Cooperative Communications for Wireless Network: Techniques and Applications in LTE-advanced Systems

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Abstract

- Cooperative communications enable efficient utilization of communication resources, by **allowing nodes** or **terminals** in a communication network to collaborate with each other in information transmission.
- We survey cooperative communication schemes and discuss their advantages in **improving system capacity and diversity**.
- We examine the applications of cooperative relaying schemes in LTE-advanced systems.
- We investigate two **intra-cell coordinated multi-point schemes** in LTE-advanced systems, and evaluate the performance of the schemes.
- Cooperative relaying leads to both network coverage extension and capacity expansion in LTE-advanced systems.
- Cooperative communications can significantly improve the system spectrum efficiency and performance.

Introduction

- Cooperative communication can be used in **improving network connectivity**, **enhancing power** and **spectrum efficiency**, and **improving communication reliability**.
- Cooperative communication is superior in **deployment flexibility** and **hardware feasibility**.
- The idea of cooperative communication can be traced back to the 1970s. Meulen constructed a three-terminal relay channel, and derived upper and lower bounds on its channel capacity.
- Later, capacity of the cooperative relay channel was investigated, and two cooperation protocols, **decode-and-forward (DF)** and **compress-and-forward (CF)**.

Cont.

- we investigate cooperative communication techniques and their applications in LTE-Advanced systems.
- We discuss their advantages in improving system capacity and diversity.
- We investigate the application of cooperative techniques in LTE-Advanced systems and study two cooperative schemes.
- By taking two intra-cell coordinated multipoint schemes as examples, we evaluate the performance of cooperative communications in LTE-Advanced systems from the network capacity perspective.

- Possible ways of realizing cooperations
  - using extra **relay nodes (RNs)** to assist the communications between sources and their corresponding destinations
  - allowing the communication nodes in a network to help each other to communicate with their corresponding destinations.
- Systems using the first way of cooperations are often referred to as relay systems.
- Systems using the second way of cooperations are often referred to as node cooperative systems.

Relay Systems

- In a relay system, sources first transmit their data to the RNs. Each RN then processes and forwards its received data information to the destination nodes following some cooperation protocols. With the received signal from the RNs, the destinations decode the data from their corresponding sources. Some basic cooperation protocols are **amplify-and-forward (AF)**, **decode-and-forward (DF)**, and **compress-and-forward (CF)**.

amplify-and-forward (AF)

- For the AF protocol, each RN simply scales its received signal according to its transmit power constraint and forwards the scaled signal in the next transmission slot.

decode-and-forward (DF)

- For the DF protocol, each RN decodes the source message from its received signal, re-encodes it into a new codeword, and transmits it in the next transmission slot.

compress-and-forward (CF)

- For the CF protocol, each RN first maps its received signal into another signal in a reduced signal space, then encodes and forwards the "compressed" signal as a new codeword by taking the signal received at the destination as side information.

cooperation schemes

- AF and CF based cooperation schemes can be viewed as "**analog**" cooperation schemes
- DF based cooperation schemes can be viewed as "**digital**" cooperation schemes.
- Depending on the network topology and the quality of the backhaul link between the source and the RN, one protocol may outperform the other in terms of system capacity or diversity.
- For systems with good backhaul links, DF based cooperation schemes are more favorable.
- While for systems with relative poor backhaul links, AF or CF based cooperation schemes are more advantageous.

Node Cooperative Systems

- In a node cooperative system, cooperations can be implemented by either joint processing among the communication terminals or by coordinating the communication strategies of the terminals.

