Modeling and Analysis of MU-CoMP HARQ in 3GPP LTE System Level Simulation

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Abstract. In modern wireless mobile networks such as LTE and LTE-Advanced, performance of cell-edge users is in greet need to be improved. Coordinated multipoint transmission/reception is raised to solve the problem in 3GPP # bis 53meeting. In this paper, we present our design of (Multi-User) MU-HARQ transmission scheme in CoMP where previous studies on (Single-User) SU-CoMP HARQ have already been submitted to ChinaCom 2011. In our design, a newly MU-HARQ transmission method is presented which will help improve target user throughput and total cell throughput under some conditions. This result is significant for 3GPP proposals.

Keywords: multi-user, CoMP, HARQ, LTE System Level Simulation.

1 Introduction

Coordinated multipoint transmission/reception (CoMP) is raised to increase cell-edge user performance and spectrum efficiency in common cellular networks [1].There is two different types of CoMP: Joint Processing (JP) and Coordinated Beamforming/ Scheduling (CB/CS). However, study and standardization of CoMP are freezed by 3GPP in around 2009 [2], further studies about physical features and performance evaluations have nearly stopped. In 3GPP specifications and proposals of release 10, conclusions and simulation results about CoMP-JP and CoMP-CB/CS have been accepted by 3GPP members [3].

In this paper, we studied and designed the HARQ scheme in CoMP transmission which has not reached any conclusions in 3GPP discussions. As we all know that HARQ is mentioned firstly in wired communications to ensure the reliability of transmission [4]. Same in wireless communications, HARQ is still important for the wireless fading channel makes the reliable transmission harder to achieve. In CoMP scenario, HARQ is more complex than non-CoMP scenario and the design of CoMP-HARQ is very important to keep the integrality of CoMP system. We mainly focus on CoMP-JP in this paper.

P. Sénac, M. Ott, and A. Seneviratne (Eds.): ICWCA 2011, LNICST 72, pp. 250–264, 2012.

This paper is organized as follows. In part 2, we introduce the system model of MU-CoMP. In part 3, our design of CoMP –HARQ process is presented and analyzed. In part 4, we present the simulation result under our Matlab-based 3GPP LTE system level simulator, brief introduction of the simulator is also introduced in this part. Conclusions are drawn in part 5.

2 System Model

In this part, system model of CoMP-JP is presented. We consider each user may have a service cell which is determined by physical attach, and other cooperative cells by system decision. Different from CoMP-JP, CoMP-CB/CS mode only allow one service link between user and target eNodeBs. This type of CoMP will reduce interference from adjacent cells using beamforming or coordinated scheduling to allocate time-frequency blocks.

At user side, CoMP-JP mode allows packets from both service cell and cooperative cells. Fig 1 shows a typical scenario of CoMP-JP and different colors indicate different cells. In original research of intra-site CoMP-JP, cooperative areas are limited to same cell, just like the same color area in figure 1. In 3GPP release 10, cooperative area has been extended to inter-site [5] just like the dotted area in figure 1.

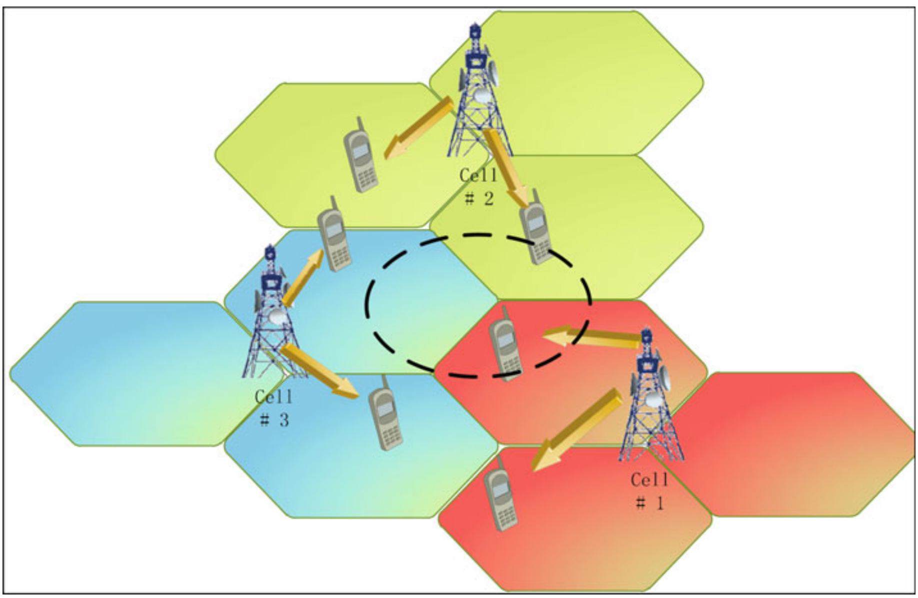

Fig. 1. A Typical System Scenario of CoMP

Sorted by coherence of the received signal, we will discuss coherent and non-coherent CoMP-JP. In coherent mode, we consider global codebook is used and same data packet is send through service cell and cooperative cell at the same time. The receiving vector can be described as follows:

$$r(k,l) = H(k,l)Us(k,l) + n(k,l)\,. \tag{1}$$

Where k the index of OFDM [7] is symbol in resource blocks and l is the index of OFDM symbols. Consider there are M transmit antennas and N receive antennas, H is the $N \times M$ channel matrix, U is the $M \times 1$ precoding matrix and n is the $N \times 1$ Additive White Gaussian Noise.

