Making Multiuser MIMO work for LTE

Rizwan Ghaffar, Raymond Knopp

Eurecom, 2229 route des Crêtes B.P.193

06904 Sophia Antipolis Cedex FRANCE

Email: rizwan.ghaffar@eurecom.fr, raymond.knopp@eurecom.fr

Abstract—**Underlining the viability of multiuser (MU) MIMO for future wireless communications as long term evolution (LTE), we propose in this paper a precoding strategy based on the low resolution LTE precoders which necessitates 2 bits feedback from the user equipment (UE). The proposed strategy encompasses geometrical interference alignment at eNodeB (LTE notation for base station) followed by the exploitation of interference structure by the UEs. On one hand, this strategy relegates the interference seen by each UE by a geometric scheduling algorithm while on the other hand, UEs exploit the structure of residual interference in the detection process.**

I. Introduction

Spatial dimension surfacing from the usage of multiple antennas promises improved reliability, higher spectral efficiency and spatial separation of users [1]. This spatial dimension (MIMO) is particularly beneficial for precoding in the downlink of multiuser (MU) cellular system, where these spatial resources can be used to transmit data to multiple users simultaneously. Future wireless systems, characterized by large number of users, are considering different precoding strategies to transmit multiple streams to different users sharing the same time-frequency resources in order to achieve high capacity gains [2]. In 3GPP Long Term Evolution (LTE) system [3], several MIMO modes of operation including precoding for SU MIMO and MU MIMO are considered. The decision on which technique to use depends on the characteristics of MIMO channel and the system parameters. In this paper, we look at the low resolution precoders of LTE [3] which necessitate barely two bits of feedback from the user equipment (UE) and investigate their effectiveness both for SU MIMO and MU MIMO modes. We propose an algorithm basing on the geometrical alignment of interference at eNodeB (LTE notation for base station) which relegates the effective interference seen by each UE. The residual interference is still significant and can be exploited in the detection process. So we propose the use of a low complexity detector [4] which not only reduces one complex dimension of the system but also exploits the interference structure in the detection process.

Regarding notations, we will use lowercase letters for scalars, lowercase boldface letters for vectors and uppercase boldface letters for matrices. $(.)^*$ and $(.)^\dagger$ indicate conjugate and conjugate transpose respectively. The paper is divided into five sections. In section II we give a brief overview of LTE while section III discusses the system model. In section IV we propose strategies for LTE SU MIMO and MU MIMO modes which is followed by the simulation results and the conclusions.

II. LTE - A brief overview

For the downlink of 3GPP LTE, 2×2 MIMO system is assumed as the baseline configuration, however configurations with four transmit or receive antennas are also foreseen and reflected in the specifications [5]. In this paper, we restrict ourselves to the baseline configuration with the eNodeB equipped with two antennas while we consider single and dual antenna UEs. The physical layer technology employed for the downlink is Orthogonal Frequency Division Multiple Access (OFDMA) combined with bit interleaved coded modulation (BICM) [6]. Several different transmission bandwidths are possible, ranging from 1.08 MHz to 19.8 MHz with the constraint of being a multiple of 180 kHz. Resource Blocks (RB) are defined as groups of 12 consecutive resource elements (REs - LTE acronym for subcarrier) with a bandwidth of 180 kHz thereby leading to the constant RE spacing of 15 kHz. For 5 MHz bandwidth, it is divided into 25 RBs. Approximately 4 RBs form a subband and the feedback is done on per subband basis. The minimum allocation in time-domain is a subframe or transmission time interval (TTI), which has a duration of 1 ms and consists of two slots. One TTI consists of 12 or 14 OFDM symbols depending on normal or extended cyclic prefix. Seven operation modes are specified in LTE downlink, however following modes are significant for MIMO transmission.

