Joint Shared Relaying and Base Station Coordination in LTE-Advanced Networks

MOUBAGOU DEFLANDRE BERTRAND, CHANG YONGYU
Information and Communication System
Beijing University of Posts and Telecommunications
Haidian disctrict 10 Xitucheng road, 100876
CHINA
deflandb@yahoo.fr

Abstract: —In order to achieve high spectral efficiency with improved peak data rates of cell-edge uses and enable an enhanced network coverage with good throughput both in downlink and uplink, LTE-Advanced proposes separately base station coordination and relaying techniques. In the purpose to increase the cell-edge user data rates beyond what can be reached by using either one of the techniques alone, this paper introduces a novel transmission scheme, which combines relaying and base station coordination together. Numerical results show that the transmission scheme is a good solution for improving the cell-edge multi-user performance. The cooperative transmission scheme can enable the simultaneous transmissions to multiple users in different cells and gain higher sum-rate capacity than those systems applying relaying or base station coordination alone.

Key-Words: —LTE-Advanced; Relaying; Base station coordination; Throughput; SNR; Inter-cell interference.

1 Introduction

LTE-Advanced (LTE-A) was introduced by 3GPP to be a candidate for IMT-Advanced, with the improvement of spectral efficiency in the uplink and downlink as a main target, especially when serving users (UE) at the cell border. LTE-A utilizes the diverse spectrum bands already applicable for Long Term Evolution (LTE), expected to enable downlink peak rates over 1Gbps at 100MHz bandwidth and in the uplink peak rates greater than 500Mbps [1].

LTE-A is an Orthogonal Frequency Division Multiplexing (OFDM) bases radio access technology, it uses full frequency reuse, which in turn leads to inter-cell interference. It includes several key technologies such as carrier aggregation, enhanced Multiple-Input Multiple-Output (MIMO), base station coordination and relaying [2].

This paper focuses on Base station coordination and relaying techniques. Base station coordination is an advanced variant of MIMO as a means of mitigating the inter-cell interference and hence improves spectral efficiency of cell border users where performance is degraded due to the inter-cell interference. Relaying is employed as low cost solution to enhanced cell coverage in difficult conditions and capacity. The concept of relaying is not new but the level of sophistication due to is amount of functionality and intelligence the relay node (RN) continues to grow. In LTE-Advanced RN is divided into a transparent type and a non-transparent type [3][4].

This paper proposes a hybrid scheme of relay and base station coordination techniques combined in one. The sum-rate capacity of the combination transmission scheme is compared with those in conventional networks and the networks applying each technology separately.

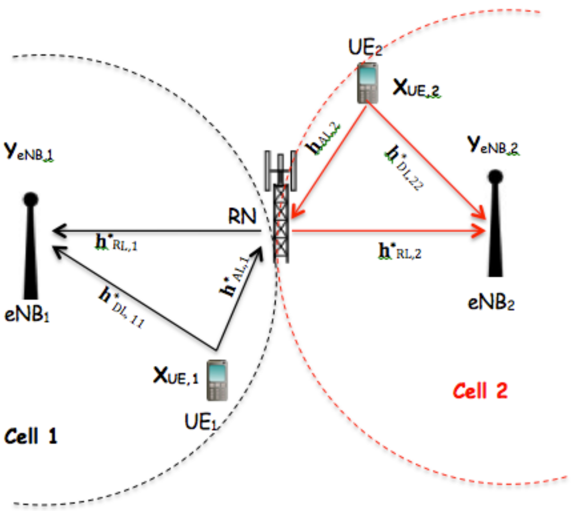
The paper is organized as follows: In section II, the analysis both in downlink and uplink transmission and their outage probabilities are formulated. The numerical results are shown in section III. Finally, conclusions are drawn in section IV.

2 System Model

There are different relay architectures for the cellular networks due to the fact that relaying does not take the inter-cell interference into consideration, we can only assume that transmissions in neighbor cells are time (or frequency) divided [5]. Other than the relay architecture defined in IEEE 802.16j, in which each relay has a single “parent” base station. In this paper, we introduce a shared relaying strategy, in which the adjacent eNBs share the same RN [6].

The advantages of shared relaying are more from the deployment point of view. It is obvious that less RNs are needed for completing the task of enhancing the wireless links in several cells [7].