DMT performance

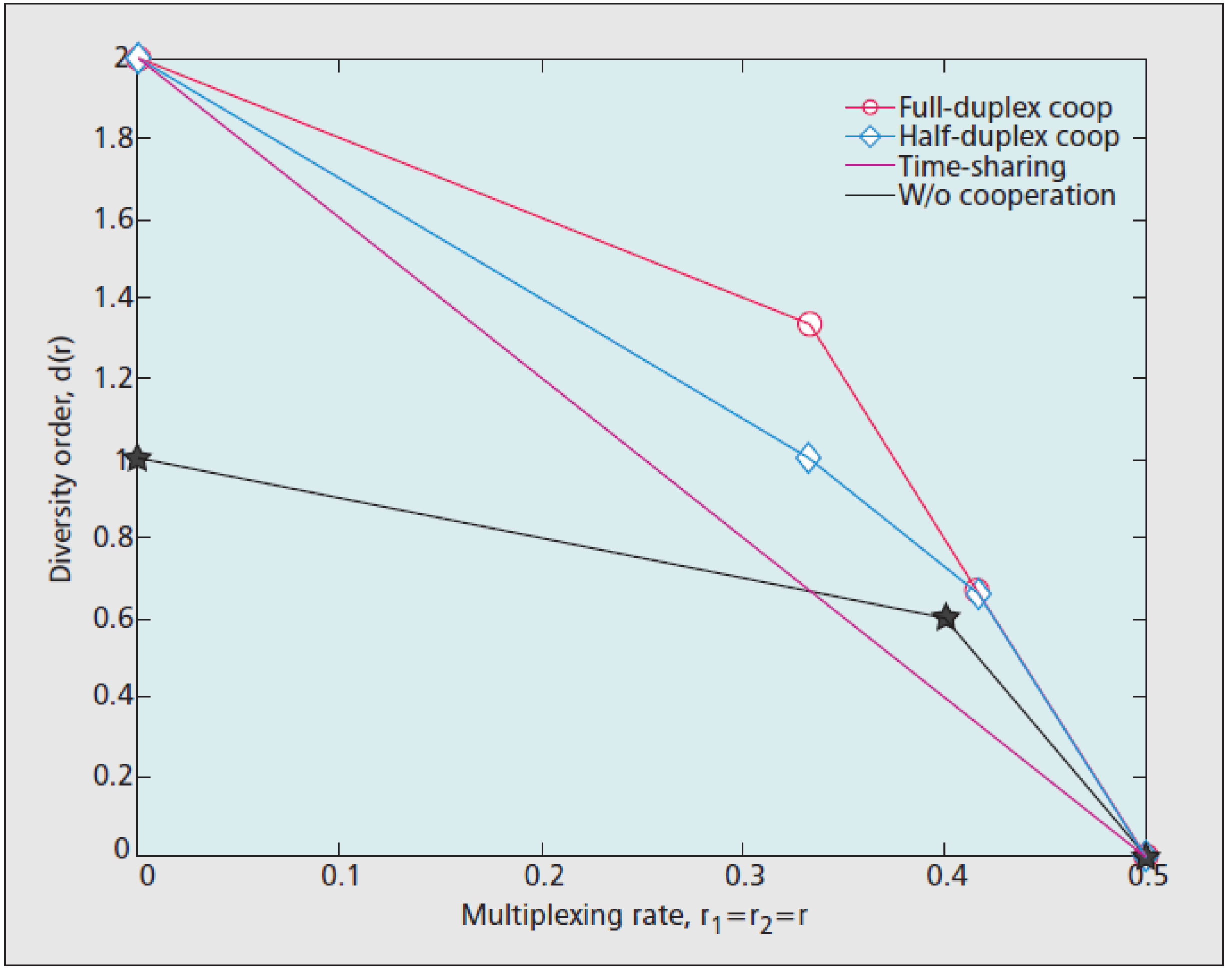


Figure 2. *DMT performance for the two-transmitter two-receiver system with joint processing at transmitters.*

