Channel Inversion CoMP Technique in Cellular System: A User-Selection Algorithm

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***Abstract*—Network coordination techniques are very promising for improving spectral efficiency over conventional cellular networks limited by inter-cell interference. Thus, Coordinated MultiPoint (CoMP) transmission and reception techniques are under consideration for LTE-Advanced to meet 4G requirements. In this work, a coordination technique for inter-cell interference cancellation is evaluated over a packetized multiuser adaptive OFDMA (Orthogonal Frequency-Division Multiple Access) system. As a result of our network coordination setup, a new question on which pair of users should be served at each physical resource comes up. A low power user selection algorithm is proposed and evaluated, and its performance is compared to that of random user selection.**

Keywords-; CoMP; LTE; MIMO; 4G; QoS

I. INTRODUCTION

Data access over mobile networks has caused an increasing demand for high data rate wireless communications, a trend which is expected to continue. Nowadays, a typical user consumes 1 Gigabyte of data per month, approximately 200% percent more than one year ago [1] [2] [3]. The current mobile networks and wireless technologies need to be improved in order to support the traffic demand.

To satisfy the high demand for wireless services, 3rd Generation Partnership Project (3GPP) has been developing a new mobile standard, referred to as Long Term Evolution (LTE). The first release of LTE (Release 8) is labeled as 3.9G as it does not meet the International Mobile Telecommunications-Advanced (IMT-Advanced) requirements for 4G. However, the evolved version of LTE (Release 10), referred to as LTE-Advanced (LTE-A), meets or exceeds the requirements of the International Telecommunication Union (ITU) for the fourth generation (4G) radio communication standard, known as IMT-Advanced. In October 2009, the 3GPP Partners formally submitted LTE-A to the ITU Radiocommunication sector (ITU-R) as a candidate for 4G IMT-Advanced [4].

In a cellular communication system such as 3GPP LTE, throughput is limited by co-channel interference, either within a cell (intra-cell interference) or from nearby cells (inter-cell interference).

Downlink intra-cell interference can be eliminated by orthogonal channel allocation. LTE radio transmission is based on Orthogonal Frequency-Division Multiple Access (OFDMA). Over frequency selective channels, OFDMA divides the transmitted bit flow into many different substreams and sends these over many different subchannels. Data from multiple users are being transmitted on parallel narrow-band subcarriers. The advantage is that each subcarrier is relatively narrowband, which decreases the effect of delay spread.

Adaptive Quadrature Amplitude Modulation (AQAM) is an adaptive digital modulation that provides the system with the ability to match the service rate to the channel quality while meeting a target Bit Error Rate (BER) [2]. Adaptive QAM and OFDMA are combined by performing adaptive modulation in each OFDM subcarrier. Although OFDMA achieves improved spectral efficiency within one cell, inter-cell interference is still preventing these technologies from coming close to the theoretical rates for multi-cell networks [5].

Inter-cell interference mainly influences the data rates of those users at the cell-edge affecting the average spectral efficiency of the cell. Using different transmission frequencies between neighboring cells, soft handoff or beam-forming multiple antennas, inter-cell interference can be reduced. Using more advanced techniques by coherently coordinating transmissions of signals across base stations, interference could be completely eliminated. Roughly speaking, multiple base stations, geographically distributed, transmit user's signal simultaneously. These signals are weighted and pre-processed so that inter-cell interference is cancelled [6] [7].

In the 3GPP standardization activities concerning LTE-Advanced [8], the coordinated base stations transmissions fall into the term of Coordinated Multi-Point (CoMP) transmission and reception. CoMP refers to a wide range of techniques with the common characteristic of dynamic coordination of transmission and/or reception at multiple geographically separated sites with the aim to enhance system performance and end-user quality [1]. 3GPP has proposed CoMP techniques as a performance enhancement for LTE-A Release 12 and beyond, to meet 4G requirements [8] [9]. These techniques are the key to achieve the needed requirements in terms of spectral efficiency and cell-edge throughput.

