DM-RS Based Open-Loop CoMP in LTE-A System

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***Abstract*—Coordinated multi-point transmission/reception (CoMP) has been identified as an important way of mitigating interference and improving spectral efficiency for cell edge users in LTE-A system. However, current CoMP studies mainly focus on joint transmission (JT), dynamic point selection (DPS) and coordinated scheduling/beamforming (CS/CB) which all fall into closed-loop category. When considering medium or high mobility users, closed-loop CoMP seems less effective, while open-loop CoMP is more preferred, which is similar to that observed between closed-loop and open-loop single user multiple-input multiple-output (SU-MIMO). In this paper, we propose open-loop CoMP transmission frameworks for both spatial multiplexing and transmit diversity. We design our open-loop CoMP schemes by reusing long term evolution (LTE) open-loop SU-MIMO structures as much as possible to alleviate standardization efforts, and especially consider support for demodulation reference signals (DM-RS) which will be prevalent in future LTE-Advanced systems. Simulation results verify the effectiveness of our proposed open-loop CoMP schemes.**

***Index Terms*—open-loop CoMP, DM-RS, LTE-A, CoMP spatial multiplexing, CoMP transmit diversity.**

I. Introduction

Heterogenous network is an important characteristic of long term evolution advanced (LTE-A) system, where macro evolved Node B (eNB) covers the wide span and low power remote radio heads (RRHs) focus on hotspots. While it does harvest performance gain from heterogeneity, it also creates more "cell edges" which are more prone to interference and may jeopardize split gain if not handled appropriately. Therefore, coordinated multi-point transmission/reception (CoMP) has drawn wide attention in LTE-A systems due to its ability of coordinating interference and improving cell edge throughput.

Currently, most CoMP studies focus on closed-loop transmission [1]-[3], e.g., joint transmission (JT), dynamic point selection (DPS) and coordinated scheduling/beamforming (CS/CB) [4] which all rely on precoding matrix indicator (PMI) feedback. For single user multiple-input multiple-output (SU-MIMO), it has been observed that open-loop strategy is easier to deploy and has better performance than closed-loop one for medium to high speed and the situations when reliable channel state information (CSI) feedback is unavailable [5]. When it comes to CoMP, similar observation between closed-loop and open-loop still holds. To cope with medium or high speed scenario where PMI feedback cannot quite follow channel variation, it is worthwhile to study open-loop CoMP schemes. Additionally, even with open-loop CoMP, user geometry will get improved [6][7], thus saving heavy feedback load required in closed-loop CoMP.

For open-loop CoMP, the literature [6] proposes to study on it and suggests some general design principles, while no specific schemes are given. A CoMP open-loop spatial multiplexing framework is proposed in [7], where different transmission points (TPs) may chose their precoders according to a pre-defined rule. Herein, we add unitary and phase rotation matrices ahead of precoders, which has been verified by simulations to be more effective and also has minor impact on standards. In [8], a CoMP transmit diversity scheme is proposed based on space frequency block code (SFBC) and cyclic delay diversity (CDD), but the phases are adjusted per subcarrier, thus not being able to support demodulation reference signal (DM-RS) demodulation which seems more efficient for CoMP operation. Compared with it, we propose a more general CoMP SFBC transmit diversity framework, and fully consider DM-RS demodulation when designing transmission strategies.

In this paper, we propose open-loop CoMP transmission frameworks for both open-loop spatial multiplexing and transmit diversity. We use CoMP JT to construct CoMP open-loop transmission, i.e., each TP shares the same source data information. Additionally, we design all our schemes by taking into the consideration of DM-RS demodulation. For open-loop CoMP spatial multipleixng, we reuse SU-MIMO open-loop CDD transmission structure to spare standardization efforts, but adjust precoders on a per resource block (RB) basis to support CoMP DM-RS demodulation. For CoMP transmit diversity, we design our schemes based on SFBC. We give a general structure for CoMP SFBC transmission, and other forms of variations can be derived from it. Also, we adjust the phase rotation or mapping of SFBC symbols on a per RB basis so as to support DM-RS demodulation. Link level simulations are performed to facilitate analysis and comparison among our proposed schemes. Also, simulation results show that our proposed open-loop CoMP schemes achieve better performance than that of methods which are directly extended from SU-MIMO.

