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1. Introduction

In LTE-A technique report (TR) [1], downlink coordinated multi-point (CoMP) transmission can be accomplished by dynamic coordination among multiple geographically separated transmission points, including

- Coordinated scheduling and/or beamforming
 - ✓ data to a single UE is instantaneously transmitted from one of the transmission points
 - ✓ scheduling decisions are coordinated to control e.g. the interference generated in a set of coordinated cells.
- Joint processing/transmission
 - ✓ data to a single UE is simultaneously transmitted from multiple transmission points, e.g. to (coherently or non-coherently) improve the received signal quality and/or cancel actively interference for other UEs

System performance for down-link CoMP has been investigated with coherent transmission in [2][3], where both sector throughput and cell coverage can be significantly improved. In most contributions, the discussions on CoMP focus on coherent transmission and pay much attention to the cell coverage. Joint processing with non-coherent transmission, however, plays an important role in remarkably improving sector throughput as well. Similar to the concept of adaptation between transmit diversity and spatial multiplexing in MIMO system, switching different types of transmission modes under different channel environments may aim to improve the overall system performance.

In this contribution, we focus on the discussion of joint processing/transmission with single UE targeting scenario. We categorize three types of CoMP transmissions with detailed formulation of signal and interference-to-noise ratio (SINR).

2. CoMP Transmission

Without loss of generality, we simply assume that a CoMP system contains two cooperative cells; one denotes anchor cell and the other denotes coordinated cell. Both cooperative cells serve certain number of subordinate user equipments (UE), who are located in the cell edge, in general. The determination of whether eNode-B belongs to anchor cell or coordinated cell is based on the long-term power strength received by each UE. Hence, the status of cells for each UE could be different dependent on UE location corresponding to pathloss and shadowing. Furthermore, it is assumed that each cell consists of M transmit antennas and each UE consists of N receive antennas.

The CoMP transmission with joint processing/transmission may be categorized into three types:

- Coherent transmission (type-0), which is cooperated in code book, control signal, and data signal. In this case, the same data with synchronized timing is transmitted from coordinated cells to CoMP UE.
- Non-coherent transmission (type-1), which is cooperated in code book, control signal, and data signal. In this case, the different data are transmitted from coordinated cells to CoMP UE.
- Non-coherent transmission (type-2), which is cooperated in code book and control signal. In this case, the individual data is transmitted from individual cell to its subordinate UE

In our discussion, the data signal(s) is precoded with proper code book(s) at OFDM sub-carrier in frequency domain, and identified by the index pair (k, l) in each sub-frame, where k is the index of resource element in each OFDM symbol, and l is the index of OFDM symbol. Then, the precoded signal is transmitted on M multiple antennas and received on N multiple antennas. The received signal vector can be formulated as

$$r(k, l) = \Gamma_0(k, l) \cdot U_0 \cdot s_0(k, l) + \Gamma_1(k, l) \cdot U_1 \cdot s_1(k, l) + \eta(k, l) \quad (\text{eq - 1})$$

where $r(k, l)$, $\Gamma_i(k, l)$, U_i , $s_i(k, l)$ and $\eta_i(k, l)$ represent the received signal, channel matrix, precoding vector, transmit signal, and additive white Gaussian noise (AWGN) vector, respectively. The size of $r(k, l)$, $\Gamma_i(k, l)$, U_i , and $\eta_i(k, l)$ are respectively $N \times 1$, $N \times M$, $M \times 1$, and $N \times 1$.

In this contribution, a linear minimum mean square error (MMSE) receiver is involved in efficiently suppressing the interference. For simplicity, furthermore, our analysis is performed under the following assumptions:

- Perfect receive timing without mismatching. We think that the timing mismatching due to received timing difference can be compensated by adjusting a linear phase [4][5].
- The long term signal power from the cooperative cell site might be somehow lower than that from the anchor cell site. However, there is no power allocation performed between anchor cell and coordinated cell.

2.1. Baseline Transmission -- Non-CoMP

As a baseline, non-CoMP transmission scheme is considered, that each cell delivers the data with individually selected codebook to its subordinate UE, and each UE simultaneously receives both the desired data from its serving cell and the interference from the neighbor cell, as illustrated in Figure 1. In this case, the UE0 served by cell-0 is only able to estimate the channel of $\Gamma_0(k, l)$ but not $\Gamma_1(k, l)$. According to $\Gamma_0(k, l)$, cell-0 properly determines the code book U_0 whereby the precoded data s_0 is transmitted to UE0. The UE0, in turn, receives the desired data signal corrupted by the interference from neighbor cell-1 and AWGN noise.