2.1 Coherent CoMP-JP

First we talk about the single user scenario. In this mode, both service cell and cooperative cell can evaluate service channel and cooperative channels and data packet is transmitted through both service and cooperative cells. This scenario is shown in the full line area shown in fig 2.

Received signal of target user is:

$$r(k,l) = (H_0(k,l)\ H_1(k,l))\binom{U_0}{U_1}s(k,l) + n(k,l)\,. \tag{2}$$

After the commonly used MMSE receiver [7], the prediction of the received signal is:

$$\hat{r}(k,l) = W(k,l) \times (H_0(k,l)\ H_1(k,l))\binom{U_0}{U_1} \times s(k,l) + W(k,l) \times n(k,l) \tag{3}$$

The MMSE detector $W(k,l)$ is calculated using the equation below:

$$W(k,l) = \binom{U_0}{U_1}^H (H_0(k,l)\ H_1(k,l))^H (k,l) \times \left\{ \begin{aligned} &(H_0(k,l)\ H_1(k,l))(k,l)\binom{U_0}{U_1}\binom{U_0}{U_1}^H (H_0(k,l)\ H_1(k,l))^H (k,l) \\ &+ \frac{R_n}{\sigma^2} \end{aligned} \right\}^{-1} \tag{4}$$

The self-correlation matrix of Gaussian noise R_n is calculated below:

$$R_n = E[n(k,l)n^H(k,l)] \tag{5}$$

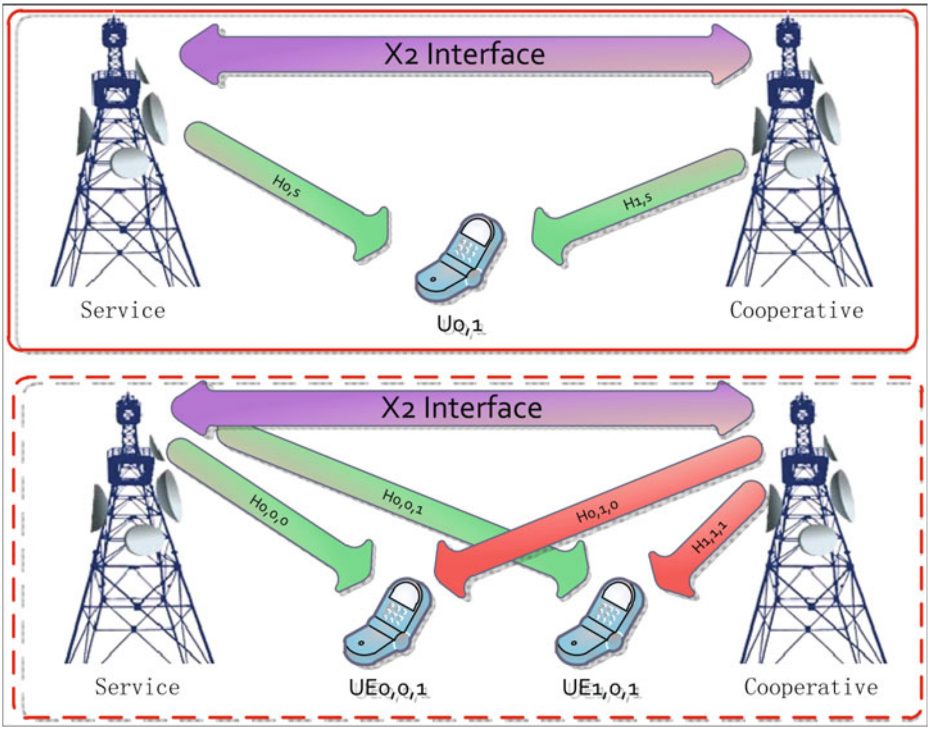

Fig. 2. Coherent CoMP-JP Scenario

The Signal to interface plus noise ratio (SINR) of the received signal is given in formula (6).

$$SINR(k,l) = \frac{\sigma^2 \left| W(k,l)(H_0(k,l)\ H_1(k,l))\begin{pmatrix} U_0 \\ U_1 \end{pmatrix} \right|^2}{W(k,l)R_n W^H(k,l)} \tag{6}$$

