A Novel Frequency Reuse Scheme for Coordinated Multi-Point Transmission

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Abstract—**Coordinated Multi-Point (CoMP) transmission is considered in 3GPP LTE-Advanced as a key technique to improve the cell-edge performance. In order to support joint resource allocation among coordinate cells in CoMP systems, efficient frequency reuse schemes need to be designed. However, most of the existing frequency reuse schemes are not suitable for CoMP transmission due to not considering multi-cell joint transmission scenario in their frequency reuse rule. To solve this problem, a cooperative frequency reuse (CFR) scheme is proposed in this paper, which divides the cell-edge area of each cell into two types of zones, and defines a frequency reuse rule to support CoMP transmission for users in these zones. Compared with the conventional soft frequency reuse (SFR) scheme, simulation results demonstrate that the CFR scheme reduces the blocking probability by more than 50%, and improves the cell-edge throughput by 30~40%, with 5~9% additional cell-average throughput.**

Keywords- LTE-Advanced, OFDM, coordinated multi-point transmission, frequency reuse

I. INTRODUCTION

Driven by the need to support data applications at higher throughputs and spectral efficiency, orthogonal frequency division multiplexing (OFDM) based multiple access is being considered as a promising multiple access method for the 4th generation (4G) wireless networks. OFDMA has been adopted as the downlink access technology of 3rd generation partnership project (3GPP) long term evolution (LTE) and LTE-Advanced standard [1-2]. OFDM can effectively eliminate the intra-cell interference. However, the inter-cell interference (ICI) is a major issue. In fact, if the networks utilize a frequency reuse factor of one, users at the cell-edge areas may suffer from serious ICI leading to poor cell-edge throughputs.

In 3GPP LTE, Inter-Cell Interference Coordination (ICIC) is considered as a promising technique to deal with the ICI mitigation issue [1]. Among the variety of ICIC strategies, the soft frequency reuse (SFR) scheme and the fractional frequency reuse (FFR) scheme are widely accepted [3-6]. Both SFR and FFR schemes are based on the idea of applying a frequency reuse factor of one in cell-center areas, and a higher reuse factor in cell-edge areas. Therefore, the ICI is reduced at the expense of the available frequency resources for each cell.

In ref. [7], the SFR scheme is extended into a three-sector scenario, which allocates no overlap frequency segment for the boundary region of neighboring sectors. In ref. [8] and ref. [9], a novel FFR scheme is proposed with frequency reuse factor of 1, where allocation priority is set for different frequency segments in each cell. In ref. [10], different frequency reuse strategies are assigned to different types of cell-edge users to avoid major ICI. Actually, all of the above schemes aim to use no overlap frequency segment in the cell-edge areas of neighboring cells to reduce ICI, without considering multi-cell joint transmission scenario in their frequency reuse rule.

In 3GPP LTE-Advanced, Coordinated Multi-Point (CoMP) transmission is proposed as a key technique to further improve the cell-edge performance in May 2008 [11]. CoMP technique implies dynamic coordination among multiple geographically separated transmission points, and can be divided into two main approaches [2]:

1) Coordinated scheduling and/or beamforming, where data to a single UE is instantaneously transmitted from one of the transmission points, and scheduling decisions are coordinated to control;

2) Joint processing/transmission, where data to a single UE is simultaneously transmitted from multiple transmission points.

With these CoMP schemes, especially for CoMP joint transmission scheme, efficient frequency reuse schemes need to be designed to support joint radio resource management among coordinate cells. However, based on the above analysis, most of the existing frequency reuse schemes are not suitable for CoMP systems due to not considerate multi-cell joint transmission scenario in their frequency plan rule.

In this paper, a novel frequency reuse scheme named cooperative frequency reuse (CFR) is proposed to support CoMP joint transmission. The cell-edge areas of each cell in the CFR scheme are divided into two types of zones. Moreover, a frequency reuse rule is defined, so as to support CoMP joint transmission among neighboring cells with the same frequency resources. Compared with the SFR scheme, our simulation results demonstrate that the CFR scheme yields higher average throughput in both cell-edge and cell-average points of view with lower blocking probability.

The remainder of this paper is organized as follows. The system model is described in section II. In Section III, the principle of the proposed CFR scheme is introduced. First, a method for cell-edge areas partition is presented. Second, a frequency reuse rule is designed for each cell cluster. Then, a

flow for UE-specific CoMP cooperating set selection is given. In section IV, system level simulation results are provided. Section V concludes the paper.