- Transmission mode 2. Fall back transmit diversity
- Transmission mode 4. Closed-loop spatial multiplexing (UEs need to have minimum of 2 antennas)
- Transmission mode 5. MU MIMO
- Transmission mode 6. Closed-loop precoding for rank=1 or SU MIMO

In transmission modes 2, 5 and 6, one data stream is transmitted to each UE using Alamouti space frequency code (mode 2) and LTE precoders (mode 5 and 6). Time-frequency resources are orthogonal to different UEs in these modes. In transmission mode 4 and 5, two parallel data streams are transmitted simultaneously by eNodeB (eNodeB has two antennas) to one UE in case of mode 4 and to two UEs in case of mode 5, sharing the same time-frequency resources. Transmission modes 4, 5 and 6 are closed loop i.e. they are based on the UE feedback which is crucial in order to select precoders taking into account current channel state. The UE feeds back a Precoding Matrix Indication (PMI), Rank Indication (RI) and Channel Quality Indication (CQI) to eNodeB. PMI is an index in the codebook for the preferred precoder to be used

by eNodeB while CQI is important for proper link adaptation. RI is to be fed back when UE has multiple antennas and is important for mode 4. The granularity for computation and signaling of PMI can range from a couple of RBs to the full bandwidth whereas RI is for the entire bandwidth. For transmission mode 5, eNodeB selects the precoding matrix such that each data stream is transmitted to the corresponding UE with maximum throughput and the interference between data streams is minimized.

Low resolution LTE precoders for transmission modes 4, 5 and 6 are based on the principle of equal gain transmission (EGT) which has more modest transmit amplifier requirements than other transmission strategies, since it does not require antenna amplifiers to modify the amplitudes of the transmitted signals. This property allows inexpensive amplifiers to be used at each antenna as long as the gains are carefully matched. For the case of eNodeB with two antennas and an associated RI value of 1, LTE proposes the use of following four precoders basing on two bits feedback from the UEs.

$$\mathbf{p} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ 1 \end{bmatrix}, \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ -1 \end{bmatrix}, \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ j \end{bmatrix}, \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ -j \end{bmatrix} \quad (1)$$

The number of precoders increases to sixteen in the case of four transmit antennas however in this paper we restrict to the case of two transmit antennas. For the case of eNodeB with two antennas and an associated RI value of 2, LTE proposes the use of following two precoder matrices on subband basis (for transmission mode 4)

$$\mathbf{P} = \frac{1}{\sqrt{4}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}, \frac{1}{\sqrt{4}} \begin{bmatrix} 1 & 1 \\ j & -j \end{bmatrix} \quad (2)$$

The columns of this precoding matrix can be swapped but for complete bandwidth. If eNodeB decides rank 1 transmission to the UE whose RI is 2, then eNodeB uses one of the columns of the precoding matrix and transmits this information to UE in DCI (downlink control information).

III. SYSTEM MODEL

We consider the downlink of a LTE system [5] where we assume the baseline configuration i.e. eNodeB has two transmit antennas. We first consider mode 5 transmission (MU MIMO)for single antenna UEs. Data is encoded and interleaved at the eNodeB which is followed by the mapping of output bits onto the RE $x_{n,k}$ using the signal map $\chi_n \subseteq \mathcal{C}$ where n indicates the UE and k indicates the RE. These are then fed to the OFDM modulator. Cascading IFFT at eNodeB and FFT at the UE with CP extension, transmission at k-th RE for UE-1 in mode 5 can be expressed as

$$y_{1,k} = \mathbf{h}_{1,k}^{\dagger} \mathbf{p}_{1,k} x_{1,k} + \mathbf{h}_{1,k}^{\dagger} \mathbf{p}_{2,k} x_{2,k} + z_{1,k}$$