The rest of this paper is organized as follows. Section II briefly reviews SU-MIMO CDD transmission, and then elaborates our CDD based CoMP open-loop spatial multiplexing structure. In Section III, the traditional SFBC method is introduced firstly, and then our SFBC based CoMP transmit diversity framework is proposed. Simulation results are given in Section IV, and conclusions are presented in Section V.

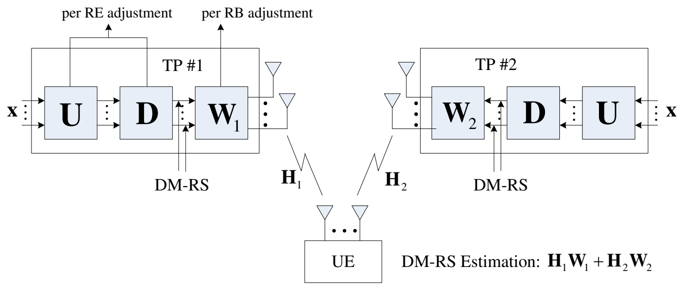

Fig. 1. Framework for CoMP open-loop spatial multiplexing.

II. CoMP Open-loop spatial multiplexing

In this section, we first briefly introduce SU-MIMO precoding for large delay CDD, and then propose CoMP open-loop spatial multiplexing schemes based on it.

A. SU-MIMO large delay CDD

For SU-MIMO, precoding with large delay CDD is used for open-loop spatial multiplexing. Assuming N_t and N_r antennas deployed at eNB and user equipment (UE) respectively, the basic input-output relationship can be expressed as follows:

$$\mathbf{y} = \mathbf{HWDUx} + \mathbf{n}, \tag{1}$$

where $\mathbf{x} \in \mathbb{C}^{L\times 1}$ denotes L-layer data streams intended for UE, $\mathbf{y} \in \mathbb{C}^{N_r\times 1}$ is the UE received vector signal, and $\mathbf{H} \in \mathbb{C}^{N_r\times N_t}$ represents the channel matrix. $\mathbf{n}$ denotes the noise vector. $\mathbf{U} \in \mathbb{C}^{L\times L}$, $\mathbf{D} \in \mathbb{C}^{L\times L}$, and $\mathbf{W} \in \mathbb{C}^{N_t\times L}$ are dedicated to CDD transmission. Currently, two or four antenna ports are supported for CDD transmission, and the way $\mathbf{U}, \mathbf{D}, \mathbf{W}$ are assigned is defined in [9]. Generally speaking, $\mathbf{U}, \mathbf{D}$ and $\mathbf{W}$ are tuned from subcarrier to subcarrier, which is not conform to DM-RS demodulation requirements.

B. CDD based CoMP open-loop spatial multiplexing

As aforementioned, SU-MIMO CDD transmission cannot be directly extended to CoMP due to DM-RS issue. Here we propose our CoMP open-loop spatial multiplexing schemes by using DM-RS demodulation. To spare standardization efforts and keep backward compatibility, we reuse SU-MIMO CDD structure as much as possible. We call the transmitter in CoMP scenario TP without distinction. Taking two-TP CoMP as an example, Fig. 1 gives the proposed framework for DM-RS based CoMP open-loop spatial multiplexing. In Fig. 1, two TPs transmit the same multi-layer data $\mathbf{x}$ to UE. The vector symbol $\mathbf{x}$ goes through the $L \times L$ unitary matrix $\mathbf{U}$ to balance signal-to-noise ratio (SNR) among layers, and then through the frequency dependent $L \times L$ diagonal matrix $\mathbf{D}$ to exploit frequency selectivity, finally through $N_t \times L$ precoder $\mathbf{W}_1$ ($\mathbf{W}_2$) to be mapped onto antenna ports. In our design, DM-RS signal only goes through $\mathbf{W}_1$ ($\mathbf{W}_2$) to be transmitted. This provides UE a convenient way to estimate the composite CoMP channel, and also keeps frequency selectivity by tuning $\mathbf{D}$ on a per resource element (RE) basis. For a particular RE (subcarrier), the UE received signal can be written as