Expanded to multi-user scenario of coherent CoMP-JP signal model as shown in dashed line area in fig 2, users are served by both service cells and cooperative cells. Both UE0 and UE1 can estimate service channels and cooperative channels and the global precoding scheme is determined by cells. For the i -th (i=0, 1) user, the received signal can be described as:

$$\begin{aligned} r(k,l) = (H_{i,0}(k,l) \quad H_{i,1}(k,l)) \times \begin{pmatrix} U_{0,0} \\ U_{0,1} \end{pmatrix} \times s_0(k,l) + \\ (H_{i,0}(k,l) \quad H_{i,1}(k,l)) \times \begin{pmatrix} U_{1,0} \\ U_{1,1} \end{pmatrix} \times s_1(k,l) + n(k,l) \end{aligned} \tag{7}$$

After the MMSE detector, the prediction of the signal is:

$$\begin{aligned}\hat{r}_i(k,l) = W_{i,0,1}(k,l)\times \\ [(H_{i,0}(k,l) \quad H_{i,1}(k,l))\times\begin{pmatrix}U_{0,0}\\U_{0,1}\end{pmatrix}\times s_0(k,l)+ \\ (H_{i,0}(k,l) \quad H_{i,1}(k,l))\times\begin{pmatrix}U_{1,0}\\U_{1,1}\end{pmatrix}\times s_1(k,l)+n(k,l)]\end{aligned} \tag{8}$$

The MMSE detector $W_{i,0,1}(k,l)$ is calculated in formula (9):

$$\begin{aligned}W_1(k,l) = \begin{pmatrix}U_{i,0}\\U_{i,1}\end{pmatrix}^H (H_{i,0}(k,l) \quad H_{i,1}(k,l))^H \times \\ \begin{Bmatrix}(H_{i,0}(k,l) \quad H_{i,1}(k,l))\begin{pmatrix}U_{0,0}\\U_{0,1}\end{pmatrix}\begin{pmatrix}U_{0,0}\\U_{0,1}\end{pmatrix}^H (H_{i,0}(k,l) \quad H_{i,1}(k,l))^H + \\ (H_{i,0}(k,l) \quad H_{i,1}(k,l))\begin{pmatrix}U_{1,0}\\U_{1,1}\end{pmatrix}\begin{pmatrix}U_{1,0}\\U_{1,1}\end{pmatrix}^H (H_{i,0}(k,l) \quad H_{i,1}(k,l))^H + \frac{R_n}{\sigma^2}\end{Bmatrix}^{-1}\end{aligned} \tag{9}$$

The received SINR is:

$$SINR_i(k,l) = \frac{\sigma^2 \left| W_{i,0,1}(k,l) H_{i,0,1}(k,l)\begin{pmatrix}U_{i,0}\\U_{i,1}\end{pmatrix}\right|^2}{\sigma^2 \left| W_{i,0,1}(k,l) H_{i,0,1}(k,l)\begin{pmatrix}U_{1-i,0}\\U_{1-i,1}\end{pmatrix}\right|^2 + W_{i,0,1}(k,l) R_n W_{i,0,1}{}^H(k,l)} \tag{10}$$

From previous analysis of coherent CoMP-JP, we can infer that the macro diversity gain will help improve throughput of cell-edge user, and HARQ design may help reduce retransmission times to improve user performance. If delay in X2 interface [8] is introduced, these set of method may have problem in transmitting both control signal and data packets.

2.2 Non-coherent CoMP-JP

The main difference between coherent and non-coherent is that data packets from service cell and cooperative cells are different at the same time. In non-coherent mode, data packet, codebook and precoding matrix are different from service cells and cooperative cells and in coherent mode, precoding matrix is designed jointly in transmit terminals.

Same in coherent mode, we will show this problem from single user to multi-user. The scenario is shown in fig 3. Single user mode is shown in full line area of fig 3.

