ON THE CAPACITY OF MIMO-WCDMA MULTICELLULAR NETWORKS WITH IDEAL POWER CONTROL

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Abstract

The goal of the study presented in this paper is to evaluate the performance of a Multiple Input Multiple Output (MIMO) network using the Wideband Code Division Multiple Access (WCDMA) physical layer protocol. In this context, several transmission techniques are evaluated. Moreover, the performance of a proposed technique that is based on the maximization of the desired signal of a Mobile Station (MS) to the total amount of interference that causes to the rest of the network is evaluated as well. As results indicate, for high data rate services this technique can achieve up to 1dB transmission power gain compared to the case where only the maximization of the desired MS's signal is considered.

1. INTRODUCTION

Modern wireless communications are coupled with high data rates over limited bandwidth areas, minimum transmission delay as well as improved Quality of Service (QoS) to mobile users. Since the adoption of the WCDMA physical layer protocol for third generation (3G) mobile wireless networks ([1]), several solutions have been proposed to further increase the spectral efficiency of these systems. 3rd Generation Partnership Project (3GPP) has recently standardized the Long Term Evolution (LTE) of 3G networks, which is an attempt to upgrade the existing infrastructure of these networks in order to support high speed data for MSs. LTE includes among others multicarrier transmission, as well as the deployment of MIMO in current networks ([2]).

In general, MIMO transmission can support either diversity combining mode or spatial multiplexing mode ([3]). In the first case, effective Bit Error Rate (BER) can be reduced, as the same information is send and received from all links of the MIMO configuration. In the second case, independent data streams are transmitted from different transmit antennas, hence increasing the overall throughput.

However, in practical wireless orientations, effective capacity using MIMO architecture may be different than the theoretical one. The reason is that Multiple Access (MAI) interference can significantly degrade the performance of these networks. The goal of the study presented in this paper is to investigate the performance of MIMO-WCDMA networks for complex network orientations (i.e. one tier of cells around the central cell, increased number of effective MSs). Unlike other studies, power control is performed according to 3GPP specifications in an attempt to accurately model the performance of these networks. Moreover, the performance of a proposed strategy that is based on the maximization of the desired MS's signal to the total amount of interference that causes to other MSs is evaluated as well.

The rest of this paper is organized as follows: In section 2 the MIMO-WCDMA simulator is described, while in section 3 description goes on with transmission and reception techniques for MIMO orientations. Results are presented in section 4, while concluding remarks are made in section 5.

2. MIMO-WCDMA SIMULATOR

A MIMO-WCDMA network with one tier of cells around the central cell is considered with three sectors per cell. Moreover, downlink transmission is assumed. All sectors employ conventional 120° sectors with radiation patterns as specified in [4]:

$$f(\varphi) = G_b - \min\left[12\left(\frac{\varphi-\varphi_s}{\varphi_{3dB}}\right)^2, A_m\right] \qquad (1)$$

for $\varphi_s - 60^o \leq \varphi \leq \varphi_s + 60^o$. In (1), $\varphi_s \in \{60^o, 120^o, 240^o\}$ is the pointing direction of the specific sector, the antenna gain G_b equals 14dBi, the 3-dB beamwidth of the antenna pattern (φ_{3dB}) is 70° and the front-to-back ratio (A_m) is 20dB.

The employed simulator is semi static; hence MSs' locations do not change during a simulation run. MSs enter the network at a sequential manner following a uniform distribution. An MS is connected to the base station (BS) with the lowest path loss (including shadowing and antenna radiation patterns). During a drop, the channel undergoes fast fading due to the motion of the MSs. For M_t antennas at the BS and M_r antennas at the MS (M_txM_r), the channel coefficient denoted as h between the q^{th} transmit antenna and the u^{th} receive antenna for the l^{th} multipath component is given by ([4]):

