Improving MU-MIMO Performance in LTE-(Advanced) by Efficiently Exploiting Feedback Resources and through Dynamic Scheduling

Ankit Bhamri*†, Florian Kaltenberger*, Raymond Knopp*, Jyri Hämäläinen†
*Eurecom, France
†Aalto University School of Electrical Engineering, Finland

***Abstract*—Multi-user MIMO communication can provide significant gains by exploiting spatial multiplexing. However, it requires better feedback to provide accurate channel state information at the transmitter (CSIT) for minimizing the multi-user interference. 3GPP LTE provides support for MU-MIMO, but it is not sufficient to extract sizable gains. In this paper, our primary goal is to efficiently exploit the system's resources for MU-MIMO in LTE. In the existing 3GPP LTE standard (Rel. 8), we observed that the transmission mode 5 (TM5) dedicated for MU-MIMO utilizes wideband feedback method for providing channel directional information/ precoding matrix indicator (CDI/PMI). The standard supports finer granularity feedback i.e. sub-band feedback method, but it's not utilized for MU-MIMO and restricted only to SU-MIMO. Therefore in this work, we propose to exploit the sub-band feedback for providing more frequent update of PMI. However, in order to support this feedback method, we need to propose a new downlink control information (DCI) format for TM5 that will contain additional fields in comparison to the existing DCI format 1D. Furthermore, to extract optimal performance at the system level, we also propose a MAC-layer scheduling algorithm that deals with resource management on sub-band basis. Utilizing these proposed methods, we show considerable gains in MU-MIMO for 3GPP LTE at the system level.**

***Keywords*: 3GPP Long Term Evolution, Channel State Information at the Transmitter (CSIT), Downlink Control Information (DCI), Multi-user MIMO (MU-MIMO), Precoding Matrix Indicator (PMI), Scheduler.**

I. Introduction

Multi-user MIMO (MU-MIMO) communication has been theoretically well studied in the past decade and it has promised considerable gains [1]. Therefore, it has made its way into major wireless standards such as 3GPP LTE and WIMAX. However, the performance of MU-MIMO has been mostly sub-optimal at the system level in wireless standards [2]. It has been observed that MU-MIMO provides marginal gain over single-user MIMO (SU-MIMO). The main reason behind this sub-optimal performance can be attributed to the lack of adequate support for extracting considerable MU-MIMO gains. MU-MIMO requires very specific techniques to deal with interference management from other user and feedback information plays a crucial role. In [3], it is shown that MU-MIMO is more sensitive to the accuracy of the CSIT in comparison to SU-MIMO and therefore, better feedback is of critical importance.

In this paper, our main goal is to abridge the gap between the theoretical gains and the system level gains provided by MU-MIMO. As stated earlier, in the existing 3GPP LTE (Rel. 8), it is seen that TM5 dedicated for MU-MIMO utilizes only wideband feedback for providing CDI (referred to as PMI in LTE) at the transmitter. This basically means that only two bits (for two transmit anetnnas) of PMI feedback is used for the entire bandwidth which is contradicting to the requirements mentioned in [3]. Therefore, in this work we propose to exploit a more enhanced feedback method for providing PMI at the transmitter. This is sub-band PMI feedback which already exists in the 3GPP standard, but is limited only to SU-MIMO transmissions till now. Using this method, the receiver (user) updates the transmitter with a two bit PMI feedback for every sub-band rather than once for wideband. This results in providing more accurate CSIT and therefore enabling better multi-user interference management. However, in order to support this feedback method for TM5, we need to improve the existing DCI format 1D for TM5. Henceforth, we propose a new improved DCI format 1E with additional fields that would allow for better management of feedback related issues in TM5. In one of our preceding works [4], DCI format 1E was briefly introduced.

Furthermore, in order to fully exploit the benefits of improved feedback at the system level in 3GPP LTE, we render a dynamic scheduling algorithm. This MAC-layer scheduler deals with resource management among multiple users on every sub-band rather than wideband and it even allows to dynamically switch between MU-MIMO and SU-MIMO between every sub-band. The basic parameters that the scheduler takes into account are sub-band PMI feedback from multiple users, their channel quality and the overall expected gain at the system level. It should be noted here that our goal is to provide MU-MIMO gains at the system level and therefore, we utilize Eurecom's OpenAir Interface platform which implements the entire protocol stack based on LTE architecture [5]. OpenAir Interface is a complete system with a dedicated hardware, firmware and RF components.

The rest of the paper is organized as follows: Section II gives a brief description of the system model. Section III and Section IV describes the new DCI format 1E and dynamic scheduler algorithm respectively. Section V presents the results comparing the performance of MU-MIMO with our proposed algorithms and modifications in 3GPP and Section VI concludes the paper.

