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Investigation on Precoding Techniques in E-UTRA and Proposed Adaptive Precoding Scheme for MIMO Systems

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Abstract- **Codebook based multiple-input multiple-output (MIMO) precoding can significantly improve the system spectral efficiency with limited feedback and has been accepted as one of the most promising techniques for the Evolved UTRA (E-UTRA). In this paper, firstly, we investigate precoding techniques through system-level simulation in E-UTRA environment including various precoding modes, precoding methods and codebooks. Then, to further exploit the system performance in universal environments, an adaptive MIMO precoding scheme is proposed, in which different precoding modes including single-user MIMO (SU-MIMO) and multiple-user MIMO (MU-MIMO), precoding methods including unitary precoding (UP) and zero-forcing beamforming (ZF-BF) for MU-MIMO, and codebooks including Grassmannian codebook and DFT codebook for MU-MIMO with ZF-BF, are semi-statically switched based on long-term information, system load and channel statistics. Particularly, the proposed scheme is much feasible for practical systems and the increase of signaling overhead can be negligible. Finally, it can be seen from the simulation results that, compared with conventional schemes with fixed precoding technique, proposed adaptive scheme can yield much improvement on spectral efficiency.**

Key words- **Adaptive precoding, MIMO, codebook, SU-MIMO, MU-MIMO, Unitary Precoding, Zero-forcing beamforming**

I. INTRODUCTION

Multiple-input multiple-output (MIMO) technology, through the use of multiple antennas at the transmitter and receiver sides, has been an area of intense research for its promise of increased spectral efficiency and reliability. By applying multiplexing and diversity techniques, MIMO technology exploits the spatial components of the wireless channel to provide capacity gain and increased link robustness. Closed-loop techniques obtain these benefits by adapting the transmit signal using downlink channel knowledge [1]. Optimal precoding, however, require perfect transmit knowledge of downlink channel. This can obtain using reciprocity of the channel in certain scenarios, e.g. time division duplex (TDD). In most case, feedback channel is necessary for conveying limited channel state information (CSI) to the transmitter [2-5].

A general approach for obtaining a precoding vector at the transmitter is limited feedback - quantization of channel information or precoding matrix at the receiver and sending it to the transmitter using a low bandwidth feedback channel. Characterizing the performance of such “closed-loop” limited feedback MIMO systems is, therefore, critical. Limited feedback precoding algorithms work by using beamforming vectors that is designed off-line [2-5]. Codebook based MIMO precoding can significantly improve the system capacity with limited feedback. It is accepted as one of the most promising techniques for E-UTRA [6-9].

In this paper, firstly, we investigate precoding techniques through system-level simulation in E-UTRA environment including various precoding modes, precoding methods and codebooks. Then, to further exploit the system performance in universal environments, an adaptive MIMO precoding scheme is proposed, in which different precoding modes including SU-MIMO and MU-MIMO, precoding methods including UP and ZF-BF for MU-MIMO, and codebooks including Grassmannian codebook and DFT codebook for MU-MIMO with ZF-BF, are semi-statically switched based on long-term information, system load and channel statistics.

The organization of this paper is as follows. System and channel models are introduced in section II; Codebook based MIMO precoding schemes are given in section III; Precoding techniques are investigated in section IV; Adaptive precoding scheme is proposed and analyzed in section V; and the conclusions are drawn in section VI.

II. SYSTEM AND CHANNEL MODELS

Consider a narrowband, frequency non-selective, Rayleigh fading MIMO channel with M_t transmit and M_r receive antennas. If s is the transmit vector of dimension M_t, then the M_r dimensional received signal x can be written as

$$x = HWs + n \tag{1}$$

where H is the $M_r \times M_t$ channel matrix coupling the transmitter and receiver antennas. W is the precoding matrix, composed of the precoding vectors selected from the codebook. n is the M_r dimensional noise vector, which is assumed to be zero mean, complex white Gaussian with covariance matrix $\sigma^2 I_Q$.

$$H = R_r^{1/2} H_{i.i.d} R_t^{1/2} \quad (2)$$

where $H_{i.i.d}$ contains independent complex i.i.d complex Gaussian entries with zero mean and unit variance, and R_t and R_r denote the transmit and receive spatial correlation matrices, respectively.

As we know, the spatial correlation depends on many physical parameters which include antenna geometry, angular spreading function and path distribution, the last two of which are dependent on the propagation environment [10]. In this paper, we assumed R_r is identity matrix and just consider the transmit spatial correlation, and it is straight forward when R_r is not identity matrix. The spatial correlation can be acquired either by uplink-downlink reciprocity of the second-order statistics or via very low rate feedback channel. Both of the above two methods can be used, and in this paper, we adopt the latter as an example.