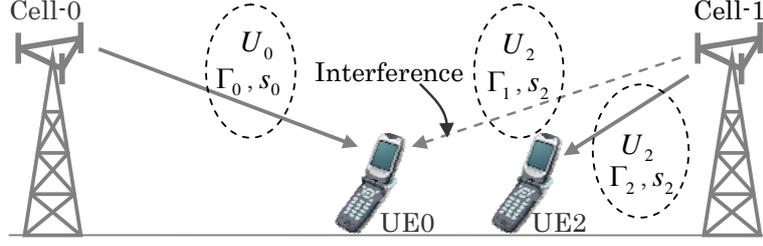


Figure 1: Non-CoMP transmission.

For this transmission mode, clearly, the equation (eq – 1) can be modified to

$$r(k, l) = \Gamma_0(k, l) \cdot U_0 \cdot s_0(k, l) + \eta'(k, l)$$

where $\eta'(k, l)$ is the interference plus AWGN noise, given by

$$\eta'(k, l) = \Gamma_1(k, l) \cdot U_2 \cdot s_2(k, l) + \eta(k, l).$$

Relying on a well-known MMSE equalization at the receiver, the estimate of data signal becomes

$$\hat{s}(k, l) = W_0(k, l) \cdot \Gamma_0(k, l) \cdot U_0 \cdot s(k, l) + W_0(k, l) \cdot \eta'(k, l).$$

Here, $W_0(k, l)$ is the MMSE weight vector with the size of $1 \times N$, given by

$$W_0(k, l) = U_0^H \Gamma_0^H(k, l) \cdot \left\{ \Gamma_0(k, l) U_0 U_0^H \Gamma_0^H(k, l) + \frac{1}{\sigma_s^2} R_{\eta'} \right\}^{-1},$$

where σ_s^2 and $R_{\eta'}$ are the transmit power of data symbol, and the noise covariance matrix, respectively given by $\sigma_s^2 = E[s(k, l) \cdot s^*(k, l)]$ and $R_{\eta'} = E[\eta'(k, l) \cdot \eta'^H(k, l)]$.

The SINR $\gamma(k, l)$ received in resource element (k, l) , therefore, can be simply derived as

$$\gamma(k, l) = \frac{\sigma_s^2 |W_0(k, l) \cdot \Gamma_0(k, l) \cdot U_0|^2}{W_0(k, l) R_{\eta'} W_0^H(k, l)}.$$

Behaviors:

- In this transmission mode, there is no cooperation performed between serving cell and neighbor cells. Therefore, there are no signals including control and data shared between the cells.

Pros:

- Simple backhaul design, and simple scheduling procedure.

Cons:

- Lower performance including sector throughput and cell coverage.

2.2. Coherent Transmission

As a CoMP joint processing/transmission [1], the coherent transmission (denoted type-0) is illustrated in Figure 2, where both anchor and coordinated cells simultaneously serve a single UE0 and deliver the same data with a universal code book. In this case, the UE0 served by anchor and coordinated cells is capable of estimating both channels of $\Gamma_0(k, l)$ and $\Gamma_1(k, l)$. According to $\Gamma_0(k, l)$ and $\Gamma_1(k, l)$, a code book $U_{0,1}$ is universally determined, and the data s is transmitted from both anchor and coordinated cells. In the UE receiver, the UE0 receives the precoded desired data which is only contaminated by AWGN noise.

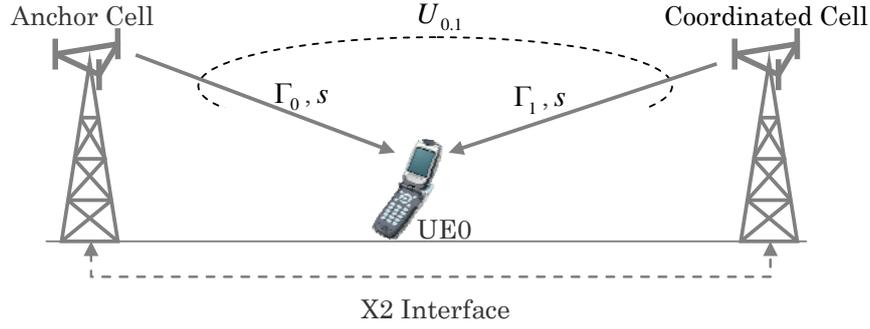


Figure 2: Coherent CoMP transmission.