II. System Model

A typical system model for downlink CoMP joint transmission is described in Fig. 1 [12]. In the system, cell users are divided into two classes, namely cell-center users (CCUs) and cell-edge users (CEUs). We assume that only CEUs can be configured to work under CoMP mode. Each CEU has a CoMP Cooperating Set (CCS), which is formed by the cells that provide data transmission service to this CEU, including its own serving cell. The CEU with more than one cell in its CCS is regarded as a CoMP CEU, which can be served by the cells contained in its CCS simultaneously with the same frequency resources. It is assumed that each cell is configured with one transmitting antenna at the base station and one receiving antenna at each user. In addition, the received signals for a CoMP user are assumed to be non-coherently added up together.

In the example of Fig. 1, Cell 1, Cell 2 and Cell 3 belong to the CCS of user 1. Hence, user 1 is regarded as a CoMP CEU, and can be simultaneously served by these three cells within the same frequency resources. In this example, user 2 is a cell-center user and it can only communicate with its serving cell, i.e., Cell 1.
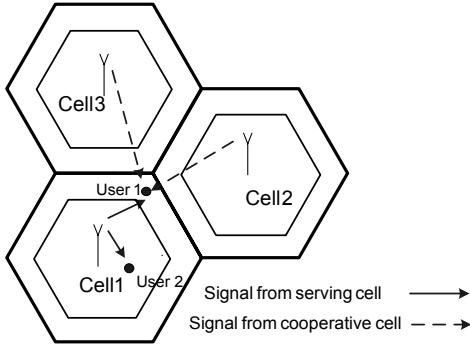

Fig.1. System Model for downlink CoMP joint transmission

Let Ψ_k denote the CCS of the kth CoMP CEU. Define $\bar{\Psi}_k$ to be the complement set of Ψ_k. Therefore, the signal to interference plus noise ratio (SINR) on the lth physical resource block (PRB) for the kth active CoMP CEU connected to the ith cell is determined as follows:

$$\gamma_{i,l}^k = \frac{\sum\limits_{s\in\Psi_k} P_{s,l}G_s^k \left|h_{s,l}^k\right|^2}{N_0 + \sum\limits_{n\in\bar{\Psi}_k} x_{n,l}P_{n,l}G_n^k}, \quad (1)$$

where $P_{s,l}$ is the transmission power from the sth cell on the lth PRB. For simplicity, $P_{s,l}$ is assumed to be constant, i.e., no power control is performed. G_s^k is the long term gain between the sth cell and the kth CoMP CEU, consisting of propagation

path loss and the shadow fading. $h_{s,l}^k$ denotes the fast fad gain on the lth PRB for the channel between the sth cell and the kth CoMP UE. N_0 is the noise power received within each PRB. Finally, $x_{n,l}$ is the allocation indicator of the lth PRB, which can be given by:

$$x_{n,l} = \begin{cases} 1, & \text{if the } l^{th} \text{ PRB is used in the } n^{th} \text{ cell} \\ 0, & \text{otherwise} \end{cases}. \quad (2)$$

In ref. [1], it was pointed out that interference coordination is handled by the system once every 100ms. The information reported by the users and used by the system is the average SINR value. Thus, $\left|h_{s,l}^k\right|^2$ is replaced by its mean value. We assume that $E\left(\left|h_{s,l}^k\right|^2\right)=1$. Then, eq. (1) can be expressed as

$$\gamma_{i,l}^k = \frac{\sum\limits_{s\in\Psi_k} P_{s,l}G_s^k}{N_0 + \sum\limits_{n\in\bar{\Psi}_k} x_{n,l}P_{n,l}G_n^k}. \quad (3)$$

In the case of CCUs, The average SINR expression on the lth PRB for the kth user of the ith cell is then given by:

$$\gamma_{i,l}^k = \frac{P_{i,l}G_i^k}{N_0 + \sum\limits_{n\neq i} x_{n,l}P_{n,l}G_n^k}. \quad (4)$$

Finally, according to Shannon theorem, the corresponding capacity to the kth user average SINR on the ith cell on the lth PRB can be expressed as:

$$C_{i,l}^k = B\log_2\left(1+\frac{\gamma_{i,l}^k}{\Gamma}\right), \quad (5)$$

where B is the bandwidth of each PRB, and Γ is the SINR gap, which is a constant related to the target BER given by [13]:

$$\Gamma = -\ln\left(5BER\right)/1.5. \quad (6)$$

III. Cooperative Frequency Reuse Scheme

In this section, we introduce the principle of the CFR scheme that can support CoMP joint transmission.