$$\mathbf{y} = \left(\mathbf{H}_1\mathbf{W}_1 + \mathbf{H}_2\mathbf{W}_2\right)\mathbf{DUx} + \mathbf{n}, \tag{2}$$

where $\mathbf{H}_1$, $\mathbf{H}_2$ denote channel matrices from two TPs respectively, and $\mathbf{n}$ is the noise. The way of choosing $\mathbf{U}$, $\mathbf{D}$, $\mathbf{W}_i\,(i = 1, 2)$ should conform with the current standard as much as possible, however, to support DM-RS demodulation, modification has to be made. DM-RS is introduced since Release 9, and it is usually used for equivalent channel estimation (e.g. $\mathbf{HW}$ in SU-MIMO). The minimum granularity of DM-RS based channel estimation is one RB, hence the used precoder must keep constant for at least one RB. DM-RS is especially efficient for CoMP JT, where UE can obtain the combined CSI of all the TPs by performing DM-RS estimation. Based on the positioned DM-RS in Fig. 1, the equivalent channel which UE can estimate is $\mathbf{H}_1\mathbf{W}_1+\mathbf{H}_2\mathbf{W}_2$. As mentioned above, $\mathbf{W}_1$, $\mathbf{W}_2$ should vary on a per RB basis. More specifically, $\mathbf{W}_1$, $\mathbf{W}_2$ should be adjusted from RB to RB, or from RB bundling to RB bundling, but not from RE to RE as in SU-MIMO CDD case. As for matrices $\mathbf{U}$, $\mathbf{D}$, we still keep them adjusted on a per RE basis to gain frequency selective diversity as much as possible. Simulation results in latter section will verify the effectiveness of keeping $\mathbf{U}$, $\mathbf{D}$.

In Fig. 1, we have established the general framework for CoMP open-loop spatial multiplexing, where $\mathbf{W}_i$ is adjusted on a per RB basis, while $\mathbf{U}$, $\mathbf{D}$ are adjusted on a per RE basis. Next, we provide possible schemes for choosing $\mathbf{U}$, $\mathbf{D}$ and $\mathbf{W}_i$. Since both TPs have common $\mathbf{U}$ and $\mathbf{D}$, we choose $\mathbf{U}$, $\mathbf{D}$ in the same way as that of SU-MIMO CDD specified in 6.3.4.2.2 of [9]. As for precoders $\mathbf{W}_1$, $\mathbf{W}_2$, the following two ways may be reasonable extension from SU-MIMO CDD.

1) $\mathbf{W}_1$ cycles among the last four precoders of the codebook specified in SU-MIMO CDD (refer to [9] for detail), while $\mathbf{W}_2$ is randomly selected from the codebook. $\mathbf{W}_1$, $\mathbf{W}_2$ are both chosen on a per RB basis.
2) Both $\mathbf{W}_1$ and $\mathbf{W}_2$ cycle among the four precoders specified in SU-MIMO CDD, but on a per RB basis. The cycling assignments of $\mathbf{W}_1$ and $\mathbf{W}_2$ conform to a pre-defined rule.

For both of the above $\mathbf{W}_i$ choosing schemes, we let $\mathbf{W}_1$ cycle among RB or RB bundling. Assuming TP1 as the serving cell, it actually works in a similar way as SU-MIMO CDD, but on a per RB basis. This makes the serving cell be able to support DM-RS based SU-MIMO open-loop spatial multiplexing [11], which can serve as a fallback mode for CoMP open-loop spatial multiplexing. As for $\mathbf{W}_2$, it is hard for TP2 to choose a suitable precoder to perform cooperation in open-loop. In 1), $\mathbf{W}_2$ is just randomly chosen, while in 2), we let $\mathbf{W}_1$, $\mathbf{W}_2$ fulfill cooperation by following some pre-defined rules. Later simulations show that 2) is not necessarily better than 1) due to the difficulty of making these rules.