In this paper, we present network coordination as a means to provide high spectral efficiency in cellular systems. This study presents a basic scenario where two base stations, connected via high speed backbone, coordinate their transmissions and pre-process the signals for cancelling inter-cell interference. Each user receives its data from both base stations improving the signal strength and with no interference, thus reaching a higher spectral efficiency. The performance of coordinated networks is compared to that of conventional networks without coordination and, as expected, it is shown that coordinated base station transmissions offers better spectral efficiency values.

Our coordinated experimental setup is not power efficient, so a new challenge comes up for selecting the users to be served at each physical resource in order to minimize the system transmission power. A user selection algorithm, based on simulation results, is proposed. This algorithm specifies resources allocation to users in order to minimize system transmission power. The proposed algorithm is evaluated and their results are compared to that of a random user selection algorithm.

The remainder of this paper is organized as follows. Section II briefly describes the fundamentals of coordinated networks, presenting the studied CoMP technique for cancelling inter-cell interference. In Section III, the system model is described. In Section IV, a user selection algorithm is proposed for system transmission power reduction. In Section V, the coordinated scenario using inter-cell interference cancellation and the proposed user selection algorithm is then evaluated. Finally, some concluding remarks are given in Section VI.

II. COMP TRANSMISSION

The basic system model is as shown in Fig. 1. Base Stations (BSs) BS1 and BS2 will operate together to transmit signals to Mobile Stations (MSs) MS1 and MS2. Both base stations will be geographically separated but connected via high speed backbone link making coordination possible. Both BSs and MSs are equipped with single antennas. Knowledge of the Channel State Information (CSI) is assumed to be perfectly available at the transmitters, as it is measured by the receivers and fed back to the BSs.

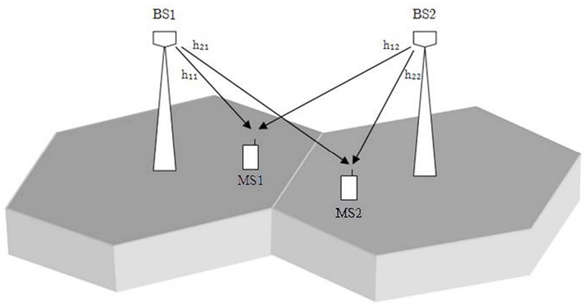

Fig. 1. System model

In a classical cell system, for BS1, BS2 is an interfering base station, and in the same way, for BS2, BS1 is an interfering base station. The received signals at MS1 and MS2, y_1 and y_2, respectively, are given by

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \tag{1}$$

where h_{ij} is the channel between terminal i and BS j, x_1 is transmitted signal by BS1 and x_2 is that by BS2. n_i is additive white Gaussian noise [10].

A basic system model for a downlink network with M single antenna base stations and N single antenna mobiles is given by

$$\mathbf{y} = \mathbf{Hx} + \mathbf{n} \tag{2}$$

where $\mathbf{H} = [h_{ij}]_{NxM}$ denotes the channel matrix, h_{ij} denotes the complex channel gain between mobile i and base station j, $\mathbf{x} = [x_1, x_2, \ldots, x_M]^T$ denotes the complex antenna inputs to the channel, $\mathbf{n} = [n_1, n_2, \ldots, n_N]^T$ denotes additive white noise and $\mathbf{y} = [y_1, y_2, \ldots, y_M]^T$ are the inputs to the receiver.

