Signaling Overhead and Feedback Delay Reduction in Heterogeneous Multicell Cooperative Networks

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***Abstract*— Heterogeneous networks (HetNets) and multicell cooperation are two key technologies in cellular networks that can improve network performance. The channel information of all the collaborating Base Stations (BSs) is one of the core factors to achieve better throughput performance gain in the coordinated multipoint (CoMP) communication. Here, we propose a novel method for handling Channel State Information (CSI) feedback in HetNet CoMP, named DCEC-HetNet: Direct CSI-feedback to Elected Coordination-station for Heterogeneous Networks. The DCEC-HetNet architecture aims to reduce the signaling overhead and feedback latency, and subsequently increase the throughput of the network. We use the Discrete Event System Specification (DEVS) formalism to model the cellular network. The simulation results demonstrate that the DCEC-HetNet architecture significantly decreases the number of CSI feedback packets being transmitted within the network, and reduces the feedback latency resulting in higher cell throughput.**

Keywords*— *CoMP, HetNet, CSI, LTE-Advanced, DEVS, CD++

I. Introduction

With the rapid development of smartphones, tablets, and mobile internet, the demand of high-speed data applications such as high quality video streaming, gaming and social networking have been growing very fast [1, 2]. In addition to the total volume of data, the number of broadband users and the demand of data rates are also increasing. For instance, the number of mobile broadband subscriptions is growing globally by around 25% each year and is expected to reach 7.7 billion by 2021. Moreover, the growth rate of mobile data traffic between the 3rd quarter of 2014 and the 3rd quarter of 2015 was about 65 percent [2]. As a result, providing services to the massive number of users and the escalating demand of mobile data traffic are two main challenges in cellular networks.

The third Generation Partnership Project (3GPP) introduced Long Term Evolution (LTE) and LTE-Advanced (LTE-A) in the Fourth Generation (4G) cellular networks [3, 4] in order to try to deal with these issues. The objectives of LTE-A networks is to improve the data rate, improve cell throughput and to provide the consistent services to the users regardless of their location. However, with the current growth of demand for data by mobile users, using LTE-A with the current 4G standard may not fully satisfy users' needs as it is expected for the network's data traffic to reach 351 Exabyte by 2025 [5]. Hence, incremental improvement of LTE-A still expected, besides the interest of new standard such as fifth generation (5G) cellular networks has also captured the attentions of researchers and engineers.

The 5G networks is expected to provide approximately a system capacity 1000 times higher, 10 times the data rates and 25 times the average cell throughput when compared to the 4G networks [5, 6]. In order to improve the cell throughput and coverage even further, LTE-A technologies propose to combine advanced algorithms with the concept of Heterogeneous Networks. In this approach, small cells are added to increase the network capacity in so-called "hot spots" where the user demand is high or network coverage is weak.

Heterogeneous cellular Networks (HetNets) are comprised of different types of wireless access nodes with different capabilities. Specifically, in LTE-A and 5G cellular networks, HetNets consist of coexisting macrocells and low-power nodes. These include RRHs (Remote Radio Heads, which do not have baseband units and are connected to the Base Stations (BS) via optical fiber); picocells (small cellular base stations implemented to cover a limited area), femtocells (self-installed by the user for the coverage of even smaller areas), and relay nodes (implemented to extend coverage at the cell's edge). These low power small cells can reduce the load of the macrocells and improve the user performance at the edge of the cells.

However, the coexistence of macro and low-power cells brings technical challenges: intercell interference coordination (ICIC, defined in 3GPP release 8 as a coordination technology used that forces UEs located at the cell edge but belonging to different cells, to use different frequencies); mobility management (a function which tracks the position of subscribers), and backhaul provisioning (setting up the connectivity of the LTE backhaul service to be consumed by end users). ICIC is of high importance [7]: as the number of cells increase, the total number of users located on the edge of the cells increase, and at the cells' edges, the users experience lower signal strength and higher interferences from neighboring cells.

In order to improve the performance of cellular HetNets by mitigating intercell interference, Coordinated Multipoint (CoMP) transmission and reception [8] is considered as an effective method, especially for cell edge users [9]. In CoMP enabled systems, the Base Stations (BSs) are grouped into cooperating clusters. The BSs of each of these clusters exchange information with one another and jointly process signals by forming virtual antenna arrays distributed in space. A cluster can be formed based on static or dynamic clustering algorithms [10]. Furthermore, multiple User Equipment (UEs) can receive their signals simultaneously from one or more transmission points in a coordinated or joint-processing manner [9, 11].

The 3GPP mobile broadband standard proposes two CoMP heterogeneous network scenarios for further study, as shown in Figure 1 [8]. Two layers of cells are considered: one with high-power macro BSs and another with low-power RRHs. The low power RRHs do not have a baseband unit (BBU), and the connection between the RRHs and the macro BSs is through optical fiber. The difference between them is that in scenario 1 each RRH has a distinct cell ID, while in scenario 2 RRHs share the same cell ID with the associated macro BS [8, 9].