where $y_{1,k}$ is the received symbol at UE-1 and $z_{1,k}$ is the zero mean circularly symmetric complex white Gaussian (ZM-CSCWG) noise of variance N_0. $x_{1,k}$ is the desired complex symbol for UE-1 while $x_{2,k}$ is the desired symbol for UE-2. These symbols are assumed to be independent and of variances
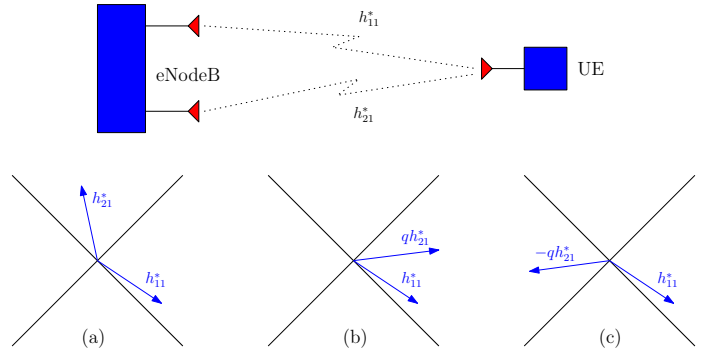

Fig. 1. (a) shows the original channel from eNodeB to UE while (b) shows the effective channel of desired signal while (c) shows the effective channel of interference of UE.

σ_1^2 and σ_2^2 respectively. $\mathbf{h}_{n,k}^{\dagger} \in \mathbb{C}^{1 \times 2}$ symbolizes the spatially uncorrelated flat Rayleigh fading MISO channel from eNodeB to n-th UE ($n = 1, 2$). $\mathbb{C}^{1 \times 2}$ denotes the two dimensional complex space. $\mathbf{p}_{n,k}$ denotes the precoding vector for n-th UE and is given by (1). We assume that eNodeB has perfect PMI feedback from all UEs, and each UE knows its own MISO channel perfectly. For dual antenna UEs, system equation is transformed as

$$\mathbf{y}_{1,k} = \mathbf{H}_{1,k} \left(\mathbf{p}_{1,k} x_{1,k} + \mathbf{p}_{2,k} x_{2,k} \right) + \mathbf{z}_{1,k}$$

where $\mathbf{y}_{1,k}, \mathbf{z}_{1,k} \in \mathbb{C}^{2 \times 1}$ are the vectors of received symbols and ZMCSCWG noise of doublesided power spectral density $N_0/2$ at two receive antennas of UE-1. $\mathbf{H}_{1,k}$ is the 2×2 MIMO channel form eNodeB to UE-1. In mode 6, system equations for single and dual antenna UEs can be written as

$$y_{1,k} = \mathbf{h}_{1,k}^{\dagger} \mathbf{p}_{1,k} x_{1,k} + z_{1,k}$$

and

$$\mathbf{y}_{1,k} = \mathbf{H}_{1,k} \mathbf{p}_{1,k} x_{1,k} + \mathbf{z}_{1,k}$$

respectively. Mode 4 being possible only for dual antenna UEs, so system equation is written as

$$\mathbf{y}_{1,k} = \mathbf{H}_{1,k} \mathbf{P}_{1,k} \mathbf{x}_{1,k} + \mathbf{z}_{1,k}$$

where $\mathbf{x}_{1,k}$ is the vector comprising two symbols directed to UE-1.

IV. PROPOSED PRECODING STRATEGY FOR LTE

In this section, we look at the effectiveness of low resolution LTE precoders and propose strategies for their effectual utilization for transmission modes 4, 5 and 6. For the ease of notations, we drop the RE index from here on. We consider two scenarios of single and dual antenna UEs.

