Performance Analysis of Downlink CoMP Transmission in Long Term Evolution-Advanced (LTE-A)

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***Abstract*—Coordinated multi-point (CoMP) has evolved as a performance-optimizing technique for cellular networks. In this paper, we investigate two different spectrum allocation schemes for CoMP (i.e., shared and dedicated) within the context of Remote Radio Head (RRH) enabled heterogeneous network (HetNet) topology. The traditional macro cell only layout serves as baseline. Using spectral efficiency and average user throughput as system level performance metrics, our results reveal that CoMP based on shared spectrum outperforms the other two. The scheme, therefore, has great potential for optimizing radio resources and boosting the performance of next-generation mobile networks.**

Keywords–Coordinated multi-point (CoMP); Remote Radio Head (RRH); user average spectral efficiency; throughput.

I. INTRODUCTION

The Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) technology, through its periodic releases advances the capabilities of cellular network technology, in order to meet the increasing demands for high-quality and broadband multimedia services. Coordinated multi-point (CoMP) and Remote Radio Head (RRH) have been recently employed to enhance the performance of current wireless systems. With these and other techniques, higher data rates and higher capacity can be attained in LTE-A networks. The main objective of CoMP is to form a cluster of adjacent macro cells to improve User Equipment (UE) throughput and average spectral efficiency [1]. However, the use of dedicated spectrum in wireless network systems is foreseen as the method implemented with CoMP to improve cell edge coverage. Hence in this paper, we shall give a performance analysis of downlink CoMP transmission in LTE-A network by comparing the obtained results of deployed conventional macro cell, CoMP using the shared spectrum (i.e., Frequency Reuse Factor (FRF) one) and CoMP using the dedicated spectrum (i.e., FRF = 3). These results are obtained using the MATLAB Vienna LTE-A Downlink System Level Simulator.

The rest of this paper is organized as follows. Section II provides a basic understanding of CoMP technique benefits used with RRH, and a brief description of the proposed scenario. Section III explains the simulation procedures and methodology of Vienna LTE-A simulator. Section IV outlines the final results obtained, by deploying shared and dedicated spectrum for CoMP and presents an insightful discussion. Finally, Section V concludes this paper and presents the future work.

II. COORDINATED MULTI-POINT (COMP) IN LONG TERM EVOLUTION-ADVANCED (LTE-A)

CoMP is the foreseen technology that improves not only the cell edge throughput, but also, the coverage and system efficiency by combining and coordinating the desired and interfered signals from multiple transmission points [1]. CoMP increases data rate and ensures consistent service quality and throughput on wireless broadband networks. Hence, the UE gets very consistent service performance and quality. Technically, CoMP allows a signal from another cell to be used as the desired signal. It is an improvement not only for throughput at the cells edges, but also, for the average cell throughput. The UE is served simultaneously by multiple transmission points from the same or different eNBs [2]. Coordinating cells enhance the service quality and the throughput. CoMP reduces the Inter-Cell Interference (ICI) by joining macro cells and eliminating handover effect [3]. Therefore, cooperative communication network improves system resource utilization and data rate. Today's deployed LTE-A networks are mostly based on macro cells. Such networks are homogeneous or HetNet [4]:

- Homogeneous: All the BSs (transmitters) belong to the same type;
- Heterogeneous: The BSs belong to different types.

To improve the cell edge coverage and the cooperative ICI, we will implement CoMP within HetNet, by deploying low power nodes (small BSs) associated with macro cells. These small BSs are formed and typically used to extend coverage in cells edges and to add network capacity in areas with dense data usage. The deployment of low-power nodes within the macro cells is foreseen as the best solution to cover any increased demand in cellular network traffic. Now, the most recent deployment in LTE-A consists of dividing the macro BS functionalities into a Base Band Unit (BBU) responsible for scheduling, and this is placed in a technical room (e.g., near the building). The RRH is the part responsible for all the radio frequency operations such as the power amplifying, filtering and carrier frequency transposition. Hence, it is always placed near to the antenna or it is integrated to it, and it is connected to the BBU via an optical fiber [5]. Figure 1 shows the RRH antenna implementation, which helps the fast coordination between transmission and reception points [6]. The optical link in between guarantee a very high transmission rate. This new system architecture separates the digital radio part BBU from the analog radio part RRH. Thus, it allows to reduce the number of equipment pieces at the site, optimize

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the operational cost, decrease the energy demand and increase the efficiency of the network [7].

