Multi-cell processing for uniform capacity improvement in full spectral reuse system

Virgile Garcia, Nikolai Lebedev, Jean-Marie Gorce

Multi-cell processing for uniform capacity improvement in full spectral reuse system

Virgile Garcia*, Nikolai Lebedev*† and Jean-Marie Gorce*
*University of Lyon, INRIA, INSA-Lyon, CITI F-69621, France
†University of Lyon, CPE Lyon BP 2077, F-69616, France

***Abstract*—In this paper, we study the potential of Multi-Cell Processing (MCP), via Base Stations (BSs) coordination, to improve the uniform capacity of a wireless network. MCP is particularly efficient for edge-cell users that experience very low SINR when an intensive spectral reuse is employed.**

We choose a baseline form of MCP to show that a simple Alamouti-like code can enhance the SINR by accounting the strongest interferer as a useful signal at the receiver.

After having introduced the formulation for uniform capacity, we numerically derive the optimal conditions to use MCP. We then validate our approach by simulation and show that this optimal MCP can increase the uniform capacity by up to a factor 2 and 6 compared to Fractional Frequency Reuse (FFR) and simple Reuse1 mode by using an urban micro-cell channel model.

***Index Terms*—Multi-cell processing, uniform cell capacity, macro-diversity, interferences coordination, small cells**

I. Introduction

The forthcoming mobile wireless networks need to face the problem of spectral resource limitation due to the continuously growing amount, rate and quality of data transmitted over the wireless channel. The inter-cell interference is recognized as one of the main capacity limiting parameters in modern cellular systems. The classical solution adopted in previous generation networks was to increase the spatial frequency reuse factor and thus the distance between the co-channel cells, aiming at the co-channel interference avoidance. Together with a closed loop power control and possibly interference cancellation performed independently in each cell, this method helped to maintain a sufficient Signal to Noise and Interference Ration (SINR) level at the user terminal (UT) to perform the correct detection. The main drawback of those techniques is the inefficient use of expensive spectral resources due to static allocation.

The emerging 4G technologies integrate the possibility of full spectral reuse (Reuse1) in each cell, which would lead to a very poor receiver SINR, especially for UTs located at the cell boundaries. The modern vision is therefore to recognize the importance of interference management (rather than mitigation) through inter-cell cooperation.

Several inter-cell interference coordination (ICIC) techniques can be found in the literature and practical system applications. The authors of [1] have provided an in-depth study of the BS cooperation on the downlink (DL) for various precoding strategies. They derived the capacity regions and bounds for various cooperative strategies including the local ones for two classes of users (inner and outer), and showed the tradeoff between the performance of MCP and the corresponding cost of cooperation. A distributed power allocation and scheduling algorithm for DL based on local SIR information only was proposed in [2]. In every slot, the most interfering resources are switched off as long as this operation contributes to the overall capacity increase.

Some of previously cited methods can be coupled with a Fractional Frequency Reuse, which consists of applying a frequency reuse of one in the inner, close to the BS regions, and a higher reuse in the outer, cell edge areas. Many variants of this method have been addressed in recent literature, and it was shown that using two reuse factors is in general better, then just one. For example, a FFR based both on the distance and receiver SINR criteria coupled to graph-based interference coordination is studied in [3]. The authors in [4] analyse the potential of FFR for ubiquitous coverage in cellular system. However, no interference coordination is studied, and only a simple path loss channel model was used.

An inter-cell cooperation scheme also called Multi-Cell Processing, or Coordinated Multiple-Point (CoMP), is expected to be an important feature in future standards like LTE-A and 802.16m. By using the MCP, multiple BS coordinate their transmissions, and the received signals combined at the UT provide the diversity gain in SINR.

From the provider's point of view, an objective consists to guarantee the uniform service in target areas, in order to provide a maximum of users with the position-independent QoS.

In this paper we study the uniform cell capacity, since in this context it is a suitable system performance metric. The uniform capacity is the criterion which defines the appropriate allocation scheme for a fixed total per-cell amount of resources, to deliver the same data transmission rate for any received SINR level at the UT. The worst SINR mobiles, will strongly unbalance the resource partitioning, monopolizing the major portion of resources. This results in a very low spectral efficiency that impacts all the users. The network with higher uniform capacity is expected to offer a more homogeneous coverage, with only few poor SINR users.