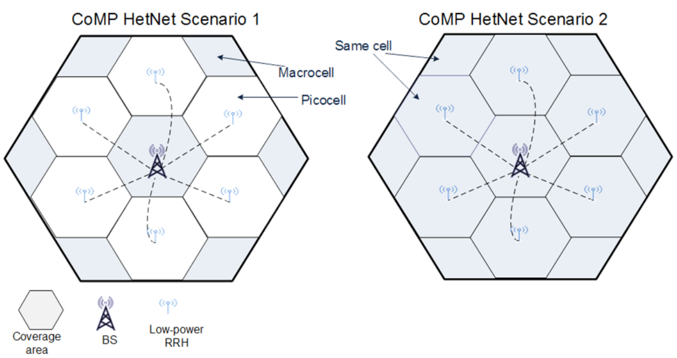

Fig. 1. Scenarios proposed by 3GPP for CoMP in HetNets

In CoMP enabled HetNets, the UEs need to estimate the Channel-State Information (CSI) and feed this information back to a scheduler. In order to do so, the UEs calculate the CSI and report it to their serving BS for adaptive transmission and appropriate radio resource management (RRM) [9, 12]. By doing so, the UEs increase the feedback overhead or signaling overhead in the network significantly [10, 11]. This will also result in an increase in the feedback latency. Another type of overhead related to CoMP is called infrastructural overhead [11, 13, 14]. In this case, the networks may require additional control units and low-latency links among the collaborating BSs, which might increase the network costs. The overhead depends on the CoMP control architecture used, as there are two types of control architectures available: Centralized and Distributed [3, 13, 14].

In the centralized architecture, a central unit is responsible for handling radio resource scheduling by processing the CSI feedback information from the UEs. This architecture suffers from signaling overhead and infrastructure overhead. It also increases the latency of the CSI feedback. In the distributed architecture, the coordinated cells exchange data and CSI over a fully meshed signaling network using X2 interfaces and a star-like S1 network. This architecture increases the signaling overhead, and it is more sensitive to error patterns since these can be different for different BSs. This could be a potential reason for further performance degradation [14].

With these issues in mind, here we propose a new HetNet CoMP control architecture named Direct CSI-feedback to Elected Coordination-station for Heterogeneous Networks (DCEC-HetNet), with the aim of reducing the signaling overhead and latency of the CSI feedback and subsequently increasing the throughput of the network [15]. As shown in [16], the throughput of the cell can increase by as much as 20% if the latency is reduced by 5 ms. DCEC-HetNet addresses the challenges mentioned above. In this architecture, one of the BSs in the CoMP cluster, elected dynamically, will act as a Coordination Station (CS), and the UEs in the CoMP Cluster with same cooperating set will send the CSI feedback to this CS only. Thereon, the CS will calculate the global CSI information, determining the cooperating set, and will be in charge of scheduling. It should be noted that a Cooperating set is a set of BSs and RRHs within the CoMP cluster that can jointly serve the UE [8].

The main goals of DCEC-HetNet is to reduce the CSI feedback latency and the signaling overhead of the network (which, eventually will increase the cell throughput), while avoiding additional infrastructure costs. There will also be no increase in the error pattern, since all the participating UEs send the CSI to the CS only after the CoMP is established. Furthermore, no additional hardware is necessary for this solution, so the costs for switching to such architecture should be small.

In order to compare the performance of the DCEC-HetNet, Centralized, and Distributed architectures, we set up simulation scenarios using the DEVS formalism. Based on the simulation results for these scenarios, we will show that DCEC-HetNet reduces the number of control packets transmitted within the CoMP network. Although it requires more control packets to elect the CS and to establish the CoMP in the beginning, it outperforms the other two architectures as time advances. Furthermore, in DCEC-HetNet the CSI feedback does not need to travel through X2 or S1 links, which reduces the feedback latency.

In the following sections, we introduce the proposed architecture in details and discuss the simulation models built using the DEVS formalism [17] and the CD++ toolkit [18]. Later, we show different simulation results that summarize the performance of the DCEC-HetNet architecture.

II. Related work

To improve the performance of cellular networks, LTE-Advanced and 5G consider a number of technologies including massive Multiple Input Multiple Output (MIMO), carrier aggregation, mm-wave communication, coordinated multipoint (CoMP) and heterogeneous networks (HetNets) [5, 19]. Among the various techniques, heterogeneous networks and CoMP have been adapted as key technologies [6, 9, 12, 19, 20]. Heterogeneous networks increase the radio resource reusability by performing cell splitting that ultimately increases the networks performance. On the other hand, CoMP improves the networks performance by mitigating the inter-cell interference. In heterogeneous CoMP networks, accurate and updated channel information plays a key role to achieve better throughput performance gain as mentioned earlier. The UE calculates the channel information and reports that to the BS through a CSI feedback message so that the BS can perform adaptive transmission and appropriate Radio Resource Management (RRM).

There are two kinds of control architectures available for CoMP transmission and reception: centralized and distributed

[13, 14, 3]. As seen in Figure 2(a), in the centralized architecture, a central unit is responsible for handling radio resource scheduling by centrally processing the feedback information from different cells in the CoMP cluster. The UEs estimate the channel state related to all the BSs and low power nodes in the cluster and feed it back to their serving BS. Then the serving BS forwards the local CSI to the central unit (CU). Finally, the CU calculates the global channel state information and feeds it back to the BSs. This architecture suffers from signaling and infrastructural overheads (as discussed earlier, this means that the network may require additional control units and links among the collaborating BSs), as well as an increase in the network latency.

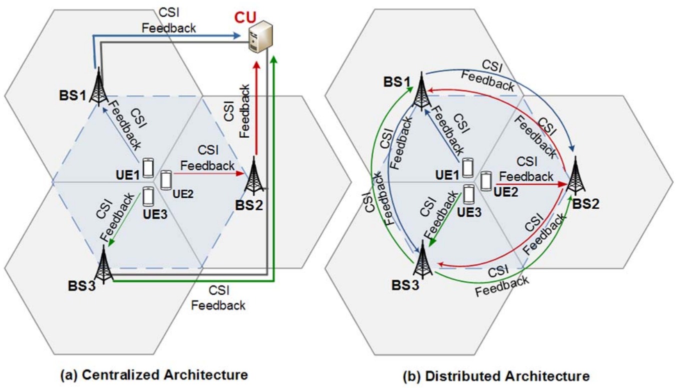

Fig. 2. Standard CoMP architectures

In the distributed architecture shown in Figure 2(b), the coordinated cells exchange data and channel state information over a fully meshed signaling network using X2 interfaces and a star-like S1 network. Prior to the download, the UEs estimate the CSI related to all the cooperating BSs and feed it back to serving BS. After receiving the channel state information from UE, cooperating BSs exchange the CSI among themselves. The BSs are in charge of scheduling independently based on their acquired global CSI. This architecture increases the signaling overhead, and is more sensitive to error patterns since these patterns can be different for different BSs. This could potentially cause further performance degradation [14].