A. Cell-edge areas partition

In a first step, a method for partitioning the cell-edge areas is proposed. Assume that every three neighboring cells are grouped into a cell cluster and respectively marked as cell 1, cell 2 and cell 3 (see Fig.2). The cell-edge area of each cell is then divided into six cell-edge zones according to the six different neighboring cells. Given the marker of each cell (cell 1, 2 or 3), the six cell-edge zones in a cell are then categorized into two types. As illustrated in Fig.2, each cell-edge zone is marked with A_i^j, where i denotes the cell to which the zone belongs, and j is the marker of the dominant interference cell of this zone. Note that $i, j = \{1, 2, 3\}$ and $i \neq j$. Hence, within a cell cluster, there are six types of cell-edge zones in total.

For simplifying expression, we just take the cell-edge zones in cell 1 into count:

Zone A_1^2 : It is the cell-edge zone of the cells marked with cell 1. Moreover, the dominant interferer of the users in this zone is the nearest neighboring cell marked with cell 2.

Zone A_1^3 : It belongs to the cells marked with cell 1. In this case, the dominant interferer is the nearest neighboring cell marked with cell 3.
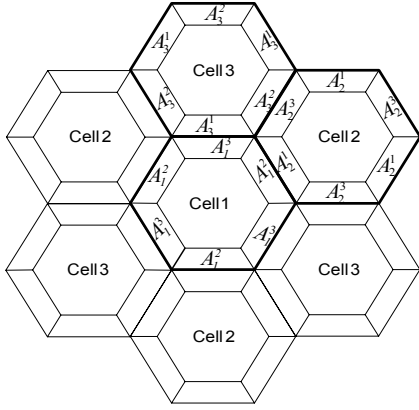

Fig.2. Cell-edge areas partition for each cell

B. Frequency reuse rule

In order to support multi-cell joint transmission with neighboring cells, a cooperative frequency subset is defined for each cell in CFR scheme. Then the resources are allocated to users in each cell cluster according to the following frequency reuse rule:

Step 1: In each cell, the whole resources are divided into two sets, G and F, where $G \cap F = \varnothing$. Resources in set G are used for CCUs in each cell, while resources in set F are used for CEUs.

Step 2: Set F is further divided into three subsets, marked by F_1, F_2, F_3, with $F_i \cap F_j = \varnothing (i \neq j)$.

Step 3: For each cell cluster, F_i is assigned for cell i as a cooperative frequency subset, which is used for providing cooperative data transmission for the CEUs in neighboring cells.

Step 4: F_j is assigned for the CEUs in cell-edge zones marked with A_i^j.

Based on the defined frequency reuse rule, the frequency allocation for each cell in the cluster is shown in Fig.3.
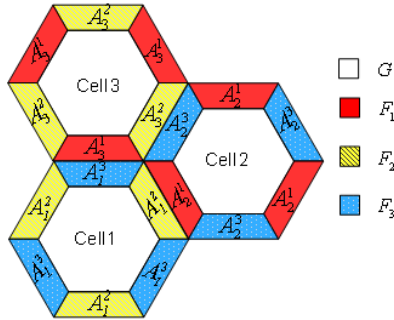

Fig.3. Frequency allocation for each cell in the cluster

On the one hand, orthogonal frequency subsets are allocated to the adjacent cell-edge zones that belong to different cells. Hence, the ICI can be reduced by using different frequency resources in adjacent areas of neighboring cells.

On the other hand, according to the frequency reuse rule, F_j is allocated for cell-edge zone A_i^j. Besides, F_j is the cooperative frequency subset for cell j, which is the dominant interference cell of zone A_i^j. Hence, for a CoMP CEU located in zone A_i^j, cell i and cell j can form a CCS and provide CoMP joint transmission with the same frequency resources selected from F_j.
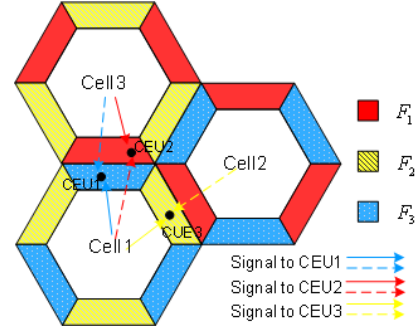

Fig.4. CoMP joint transmission in the CFR system

As shown in Fig.4, when CEU 1 in zone A_1^3 is regarded as a CoMP CEU, its dominant interference cell marked with cell 3 and the serving cell marked with cell 1 can form a CCS. Then CEU 1 can be served by these two cells with the same frequency resources selected from set F_3.

