Achievability of the Channel Reciprocity and its Benefit in TDD System

Zhihua Shi, Qixing Wang, Jing Jin, Dajie Jiang, Guangyi Liu
China Mobile Research Institution
Beijing, P.R.China
Email: shizhihua@chinamobile.com, wangqixing@chinamobile.com

Abstract—**For the shared frequency band between uplink and downlink, the channel reciprocity has been regarded as the most important advantage of a TDD system, in which the eNB can obtain the downlink channel state information (CSI) based on the uplink channel estimation, and thus perform advanced multi-antenna technologies to enhance the downlink transmission in TD-LTE/TD-LTE-Advanced systems. In this paper, the achievability of the TDD channel reciprocity from the product implementation point of view is analyzed and some measurement results of the hardware response difference before and after the antenna calibration have been shown to verify the achievability. Based on the channel reciprocity of TDD system, the performance of Single-User and Multiple-User Beamforming (SU/MU-BF) and Coordinated Multipoint Transmission (CoMP) have been enhanced significantly.**

Keywords- Channel reciprocity, SU-BF, MU-BF, CoMP

I. INTRODUCTION

As is well known, the downlink and uplink transmissions share the same frequency band in a TDD wireless communication system, thereby leading to its inherent characteristic – channel reciprocity [1-2]. That is to say, the channel state information (CSI) of the downlink transmission can be estimated via that of the uplink transmission, and vice versa.

As one of the key characteristics of TDD systems, channel reciprocity can be exploited to facilitate adaptive transmission to improve the system performance, without feedback overhead penalty. Specifically, the channel reciprocity is of great importance for TD-LTE/TD-LTE-Advanced systems since the performance enhancements of TD-LTE/TD-LTE-Advanced systems are fundamentally based on advanced multi-antenna technologies [3].

However, the achievable performance gains of various multi-antenna schemes depend on the accuracy of the CSI at the transmitter (CSIT). For LTE FDD systems, CSIT are usually obtained via a large amount of feedback, thereby resulting in significant feedback overhead and considerable waste of bandwidth. Currently, more complex and more advanced Multiple-Input and Multiple-Output (MIMO) schemes, e.g. MU-MIMO and CoMP [4-6], have been introduced to the further revolution of LTE for better system performance. On the other hand, “there is no such thing as a free lunch”. These new schemes raise the increased demand of more accurate CSIT, which would be a crucial limit for their applications.

In contrast, TD-LTE/TD-LTE-Advanced systems can benefit from the channel reciprocity so that the accurate CSIT can be obtained without additional feedback overhead. Therefore, TD-LTE/TD-LTE-Advanced is much easier to support Multiuser MIMO (MU-MIMO) and CoMP. Specifically, the potential advantages of channel reciprocity in TD-LTE/TD-LTE-Advanced consists of the following aspects:

1） Reduce the feedback overhead in uplink

2） Reduce the latency of obtaining CSIT due to the avoidance of feedback

3） Facilitate various advanced multi-antenna schemes including Single-user Beamforming (SU-BF) , Multi-user Beamforming (MU-BF), and CoMP.

In this paper, the achievability of channel reciprocity in TDD system is analyzed first and how to obtain the channel reciprocity is introduced. With channel reciprocity, the eNB obtain downlink channel state information (CSI) through uplink sounding reference signal (SRS) [7], and thus perform several advanced multi-antenna technologies to enhance the downlink transmission in TD-LTE/TD-LTE-Advanced, e.g., SU-BF, MU-BF and CoMP. Finally, the performance evaluation shows that these enhanced downlink transmissions can bring significant gains to both the average sector throughput and the cell-edge user throughput.