III. Codebook Based MIMO Precoding Schemes

Closed loop MIMO transmission schemes can be classified into two modes: SU-MIMO and MU-MIMO. As shown in Fig.1, in SU-MIMO only a single user is scheduled on all MIMO layers within a resource block (RB) [6]. In a MU-MIMO spatial multiplexing scheme, multiple users are scheduled in the same RB [7-9]. SU-MIMO is adopted to maximize the peak data rate while MU-MIMO is used to maximize the system spectral efficiency.

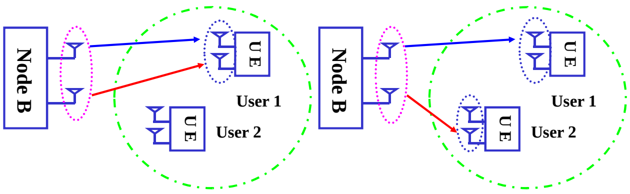


Fig. 1(a) SU-MIMO mode **Fig. 1(b)** MU-MIMO mode

In closed loop MU-MIMO, channel knowledge of the different UEs is exploited to schedule multiple UEs on the same RBs. Multiplexed UEs on the same RBs can be separated in the spatial dimension by designing appropriate transmit and receive antenna weight vectors. Under limited feedback conditions, quantized version of the MIMO channels or precoding matrix is fed back by each UE to the Node B instead of the perfect information.

There are two categories of MU-MIMO precoding schemes, UP and ZF-BF [7-9] discussed in E-UTRA. In both of the two schemes, UE will feed back channel quality indicator (CQI), and Node B will determine which UEs are selected to share the same RB and transmit data. But there are also differences between these two precoding schemes.

As shown in Fig. 2, in UP, each UE reports its preferred precoding vector index (PVI) and preferred precoding matrix index (PMI) together with CQI. The separation of multi-user interference is done at UE, and the number of multiplexed streams is limited by the number of UE receive antenna. Moreover, the performance suffers from user pairing problem.

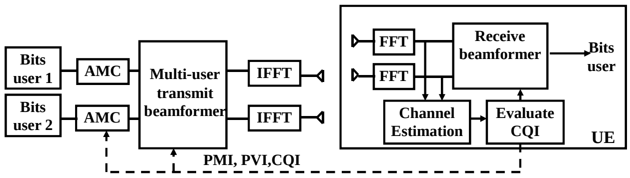


Fig. 2 MU-MIMO Unitary Precoding

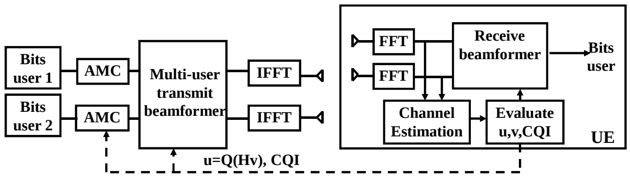


Fig. 3 MU-MIMO ZF-BF

While in ZF-BF as shown in Fig.3, each UE reports its quantized channel together with CQI. The separation of multi-user interference is done at Node B. In Fig. 3, the codeword u is selected from a codebook for each RB to best represent the vector quantity Hv where v is the receive beamformer and H is the channel matrix corresponding to the RB. This mapping is represented by vector quantization function $Q(\bullet)$ in Fig. 3. Moreover, for MU-MIMO with ZF-BF, two kinds of codebook, Grassmannian codebook and DFT codebook [7-9], can be utilized for quantization of channel vector.

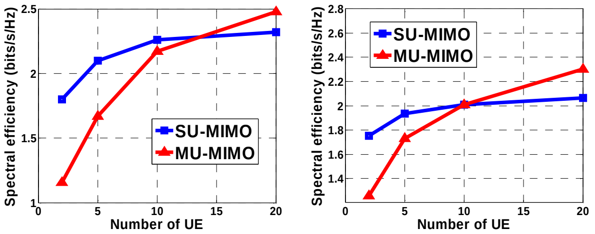
IV. Investigation on Precoding Techniques

In this section, we investigate various precoding techniques for E-UTRA through system-level simulation, including various precoding modes, precoding methods and codebooks. Table 1 gives the major parameters in the system-level simulation. In addition, for SU-MIMO, rank adaptation is adopted [6]. For MU-MIMO, DFT codebook (2 bits) is used for UP, and DFT codebook and Grassmannian codebook (UE 3bits, Node B 4bits) are used for ZF-BF [7-9].

