On Synchronization Requirements and Performance Limitations for CoMP Systems in Large Cells

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Abstract—We consider coordinated multi-point systems where multiple base stations apply a joint signal processing in the uplink and downlink. Large distances between the base stations result in unavoidable differences in time of arrival between the users’ signals which in turn lead to inter-symbol interference in OFDM systems if the cyclic prefix length is exceeded. Moreover, carrier frequency offsets which are caused by imperfect oscillators lead to inter-carrier interference and are in particular a problem in the downlink due to the feedback delay of the measured channel state information. In this paper we derive metrics for evaluating the impact of time and frequency asynchronisms in CoMP systems with large base station distances. We compare performance results for CoMP and single user transmission techniques in a selected transmission scenario where we use a 3GPP/LTE baseline system.

I. INTRODUCTION

In current standardization activities of 3GPP/LTE coordinated multi-point (CoMP) systems gain a lot of attention (see e.g. [1]) since they can significantly increase the spectral efficiency particularly at cell edges. One key technology of these systems is the usage of orthogonal frequency division multiple access (OFDMA) in conjunction with spatial multiplex schemes where geographically separated base stations (BS) and user terminals (UT) form a virtual multiple-input and multiple-output (MIMO) antenna array and transmit data on the same time and frequency resources. As the base stations are connected via backhaul, they can perform joint signal processing techniques in order to cancel the multi-user interference (MUI) (see e.g. [2]). The practicability of these system has been recently shown in the German research project EASY-C (see e.g. [3]).

The investigations so far have mainly focused on urban areas with small inter-site distances (ISD). In rural areas cell radii are typically large, i.e. the distances \(d\) between the users and base stations can differ significantly. If CoMP should be employed in those systems as well, the problem of unavoidable time differences of arrival (TDOA):

\[
\Delta t_d = (d_{\text{max}} - d_{\text{min}})/c
\]

occurs (\(c\) is used as speed of light here) which depend on the distance difference between the transmit and receiver stations (see e.g. [4]). As it is widely known, these TDOAs need to be within the inter-symbol interference (ISI) free range of the cyclic prefix (CP) that is used to avoid the coupling between consecutive OFDM symbols. Otherwise the orthogonality among the subcarriers is destroyed which leads to a coupling between adjacent subcarriers (see e.g. [5], [6], [7]). On the left side of Fig. 1 we show the maximum occurring TDOA in a downlink (DL) scenario with 3 time synchronized cooperating BSs in a deployment with an ISD of 5000m.

Another effect that needs to be considered in CoMP systems is the carrier frequency offset (CFO) between different transmit stations due to imperfect local oscillators. The effect of frequency asychronisms is similar to that of timing mismatches. Thus in this case inter-carrier interference (ICI) occurs as well. This is in particular a problem in DL CoMP, since the channel changes within the feedback delay time between the DL channel measurement at the UTs and the precoding filter computation at the BSs (see e.g. [8]). However, with larger distance differences between the transmitters, the link separation:

\[
\Delta \psi_d = (d_{\text{max}}/d_{\text{min}})^\eta
\]

which is the ratio between the maximum and minimum signal power at one antenna element, also increases such that the desired signal portions as well as the asynchronous interference are decoupled between the transmitters (\(\eta\) denotes the pathloss exponent here). The maximum occurring link separation for a rural non-line-of-sight scenario is shown on the right side of Fig. 1.

![Fig. 1: Maximum TDOA (left) and link separation (right) for downlink CoMP with 3 cooperating base stations](image-url)

The goal of this paper is to derive convenient metrics that can be used for approximating the impact of time and frequency asynchronisms on the CoMP system performance as well as to derive synchronization requirements for the parameter design in cooperating base station systems. Furthermore a performance comparison in terms of the spectral efficiency...
shall show whether a joint signal processing is beneficial in large cells with asynchronisms regarding to single user transmissions on orthogonal resources.

The paper is organized as follows: In section II we derive our underlying analytical system model which is then used in section III for a detailed analysis of the asynchronous interference power based on a deterministic transmission model. In section IV we present a framework for analyzing joint transmission systems with asynchronisms which is used for a numerical system performance analysis in a cellular downlink CoMP scenario. Section V summarizes the main results.