II. CHALLENGES

As discussed above, channel reciprocity promises many potential advantages. In a practical system, the equivalent channel consists of the transmitter (Tx) RF chain, the physical wireless channel and the receiver (Rx) RF chain. However, TDD transmission only assures channel reciprocity for the physical propagation channel. In practical systems, different RF chains are used in reception and transmission for each antenna and the response properties of RF chains for different antennas vary much due to lots of factors, e.g., temperature, humidity, etc. Hence, whenever there is a noticeable difference between the transfers characteristics of various (samples of) analog parts used at Tx/Rx, there is no reason to assume reciprocity of these variations at Tx/Rx and therefore reciprocity of the equivalent channel. Fig.1 illustrates that the

CHINACOM 2010, August 25-27, Beijing, China

DOI 10.4108/chinacom.2010.155

reciprocity of Tx/Rx chains doesn't hold in principle. Fig.2 gives the measured magnitudes of 8 Tx/Rx RF chains of a commercial TD-SCDMA system, which proves that the reciprocity doesn't hold for Tx/Rx RF chains. As a result, some remedy methods such as antenna calibrations are necessary to fully exploit the equivalent channel reciprocity.

III. ACHIEVABILITY OF CHANNEL RECIPROCITY

As one kind of effective antenna calibration, self-calibration has been employed in the commercial TD-SCDMA systems. It has been proved that self-calibration works well in practical TD-SCDMA systems [8].

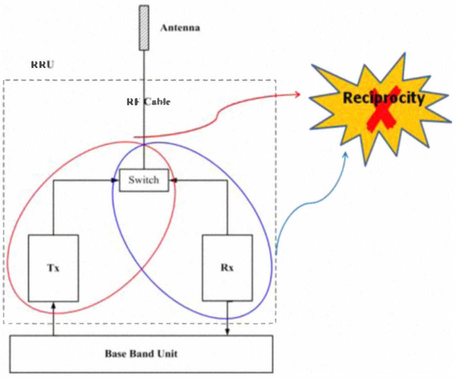
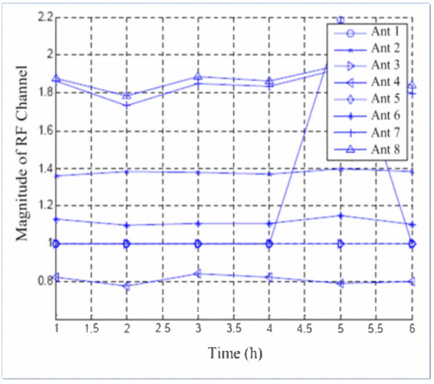
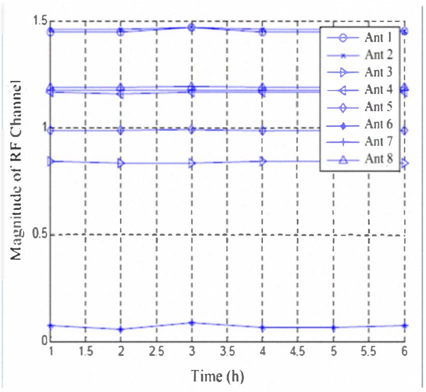


Fig.1 Illustration of Rx/Tx Chains



(a)Tx RF Chains



(b)Rx RF Chains

Fig.2 Magnitudes of Tx/Rx RF chains (measured from TD-SCDMA systems)

The aims of the antenna self-calibration include:

- Adjusting the calibration coefficients to ensure that the "effective" transfer functions of all the Tx RF channels with calibration are the same
- Adjusting the calibration coefficients to ensure that the "effective" transfer functions of all the Rx RF channels with calibration are the same

We now describe the procedures of self-calibration for Rx/Tx RF chains from a high-level point of view, and more details are omitted since it is an implementation issue depending on the vendors.