1. SU/MU MIMO

In Fig. 4, we present the comparison of spectral efficiency between SU-MIMO and MU-MIMO under different spatial correlation and number of UE.

It can be seen that when number of UE is small, SU-MIMO performs better than MU-MIMO, however when number of UE increases, MU-MIMO improves spectral efficiency greatly and performs better than SU-MIMO. The reason is that due to limited feedback, UE pairing, i.e., only the UEs with same PMI but different PVI can be paired, is a big problem for MU-MIMO, especially when the number of UE is small. When UEs can not be paired, only single stream can be transmitted and spatial multiplexing gain is lost. However, UE pairing problem is vanished when the number of UE is large enough, and MU-MIMO can outperform SU-MIMO due to increased degree of freedom, i.e., spatial domain, for user scheduling.



(a) Spatial correlation=0 **(b)** Spatial correlation=1

Fig. 4 SU/MU MIMO performance under different spatial correlation environments

Moreover, it can be seen from Fig. 4 (a) and Fig. 4 (b) that the crossing point (number of UE) between SU-MIMO and MU-MIMO varies, depending on the channel correlation. It is reduced with spatial correlation increased. This is because as the spatial correlation increases, SU-MIMO could support less data streams than MU-MIMO. Especially when spatial correlation is equal to 1, SU-MIMO can only support single data stream, while MU-MIMO can support multiple users. So the gain of MU-MIMO related to SU-MIMO for large number of UE is increased for high transmit correlation scenario.

2. Unitary precoding and ZF-BF for MU-MIMO

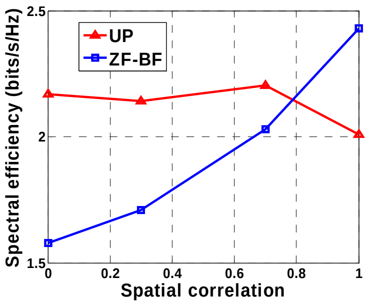


Fig. 5 Performance for UP and ZF-BF

In Fig. 5, we present the comparions of spectral efficiency between UP and ZF-BF under different spatial correlation scenarios.

We can see that from Fig.5 that when spatial correlation is low UP performs better than ZF-BF and when spatial correlation is high ZF-BF performs better than UP. The reason is that for high transmit correlation scenario, the multiplicity of PVI feedback for one UE is reduced both in time and frequency domain so that the UE pairing problem becomes more severe. On the other hand, the increased transmit correlation is beneficial to ZF-BF (with DFT codebook) since the error of channel quantization is reduced with transmit correlation increased.

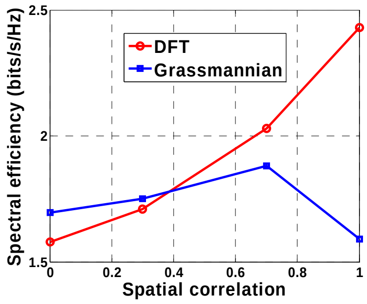


Fig. 6 Performance for different codebooks

Fig. 6 shows the performance comparison of ZF-BF with different codebooks, Grassmannian codebook and DFT codebook. Since the Grassmannian codebook is near optimal for non-correlated environment, it can outperform DFT codebook for low transmit correlation scenario. However, for high transmit correlation scenarios, it can be seen that DFT codebook is more effective because that the amplitude difference of channel information between different transmit antenna is reduced in this case, and constant module DFT codebook will bring less quantization error than non-constant module Grassmanian codebook.

V. Adaptive Precoding Scheme

In previous section, we compare the performance of various precoding techniques for E-UTRA, including various precoding modes, precoding methods and codebooks. It can be seen that none of the single fixed method can be optimal in universal environments.

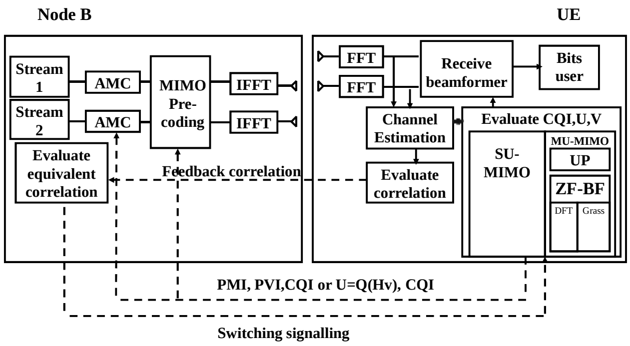


Fig. 7 Node B and UE structure

Therefore, in this section, we propose an adaptive MIMO precoding scheme in which different precoding modes including SU-MIMO and MU-MIMO, precoding methods including UP and ZF-BF for MU-MIMO, and codebooks including Grassmannian codebook and DFT codebook for MU-MIMO with ZF-BF, are semi-statically switched based on long-term information, system load and channel statistics. Fig. 7 shows the overall structure for the proposed scheme.

