A Proposal on Network Control Architecture for CoMP JT with IP Network between eNBs

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Abstract— **CoMP JT (coordinated multi-point joint transmission) is being discussed in 3GPP (3rd Generation Partnership Project). User data is simultaneously transmitted from multiple eNBs (evolved NodeB) to a UE (User Equipment) to improve the cell edge performance. The important point here is that not only the throughput of the CoMP UE but also the total throughput of the system must be improved by initiating CoMP JT. Therefore a novel network control architecture is required to optimize the total system throughput by initiating or terminating CoMP JT. In this paper, we propose a network control architecture for CoMP JT that works over an IP backhaul network between eNBs. To mitigate the transmission delay of IP packets, two levels of time scale are introduced. The radio resource for CoMP JT is allocated every several hundreds of milliseconds. On the other hand, modulation and coding scheme (MCS) for link adaptation is calculated every millisecond. The proposed network control architecture is working without a central control entity. This distributed architecture is suitable for LTE-A (Long Term Evolution Advanced). It is also possible to eliminate inter-cluster interference with this proposed architecture.**

Keywords- Communication system control, Mobile communication, Network interface, Protocols.

I. INTRODUCTION

Inter-cell interference is one of the limiting factors in today's mobile systems including LTE and LTE-A. Since all radio resources are reused in every cell or sector, the users located at the cell edge area experience performance degradation due to the interference from neighboring cells. Downlink CoMP JT is a technology that is discussed in 3GPP to mitigate the inter-cell interference [1]. By transmitting signal from multiple eNBs to a UE in a coordinated way, the signal from the neighboring cell is regarded as enhancement rather than interference. In this way, it is possible to improve the throughput performance of cell edge users [2]. Although the cell edge performance is greatly improved by this technique, it is not an easy task to increase the total system throughput.

It is pointed out in [3-5] that only cell-edge UEs should perform CoMP JT because CoMP JT consumes radio resources from multiple cells if CoMP SU (single user) MIMO (multiple-input and multiple-output) is used. Since inter-cell interference is very weak at cell-center, cell-center UEs should not perform CoMP JT to avoid too much radio resource consumption. Therefore an optimization method is required to decide whether a UE should perform CoMP JT or not. It is proposed in [3] that a UE is classified into cell-edge or cell-center by the received SINR (signal to interference and noise ratio). Then CoMP JT is executed only for cell-edge UEs with pre-assigned frequency resources from multiple cells. Cell-center UEs are operating in non-CoMP mode, i.e. single-cell transmission. The drawback of this method is that flexible frequency resource allocation is impossible because frequency resources are pre-assigned. Liu et al. proposed another optimization method [6]. The scheduler in eNB compares the priority of a cell-edge UE and the average priority of cell-center UEs for each resource block, which is a block of time-frequency resources. If the priority for the cell-edge UE is higher than the average, the scheduler allocates the resource block to the cell-edge UE for CoMP JT. Otherwise, the scheduler selects non-CoMP mode. Since the decision is made per resource block basis rather than pre-assigned frequency resources, additional gain is obtained in terms of total system throughput. Yet another optimization method is proposed in [7, 8], in which the scheduler estimates the throughput with and without CoMP JT. If the throughput with CoMP JT is higher than without CoMP JT, CoMP JT is initiated and the total system throughput is improved.

The optimization methods given above are based on a centralized architecture. There is a central scheduler in which the feedback information from all UEs in all (or clustered) cells are processed every TTI (transmission time interval), which is 1ms in LTE, to decide whether CoMP is initiated or not and which radio resources are allocated to the CoMP UE. On the other hand, LTE has a distributed architecture in which eNBs are connected by IP backhaul networks. The scheduler that is implemented in each eNB processes the feedback information from local UEs to assign local radio resources for the local UEs. A distributed architecture that can deal with CoMP JT is possible [9, 10]. In our previous work, we proposed a distributed architecture in which the schedulers of adjacent eNBs negotiate on radio resource allocation for CoMP JT over an IP network interface called X2 [11].