In a coordination scenario, where all M base stations act together, each mobile may receive useful signals from all base stations. If a linear spatial precoding matrix $\mathbf{A} \in C^{MxN}$ is used to map the data symbols to the antenna outputs, i.e.,

$$\mathbf{x} = \mathbf{As} \tag{3}$$

where s denotes the vector of data symbols given by $\mathbf{s} = [s_1, s_2, \ldots, s_N]^T$ then the antenna output at the jth base station is a linear combination of N data symbols,

$$x_j = \sum_{i=1}^{N} A_{ji} s_i \tag{4}$$

Selecting a proper precoding matrix $\mathbf{A}$ allows interference cancellation. A simple form of coordination, called Channel Inversion (CI) or Zero-Forcing (ZF) [1] [2] [6] [9], uses a pseudo-inverse precoding matrix given by

$$\mathbf{A} = \mathbf{H}^{\dagger} (\mathbf{HH}^{\dagger})^{-1} \tag{5}$$

According to this, when $N = M$, (3) becomes simply $\mathbf{x} = \mathbf{H}^{-1}\mathbf{d}$ [6] [9].

The received signal according to (2), (3) and (5) is given by

$$\mathbf{y} = \mathbf{Hx} + \mathbf{n} = \mathbf{HH}^{\dagger} (\mathbf{HH}^{\dagger})^{-1}\mathbf{s} + \mathbf{n} = \mathbf{s} + \mathbf{n} \tag{6}$$

Thus the ith mobile receives $y_i = s_i + n_i$. All network antennas in range can help in the transmission of each message, but the message is received only by the intended user with no interference [6].

Notice that according to (6) the system model corresponds to an Additive White Gaussian Noise (AWGN) channel where inter-cell interference has been cancelled. To achieve this is not free: depending on the actual channel the precoder should compensate the channel's effects causing fluctuations on the system transmission power. These fluctuations will require a large normalization factor in a real system, which will dramatically reduce the Signal-to-Noise Ratio (SNR) at receivers.

III. SYSTEM MODEL

Orthogonal Frequency Division Multiplexing (OFDM) is a modulation technique widely used to counteract the effects of Inter Symbol Interference (ISI) in frequency selective channels [2]. OFDM divides the transmission band in a large number of sub-bands narrow enough to be considered flat. An Inverse Fast Fourier Transform (IFFT) efficiently performs the modulation process. Its reciprocal process, the forward Fast Fourier Transform (FFT), is used to recover the data as a cyclic extension of the OFDM symbol eliminating the residual ISI. In this way, OFDM can be considered as a time-frequency squared pattern, where each bin can be addressed independently.

Modulation of the OFDM subcarriers is analogous to that of the conventional single carrier systems. Supported downlink data-modulation schemes are Binary Phase-Shift Keying (BPSK), Quadrature Phase-Shift Keying (QPSK), 16QAM, and 64QAM (as those in LTE). The number of bits allocated to each subcarrier can be modified on a symbol basis to simultaneously track the time variant frequency response of the channel and fulfill the BER service requirements.

When OFDM is also used as multiplexing technique, the term OFDM Access (OFDMA) is preferred. In this case, a block of bins is assigned to a single user in what can be considered a hybrid Time Division Multiple Access–Frequency Division Multiple Access (TDMA-FDMA) technique.

In this work, the physical resources to be assigned to users are formed by one subcarrier in one symbol time, thus OFDMA systems allow subsets of the subcarriers to be allocated dynamically among the different users on the channel. A Round Robin (RR) scheduling algorithm has been used in order to allocate resources to users. Round Robin is a fixed no opportunist scheduling algorithm which dispenses system resources equally among users following a cyclic order. Users are located in an imaginary line between BS1 and BS2 and the distance to their respective BSs is defined for each user and simulation.

Perfect channel state information (CSI) is assumed at the transmitter. As a consequence, results obtained here are upper bounds for those in a practical system.

The setup is according to system model of Fig. 1. Two hexagonal cells with a base station located at the center and where each base is loaded with one mobile. The cell radius considered is set to *Rcell* meters.