In this paper, $\mathbf{h}_{AL,k}$ is the channel gain for the access link from the RN to the kth UE, $\mathbf{h}_{DL,k}$ is the direct link channel gain from the mth eNB and the kth UE, and $\mathbf{h}_{RL,m}$ is the relay link channel gain from the mth eNB to the RN. $\mathbf{x}_{eNB,m}$, $\mathbf{x}_r$ and $\mathbf{x}_{UE,k}$ are the signals transmitted by the mth eBN, the RN and the kth UE respectively, and the individual power levels are $\varepsilon\left\{\left|\mathbf{x}_{eNB,m}\right|^2\right\}=\mathbf{P}_{eNB,m}$, $\varepsilon\left\{\left|\mathbf{x}_r\right|^2\right\}=\mathbf{P}_{RN}$ and $\varepsilon\left\{\left|\mathbf{x}_{UE,k}\right|^2\right\}=\mathbf{P}_{UE,k}$. The total power allowed in the uplink for the UEs is $\mathbf{P}_{eNB}=\mathbf{P}_{eNB,1}+\mathbf{P}_{eNB,2}$ and the maximum power allowed in the downlink for eNBs is $\mathbf{P}_{eNB}=\mathbf{P}_{eNB,1}+\mathbf{P}_{eNB,2}$. $\mathbf{y}_{eNB,m}$, $\mathbf{y}_r$ and $\mathbf{y}_{UE,k}$ are the receive signals at the mth eNB, the RN and the kth UE, respectively. $\mathbf{n}_{eNB,m}$, $\mathbf{n}_r$ and $\mathbf{n}_{UE,k}$ are the noises observed at the mth eNB, the RN and the kth UE, with variances σ^2, σ_r^2 and σ^2 respectively. The channel gains in the uplink are assumed to be conjugate transposes of those in the downlink. The RN is assumed to be in full duplex Amplify and Forward (FDX AF) mode in this scheme so that the processing time on the RN can be ignored compared with the pilot time period.



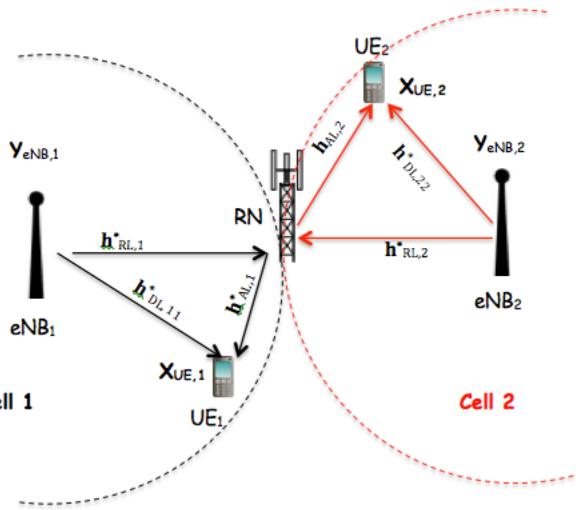


Fig. 1 Uplink (above) and downlink (below) transmissions with shared relaying

The Fig. 1 shows the transmission in the uplink and downlink phases for the system with shared relaying, where the black lines denote transmission in the first time slot and red lines denote transmission in the second time slot. Assuming that the channel is a constant over two time slots, the receive signal at UE is

$$\mathbf{y}_{AF}^{FDX}[t]=\underbrace{\left(\mathbf{h}_{DL}+\mathbf{h}_{AL}\mathbf{g}_{AF}\mathbf{h}_{RL}\right)}_{\tilde{\mathbf{h}}}\mathbf{x}[t]+\underbrace{\left(\mathbf{h}_{AL}\mathbf{g}_{AF}\mathbf{n}_r+\mathbf{n}\right)}_{\tilde{\mathbf{n}}} \quad (1)$$

The mutual information of FDX AF relaying can be evaluated according to the Shannon theory for bandwidth limited Gaussian channel as

$$\mathbf{I}_{AF}^{FDX}=\log_2\left(1+\frac{\mathbf{P}_{eNB}\left|\tilde{\mathbf{h}}\right|^2}{\sigma^2\eta}\right) \quad (2)$$

where $\tilde{h}$ is defined in (1) and $\sigma^2\eta$ is the noise power at the UE.

The scheduler allocates one time slot for one cell sequentially, for FDX AF, as indicated in (2), the sum-rate capacity for the shared relay system in the downlink phase is

$$C_{SR}^{DL}=\frac{1}{2}\left(\log_2\left(1+\frac{\mathbf{P}_{eNB}\left|\tilde{\mathbf{h}}_1\right|^2}{\sigma^2\eta_1}\right)+1+\frac{\mathbf{P}_{eNB}\left|\tilde{\mathbf{h}}_2\right|^2}{\sigma^2\eta_2}\right) \quad (3)$$

where the subscript SR denotes the shared relaying and the factor $\frac{1}{2}$ is for averaging the rates in two time slots. The other elements can be defined as