**Notation:** Boldface letters denote matrices and underlined letters vectors, respectively. We use \([\cdot]\) for indexing an element of a vector or matrix. Lowercase letters describe variables in the time domain and uppercase letters variables in frequency domain, respectively. \((\cdot)^H\) is used as conjugate transpose operator. The operator \(E(\cdot)\) expresses the expectation value.

### II. Analytical System Model

Throughout the paper we basically assume a system with \(K\) transmitters, each equipped with one transmit antenna, and \(M\) receiver stations, each equipped with one receive antenna. For the data transmission over the air channel we use the OFDMA modulation with a DFT size of \(Q\). The usage of a cyclic prefix of length \(N_{CP}\) in OFDMA leads to a decoupling of the ISI channel in time domain to separate flat channels in frequency domain if the channel decay is within the cyclic prefix and the coherence bandwidth is larger than subcarrier bandwidth.

Under these assumptions we can use the linear transmission model in the \(o\)-th OFDM symbol on the \(q\)-th subcarrier with:

\[
Y_{o,q} = H_{o,q} \sqrt{P}_{o,q} X_{o,q} + V_{o,q}
\]

where the transmit symbol vector is defined as \(X_{o,q} \in \mathbb{C}^{K \times 1}\) and \(Y_{o,q} \in \mathbb{C}^{M \times 1}\), respectively. \(V\) represents the AWGN with \(V \sim \mathcal{N}(0, \sigma_v^2)\). The coefficients of the channel matrices \(H_{o,q}\) are the Fourier transform of the link specific discrete channel impulse responses \(h\) of length \(L\). Each element \(h_i\) of \(h\) is modeled as \(h_i[\lambda] \sim \mathcal{N}(0, \sigma^2_{h[\lambda]})\) where \(\sigma^2_{h[\lambda]}\) is the corresponding channel tap power given by the power delay profile. The matrix \(P\) is a diagonal power scaling matrix in order to adjust the power of the transmit symbols according to a target value.

As already mentioned, in our work we want to investigate the impact of distance dependent path delays \(\tau_{d}^{m,k} = \tau_{d}^{m,k}/\epsilon\), CFOs \(f_{C}^{m,k} = f_{C,k} - f_{C,m}\) as well as a distance dependent pathlosses \(\psi_{d}^{m,k}\) between the \(k\)-th transmit and the \(m\)-th receiver station. Although we always assume that synchronization procedures are used in order to compensate \(\tau_{d}^{m,k}\) and \(f_{C}^{m,k}\) as well as power control techniques to compensate \(\psi_{d}^{m,k}\), in CoMP systems each transmitter is only able to be aligned to one receiver. This leads to the introduced TDOAs \(\Delta_{d}^{m,k} = \tau_{d}^{m,k} - \tau_{d}^{m,k}\), link separations \(\Delta_{p}^{m,k} = \psi_{d}^{m,k}/\max\{\psi_{d}^{m,k}\}\), and frequency mismatches \(\Delta_{f}^{m,k} = f_{C}^{m,k} - \max\{f_{C}^{m,k}\}\). For more general statements we use the normalized frequency mismatch \(\Delta_{e}^{m,k} = \Delta_{f}^{m,k}/B_{SC}\) in the following, where \(B_{SC}\) denotes the subcarrier bandwidth. If the discrete symbol timing offset (STO) \(\Delta_{S}^{m,k} = (\Delta_{f}^{m,k}/T_{S})\) sampled w.r.t the symbol time \(T_{S}\) is larger than \(N_{CP} - L\) or the frequency mismatch \(\Delta_{e}^{m,k}\) is larger than zero, the decoupled linear transmission model for one subcarrier in Eq. (3) does not hold anymore.

As we have shown in [5], the time and frequency asynchronisms lead to a coupling of adjacent subcarriers and consecutive OFDM symbols. If we define \(Z_{o,q} = f(\Delta_{S}^{m,k}, \Delta_{e}^{m,k}, \Delta_{p}^{m,k}, q^{m,k}, Q, N_{CP})\) as the representation of the interference channel we can reformulate Eq. (3) to:

\[
Y_{o,q} = Z_{o,q} \sqrt{P}_{o,q} X_{o,q} + \sum_{v \in Q \setminus q} Z_{o,v} \sqrt{P}_{o,v} X_{o,v} + V_{o,q}
\]

\[
Y_{o,q} = Z_{o,q} \sqrt{P}_{o,q} X_{o,q} + \sum_{v \in Q \setminus q} Z_{o,v} \sqrt{P}_{o,v} X_{o,v} + V_{o,q}
\]

where the adjacent subcarriers are denoted by the index \(l\), and \(o-1\) indicates a previous OFDM symbol. The asynchronism interference part can be condensed to \(U_{o,q}\) in order to focus on the original filter problem by estimating \(X_{o,q}\) using the observations \(Y_{o,q}\).