In this paper, we discuss the network control architecture for CoMP JT to optimize the total system throughput in the distributed architecture. CoMP SU MIMO is assumed as the technology used for CoMP JT. Two different levels of time scale are introduced in the control architecture. The radio resource allocation for CoMP JT is optimized every hundreds of milliseconds by the negotiation between the schedulers in neighboring eNBs. On the other hand, MCS are optimized every millisecond without the negotiation. In this way, the total system throughput is optimized by allocating radio resources for CoMP UEs as well as non-CoMP UEs using an IP network.

The rest of this paper is organized as follows. In section II, the basic concept of the proposed network control architecture is described. Section III gives the examples of the total cell throughput optimization using the proposed network control architecture. There are two possible implementations, frequency domain and time domain resource allocation. We explain the basic procedure for both implementations here. In section IV, the proposed method is applied to more realistic but complicated multiple-CoMP-UE scenario. Finally, concluding remarks are stated in section V.

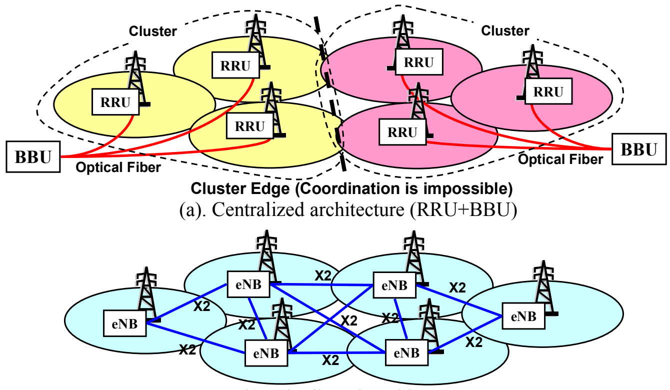
II. DISTRIBUTED ARCHITECTURE FOR COMP JT

There are two possible architectures for the control of CoMP JT, centralized and distributed. In the centralized architecture, all the feedback information must be collected at a central node to decide the radio resource allocation for UEs. In reality, the centralized architecture is impossible due to the delay of IP backhaul network. (In 3GPP, typical delay over X2 is assumed at 10ms [12].) Therefore an RRU (remote radio unit) based solution is used as a technique to avoid the delay [13]. However, the RRU based architecture has a problem. It is impossible to control tens of RRUs by a central scheduler called BBU (baseband unit). Therefore a group of RRUs that are controlled by a BBU must work as a cluster. Fig. 1 (a) shows an example of the cell design with the clusters. In this configuration, it is impossible to avoid inter cluster interference because no coordination is applied at the cluster edge. This motivates us to develop a CoMP JT system with a distributed architecture that works with IP network. We can obtain better total system throughput with the distributed architecture because CoMP JT is possible at all the cell edges and the inter cluster interference is avoided, as shown in Fig. 1 (b).

In our previous work, we proposed a distributed architecture that can control CoMP JT [11]. Fig. 2 shows the data flow of the distributed architecture with two eNBs and one UE. This architecture is based on LTE and there is no central scheduler. In this particular example, the UE is located at cell-center in cell 1 at first. Then the UE moves to the cell-edge between cell 1 and 2 and finally it stops at cell-center in cell 2. As soon as the UE enters the cell-edge, CoMP JT is initiated. The downlink data for the UE is processed by layer 2 in eNB1 and MAC PDUs (protocol data unit) are produced. They are copied and transported to eNB2 (the solid black line in Fig. 2) via X2. The physical layer (PHY) process is carried out at both eNBs in parallel. Finally the data is transmitted from two synchronized eNBs to the UE in a coordinated manner.

Based on our previous work, we propose a novel network control architecture, in which two levels of timescale are introduced as a radio resource control cycle, to optimize the total system throughput with CoMP JT. The radio resource for CoMP JT can be allocated in a longer time period (ΔT) because it requires negotiation between eNBs over X2. If we set ΔT at hundreds of milliseconds, we can optimize the radio resources for CoMP JT according to the traffic pattern or traffic volume [14, 15]. On the other hand, MCS can be calculated in a very short time (typically at milliseconds) to adapt the MCS to the instantaneous radio channel condition. Note that MCS is calculated every TTI in LTE.