$$\begin{cases}\tilde{\mathbf{h}}_1=\mathbf{h}_{DL,11}+\mathbf{h}_{AL,1}\mathbf{g}_{AF,1}\mathbf{h}_{RL,1}\\ \tilde{\mathbf{h}}_2=\mathbf{h}_{DL,22}+\mathbf{h}_{AL,2}\mathbf{g}_{AF,2}\mathbf{h}_{RL,2}\end{cases},$$

$$\begin{cases} \eta_1 = 1+|h_{AL,1}|^2 |g_{AF,1}|^2 \dfrac{\sigma_r^2}{\sigma^2} \\ \eta_2 = 1+|h_{AL,2}|^2 |g_{AF,2}|^2 \dfrac{\sigma_r^2}{\sigma^2} \end{cases} \text{ and } \begin{cases} g_{AF,1} = \sqrt{\dfrac{P_{RN}}{P_{eNB}|h_{RL,1}|^2+\sigma^2}} \\ g_{AF,2} = \sqrt{\dfrac{P_{RN}}{P_{eNB}|h_{RL,2}|^2+\sigma_r^2}} \end{cases}$$

Similarly, in the uplink phase, the sum-rate capacity is

$$C_{SR}^{UL} = \frac{1}{2}\left(\log_2\left(1+\frac{P_{UE}|\tilde{h}_1^{UL}|^2}{\sigma^2\eta_1^{UL}}\right)+1+\frac{P_{eNB}|\tilde{h}_2^{UL}|^2}{\sigma^2\eta_2^{UL}}\right) \quad (4)$$

where

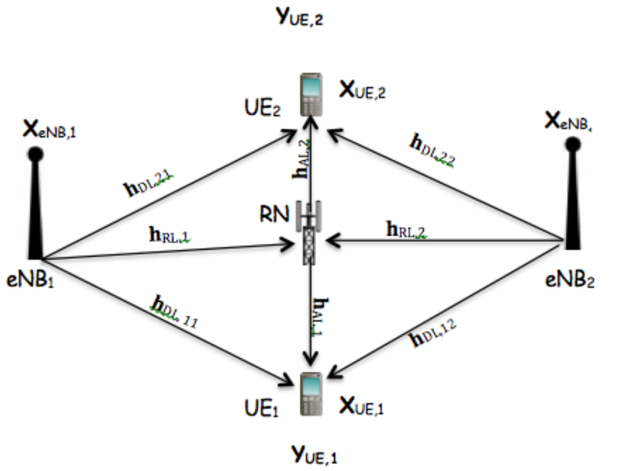
$$\begin{cases} \tilde{h}_1^{UL} = h^*_{DL,11}+h^*_{AL,1}\, g^{UL}_{AF,1}\, h^*_{RL,1} \\ \tilde{h}_2^{UL} = h^*_{DL,22}+h^*_{AL,2}\, g^{UL}_{AF,2}\, h^*_{RL,2} \end{cases},$$

$$\begin{cases} \eta_1^{UL} = 1+|h_{RL,1}|^2 |g^{UL}_{AF,1}|^2 \dfrac{\sigma_r^2}{\sigma^2} \\ \eta_2^{UL} = 1+|h_{RL,2}|^2 |g^{UL}_{AF,2}|^2 \dfrac{\sigma_r^2}{\sigma^2} \end{cases}$$

and

$$\begin{cases} g^{UL}_{AF,1} = \sqrt{\dfrac{P_{RN}}{P_{UE}|h^*_{AL,1}|^2+\sigma_r^2}} \\ g^{UL}_{AF,1} = \sqrt{\dfrac{P_{RN}}{P_{UE}|h^*_{AL,2}|^2+\sigma_r^2}} \end{cases}$$

The system applying the combination of shared relaying and base station coordination is as shown in Fig. 2



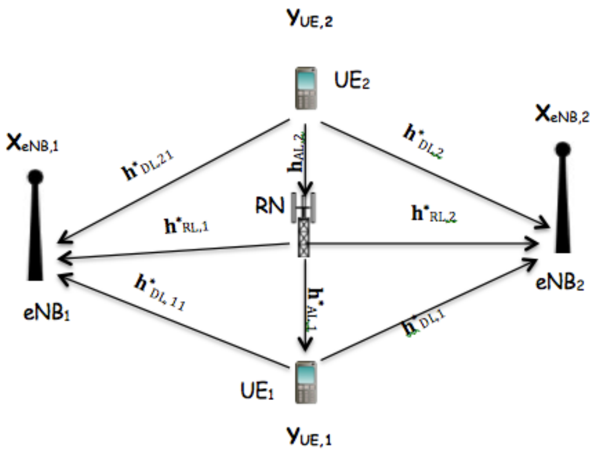


Fig. 2 Uplink (above) and Downlink (below) transmission in the combination scheme