### III. Asynchronous Interference Power Analysis

If we take Eq. (4) and consider only flat channels we can calculate the mean receive symbol power at the \(m\)-th receive antenna averaged over transmit data, noise as well as channel realizations by:

\[
\sigma^{2}_{Y,m} = \mathbb{E}\left\{Y_{o,q}^{m} Y_{o,q}^{mH}\right\} = \left|E_{o,q}^{m,k}\right|^{2} \psi_{d}^{m,k} + \sum_{i=1}^{K} \left|E_{o,q}^{i,m}\right|^{2} \psi_{d}^{i,m} + \sum_{i=1}^{K} \left|E_{o-1,l}^{i,m}\right|^{2} \psi_{d}^{i,m} + \sigma^{2}_{V}
\]

where we assume \(\mathbb{E}\left\{X_{o,q}^{mH} X_{o,q}\right\} = 1\), \(\mathbb{E}\left\{H_{o,q}^{H} H_{o,q}\right\} = 1\) and \(\mathbb{E}\left\{V_{o,q} V_{o,q}^{H}\right\} = \sigma^{2}_{V}\). The values \(\left|E_{o,q}^{m,k}\right|^{2}\) represent the coupling power between adjacent subcarriers and OFDM symbols and are given by (see [5] for more details):

\[
\left|E_{o,q}^{m,k}\right|^{2} = \begin{cases} \left(\frac{Q}{\sigma^{2}_{v}}\right)^{2} \frac{1}{\sin^{2}\left(\frac{\pi \kappa m,k}{Q}\right)} \rho_{m,k}^{m,k} = 0, \\ \left(\frac{Q}{\sigma^{2}_{v}}\right)^{2} \frac{1}{\sin^{2}\left(\frac{\pi \kappa m,k}{Q}\right)} \rho_{m,k}^{m,k} > 0. \end{cases}
\]

\[
\left|E_{o-1,l}^{m,k}\right|^{2} = \begin{cases} \left(\frac{Q}{\sigma^{2}_{v}}\right)^{2} \frac{1}{\sin^{2}\left(\frac{\pi \kappa m,k}{Q}\right)} \rho_{m,k}^{m,k} = 0, \\ \left(\frac{Q}{\sigma^{2}_{v}}\right)^{2} \frac{1}{\sin^{2}\left(\frac{\pi \kappa m,k}{Q}\right)} \rho_{m,k}^{m,k} > 0. \end{cases}
\]
with \( \kappa^{m,k} = \Delta \epsilon^{m,k} + \frac{l - q}{l} \forall l \neq l\ldots Q \) and \( N_B = Q + N_{CP} \).

The values \( a^{m,k} \) and \( b^{m,k} \) are defined as:

\[
\{a^{m,k}, b^{m,k}\} = \begin{cases} \{N_B - \Delta \mu^{m,k}, \Delta \mu^{m,k} - N_{CP}\} & \Delta \mu^{m,k} > N_{CP} \\ Q & \text{otherwise} \end{cases}
\]

The loss of available signal power over time for one subcarrier can be obtained by:

\[
\left(\frac{E_{m,k}^m}{E_{m,k}^o}\right)^H E_{m,k}^o \left(\frac{E_{m,k}^m}{E_{m,k}^o}\right) = \frac{a^{m,k}}{b^{m,k}}
\]