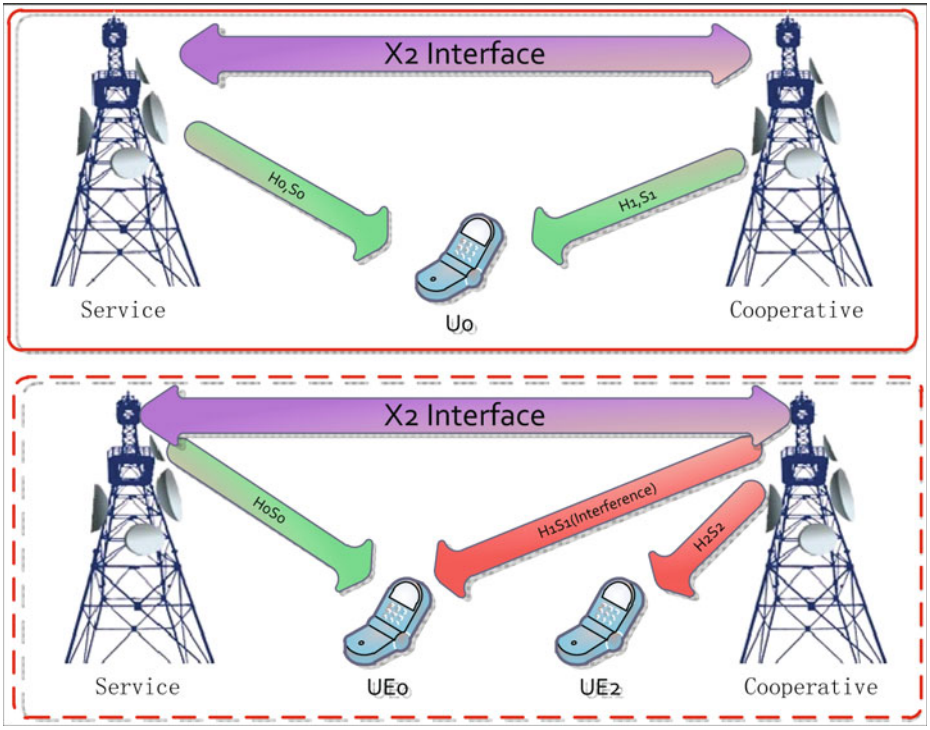

Fig. 3. Non-Coherent CoMP-JP Scenario

The received signal after MMSE detector can be described as:

$$\hat{r}_i(k,l) = W_i(k,l) \times \{H_0(k,l) \times U_0 \times s_0(k,l) + H_1(k,l) \times U_1 \times s_1(k,l) + n(k,l)\} \tag{11}$$

Where $W_i(k,l)$ is the MMSE detector and can be described as:

$$W_i(k,l) = U_i^{\ H} H_i^{\ H}(k,l) \times \begin{Bmatrix} H_0(k,l)U_0U_0^{\ H}H_0^{\ H}(k,l) + \\ H_1(k,l)U_1U_1^{\ H}H_1^{\ H}(k,l) + \dfrac{R_n}{\sigma^2} \end{Bmatrix}^{-1} \tag{12}$$

So the SINR of data packet s_i is calculated using formula (13):

$$r_i(k,l) = \frac{\sigma^2 \,|W_i(k,l)H_i(k,l)U_i\,|^2}{\sigma^2 \,|W_i(k,l)H_{1-i}(k,l)U_{1-i}\,|^2 + W_i(k,l)R_nW_i^{\ H}(k,l)} \tag{13}$$

Expand the scenario to multi-user shown in dashed line area of fig 3, we consider that service cell and cooperative cells serves different users and send different data packet using their own codebook. UE0 can estimate service channel and cooperative channel but UE2 in cooperative cell can only get its own channel. In this mode, the estimation of received signal is given in formula (14).

$$\hat{r}(k,l) = W_0(k,l)\times \{H_0(k,l)\times U_0 \times s_0(k,l) + H_1(k,l)\times U_1 \times s_1(k,l) + n(k,l)\} \tag{14}$$

The MMSE detector $W_0(k,l)$ can be described as:

$$W_1(k,l) = U_0{}^H H_0{}^H(k,l)\times \left\{ \begin{array}{l} H_0(k,l)U_0U_0{}^H H_0{}^H(k,l) + \\ H_1(k,l)U_1U_1{}^H H_1{}^H(k,l) + \dfrac{R_n}{\sigma^2} \end{array} \right\}^{-1} \tag{15}$$

Easily we can get the SINR of the data which is shown in formula (16).

$$SINR(k,l) = \frac{\sigma^2 \,|W_0(k,l)H_0(k,l)U_0|^2}{\sigma^2 \,|W_0(k,l)H_1(k,l)U_1|^2 + W_0(k,l)R_nW_0{}^H(k,l)} \tag{16}$$

After the detailed analysis of CoMP-JP scenario, we can infer that cooperative transmission in both coherent and non-coherent mode will have diversity gain and improvement of throughput. The difference is that data transmitted in X2 interface. In this paper, we do not consider delays and capacity of X2 interface.

3 Design of Multi-user CoMP-HARQ

Received SINR of data packets is always used to design link transmission scheme, the received SINR is also the infrastructure of our MU CoMP-HARQ. In previous work of 3GPP release 10 [9], design for HARQ process hasn't reached any conclusions. In standardization of 3GPP release 11, influence of CoMP-HARQ and design of HARQ will be studied. We raised our design of MU CoMP-HARQ in this paper, the design will help improve performance and reduce Block Error Rate (BLER).

Previous work of SU CoMP-HARQ shows that the retransmission link selection scheme can improve average throughput and reduce retransmission times, this part of work has been submitted to ChinaCom 2011 conference [10]. In this paper, we extend the scenario to multi-user.

In 3GPP LTE transmission system, HARQ packet is scheduled before data packet. Commonly, HARQ packet is not treated specially. Consider that HARQ packet contains redundant information for previous error packet which needs to be demodulated immediately, so the less retransmission times it takes the better performance user will get.