Our main objective is to evaluate the potential of multi-cell processing to increase the uniform capacity, through

This work has been carried out in the frame of the joint lab between INRIA and Alcatel-Lucent Bell Labs on "self organizing networks"

increasing the edge users' SINR. We adopt a very simple MISO transmission strategy based on "matrix A" issued from standards [5], that allows to select up to 4 transmit antennas. We qualify our MCP method as optimal, since for any location, we choose the number of cooperating BSs such that the resource cost is minimal. The obtained baseline performance of this optimal MCP is superior to other existing resource partitioning methods (Reuse1, Reuse2, FFR).

Section II introduces the uniform capacity, Section III presents the system model, and decribes the multi-cell processing method for 1D and 2D scenarii. The performance analysis of MCP in comparison with other methods for 1D and 2D cases is provided, respectively, in Section IV and Section V. Section VI draws a conclusion and derives the perspectives for this study.

II. Uniform capacity

In a uniform capacity approach, the capacity at any location x in a given cell is defined to be constant and independent on the SINR level $\gamma(x)$ at this location. The uniform capacity may also be called a *ubiquitous capacity* or a *maximum fairness*. This uniform capacity constraint C_u is defined as follows:

$$\forall x, C(x) = C_u \ , \qquad (1)$$

which leads to

$$C_u = w(x)\log_2(1+\gamma(x)), \quad \forall x \qquad (2)$$

where $w(x)$ is the portion of bandwidth (or amount of resources) allocated to the position x. C_u is the normalised constant capacity that any user at any location x of a given cell will achieve. In a continuous formulation, i.e. considering a density of users distributed in a cells, we consider all possible x locations. C_u can then be defined in [bit/s/Hz/user] . The cell sum capacity C_{tot} of a cell, in [bit/s/Hz], is the total capacity reached in a given cell for an unitary bandwidth. C_{tot} can be derived as $C_{tot} = C_u\ D\ S_{cell}$, where S_{cell} is the area of the cell and D its user's density. In each cell, the total available amount of resources is limited: $\int_{cell} w(x)dx \le W_{tot}$. Combining this with the equation (2) immediately gives:

$$\int_{cell} \frac{C_u}{\log_2(1+\gamma(x))}\ dx \le W_{tot} \ , \qquad (3)$$

which, in the case of full resource use leads to:

$$C_u = \frac{W_{tot}}{\int_{cell} \frac{dx}{\log_2(1+\gamma(x))}} \ . \qquad (4)$$

Then, it is straightforward from equations (2) and (4):

$$w(x) = \frac{W_{tot}}{\int_{cell} \frac{dx}{\log_2(1+\gamma(x))}} \cdot \frac{1}{\log_2(1+\gamma(x))} \ . \qquad (5)$$

Provided the knowledge of $\gamma(x)$ for any location x, the equation (5) enables us to compute the portion of resources to be allocated to an UT placed at x. Thanks to this definition, all users obtain the same capacity independently of their SINR. The factor $1/\log_2(1+\gamma(x))$ in equation (5) is viewed as the BS-local "resource cost" for user at x and only depends on $\gamma(x)$. The minimisation of this criterion will result in the increase of system efficiency. We notice that the definition of $w(x)$ provided in equation (5) satisfies the total available resources constraint.

III. System model

In present study, the whole system is considered as a snapshot and time dimension is therefore omitted. The users are supposed to be uniformly and continuously distributed in space over the considered cellular network both for 1D and 2D scenarii. This continuous formulation allows us to define a per cell capacity that depends only on users' density. The system is supposed to be fully loaded, i.e. all resources are used by all stations.

We consider the DL transmission with no Channel State Information at Transmitter (CSIT) available at BS. Indeed, even a perfect CSIT is difficult to obtain in realistic networks. Moreover, in order to fully benefit from the MCP, not only the CSIT from a BS to its mobiles, but also the CSIT from this BS to neighbouring BSs' users is needed, difficult to obtain in real-time. We rather assume that a central (or distributed) coordinator performs the scheduling scheme selection and resources allocation to the BSs, based on UT received power level made available via feedback for handover purposes. We consider a full spectrum reuse system, and the multi-cell processing is designed to use the whole available spectral resources in each cell in a coordinated manner. The combination of signals from two or more BSs allows users to improve their SINR level: the interference level is strongly decreased by using the strongest interferers as useful signals.