As channel model, frequency selective Rayleigh fading channel parameters have been employed. We assume path loss Hata model [2] in urban areas including lognormal shadowing with a standard deviation of σ dB. Propagation losses and shadowing have been included to channel matrix $\mathbf{H} = [h_{ij}]_{NxM.}$ Being h_{ij} independent normal random variables with zero mean and unit variance modeling the normalized complex channel gain between mobile i and base station j, and g_{ij} being the propagation losses including shadowing between mobile i and base station j, channel matrix $\mathbf{H}$ is given by

$$H = \begin{bmatrix} g_{11}h_{11} & g_{12}h_{12} \\ g_{21}h_{21} & g_{22}h_{22} \end{bmatrix} \tag{8}$$

In our two base stations OFDMA system model, each BS will serve to the mobile in its own cell coverage, thus a pair of users is served in each resource unit, formed by one subcarrier in one symbol time. Furthermore, in our coordinated scenario according to (4) the precoder makes system transmission power variable. This brings us up a new challenge: a user selection algorithm could be defined, which allows to choose the best pair of users available for resource allocation, in terms of system transmission power reduction.

When $N = M$ and according to (3) and (5) complex antenna inputs to the channel from BS1 and BS2 are given by

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} g_{11}h_{11} & g_{12}h_{12} \\ g_{21}h_{21} & g_{22}h_{22} \end{bmatrix}^{-1} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} \tag{9}$$

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \frac{1}{\det(\boldsymbol{H})} \begin{bmatrix} g_{22}h_{22} & -g_{12}h_{12} \\ -g_{21}h_{21} & g_{11}h_{11} \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} \tag{10}$$

where x_i denotes the complex antenna inputs to the channel and s_i is the ith mobile's complex data symbol.

According to (10), system transmission power for BS1 and BS2 depends on *det* ($\mathbf{H}$) given by

$$det\,(\mathbf{H}) = g_{11}g_{22}h_{11}h_{22}\text{-}g_{12}g_{21}h_{12}h_{21} \qquad (11)$$

Notice according (10) that, when an inverse precoding matrix is applied to the input symbols, the transmission power for BS1 and BS2 is modified. Thus, precoding causes system transmission power fluctuations. An ill-conditioned channel matrix will cause enormous final transmission power. This is the price that must be paid in order to achieve inter-cell interference be identically to zero maintaining SNR level at the receivers.

IV. User selection algorithm

In this section, a user selection algorithm for system transmission power reduction is proposed.

As we mention before, according to (10) and (11) the precoder causes fluctuations on system transmission power in order to compensate the channel's effects.

In a real scenario, a power constraint should be applied in order to maintain a fixed transmission power. Then, a large normalization factor should be used that would dramatically reduce the SNR at the receivers. Our theoretical study is based on how channel inverse precoding technique affects to system transmission power, so no power constraint will be applied. It will conduct us to get an unreasonable amount of transmission power but it will be essential to not cover up transmission power results. In this way, the results will be able to be analyzed in order to define a more efficient transmission power user selection algorithm. Once the algorithm has been defined it could be applied in a real scenario where a power constraint has been used.

According to (11) it can be deduced that minimum system transmission power corresponds to a situation as showed in Fig. 2. In this scenario, is very probable that *det*(**H**), has a maximum value and, as a consequence, system transmission power according to (10) will be minimum.

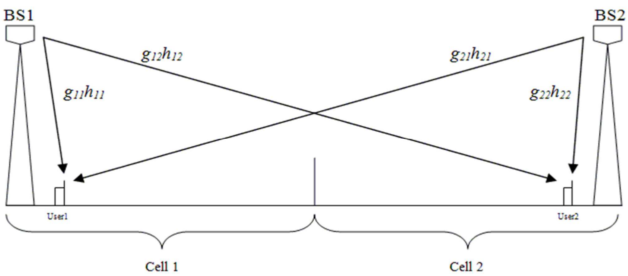

Fig. 2. Minimum sytem transmission power scenario

In the same way, maximum system transmission power corresponds to a scenario as showed in Fig. 3. In this situation, *det*(**H**) has probably a minimum value and therefore according to (10) system transmission power will be maximum.