No matter which way $\mathbf{W}_1$ and $\mathbf{W}_2$ are determined, UE will obtain $\mathbf{H}_1\mathbf{W}_1 + \mathbf{H}_2\mathbf{W}_2$ based on DM-RS estimation. Besides, $\mathbf{U}$, $\mathbf{D}$ cycling rule is known on both sides in advance. Therefore, UE can get the equivalent channel $\mathbf{H}_e = \left(\mathbf{H}_1\mathbf{W}_1 + \mathbf{H}_2\mathbf{W}_2\right)\mathbf{DU}$ for each RE. Then UE can use $\mathbf{H}_e$ to construct any type of MIMO receiver to detect the transmitted signal $\mathbf{x}$. For example, the minimum mean square error

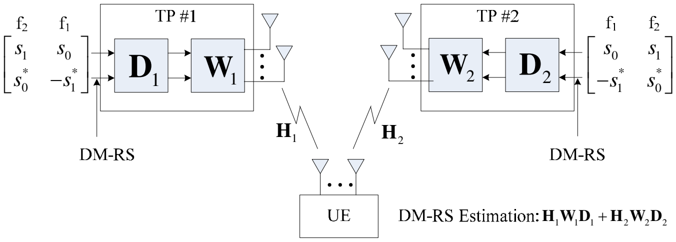

Fig. 2. General framework for CoMP transmit diversity.

(MMSE) receiver can be written as

$$\mathbf{R}^H = \left(\mathbf{H}_e^H \mathbf{H}_e + \sigma^2 \mathbf{I}\right)^{-1} \mathbf{H}_e^H, \tag{3}$$

where σ^2 denotes the variance of noise.

III. CoMP TRANSMIT DIVERSITY

For open-loop CoMP, spatial multiplexing has been discussed in the previous section. In this section, we first briefly review SU-MIMO SFBC transmission, and then introduce our proposed CoMP transmit diversity framework.

A. SU-MIMO SFBC

Taking a 2×2 SU-MIMO system as an example, SFBC transmission is implemented by sending the following code:

$$\mathbf{x} = \begin{bmatrix} s_0 & s_1 \\ -s_1^* & s_0^* \end{bmatrix} = \begin{bmatrix} \mathbf{x}_1 & \mathbf{x}_2 \end{bmatrix}, \tag{4}$$

where the two column vectors $\mathbf{x}_1$ and $\mathbf{x}_2$ denote the transmitted vector signals on subcarriers f_1 and f_2 respectively. Correspondingly, UE will receive signals on both subcarriers f_1 and f_2, and then jointly combines them to recover desired scalar signals s_0, s_1 [10].

B. SFBC based CoMP transmit diversity

In this subsection, we propose our CoMP SFBC transmission schemes while taking DM-RS demodulation into consideration. Fig. 2 gives the general framework for our proposed CoMP transmit diversity by taking an two-TP case as an example. In Fig. 2, both TPs (each with N_t antennas) transmit the same SFBC code to UE (with N_r antennas). SFBC block goes through the frequency dependent diagonal 2×2 matrix $\mathbf{D}_1$ ($\mathbf{D}_2$) to gain possible frequency diversity and coherent combination, and then gets mapped onto antenna ports by $N_t \times 2$ precoder $\mathbf{W}_1$ ($\mathbf{W}_2$). To support DM-RS demodulation, $\mathbf{D}_i$, $\mathbf{W}_i$ ($i = 1, 2$) should be tuned on a per RB basis, i.e, all the SFBC symbols in one RB (or RB bundling) share the same $\mathbf{D}_i$, $\mathbf{W}_i$. Therefore, DM-RS is positioned ahead of $\mathbf{D}_i$. Denoting the UE received vector signals on subcarrier f_1, f_2 as $\mathbf{y}_1$, $\mathbf{y}_2$ respectively, we have

$$\mathbf{y}_1 = \left(\mathbf{H}_1\mathbf{W}_1\mathbf{D}_1 + \mathbf{H}_2\mathbf{W}_2\mathbf{D}_2\right)\mathbf{x}_1 + \mathbf{n}_1, \tag{5}$$

$$\mathbf{y}_2 = \left(\mathbf{H}_1\mathbf{W}_1\mathbf{D}_1 + \mathbf{H}_2\mathbf{W}_2\mathbf{D}_2\right)\mathbf{x}_2 + \mathbf{n}_2, \tag{6}$$

where $\mathbf{x}_1$, $\mathbf{x}_2$ are given in (4), $\mathbf{H}_i$ is defined as previously, and $\mathbf{n}_1$, $\mathbf{n}_2$ denote noise on f_1, f_2 respectively. $\mathbf{H}_i$ usually does not change much across adjacent subcarriers. Based on DM-RS, UE can obtain the following equivalent channel:

$$\mathbf{H}_e = \mathbf{H}_1\mathbf{W}_1\mathbf{D}_1 + \mathbf{H}_2\mathbf{W}_2\mathbf{D}_2 = \begin{bmatrix} \mathbf{h}_{e1} & \mathbf{h}_{e2} \end{bmatrix}, \tag{7}$$

where $\mathbf{h}_{e1}$, $\mathbf{h}_{e2}$ denote the two columns of $\mathbf{H}_e$. Then UE can recover scalar symbols s_0, s_1 as

$$\hat{s}_0 = \frac{1}{\|\mathbf{H}_e\|_F^2}\left(\mathbf{h}_{e1}{}^H \mathbf{y}_1 + \mathbf{h}_{e2}{}^T \mathbf{y}_2^*\right), \tag{8}$$

$$\hat{s}_1 = \frac{1}{\|\mathbf{H}_e\|_F^2}\left(-\mathbf{h}_{e2}{}^T \mathbf{y}_1^* + \mathbf{h}_{e1}{}^H \mathbf{y}_2\right). \tag{9}$$

According to [10], SNR for both s_0 and s_1 can be given by

$$\rho = \frac{\|\mathbf{H}_e\|_F^2 P}{\sigma^2}, \tag{10}$$

where P denotes the power of scalar symbol s_i, and σ^2 is the variance of noise. In the following, we propose possible schemes for selecting $\mathbf{W}_i$ or $\mathbf{D}_i$, while keeping maximizing SNR ρ in mind.

Fig. 2 gives the general framework, but not all the $\mathbf{W}_i$, $\mathbf{D}_i$ components are indispensable. For example, we will conceive our first scheme by discarding $\mathbf{D}_i$. It can be seen from equation (10) that SNR depends on $\|\mathbf{H}_e\|_F^2$, which can be rewritten as

$$\|\mathbf{H}_e\|_F^2 = \|\mathbf{H}_1\mathbf{W}_1 + \mathbf{H}_2\mathbf{W}_2\|_F^2 = \|\mathbf{H}\mathbf{W}\|_F^2 \tag{11}$$

when $\mathbf{D}_i$ is discarded, where $\mathbf{H} = \begin{bmatrix} \mathbf{H}_1 & \mathbf{H}_2 \end{bmatrix}$ denotes the composite channel, and $\mathbf{W} = \begin{bmatrix} \mathbf{W}_1^H & \mathbf{W}_2^H \end{bmatrix}^H$ is the composite precoding matrix. In open-loop, TP is responsible for assigning suitable $\mathbf{W}_i$. To maximize (11), TP can treat $\mathbf{W}$ as a whole, and chooses $\mathbf{W}$ from the codebook on a per RB basis. This makes sense since the codebook is designed to maximize $\|\mathbf{H}\mathbf{W}\|_F^2$ to some extent. Having $\mathbf{W}$, each TP can get $\mathbf{W}_i$ correspondingly. Also, another scheme can be obtained by letting each TP choose $\mathbf{W}_i$ from the codebook by himself. To cope with the situation where antennas are geographically separated in CoMP, a frequency dependent matrix $\mathbf{D}_i$ can be applied to one TP to make some phase adjustment. Similarly, $\mathbf{W}_i$ can also be discarded, leaving only frequency dependent $\mathbf{D}_i$ matrix used at each TP. This aims to seek possible coherent combination at UE, and exploits frequency selectivity gain. Above all, the three specific CoMP transmit diversity schemes are summarized as follows:

1) No $\mathbf{D}_i$ matrices are used. $\mathbf{W}$ is cyclically assigned from the corresponding codebook on a per RB basis. The signal received at UE can be expressed as

$$\mathbf{y}_i = \left(\mathbf{H}_1\mathbf{W}_1 + \mathbf{H}_2\mathbf{W}_2\right)\mathbf{x}_i + \mathbf{n}_i. \tag{12}$$