The signal to asynchronous interference plus noise ratio (SINR) for the link between one transmitter \( k \) and one receiver \( m \) on the \( q \)-th subcarrier is given as:

\[
\text{SINR}^m q = \frac{\left| E_{o,q}^{m,k} \right|^2 \frac{\psi_{o,q}^k}{\psi_{m,k}^q}}{\frac{Q}{Q} \sum_{\forall l \neq q} \left( \left| E_{o,q}^{m,l} \right|^2 + \sum_{\forall l \neq q} \left| E_{o,q}^{m,l} \right|^2 \right) + \sigma^2}
\]

\[
= \frac{\frac{Q}{Q} \sin^2 \left( \frac{\pi \epsilon^{m,k}}{Q} \right)}{\sin^2 \left( \frac{\pi \epsilon^{m,k} + \Delta \epsilon^{m,k}}{Q} \right)} \left( 1 + \sigma^2 \frac{\psi_{m,k}^q}{\psi_{o,q}^k} \right) - 1
\]

where we exploited the relation that the asynchronous interference power for one link can be obtained as:

\[
\sigma_{\Delta m,k}^2 \sum_{\forall l \neq q} \left| E_{o,q}^{m,l} \right|^2 + \sum_{\forall l \neq q} \left| E_{o,q}^{m,l} \right|^2 = 1 - \frac{1}{Q^2} \sin^2 \left( \frac{\pi \epsilon^{m,k} + \Delta \epsilon^{m,k}}{Q} \right)
\]

If we consider a CoMP system where transmitters allocate the same time and frequency resource and furthermore assume that the \( k \)-th transmitter is aligned to the \( n \)-th receiver, the link SINR changes to:

\[
\text{SINR}^n q = \frac{1}{\left( \frac{Q}{Q} \sin^2 \left( \frac{\pi \epsilon^{m,k}}{Q} \right) \right)} \left( 1 + \sigma^2 \frac{\psi_{m,k}^q}{\psi_{o,q}^{m,k}} \right) - 1
\]

where we expect that the underlying distance dependent pathloss model is equal for each link.

The data symbols on the desired \( q \)-th subcarrier are also attenuated since the available signal power is spread over frequency and time. In the considered CoMP case this leads to a decoupling between the transmitters so that the entries of the channel matrix \( \mathbf{Z}_{o,q} \) in Eq. (4) do not have equal power anymore. In Eq. (2) we defined the link separation factor as the ratio between the maximum and minimum available signal power that shall give us a metric to assess how large the decoupling between the transmitters at one receive antenna is. We can define a similar metric as the ratio between the link SINR of the synchronized link \( m, i \) which is equal to \( 1/\sigma_V^2 \) and the SINR of the asynchronous link \( m, k \) which leads to the expression:

\[
\Delta \psi_q = \frac{\text{SINR}^m q}{ \text{SINR}^m i} = \frac{Q^2 \sin^2 \left( \frac{\pi \epsilon^{m,k}}{Q} \right)}{\sin^2 \left( \frac{\pi \epsilon^{m,k} + \Delta \epsilon^{m,k}}{Q} \right)} \left( 1 + \frac{\left( d_{m,k}^{\mu} \right)^2}{\left( d_{m,i}^{\mu} \right)^2} \right) - 1
\]

That ratio now gives us the relation between the noise power, the pathloss and the impact of the asynchronous interference. If we take a closer look into that equation we can derive some interesting properties. In the case of small time and frequency mismatches that expression tends to Eq. (2). If the impact of the asynchronous interference becomes larger we can see that the decoupling ratio then depends on the noise power as well as the pathloss dependent link separation.

In Fig. 2 we evaluated the expressions (10), (11), and (12) for a symmetric CoMP scenario with three users and three base stations, where the users move from the cell corner directly to their serving base stations. We used an ISD of 5000m again such that the occurring TDOAs and separation factors are comparable with Fig. 1. The diameter of the cell which is served by one base station is defined as \( D = ISD/\sqrt{3} \). The distance from the cell corner to the user positions is given by \( d_C \), so that the distance of the direct link can be calculated by \( d_1 = D - d_C \) and the two indirect links to the non serving base stations with \( d_2 = (D^2 + d_C D + d_C^2)^{1/2} \). For a given \( \Delta \mu \) the distance to the cell corner can be determined with \( d_C = (\Delta d + 2D)/(3D/\Delta d + 2) \) and \( \Delta d = \Delta \mu T_S \). The pathloss dependent link separation factor can then be obtained by \( \Delta \psi_d = (d_2/d_1)^\kappa \).