For this CoMP transmission mode, the equation (eq – 1) can be modified to

$$r(k, l) = \Gamma_{0,1}(k, l) \cdot U_{0,1} \cdot s(k, l) + \eta(k, l)$$

where the size of $\Gamma_{0,1}(k, l)$ and $U_{0,1}$ are respectively $N \times 2M$ and $2M \times 1$. $\Gamma_{0,1}(k, l)$ and $U_{0,1}$ are given by

$$\Gamma_{0,1}(k, l) = [\Gamma_0(k, l) \quad \Gamma_1(k, l)],$$

and

$$U_{0,1} = \begin{bmatrix} U_0 \\ U_1 \end{bmatrix}.$$

Relying on a well-known MMSE equalization at the receiver, the estimate of data signal becomes

$$\hat{s}(k, l) = W_{0,1}(k, l) \cdot \Gamma_{0,1}(k, l) \cdot U_{0,1} \cdot s(k, l) + W_{0,1}(k, l) \cdot \eta(k, l).$$

Here, $W(k, l)$ is the MMSE weight vector with the size of $1 \times N$, given by

$$W_{0,1}(k, l) = U_{0,1}^H \Gamma_{0,1}^H(k, l) \cdot \left\{ \Gamma_{0,1}(k, l) U_{0,1} U_{0,1}^H \Gamma_{0,1}^H(k, l) + \frac{1}{\sigma_s^2} R_\eta \right\}^{-1},$$

where R_η is the noise covariance matrix, given by $R_\eta = E[\eta(k,l) \cdot \eta^H(k,l)]$.

The SINR $\gamma(k,l)$ received in resource element (k,l) , therefore, can be simply derived as

$$\gamma(k,l) = \frac{\sigma_s^2 |W_{0,1}(k,l) \cdot \Gamma_{0,1}(k,l) \cdot U_{0,1}|^2}{W_{0,1}(k,l) R_\eta W_{0,1}^H(k,l)}$$

Behaviors:

- The same data and control signals through backhaul channel (e.g., X2 interface) are shared between anchor and coordinated cells.

Pros:

- Significant macro-diversity gain and joint precoding gain.
- Good cell coverage and somewhat sector throughput improvement.

Cons:

- It is complicated due to data and control signals sharing through backhaul channel. In addition, it may require some timing different control (e.g., transmission phase shifting) to ensure the coherent reception.

2.3. Non-Coherent Transmission (Type-1)

As a CoMP joint processing/transmission [1], the non-coherent transmission (denoted type-1) is illustrated in Figure 3, where both anchor and coordinated cells simultaneously serve a single UE0 but deliver different data with individual code book. In this case, the UE0 served by anchor and coordinated cells is capable of estimating both channels of $\Gamma_0(k,l)$ and $\Gamma_1(k,l)$. According to $\Gamma_0(k,l)$ and $\Gamma_1(k,l)$, the code books U_0 for anchor cell and U_1 for coordinated cell are cooperatively determined, whereby the precoded data s_0 is transmitted from anchor cell and the precoded data s_1 is from coordinated cell. In the UE receiver, the UE0 receives the desired data which is contaminated by a small amount of leaked interference due to limited available code books, and AWGN noise.

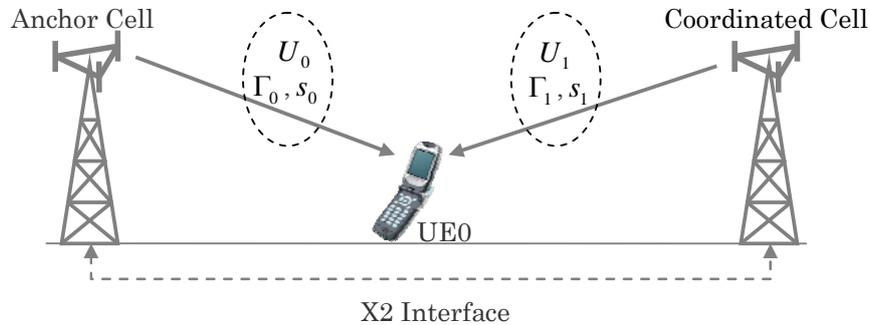


Figure 3: Non-coherent CoMP transmission.