In proposed scheme, different precoding methods are semi-statically switched based on long-term information, system load and channel statistics. Therefore, it is much feasible for practical systems and the increase of signaling

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overhead can be negligible. The flow chart of the process of proposed scheme is demonstrated in Fig. 8.

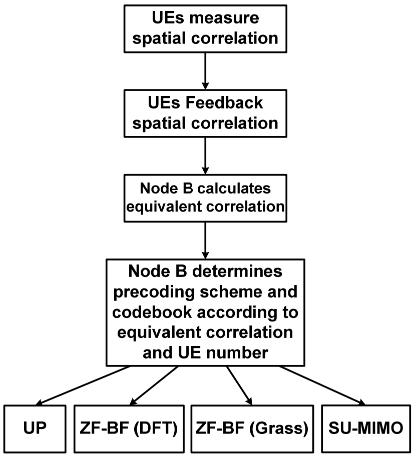

Fig. 8 Flow chart of proposed adaptive scheme

The detailed algorithm is as follows. First, each UE in the cell measures the spatial correlation respectively.

$$Corr_k^{Tx} = E\left\{H_k^H H_k\right\} \tag{3}$$

where $Corr_k^{Tx}$ is the downlink transmit spatial correlation corresponding to UE k. H_k is the channel matrix for UE k, and E{} is the expected value. Then each UE feeds back the measured spatial correlation $Corr_k^{Tx}$ to Node B. After receiving the feedback from UEs, Node B calculates the equivalent spatial correlation $Corr_{eq}$ according to the different spatial correlation from UEs.

$$Corr_{eq} = \frac{1}{K}\sum_{k=1}^{K} Corr_k^{Tx} \tag{4}$$

where K is the UE number is the cell. Finally, Node B will determine precoding scheme and codebook according to equivalent correlation and number of UE in the cell and signals UEs to launch switching.

In the following, for simplicity, we mainly discuss switching between two precoding schemes, which is a special case of the overall proposed adaptive scheme.

A. SU/MU switching

From the analysis of the previous section, SU-MIMO and MU-MIMO is preferred with different number of UEs and the number is various with different transmit correlation scenario. As shown in Fig. 8, after calculating the equivalent spatial correlation, Node B obtains the switching threshold corresponding to the equivalent spatial correlation based on the investigation through offline simulation in section IV. Then Node B compares UE number with the threshold. If the UE number is larger than threshold, Node B will signal UEs and launch switching from SU-MIMO mode to MU-MIMO mode; otherwise, when the UE number is small than threshold, Node B will signal UEs and launch switching from MU-MIMO mode to SU-MIMO mode.

We evaluate performance based on system-level simulation for E-UTRA. The spatial correlation is uniformly distributed between 0 and 1 and the UE number is uniformly distributed between 1 and 20. From Fig. 9, we can see that our proposed scheme of switching between SU and MU MIMO with different UE number and spatial correlation can achieve much performance gain related to fixed SU-MIMO or MU-MIMO transmission.

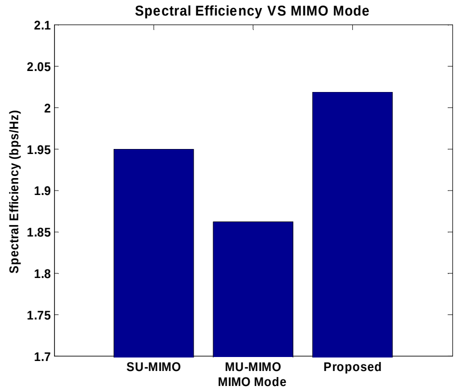

Fig. 9 Performance comparison for SU/MU MIMO switching

B. Precoding Switching for MU-MIMO

From the analysis of the previous section, for MU-MIMO, UP is preferred for low transmit correlation case and ZF-BF is preferred for high transmit correlation case. Similar to process of switching between SU and MU-MIMO, Node B compares the equivalent spatial correlation with the threshold obtained through offline simulation in section IV, and determine the corresponding precoding method. In the performance evaluation is based on system-level simulation for E-UTRA. The UE number is 10 UEs per sector. The spatial correlation is uniformly distributed between 0 and 1.