In Fig. 2a we depict the impact of different TDOAs and CFOs to the asynchronous interference power. An important observation is that the asynchronous interference only becomes
critical in high SNR regions. The peak of the maximum interference can be determined at \( \approx 15\text{dB} \). Until the cyclic prefix limit is exceeded we only see the effect of the CFO. Afterwards the combined effect of the STO as well as the CFO can be observed, but as it can be recognized the dominating distortion is caused by the STO. Since the CFO is usually smaller than 2-3% of the subcarrier bandwidth we can derive that this will not degrade the CoMP performance severely. With increasing \( \Delta \mu \) the link separation also increases which leads to an attenuation of \( \sigma_f^{\text{in},k} \). But also the usable signal power decreases which is shown in Fig. 2b for different pathloss exponents \( \eta \). The resulting extended link separation is depicted in Fig. 2c for different noise power values. As we already observed in Fig. 2a, in low SNR regions the pathloss dependent link separation is dominating while at higher SNR the links get decoupled faster since the usable signal power from the interferers is attenuated additionally through the asynchronisms.

IV. NUMERICAL SIMULATION RESULTS FOR A DOWNLINK JOINT TRANSMISSION SETUP

In section III we did not consider any signal processing at the transmitter or receiver side that aims to cancel the multi user interference as well as the asynchronous interference. If we assume a signal transmission with a precoding filter \( W_{a,q} \in \mathbb{C}^{M \times K} \) and a equalizing filter \( G_{a,q} \in \mathbb{C}^{K \times M} \) at the receiver side we can rewrite Eq. (4) to:

\[
\hat{X}_{a,q} = G_{a,q} Z_{a,q} \hat{X}_{a,q} + G_{a,q} \left( \sum_{l \in Q} Z_{a-1,l} \hat{X}_{a-1,l} + Y_{a,q} \right)
\]

(13)

where the transmit symbols are now given by \( \hat{X} = W_{a,q} V P_{a,q} \hat{X}_{a,q} \). The covariance matrix of the observations can be stated as:

\[
\Phi_{YY} = \mathbb{E} \{ Y Y^H \} = Z W P W^H Z^H + \Phi_{UU} + \Phi_{VV} \]

(14)

were we assume a unit symbol power with \( \Phi_{xx} = \text{I} \) again. For the sake of simplicity the indices \( a,q \) will omitted from now. The asynchronous interference power \( \Phi_{uu} \) can be calculated with:

\[
\Phi_{UU} = \mathbb{E} \{ U U^H \} = \sum_{l \in \mathcal{Q} \setminus q} Z_{a,l} W_{a,l} P_{a,l} W_{a,l}^H Z_{a,l}^H + \sum_{l \in \mathcal{Q}} Z_{a-1,l} W_{a-1,l} P_{a-1,l} W_{a-1,l}^H Z_{a-1,l}^H
\]

(15)

and depends on the precoding filters of the adjacent subcarriers as well. Eq. (13) can be used to derive some general expressions for the used filters. In a CoMP system usually the users can not cooperate so that in the uplink case the precoder is set to \( W = \text{I} \) and in the downlink case the equalizer is set to \( G = \text{I} \). An expression for the interference aware uplink joint detection filter is already given in [9]. We want to concentrate on downlink joint transmission in this paper. The asynchronous interference aware precoding filter that solves the mean squared error condition:

\[
W = \arg \min_{\{W_{\beta}\}} \left\{ \mathbb{E} \left\{ \|X - \hat{X} \|^2 \right\} \mid \mathbb{E} \left\{ \|W \sqrt{\sum_{k} F_k} \|^2 \right\} = P_{\text{max}} \right\}
\]

can be stated as (see e.g. [10]):

\[
W_{WF} = Z^H \left( Z Z^H + \frac{\text{tr}(\Phi_{VV} + \Phi_{uu})}{P_{\text{max}}} \text{I}_K \right)^{-1} \Phi_{VV}
\]

(16)

\[
\beta_{WF} = \sqrt{\frac{P_{\text{max}}}{\text{tr}\left( (Z Z^H + \Phi_{VV}^{-2} Z Z^H) \right)}}
\]

(17)

We introduced a sum power constraint \( P_{\text{max}} \) here such that the transmit power scaling matrix is given as \( \sqrt{P} = \beta \text{I} \). This scaling needs to be reversed at the receiver side by setting \( G = \beta^{-1} \text{I} \). The SINR for the \( k \)-th user stream on the \( q \)-th subcarrier at the receiver can be expressed by:

\[
\text{SINR}_q^k = \frac{\left( Z_k^k \right)^H W^H \left( W_k^k \right)^H Z_k^k}{\sum_{k=1}^K \left( Z_k^k \right)^H W^H \left( W_k^k \right)^H Z_k^k + \sigma_f^2 + \sigma_e^2}
\]