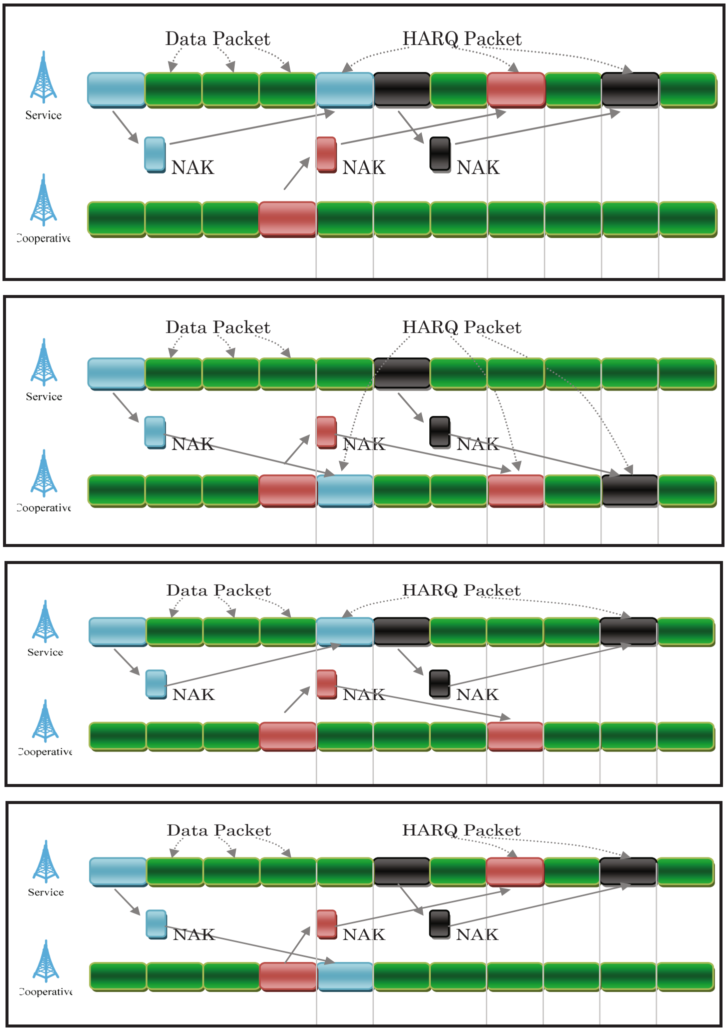

Fig. 4. Scenarios of CoMP-HARQ

Figure 4 shows four different policies of CoMP-HARQ. From top to bottom, they are:

1. Retransmission from only service cell
2. Retransmission from only cooperative cells
3. Retransmission from where error packet from
4. Retransmission from best link (e.g. best receive SINR)

Theoretically, HARQ is an auxiliary transmission function used to ensure probability of success and reduce BLER. The four different policies cause different performance in 3GPP LTE system level simulation. Referring to commonly dynamic cell selection (DCS) scheme in CoMP-JP, we expand the use of DCS in CoMP-HARQ.

After deep study of CoMP-JP related proposals [11], we introduce our MU-CoMP process. The process of CoMP-HARQ is shown below:

1. Target cell-edge user measure Reference Signal Receiving Power(RSRP) or Reference Signal Receiving Quality (RSRQ) and send to service eNodeB;
2. According to RSRP/RSRQ and CQI/PMI, eNodeB decide CoMP transmission points and calculate scheduling for target user and decide the best retransmission link for HARQ packet;
3. Service eNodeB send scheduling, data packet, HARQ and control signal to cooperative cells through X2 interface;
4. In given TTI, servicing eNodeB send downlink assignment to CoMP UE and cooperative eNodeB send data to CoMP UE;
5. After getting all required information from servicing eNodeB and cooperative eNodeB, CoMP UE will demodulate signal to decide ACK/NACK;
6. Servicing eNodeB will decide whether a retransmission is needed, if needed, go to step 2 and decide a best retransmission link among all existed links

Note that the downlink HARQ is a nonsynchronous process, so both data packet and retransmission packet have similar scheduling policy. In step 2, we mention that eNodeB will decide the best transmission link for retransmission packet. In this paper, the best link is chosen using uplink feedback of target user. In part 2, both coherent and non-coherent scenario, user will be able to calculate received SINR according to formula (6) (10) (13) (16), and eNodeB will scheduler CoMP UE using the ‘out-of-date’ information.

In a very short time interval such as a timeslot in LTE system, the large scale information of channel such as path loss and shadow fading nearly remain stationary [12] and the small scale information such as Doppler and multi path information will change fast. In a statistical result show in next part, dynamic link selection for HARQ packet is a delay-sensitive process, delay of X2 interface will affect the performance. There may also some other policies of HARQ design that will work better than DCS-HARQ.

4 Simulation and Analysis

Under the widely used 3GPP LTE system level simulation [13], we performed our DCS HARQ design in MU-CoMP. In this part, we mainly performed two parts of work. Firstly, we make a comparison of DCS-HARQ and non DCS-HARQ; secondly, we studied the influence of delay in X2 interface.