What's more, we can see that the whole frequency resources could be reused in all cells. Hence, the CFR scheme can achieve a frequency reuse factor of 1.

C. CCS selection algorithm

In this subsection, we use the active set algorithm of [14] to perform the CCS selection. Let N denote the total number of cells in the system, M denote the maximum number of cells in a CCS of a CEU. The kth CEU's CCS, denoted as Ψ_k, can then be selected according to the user's long term gain G_k^i as follows:

Algorithm: CCS Selection
①   Initialization $\Psi_k \leftarrow \varnothing$, $count \leftarrow 0$.
②   Calculate G_k^i between the kth CEU and the ith cell, for $i = 0,...,N-1$. $G \leftarrow \left\{ G_k^0, G_k^1, ..., G_k^{N-1} \right\}$

③   Find serving cell for k^{th} CEU
     $i \leftarrow \arg\max \left(G_k^i \right), G_k^i \in G$
     $s \leftarrow i$

④   Update

$$\Psi_k \leftarrow \Psi_k \cup \left\{ i^{th}\ cell \right\}$$
$$count \leftarrow count + 1$$

⑤ If $count < M$,

$$G \leftarrow G - \left\{ G_k^i \right\}$$
$$i \leftarrow \arg\max \left(G_k^i \right), G_k^i \in G$$

Else stop.

⑥ If $G_k^s - G_k^i \le thr$, go to ④

Else stop.

In ref. [15], it is proved that a maximum size of UE-specific CoMP cooperating set equal to 2 is enough to achieve CoMP gain for 3GPP case 1. Hence, the value of M is set to 2 in this paper. CEUs with two cells in their CCS are regarded as CoMP CEUs, whose SINR can be improved by CoMP joint transmission with the same frequency resources according to the proposed frequency reuse rule.

IV. SIMULATION RESULTS

In this section, system level simulations are performed to evaluate the performance of the proposed CFR scheme. As performance metrics, we use the blocking probability and the average throughput in both the cell-edge and cell-average points of view.

The universal frequency reuse (UFR), where PRBs are randomly assigned to the different users in each cell irrespective of their category (CEU or CCU), is taken as a reference scheme. A second reference scheme is the SFR scheme, which assigns a fixed non-overlapping cell edge bandwidth to a cluster of three adjacent cells [3]. For the proposed CFR scheme, two cases are studied, where Thr is set to 0 dB and 5 dB, respectively.

We focus on an OFDMA-based downlink cellular system. A number of users are uniformly dropped within each cell. The basic resource element considered in the system is the PRB, which consists of 12 contiguous subcarriers. It is assumed that all the available PRBs are transmitted with equivalent power. Only one PRB can be assigned to each active UE. Table I lists the main simulation parameters, based on ref. [2].

TABLE I. SIMULATION PARAMETERS

Parameters	Values
Carrier Frequency	2 GHz
Bandwidth	10 MHz
Subcarrier spacing	15 kHz
Number of PRBs	50
Number of cells	21
Cell radius	500m
Maximum power in BS	46 dBm
Distance-dependent path loss	L=128.1+37.6log10 d (dB), d in km
Shadowing factor variance	8dB
Shadowing correlation distance	50m
Inter cell shadowing correlation	0.5