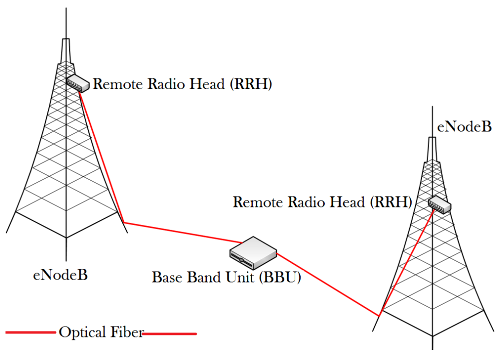

Figure 1. Remote Radio Head (RRH) Deployment

As it is depicted in Figure 2, CoMP technique is classified into coordinated scheduling / coordinated beam-forming (CS/CB) and Joint Point (JP). JP is divided into two different types Joint Transmission (JT) and Transmission Point Selection (TPS).

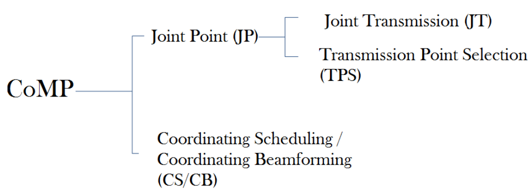

Figure 2. Types of CoMP

As shown in Figure 3, CS/CB is characterized by multiple coordinated transmission points sharing only the Channel State Information (CSI) for multiple UE, while data for a signal user is only available and transmitted from one Transmission Point (TP) [8].

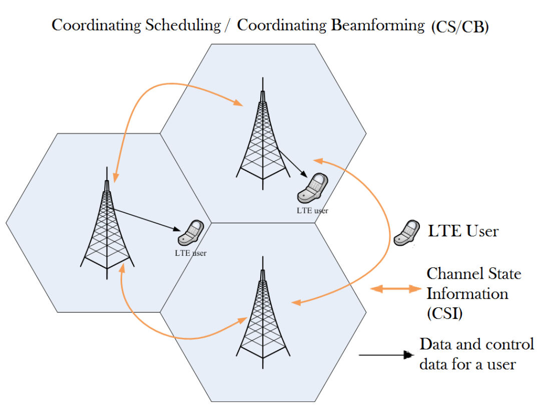

Figure 3. coordinated scheduling / coordinated beam-forming (CS/CB)

Next, we will detail the two parts of CoMP JP scheduling, which is characterized by simultaneous control data transited from multiple points to a single user.

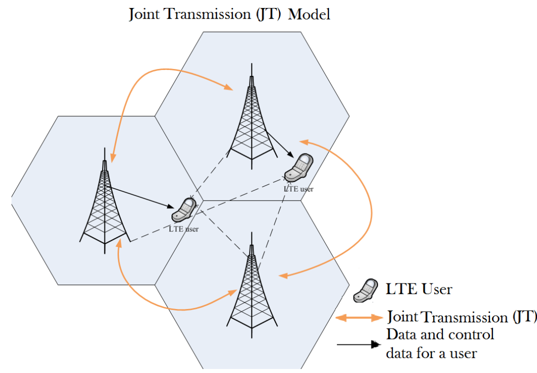

Figure 4. Joint Transmission (JT)

Figure 4 shows that, for JT, the data is simultaneously available at multiple coordinated TPs. Hence, simultaneous data and control data are transmitted from multiple eNBs. JTs convert an interference signal to a desired one [8].