2) $\mathbf{W}_1$ is randomly chosen from the codebook on a per RB basis, and so is $\mathbf{W}_2$. $\mathbf{D}_2$ is a frequency (RB) dependent diagonal matrix used by TP2, and has the form of

$$\mathbf{D}_2 = \begin{bmatrix} e^{j\phi_1 k} & 0 \\ 0 & e^{j\phi_2 k} \end{bmatrix}, \tag{13}$$

where k is the RB index, and ϕ_i is the pre-defined parameter. The signal received at UE is given by

$$\mathbf{y}_i = \left(\mathbf{H}_1\mathbf{W}_1 + \mathbf{H}_2\mathbf{W}_2\mathbf{D}_2\right)\mathbf{x}_i + \mathbf{n}_i. \tag{14}$$

3) No $\mathbf{W}$ is used. $\mathbf{D}_2$ is used at TP2, and has the same form as (13). The signal received at UE is written as

$$\mathbf{y}_i = (\mathbf{H}_1 + \mathbf{H}_2\mathbf{D}_2)\,\mathbf{x}_i + \mathbf{n}_i. \tag{15}$$

It is worth noting that both $\mathbf{W}_i$ and $\mathbf{D}_i$ should be adjusted from RB to RB, or from RB bundling to RB bundling to support DM-RS demodulation. Then UE can perform demodulation according to (7)-(9).

IV. Simulation Results

In this section, we give link level simulation results for both CoMP open-loop spatial multiplexing and CoMP transmit diversity. Simulation conforms to general LTE downlink structures, where data on each antenna port are transformed into OFDM symbols to get transmitted. Throughout this section, system bandwidth is assumed to be 10MHz, FFT size is 1024, and transmission time interval (TTI) is set to 1 ms. Besides, physical downlink shared channel (PDSCH) data are transmitted over 6 RBs out of a total of 50 RBs, and RE mapping considers one common reference signal (CRS) and two DM-RS overhead for each RB. Turbo coding (1/3 coding rate) is used and we use block error rate (BLER) as performance evaluation.

In Fig. 3, BLER curves are given for different CoMP open-loop spatial multiplexing schemes. We assume two TPs each with 4 Tx antennas and one UE with 2 Rx antennas. The path loss difference between these two TPs is assumed to be 6 dB. ETU channel with medium correlation is applied, and UE speed is 30km/h. Rank indicator (RI) is set to 2, and modulation and coding scheme (MCS) index is 2. MMSE receiver is used at UE. Four CoMP spatial multiplexing schemes are compared as follows:

- Scheme 1: $\mathbf{W}_1$ cycles among the last four precoders from the 4-antenna 2-layer codebook, $\mathbf{W}_2$ is randomly chosen from this codebook. Neither $\mathbf{D}$ nor $\mathbf{U}$ matrix is applied.
- Scheme 2: $\mathbf{W}_1$ cycles and $\mathbf{W}_2$ is randomly chosen just as Scheme 1, but with $\mathbf{D}, \mathbf{U}$ matrices applied.
- Scheme 3: $\mathbf{W}_1$ cycles as Scheme 1, $\mathbf{W}_2$ cycles in the same way as $\mathbf{W}_1$, i.e. $\mathbf{W}_2 = \mathbf{W}_1$ always holds. $\mathbf{D}, \mathbf{U}$ matrices are applied.
- Scheme 4: $\mathbf{W}_1$ cycles as Scheme 1, $\mathbf{W}_2$ cycles in reverse order with $\mathbf{W}_1$, e.g., if $\mathbf{W}_1$ chooses $\mathbf{W}(1)$, $\mathbf{W}(2)$, $\mathbf{W}(3)$, $\mathbf{W}(4)$, then $\mathbf{W}_2$ chooses $\mathbf{W}(4)$, $\mathbf{W}(3)$, $\mathbf{W}(2)$, $\mathbf{W}(1)$ accordingly. Also $\mathbf{D}, \mathbf{U}$ matrices are applied.