Two models are studied here. First, a simple 1D continuous linear network with regularly spaced BSs is presented to serve an example to understand how the MCP contributes to the uniform capacity improvement. It also allows the derivation of the corresponding analytical model. Next, a more realistic 2D system is investigated.

A. Channel model

All BS are assumed to transmit with a constant power level P at any resource, i.e. no power control is performed. Antenna gains are supposed to be 1 since we use omnidirectional antennas. No fading is considered in this study and shadowing will be introduced depending on the scenario.

In general, a SINR of a mono-antenna signal (γ_1) at a point x attached to cell i can be written as:

$$\gamma_1(x) = \frac{P_i(x)}{\sum_{j\neq i} P_j(x) + n_0} \ , \qquad (6)$$

For any cell i, the received power at x is $P_i(x) = PKd_i^{-\alpha}(x)$, where K is the constant attenuation factor $K = (\frac{c}{4\pi f})^2$, which equals -43 dB for $f = 3.5$ GHz [6], c is the speed of light, $d_i(x)$ is the distance from BS i to location x in meters, α is the path loss exponent and n_0 is the thermal noise power.

For any spectral sharing method used in this study, the system is considered interference limited rather than only noise limited.

B. Downlink macro-diversity

Macro-diversity is used here like a distributed MISO technique, while we assume users have only one receiving antenna. We then define the resulting SINR at a location x using the macro-diversity between BS i and k :

$$\gamma_2(x) = \frac{P_i(x) + P_k(x)}{\sum_{j \neq i,k} P_j(x) + n_0} \quad (7)$$

This SINR can be obtained by an Alamouti scheme (2x1 MISO) without any CSIT knowledge. For 1D model, we only consider a 2x1 macro-diversity. For 2D model, we also consider the possibility to use a 3x1 or 4x1 MISO. The corresponding SINR can be written as:

$$\gamma_3(x) = \frac{P_i(x) + P_k(x)}{\sum_{j \neq i,k,l} P_j(x) + n_0};\ \gamma_4(x) = \frac{P_i(x) + P_k(x)}{\sum_{j \neq i,k,l,m} P_j(x) + n_0}, \quad (8)$$

k, l, m being the BSs used for macro-diversity. These SINR are due to Alamouti scheme created by 2 active BSs, while the other cooperating BSs are kept silent. This is the so called "Matrix A" in standards like 802.16e [5]. We choose the 2 strongest received signals to be the active part of the Matrix A, since standard offers the possibility to choose the permutation to use.

This formulation is obviously a baseline performance for MCP techniques. More efficient schemes could be used using more than 1 antenna at receivers, or assuming to know the instant CSIT (for example, Zero-Forcing, Dirty-Paper-Coding, Beam-Forming...[1], [7]), that promise a strong improvement of this simple MCP capacity scheme.

C. Scenarii

1) 1D scenario: In the first scenario the BSs are placed along the line (Figure 1). Similar models exist: Wyner's [8] is simple and considers only adjacent cells as interferers, with discrete path gain channel. A more elaborated model in [9] accounts for multiple tiers interferences and a path gain varying depending on the users locations. To couple our continuous approach with the simplicity of a 1D model, we consider few adjacent cells and a distance dependent path gain. We consider 4 regularly spaced BSs Z, A, B and C. For any UT at x attached to the BS A, the received SINR is:

$$\gamma(x) = \frac{P_A(x)}{P_B(x) + P_C(x) + P_Z(x) + n_0} \quad (9)$$

$$= \frac{d_A^{-\alpha}(x)}{d_B^{-\alpha}(x) + d_C^{-\alpha}(x) + d_Z^{-\alpha}(x) + \frac{n_0}{PK}}. \quad (10)$$

When using the MCP technique, the cells A and B can coordinate their signals, and adjacent cells (C and Z) of this cooperation would then be viewed as interferers.

2) 2D scenario: The 2D model is based on a classical hexagonal pattern and is still using an uniform distribution of users. In order to have a more realistic channel model, the shadowing is generated with a Sum-of-Sinus method [10] that allows parametrizable correlation distances. The received signal power at x from BS i can now be written as $P_i(x) = PK \cdot Sh_i(x) \cdot d_k^{-\alpha}(x)$, where $Sh_i(x)$ is the corresponding shadowing that follows a log-normal distribution $Sh_{dB} \sim \mathcal{N}(0dB, \sigma^2)$, with σ its standard deviation (dB).