Rate region results

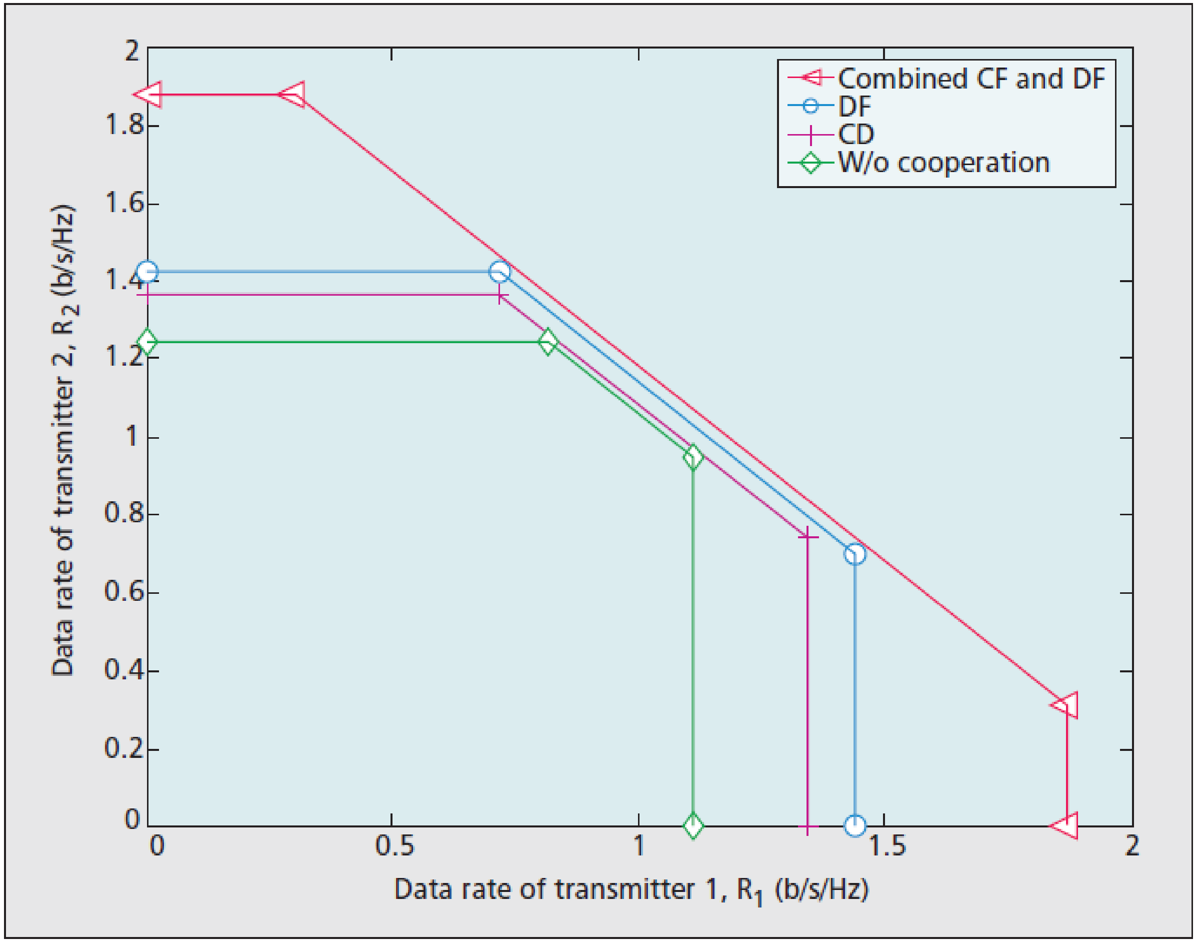


Figure 1. *Rate region results for the two-transmitter two-receiver system with joint processing at transmitters.*

Joint processing based node cooperations

- User data is first exchanged among the terminals and then jointly transmitted/received by multiple transmission/reception points.
- User data exchange can be implemented via the backhaul link using the cooperation protocols mentioned above.
- Each terminal can be viewed as a RN for the other terminals. With the data information of one another, the cooperative terminals form a distributed antenna array.
- Transmission schemes designed for the conventional co-located multiple-antenna systems, such as space-time coding and successive cancellation/decoding, can be applied in the distributed multiple-antenna system.

terminals coordinate in their communication strategies

- power/frequency allocation and beamforming directions, with the aim to minimize the mutual interference at the corresponding destinations.
- To implement the coordinated transmission, channel state information (CSI) should be shared among terminals, while exchanging data information is not necessary.

Application of Cooperative Communications in LTE-Advanced Systems

- Initiated in 2004, LTE is a standard developed by the Third Generation Partnership Project (3GPP) for high-speed, high-spectral-efficiency, and very low-latency wireless communication, which is often regarded as fourth-generation (4G) wireless communication.
- Over a radio frequency (RF) bandwidth of 20 MHz, the data rate in LTE systems can be as high as 300 Mb/s in the downlink and 75 Mb/s in the uplink.

Cont.