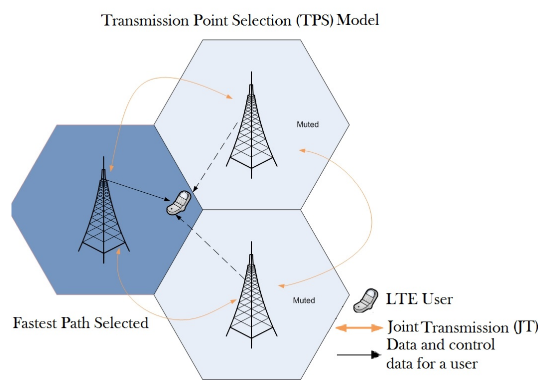

Figure 5. Transmission Point Selection (TPS)

As seen in Figure 5, TPSs transmit data from one TP of CoMP, among multiple TPs at each time instance and only one cell is fast selected to perform the transmission. Thus, the others are muted with simultaneous control data transmission from multiple TPs. To sum up, in this paper we will work with the JT CoMP scheduling.

To study the different possible network topologies and backhaul characteristics of CoMP, 3GPP has focused on different scenarios [9]:

- Scenario 1: The same macro BS controllers coordination between the cells (sectors) where we will not need any backhaul connection.
- Scenario 2: The macro network coordinated cells belonging to different radio sites.
- Scenario 3: The macro cell and the low-power transmit and receive points within its coverage are coordinated and each point controls its own cell (with its own cell identity).
- Scenario 4: The same deployment as the latter, except that the low-power transmit/receive points constitute distributed antennas (via RRH) of the macro cell, thus it is all associated with the macro cell identity.

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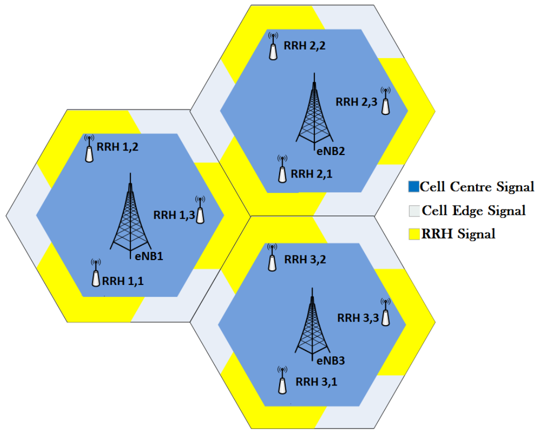

Figure 6. CoMP deploying RRH antennas

As depicted in Figure 6, the deployment of scenario 4, using CoMP, allows each point to be controlled by its own BS and all the RRH are controlled by the same BS. Overall, the implementation of RRH within CoMP extends the cell-edge coverage, thus, the average throughput of each UE increases even in the area with dense data traffic.

III. Simulation Procedure

The analysis of single-cell multi-user and multi-cell multi-user scenarios require a large amount of operational and computing effort. Thus, to reduce it, we utilize the freely available Vienna LTE-A simulator version v1.8r1375. Basically, it is composed of LTE physical layer and LTE SLS. As a free simulator under a non commercial open source academic-use license, it enables researchers to implement and test wireless cellular system algorithms in the context of LTE-A [10]. The simulation for mobile communication systems includes the LTE physical layer simulator and LTE SLS. Both are widely employed to evaluate the associated cellular network performances. LTE physical layer simulator focuses on the performance of a transmission between BSs and Mobile Station (MS)s. The performance metrics usually include the Block Error Ratio (BLER), Signal Noise Ratio (SINR) and achievable rate.

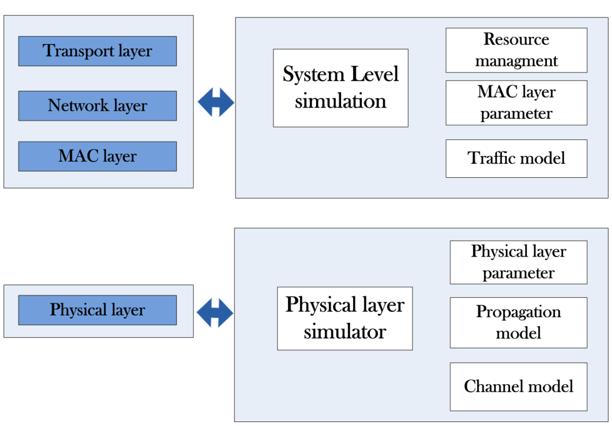

Figure 7. Component layers and model for simulation methodology [2]