Proposed strategies in the case of single antenna UEs are based on the matched filter (MF) precoders which are characterized by low complexity as their computation involves merely a conjugate operation. In accordance with the low resolution LTE precoders, UEs initially compute their MF precoders i.e. UE-1 measures its channel $\mathbf{h}_1^{\dagger} = [h_{11}^* \quad h_{21}^*]$ from the eNodeB and consequently computes the MF precoder
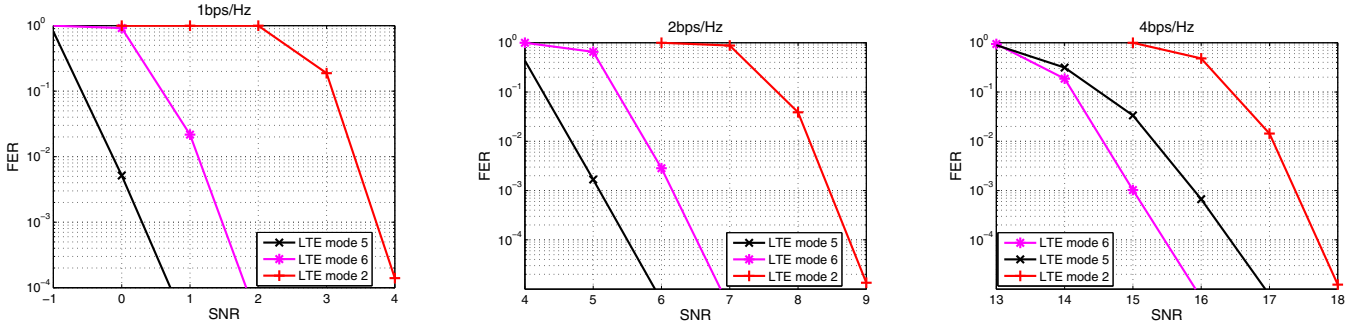
Fig. 2. Downlink channel with $n_t = 2$ and 2 single antenna users. 3GPP LTE rate $1/3$ turbo code is used with different puncturing patterns.

i.e. $\begin{bmatrix} h_{11} & h_{21} \end{bmatrix}^T$ (the normalized version involves a division by $\|\mathbf{h}_1\|$). As LTE precoders are characterized by unit coefficients as their first entry so UE normalizes first coefficient of the MF precoder i.e.

$$\mathbf{p}_{1,MF} = \frac{h_{11}^*}{|h_{11}|^2} \begin{bmatrix} h_{11} \\ h_{21} \end{bmatrix} = \begin{bmatrix} 1 \\ h_{11}^* h_{21}/|h_{11}|^2 \end{bmatrix} \quad (3)$$

Second coefficient indicates the phase between two channel coefficients. Now basing on the minimum distance between $\mathbf{p}_{1,MF}$ and $\mathbf{p}$ in (1), one of the four precoders is selected by the UE-1 and the index of that precoder is fed back to the eNodeB. Let that precoder be $\mathbf{p}_1 = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ q \end{bmatrix}$, $q \in [\pm 1, \pm j]$. From the geometrical perspective, this precoder once employed by the eNodeB would align h_{21}^* with h_{11}^* in the complex plane so as to maximize the received signal power i.e. $|h_{11}^* + q h_{21}^*|^2$ subject to the constraint that the precoder allows rotation of h_{21}^* by $0°, \pm 90°$ or $180°$. Therefore this precoding ensures that h_{11}^* and h_{21}^* lie in the same quadrant as shown in Fig. 1. Basing on the knowledge of the requested precoders of the UEs and the dynamics of the corresponding channels, eNodeB decides the transmission modes for different UEs. For mode 6 (SU MIMO), eNodeB employs the requested precoders for transmission to the corresponding UEs. Same would be the case for mode 5 (MU MIMO) where we further propose a scheduling algorithm where eNodeB selects the second UE in each group of allocatable RBs whose requested precoder $\mathbf{p}_2$ is $180°$ out of phase from the precoder $\mathbf{p}_1$ of the first UE to be served in the same RBs i.e. the precoder matrix is given as $\mathbf{P} = \frac{1}{\sqrt{4}} \begin{bmatrix} 1 & 1 \\ q & -q \end{bmatrix}$. So the received signal by UE-1 is given as

$$y_1 = \frac{1}{\sqrt{4}} (h_{11}^* + q h_{21}^*) x_1 + \frac{1}{\sqrt{4}} (h_{11}^* - q h_{21}^*) x_2 + z_1 \quad (4)$$

In this algorithm, selection of the precoder for each UE would ensure maximization of its desired signal strength i.e. $\left| \mathbf{h}_1^\dagger \mathbf{p}_1 \right|^2$ for the first UE and $\left| \mathbf{h}_2^\dagger \mathbf{p}_2 \right|^2$ for the second UE while selection of the UE pairs with out of phase precoders would ensure minimization of interference strength seen by each UE i.e. $\left| \mathbf{h}_1^\dagger \mathbf{p}_2 \right|^2$ for the first UE and $\left| \mathbf{h}_2^\dagger \mathbf{p}_1 \right|^2$ for the second UE.