In [21], the authors propose a distributed architecture for CoMP Joint Transmission (JT), which works over an IP backhaul network between BSs. They introduce two levels of time scales: (1) radio resources for CoMP JT are allocated every several 100s of milliseconds; (2) modulation and coding schemes for link adaptation are calculated every millisecond. In [22], the authors presented a centralized MAC approach for CoMP joint transmission. In this approach, the base stations are grouped in clusters. Within a cluster, one of the cells is preconfigured as the head sector and the others act as proxies.

Gao et al. propose a modified version of an existing algorithm for dynamic cell selection in CoMP. They extended the dynamic cell selection method to a Multi-Cell scenario [23], which originally is limited to one chosen transmission cell. Paper [24] studies the performance analysis of the CoMP joint processing (JP) transmission in HetNet scenarios. Geirhofer and Gaal in [25] discuss CoMP in different HetNet scenarios. They also analyze CoMP schemes and the deployment architectures as well as the benefits and drawbacks of them. In [26], the authors propose an analytical framework to quantify the impact of overhead delay for CoMP evaluation in heterogeneous cellular networks. They also apply the framework to downlink CoMP zero-forcing beamforming.

As we mentioned earlier, we built models and ran simulations of various scenarios of our DCEC-HetNet, centralized and distributed architectures. For modeling and simulation, we used the Discrete Event Systems Specifications (DEVS), a formal modeling and simulation (M&S) methodology [27]. DEVS is one of the most powerful methodologies for M&S of discrete-event dynamic systems. A real world dynamic system modeled with DEVS is described as composed of atomic (behavioral) models and hierarchically combined coupled (structural) models. The atomic component of the model represents the behavior of a part of the system. An atomic model changes its state, if it receives an input via the input port or at the end of the time delay, whichever happens first.

CD++ is a toolkit that implements DEVS theory [18, 28]. It provides an environment to execute DEVS and Cell-DEVS models. DEVS provides a number of advantages for modeling and simulation of real world systems [27]. The hierarchical and modular nature of DEVS allows the description of the multiple levels, and enhances the reusability of a model. It reduces the computational time by reducing the number of calculation for a given accuracy. The same model could be extended with different DEVS-based simulators, allowing for portability and interoperability at a high level of abstraction. Finally, the use of formal modeling techniques enables automated model verification [27].

In [28], we discussed the use of DEVS and Cell-DEVS for M&S of various wireless network applications. Particularly, M&S of a cellular network covering a wide geographical area including various Cells and many UEs has also been presented in the paper. In [27], we also showed that DEVS could be a useful tool for performing modeling and simulation of large-scale web search engines.

III. Coordination Station Election and CSI Feedback

The control architecture of CoMP can be defined as the way participating cell sites coordinate to handle interference and scheduling, based on which cooperating BSs serve the UEs. There are two types of control architectures available for heterogeneous CoMP networks, as we mentioned earlier. The CSI feedback procedure is also different in different control architectures.

In case of DL transmission, the CoMP signaling overheads are related to the inherent need of CSI at the transmit end [11]. This global CSI feedback process could be different based on the architecture of the CoMP. Two major challenges of the conventional CoMP architectures are the CSI Feedback latency and signaling overhead. Latency is inversely related to the throughput of the network, in particular for the coordinated schemes. However, if the feedback latency of the cooperating network is greater than the CSI feedback periodicity, then the scheduler will receive a backdated CSI. Hence, in the DCEC-HetNet architecture, our goal is to reduce the CSI feedback overhead and latency in order to improve the cell throughput.

In cellular networks, the main mechanisms for overhead and latency reduction are network architecture optimization, faster feedback process, shorter transmission time interval (TTI) and QoS load differentiations [29]. We propose a new architecture for heterogeneous CoMP networks that addresses overhead and latency discussed above. This architecture, named *Direct CSI-feedback to Elected Coordination-station for Heterogeneous Networks* (DCEC-HetNet), uses one of the BSs in the CoMP cooperation set as a *Coordination Station* (CS) dynamically.

As we mentioned earlier, in order to elect a Coordination Station (CS) dynamically we use the following algorithm:

1. *A serving BS receives the CSI Feedback and calculates the CoMP cooperating set.*
2. *If a CoMP cooperating set contains more than one BSs, the serving BS in the CoMP set declares itself as a CS*
3. *The declared CS sends a CS-Declaration message to other BSs in the set (containing the ID of the sender, the ID of the CS, and the cell throughput of the CS)*
4. *After receiving the message, other BSs in the set compare their throughput with the received CS throughput.*
    a. *If the received CS throughput is higher or equal than the recipient's throughput (or the current), the CS ID will change to the received ID. The recipient then forwards the new CS information to the BSs in the cooperation set except the sender.*
    b. *If the received CS throughput is equal to its own throughput (or the current), and the CS ID is smaller than its own ID (or the current), the current CS ID will become the received CS ID. The recipient then forwards the new CS information to the BSs in the cooperation set except the sender.*
    c. *If the received CS throughput and ID are equal to the current CS throughput and ID, the CS has been elected. Stop.*
    d. *Otherwise, the recipient BS declares itself as the new CS and sends a CS-Declaration message to the other BSs in the CoMP cooperation set.*
5. *If the cell throughput or cooperating set change, go back to step 2.*