Fig. 3 shows a typical example of CoMP JT with the proposed architecture when UE moves as shown in Fig. 2. As soon as the UE enters cell-edge, the resource managers of both eNBs negotiate over X2 whether CoMP JT should be initiated (the red line in Fig. 2). Once they decide to initiate CoMP JT, the radio resources for CoMP JT are allocated to the UE. Since the UE uses radio resources in cell 1 as well as cell 2 for CoMP JT, the negotiation between the resource managers in eNB1 and eNB2 over X2 is essential to avoid the radio resource contention between the cells. Then the allocated radio resources for CoMP JT in cell 2 are passed to eNB1 so that the CoMP scheduler in eNB1 can calculate the suitable MCS for the CoMP UE every TTI by itself. Therefore the negotiation over X2 is not required for the MCS calculation. (See [11] for detail.) After ΔT, the resource managers negotiate again to check whether CoMP JT should be continued or not. If CoMP JT continues, the radio resource allocation can be modified because the traffic pattern or traffic volume for the UE might be changed during ΔT. This process is repeated every ΔT until at last the resource managers jointly decide that it is time to terminate CoMP JT.



(a). Centralized architecture (RRU+BBU)

(b). Distributed Architecture

Figure 1. Comparison between centralized and distributed architectures.

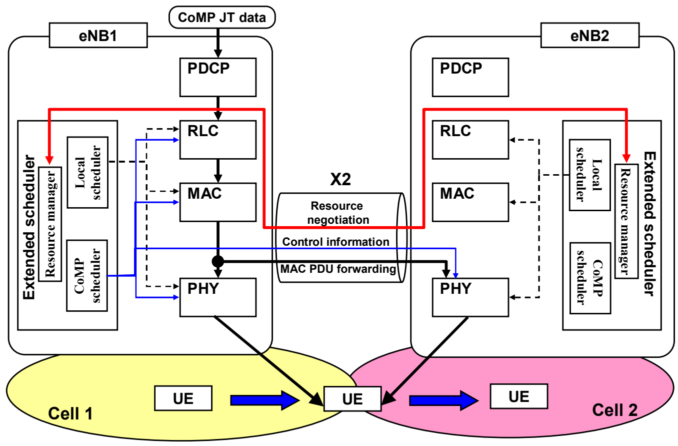


Figure 2. CoMP JT in distributed architecture.

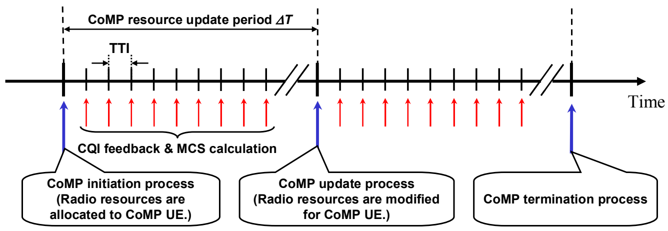


Figure 3. Typical life cycle of CoMP JT.

III. EXAMPLE OF COMP INITIATION/TERMINATION PROCESS

In this section, we explain CoMP JT initiation/termination process in a simple scenario shown in Fig. 4. UE2 and UE3 are located at cell-center in cell 1 and cell 2, respectively. UE1 moves from cell 1 to cell 2 and executes CoMP JT at the cell-edge. In this scenario, when UE1 executes CoMP JT, a part of the radio resources in cell 2 are allocated to UE1. Though the throughput for UE1 is improved by the CoMP JT, the throughput performance for UE3 may be degraded because the radio resources allocated for UE3 is reduced. Therefore we need to control the timing of CoMP JT initiation/termination to optimize the total system throughput.

In the explanation below, CoMP JT initiation/termination is decided based on the throughput estimation algorithm proposed in [7]. The decision process is depicted in Fig. 5. First, eNB1 receives feedback information that includes channel state information (CSI) from UE1 and UE2. The resource manager in eNB1 (see Fig. 2) estimates the throughput for UE1 by using the CSI from UE1. (See [16] for the detail of the throughput estimation.) There are two kinds of throughput estimation for UE1, "with CoMP JT" and "without CoMP JT". Hereafter, C_{nC} and C_{nS} represent estimated throughput values for UE-n with and without CoMP JT, respectively. C_{1C} and C_{1S} are estimated by the resource manager in eNB1 at "throughput estimation 1" in Fig. 5. The estimated values are reported from eNB1 to eNB2 by using CoMP request message as shown in Fig. 5.