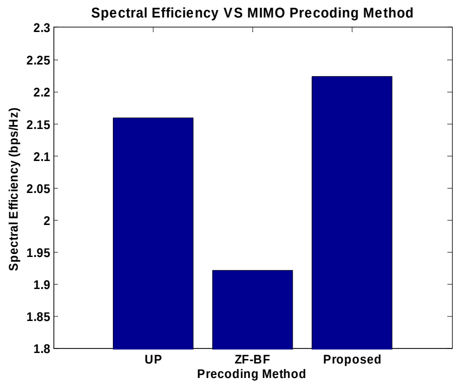

Fig. 10 Performance comparison for UP and ZF-BF switching

Fig. 10 demonstrates that compared with the conventional UP and ZF-BF, the proposed adaptive scheme precoding switching achieves higher spectral efficiency.

C. Codebook Switching for ZF-BF

The process of switching between different codebook is similar to that between UP and ZF-BF, but with different threshold. Fig. 11 demonstrates that compared with the conventional ZF-BF, the proposed adaptive scheme precoding switching achieves higher spectral efficiency. We evaluate performance based on system-level simulation for E-UTRA. The UE number is 10 per sector. The spatial correlation is uniformly distributed between 0 and 1.

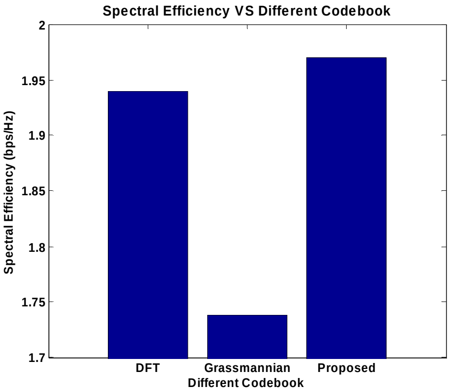

Fig. 11 Performance comparison for codebook switching

D. Signalling overhead analysis

In the proposed adaptive scheme, for the uplink, spatial correlation needs to be calculated and fed back to Node B, and it can be long-term based such as thousands of TTIs. Therefore, the increased signaling overhead is very small. In addition, the spatial correlation can alternatively be acquired in Node B directly by the uplink-downlink reciprocity, and then uplink signaling is not needed. For the downlink, the very small signaling, 1 or 2 bits, is needed to single the UE the switching results, it is also long-term based and can almost be neglected.

VI. Conclusion

In this paper, we investigate various precoding techniques in E-UTRA through system-level simulation. From the results, we can see that SU-MIMO is preferred in small number of UE case, MU-MIMO is preferred in large number of UE case, and the spatial correlation affects the crossing point. Moreover, ZF-BF can outperform UP, and DFT codebook can outperforme ZF-BF for high transmit correlation scenarios. Then, an adaptive MIMO precoding scheme is proposed accordingly in which different precoding modes, precoding methods and codebooks are semi-statically switched based on long-term information, system load and channel statistics. The proposed scheme is much practical due to very small increase of signaling and effective due to much gain in terms of average spectral efficiency verified by simulation results.

TABLE 1. SYSTEM PARAMETERS

Parameter		Assumption
Cellular layout		Hexagonal grid, 19 cell-sites, 3 sectors per cell-site
Transmitter antenna pattern of Node B (Antenna gain)		3-sector antenna pattern, 70 degree sector beam (14dB)
Inter-site distance (ISD)		500 m
Distance-dependent path loss		L=128.1 + 37.6log10(.R), R in km
Penetration Loss		20dB
Shadowing standard deviation		8 dB
Channel model		Typical Urban channel model
Transmission power of Node B		46 dBm
Terminal noise density		-174 dBm
Transmission bandwith		10 MHz
FFT Size		1024
Occupied sub-carrier number		601
RB size		12 sub-carriers
Sub-frame (TTI) length		1 msec
Number of antennas		2 antennas (Node B) 2 antennas (UE)
Maximum Doppler Frequency		5.5Hz
Scheduling algorithm		Proportional Fairness
Traffic model		Full queue traffic
Modulation and coding schemes		QPSK: 1/3, 1/2, 2/3, 3/4 16QAM: 1/2, 2/3, 3/4, 4/5 64QAM: 2/3, 3/4
Target PER		10%
Feedback granularity of PVI (CDI)		5RBs
Feedback granularity of CQI		1 RB
Control delay of AMC and scheduling		3 msec
HARQ		No
Channel estimation		Ideal
CQI estimation		Ideal
Shadowing correlation	Between cells	0.5
	Between sectors	1.0
Minimum distance between UE and cell		>= 35 meters

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