4.1 Brief Introduction of Our Matlab-Based LTE System Level Simulator

In order to verify and evaluate physical concepts and new methods in 3GPP LTE system, 3GPP has established a set of standards and simulation scenarios to ensure the comparability of the simulation. In most 3GPP members, the LTE system and link level simulator are secured as commercial secrets. In our Matlab-based simulator [15], there are three basic functional parts. In initialize part, parameters of eNodeBs, UEs and channel matrix are generated; in transmission part, abstract of system level transmission is performed, eNodeBs will schedule each attached users. In CoMP mode, the cycle control sub function decides CoMP points of current TTI and performs link transmission; in evaluation part, output of all results is gathered.

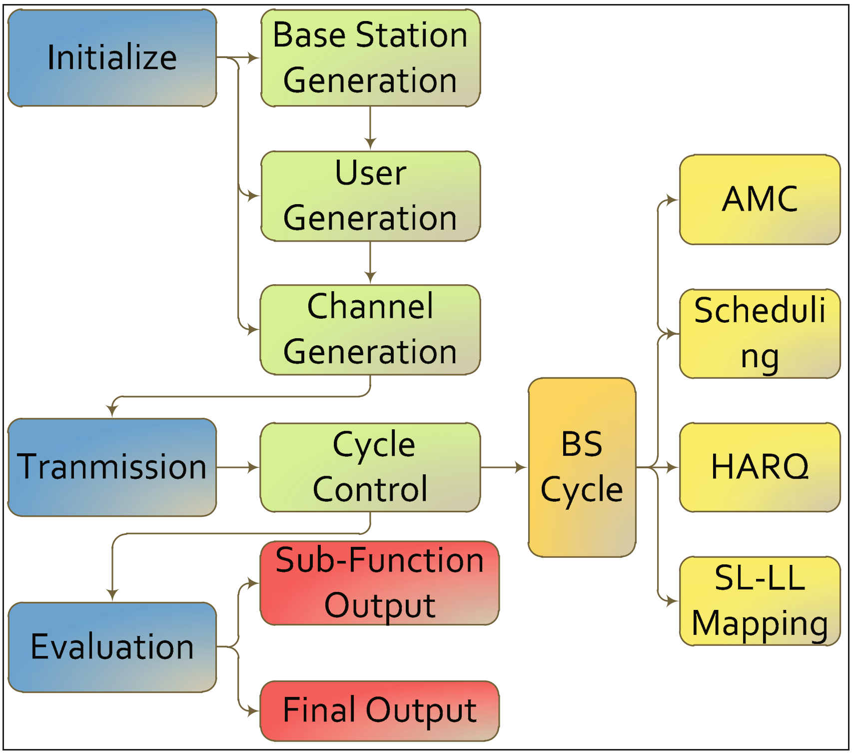

Fig. 5. Process of our LTE System Level Simulation

4.2 Compare of DCS-HARQ and Non DCS-HARQ

In this part, we compare the average retransmission times and average throughput of target users and CoMP cells. Simulation assumptions and parameters are listed in table 1.

In each simulation cycle, we consider the 10% users who have the worst SINR working in CoMP mode. Statistically, these set of users always located at the edge of the cell. We will trace one of them that will represent the performance of these set of users. In order to get a statistical result, we repeated the simulation for 1000 times and get the average performance. Note that the random seed to generate the channel changed in every Monte Carlo simulation.

Table 1. Simulation Assumptions and Parameters

Name	Value
Channel Model	SCME, urban macro
Carrier Frequency	2GHz
Tx Antenna	2
Rx Antenna	2
Transmit Power	46dBm
BS Number	19
Sectors per BS	3
Users in Simulation	dynamic
Bandwidth	10MHz
SL to LL Mapping	EESM
Inter-site distance	500m
Pathloss Model	L = 128.1+37.6log10(R)
Shadowing Std	4dB
HARQ Scheme	CC
AMC Table	QPSK(R ={1/8, 1/7, 1/6, 1/5, 1/4, 1/3, 2/5, 1/2, 3/5, 2/3, 3/4, 4/5}) 16QAM(R = {1/2, 3/5, 2/3, 3/4, 4/5})
UE Sig Processing	MMSE
Max Re-trans times	4
UE Speed	3KM/h
Channel Estimation	Ideal
Simulation TTIs	1000

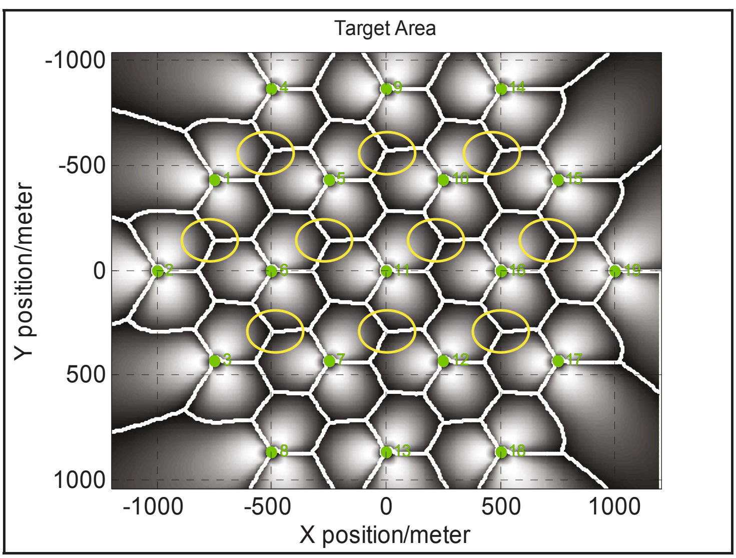

Fig. 6. Simulation Target Area [10]