Second, the resource manager in eNB2 estimates C_{3C} and C_{3S} by using the CSI from UE3. After eNB2 receives the CoMP request message from eNB1 that includes C_{1C} and C_{1S} the estimated throughput values are compared by the following formula,

$$C_{1C} \geqq \alpha(C_{1S} + C_{3S}), \text{ where } 0 \leqq \alpha \leqq 1. \qquad (1)$$

Here, RHS of (1) represents the estimated throughput when CoMP JT is not executed. The LHS of (1) represents the estimated throughput when CoMP JT is executed. The parameter α is used for adjusting the balance between total system throughput and cell-edge throughput. For large α, higher total system throughput is obtained though cell-edge throughput is low. For smaller α, the result will be other way round. Therefore α should be determined by the policy of operators. If the condition (1) is true, the resource manager in eNB2 thinks that CoMP JT should be initiated. Therefore eNB2 allocates a part of radio resources in cell 2 to UE1 for CoMP JT. (This is the process executed in "throughput estimation 2" in Fig. 5.) The allocated resources are passed to eNB1 so that the CoMP scheduler in eNB1 can calculate MCS for UE1 by itself. For this purpose, CoMP response message shown in Fig. 5 informs the allocated radio resources from eNB2 to eNB1.

Third, eNB1 checks if the allocated radio resources by eNB2 are suitable for CoMP JT. Then eNB1 makes the final decision whether UE1 should initiate CoMP JT. CoMP start notification message is sent from eNB1 to eNB2 to inform the final decision. If CoMP JT is initiated, the radio resources are reserved at both eNBs. At the same time, another CoMP start notification is sent from eNB1 to UE1 to trigger CoMP JT.

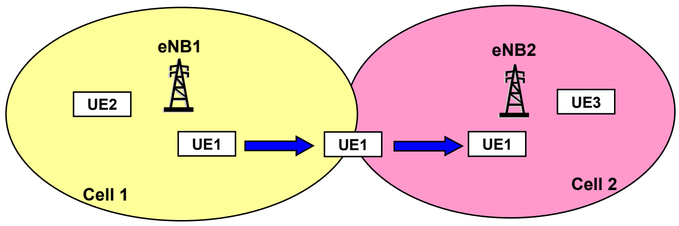


Figure 4. Example of total cell throughput optimization with CoMP JT.

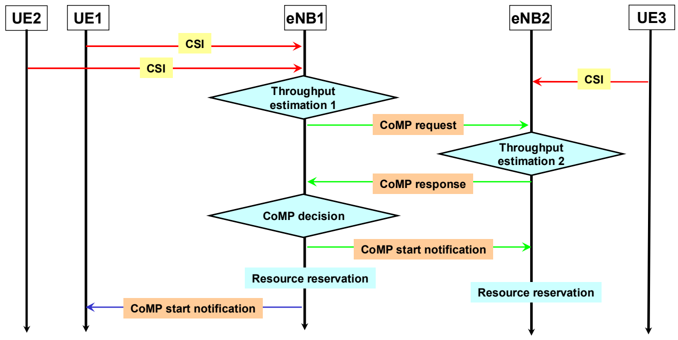


Figure 5. CoMP decision process for total throughput optimization.

The decision process shown in Fig. 5 is applied not only for CoMP initiation but also for CoMP update and CoMP termination shown in Fig. 3. Every ΔT, the resource manager in eNB1 negotiates with the counterpart in eNB2 over X2 by using the process shown in Fig. 5 and checks whether CoMP JT should be executed in next ΔT by using (1). If the resource managers decide to continue CoMP JT, the radio resources are allocated for CoMP JT. (The allocated radio resources may be different from the previous allocation.) Otherwise, CoMP JT is terminated and the allocated radio resources are released. Hereafter, the process shown in Fig. 5 is called "CoMP decision process" in this article.