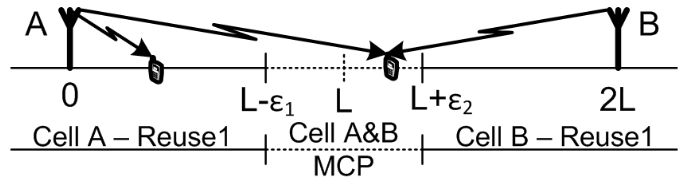

Fig. 1. Reuse1 and MCP zones in a 1D system for overlapping cells.

IV. 1D SCENARIO PERFORMANCE ANALYSIS

A. SINR and uniform capacity formulations

As introduced in previous section, to perform an efficient macro-diversity, we need to compare the capacity obtained by a single antenna transmission, and a BSs coordination. The target uniform capacity being the same everywhere on the cell, it depends not only on a particular user's SINR, but on all users' SINR. To maximise the uniform capacity, the resource consumption for every user has to be optimised. The total resources needs of all users is described as $\int \frac{dx}{\log_2(1+\gamma(x))}$, and determinates the achievable capacity.

In a cooperating network the total resource need of a cell includes not only its own users' consumption, but also the neighbouring cells users' consumption, with which the studied cell performs MCP (see Figure 1). The uniform capacity can be written:

$$C_u = \frac{W_{tot}}{\int_0^{L-\epsilon_1} \frac{dx}{\log_2(1+\gamma_1(x))} + \int_{L-\epsilon_1}^{L} \frac{dx}{\log_2(1+\gamma_2(x))} + \int_L^{L+\epsilon_2} \frac{dx}{\log_2(1+\gamma_2(x))}} \quad (11)$$

Considering a symmetric system, one can write:

$$C_u = \frac{W_{tot}}{\int_0^{L-\epsilon} \frac{dx}{\log_2(1+\gamma_1(x))} + 2\int_{L-\epsilon}^{L} \frac{dx}{\log_2(1+\gamma_2(x))}}\ , \quad (12)$$

where $L - \epsilon$ is a switching point between the Reuse1 and MCP modes. The radius of each cell is L. The cell A, is the attached cell placed at 0, and the interfering cells B, C and Z are placed, respectively, at $+2L$, $+4L$ and $-2L$. Since for now only the path loss is considered, for any $x \in]0, L]$ one can write the SINRs as:

$$\gamma_1(x) = \frac{x^{-\alpha}}{(2L-x)^{-\alpha} + (4L-x)^{-\alpha} + (2L+x)^{-\alpha} + \frac{n_0}{PK}}; \quad (13)$$

$$\gamma_2(x) = \frac{(2L-x)^{-\alpha} + x^{-\alpha}}{(4L-x)^{-\alpha} + (2L+x)^{-\alpha} + \frac{n_0}{PK}}\ . \quad (14)$$

B. Transmission mode selection criteria

According to equation (12), the uniform capacity is maximised, when the switching distance equals $L - \epsilon_0$, with ϵ_0 given by the solution of:

$$\min_{\epsilon} \left(\int_0^{L-\epsilon} g_1(x)dx + \int_{L-\epsilon}^{L} g_2(x)dx \right) \quad (15)$$

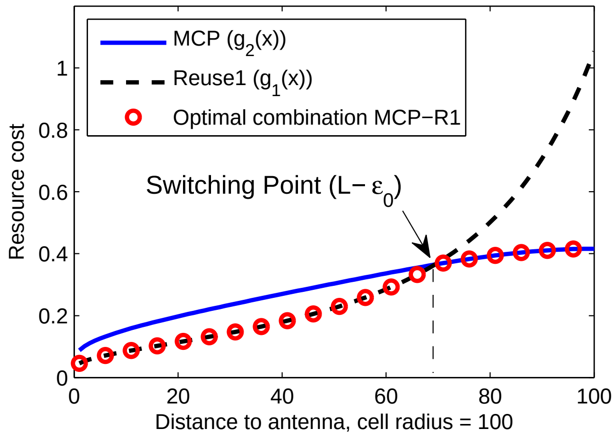

Fig. 2. Resource needs vs distance to BS. Black dashed line: standard transmission with 1 antenna $g_1(x)$; blue solid line: 2x1 MCP transmission $g_2(x)$ and red circles: optimal combination of both.