Procedure of self-calibration for Rx RF chains:

(1) Calibration network sends calibration reference signals (RS) into the Rx RF chains
(2) Calibration network receives the signals passing through Rx RF chains
(3) Calibration network estimates the transfer function of each Rx RF chain by exploiting the orthogonality of the calibration RS
(4) Calibration network determines the calibration coefficient for each Rx RF chain

Procedure of self-calibration for Tx RF chains:

(1) Calibration network sends calibration reference signals (RS) into the Tx RF chains
(2) Calibration network receives the signals passing through Tx RF chains
(3) Calibration network estimates the transfer function of each Tx RF chain by exploiting the orthogonality of the calibration RS
(4) Calibration network determines the calibration coefficient for each Tx RF chain

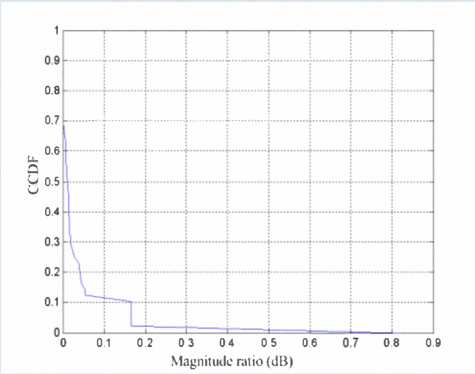
Fig.3 provides a measurement result from TD-SCDMA systems to show that with self-calibration, the magnitude differences of Tx/Rx RF chains are very small. This conclusion also applies to the phase differences. From these results, we can see that antenna self-calibration is a promising approach to ensure the attainability of full channel reciprocity.

In TD-SCDMA systems, the antenna self-calibration operations are implemented during the guard time. Due to the variety of RF channels are very slow, self-calibration are usually carried out once per one or more hours. All the aforementioned rules will also apply to TD-LTE systems.

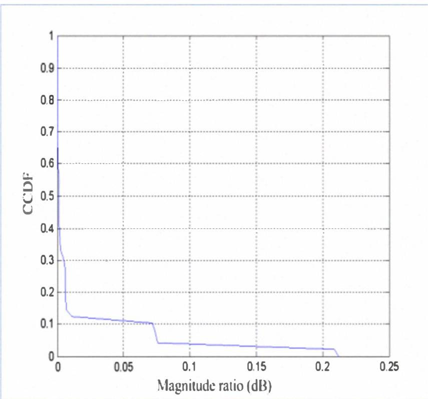
Please note that although self-calibration can be used in user equipment (UE) in principle, at the current stage self-calibration is only employed in base stations due to the limits of current hardware implementation.

IV. ENHANCED DOWNLINK TRANSMISSION WITH CHANNEL RECIPROCITY

Since the uplink and downlink share the same frequency band in TDD system, the instantaneous downlink channel information of each UE can be obtained by eNB from measurements of the uplink SRS based on the channel reciprocity. Based on the instantaneous channel information, the eNB can perform several advanced multi-antenna technologies to enhance the downlink transmission in TD-LTE/TD-LTE-Advanced, such as BF and CoMP.



(a)Tx RF Chains



(b)Rx RF Chains

Fig.3 Magnitude Differences of Tx/Rx RF chains with antenna self-calibration

A. *SU/MU-BF in TD-LTE/TD-LTE-Advaned*

In SU-BF, the transmitter can utilize downlink channel state information to perform beamforming to focus the transmit power on the desired direction. In MU-BF, based on the downlink channel state information, UE pairing for MU-MIMO transmission is performed and beamforming weight vectors which can effectively mitigate the interference among the users and increase the system spectral efficiency are calculated according to some interference nulling criteria.

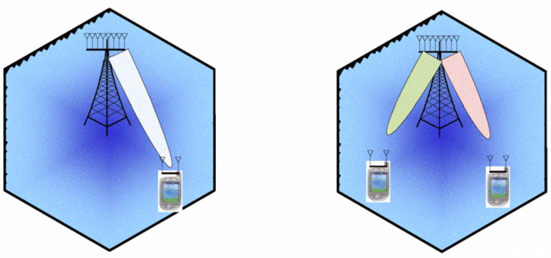


Fig.4 Illustration of SU-BF and MU-BF

B. *Coordianted multi-point transmission in TD-LTE-A*

Inter-cell interference (ICI) has been regarded as the key factor to limit the further improvement of LTE-Advanced systems. Coordinated Multi-Point transmission /reception (CoMP) is one of the candidate techniques for LTE-Advanced systems to increase the cell average and cell edge user throughput in the downlink.