In the downlink phase, assuming $\mathbf{H} = \begin{pmatrix} h_{DL,11} & h_{DL,21} \\ h_{DL,12} & h_{DL,22} \end{pmatrix}$ is the channel matrix from eNBs to UEs and $\mathbf{h}_r = \begin{pmatrix} h_{RL,1} & h_{RL,2} \end{pmatrix}$ is the channel vector from eNBs to RN, the RN receives

$$y_r = \mathbf{h}_r \mathbf{x}_{eNB} + \mathbf{n}_r \quad (5)$$

where $\mathbf{x}_{eNB} = \begin{pmatrix} x_{eNB,1} \\ x_{eNB,2} \end{pmatrix}$ is the transmit signal vector from the eNBs. The RN is assumed to be FDX AF, therefore the forward signal is

$$x_r = g_{AF} y_r \quad (6)$$

The amplification can be expressed by

$$g_{AF} = \sqrt{\frac{P_{RN}}{P_{eNB,1}|h_{RL,1}|^2 + P_{eNB,2}|h_{RL,2}|^2 + \sigma_r^2}} \quad (7)$$

where the denominator denotes the power of receive signal at the RN. At the *k*th UE, the receive signal is the addition of the signals from the eNBs and the RN. It can be modeled as

$$\begin{aligned} y_{UE,k} &= \mathbf{h}_k \mathbf{x}_{eNB} + h_{AL,k} x_r + n_{UE,k} \\ &= \underbrace{\left(\mathbf{h}_k + h_{AL,k} g_{AF} \mathbf{h}_r\right)}_{\tilde{\mathbf{h}}_k} \mathbf{x}_{eNB} + \underbrace{\left(h_{AL,k} g_{AF} n_r + n_{UE,k}\right)}_{\tilde{n}_{UE,k}} \end{aligned} \quad (8)$$

where $\mathbf{h}_k = \begin{pmatrix} h_{DL,1k} & h_{DL,2k} \end{pmatrix}$ is the channel from eNBs to the *k*th UE and equal to the *k*th row of , $\tilde{\mathbf{h}}_k$ is the channel vector and $\tilde{\mathbf{n}}_{UE,k}$ is the amplified noise with power $\tilde{N}_{UE,k} = \left|h_{AL,1}\right|^2 \left|g_{AF}\right|^2 \sigma_r^2 + \sigma^2$.

The system can be treated as a multi-user MIMO system with two distributed transmits antennas and two independent receive antenna. In order to cancel inter-cell interference, zero-forcing pre-coding is applied at the eNBs, i.e. the condition $\tilde{\mathbf{h}}_k \mathbf{w}_i = \mathbf{0}$, for any $i \neq k$, should be satisfied. $\mathbf{w}_i$ is the *i*th column of the pre-coding matrix $\mathbf{W} = \begin{pmatrix} \omega_{11} & \omega_{21} \\ \omega_{12} & \omega_{22} \end{pmatrix}$. Then the sum-rate capacity is

$$C_C^{DL} = \log_2\left(1 + \frac{\left|\tilde{\mathbf{h}}_1 \mathbf{w}_1\right|^2}{\tilde{N}_{UE,1}}\right) + \log_2\left(1 + \frac{\left|\tilde{\mathbf{h}}_2 \mathbf{w}_2\right|^2}{\tilde{N}_{UE,2}}\right) \tag{9}$$

where the subscript C denotes the combination transmission scheme, $\tilde{\mathbf{h}}_k$ and $\tilde{N}_{UE,k}$ are as shown in (11). In the uplink phase, assuming $\mathbf{H}^* = \begin{pmatrix} h_{DL,11}^* & h_{DL,12}^* \\ h_{DL,21}^* & h_{DL,22}^* \end{pmatrix}$ is the channel matrix from UEs to eNBs and $\mathbf{h}_r^{UL} = \left(h_{AL,1}^* \; h_{AL,2}^*\right)$ is the channel vector from UEs to the RN, the RN receives

$$y_r^{UL} = \mathbf{h}_r^{UL} \mathbf{x}_{UE} + n_r \tag{10}$$

where $\mathbf{x}_{UE} = \begin{pmatrix} x_{UE,1} \\ x_{UE,2} \end{pmatrix}$ is the transmit signal vector from the UEs. The RN is assumed to be FDX AF, so the forward signal in the uplink is

$$x_r^{UL} = g_{AF}^{UL} y_r^{UL} \tag{11}$$

The amplification gain can be expressed by

$$g_{AF}^{UL} = \sqrt{\frac{P_{RN}}{P_{UE,1}\left|h_{AL,1}\right|^2 + P_{UE,2}\left|h_{AL,2}\right|^2 + \sigma_r^2}} \tag{12}$$

where the denominator denotes the power of receive signal at the RN. It can be modeled as