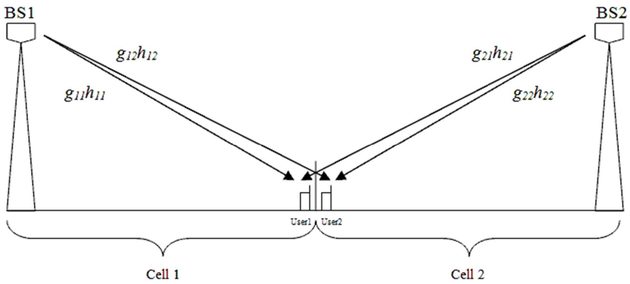

Fig. 3. Maximum system transmission power scenario

Given a fixed position for user1 and variable position for user2 as shown in Fig. 4

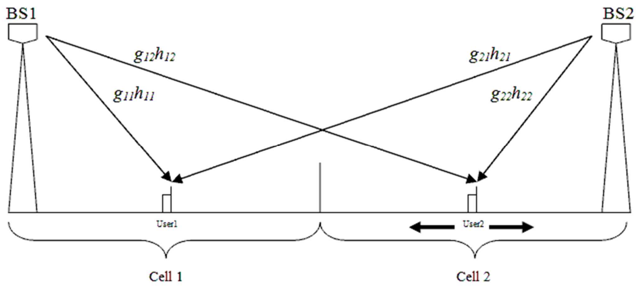

Fig. 4. System transmission power dependence scenario

It can be deduced according to (10) and (11) that if user 2 moves close to cell edge *det*(**H**) value is probably reduced and therefore transmission power is increased. Otherwise, if user 2 moves close to its BS, *det*(**H**) value is probably increased and therefore transmission power is reduced.

We can conclude that we need high values for *det*(**H**) in order to have a lower system transmission power. To achieve this, user 1 and user 2 should be the most far away between them as possible. So for a fixed position of one user its pair, to be served in the same resource block, should be selected as far as possible.

Thus, taking into account the above and based on system transmission power results showed in Fig. 7, we propose the following criterion for user's pair selection:

$$\mathbf{d_2 \leq Rcell - d_1} \qquad (12)$$

being d_1 and d_2 distances MS1 to BS1 and MS2 to BS2 respectively. *Rcell* denotes cell radius as defined above. Selecting user pairs, to be served in the same resource block, following (12) ensures a lower system transmission power, as we will show in the next section. The lower is d_2 respect to *Rcell* - d_1, the lower will be system transmission power.

In the next section, the proposed algorithm is compared to a random user pair selection.

V. SIMULATION RESULTS

In this section, we compare the performance of the coordinated networks to that of conventional cellular networks with inter-cell interference. After that, we show how the proposed algorithm for user pairs to be served at each physical resource obtains better results in terms of transmission power. First of all, we evaluate the performance of network coordination and we show that coordination is successful in eliminating inter-cell interference. Second, based on simulations results, we compare user selection algorithm with random user selection. Then, we analyze the results and we show how the proposed algorithm minimizes the system transmission power.

The basic experimental setup is based on Fig. 1, two hexagonal cells with a base station located at the center and where each base is loaded with one mobile. The SUI-4 (Modified Stanford University Interim) [12] channel model parameters have been used. Two base stations antennas allow two simultaneously transmissions over 16 subcarriers (N_c = 16). As previously described, path loss Hata model in urban areas [2] including lognormal shadowing with a standard deviation of 10 dB is assumed. Cell's radius is 500m and noise power spectral density is -174dBm/Hz [13].

Main configuration parameters are summarized in Table I.