II. System Description

A. System Modeling

Fig. 1 shows the scenario which we have investigated for our system level study. System consists of a single-cell multi-user environment with N users having one antenna each and a base station with two transmit antennas.

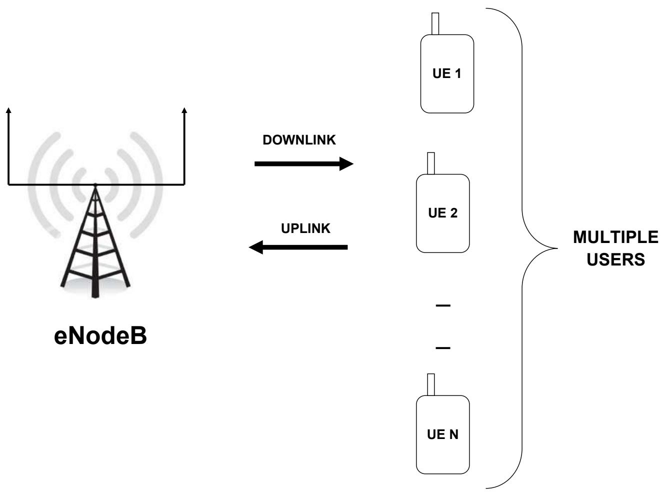

Fig. 1. A Single Cell Multi-user Environment

With two transmit antennas at the base station, we can schedule maximum two users in the same time-frequency resources for downlink in MU-MIMO communication. Therefore our task is to select best possible pair for every sub-band to achieve the maximum possible throughput. The algorithm behind this selection procedure is discussed in section IV. To give a clear picture of the MU-MIMO communication and to exhibit the importance of our proposed methods, Figure 2 shows a process cycle for a communication link between eNodeB (eNB) and user equipment (UE). Note that Figure 2 does not indicate all the blocks of wireless communication link, instead it points out the processes relevant to our study of MU-MIMO.

As can be seen from Figure 2, the eNB modeling consists of three blocks i.e. pre-processor, scheduler and precoder/beamformer. If the users are not scheduled in an efficient manner, then beamforming techniques do not deal effectively with the interference from other users. Therefore, we have proposed a block named pre-processor which deals

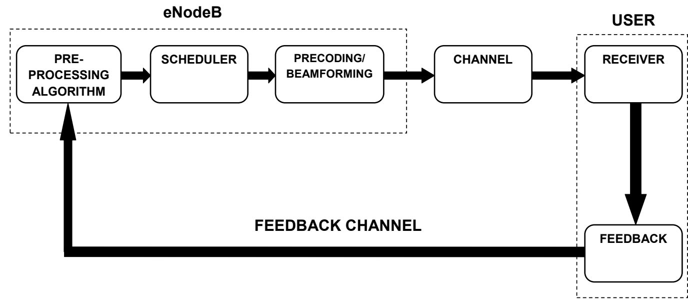

Fig. 2. Process Cycle for MU-MIMO Communication

with the process of user selection based on feedback and then passing the information of selected users to the main scheduler. We have also proposed changes in the feedback block that are discussed in Section III.

B. Channel Modeling

The propagation channel plays a crucial role in the performance of MU-MIMO communication, therefore it needs to be carefully modeled taking into account the real channel conditions. For our system, we have used 8-tap Rayleigh fading channel for downlink and 1-tap Ricean channel for uplink. The channels for different users transmitting at the same time are correlated depending on their locations. The users are randomly distributed in a single cell and are moving according to the mobility model described in [6]. Noise is modeled as additive white Gaussian noise (AWGN) with zero mean and unit variance at the receiver.

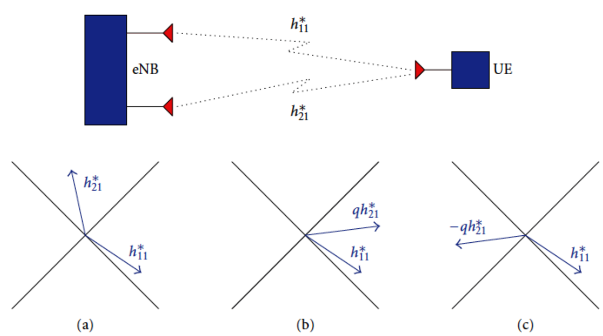

Fig. 3. (a) shows the original channel from eNB to user, (b) shows the effective channel of the desired signal and (c) shows the effective channel of the interference of user

C. Receiver Structure

For robust downlink detection at the user in MU-MIMO transmissions, we utilize low complexity interference-aware receiver (IA-receiver) proposed in [7]. Instead of assuming the interference at the receiver as Gaussian, it rather exploits the structure of residual interference since it can only have discrete constellations. The basic principle of this receiver is to maximize the channel of the desired signal and minimize the interference channel as shown in Figure 3 [2].