Among the above four schemes, $\mathbf{W}_1$, $\mathbf{W}_2$ are adjusted from RB to RB to support DM-RS demodulation, while $\mathbf{D}, \mathbf{U}$ are tuned from RE to RE to exploit frequency selectivity. Scheme 1 is a direct way to perform CoMP open-loop spatial multiplexing, and thus can serve as a baseline. Scheme 2 is equivalent to method 1) in Section II B, while Scheme 3 and 4 are both special cases of method 2) in Section II B where cycling follows different pre-defined rules. From Fig. 3, it firstly can be seen that Scheme 1 cannot compete with the other $\mathbf{D}, \mathbf{U}$ applied schemes. Hence it is necessary to keep $\mathbf{D}, \mathbf{U}$ in open-loop CoMP structures to gain from frequency selectivity. Secondly, among schemes 2-4 which all have $\mathbf{D}, \mathbf{U}$

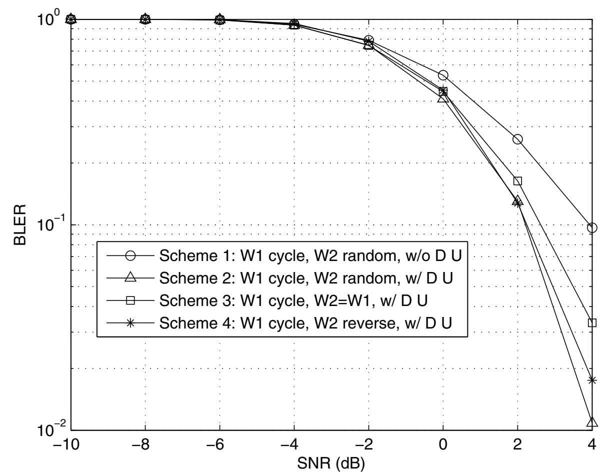

Fig. 3. BLER for different CoMP spatial multiplexing schemes, ETU medium correlation channel, 6dB path loss difference, UE speed 30km/h, RI = 2, MCS index = 2.

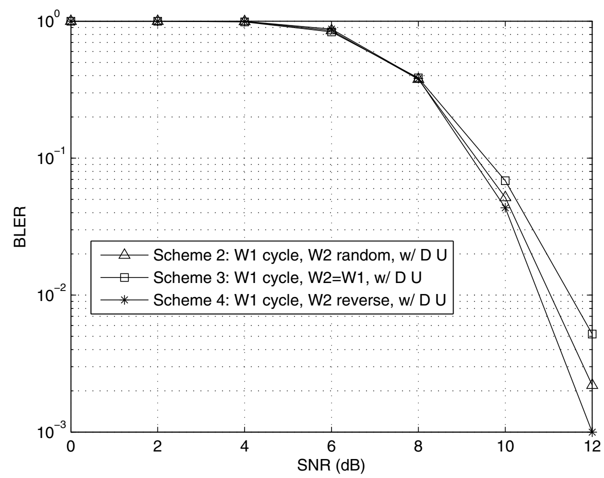

Fig. 4. BLER for different CoMP spatial multiplexing schemes, ETU low correlation channel, 6dB path loss difference, UE speed 30km/h, RI = 2, MCS index = 10.

applied, we see that Scheme 2 (chosen randomly) performs better than schemes 3 and 4 (following rules). However, in another simulation scenario where low correlation ETU channel is applied, and MCS index is set to 10, Scheme 2 performs better than Scheme 3, but worse than Scheme 4 as shown in the SNR region of Fig. 4. From figures 3, 4, we can see that following certain pre-defined rules does not necessarily perform better than the randomly chosen case. Therefore, the randomly chosen method (Scheme 2) may serve as a benchmark for $\mathbf{D}, \mathbf{U}$ applied schemes. For any further performance improvement, the pre-defined rules must be designed appropriately, which are also our future work. As for the intuitive ones with the same cycling order (Scheme 3) or reverse cycling order (Scheme 4), they seem not to be effective enough.

Fig. 5 gives BLER performance for different CoMP transmit diversity schemes. We assume that each TP deploys 2 Tx antennas, path loss difference is 10 dB, and RI is set to 1. The other parameters are the same as that of Fig. 3. SFBC is used for transmit diversity, and UE recovers signals according to (8) (9). The following five schemes are compared:

- Scheme 1: Scheme 1) in Section III B, where $\mathbf{W}$ is cyclically selected from the last four precoders of the 4-antenna 2-layer codebook.
- Scheme 2: Scheme 2) in Section III B. As previously observed, imposing rules upon $\mathbf{W}_i$ selection is not necessarily effective, here we only choose $\mathbf{W}_i$ randomly from the 2-antenna 2-layer codebook.
- Scheme 3: Scheme 3) in Section III B.
- Scheme 4: Extension from LTE SU-MIMO 4 Tx transmit diversity to CoMP, i.e., combination of SFBC and frequency switched transmit diversity (FSTD).
- Scheme 5: Each TP transmits the same SFBC symbols without using $\mathbf{D}_i$ and $\mathbf{W}_i$.