Figure 3 shows a simplified signaling procedure of the proposed scheme. UE reports the CSI feedback to its serving RRH for instance in the figure 3 UE1 send CSI feedback to RRH11. RRH11 forwards the CSI to BS1. After receiving the information from the RRH, BS1 calculates the *cooperating* set for UE1. To calculate the *cooperating* set, BS1 checks the channel quality and compares the predefined CoMP threshold (6dB as discussed in [30, 31]) to the received data. If the *cooperating* set contains more than one BS, the serving BS (BS1) initiates the election algorithm to elect the CS by sending a CoMP request message to the other BSs in the *cooperating* set such as BS2 or/and BS3 with his own cell throughput. After receiving the CoMP request, BS2 or/and BS3 will check their own resources and compare the received throughput with their own. Based on the availability of resources they will send back a request grant/reject message, including the highest throughput. After receiving the responses from the other BSs, the serving BS (BS1) will make a decision about the CS and it will advertise it to the other BSs (BS2 and BS3) and the UE1 by a CoMP notification message. Finally, the UE will reply using the ACK message and will switch to the CoMP mode. After the establishment of the CoMP and when the CS has been elected, the UE sends the CSI feedback only to the CS, as shown in Figure 4.

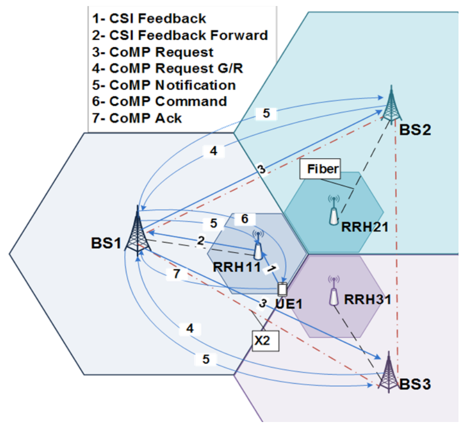

Fig. 3. Message transfer to elect CS and establish CoMP in DCEC-HetNet

As previously discussed, all the UEs in the CoMP cluster with the same cooperating set will send the CSI feedback directly to the same CS only. Therefore, CSI feedback does not need to travel any additional X2, S1or fiber channels when the UE is in the CoMP, which results in avoiding extra latency of the CSI feedback transmission as well as reducing the overhead in the network. Figure 4 shows a simplified view of the proposed CSI feedback architecture after the CS has been elected in CoMP.

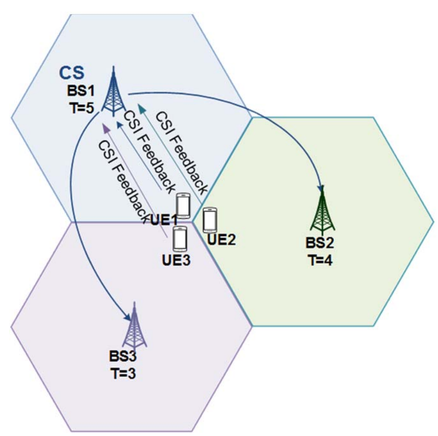

Fig. 4. Simplified view of the CSI feedback process for the DCEC-HetNet architecture after CoMP has been established and CS has been elected

IV. Modeling the CoMP HetNet Using DEVS

To study the control architecture of the HetNet CoMP employing the DCEC-HetNet algorithm, we have defined a DEVS model. The model consists of various atomic and coupled models as shown in Figure 5.

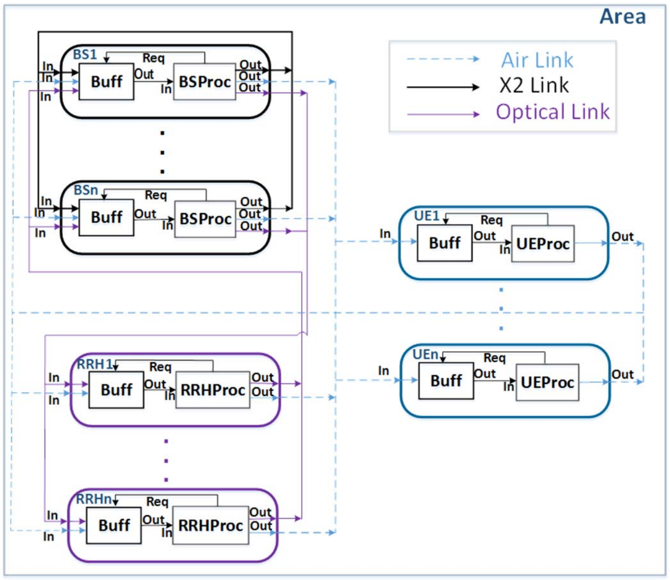

Fig. 5. Simplified DEVS model for CoMP HetNet control architecture

The top level coupled model is the CoMP geographic area, which includes a number of cells. Each cell contains one BS, multiple RRHs and many UEs. In this paper, we assume a CoMP cluster with 3 macro cells having 3 BSs and four RRHs as shown in Figure 6. The numbers of UEs vary based on different scenarios. We will not discuss the details of the clustering procedure and formation [10] as it is out of the scope of this paper. Each BS, RRH and UE coupled model is composed of two atomic models named *Buff* and *Proc*. The *UEProc* generates the CSI feedback based on the signal strength received from cooperating BSs & RRHs and sends it to the BS *Buff* or RRH *Buff* through the output port (Out) every 5 ms. The BS *Buff* acts as a buffer for the BS. Once the BS receives a message, the BS *Buff* pushes it in a queue. The message is popped out from the queue and forwarded to the *BSProc* when a request is received from the processor. The *BSProc* executes the algorithm discussed earlier in this section to calculate a CoMP cooperating set and to elect a CS. In the above Figure 5, the black solid links connecting the BSs represent the X2 links and the purple solid lines connecting the BSs and the RRHs represent optical links. Moreover, the number of BSs, RRHs and UEs can be increase based on the simulation scenario.