- To support high-speed communication, several core techniques have been developed in LTE-A, such as high order multiple-antenna transmission and reception (also known as multiple-input-multiple-output, MIMO), self-organizing network operation, heterogeneous deployment, and cooperative communication.
- In this section, we will investigate the application of cooperative communication in LTE-A.

coordinated multi-point (CoMP)

- In release 10 of LTE-A standards, both relay communication and node cooperative communication as discussed in the previous section are considered.
- Specifically, node cooperative communication is known as coordinated multi-point (CoMP) transmission or reception and is implemented by joint processing and/or coordinated transmission among the base stations (eNB) for serving the user equipment (UE) in the network.
- RNs are also deployed in LTE-advanced systems to assist the communication between the eNBs and the UEs. Compared to the eNB, RN transmits at a lower power and covers a smaller area.

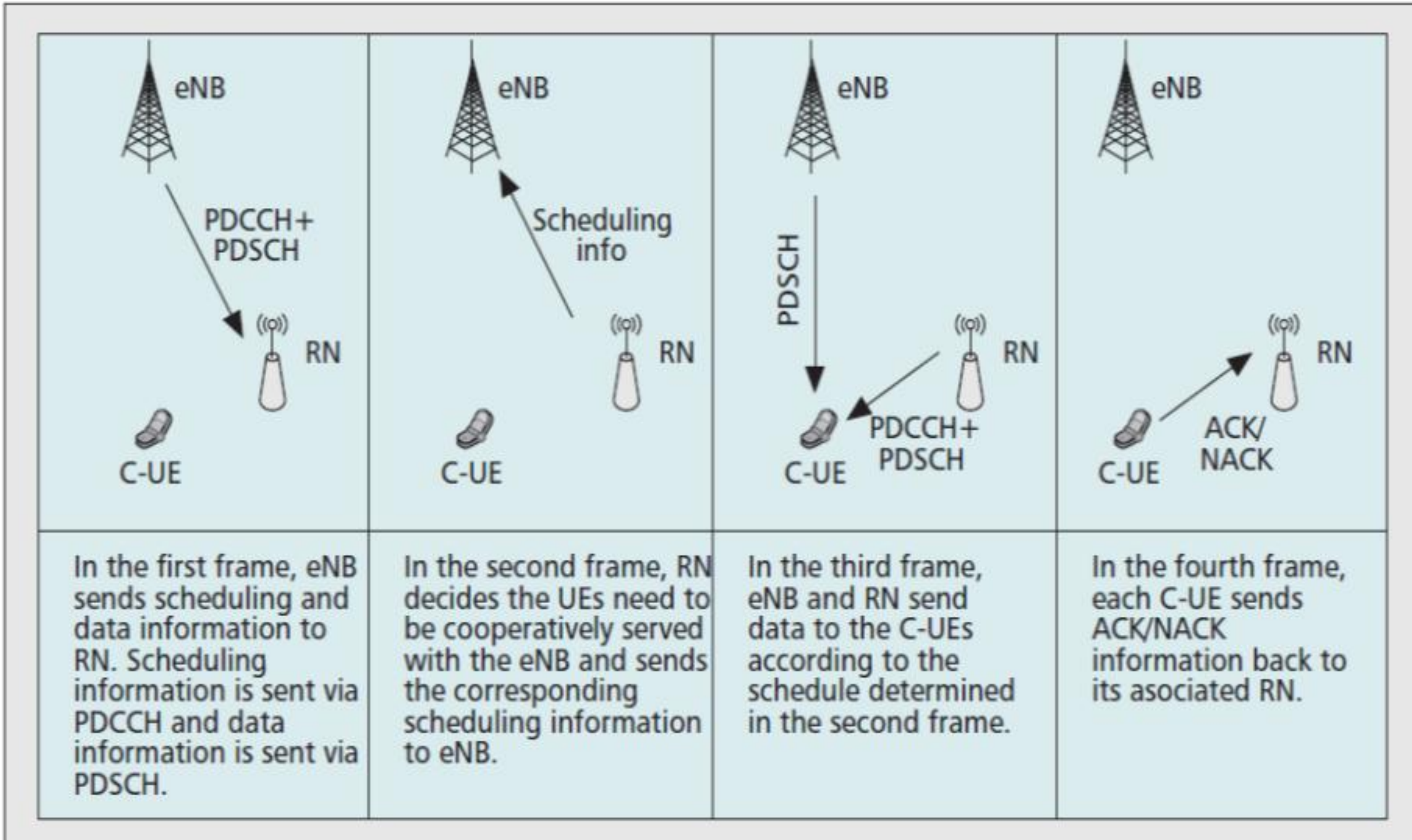
Cont.