For this CoMP transmission mode, the formula of received signal is similar to the equation (eq – 1). In addition, relying on a well-known MMSE equalization at the receiver, the estimate of data signal can be formulated as

$$\begin{bmatrix} \hat{s}_0(k,l) \\ \hat{s}_1(k,l) \end{bmatrix} = \begin{bmatrix} W_0(k,l) \\ W_1(k,l) \end{bmatrix} \cdot \{\Gamma_0(k,l) \cdot U_0 \cdot s_0(k,l) + \Gamma_1(k,l) \cdot U_1 \cdot s_1(k,l) + \eta(k,l)\}.$$

Here, $W_0(k,l)$ and $W_1(k,l)$ are the MMSE weight vector with the size of $1 \times N$, given by

$$W_0(k,l) = U_0^H \Gamma_0^H(k,l) \cdot \left\{ \Gamma_0(k,l) U_0 U_0^H \Gamma_0^H(k,l) + \Gamma_1(k,l) U_1 U_1^H \Gamma_1^H(k,l) + \frac{1}{\sigma_s^2} R_\eta \right\}^{-1},$$

and

$$W_1(k,l) = U_1^H \Gamma_1^H(k,l) \cdot \left\{ \Gamma_0(k,l) U_0 U_0^H \Gamma_0^H(k,l) + \Gamma_1(k,l) U_1 U_1^H \Gamma_1^H(k,l) + \frac{1}{\sigma_s^2} R_\eta \right\}^{-1}.$$

The SINR $\gamma_0(k,l)$ for the first data packet s_0 and $\gamma_1(k,l)$ for the second data packet s_1 are respectively given by

$$\gamma_0(k,l) = \frac{\sigma_s^2 |W_0(k,l) \cdot \Gamma_0(k,l) \cdot U_0|^2}{\sigma_s^2 |W_0(k,l) \cdot \Gamma_1(k,l) \cdot U_1|^2 + W_0(k,l) R_\eta W_0^H(k,l)},$$

and

$$\gamma_1(k,l) = \frac{\sigma_s^2 |W_1(k,l) \cdot \Gamma_1(k,l) \cdot U_1|^2}{\sigma_s^2 |W_1(k,l) \cdot \Gamma_0(k,l) \cdot U_0|^2 + W_1(k,l) R_\eta W_1^H(k,l)}.$$

In this case, the constraints of selecting the code books for precoding and MMSE weight should satisfy

$$|W_0(k,l) \cdot \Gamma_1(k,l) \cdot U_1| \approx |W_1(k,l) \cdot \Gamma_0(k,l) \cdot U_0| \approx 0.$$

Behaviors:

- The different data and control signals through backhaul channel (X2 interface) are shared between anchor and coordinated cells.

Pros:

- Significant macro precoding gain.
- Good sector throughput and somewhat cell coverage improvement.
- Successive interference cancellation (SIC) is available.
- It does not need some timing difference adjustment, i.e., transmission phase shifting.

Cons:

- It is complicated due to data and control signals sharing through backhaul channel.

2.4. Non-Coherent Transmission (Type-2)

As a CoMP joint processing/transmission [1], the non-coherent transmission (denoted type-2) is illustrated in Figure 4, where both anchor and coordinated cells serve different UEs and deliver different data with cooperative code books. In this case, the UE0 served by anchor cell is capable of estimating both channels of $\Gamma_0(k,l)$ and $\Gamma_1(k,l)$, whereas the UE2 served by coordinated cell is only able to estimate the channel of $\Gamma_2(k,l)$. According to $\Gamma_0(k,l)$ and $\Gamma_1(k,l)$, the code books U_0 for anchor cell and U_1 for coordinated cell are cooperatively determined. In turn, the data s_0 precoded with U_0 is transmitted from anchor to UE0 while the data s_2 precoded with U_1 is transmitted from coordinated cell to UE2. In the UE receiver, the UE0 receives the desired data which is contaminated by a small amount of leaked interference due to limited available code books, and AWGN noise.