V. Simulation Results

In this section, we explain different simulation scenarios and the results we obtained for the proposed control architecture and two other conventional control architectures discussed in the previous sections. Figure 6 shows the simplified network architecture of a sample simulation scenario that we have used to test our proposed control architecture. The initial model uses 3 macro cells with 3 BSs and 4 RRHs. The number of UEs varies in different simulation scenarios. We have considered 3 macro cells, since most of the research on CoMP performance analysis shows that CoMP provides the best performance with the cooperation of 3 cells [10, 31].

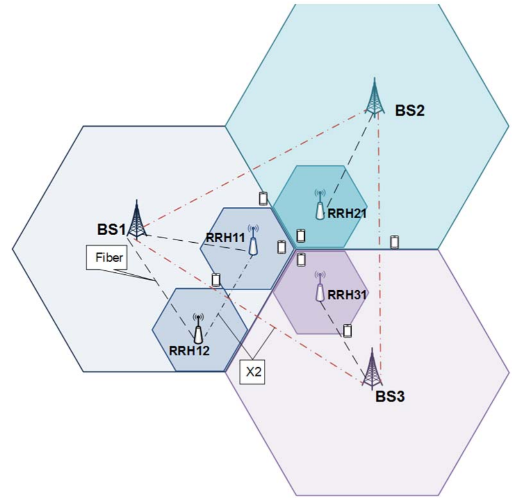

Fig. 6. Basic architecture for the simulation scenario

To evaluate the potential of the DCEC-HetNet control architecture, we ran a series of simulations on this model, based on the initial conditions summarized in Table 1 [32]. We have chosen our cell radius and antenna gain parameters to align with the specifications outlined in LTE release 12. As suggested in [33], the frequency has been set to 900 MHz, the cell radius has been set to 500 m, and the antenna gain has been set to 12 dBi for the BS and 0 dBi for the UE. Based on [3, 32] the CSI feedback frequency has been set to 5 ms.

In our simulation scenarios, cells are considered to be macro cells in the urban area. A typical transmission power for a macro cell base station is normally between 43 dBm to 48dBm and RRH transmit power between 23 dBm to 30 dBm. Hence, we set the transmit power for a BS to 46dBm and the RRH to 30 dBm [34]. The received signal power at each UE is calculated based on the following formula [32]:

$$Pr = Pt - Max\,(Lpath - Gt - Gr\,,\, MCL) \quad (1)$$

Where Pr is the received signal power, Pt is the transmitted signal power of the BS, Gt is the transmitting antenna gain, Gr is the receiver antenna gain and Lpath is the path loss. Minimum coupling loss (MCL) is considered to be 70 dB, the BS antenna gain is considered to be 12 dBi and the UE antenna gain is considered as 0 dBi [32].

Here we consider the propagation model for urban area [32].

$$Lpath = l + LogF \quad (2)$$

Where l is calculated based on the following formula:

$$l = 40 * (1 - 4 * 10^{-3} * B_h) * \log_{10}(d) - 18 * \log_{10}(B_h) + 21 * \log_{10}(f) + 80dB \quad (3)$$

Here, B_h is the base station height, which we considered to be 15 meters, d is the distance between UE and BS and *f* is the carrier frequency.

After calculating the received power by UEs, a CSI feedback message being generate and sent this to the BSs. In our simulation, BSs generate the cell throughput at random to elect the CS. Based on the literature in this area, we considered the

CoMP threshold as 6dB [30, 31] to find the CoMP cooperating set dynamically.

TABLE 1. SIMULATION ASSUMPTIONS

Parameters	Values
Number of macro BS	3
Number of RRHs	4
Number of UEs	50, 100 , 150 and 200
UE Distribution	Uniform: randomly in the CoMP area
Frequency	900 MHz
BS Transmit Power	46 dBm
RRH Transmit Power	30 dBm
Cell Radius	500 m
Antenna gain	12 dBi (BS), 05 dBi (RRHs) and 0 dBi (UEs)
MCL	70 dB
LogF	10 dB
Cell Throughput	Uniform: randomly generated
CSI Feedback periodicity	5 ms
CoMP Threshold	6 dBm
Traffic Model	Full buffer

In order to be able to analyze the advantages and disadvantages of the DCEC-HetNet architecture over the distributed and centralized CoMP, we have simulated the above-mentioned architectures using different scenarios. The results of these simulations will be discussed later in this section. To simulate the distributed CoMP architecture we assume that the BSs are synchronized.

Figure 7 shows the aggregate number of control packets transmitted in the HetNet CoMP scenario discussed above as a function of time for the DCEC-HetNet architecture and the two conventional architectures. Here we consider the control packets to be CSI feedback (from UE to BS and UE to RRH), CSI feedback forward (from BS to BS, RRH to BS and BS to CU), and the overhead related to the election algorithm.