For the above five schemes, $\mathbf{W}_i$ $(\mathbf{W})$, $\mathbf{D}_i$ are both adjusted from RB to RB to support DM-RS demodulation, and $\mathbf{D}_2$ in (13) is set to $\mathbf{D}_2 = \begin{bmatrix} e^{j\pi k} & 0; 0 & e^{j\pi k} \end{bmatrix}$ in simulations. Schemes 1-3 have been introduced in Section III B. Scheme 4 is obtained by treating the two TPs together as one 4-antenna transmitter, and reusing SU-MIMO 4 Tx transmit diversity while considering DM-RS demodulation. Actually, Scheme 4 can be equivalently obtained by letting $\mathbf{W}^{(i)} = \begin{bmatrix} 1 & 0; 0 & 0; 0 & 1; 0 & 0 \end{bmatrix}$, $\mathbf{W}^{(i+1)} = \begin{bmatrix} 0 & 0; 1 & 0; 0 & 0; 0 & 1 \end{bmatrix}$ and not using $\mathbf{D}_i$ in Fig. 2 framework, where i and $i+1$ index two consecutive RBs. Scheme 5 is the simplest way to implement CoMP SFBC transmission, where the same SFBC codes are transmitted directly from two TPs without any rotation/mapping optimization. From Fig. 5, it can be observed that Scheme 3 always has the best BLER performance, while Scheme 2 performs second-best. This is encouraging since Scheme 3 will be both simple (only $\mathbf{D}_2$ applied) and effective. Scheme 2 may get improved by making suitable rules for choosing $\mathbf{W}_i$, $\mathbf{D}_i$ matrices. As for Scheme 1, it performs even worse than Scheme 5 in low SNR regime, while gets better for relatively high SNR. This is due to the reason that the codebook which is originally designed for co-located antennas does not adapt to the separated-antenna situation in CoMP. Maybe this problem will get relieved and Scheme 1 still performs effectively if new codebook for separated antennas is introduced in future standards. Scheme 5 is not as good as Scheme 2, 3 which have been optimized to some extent by using $\mathbf{W}_i$ or $\mathbf{D}_i$. Although Scheme 4 is competitive for SU-MIMO, it does not perform well for the large path loss difference case (10 dB here) in CoMP.

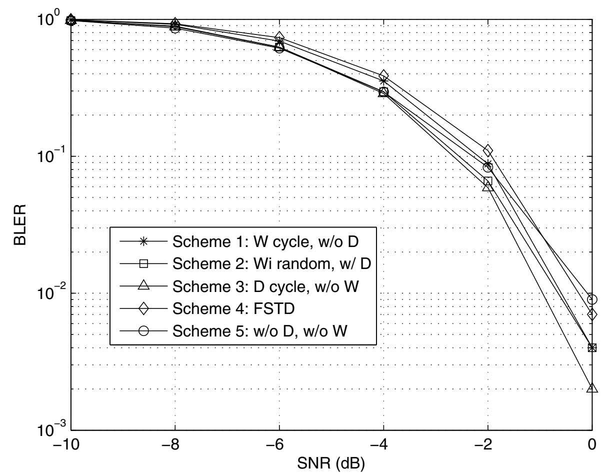

Fig. 5. BLER for different CoMP transmit diversity schemes, ETU medium correlation channel, 10dB path loss difference, UE speed 30km/h, RI = 1, MCS index = 2.

V. Conclusion

In this paper, we propose possible open-loop CoMP frameworks for LTE-A systems, while especially taking support for DM-RS into consideration. Both CoMP open-loop spatial multiplexing and CoMP transmit diversity schemes are proposed, where DM-RS are appropriately positioned and precoders/phase rotation matrices are assigned on a per RB basis to support DM-RS demodulation. Simulations provide BLER performance comparison for our proposed schemes, and also show that our schemes generally achieve better performance than that of methods which are directly extended from open-loop SU-MIMO.

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