$$h=\sqrt{\frac{P_l\sigma_{SF}}{M}}\sum_{m=1}^{M}\begin{pmatrix}\sqrt{G_{BS}\left(\theta_{l,m,AoD}\right)}\exp\left(j\left[k_w d_q\sin\left(\theta_{l,m,AoD}\right)+\Phi_{l,m}\right]\right)\times\\ \sqrt{G_{MS}\left(\theta_{l,m,AoA}\right)}\exp\left(j\left(k_w d_u\sin\left(\theta_{l,m,AoA}\right)\right)\right)\end{pmatrix} \tag{2}$$

where j is the imaginary unit, P_l is the power of the l^{th} path, σ_{SF} is the lognormal shadow fading, M is the number of sub-paths per path, $\theta_{l,m,AoD}$ and $\theta_{l,m,AoA}$ are the angles of departure (*AoD*) and arrival (*AoA*) respectively for the m^{th} subpath of the l^{th} path, $G_{BS}(\theta_{l,m,AoD})$ is the BS antenna gain for each array element and $G_{MS}(\theta_{l,m,AoA})$ is the MS antenna gain for each array element for the *AoD* and *AoA* respectively. Moreover, $\Phi_{l,m}$ is the phase of the m^{th} subpath of the l^{th} path, uniformly distributed in [0,2π].

Finally, k_w is the wave number 2π/λ where λ is the carrier wavelength in meters, d_q is the distance in meters of BS antenna element q from the reference (q = 1) antenna and d_u and is the distance in meters of MS antenna element u from the reference (u = 1) antenna. The positions of the MSs, the path-losses, as well as the shadow fading remain constant during at each drop. Moreover, all *AoA*s and *AoD*s change at the beginning of each frame. Typical values for the number of multipaths and the number of subpaths per multipath are L = 6 and M = 20, respectively. All the simulation parameters are summarized in table I.

3. MIMO-WCDMA TRANSMISSION TECHNIQUES

As specified in [5], the effective Signal to Interference plus Noise Ratio (SINR) for the k^{th} MS will be given by:

$$SINR_k=\frac{P_s}{P_{ISI}+\sum\limits_{i=1,i\neq k}^{K}P_{MAI.i}+P_N} \tag{3}$$

where:

$$P_{s,k}=\left(\left(\sum_{l=1}^{L}\mathbf{r}_{k,l}\mathbf{H}_{k,s(k),l}\mathbf{w}_k\right)^{\mathrm{H}}\sum_{l=1}^{L}\mathbf{r}_{k,l}\mathbf{H}_{k,s(k),l}\mathbf{w}_k\right)p_k \tag{4}$$

$$\begin{aligned}P_{ISI}=&\left|\sum_{l=1}^{L}\sum_{\substack{l'=1\\l'\neq l}}^{L}\left(\mathbf{r}_{k,l}\mathbf{H}_{k,s(k),l'}\mathbf{w}_k\right)\sqrt{p_k}\left(\rho_{k,k,|l-l'|}+\overline{\rho}_{k,k,|l-l'|}\right)\right|^2+\\&\sum_{l=1}^{L}\left(\mathbf{r}_{k,l}\mathbf{H}_{k,s(k),l}\mathbf{w}_k\sqrt{p_k}\right)^{\mathrm{H}}\sum_{l=1}^{L}\sum_{\substack{l'=1\\l'\neq l}}^{L}\left(\mathbf{r}_{k,l}\mathbf{H}_{k,s(k),l'}\mathbf{w}_k\sqrt{p_k}\right)\left(\rho_{k,k,|l-l'|}+\overline{\rho}_{k,k,|l-l'|}\right)+\\&\sum_{l=1}^{L}\left(\mathbf{r}_{k,l}\mathbf{H}_{k,s(k),l'}\mathbf{w}_k\sqrt{p_k}\right)\left(\sum_{l=1}^{L}\sum_{\substack{l'=1\\l'\neq l}}^{L}\left(\mathbf{r}_{k,l}\mathbf{H}_{k,s(k),l'}\mathbf{w}_k\sqrt{p_k}\right)\left(\rho_{k,k,|l-l'|}+\overline{\rho}_{k,k,|l-l'|}\right)\right)^{\mathrm{H}}\end{aligned} \tag{5}$$