$$\begin{aligned} \mathbf{y}_{eNB} &= \mathbf{H}^* \mathbf{x}_{eNB} + \begin{pmatrix} h_{RL,1}^* \\ h_{RL,2}^* \end{pmatrix} x_r + \mathbf{n}_{eNB} \\ &= \underbrace{\begin{pmatrix} h_{DL,11}^* + h_{RL,1}^* g_{AF}^{UL} h_{AL,1}^* & h_{DL,12}^* + h_{RL,1}^* g_{AF}^{UL} h_{AL,2}^* \\ h_{DL,21}^* + h_{RL,2}^* g_{AF}^{UL} h_{AL,1}^* & h_{DL,22}^* + h_{RL,2}^* g_{AF}^{UL} h_{AL,2}^* \end{pmatrix}}_{\mathbf{H}^{UL}} \mathbf{x}_{UE} \\ &+ \underbrace{\begin{pmatrix} h_{RL,1}^* g_{AF}^{UL} n_r + n_{eNB,1} \\ h_{RL,2}^* g_{AF}^{UL} n_r + n_{eNB,2} \end{pmatrix}}_{\tilde{\mathbf{n}}_{eNB}} \end{aligned} \tag{13}$$

where $\mathbf{H}^{UL}$ is the equivalent channel matrix and the noise power at each eNB is then $\tilde{N}_{eNB,m} = \left|h_{RL,m}\right|^2 \left|g_{AF}\right|^2 \sigma_r^2 + \sigma^2$, scale the noises power to unit, rewrite (16) as

$$\begin{aligned} &\underbrace{\begin{pmatrix} \tilde{N}_{eNB,1}^{-1/2} y_{eNB,1} \\ \tilde{N}_{eNB,2}^{-1/2} y_{eNB,1} \end{pmatrix}}_{\tilde{\mathbf{y}}_{eNB}} = \\ &\underbrace{\begin{pmatrix} \tilde{N}_{eNB,1}^{-1/2}\left(h_{DL,11}^* + h_{RL,1}^* g_{AF}^{UL} h_{AL,1}^*\right) & \tilde{N}_{eNB,1}^{-1/2}\left(h_{DL,12}^* + h_{RL,1}^* g_{AF}^{UL} h_{AL,2}^*\right) \\ \tilde{N}_{eNB,2}^{-1/2}\left(h_{DL,21}^* + h_{RL,2}^* g_{AF}^{UL} h_{AL,1}^*\right) & \tilde{N}_{eNB,1}^{-1/2}\left(h_{DL,22}^* + h_{RL,2}^* g_{AF}^{UL} h_{AL,2}^*\right) \end{pmatrix}}_{\tilde{\mathbf{H}}^{UL}} \mathbf{x}_{UE} \\ &+ \underbrace{\begin{pmatrix} \tilde{N}_{eNB,1}^{-1/2}\left(h_{RL,1}^* g_{AF}^{UL} n_r + n_{eNB,1}\right) \\ \tilde{N}_{eNB,2}^{-1/2}\left(h_{RL,2}^* g_{AF}^{UL} n_r + n_{eNB,2}\right) \end{pmatrix}}_{\tilde{\mathbf{n}}_{eNB}} \end{aligned} \tag{14}$$

where $\tilde{\mathbf{y}}_{eNB}$, $\tilde{\mathbf{H}}^{UL}$ and $\tilde{\mathbf{n}}_{eNB}$ denote scaled version of receive signal vector, channel matrix and noise vector, respectively.

Since we consider the uplink transmissions are also MIMO multiple accessing, so the uplink capacity can be expressed as

$$C_C^{UL} = \log_2 \det\left(\mathbf{I} + \tilde{\mathbf{h}}_1^{UL} P_{UE,1} \tilde{\mathbf{h}}_1^{UL*} + \tilde{\mathbf{h}}_2^{UL} P_{UE,2} \tilde{\mathbf{h}}_2^{UL*}\right) \tag{15}$$

where $\tilde{\mathbf{h}}_1^{UL}$ and $\tilde{\mathbf{h}}_2^{UL}$ are the first and second column of the uplink channel matrix $\tilde{\mathbf{H}}^{UL}$.

3 Numerical Results

The performance is evaluated by using Monte Carlo simulations [8]. The parameters of the simulation are given in Table 1. The simulated cluster is composed of two cells with one UE located in each cell-edge. Simulations are done to show the sum-rate capacities in uplink and downlink transmission of four scenarios: the conventional system; the system with shared relay; the system with base station coordination; the system with the combination of shared relaying and base station coordination.