There are two possible implementations depending on how to allocate radio resources, time domain and frequency domain. Both implementations are explained in detail in the following subsections. Note that time-frequency domain allocation is also possible and it is realized by a simple extension of the time domain allocation and the frequency domain allocation.

A. *Frequency domain scheduling*

In frequency domain allocation, user data traffic is allocated to a block of frequency resources during CoMP JT. In 3GPP terminology, it is called as a resource block (RB). Fig. 6 shows an example of frequency domain allocation under the scenario shown in Fig. 4. In this particular example, there are six RBs in each eNB. Before CoMP initiation, UE1 and UE2 share the RBs in eNB1. UE3 occupies all the RBs in eNB2.

Just after UE1 enters the cell edge, the CoMP decision process shown in Fig. 5 is triggered and RB1-2 in eNB1 and eNB2 are allocated to UE1 for CoMP JT. The MCS for UE1 is calculated by the CoMP scheduler in eNB1 using RB1-2. Therefore no negotiation is required between the resource managers in eNB1 and eNB2 for the following ΔT. RB3-6 in eNB1 are allocated to UE2 and the MCS for UE2 is calculated by the local scheduler in eNB1. RB3-6 in eNB2 are allocated to

UE3 and the MCS for UE3 is calculated by the local scheduler in eNB2. This RB allocation is not changed during ΔT.

Then second CoMP decision process is triggered and it is decided that CoMP JT continues for the next ΔT. This time RB1-3 in eNB1 and eNB2 are allocated to UE1 for CoMP JT. The MCS for UE1 is calculated by the CoMP scheduler in eNB1 using RB1-3. RB4-6 in eNB1 are allocated to UE2 and RB4-6 in eNB2 are allocated to UE3. Then third CoMP decision process is triggered and this time the resource managers in eNB1 and eNB2 jointly decide to terminate CoMP JT. Since UE1 is handed over from cell 1 to 2, UE2 occupies all the RBs in eNB1 and UE1 and UE3 share the RBs in eNB2.

B. *Time domain scheduling*

In time domain allocation, user data traffic is allocated to timeslots during CoMP JT. In a similar way with LTE, a timeslot with TTI (1ms) is considered here. Fig. 7 shows an example of time domain allocation under the scenario shown in Fig. 4. A sequence number that begins just after the CoMP decision processes is assigned to each timeslot. Before CoMP initiation, UE1 and UE2 use timeslots in eNB1 with a round robin manner and UE3 occupies all the timeslots in eNB2.

Just after UE1 enters the cell edge, CoMP decision process shown in Fig. 5 is triggered and timeslots $3N+1$ in eNB1 and eNB2, where N represents a natural number, are allocated to UE1 for CoMP JT. The MCS for UE1 is calculated by the CoMP scheduler in eNB1 using timeslots $3N+1$. Therefore no negotiation is required between the resource managers in eNB1 and eNB2 for the following ΔT. Timeslots $3N$ and $3N+2$ in eNB1 are allocated to UE2 and the MCS for UE2 is calculated by the local scheduler in eNB1. Timeslots $3N$ and $3N+2$ in eNB2 are allocated to UE3 and the MCS for UE3 is calculated by the local scheduler in eNB2. This timeslot allocation is not changed during ΔT.

Then second CoMP decision process is triggered and it is decided that CoMP JT continues for the next ΔT. This time timeslots $2N+1$ in eNB1 and eNB2 are allocated to UE1 for CoMP JT. The MCS for UE1 is calculated by the CoMP scheduler in eNB1 using timeslots $2N+1$. Timeslots $2N$ in eNB1 are allocated to UE2 and timeslots $2N$ in eNB2 are allocated to UE3. Then third CoMP decision process is triggered and this time the resource managers in eNB1 and eNB2 jointly decided to terminate CoMP JT. Since UE1 is handed over from cell 1 to 2, UE2 occupies all the timeslots in eNB1 and UE1 and UE3 share the timeslots in eNB2.