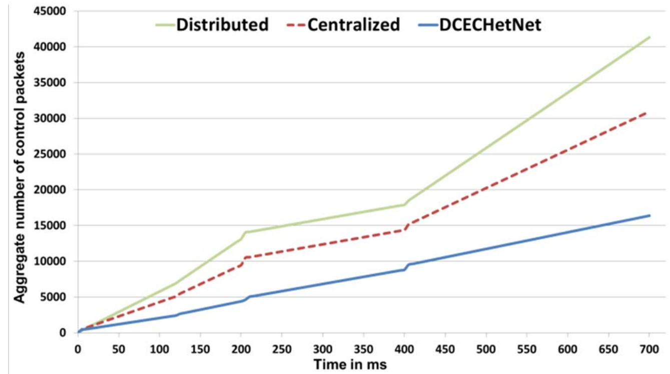

Fig. 7. Comparison of DCEC-HetNet, Centralized, and Distributed architectures based on aggregate number of packets with respect to time.

In this case, the CSI feedback periodicity is 5 ms and the number of UEs is 100. The results of the conducted simulations show that, after some time, the DCEC-HetNet architecture has linear growth in terms of the total number of control packets in the network. This time is reached after CoMP has been established and the CS has been elected. After this time, no extra control messages related to the DCEC-HetNet architecture are exchanged, but for the other cases CSI feedback messages are still needed to travel through X2 or S1 links. At 120 ms some new UEs join CoMP and at about 200 ms some UEs leave CoMP. Finally some UEs joined CoMP again and stay in CoMP until end of the simulation. Figure 7 demonstrates that the DCEC-HetNet architecture outperforms the other two architectures with respect to CSI feedback overhead in HetNet CoMP.

In Figure 8, we show a comparison among the CoMP architectures with respect to the number of control packets in the network as a function of the number of UEs. In this case, 3 BSs, 3 RRHs and different set of UEs (50, 100, 150 and 200) are simulated for 700 ms. By increasing the number of UEs in the HetNet CoMP session, the required control packets increase slower in DCEC-HetNet than the other two approaches. Therefore, if number of UE increases in the network, the DCEC-HetNet needs less control messages to travel within the network.

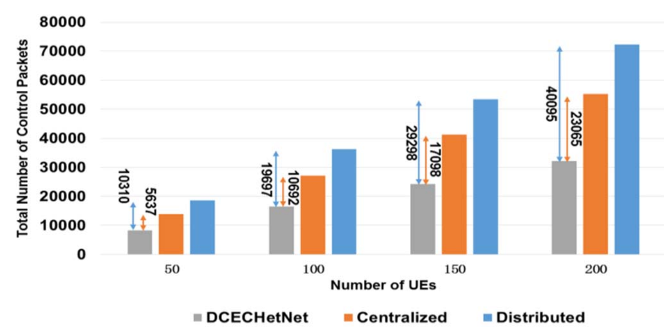

Fig. 8. DCEC-HetNet, Centralized, and Distributed architectures based on the number of control packets in the network with respect to the number of UEs in 700 ms

Figure 9 shows the number of control packets transmitted in a certain period for each of the architectures. In this simulation, the number of UEs is 100. The results of the conducted simulations show that, initially the DCEC-HetNet architecture needs more packets than Distributed architecture but after CoMP is established and the CS is elected, DCEC-HetNet requires less control packets to be transmitted in the network. This is because in this architecture no extra control messages need to be exchanged through the x2 or S1 links after the CS has been elected. At 120 ms some new UEs join CoMP and at about 200 ms all the UEs leave from CoMP. Finally all of the UEs join the CoMP again and stay in the CoMP until end of the simulation.

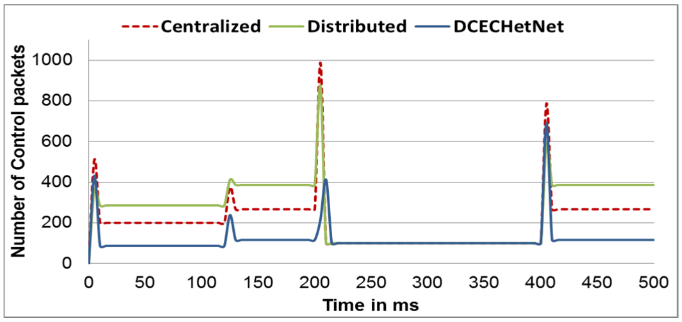

Fig. 9. Comparison of DCEC-HetNet, Centralized, and Distributed architectures based on number of packets with respect to time for 100 UEs.

Figure 10 shows the number of control packets in each 10 ms time intervals for all the three architectures with 200 UEs. In this figure, the three bars in every group represent the three architectures in the following order: DCEC-HetNet, Centralized and Distributed. This is shown in the upper left part of the figure. The darker part of each bar shows the number of CSI Feedback packets which travel from UE to BS and UE to RRH. The lighter part shows the CSI feedback forwards from BS to BS, BS to CU and the overhead related to the election algorithm. The control packets are measured from the moment that the CoMP is initiated until the end of the simulation time for every 10 ms. The results of the conducted simulations show that in the beginning of the establishment of CoMP, the DCEC-HetNet control architecture will require additional control packets to be sent over the backhaul, but after the establishment of the CoMP there will be no control packets transmitted except the CSI feedback from the UE to the CS. As clearly seen in Figure 10, no additional control packets transmitted from BS to BS within the 20 ms to 120ms (inclusive) timeframe in DCEC-HetNet. In the 130 ms to 140 ms timeframe, several new UEs join the CoMP which results in some additional control packets being transmitted through the backhaul to elect the CS. After time 120 ms, there will be no additional control packets required since the CS election has been completed. On the other hand, the other two conventional architectures need the CSI feedback to be forwarded over the backhaul every time. Here we consider the feedback delay as the total time between measuring the CSI at the UE and using it during the scheduling. In most practical systems, the CSI feedback consists of processing time, transmission time and waiting time for the scheduler [22]. Therefore, according to the result of the simulation, as seen in Figure 10, we can see that the DCEC-HetNet architecture reduces the CSI feedback latency compared to the other two control architectures since in this case CSI feedback does not need to travel BS to BS or BS to CU through X2, S1 or fiber link after the CS elected.