Note that this maximization and minimization is subject to the constraint of LTE precoders.

Let θ be the angle between h_{11}^* and h_{21}^* which can be calculated as $\theta = \cos^{-1} \left(\frac{(h_{11} h_{21}^*)_R}{|h_{11}||h_{21}|} \right)$ where $(.)_R$ indicates the real part. Conditioned on the use of this precoding matrix, strength of the desired signal for the first UE is given as

$$= \sigma_1^2 |h_{11}^* + q h_{21}^*|^2 / 4$$
$$= \sigma_1^2 \left(|h_{11}|^2 + |h_{21}|^2 + 2 |h_{11}| |h_{21}| \max (|\cos \theta|, |\sin \theta|) \right) / 4$$

whereas strength of the interference signal seen by the first UE is given as

$$= \sigma_2^2 |h_{11}^* - q h_{21}^*|^2 / 4$$
$$= \sigma_2^2 \left(|h_{11}|^2 + |h_{21}|^2 - 2 |h_{11}| |h_{21}| \min (|\cos \theta|, |\sin \theta|) \right) / 4$$

Though this precoding and scheduling would ensure minimization of interference under the constraint of low resolution LTE precoders, the residual interference would still be significant. This interference is from finite alphabets and its structure can be exploited in the detection process however this exploitation comes at the cost of enhanced complexity. Here we propose the use of low complexity detectors by UEs [4] which on one hand reduce one complex dimension of the system while on the other exploit interference structure in the detection of desired stream.

Now we consider second scenario of dual antenna UEs while eNodeB is also equipped with two antennas. For modes 5 and 6, UEs select the precoding vectors $\mathbf{p}$ which maximizes the desired signal strength i.e. $\|\mathbf{Hp}\|^2$. For mode 5, eNodeB schedules two UEs on the same RB which have requested 180 degrees out of phase precoders. This strategy ensures maximization of the desired signal strength and minimization of the interference strength. As in this scenario, UE has two antennas so transmission mode 4 can also be applied. As already discussed in sec. II, there are two possible choices of precoding matrices (subband basis) with the possibility of swapping the columns on complete band. If the RI is two, then UE feeds back the desired precoding matrix as given in (2). Here we propose SIC based detection by UEs. Choice of precoding matrices on subband basis leads to the following post processing ratios of the strength of first stream to that of
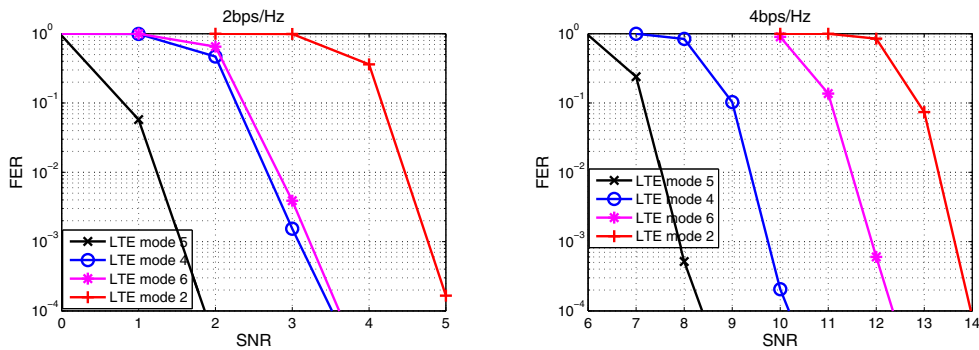
Fig. 3. Downlink channel with eNodeB with 2 antennas and 2 dual antenna UEs. 3GPP LTE rate $1/3$ turbo code is used with different puncturing patterns.

the second stream.

$$\left(\frac{\|\mathbf{h}_1 + \mathbf{h}_2\|^2}{\|\mathbf{h}_1 - \mathbf{h}_2\|^2}, \frac{\|\mathbf{h}_1 + j\mathbf{h}_2\|^2}{\|\mathbf{h}_1 - j\mathbf{h}_2\|^2} \right)$$

We propose that maximum of the two is selected which ensures first stream to be stronger than second stream. First stream is detected and subsequently stripped off leading to the detection of the second stream.