IV. REALISTIC SCENARIO WITH MULTIPLE COMP UES

We will apply the proposed network control architecture to a case in which there are multiple CoMP UEs. Generally speaking, a UE crosses a cell border at a different time from the other UE(s). As an example, we will use the scenario shown in Fig. 8. There are four phases in the scenario. In phase I, UE1 and UE2 stay in cell 1, UE3 stays in cell 2, and UE4 and UE5 stay in cell 3. In phase II, UE1 enters the cell-edge area between cell 1 and cell 2. In phase III, UE4 enters the cell edge area between cell 2 and cell 3, while UE1 stays in the cell-edge area. Phase IV, UE1 leaves the cell-edge area, while UE4 stays

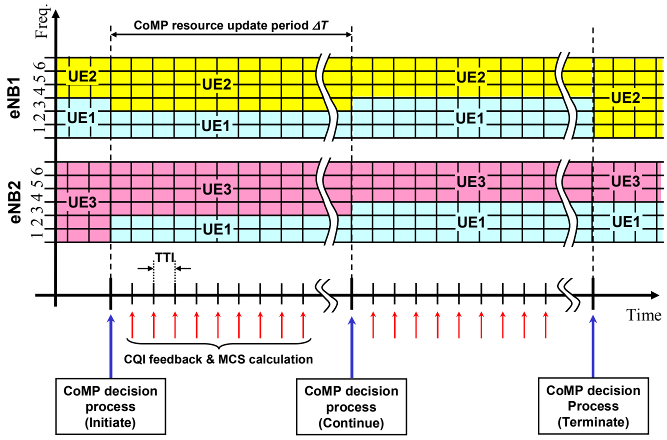


Figure 6. Resource allocation example for frequency domain scheduling.

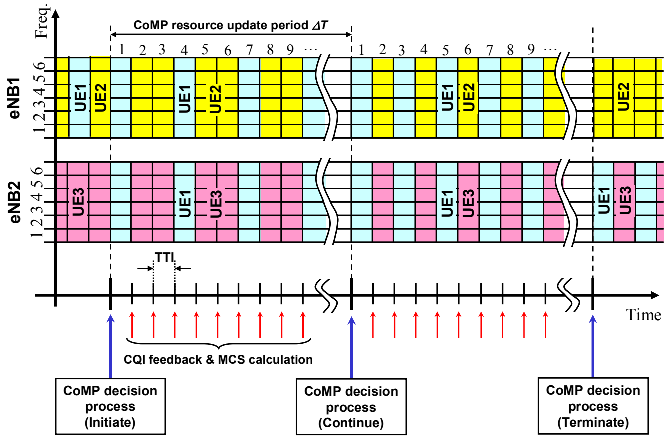


Figure 7. Resource allocation example for time domain scheduling.

in the cell-edge area. At the transition stage between phase II and III, i.e., when UE4 just enters into the cell-edge (the red arrow in Fig. 8), the radio resource in cell 2 is already allocated to UE1 and UE3 for the duration of ΔT. Therefore UE4 cannot initiate CoMP JT as soon as UE4 enters the cell edge. This is one of the problems when using two different time scale, ΔT and TTI.

One of the possible solutions for this problem is shown in Fig. 9. While in phase II, the resource managers in eNB1 and eNB2 are repeating the CoMP decision process every ΔT. Then UE4 enters into the cell edge and eNB3 sends CoMP start request to eNB2 to initiate CoMP JT for UE4. At this point, the radio resources in cell 2 are already allocated to UE1 and UE3. Therefore eNB2 does not issue CoMP response to eNB3 immediately. When next CoMP decision process is triggered by UE1, CoMP request is arrived from eNB1 to eNB2. Here, eNB2 is able to decide whether CoMP should be initiated for UE4 and whether CoMP should be continued for UE1 because the estimated throughputs for all the related UEs are available at eNB2. (This process is executed in "throughput estimation 2" in Fig. 9.) Then eNB2 issues CoMP response messages to eNB1 as well as eNB3 to inform the initiation/continue/ termination decision as well as radio resource allocation.