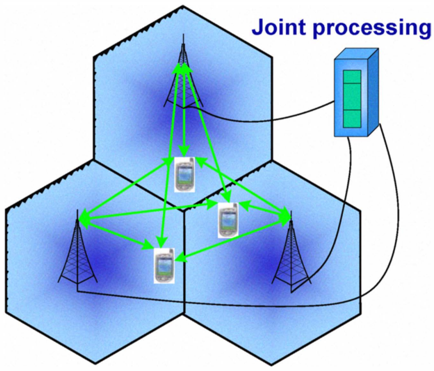


Fig.5 Illustration of CoMP with three cells

V. SIMULATION RESULTS

A. *Simulation Assumptions*

In this section, the performance of the multiple-antenna schemes based on channel reciprocity is compared to that of traditional TD-LTE system using codebook based precoding [9] in terms of cell-edge and average sector throughput. The number of transmit antennas per sector is 4 and the number of receive antennas per UE is 2. UEs can adaptively choose single or dual streams according to the maximal throughput principle. Minimum mean square error (MMSE) receiver is adopted to demodulate the transmitted signal vectors.

In order to reduce the complexity and achieve fairness among users, proportional fair (PF) scheduling [10] method is applied. The minimum unit for resource allocation based on OFDMA frame structure is one RB which composed of 12 consecutive subcarriers in the frequency domain and 7 OFDM symbols in the time domain [9]. The detailed simulation parameters are listed in Table I.

TABLE I. SIMULATION PARAMETERS

Parameters	Value
Layout	3-sectorized hexagonal grid with 19 cells and wrap-around
Carrier frequency	2.5 GHz
ISD	200 m
Bandwidth	10 MHz
FFT size	1024
Number of subcarriers available	600
eNB Max transmission power	41 dBm
Ave. Num of users per sector	10
User distribution	Uniform, 50% indoor, 50% outdoor

Traffic model	Full Buffer
UE speed	3 Km/h
Lognormal shadowing	Gaussian distribution with 0 mean, 8 dB standard deviation
Penetration loss	20 dB
Channel model	ITU-UMi[11]
BLER target	10%
Channel estimation	Ideal
Network synchronization	Synchronized

Adaptive modulation and coding (AMC) is used with various modulation and coding schemes with QPSK, 16-QAM, and 64- QAM, and coding rate ranging from 0.117 to 0.925 [9].

B. *The Spectrum Efficiency*

The downlink spectrum efficiency (SE, in bps/Hz/sector) results are presented in fig. 6 and fig. 7, where the cell-edge user throughput is defined as the 5th percentile point of the cumulative distribution function (CDF) of users average packet throughput.