Figure 7 shows the relationship between the LTE-A physical layer and other components in communications. For the purpose of theoretical studies, the performance of modulation and demodulation or coding and decoding schemes in different radio channel models can be obtained from the LTE-A physical layer simulator. The scenario for LTE-A SL Simulator generally consists of a network with multiple BSs and MSs. LTE SLS focuses on the application layer performance metrics as expressed by system throughput, user fairness, user-perceived Quality of Service (QoS), handover delay or success rate. The LTE SLS concentrates on the higher layers above the physical layer, such as the MAC layer, transport layer, network layer, and application layer. Figure 7 shows the component layers related to LTE SLS. For the purpose of theoretical studies, the performance of resource allocation, handover, cell deployment, or other strategies can be obtained from LTE SLS [11].

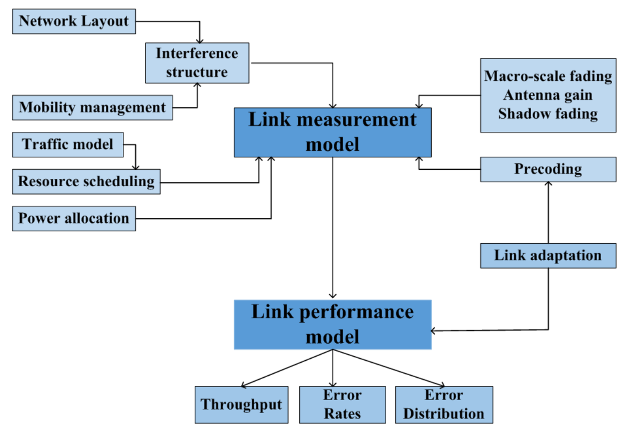

Figure 8. Schematic block diagram of LTE-A SL Simulator [12]

In Figure 8, LTE SLS is done by pre-generating the parameters off-line and using them later during run-time. In this section, we explain the simulation procedure using Vienna LTE-A simulator and LTE SLS. The performances of LTE SLS helps in simulating the totality of radio links between the UE and eNBs, through a vast amount of power that would be required [13]. Thereby, we define a Region Of Interest (ROI) in which the UEs and eNBs are positioned during a simulation length defined by Transmission Time Intervals (TTI)s.

We will analyze the results of three implemented simulation scenarios:

- The basic macro-cell deployment,
- The CoMP with RRH antennas deploying shared spectrum (FRF = 1),
- The CoMP with RRH antennas using dedicated spectrum (FRF >1).

The dedicated spectrum allows UEs to get not only enough resources even at the cell edges, but also an increased average throughput of each UE, no matter where its location. Accordingly, in dedicated spectrum we divide in multiple parts our bandwidth, thus, it can cover all the macro cell's area in moderate way [14]. Also, we focus on dense traffic area by giving it a larger part of the bandwidth compared to others, that may not need such a large part of the spectrum. However, in the case of a shared spectrum, the use of all the bandwidth in the cell center affects the edges coverage, where users are starved of capacity.

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After exploring the spectral efficiency and the average throughputs, we will compares the results. This is achieved by setting the optional parameters in the loaded configure file of Vienna LTE-A simulator which provides the inbuilt shared spectrum scheduler. To implement the dedicated spectrum, the concept of 'ffrscheduler' is implemented in LTE SLS as a scheduler which allows to specify two independent parts, which are the Fully Reuse (FR) and Partly Reuse (PR)). LTE-config.scheduler is the type of scheduler to use in this case, with the Fractional Frequency Reuse (FFR) parameter which provides FR and PR [15].