$$P_{MAI,i}=\left(\left|\sum_{l=1}^{L}\sum_{l'=1}^{L}\left(\mathbf{r}_{k,l}\mathbf{H}_{k,s(i),l'}\mathbf{w}_i\right)\left(\rho_{k,i,|l-l'|}+\overline{\rho}_{k,i,|l-l'|}\right)\right|^2\right)p_i \tag{6}$$

$$P_N=N_o\sum_{l=1}^{L}\left\|\mathbf{r}_{k,l}\right\|_F^2 \tag{7}$$

In (4) – (7), p_k is the transmission power for the k^{th} MS, $s(k)$ is the k^{th} MS's serving sector, $\mathbf{H}_{k,s(i),l}$ is the l^{th} multipath component of dimensions M_rxM_t from the i^{th} MS's serving sector to the k^{th} MS and N_o is the thermal noise power. Each element of the matrix $\mathbf{H}_{k,s(i),l}$ is calculated according to (2). Finally, $\mathbf{w}_k$ is the M_tx1 transmit weight vector assuming diversity combining mode and $\rho_{k,i,l}$, $\overline{\rho}_{k,i,l}$ are the partial cross-correlations of the spreading sequences ([5]).

In order to exploit diversity from frequency selective fading, each MS is equipped with a 2-D RAKE receiver. The 1xM_r MRC multiplying vector is:

$$\mathbf{r}_{k,l}=\left(\mathbf{H}_{k,s(k),l}\mathbf{w}_k\right)^{\mathrm{H}} \tag{8}$$

for 1≤l≤L. In this study several approaches to transmit beamforming are evaluated. With respect to [5], the performance of the uniform and random power allocation strategies, the maximization of the desired MS's signal as well as per RAKE maximization of Signal to Noise Ratio (SNR) are analysed assuming a MIMO-WCDMA orientation where power control is performed according to 3GPP specifications (i.e. closed loop power control with 1dB step). In [5], the performance of the maximization of the Signal to Jamming plus Noise Ratio was also analysed:

$$\mathrm{SJNR}_k\approx\frac{\mathbf{w}_k^{\mathrm{H}}\left(\left(\sum_{l=1}^{L}\mathbf{r}_{k,l}\mathbf{H}_{k,s(k),l}\right)^{\mathrm{H}}\sum_{l=1}^{L}\mathbf{r}_{k,l}\mathbf{H}_{k,s(k),l}\right)\mathbf{w}_k}{\mathbf{w}_k^{\mathrm{H}}\left(\sum\limits_{i=1,i\neq k}^{K}\left(\sum\limits_{l=1}^{L}\mathbf{H}_{i,s(k),l}^{\mathrm{H}}\mathbf{H}_{i,s(k),l}\left(\left|\rho_{k,i,l}\right|^2+\left|\overline{\rho}_{k,i,l}\right|^2\right)\right)\right)\mathbf{w}_k} \tag{9}$$

which is a function of the desired MS's weight vector only. Hence, denoting $X_m(\mathbf{Y}_k)$ the eigenvector corresponding to the maximum eigenvalue of matrix $\mathbf{Y}_k$, the weight vector in the proposed transmission scheme that maximizes the SJNR ratio is given by:

$$\mathbf{w}_k = X_m\left(\mathbf{Y}_k\right) \tag{10}$$

$$\mathbf{Y}_k = \left(\sum_{i=1, i\neq k}^{K} \left(\sum_{l=1}^{L} \mathbf{H}_{i,s(k),l}^{\mathrm{H}} \mathbf{H}_{i,s(k),l} \left(\left|\rho_{k,i,l}\right|^2 + \left|\bar{\rho}_{k,i,l}\right|^2 \right) \right) \right)^{-1} \times \left(\left(\sum_{l=1}^{L} \mathbf{r}_{k,l} \mathbf{H}_{k,s(k),l} \right)^{\mathrm{H}} \sum_{l=1}^{L} \mathbf{r}_{k,l} \mathbf{H}_{k,s(k),l} \right) \tag{11}$$

At this point it should be noted that in the evaluation of the MSJNR algorithm only the co-sector MSs are included, as it is assumed that undergo greater amount of interference from the desired MS relevant to the MSs of other sectors.