For our study, we have utilized QPSK-QPSK IA-receiver with a maximum modulation and coding scheme (MCS) of 9 in 3GPP LTE. In addition to this, the IA-receiver has a low complexity in comparison to other receivers used for MU-MIMO detection. Henceforth we provide a low complexity and practical system by integrating our proposed methods along with this receiver structure to demonstrate the performance of MU-MIMO for commercial 3GPP LTE systems.

III. Downlink Control Information

In 3GPP LTE Rel. 8, TM5 is dedicated for MU-MIMO communications. As mentioned earlier, this TM utilizes only wideband feedback method for PMI which is referred to as feedback mode 3-1 in the standard [8]. In this method, only two bits of feedback are used to provide the user's PMI to the eNB and it is not enough to extract sizable gains from MU-MIMO. Therefore we propose to utilize sub-band feedback method for PMI information. This feedback method already exists in the standard and is referred to as feedback mode 1-2 which is currently utilized only for SU-MIMO [8]. By utilizing feedback mode 1-2 for MU-MIMO in TM5, we can provide more accurate PMI to the eNb. However the existing DCI format 1D cannot provide enough support to exploit this feedback mode for TM5.

When the eNB receives the feedback from the user, it utilizes this feedback information to define the parameters for next downlink transmission to that user. Before the data transmission on downlink, the eNB must inform the user about these downlink parameters through DCI on Physical Downlink Control Channel (PDCCH). Therefore when the eNB receives the PMI feedback from user, it must inform the user about the PMI to be used for downlink with a DCI bit field called as transmitted PMI (TPMI) [9]. This bit field does not exist in DCI format 1D and therefore, format 1D cannot be used with feedback mode 1-2. Hence, we propose a new new DCI format 1E which contains TPMI bit field in addition to the existing fields. With this field, the eNB can inform the user about the PMI to be used for downlink on every sub-band. With this additional TPMI field the overhead cost increases by 3 bits, but as a result we expect to improve the overall downlink throughput in comparison to DCI format 1D with 3 bits less overhead. Therefore, the gains expected are much more than the feedback cost. Table 1 shows the information that is transmitted with our new DCI format 1E.

DCI Field	Bits Used
Transmitted PMI (TPMI)	3
Redundancy Version (RV)	2
New Data Indicator (NDI)	1
Modulation and Coding Scheme (MCS)	5
HARQ Process Indicator (HARQ PID)	4
Downlink Assignment Index (DAI)	2
Transmit Power Control (TPC)	2
Resource Block Assignment (RBALLOC)	13
Resource Allocation Header (RAH)	1
Downlink Power Offset (DL POW OFF)	1

TABLE I
Downlink Control Information (DCI) Format 1E

This DCI format supports a system with 25 resource blocks (5MHz transmission bandwidth) and two antennas at base station. Note that downlink power offset field is specific for TM5 only. It already exists in DCI format 1D and it is being utilized the similar way in DCI format 1E. Downlink power offset is required to indicate whether the transmissions are done in SU-MIMO mode or MU-MIMO mode. When it is set to 1, SU-MIMO mode is being used and for 0, MU-MIMO is used for transmissions. All the other fields mentioned in the table are according to the 3GPP LTE specifications [9].

In 3GPP LTE Rel. 10, a new DCI format 2C is introduced for MU-MIMO transmissions in TM9, which do not contain TPMI field [10]. However, user-specific demodulation reference signal (DMRS) has been introduced in Rel. 10 which requires changes in the transmission resources structure. Therefore in comparison to the support for MU-MIMO in Release 10, our new DCI format 1E provides a simple yet effective solution without the need of user-specific DMRS which requires extra transmission resources.

IV. MAC-layer Scheduler

Now, in order to fully exploit the benefits of feedback mode 1-2, we describe a dynamic scheduling algorithm in this section. Figure 4 shows the sequential steps involved in this scheduling algorithm.