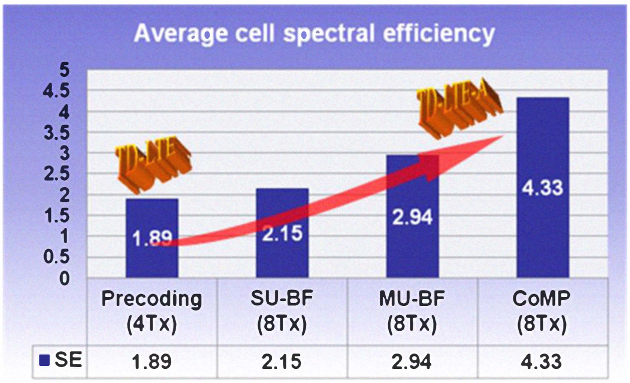


Fig. 6 Average cell spectral efficiency

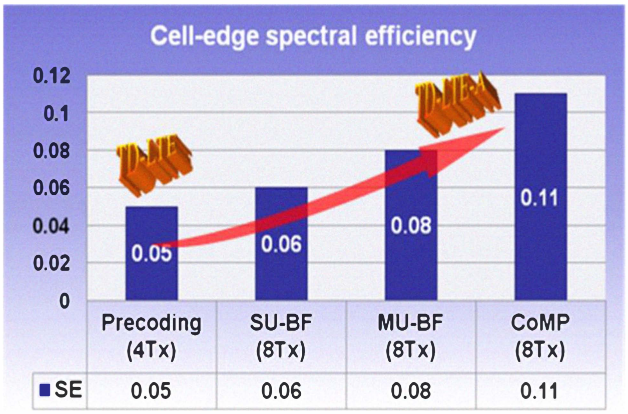


Fig. 7 Cell-edge spectral efficiency

Compared to codebook based precoding, SU-BF, MU-BF and CoMP increase the downlink average cell SE by 14%, 56% and 129%; and the cell edge SE is improved by 20%, 60% and 120%, respectively. From this, we can see that the enhanced downlink transmission with channel reciprocity significantly improves system performance.

VI. Conclusions

In this paper, the achievability of channel reciprocity in TDD systems is analyzed and how to obtain the channel reciprocity by antenna self-calibration is introduced. Some results of the antenna self-calibration has been shown to verify the effect from the commercial TD-SCDMA systems. Based on this, the enhanced downlink transmission with channel reciprocity, such as SU/MU-BF and CoMP are evaluated. System level simulation results have shown that SU/MU-BF and CoMP have significant gain over the traditional codebook based precoding in terms of average cell throughput and cell-edge user throughput when the channel reciprocity of TDD can be guarenteed.

ACKNOWLEGEMENT

The research is supported by China Important National Science and Technology Specific Projects with No. 2009ZX03007-003-01.

References

[1] A.R.Dias, D.Bateman and K.Gosse, "Impact of RF front-end impairments and mobility on channel reciprocity for closed-loop multiple antenna techniques," Proc. 15th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, vol. 2, pp. 1434 – 1438, 2004.

[2] Jiann-Ching Guey and L.D.Larsson, "Modeling and evaluation of MIMO systems exploiting channel reciprocity in TDD mode," Proc. IEEE 60th Vehicular Technology Conference, vol. 6, pp. 4265 – 4269, 2004.

[3] P.E.Mogensen, T.Koivisto, K.I.Pedersen, et al, "LTE-Advanced: The path towards gigabit/s in wireless mobile communications," Proc. 1st International Conference on Wireless Communication, Vehicular Technology, Information Theory and Aerospace & Electronic, pp. 147 – 151, 2009.

[4] Xiaolin Hou, Zhan Zhang and Kayama, H, "Adaptive Multi-Tx Multi-Rx MIMO Transmission Scheme for LTE-Advanced Downlink," Proc. IEEE Global Telecommunications Conference, pp. 1 – 7, 2009.

[5] Qixing Wang, Dajie Jiang, Guangyi Liu and Zhigang Yan, "Coordinated Multiple Points Transmission for LTE-Advanced Systems," Proc. 5th International Conference on Wireless Communications, Networking and Mobile Computing, pp. 1 – 4, 2009.

[6] Qixing Wang, Dajie Jiang, Jing Jin, et al, "Application of BBU+RRU Based Comp System to LTE-Advanced," Proc. IEEE International Conference on Communications Workshops, pp. 1 – 5, 2009.

[7] 3GPP TR 36.814 v9.0.0, "Further Advancements for E-UTRA; Physical Layer Aspects (Release 9)", Mar. 2010.

[8] Xiangdong Jia and Haibao Ding, "The Reciprocity Characteristic of Smart Antennas in CDMA System," Proc. International Conference on Networks Security, Wireless Communications and Trusted Computing, vol. 1, pp. 412 – 416, 2009.

[9] 3GPP TS 36.211 v9.0.0, "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation," Dec. 2009.

[10] M. Kaneko, P. Popovski, and J. Dahl, "Proportional Fairness in Multi-Carrier System with Multi-Slot Frames: Upper Bound and User Multiplexing Algorithms," IEEE Trans. on Wireless Communications, vol. 7, no. 1, pp. 22 – 26, 2008.

[11] Report ITU-R M.2135, "Guidelines for evaluation of radio interface technologies for IMT-Advanced," 2008.