TABLE I
SIMULATION CONDITIONS

Parameter	Value
Carrier frequency	5 GHz
System bandwidth	1.75 MHz
Sampling frequency	2 MHz
Noise PSD	-174 dBm/Hz
Channel model	SUI-4 [12]
MSs Velocity	5 Km/h
Cell's Radius	500m

Fig. 5 shows system spectral efficiency in bit/s/Hz for coordinated transmission applying channel inversion technique versus conventional not coordinated network. P_{tx} corresponds to base stations transmission powers, P_n is the noise power and L_{pmax} corresponds with the maximum losses that an UE located at cell-edge would suffer. Simulation results are given for a fixed location for both MS1 and MS2. MS1 has been located to d_1 = 150m and MS2 to d_2 = 250m, being, as we mention above, d_1 and d_2 distances MS1 to BS1 and MS2 to BS2 respectively.

For the uncoordinated scenario at low $P_{tx}/P_n - L_{pmax}$ values the noise is the determining factor, while at high $P_{tx}/P_n - L_{pmax}$ values is the inter-cell interference. Thus, we can observe how at high $P_{tx}/P_n - L_{pmax}$ values the efficiency is limited by inter-cell interference.

For the coordinated scenario, the determining factor is only the noise; here inter-cell interference has been cancelled, so the efficiency depends only on SNR values at receivers. Furthermore, it can be observed at low $P_{tx}/P_n - L_{pmax}$ values the steeped form of the graph corresponding to adaptive modulation transmission. In this case, at high $P_{tx}/P_n - L_{pmax}$ values, the efficiency is limited for the maximum constellation used (64QAM).

The simulation results show that coherent coordination transmission improves the spectral efficiency by about a factor of 1.875, that is, an enhancement of 87.5% is obtained when coordinated transmission is used.

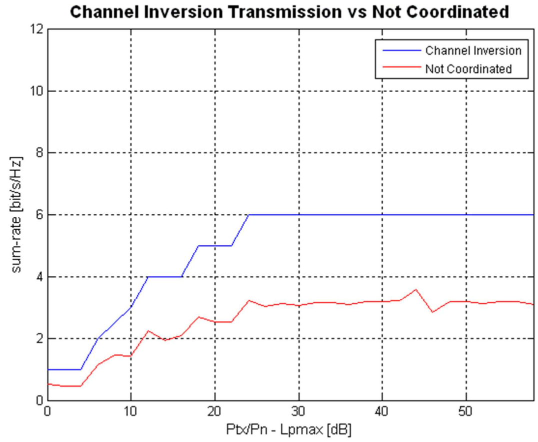

Fig. 5. System spectral efficiency when coordinated Channel Inversion transmission technique is used vs. not coordinated transmission

Fig. 6 shows bit error rate (BER) versus SNR for coordinated transmission when channel inversion precoding is applied.

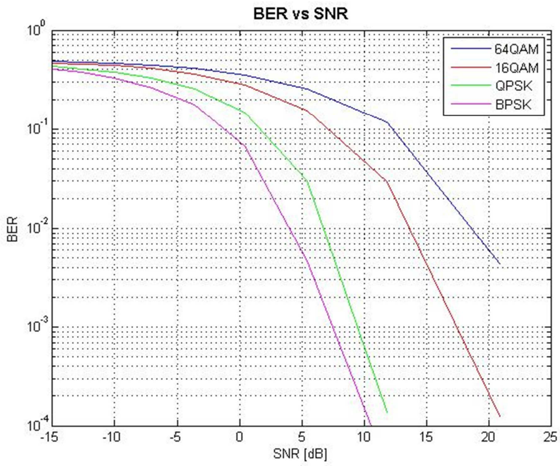

Fig. 6. BER vs. SNR for coordinated transmission

We can observe how inter-cell interference has been cancelled and BER values are the typical of an AWGN channel, as expected according to (6).

Simulation results for system transmission power according to (10) vs d_1 and d_2 are shown in Fig. 7. The base stations transmission powers configured for both BS1 and BS2 are fixed to P_t = 40dBm. MS1 and MS2 locations have been configured in steps of 50m (distance from MS to BS) in order to obtain the grid of possible locations.