A compatible pair of users with orthogonal PMIs is selected for every sub-band such that it ensures minimization of interference from other user and maximization of desired signal at the receiver. The precoding matrix for a pair of orthogonal PMIs in LTE can be given as

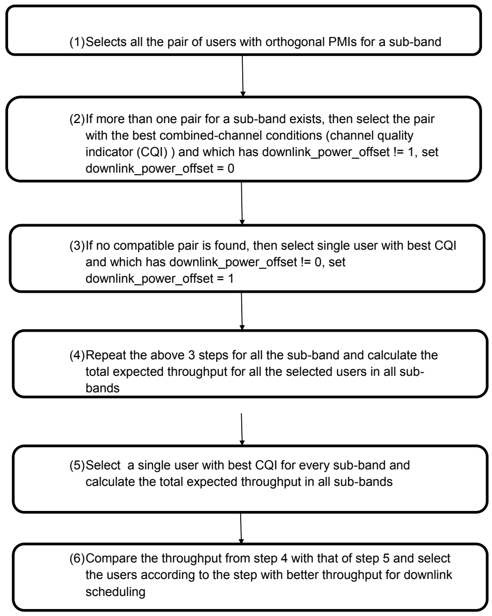

Fig. 4. Pre-Processor Scheduling Algorithm

$$\frac{1}{\sqrt{4}}\begin{bmatrix}1 & 1\\ q & -q\end{bmatrix}$$

where $q = [+1, -1; +j, -j]$.

Therefore, the received signal at the first user is

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

where x_1 and x_2 are the complex symbols for user 1 and user 2 respectively, h_{11}^* is the transpose of the channel from transmit antenna 1 to user 1, h_{21}^* is the transpose of the channel from transmit antenna 2 to user 1 and z_1 is the noise. In the received signal the first term is the desired part which is maximized and second term is interference which is minimized because of this scheduling.

This scheduling algorithm also takes those scenarios into the account in step 6 of Figure 4, when SU-MIMO might be expected to have better throughput that MU-MIMO. Therefore, it can be deduced that this scheduler does not blindly schedule users for MU-MIMO transmission, but rather follow a dynamic approach for switching between MU-MIMO and SU-MIMO to provide optimal system level performance.

V. System Level Results

In this section we show the performance comparison in terms of average system throughput. The results are obtained from system level simulations involving all the protocol layers in LTE architecture. The key simulation parameters are given in Table II.

Parameters	Values
Transmission Bandwidth	5MHz (25 RBs)
Number of Sub-bands	7 (6x4 RBs + 1x1 RBs)
Frame Configuration	TDD Config. 3
Number of Frames Simulated	1500
Maximum MCS	9 (QPSK Constellation)
Traffic Model	Full Traffic Buffer

TABLE II
Simulation Parameters

In Figure 5, we provide a comparison between the existing 3GPP LTE standard with DCI format 1D and our proposed DCI format 1E in terms of percentage of MU-MIMO transmissions. As we can see in Table 2, there are 1500 frames simulated, so in Figure 5 we observe the percentage of frames with MU-MIMO transmissions for different number of users. This statistic is critical in understanding the advantage of utilizing feedback mode 1-2. With feedback mode 1-2, the probability of finding 2 users with orthogonal PMI is more in comparison to feedback mode 3-1 used in standard. This increased probability of finding orthogonal users results directly in increased number of MU-MIMO transmissions and Figure 5 is presented in support of this statement.

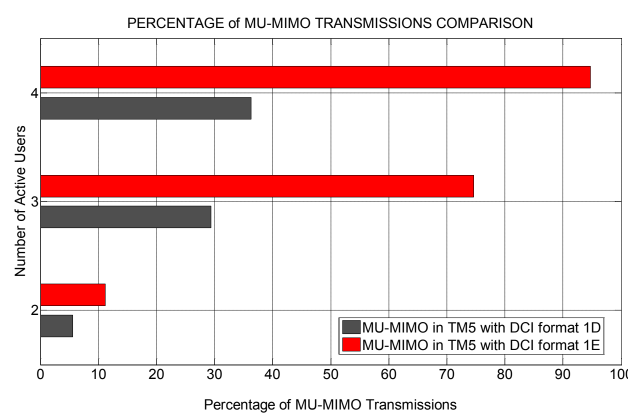

Fig. 5. Percentage of Transmissions in MU-MIMO for TM5

Figure 6 gives the performance measurement in terms of average system throughput. Now there are some key observations to be made from Figure 6. Firstly, the average throughput for MU-MIMO with DCI format 1E is better than that of DCI format 1D for any number of users. This is a direct result of finer granularity feedback mode 1-2 and dynamic scheduler for every sub-band. Secondly, the average throughput increases with increasing number of users. This is because the probability of finding orthogonal users increases with increasing number of users. Thirdly, DCI format 1E is more sensitive to increasing number of users in comparison to format 1D since the rate of increase of throughput is more for format 1E. Lastly, we can observe that the performance of MU-MIMO in TM5 is almost same as SU-MIMO in TM2 for 2 users in the system. However, the performance improves significantly for MU-MIMO with increasing number of users.