Table 1. Simulation parameters

Parameter	**Value**
Number of eNB	2
Number of RN	1
Number of UE per cell	1
Number of antennas on each equipment	1
Height of eNB	25m
Height of RN	25m
Height of UE	1.5m
Number of realization	1000
Cell radius	876m
Noise power	- 144 dBW
Distance between the eNB and UE in the same cell	700m
Distance between the eNB and UE in the different cell	1052m
Distance between the RN and the UE	176m
Total transmission power of eNB/ RN/ UE respectively	17dBW/ 14dBW/ 5dBW

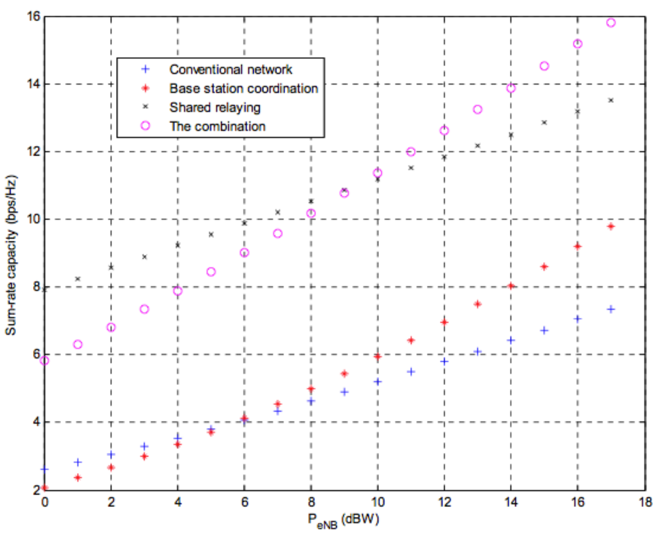


Fig. 3 Downlink sum-rate capacity versus P_{eNB}

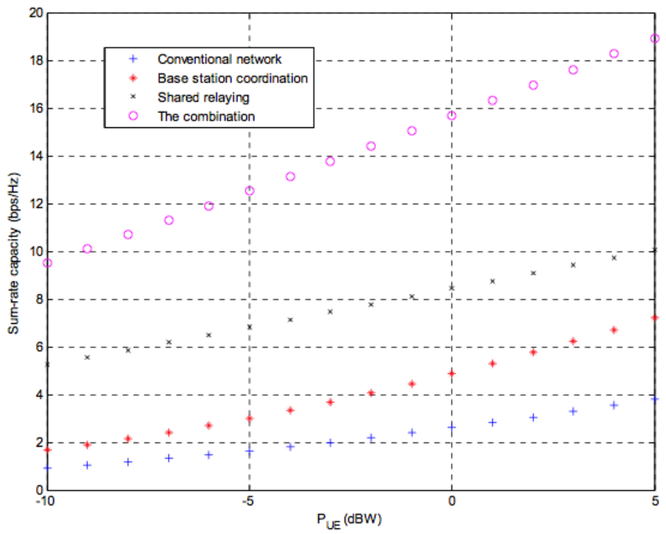


Fig. 4 Uplink sum-rate capacity versus P_{UE}

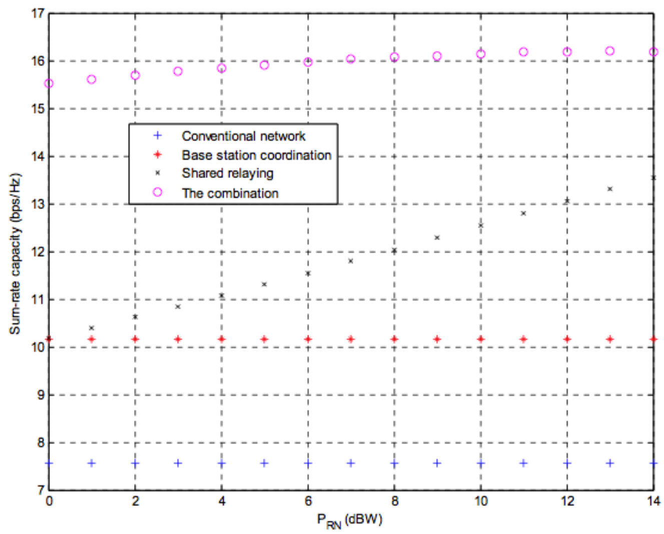


Fig. 5 Downlink sum-rate capacity versus P_{RN}

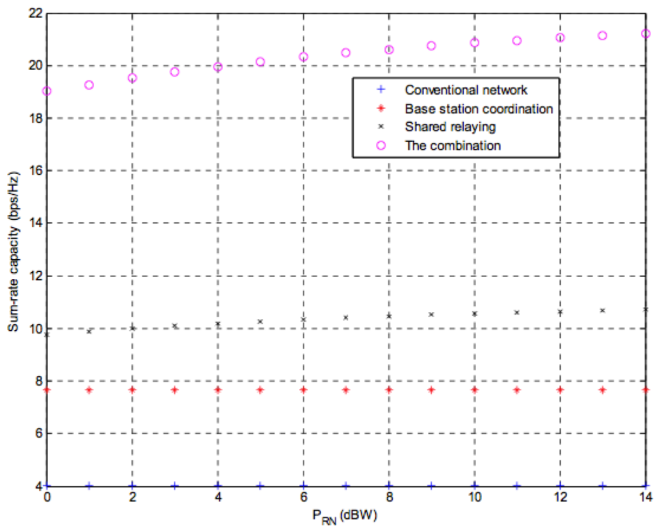


Fig. 6 Uplink sum-rate capacity versus P_{RN}

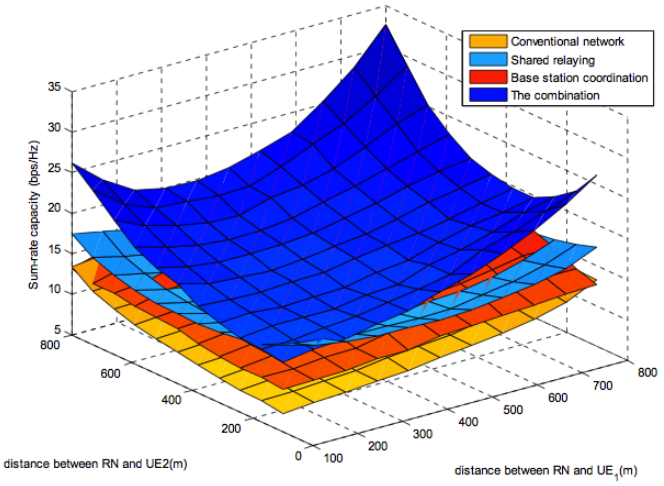


Fig. 7 Downlink sum-rate capacity versus distance apart from RN

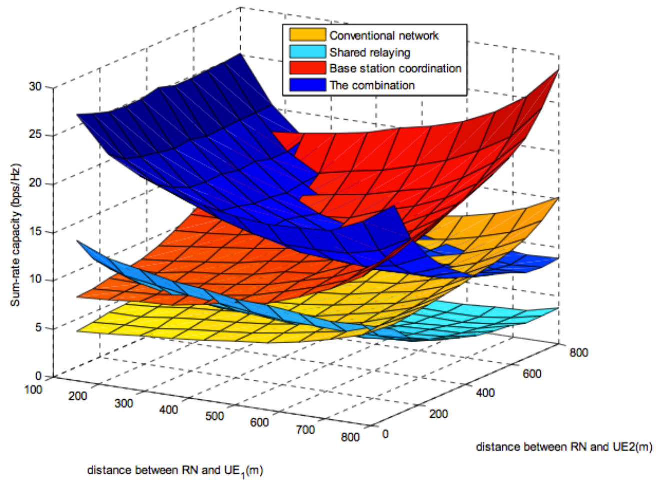


Fig. 8 Uplink sum-rate capacity versus distance apart from RN