- The deployment of RNs introduces low power nodes on top of the conventional macro-BSs in the cellular system. Each UE can either communicate directly with the eNB or via the help of low power RNs.
- In this way, cell edge or remote UEs can be better served and the network coverage and capacity can both be enhanced. Since in implementing relay communication, user data is available at both the donor eNB and the RN, it is possible to implement CoMP within a cell by doing joint processing at the donor eNB and the RN within the cell. Such a combination of relay communication and CoMP has been proposed for consideration in LTE release-11 and beyond.

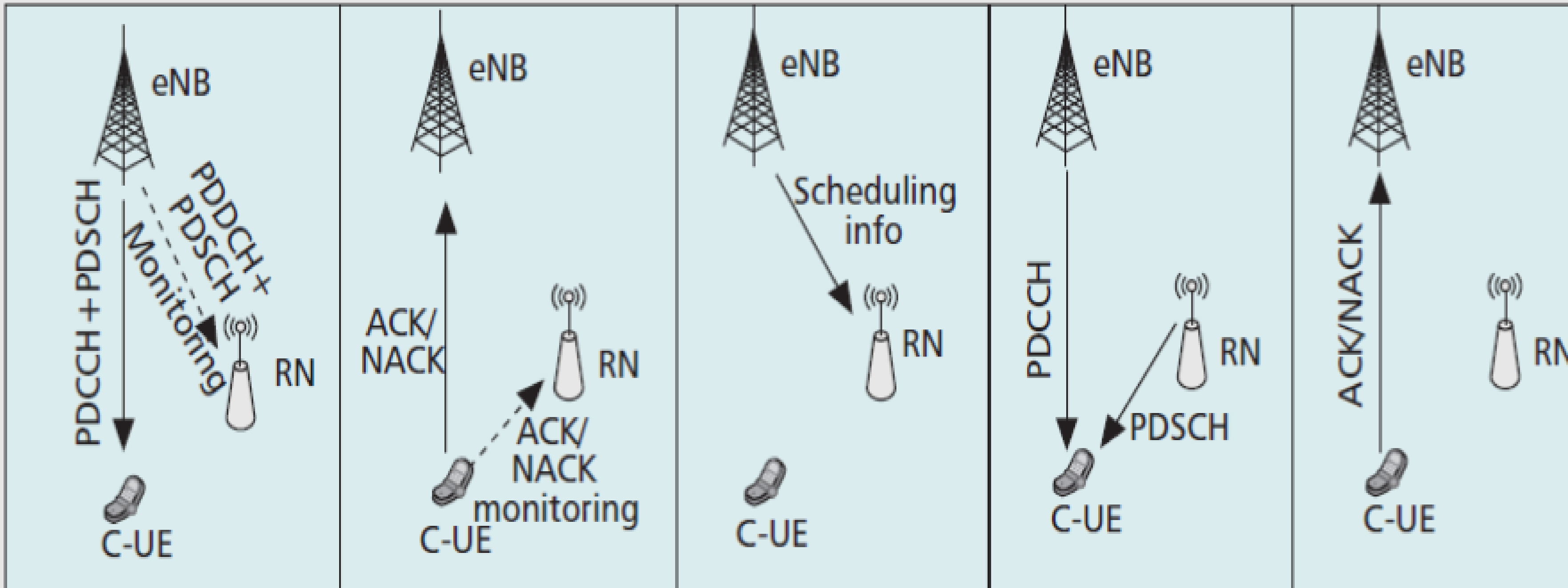
Two schemes

- In this section, we show two schemes for implementing the intra-cell CoMP by taking RN as a transmission point. The performance of the two schemes will be numerically evaluated and compared with the performance of systems without intra-cell CoMP. We focus on the downlink communication and consider an **orthogonal frequency division multiple access (OFDMA)** based physical transmission scheme.