4. RESULTS

All simulation parameters are summarized in Table I. Each simulation scenario consists of a network topology with one tier of cells around the central cell, while data services of 120 Kbps are also considered. Unlike [5], where power control was considered only in a frame by frame basis, in this study it is performed analytically according to 3GPP specifications. For this reason, in every frame with duration 10ms (i.e. 38400 chips assuming bandwidth equal to 3.84MHz) and 15 slots per frame, the SINR value per MS is fed back to the transmitter which decides either to increase or decrease transmission power with 1dB step in every deviation from the target SINR.

In Figures 1 and 2, in the horizontal axis is the number of active MSs per sector, while in the vertical axis is the central cell's transmission power in dBm. Note that in Figure 1 there are up to 4 MSs per sector, while in Figure 2 up to 7 MSs. For more MSs in the network then outage takes place. As it can be observed from Figure 1, where 5 dB required E_b/N_o is assumed, then there are no significant differences among PRMSNR, MSNR and MSJNR strategies. However, from Figure 2 and 7 dB required E_b/N_o, then for 4 active MSs there is transmission gain almost 1dB, as MSNR strategy requires 24dBm while MSJNR strategy requires 23 dBm. In this case, actual capacity is 4x3x120Kbps = 1440 Mbps (product of active users per sector with sectors per cell and rate per MS).

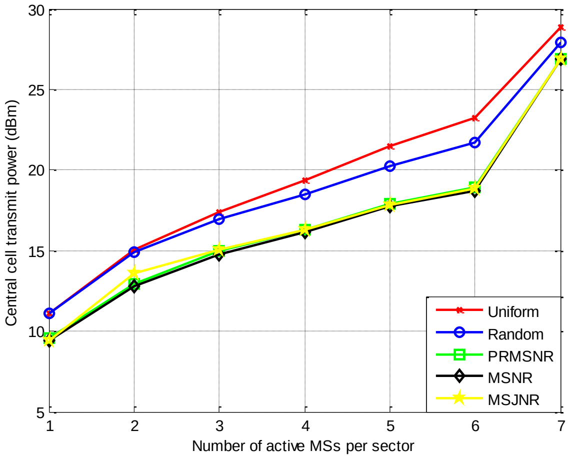

Figure 1: Total transmission power for data services of 120 Kbps and 5dB required E_b/N_o

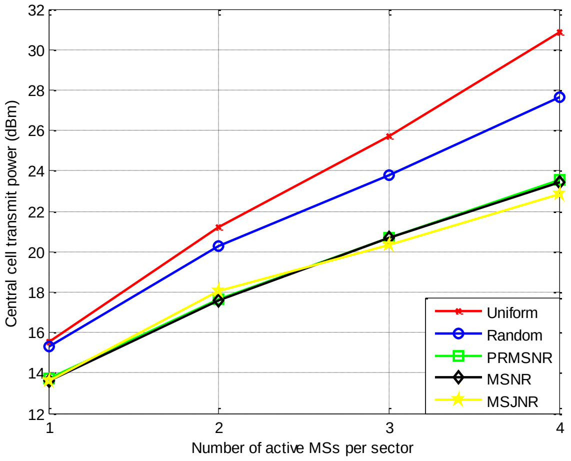

Figure 2: Total transmission power for data services of 120 Kbps and 7dB required E_b/N_o

TABLE I
SIMULATION PARAMETERS

Parameter	Assumption
Environment	Urban macrocell
Cells	7
Sectors per cell	3
Cell radius	1000 m
Carrier frequency	2 GHz
BS height	30 m
MS height	1.5 m
Propagation	Okumura - Hata,pathloss exponent 3.5
Std for shadow fading	8 dB
Power delay profile	Uniform
Number of drops (*D*)	1000
Frames per drop (*F*)	100
Bits per frame (*B*)	200
Multipath components (*L*)	6

5. CONCLUSIONS

The performance of multicellular MIMO-WCDMA networks has been analysed, according to 3GPP specifications (channel modelling and power control). Ongoing research includes among others the extension of these results for other orientations (i.e. two tiers of cells) and services as well.

References

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