Fig. 5 shows the blocking probability of the proposed CFR scheme and the conventional SFR scheme as a function of the loading factor. We can see that the CFR scheme outperforms the SFR scheme. Specially, the blocking probability reduced by the CFR scheme is 50% more than the SFR scheme. For example, if it is required that the blocking probability must not exceed 5%, Fig. 5 indicates that the admissible loading factor of the SFR scheme is only 30%, while the admissible loading factor of the proposed CFR scheme is more than 60% of the total frequency resource. This improvement in the CFR scheme results from the frequency reuse rule designed for each cell cluster. According to the frequency reuse rule, the number of available frequency resources for the cell-edge areas of each cell is twice more than the conventional SFR scheme.
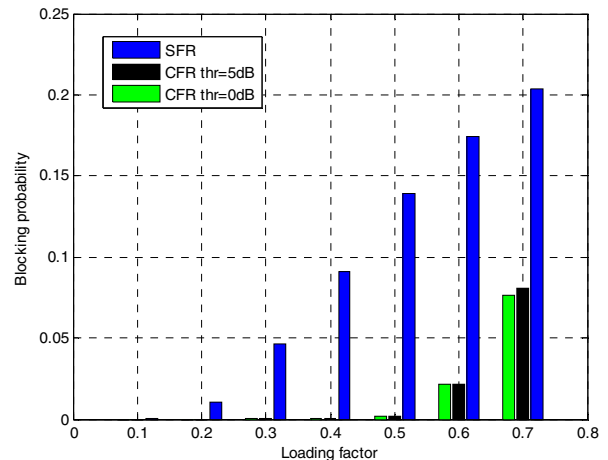

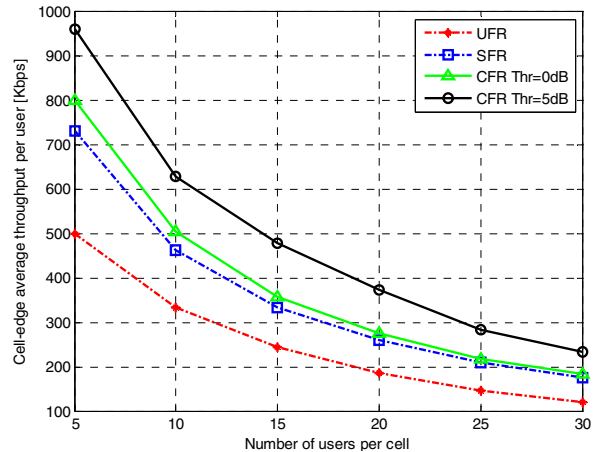Fig.5. Blocking probability as a function of the loading factor

Fig.6. Cell-edge average throughput per user

Fig. 6 shows the cell-edge average throughput per user for the three different frequency reuse schemes considered in this paper. It can be seen that the average throughput per CEU decreases as the number of users increases in all the three schemes. This is mainly due to the increase in the probability of PRBs collision as the number of users grows. In other

words, the ICI increases when the average number of users per cell grows. Moreover, compared with the UFR scheme, both the CFR scheme and the SFR scheme yield a significant improvement in terms of cell-edge average throughput owing to the frequency reuse plans designed for cell-edge areas.

We can also observe that the proposed CFR scheme achieves higher cell-edge average throughput than the SFR scheme. When *Thr* is 0 dB, no user works under CoMP mode. Compared with the SFR scheme, the cell-edge average throughput is improved by 4 to 8%, which is achieved mainly owing to the frequency reuse rule designed in the CFR scheme. When *Thr* is set to 5dB, the throughput raised by the proposed CFR scheme is 30 to 40% more than the SFR scheme, since part of the CEUs are regarded as CoMP users whose throughput can be further improved by CoMP joint transmission.
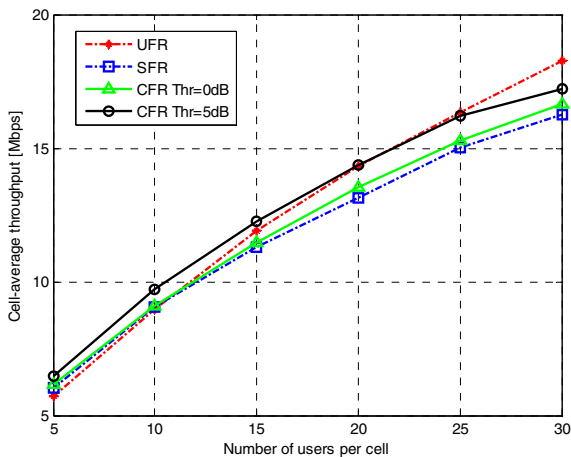

Fig.7. Cell-average throughput as a function of the number of users per cell

Fig. 7 shows the cell-average throughput of the proposed CFR scheme and the two conventional frequency reuse schemes as a function of the number of users per cell. From the graph, we can see that the cell-average throughput of the proposed CFR scheme outperforms that of the SFR scheme due to the better cell-edge performance and lower blocking probability. When *Thr* is set to 0dB, the cell-average throughput is improved by 1 to 3%. While when *Thr* is set to 5dB, the cell-average throughput is improved by 5 to 9%.