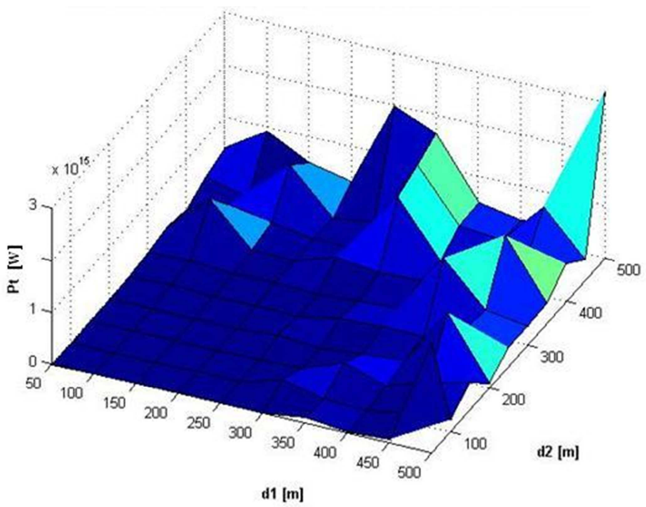

Fig. 7. System Transmission Power vs. d_1 and d_2

Fig. 7 shows that lower system transmission power is obtained when MS1 and MS2 are very close to their respective base stations. The worst or higher system transmission power values are obtained when both MSs are in the cell-edge. It is distinguished approximately two zones separated by those values d_1=d_2. In order to have lower system transmission power values, pairs of users must be selected in the region area $d_2 \leq Rcell - d_1$ as proposed according to (12). Notice that system transmission power values are unreasonably high. As we commented in Section IV, this is because power normalization factor has not been used in order to study how channel inverse precoding technique affects to system transmission power.

Applying the user selection algorithm proposed for resource allocation in Section IV, in the worst case, that is, when the equality is fulfilled in (12), i.e., $d_2 = Rcell - d_1$, ensures keeping in the limit of lower transmission power values zone. A comparison has been done in this case between the proposed user selection algorithm and a random algorithm selecting user pairs randomly. The results have been obtained for ten users at each cell. Five significant different realizations using the same users group and served in the same cyclic order have been used. For user selection algorithm proposed the same user pairs from the users group that fulfill the algorithm in the worst case, i.e., $d_2 = Rcell - d_1$, have been used for each realization. From the point of view of the random algorithm, user pairs have been selected randomly for each realization from users group. Results are given in Table II.

TABLE II
TRANSMISSION POWER

No.	Proposed Algorithm [dBm]	Random Algorithm [dBm]
1	175.2276	176.9869
2	175.2276	178.2176
3	175.2276	175.2295
4	175.2276	176.1282
5	175.2276	177.3151

Table II shows that in all occasions we get better results applying the proposed algorithm in the worst case than applying a random algorithm for selecting user pairs. Approximately, an enhancement of 46.76% on average, computed in linear with Watt, is obtained when user pairs are selected following the algorithm instead of randomly. Obviously, this enhancement is in the worst case; it will be higher if pairs of users are selected inside the zone of lower system transmission power instead of on the limit.

VI. CONCLUSIONS

In this paper, we have shown that using coordinated transmission in a cellular network improves spectral efficiency. In spite of its simplicity, base station coordination technique of channel inversion achieves its goal of cancelling inter-cell interference. However, it is not free as precoder causes system transmission power fluctuations due to the stringent requirement that the interference at the receivers be identically to zero.

A user selection algorithm has been proposed for resource allocation, where user pairs are selected in the region area $d_2 \leq Rcell - d_1$. The user pair criterion proposed solely depends on the distance between mobile stations, but it is shown that results with the proposed algorithm are always better, in terms of system transmission power, than applying an algorithm where user pairs are randomly selected.

In future works, the user selection algorithm may be improved. An algorithm also dependent on the users' channel gains not only on their mutual distance could be proposed.

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