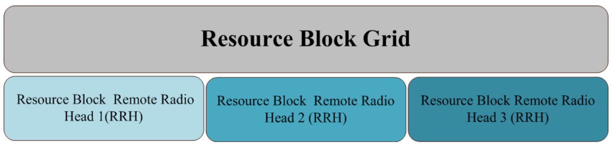

Figure 9. Resource Block Grid Schedule

Figure 9 shows the Resource Block (RB) grid is divided into three equal parts for each RRH antenna using the FRF = 3. Each PR part uses 1/3 of the remaining bandwidth 20 MHz. When simulating, only an integer-valued number of RBs can be scheduled to the FR/PR parts, which means that, for a 20MHz bandwidth (100 RB), the minimum value of FR is 0.01, as 100 is not divisible by 3 (99 is divisible by 3). So, we have 99 RBs and each PR will takes 0.33.

IV. RESULTS DISCUSSION

In this section, we present the simulation results and analyze the performance of deployed basic macro-cell, CoMP using shared then dedicated spectrum. Next, we explore various performance metrics to show the effectiveness of the proposed scenario such as:

- The SINR,
- The UE average spectral efficiency(bit/Hz),
- The UE average throughput (Mb/s).

The following results are obtained by deploying basic macro-cell and using Vienna LTE-A simulator.

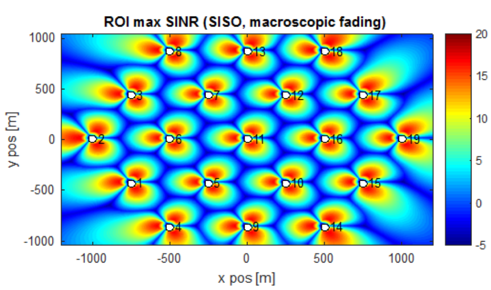

Figure 10. Region Of Interest (ROI) with the different SINR values

Figure 10 shows the values of SINR represented in color code. Blue refers to the lowest SINR value which means bad quality connection for the users at the cell edge. Thereafter, the colors go from blue with minimum SINR value -5 dB to red with maximum SINR value 20 dB. The red signal is in the cell center and it means uninterrupted connection for the desired throughput. However, the cell edges have negligible coverage. There are 19 tri-sector eNBs, present within the ROI (i.e., the serving area).

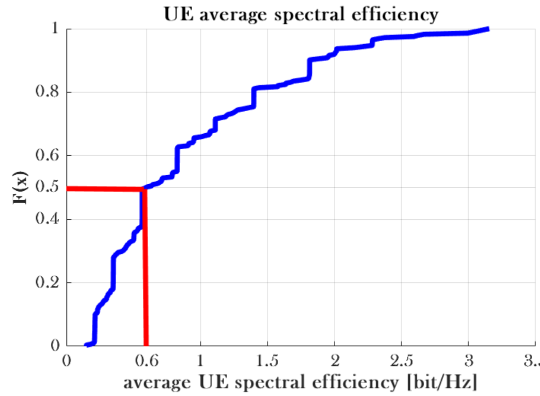

Figure 11. UE Average spectral efficiency (bit/Hz) versus F(x)

From the graph shown in Figure 11, it can be said that for a probability function F(x)= 0.5, the UE average spectral efficiency is equal to 0.6 (bit/Hz).

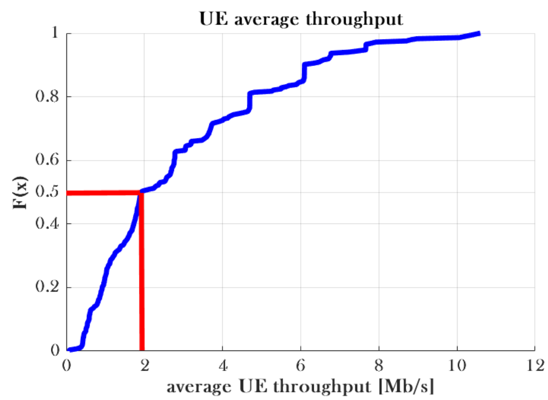

Figure 12. UE Average throughput (Mb/s) versus F(x)

Figure 12 follows the same interpretation as the latter, for F(x)= 0.5 the UE average throughput is equal to 2(Mb/s). In the following graphs, we discuss the results of CoMP using shared scheduling spectrum.