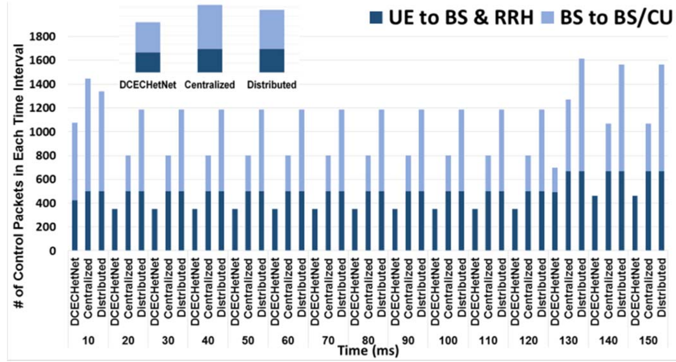

Fig. 10. DCEC-HetNet, Centralized and Distributed based on the number of packets traveled in UEs to BSs and the Backhaul. Each three bar group represents 10 ms (detailed view on the top left)

According to the simulation results, shown in Figures 7, 8, 9 and 10 we can say that the DCEC-HetNet control architecture has the potential to reduce the signaling overhead as well as the CSI feedback latency in the HetNet CoMP with respect to other conventional CoMP approaches, without the need to change the periodicity of the CSI feedback. The reduction of the CSI feedback overhead and latency eventually improve the network throughput [35, 36].

VI. Conclusion and Future Work

Heterogeneous networks extend cellular networks by introducing small cells with different powers to provide coverage and capacity. On the other hand, the main goal of the CoMP approach is to improve the data rate especially for the cell edge users as well as to increase the throughput of the network. However, the two standard architectures (Centralized and Distributed) of HetNet CoMP face some challenges such as latency, signaling overhead and infrastructural overhead. In this work, we introduced new control architecture for CSI feedback scheme, based on dynamic coordination station (CS) for CoMP HetNet. This approach reduces the CSI feedback overhead and feedback latency so that the overall throughput of the network can be improved. The CS election algorithm has been implemented with CoMP in the HetHet scenarios mentioned in the previous sections of this paper. We have also shown how this DCEC-HetNet control architecture for CoMP reduces the CSI overhead and the CSI feedback latency compared to two other standard CoMP approaches. A potential possibility to expand this work is to extend the DCEC-HetNet approach for 5G cellular networks. We could also investigate the device-to-device (D2D) communication among the UEs and machine-to-Machine (M2M) communication. Since, the elected CS knows all the participating BSs and UEs in the same cooperating set D2D communication within the CoMP threshold with dynamic CS could be a potential approach for substantial gains in the capacity and performance of cellular networks in the future.

References

[1] Cisco, "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2015–2020 White Paper," Cisco, 2016.

[2] Ericsson, "Ericsson Mobility Report," 2015. [Online]. Available: http://www.ericsson.com/res/docs/2015/mobility-report/ericsson-mobility-report-nov-2015.pdf. [Accessed 26 March 2016].

[3] I. F. Akyildiz, D. M. Gutierrez-Estevez and E. C. Reyes, "The evolution to 4G cellular systems: LTE-Advanced," *Physical Communication,* vol. 3, pp. 217-244, 2010.

[4] M. Tavanpour, M. Moallemi, G. Wainer, J. Mikhail, G. Boudreau and R. Casselman, "Shared segmented upload in mobile networks using coordinated multipoint," in *Performance Evaluation of Computer and Telecommunication Systems*, Monterey, CA, 2014.

[5] M. Peng, Y. Li, Z. Zhao and C. Wang, "System architecture and key technologies for 5G heterogeneous cloud radio access networks," *IEEE Network,* vol. 29, no. 2, pp. 6-14, 2015.

[6] C.-X. Wang, F. Haider, X. Gao, X.-H. You, Y. Yang, D. Yuan, H. Aggoune, H. Haas, S. Fletcher and E. Hepsaydir, "Cellular architecture and key technologies for 5G wireless communication networks," *IEEE Communications Magazine,* vol. 52, no. 2, pp. 122 - 130, 2014.

[7] D. Lopez-Perez, İ. Güvenc and a. X. Chu., "Mobility management challenges in 3GPP heterogeneous networks," *Communications Magazine,* vol. 50, no. 12, pp. 70-78, 2012.

[8] 3GPP, "3GPP TR 36.819 version 11.2.0," 09 2013. [Online].

[9] M. Ding and H. Luo, Multi-point Cooperative Communication Systems: Theory and Applications, Shanghai Jiao Tong University Press, Shanghai and Springer-Verlag Berlin Heidelberg, 2013.

[10] P. Marsch and G. P. Fettweis, Coordinated Multi-Point in Mobile Communications: From Theory to Practice, Cambridge University Press, 2011.

[11] B. Özbek and D. L. Ruyet, "Feedback Strategies for Multicell Systems," in *Feedback Strategies for Wireless Communication*, New York, Springer, 2014, pp. 249-293.

[12] S. Sun, Q. Gao, Y. Peng, Y. Wang and L. Song, "Interference Management Through CoMP in 3GPP LTE-Advanced Networks," *IEEE Wireless Communications,* vol. 20, no. 1, pp. 59-66, 2013.

[13] A. Papadogiannis, H. Bang, D. Gesbert and E. Hardouin, "Efficient Selective Feedback Design for Multicell Cooperative Networks," *IEEE Transactions on Vehicular Technology,* vol. 60, no. 1, pp. 196-205, 2011.