Intra-cell CoMP scheme-1



Intra-cell CoMP scheme-2



In the first frame, eNB transmits scheduling and data information to the UEs. RN monitors the transmission.	In the second frame, UE sends ACK/NACK back to the eNB.	In the third frame, UE sends the scheduling information to the RN to arrange retransmission.	In the fourth frame, RN retransmits data information to the UE according to the schedule set in the third frame.	In the fifth frame, each UE sends ACK/NACK information back to its associated eNB.

Performance Evaluation and Discussion

- We evaluate the performance of the two intra-cell CoMP schemes in a cellular network with a 19-cell 3-sector three-ring hexagonal cell structure. Four RNs are uniformly deployed in each sector.
- Simulation setup follows the guidelines for Case 1. Transmit power of the BS is 46 dBm (40 W) and transmit power of the RN is 30 dBm (1 W). All the UEs are uniformly distributed in the network.

Cont.

- Each UE represents an adaptive multi-rate based VoIP user with a rate of 8.6 kb/s. The capacity of the network can thus be evaluated as the maximum accepted number of UEs per cell. We compute the network capacity and the distribution of the received signal-to-interference-noise-ratio (SINR) at the UEs for the two intra-cell CoMP schemes.

Performance of the first intra-cell CoMP schemes

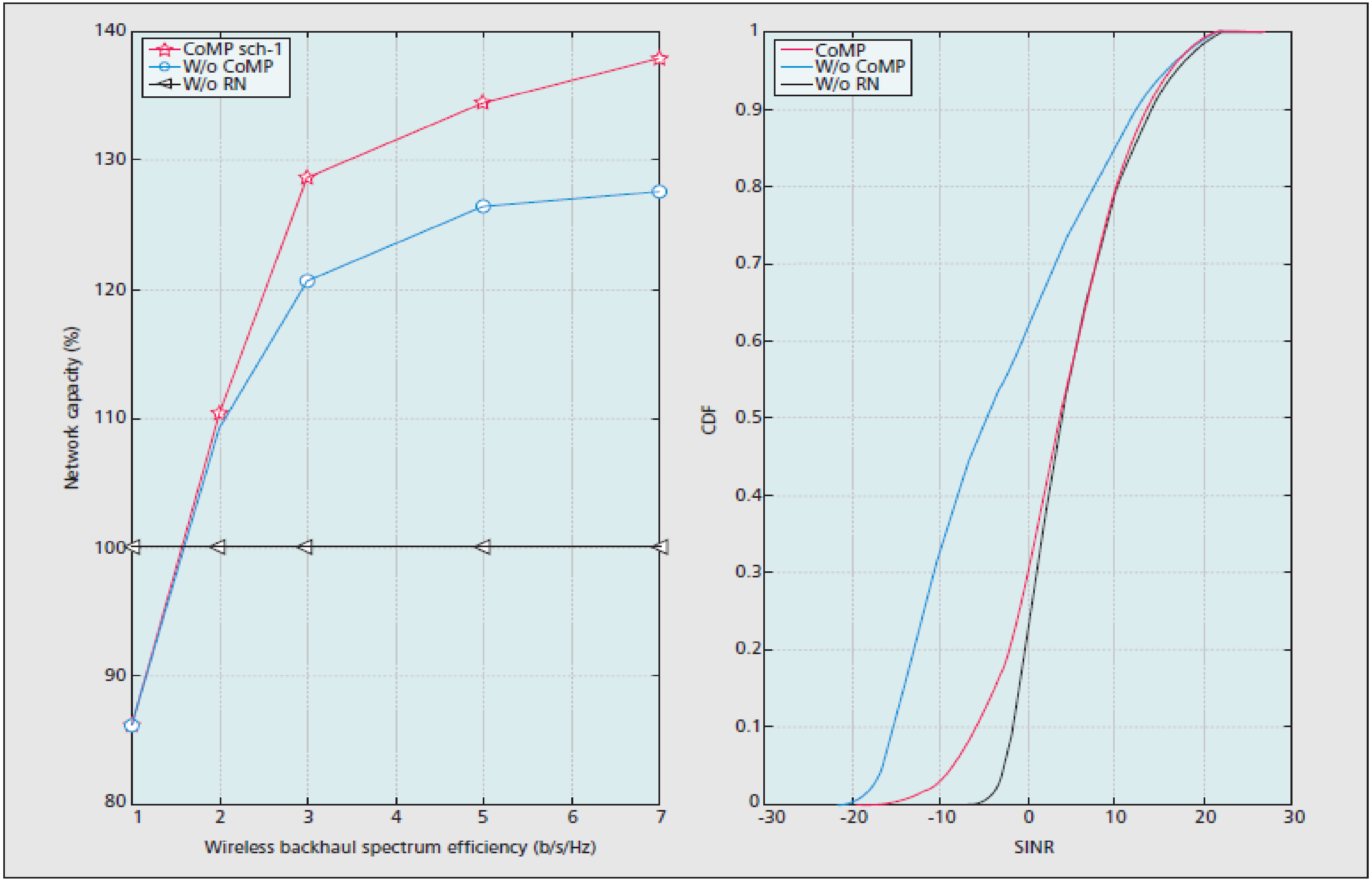


Figure 5. *Performance of the first intra-cell CoMP schemes.*

For the *u*-th C-UE in the first intra-cell CoMP scheme

$$\mathrm{SINR}_u^{\mathrm{sch1}} = \frac{\left|h_{b,u}\right|^2 P_b + \left|h_{r,u}\right|^2 P_r}{I_u + N_0}, \quad (1)$$

$$\mathrm{MI} = t_1 \log\left(1 + \frac{\left|h_{b,u}\right|^2 P_b}{I_{u,1} + N_0}\right) + t_4 \log\left(1 + \frac{\left|h_{r,u}\right|^2 P_r}{I_{u,4} + N_0}\right), \quad (2)$$

$$\mathrm{SINR}_u^{\mathrm{sch2}} = \frac{\left(\left|h_{b,u}\right|^2 P_b + I_{u,1} + N_0\right)^{\frac{t_1}{T}} \times \left(\left|h_{r,u}\right|^2 P_r + I_{u,4} + \boldsymbol{N}_0\right)^{\frac{t_4}{T}}}{\left(I_{u,1} + N_0\right)^{\frac{t_1}{T}} \left(I_{u,4} + N_0\right)^{\frac{t_4}{T}}} - 1, \quad (3)$$

where $T = t_1 + t_4$.