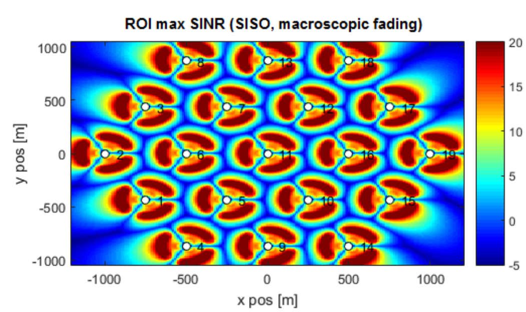

Figure 13. ROI with the different SINR values

Similarly, Figure 13 presents CoMP using shared spectrum footprint. In this proposed scenario, we get SINR values higher in RRH antennas sectors. The propagation of blue is reduced

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and almost disappears, while the red is spreading in all the cell area.

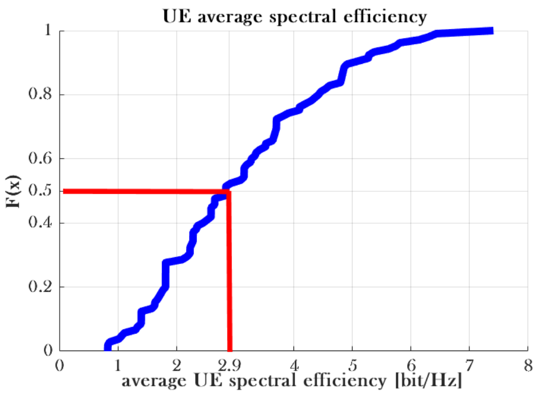

Figure 14. UE Average spectral efficiency (bit/Hz) versus F(x)

From the plot in Figure 14, it can bee seen that the UE average spectral efficiency for F(x) = 0.5 is 2.9 (bit/Hz). Intuitively, we can say that the implementation of CoMP using shared spectrum increases the average spectral efficiency two times compared to the previous scenario.

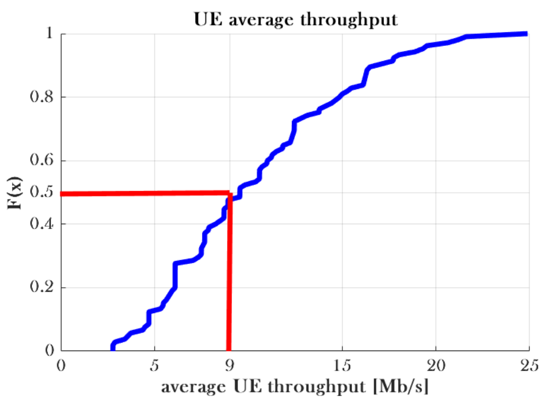

Figure 15. UE Average throughput (Mb/s) versus F(x)

The result plotted in Figure 15 shows that using a shared spectrum combined with CoMP provides higher UE average throughput than using only the conventional scheme. With the conventional scheme, the average throughput is 2 (Mb/s), and when RRH is combined with CoMP techniques, we obtain for F(x) = 0.5 the average throughput of 9 (Mb/s).

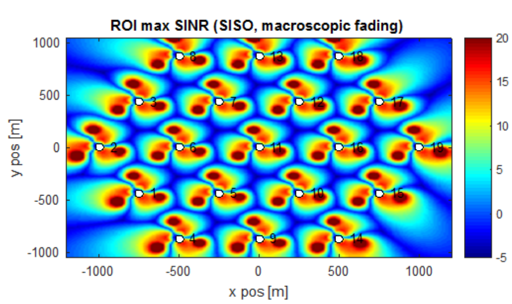

Figure 16. Footprint of ROI with SINR values

Figure 16 is the result from CoMP using dedicated scheduling spectrum. As we can see, implementing CoMP with a dedicated spectrum scheduler grid makes the SINR values higher in a big part of the cell. However, the SINR performance decreases when we dedicate the spectrum.

As we can see in Figure 16, the effect of dedicating the spectrum is causing a degradation of the SINR. Using shared spectrum combined with CoMP provides higher SINR than using dedicated spectrum.