In the coordinated cell, relying on the restricted code book U_1 which is determined and forwarded by the anchor cell, the scheduler selects the best active UE who properly matches the code book U_1 for transmission. Although the restricted code-book U_1 is not the best candidate, we believe that the precoding implemented for the selected UE in consideration of the code-book restriction should be still able to achieve the high throughput among the UEs.

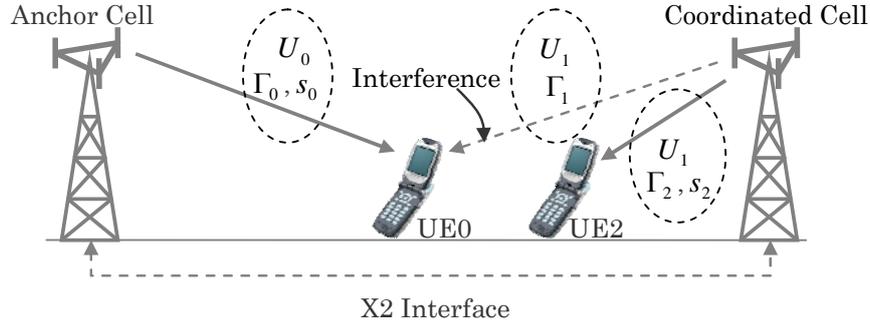


Figure 4: Non-coherent CoMP transmission.

For this CoMP transmission mode, the equation (eq – 1) can be modified to

$$\hat{s}_0(k,l) = W_0(k,l) \cdot \{\Gamma_0(k,l) \cdot U_0 \cdot s_0(k,l) + \Gamma_1(k,l) \cdot U_1 \cdot s_2(k,l) + \eta(k,l)\}.$$

Here, $W_0(k,l)$ is the MMSE weight vector with the size of $1 \times N$, given by

$$W_0(k,l) = U_0^H \Gamma_0^H(k,l) \cdot \left\{ \Gamma_0(k,l) U_0 U_0^H \Gamma_0^H(k,l) + \Gamma_1(k,l) U_1 U_1^H \Gamma_1^H(k,l) + \frac{1}{\sigma_s^2} R_\eta \right\}^{-1}.$$

The SINR $\gamma_0(k,l)$ received in resource element (k,l) are represented as

$$\gamma_0(k,l) = \frac{\sigma_s^2 |W_0(k,l) \cdot \Gamma_0(k,l) \cdot U_0|^2}{\sigma_s^2 |W_0(k,l) \cdot \Gamma_1(k,l) \cdot U_1|^2 + W_0(k,l) R_\eta W_0^H(k,l)}$$

In this case, the constraint of selecting the precoder book and MMSE weight should satisfy

$$|W_0(k,l) \cdot \Gamma_1(k,l) \cdot U_1| \approx 0.$$

Behaviors:

- Only control signal through backhaul channel (X2 interface) is shared between anchor and coordinated cells.

Pros:

- Achievable precoding gain.
- Good sector throughput.
- It is comparably simple due to the limited backhaul burden

Cons:

- No cell coverage improvement.

3. Conclusions

In this contribution, we have discussed CoMP transmission using joint processing/transmission mechanism. Three types of CoMP transmission modes have been categorized with detailed derivation in terms of SINR. It is suggested that at this stage, the different types of CoMP transmission modes should be further studied in order to realize proper transmissions and improve both sector throughput and cell coverage under different channel environments.

Reference

- [1] 3GPP TR 36.814, "Further Advancements for E-UTRA Physical Layer Aspects", Release-9, V0.4.1, February 2009.
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- [3] 3GPP TSG RAN1 #56, R1-090822, Huawei, "System Performance Evaluation of Downlink CoMP", Feb. 9-13, 2009.
- [4] 3GPP TSG RAN1 #56, R1-090951, Fujitsu, "Pseudo Transmission Timing Control using Cyclic Shift for Downlink CoMP Joint Transmission", Feb. 9-13, 2009.
- [5] 3GPP TSG RAN1 #55BIS, R1-090142, Nortel, "Performance evaluation of CoMP solutions", Jan. 12-16, 2009.