(18)

where \( W_k^k \) is the \( k \)-th column of \( W \) and \( Z_k^k \) is the \( k \)-th column of \( Z = Z^H \). The asynchronous interference power part \( \sigma_e^2 \) can be then obtained by:

\[
\sigma_e^2 = \sum_{q \in \mathcal{D} \setminus l} (Z_{a,q})^H W_{a,q} P_{a,q} W_{a,q}^H Z_{a,q}^H + \sum_{q \in \mathcal{D}} (Z_{a-1,q}^k)^H W_{a-1,q}^H W_{a-1,q}^H Z_{a-1,q}^k
\]

(19)

The SINR expression of Eq. (18) is now used for evaluating the downlink joint transmission performance on system level. Therefore we selected a cellular transmission scenario where three users are locally grouped and three cooperating base stations form a cluster for joint signal processing. In an rural area such an scenario could occur if CoMP shall be used to provide users in a small village with a larger data rate without increasing the number of existing base stations.

The baseline in terms of large and small fading channel parameters as well as the OFDM transmission setup is taken from the current 3GPP/LTE standard (see e.g. [1]). We used the rural macro pathloss model with an antenna pattern here in order to obtain the signal power levels at each point of the investigated grid in the cellular system model. For each possible location of the receiver group we calculate the occurring TDOAs and separation factors where we assume that the base stations always transmit with full power and do not change their timing. The receivers can then only compensate the timing mismatches to the nearest base station. The TDOAs and link separations are used to generate the asynchronous
interference channel where we assume a flat channel model again to make the results comparable to those derived in section III. For one channel realization we calculated the precoding filters as well as the corresponding SINR values for each user stream. It is worth mentioning that we always assume that we have perfect channel knowledge and unlimited backhaul between the base stations here.

As evaluation metric we used the mean spectral efficiency which is calculated by:

$$\frac{C_{max}}{[\text{Bit/s/Hz}]} = \mathbb{E} \left\{ \sum_{k=1}^{K} \log_2 (1 + \text{SINR}_k) \right\} \frac{N_S N_{DFT}}{K (N_{DFT} + N_{CP})}$$

where we form the sum over all $K$ user SINRs at the receiver to get the maximum achievable spectral efficiency. In order to take the overhead between the lengths of one OFDM symbol and the cyclic prefix into account, the spectral efficiency is scaled respectively. $N_S$ denotes the number of spatial streams.

In Fig. 3 we show results for the described DL CoMP scenario for 1000 channel realizations. On the left side the asynchronous interference to noise power ratio $\frac{\sigma_k^2}{\sigma_r^2}$ is depicted. As expected, from the point where the CP limit is exceeded the asynchronous interference increases before it is attenuated due to the link separation. In the middle of Fig. 3 we see the gain of spectral efficiency between joint signal processing of three users on the same frequency resource ($N_S = 3$) and the single user transmission on orthogonal resources ($N_S = 1$). Except positions very close to the BSs, in the largest part of the cell area, a gain of joint signal processing is attained. On the right side of Fig. 3 we depicted the gain of spectral efficiency where we compared a transmission with a common short CP as defined by 3GPP/LTE and a CP length which is adapted to the cover the entire cell area. As one can observe in this scenario the loss of spectral efficiency due to the asynchronous interference is more severe than the loss due to the CP extension.

V. CONCLUSION

In this paper we presented metrics based on a deterministic transmission model that can be used for an approximation of the impact of asynchronisms in CoMP systems, namely symbol timing offsets as well as carrier frequency offsets. We have shown that the asynchronous interference only becomes critical in high SNR regions if the asynchronous interference power increases the noise power level. The extended link separation metric can be used to show how large two signals at one receive antenna are decoupled by their receive powers. Furthermore we presented an framework for simulating downlink joint transmission systems with asynchronous interference. We compared the system performance of a downlink CoMP setup with a single user transmission setup, as well as with a setup that used an extended cyclic prefix in order to avoid the asynchronous interference in terms of the maximum achievable spectral efficiency. We have shown that the gain of using CoMP in large cells compared to single user transmissions is larger than the degradation due to asynchronisms.

REFERENCES