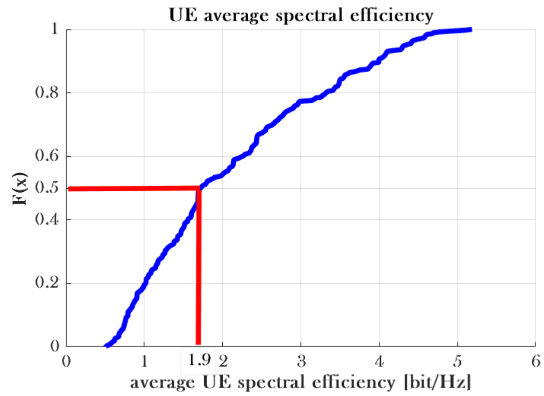

Figure 17. UE average spectral efficiency (bit/Hz) versus F(x)

Figure 17 depicts the UE average spectral efficiency versus F(x). From the graph for F(x)= 0.5 the average spectral efficiency is 1.9 (bit/Hz). The performance decreases when compared with previous CoMP results.

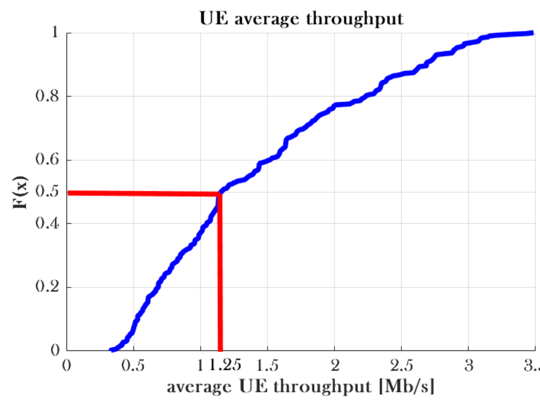

Figure 18. UE average throughput (Mb/s) versus F(x)

The graph of UE average throughput (Mb/s) is depicted in Figure 18. For F(x)= 0.5 the average throughput is 1.25 (Mb/s). The throughput performance decreases with dedicating the spectrum.

TABLE I. DIFFERENT MATLAB RESULTS

	UE average spectral efficiency (bit/Hz)	*UE average cell throughput (Mb/s)*
Basic macro BS	0.6	2
CoMP using shared spectrum	2.9	9
CoMP using dedicated spectrum	1.9	1.25

The performance was evaluated in terms of SINR, average spectral efficiency and average throughput. The results show that the SINR increases when we implement CoMP. The average throughput and the average spectral efficiency are also higher for CoMP using shared spectrum. The use of RRH and

CoMP methods almost double the average spectral efficiency compared to that for conventional scheme. The throughput is also higher when shared spectrum and CoMP are employed simultaneously compared to that when CoMP using dedicated spectrum is employed. This shows that shared spectrum within CoMP methods can reduce the ICI effectively. The SINR performance decreases with increasing the number of FRF in dedicated spectrum. However, the average throughput improves by approximately 9 times when shared spectrum within CoMP techniques are employed.

V. Conclusion

In this paper, we had focused on CoMP topology using different frequency spectrum design shared and dedicated for wireless communication systems, namely within the context of RRH antennas, and HetNet scenarios. Performance results are obtained not only in terms of UE average spectral efficiency, but also in terms of UE throughput, that is now increasingly became an important design indicator for planning, deploying and optimizing next generation mobile networks. One of the simplest ways of improving system performance is to enhance the signal power. This goal can be achieved using LTE SLS to joint transmission down link CoMP scheme. As the same frequency bandwidth is used, the system is very sensitive to ICI. The utilized CoMP scheme with dedicated spectrum is introduced to improve the performance of cell edge users by customizing the repartition of bandwidth. The use of shared spectrum increases the cell average throughput. The simulation setup is based on 3GPP Technical Specification Group reports. CoMP plays an important role in improving the system performance and, therefore, this work can be extended such that the optimal parameters are determined for the CoMP and further parameters can be analyzed to optimize the system capacity and end-to-end delay.