V. SIMULATION RESULTS

We now simulate the downlink of LTE system considering two scenarios of single and dual antennas. As a reference we consider fall back transmit diversity scheme (LTE mode 2 - Alamouti space frequency code) and compare it with the modes 4, 5 and 6 employing LTE low resolution precoders. In accordance with 3GPP LTE, we consider BICM OFDM based transmission from eNodeB equipped with two antennas using rate-$1/3$ LTE turbo code [7] with rate matching to rate $1/2$ and $1/4$ [1].

We consider ideal OFDM system (no ISI) and analyze the system in frequency domain where the channel has iid Gaussian matrix entries with unit variance and is independently generated for each channel use. We assume no power control at eNodeB so all streams have equal power distribution. Error free feedback of 2 bits is assumed for LTE precoders. Furthermore, all mappings of coded bits to QAM symbols use Gray encoding. We focus on the frame error rates (FER) while frame length is fixed to 1056 information bits. The UEs employ low complexity detectors [4] which have the inherent ability of exploiting interference structure in the detection of the desired stream. Fig. 2 shows that the proposed transmission strategy for mode 5 (MU MIMO) has more than 3 to 4 dB gain over mode 2 (Alamouti transmit diversity scheme) for low spectral efficiencies. However the gap reduces for higher spectral efficiencies. Mode 6 (SU MIMO) performs better than mode 5 (MU MIMO) at higher spectral efficiencies. Fig. 2 shows the results for dual antenna UEs. It shows that both at low and high spectral efficiencies, mode 5 (MU MIMO) outperforms other transmission modes. Mode 4 (closed loop

SU MIMO spatial multiplexing) performs better than mode 2 (transmit diversity) and mode 6 (closed loop SU MIMO rank 1 transmission) and the gap increases as the spectral efficiency increases. These results amply manifest the possible gains of MU MIMO in LTE even with the low resolution precoders.

VI. CONCLUSION

In this paper we have looked at the possible employment of low resolution LTE precoders for MU MIMO transmission (mode 5) basing on a geometric alignment and scheduling algorithm to mitigate interference seen by each UE combined with a low complexity detector to exploit the structure of residual interference. We have shown by system level simulations that mode 5 (MU MIMO) performs better than other transmission modes.

REFERENCES

[1] I. E. Telatar, "Capacity of multiantenna Gaussian channels," *European Transactions on Telecommunications*, vol. 10, no. 6, pp. 585–595, Nov./Dec 1999.
[2] C. Ribeiro, K. Hugl, M. Lampinen, and M. Kuusela, "Performance of linear multi-user MIMO precoding in LTE system," in *3rd International Symposium on Wireless Pervasive Computing, 2008. ISWPC 2008.*, pp. 410 –414.
[3] LTE, *Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation, Release 8, V.8.6.0.* 3GPP TS 36.211, 2009.
[4] R. Ghaffar and R. Knopp, "Linear precoders for multiuser MIMO for finite constellations and a simplified receiver structure under controlled interference," in *Asilomar Conference on Signals, Systems and Computers*, Nov. 2009.
[5] LTE, *Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Layer Procedures, Release 8, V.8.6.0.* 3GPP TS 36.213, 2009.
[6] G. Caire, G. Taricco, and E. Biglieri, "Bit-interleaved coded modulation," *IEEE Transactions on Information Theory*, vol. 44, no. 3, pp. 927–946, May 1998.
[7] LTE, *Evolved Universal Terrestrial Radio Access (E-UTRA); Channel Coding and Multiplexing, Release 8, V.8.6.0.* 3GPP TS 36.212, 2009.

[1]The LTE turbo decoder design was performed using the coded modulation library www.iterativesolutions.com