[14] A. Papadogiannis, E. Hardouin and D. Gesbert, "Decentralising Multicell Cooperative Processing: A Novel Robust Framework," *EURASIP Journal on Wireless Communications and Networking,* vol. 2009, April 2009.

[15] B. U. Kazi, G. A. Wainer, G. Boudreau and R. Casselman, "Coordinated Multi--Point (CoMP) Method And Systems Using a Coordination Station". Canada Patent P47112 US2, 2015.

[16] "Backhauling X2," Cambridge Broadband Networks, April 2011. [Online]. Available: http://cbnl.com/resources/backhauling-x2. [Accessed February 2016].

[17] B. Zeigler, H. Praehofer and T. Kim, Theory of modeling and simulation, San Diego, CA: Academic Press, 2000.

[18] G. A. Wainer, Discrete Event Modeling and Simulation A Practitioner's approach, Boca Raton, FL: CRC Press, Taylor & Francis Group, 2009.

[19] V. Jungnickel, K. Manolakis, W. Zirwas, B. Panzner, V. Braun, M. Lossow, M. Sternad, R. Apelfröjd and a. T. Svensson, "The role of small cells, coordinated multipoint, and massive MIMO in 5G.," *Communications Magazine,* vol. 52, no. 5, pp. 44-51, 2014.

[20] J. Lee, Y. Kim, H. Lee, B. L. Ng, D. Mazzarese, J. Liu, W. Xiao and Y. Zhou, "Coordinated Multipoint Transmission and Reception in LTE-Advanced Systems," *IEEE Communications Magazine,* vol. 50, no. 11, pp. 44-50, 2012.

[21] T. Okamawari, H. Hayashi and T. Fujii, "A Proposal on Network Control Architecture for CoMP JT with IP Network between eNBs," in *IEE Vehicaular Technology Conference*, Yakohama, 2012.

[22] S. Brueck, L. Zhao, J. Giese and A. Amin, "Centralized Scheduling for Joint Transmission Coordinated Multi-Point in LTE-Advanced," in *International ITG Workshop on Smart Antennas (WSA)*, Bremen, 2010.

[23] Y. Gao, Y. Li, H. Yu and S. Gao, "Performance of Dynamic CoMP Cell Selection in 3GPP LTE System Level Simulation," in *IEEE 3rd International Conference on Communication Software and Networks*, Xi'an, 2011.

[24] Y. Gao, Y. Li, H. Yu and a. S. Gao., "Performance analysis of dynamic CoMP cell selection in LTE-advanced heterogeneous networks scenario," in *International Conference on Uncertainty Reasoning and Knowledge Engineering (URKE)*, Bali, Indonesia, 2011.

[25] S. Geirhofer and a. P. Gaal, "Coordinated multi point transmission in 3GPP LTE heterogeneous networks," in *In Globecom Workshops (GC Wkshps)*, Anaheim, CA, 2012 .

[26] P. Xia, C.-H. Liu and a. J. G. Andrews., "Downlink coordinated multi-point with overhead modeling in heterogeneous cellular networks," *IEEE Transactions on Wireless Communications,* vol. 12, no. 8, pp. 4025-4037, 2013.

[27] A. Inostrosa-Psijas, G. Wainer, V. Gil-Costa and M. Marin, "DEVS Modeling of Large Scale Web Search Engines," in *Proceedings of the 2014 Winter Simulation Conference*, Savannah, GA, 2014.

[28] G. A. Wainer, M. Tavanpour and E. Broutin, "Application of the DEVS and Cell-DEVS formalisms for modeling networking applications," in *Proceedings of the Winter Simulation Conference (WSC)*, Washington, DC, 2013 .

[29] T. Blajic, D. Nogulic and M. Druzijanic, "Latency Improvements in 3G Long Term Evolution," 2007. [Online]. Available: http://www.ericsson.com/hr/about/events/archieve/2007/mipro_2007/mipro_1137.pdf. [Accessed September 2015].

[30] G. Cili, H. Yanikomeroglu and F. R. Yu, "Cell Switch Off Technique Combined with Coordinated Multi-Point (CoMP) Transmission for Energy Efficiency in Beyond-LTE Cellular Networks," in *Communications (ICC), 2012 IEEE International Conference on*, Ottawa, ON, 2012.

[31] X. Zhang and X. Zhou, LTE-Advanced Air Interface Technology, CRC Press, 2012.

[32] ETSI, "3GPP TR 36.942 version 13.0.0 Release 13," 01 2016. [Online]. Available: http://www.etsi.org/deliver/etsi_tr/136900_136999/136942/13.00.00_60/tr_136942v130000p.pdf. [Accessed February 2016].

[33] ETSI, "3GPP TS 36.211 version 13.0.0 Release 13," 01 2016. [Online]. Available: http://www.etsi.org/deliver/etsi_ts/136200_136299/136211/13.00.00_60/ts_136211v130000p.pdf. [Accessed February 2016].

[34] B. Mondal, E. Visotsky, T. Thomas, X. Wang and A. Ghosh, "Performance of downlink comp in LTE under practical constraints," in *IEEE 23rd International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC)*, Sydney, NSW , 2012.

[35] B. Mielczarek and W. Krzymien, "Influence of CSI Feedback Delay on Capacity of Linear Multi-User MIMO Systems," in *IEE Wireless Communications and Networking Conference*, Kowloon, 2007.

[36] L. Shi, Z. Hu, T. Zhang and Z. Zeng, "Performance Analysis of Delayed Limited Feedback Based on Per-cell Codebook in CoMP Systems," in *2015 IEEE Wireless Communications and Networking Conference (WCNC 2015)*, New Orleans, 2015.