Fig. 10 shows the resource allocation example by using the frequency domain allocation for the multiple-CoMP-UE scenario shown in Fig. 8. Just after UE4 enters into the cell edge, the negotiation process shown in Fig. 9 is executed between the resource managers in eNB1, eNB2 and eNB3 and it is decided that UE1 continues CoMP JT and UE4 initiates CoMP JT. Then RB1-2 in eNB1 and eNB2 are allocated to UE1 for the following ΔT. The MCS for UE1 is calculated by the CoMP scheduler in eNB1 using RB1-2. RB3-4 in eNB2 are allocated to UE3 and the MCS for UE3 is calculated by the local scheduler in eNB2 using RB3-4. RB5-6 in eNB2 and eNB3 are allocated to UE4 and the MCS for UE4 is calculated by the CoMP scheduler in eNB3 using RB5-6. In this way, it is possible to overcome the multiple-CoMP-UE problem.

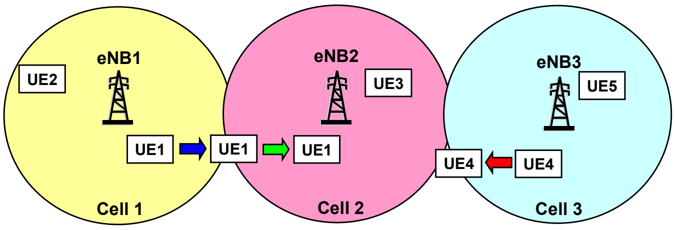


Figure 8. Example of total cell throughput optimization with multiple CoMP UEs.

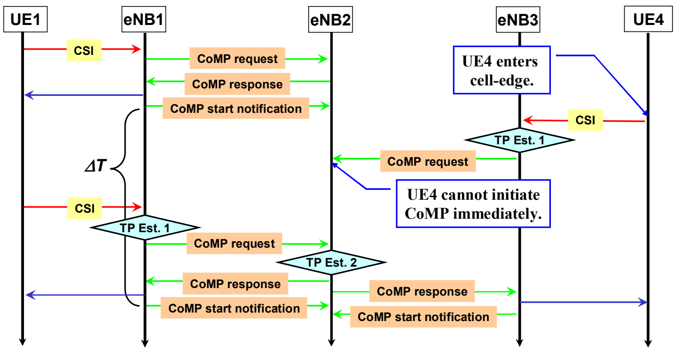


Figure 9. CoMP decision process for total throughput optimization with multiple CoMP UEs. ("TP Est." stands for throughput estimation.)

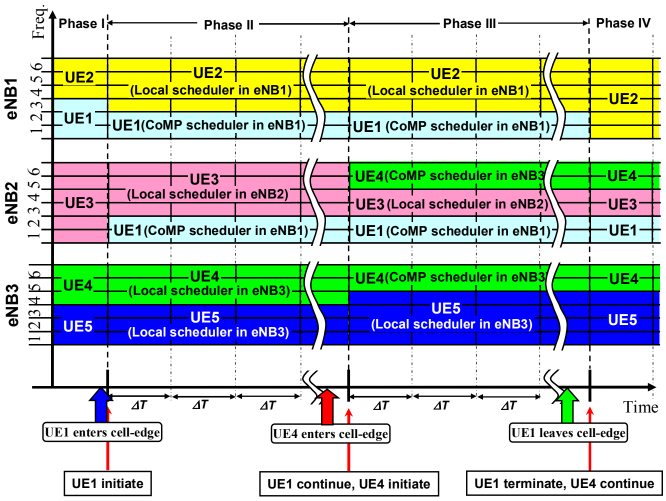


Figure 10. Resource allocation example for frequency domain scheduling with multiple CoMP UEs.

V. CONCLUSION

In this paper, we have proposed a network control architecture for CoMP JT with distributed eNBs connected by an IP backhaul network. Two levels of timescale, TTI and ΔT, are introduced to optimize the total system throughput. The proposed architecture works on an IP network because frequent negotiations between eNBs for the resource allocation of CoMP JT are avoided by using a longer time scale ΔT. Therefore, we can build a CoMP JT capable LTE-A system in which inter-cluster interference is eliminated.

ACKNOWLEDGMENT

Part of this work is carried out under the grant "R&D on the cooperative control technologies for multiple base stations in an environment consisting of various cell sizes," which is funded by the Ministry of Internal Affairs and Communications of Japan.

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