Figure 6 represents the simulation scenario of our assumption. Different in 3GPP release 10, we mainly focus on inter-site CoMP which may be discussed in 3GPP release 11 [15].The green dots with different number indicate center of eNodeBs, yellow circle represents our target areas. Users located in the yellow area will receive low SINR in very high probability. In this part, we consider that there is no delay in X2 interface.

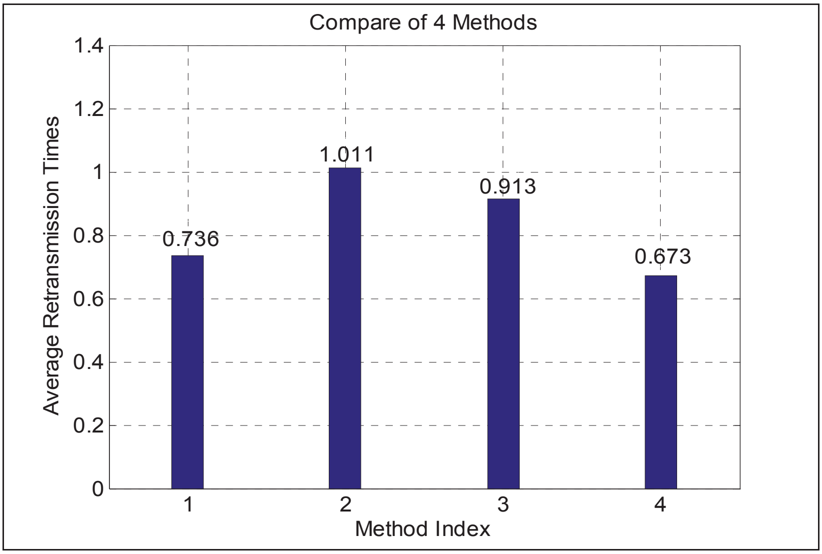

Fig. 7. Compare of Target User Average Retransmission Times

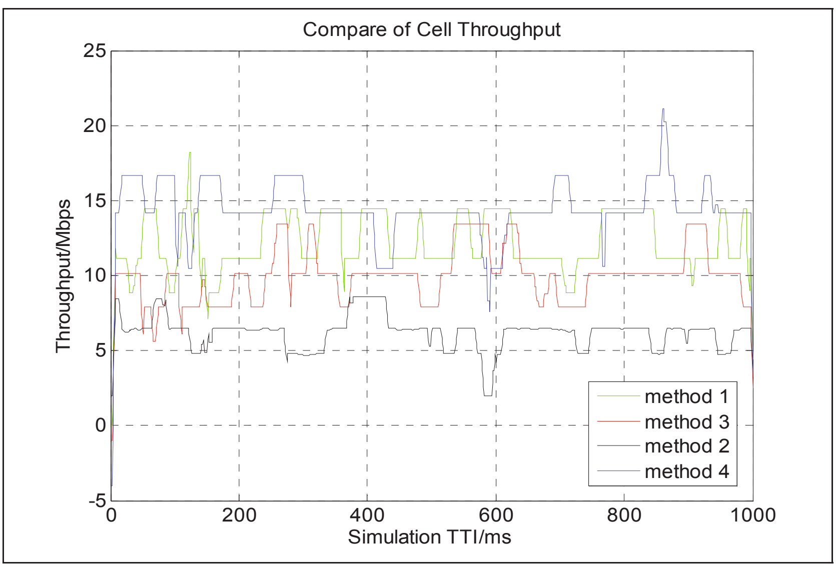

Fig. 8. Compare of Total CoMP Cell Throughput of One Simulation

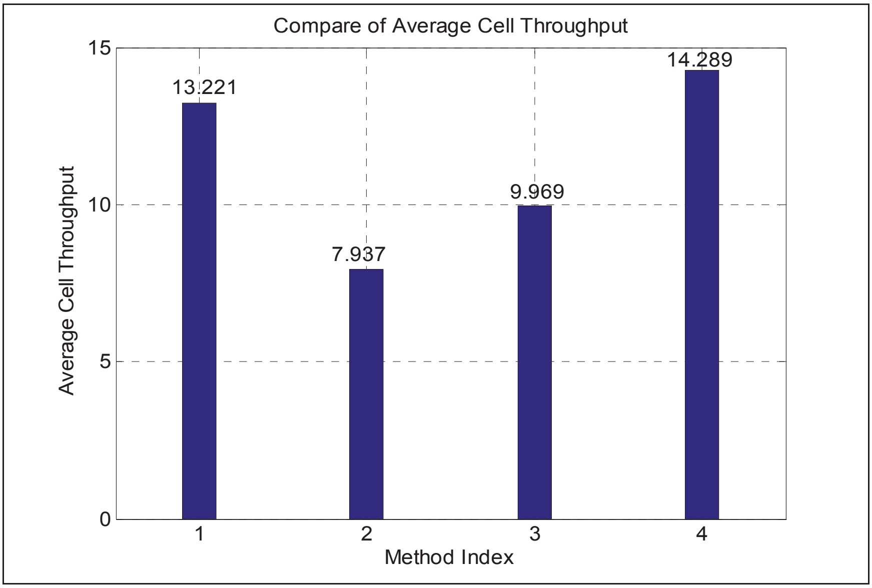

Fig. 9. Compare of Total Cell Throughput

Figure 7~9 shows the simulation result under our Matlab-based simulator. The four different method of CoMP-HARQ are described in figure 4. In figure 7, we compare the average retransmission times of target CoMP user. In one complete simulation, we average the retransmission times of all 1000 timeslots and repeat the same experiment 1000 times to get the final average result. It is obvious that our DCS-HARQ method can reduce retransmission times than other three methods. Figure 8 and 9 are the total CoMP cell throughput. Corroborating to figure 7, we can see that the DCS-HARQ will increase total cell throughput. The gain is from chase combine of HARQ process. These set of simulation results proved that our DCS-HARQ method can increase cell throughput in statistical point of view with merely no other costs. This is a very meaningful result for 3GPP release 11 proposals.

4.3 Analysis of Delay in X2 Interface