When the only channel effect is path loss, the solution consists to determine the value ϵ_0 of x for which $g_1(x) = \frac{1}{\log_2(1+\gamma_1(x))}$ and $g_2(x) = \frac{2}{\log_2(1+\gamma_2(x))}$ are equal. Thus, for every $x \in [L-\epsilon_0, L]$ we should use the MCP mode to optimise the overall cell resource sharing.

C. Numerical results

By solving the equation (15) numerically, we find that without shadowing nor fading, $\epsilon_0 = 0.31L$ (for $\alpha = 3$). Figure 2 explicitly shows that MCP should be preferred to a single BS transmission when users' location is $x > L-\epsilon_0$, since the latter needs a greater amount of resources. For example, at the cell border $x = L$ a user in Reuse1 mode needs 2.5 times more resources to reach the uniform capacity than if the MCP mode was used.

The selection of either Reuse1 or MCP mode based on this optimal limit considerably decreases the total resource needs in the cell. This strategy implies the uniform capacity gain of 30% over the full Reuse1 mode (the optimal FFR mode offers the comparable gain of 32% over the Reuse1), with a path loss exponent $\alpha = 3$ and no shadowing. While the position of this switching point is relatively constant with the path loss exponent (when $2 < \alpha < 4$, ϵ_0 only varies between $0.32L$ and $0.30L$), the uniform capacity of the cell is more dependent on path loss exponent and shadowing parameters.

Thanks to the macro-diversity effect, the optimal MCP is less affected by the shadowing effect than other methods, and its spectral efficiency degrades only a few with stronger shadowing. Figure 3 shows that for all studied methods, the spectral efficiency increases with the path loss exponent due to the reduced level of interference. However, it can be noticed that for bigger values of α, the performance gap between the optimal MCP and FFR2 is reduced. Figures 3 and 4 show that the optimal MCP offers higher uniform capacity than Reuse1 or Reuse2, for any path loss and shadowing conditions. From Figure 4, we can deduce that the optimal MCP appears

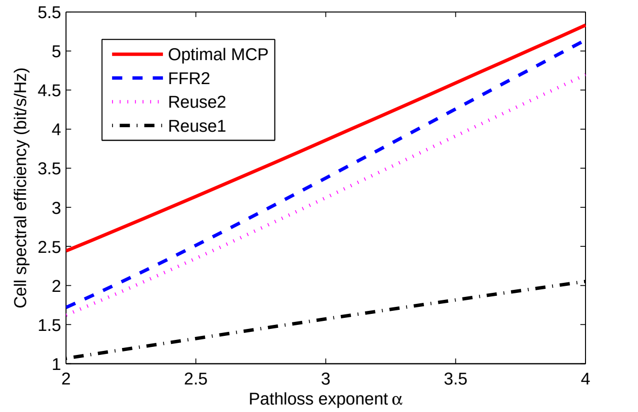

Fig. 3. Cell spectral efficiency for 1D system, as a function of path loss exponent for a given shadowing standard deviation of 5 dB.

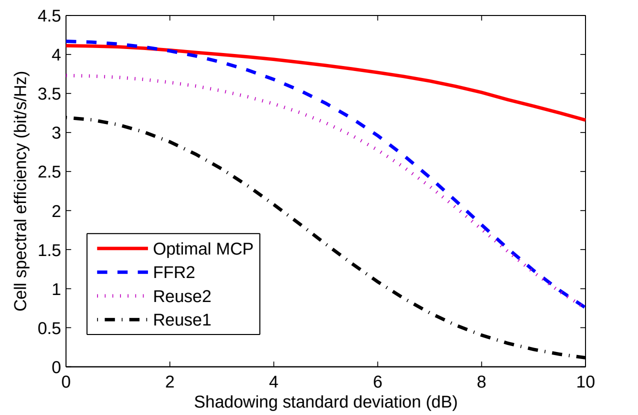

Fig. 4. Cell spectral effiency for 1D system, in function of the shadowing standard deviation, experiencing a path loss exponent. $\alpha = 3$.

to be more efficient compared to FFR2, when the shadowing standard deviation is beyond 2 dB, which is even below the standard shadowing observed for small cells [11].

To take an example, in a typical urban cell environment, with the shadowing standard deviation of 5 dB and $\alpha = 3$, the optimal MCP outperforms FFR2 by 10.7%, Reuse2 by 19.4% and Reuse1 by 114%. Thus, we can claim that for such realistic scenarii, the MCP turns out to be the most efficient communication strategy among the four studied methods.