Fig. 3 and 4 show the relationships between sum-rate capacities and eNB transmits antenna power in the downlink phase and UE transmits antenna power in the uplink phase, respectively. Generally the sum rates are increasing with the antennas power, since higher transmitted power leads to higher SNR [9]. In the downlink, because of the sub-optimal nature of zero-forcing pre-coding, the combination of shared relaying and base station coordination outperforms the others at high transmit power ($>9\text{dBW}$) and the shared relaying is the best choice when transmit power of eNB is lower than 9dBW. This results also implies the main contribution in the performance improvement is done by the RN. The close distance between the RN and UE causes this consequence. For a simple calculation, following the simulation parameters in the downlink phase, when $P_{eNB} = 0\text{dBW}$, $P_{RN} = \frac{1}{2}P_{eNB} = -3\text{dBW}$ a typical receive SNR of the DL at the UE is $\frac{P_{eNB}}{\sigma^2}\left|h_{DL,11}\right|^2 \approx 15.5\text{dB}$, and a typical receive SNR of the AL at the UE is $\frac{P_{RN}}{\sigma^2}\left|h_{AL,1}\right|^2 \approx 36.5\text{dB}$. So that the transmissions of the RN dominate the order $C_C^{UL} > C_{SR}^{UL} > C_{BSC}^{UL} > C_{CON}^{UL}$ (subscript BSC and CON denotes base station coordination and conventional respectively).