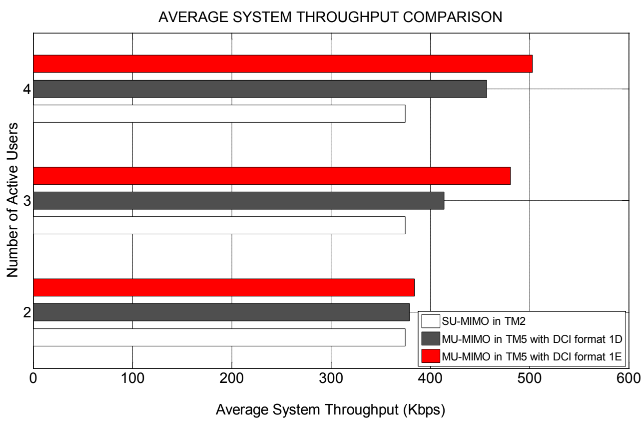

Fig. 6. Average System Throughput Comparison

VI. Conclusions

For 3GPP LTE standards, we propose a new DCI format 1E for MU-MIMO transmissions to support sub-band PMI feedback giving channel direction information more frequently. This new DCI format 1E is proposed as an alternative to DCI format 1D for MU-MIMO transmissions in TM5. The DCI format 1E utilizes the feedback mode 1-2 defined in 3GPP LTE instead of feedback mode 3-1 which is supported by DCI format 1D. Furthermore, we propose a scheduling algorithm for exploiting sub-band PMI to schedule users on sub-band basis rather than entire bandwidth. Therefore, this algorithm allows switching between MU-MIMO mode and SU-MIMO mode in frequency domain (sub-band basis). The results in the previous section determine that these proposed methods provide significant gains for the overall system throughput due to increasing percentage of MU-MIMO transmissions. It can be deduced that MU-MIMO provides sizable gains when the number of active users is large.

Acknowledgment

This work is funded by European Commission through project Spectrum Aggregation and Multi-user MIMO: Real-World Impact (SAMURAI) (ICT/FP7). We would also like to acknowledge Biljana Badic from Intel Mobile Communications, Germany for her guidance and supervision during the course of this work.

References

[1] Caire G., Jindal, N., Kobayashi M. and Ravindran N. Multi-user MIMO Achievable Rates With Downlink Training and Channel State Feedback, *IEEE Transactions on Information Theory*, vol. 56, no. 6: pp.2845-2866, May 2010.

[2] Jonathan Duplicy, Biljana Badic, Rajarajan Balraj, et al. MU-MIMO in LTE Systems, *EURASIP Journal on Wireless Communications and Networking*, vol. 2011, 2011.

[3] Ravindran N. and Jindal N. Multi-User Diversity vs. Accurate Channel Feedback for MIMO Broadcast Channels , *IEEE International Conference on Communications, 2008*, pp: 3684-3688, May 2008.

[4] A.F. Cattoni,H.T. Nguyen, J. Duplicy, et al. Multi-User MIMO and Carrier Aggregation in 4G Systems: the SAMURAI Approach , *WCNC 2012 Workshop on 4G Mobile Radio Access Networks*, April 2012.

[5] OpenAir Interface Platform, *Eurecom.* URL http://www.openairinterface.org/

[6] Ben Romdhanne Bilel, Navid Nikaein, Raymond Knopp and Christian Bonnet. OpenAirInterface large-scale wireless emulation platform and methodology, *PM2HW2N'11, 6th ACM International Workshop on Performance Monitoring, Measurement and Evaluation of Heterogeneous Wireless and Wired Networks*, pp: 109-112, October2011

[7] Ghaffar R. and Knopp R. Interference-Aware Receiver Structure for Multi-User MIMO and LTE, *EURASIP Journal on Wireless Communications and Networking*, vol. 2011, 2011.

[8] 3GPP TS 36.213. Evolved Universal Terrestrial Radio Access: Physical Layer Procedures. ver. 8.6.0, March 2009. URL http://www.3gpp.org/ftp/specs/ html-info/36213.htm.

[9] 3GPP TS 36.212. Evolved Universal Terrestrial Radio Access: Multiplexing and Channel Coding. ver. 8.6.0, March 2009. URL http://www.3gpp.org/ftp/ specs/html-info/36212.htm.

[10] 3GPP TS 36.212. Evolved Universal Terrestrial Radio Access: Multiplexing and Channel Coding. ver. 10.0.0, Jan 2011. URL http://www.3gpp.org/ftp/ specs/html-info/36212.htm.