V. 2D Scenario Performance Analysis

A. Algorithm

We assume that every UT feeds back the measured received power levels from the neighbour BSs. Based on these measurements, the BSs (or any network manager) can compute the SINRs described in equations (6), (7) and (8). Based on these SINRs, the optimal MCP is obtained by comparing the resource costs of 1, 2, 3 or 4 coordinated BSs at every location in the cell. To maximise the global system capacity, for every location x, it is decided whether one of the MCP schemes or just a simple Reuse1 mode is used.

The total resource cost needed by a Nx1 MCP, is $\frac{N}{\log_2(1+\gamma_N(x))}$. This is straightforward from the observation that a Nx1 MCP consumes a fraction $\frac{1}{\log_2(1+\gamma_N(x))}$ of resources at the BS to which the UT is attached and also the same resource portion at all other BSs concerned by the MCP.

For any x, the selection of the optimal $N_x \times 1$ MCP mode is given by N_x that satisfies:

$$\min_N \frac{N}{\log_2(1+\gamma_N(x))} \tag{16}$$

Every location x is then attributed to a set of antennas $\mathcal{S}_x, |\mathcal{S}_x|=N_x$ ($|\mathcal{S}_x|=1$ means no coordination mode—Reuse1 is chosen for this location). To compute the uniform capacity of BS B, we cumulate the resource cost over all locations $\{x : B \in \mathcal{S}_x\}$.

$$C_{u,B} = \frac{W_{tot}}{\int_{\{x:B\in\mathcal{S}_x\}} \frac{dx}{\log_2(1+\gamma_{N_x}(x))}} \tag{17}$$

The Fractional Frequency Reuse with a pattern of 4 cells (FFR4) used for comparison applies a similar way of sharing good and bad users. Two modes are available : Reuse1 for inner users and Reuse4 for outer users. These two modes need to share the total available bandwidth. Reuse1 mode gets pW_{tot}, $0 < p < 1$. The 4 cells of a pattern equally share the rest of resource $(1-p)W_{tot}$ for their Reuse4 mode. For obvious practical reasons, this resource sharing has to be static to avoid frequency overlap between adjacent cells that would strongly decrease the interest of the Reuse4 mode. The frequencies using Reuse4 mode benefit from the transmit power 4 times higher (+6dB) than Reuse1 ones, in order to have a total per cell power similar to reuse1 or MCP, and a stronger signal at borders.

Allocation of resource in FFR4 has been made so that users in both modes achieve the same capacity. In a cell, the Reuse4 users' resources are accounted 4 times, since the same amount of resources has to be reserved in the 3 other cells of the pattern.

Let's call $\mathcal{X}_{B,1}$ the set of locations x attached to cell B using the Reuse1 resources, and $\mathcal{X}_{B,f}$ the set of locations x using the protected Reuse4 resources. The uniform capacity of the cell B is derived as (similar reasoning can be found in [4]):

$$C_{u,B}^{ffr} = \frac{W_{tot}}{\int_{x\in\mathcal{X}_{B,1}} \frac{dx}{\log_2(1+\gamma_1(x))} + \int_{x\in\mathcal{X}_{B,f}} \frac{4\ dx}{\log_2(1+\gamma_f(x))}}, \tag{18}$$

where the SINR in Reuse4 mode is $\gamma_f(x)$, defined as

$$\gamma_f(x) = \frac{P_i^f(x)}{\sum_{j\neq i} P_j^f(x)c_j^f + n_0}, \text{ with } c_j^f = \begin{cases} 1, & j \text{ co-channel} \\ 0, & \text{otherwise} \end{cases} \tag{19}$$

with $P_i^f(x)$ is the power received at x from the BS i on Reuse4 frequencies.

Parameters	Value
Cell radius R	100 m
path loss exponent α	3.5
Transmit power + gains P	40 dBm
Center frequency f	3.5 GHz
Thermal Noise	-174 dBm/Hz
Bandwidth	20 MHz
Shadowing decorrelation	$1/e$ at 25m
Reuse1 portion of bandwidth p	30 %

TABLE I
SIMULATION PARAMETERS

B. Simulation results

In this section the simulation results for a continuous model for MCP and FFR4 are presented. The performance of these two methods is compared, based on the criteria previously defined by equations 17 and 18. The fixed simulation parameters are presented in Table I.

