *IEEE Transactions on Communications* 2006; 54(3) : 563-573.
[13] Heath R.W., Jr., Paulraj A.J., Antenna selection for spatial multiplexing systems based on minimum error rate, *IEEE International Conference on Communications*; 2276-2280.
[14] Ghrayeb A., Duman T.M., Performance analysis of MIMO systems with antenna selection over quasi-static fading channels, *IEEE Transactions on Vehicular Technology* 2003; 52(2) : 281-288.
[15] Yangyang Zhang, Gan Zheng, Chunlin Ji, Kai-Kit Wong, Edwards D.J., Tiejun Cui, Near-optimal joint antenna selection for amplify-and-forward relay networks, *IEEE Wireless Communications & Signal Processing* 2009: 1-5
[16] Jiann G., Ching G., Larsson L. D., Modeling and evaluation of MIMO systems exploiting channel reciprocity in TDD mode, *IEEE Vehicular Technology Conference Proceedings* 2004; 6: 4265-4269.
[17] Tolli A., Codreanu M., Compensation of interference non-reciprocity in adaptive TDD MIMO-OFDM systems, *International Symposium on Personal, Indoor, and Mobile Radio Communications* 2004; 2: 859-863.
[18] Kim D., Torlak M., Rapid prototyping of a cost effective and flexible 4×4 mimo testbed, *IEEE Sensor Array and Multichannel Signal Processing Workshop* 2008: 5-8.
[19] Nishimori K., Kudo R., Honma N., Takatori Y., Ohta Atsushi., Okada K., Experimental evaluation using 16 × 16 multiuser MIMO testbed in an actual indoor scenario, *IEEE Antennas and Propagation Society International Symposium* 2008: 1-4.
[20] Azami F., Ghorssi A., Hemesi H., Mohammadi A., Abdipour A., Design and implementation of a flexible 4×4 MIMO testbed, , *International Symposium on Telecommunications* 2008: 268-272.
[21] Chen S., Jun C., Ohira T., Handbook on Advancements in Smart Antenna Technologies for Wireless Networks, *Information Science Reference* 2009: 474-499.
[22] Uthansakul P., Bialkowski K., Bialkowski M., Postula A., Assessing an FPGA Implemented MIMO Testbed with the Use of Channel Emulator, *International Conference on Microwaves, Radar and Wireless Communications* 2006: 410-413.
[23] Onizawa T., Ohta A., Asai Y., Experiments on FPGA-Implemented Eigenbeam MIMO-OFDM With Transmit Antenna Selection, *IEEE Transactions on Vehicular Technology* 2009: 1281-1291.
[24] Heather MacLeod, Chris Loadman, Zhizhang (David) Chen, Experimental Studies of the 2.4-GHz ISM Wireless Indoor Channel, 3rd *Annual Communication Networks and Services Research Conference*, 2005, 63-68.

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