In this part, we present our simulation result in consideration of delays in X2 interface. The existed result of delays in X2 interface shows that delays will affect performance of CoMP. The simulation assumptions and parameters are the same in part 4.2.

We compare the influence delays using our DCS-HARQ method in MU-CoMP HARQ. In non-CoMP mode, delay tolerance of successfully receive a packet is set to 3ms [16], and in CoMP mode, the tolerance will be longer. In our simulation, we take 0ms, 3ms, 5ms ,10ms and 18ms as an example [17].

Figure 10 shows the simulation result of delays in X2 interface. We can infer that when delay is less than 5ms, the influence is little. When delay is larger than 10ms, it will encumber the system performance. So new design of X2 interface is needed in CoMP-JP where there is much information need to be exchanged using X2 interface.

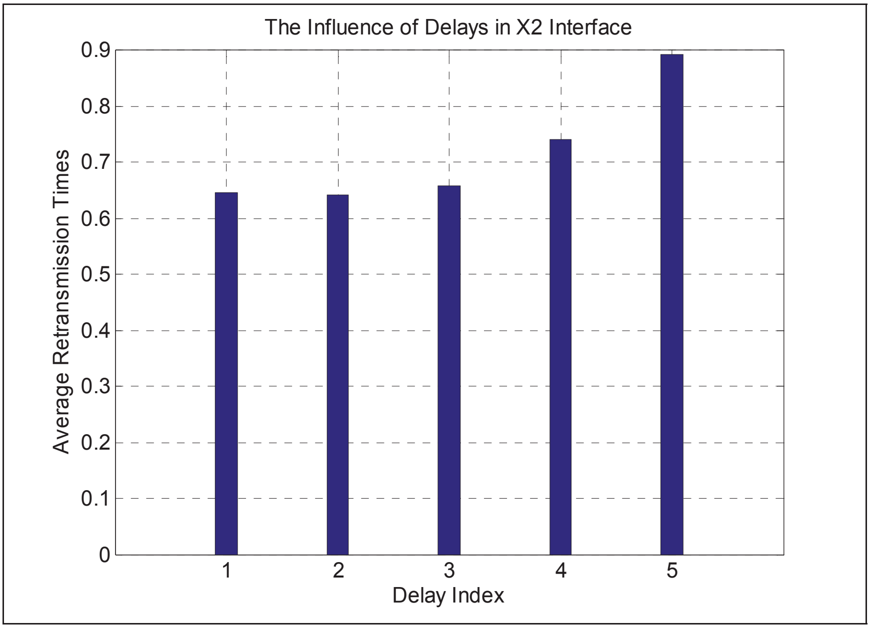

Fig. 10. The Influence of Delays in X2 Interface

5 Conclusion

In this paper, we studied the MU HARQ process in CoMP-JP scenario and raised our own DCS-HARQ method which is proved effective to improve system performance and reduce system retransmission times with little system costs. Analysis of delays in X2 interface is also given in this paper. We strongly recommend that in CoMP-JP mode, capacity and delay features need to be improved to satisfy the need of CoMP. This is a meaningful method for 3GPP LTE standardization of release 11.

Acknowledgment. This work is funded as part of the National Basic Research Program of China (2007CB310608), National Natural Science Foundation of China (60872063), China's 863 Project (2009AA011501), National S&T Major Project (2008ZX03O03-004) and PCSIRT, whose funding support is gratefully acknowledgment.

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