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References

[1] D. Lee, H. Seo, B. Clerckx, E. Hardouin, D. Mazzarese, S. Nagata, and K. Sayana, "Coordinated multipoint transmission and reception in lte-advanced: deployment scenarios and operational challenges," *IEEE Communications Magazine*, vol. 50, no. 2, pp. 148–155, February 2012.

[2] L. Chenand, W. Chen, B. Wang, X. Zhang, H. Chen, and D. Yang, "System-level simulation methodology and platform for mobile cellular systems," *IEEE Communications Magazine*, vol. 49, no. 7, pp. 148–155, July 2011.

[3] M. Taranetz, T. Blazek, T. Kropfreiter, M. K. Mller, S. Schwarz, and M. Rupp, "Runtime precoding: Enabling multipoint transmission in lte-advanced system-level simulations," *IEEE Access*, vol. 3, pp. 725–736, 2015.

[4] A. Damnjanovic, J. Montojo, Y. Wei, T. Ji, T. Luo, M. Vajapeyam, T. Yoo, O. Song, and D. Malladi, "A survey on 3gpp heterogeneous networks," *IEEE Wireless Communications*, vol. 18, no. 3, pp. 10–21, June 2011.

[5] I. L. Cherif, L. Zitoune, and V. Vque, "Performance evaluation of joint transmission coordinated-multipoint in dense very high throughput wlans scenario," in *2015 IEEE 40th Conference on Local Computer Networks (LCN)*, Oct 2015, pp. 426–429.

[6] Y. Jie, A. Alsharoa, A. Kamal, and M. Alnuem, "Self-healing solution to heterogeneous networks using comp," in *2015 IEEE Global Communications Conference (GLOBECOM)*, Dec 2015, pp. 1–6.

[7] S. Yi and M. Lei, "Backhaul resource allocation in lte-advanced relaying systems," in *2012 IEEE Wireless Communications and Networking Conference (WCNC)*, April 2012, pp. 1207–1211.

[8] M. Sawahashi, Y. Kishiyama, A. Morimoto, D. Nishikawa, and M. Tanno, "Coordinated multipoint transmission/reception techniques for lte-advanced [coordinated and distributed mimo]," *IEEE Wireless Communications*, vol. 17, no. 3, pp. 26–34, June 2010.

[9] Y. N. R. Li, J. Li, W. Li, Y. Xue, and H. Wu, "Comp and interference coordination in heterogeneous network for lte-advanced," in *2012 IEEE Globecom Workshops*, Dec 2012, pp. 1107–1111.

[10] A. Marotta, K. Kondepu, F. Giannone, S. Doddikrinda, D. Cassioli, C. Antonelli, L. Valcarenghi, and P. Castoldi, "Performance evaluation of comp coordinated scheduling over different backhaul infrastructures: A real use case scenario," in *2016 IEEE International Conference on the Science of Electrical Engineering (ICSEE)*, Nov 2016, pp. 1–5.

[11] S. H. Park, O. Simeone, O. Sahin, and S. Shamai, "On remote radio head selection for the downlink of backhaul constrained network mimo systems," in *2014 48th Annual Conference on Information Sciences and Systems (CISS)*, March 2014, pp. 1–5.

[12] J. C. Ikuno, M. Wrulich, and M. Rupp, "System level simulation of lte networks," in *2010 IEEE 71st Vehicular Technology Conference*, May 2010, pp. 1–5.

[13] D. Matsuo, R. Rezagah, G. K. Tran, K. Sakaguchi, K. Araki, S. Kaneko, N. Miyazaki, S. Konishi, and Y. Kishi, "Shared remote radio head architecture to realize semi-dynamic clustering in comp cellular networks," in *2012 IEEE Globecom Workshops*, Dec 2012, pp. 1145–1149.

[14] K. Bkowski, M. Rodziewicz, and P. Sroka, "System-level simulations of selected aspects of 5g cellular networks," in *2015 International Symposium on Wireless Communication Systems (ISWCS)*, Aug 2015, pp. 711–715.

[15] Y. Wang, J. Xu, and L. Jiang, "Challenges of system-level simulations and performance evaluation for 5g wireless networks," *IEEE Access*, vol. 2, pp. 1553–1561, 2014.

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