It can be seen that when the number of users per cell is small, i.e. less than 15, the CFR scheme with *Thr* equal to 5dB achieves the best results among the three schemes under consideration. When the number of users is large, the UFR scheme achieves better results than the proposed CFR scheme. However, the payoff for this higher average cell throughput of the UFR scheme is a huge decrease in the cell-edge average throughput, which can be observed from Fig. 6.

V. CONCLUSION

In this paper, a novel frequency reuse scheme, named cooperative frequency reuse (CFR), is proposed to support CoMP joint transmission and further improve cell-edge performance. First, a method for cell-edge areas partition is proposed, which divides the cell-edge areas of each cell into two types of zones. Then, a frequency plan rule is defined for each cell in the cluster, which assigns a cooperative frequency subset for each cell and allows CoMP users in cell-edge zones to be served by multi-cell joint transmission with the same frequency resources. Our simulation results demonstrate that the proposed CFR scheme significantly outperforms the conventional SFR scheme in terms of blocking probability, cell-edge average throughput and cell-average throughput.

REFERENCES

[1] 3GPP TR 25.814 v7.1.0, "Physical layer aspects for evolved UTRA (Release 7)," Sept. 2006.

[2] 3GPP TR 36.814 v1.0.1, "Further Advancements for E-UTRA Physical Layer Aspects (Release 9)," Mar. 2009.

[3] R1-050507, "Soft frequency reuse scheme for UTRAN LTE," Huawei, 3GPP TSG RAN WG1 Meeting #41, May 2005.

[4] J. Tomcik, Qualcomm, "MBFDD and MB TDD wideband mode," IEEE 802.20-05/68r1, Jan. 2006.

[5] S. E. Elayoubi, O. B. Haddada, and B. Fourestie, "Performance Evaluation of Frequency Planning Schemes in OFDMA-based Networks," *IEEE Trans. Wireless Commun.*, vol. 7, no. 5, pp. 623–1633, May 2008.

[6] Huiling Jia, Zhaoyang Zhang, Guanding Yu, Peng Cheng, and Shiju Li, "On the Performance of IEEE 802.16 OFDMA System under Different Frequency Reuse and Subcarrier Permutation Patterns," in *Proc. IEEE International Conference on Communications (ICC-2007)*, pp. 5720-5725, Jun. 2007.

[7] Haipeng Le, Lei Zhang, Xin Zhang, and Dacheng Yang, "A Novel Multi-Cell OFDMA System Structure using Fractional Frequency Reuse," *IEEE Personal, Indoor and Mobile Radio Communications (PIMRC)*, pp. 1-5, 2007.

[8] Ki Tae Kim, Seong Keun Oh, "A Universal Frequency Reuse System in a Mobile Cellular Environment," *IEEE Vehicular Technology Conference (VTC 2007-Spring)*, pp. 2855-2859, 2007.

[9] Ki Tae Kim, Seong Keun Oh, "An Incremental Frequency Reuse Scheme for an OFDMA Cellular System and Its Performance" *IEEE Vehicular Technology Conference (VTC 2008-Spring)*, pp. 1504-1508, May 2008.

[10] Xu Fangmin, Tao Xiaofeng, Zhang Ping, "A Frequency Reuse Scheme for OFDMA Systems", *Journal of Electronics&Information Technology*, vol. 3, no. 4, pp. 903-906, Apr. 2009.

[11] R1-082024, "A discussion on some technology components for LTE-Advanced," Ericsson, 3GPP TSGRAN WG1 #53, May 2008.

[12] R1-083569, "Further discussion on Inter-Cell Interference Mitigation through Limited Coordination," Samsung, 3GPP TSGRAN WG1 #54bits, Oct. 2008.

[13] A. J. Goldsmith and S.-G. Chua. Variable-rate variable-power MQAM for fading channels, *IEEE Trans. Commun.*, vol. 45, no. 10, pp. 1218–1230, Oct. 1997.

[14] G. Piñero, C. Botella, A. González, M. de Diego and N. Cardona, "Downlink power control and beamforming for a cooperative wireless system," *IEEE Personal, Indoor and Mobile Radio Communications (PIMRC)*, pp. 974-978, 2004.

[15] R1-091688, "Potential gain of DL CoMP with joint transmission," NEC Group, 3GPP TSGRAN WG1 #57, May. 2009.