Fig. 5 and 6 show how sum-rate capacities change with the increasing of RN transmit power. The performances of convention system and coordinated eNBs stay unchanged since there's no RN deployed in these two cases. We can see that in the downlink phase, when the power of RN increases from 0dBW to 14dBW, the capacity of the combination case grows with 0.5bps/Hz while the capacity of share relaying system increases with 3.5bps/Hz. In the uplink phase, for 14dB increase in power of the RN, the capacity of the combination case grows with 2bps/Hz while the capacity of share relaying system increases with 1bps/Hz. Assume that the eNBs, the RN and UEs are aligned in a straight line, which means if the distance between the RN and UE_1 is d_1 (originally in table 1, $d_1 = 176\text{m}$), then the distance between UE and eNB_1 is $876 - d_1\ (\text{m})$ and the distance between UE and eNB_2 is $876 + d_1\ (\text{m})$. Then we show the influences of UEs' locations to the system sum-rate capacities. Set P_{eNB} and P_{RN} at the maximum and varying the distances between the RN and UEs d_1 to draw a 3-D surface.

Fig. 7 shows the influences of UEs' locations in the downlink transmissions. With the highest transmitted power levels on both RN and eNBs, we change the positions of UEs along a path from RN to eNB. The combination of shared relaying with base station coordination outperforms the others in all the covered area [10].

Fig 8 shows the influences of UEs' locations in the uplink phase. With the highest transmitted power levels on both RN and eNBs, we change the positions of UEs along a path from RN to eNB. The combination of shared relay with base station coordination outperforms the others in the region where the UEs are close to the RN and the pure base station coordination seems to be the best choice for the case that all the UE are located near the their "parent" eNBs. When the UEs are far away from the RN, the useful signal receive at the RN from UEs is very weak. Since the RN is FDX AF, the signal it forwards will contain a large proportion of noises. That is the reason why the shared RN plays a negative role for the system capacity in the uplink when the UEs are not at the cell board [11].

From fig 3 to 8, we can conclude that the combination of techniques is feasible and efficient methods to enhance the cell edge performance. For the cell-edge UEs, they mainly benefit from the assistant of the RN. However, if all the UEs are close to the eNBs, the combination scheme may not have the best performance. The control point should do the scheduling task based on the channel state information and decide the most suitable transmission scheme for the specific users at the specific positions.

4 Conclusion

The combination scheme is proposed based on the idea that enhancing the wireless link and reducing the inter-cell interference could be done concurrently. A shared relay node is chosen as the relay architecture for the reason that less RN deployments are required in the network. Numerical results show that this transmission scheme can enable the simultaneous transmissions to multiple users in different cells and gain higher sum-rate capacity than those systems applying relaying or base station coordination alone. So that it is a good solution for improving the cell-edge multi-user performance.

References:

[1] M. K. Karakayali, G. J. Foschini, and R. A. Valenzuela, Network coordination for spectrally efficient communications in cellular systems, IEEE wireless communications, vol.13, no.4, pp. 56-61, 2006.

[2] H. Zhang and H. Dai, Cochannel interference mitigation and cooperative processing in downlink multicell multiuser MIMO networks, EURASIP Journal on wireless communications and networkinh, vol.2, pp. 222-235, 2004.

[3] R. Pabst, B. H. Walke, D. C. Schultz, et al., Relay-based deployment concepts for wireless and mobile broadband radio, IEEE Communications magazine, vol.42, pp. 66-73, 2007.

[4] O. Oyman, N. J. Laneman, and S. Sandhu, Multihop relaying for broadband wireless mesh networks: from theory to practice, IEEE Communication magazine, vol.42, no.11, pp. 116-122, 2007.

[5] H. Huang and M. Trivellato, Performance of multiuser MIMO and network coordination in downlink cellular network, in proceedings of the 6th International Symposium on Modeling and Optimization in Mobile, Ad Hoc and wireless network, pp. 85-90, 2008.

[6] W. Steven et al., Relay Architectures for 3GPP LTE-Advanced, in EURASIP Journal on wireless communication and networking, vol.09, 2009.

[7] D. Gesbert et al., Multi-cell MIMO cooperative networks: a new look at interference, IEEE JSAC, vol.28, no.9, 2010.

[8] IST-4-027756 WINNER II, Deliverable D3.5.1 Relay concepts and calibration cases issue 2, Dec. 2006.

[9] H. Viswanathan and S. Mukherjee, Performance of cellular networks with relays and centralized scheduling, Wireless communication, IEEE Transactions on, vol.5, pp. 2318-2328, 2005.

[10] So, B. Liang, Effect of relaying on capacity improvement in wireless Local Area Networks, WCNC 2005, 13-17, vol.3, pp. 1539-1544, 2005.

[11] J. Lee et al., Coordinated multipoint transmission and reception in LTE-Advanced systems, IEEE Communication magazine, vol.50, no.11, pp. 44-50, 2012.