Performance of the second intra-cell CoMP schemes

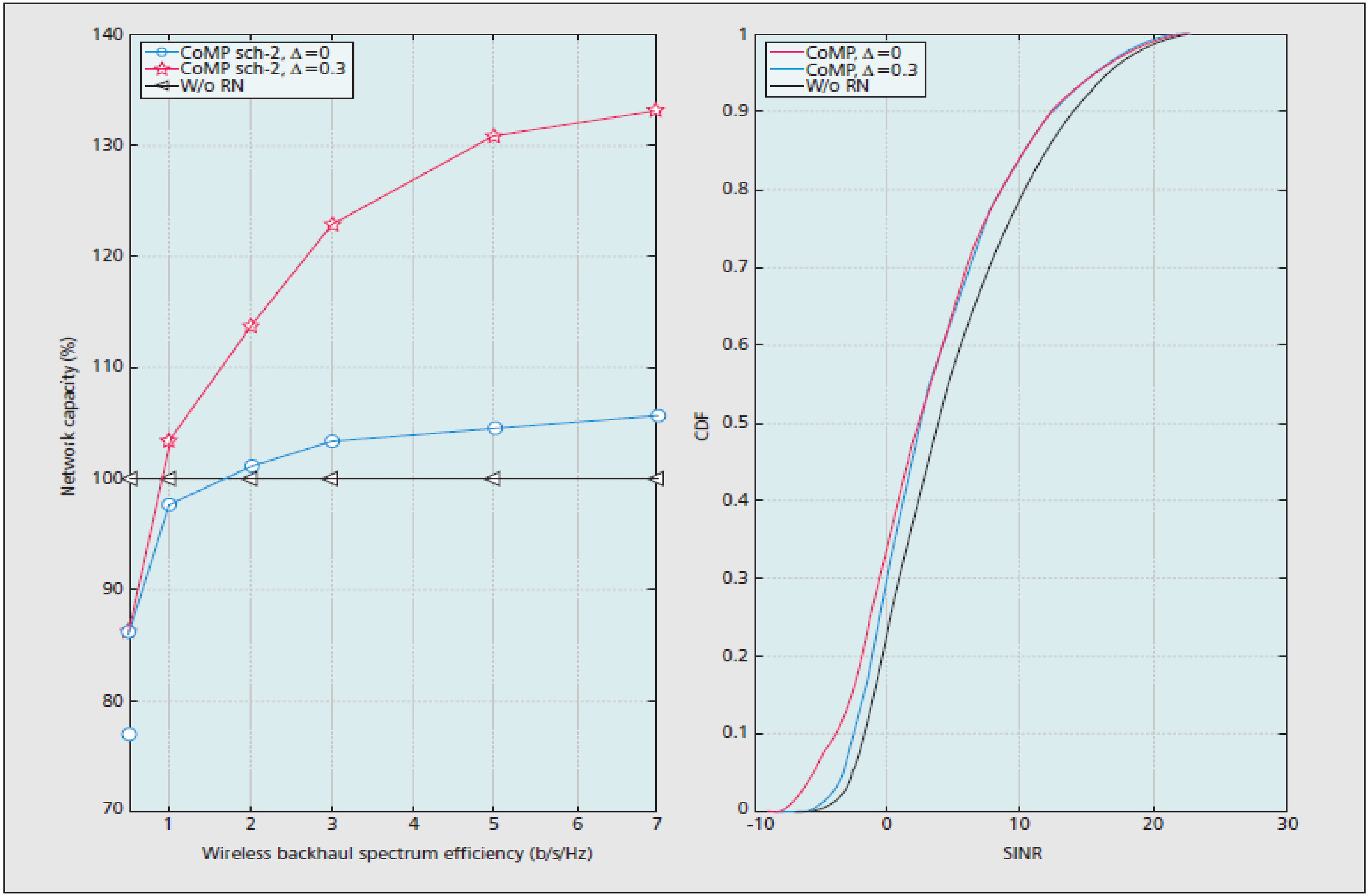


Figure 6. *Performance of the second intra-cell CoMP schemes.*

Conclusion

- We investigate techniques of realizing cooperative communications and the applications of cooperative communication schemes in LTE-advanced systems.
- We first study the up-to-date cooperation techniques for wireless communication networks and evaluate their performance from the network capacity and diversity perspective.
- We then examine the applications of cooperative communication in LTE-advanced systems. Two intra-cell CoMP schemes for the LTE-advanced systems are investigated, where RNs are taken as transmission points in CoMP.

References

[1] E. C. van der Meulen, "Three-Terminal Communication Channels," *Advanced Applied Probability*, vol. 3, 1971, pp. 120–54.

[2] T. M. Cover and A. A. El Gamal, "Capacity Theorems for the Relay Channel," *IEEE Trans. Info. Theory*, vol. 25, Sept. 1979, pp. 572–84.

[3] A. Ozgür, O. Lévêque, and D. Tse, "Hierarchical Cooperation Achieves Optimal Capacity Scaling in Ad Hoc Networks," *IEEE Trans. Info. Theory*, vol. 53, Oct. 2007, pp. 3549–72.

[4] Q. Li, K. H. Li, and K. C. Teh, "An Achievable Rate Region for the Cognitive Interference Channel with Causal Bi-Directional Cooperation," *IEEE Trans. Vehic. Tech.*, vol. 59, May 2010, pp. 1721–28.

[5] Q. Li, K. H. Li, and K. C. Teh, "Diversity-Multiplexing Trade-Off of Fading Interference Channels with Source Cooperation and Partial CSIT," *IEEE Trans. Info. Theory*, vol. 57, May 2011, pp. 2781–804.

[6] V. R. Cadambe and S. A. Jafar, "Interference alignment and degrees of freedom of the K-user Interference Channel," *IEEE Trans. Info. Theory*, vol. 54, Aug. 2008, pp. 3425–41.

[7] J. Huang, R. A. Berry, and M. L. Honig, "Distributed Interference Compensation for Wireless Networks," *IEEE JSAC*, vol. 24, May 2006, pp. 1074–84.

[8] Alcatel-Lucent Technology, "Lightradio Portfolia," white paper, 2010.

[9] 3GPP TR36.814, "Further Advancements for E-UTRA Physical Layer Aspects," v9.0.0, Mar. 2010.

[10] Huawei, "Discussion on relay in CoMP," 3GPP TSG RAN WG1 meeting #57bis, Jun. 2009.