In our simulation setup, the mobiles are attached to the closest BS. The latter is the strongest in the absence of shadowing and is expected to stay the best in average over shadowing. The introduction of shadowing in the model modifies the signal strength at the receiver. As mentioned previously, in our case (which holds for most practical cellular systems), the mobiles are not necessarily reattached to the strongest BS in case of local channel variation, in order to keep a handover margin to avoid the ping-pong effect and the induced signalling cost.

Note, that we account for all the incoming co-channel interference, and not only the one from the direct neighbouring cells, or the first tier of co-channel cells.

1) Shadowing impact on uniform capacity.: Without fading nor shadowing, the only channel parameter is the path loss exponent. Thus, the distance between the BS and the mobile is the only criterion to impact the solution of equation 16. Optimal MCP and FFR4 are applied in low SINR zones (i.e. at cells' edges) for 21% and 44% of the cell surface.

The simulation results are presented in Figure 5. As well as for the 1D model, the 2D model shows that the optimal MCP performs slightly below the FFR4, when no shadowing

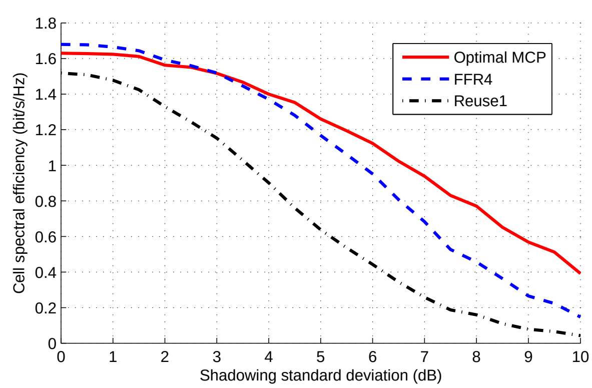

Fig. 5. Uniform capacity for 2D simulation versus shadowing standard deviation level (dB) ($\alpha = 3.5$)

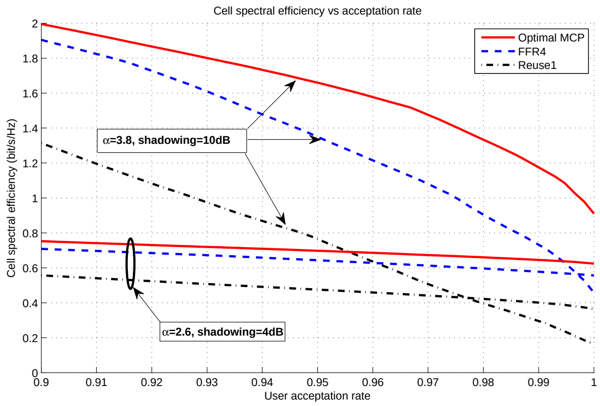

Fig. 6. Uniform capacity for 2D simulation versus active users

occurs, due to the lack of diversity. In these case, the optimal MCP obtains a gain of 8% over Reuse1 and FFR4 performs 3% better than the optimal MCP.

We observe that the optimal MCP outperforms FFR4 and of course the Reuse1, when the shadowing standard deviation is beyond 3 dB, that is for the most of practical shadowing scenarii. For example, at 8 dB of shadowing level, the optimal MCP offers 69% capacity gain over the optimal FFR, and has 4.8 times greater capacity than Reuse1.

2) Worst SINR users' effect.: The following results are issued from simulations performed for two sets of simulation parameters representing the line-of-sight (LOS) and no line-of-sight (nLOS) in urban micro-cell environments, issued from [11]. These parameters are chosen as follows: for the LOS case, the shadowing standard deviation is 4 dB and path loss exponent $\alpha = 2.6$, for the nLOS these parameters are respectively 10 dB and $\alpha = 3.8$.

The Figure 6 presents the sum capacity of the uniform capacity cell when a small percentage of users (the users with the worst reception quality) is dropped. For example, it can be seen that MCP can provide the same capacity as FFR4 and Reuse1 when the two latter reject respectively 2% and 6.5% of its users in nLOS case. If all users are accepted, the optimal MCP's capacity is twice that of FFR4 and 6 times higher than Reuse1. In the case of LOS, these percentages of rejected users for FFR4 and Reuse1 are respectively 5% and 15%.

This also confirms the fact that the worst percentiles' users have a strong negative impact on the global cell's capacity, since they need a big quantity of resources—as few as 1% of worst users can divide the uniform capacity by a factor up to 2 for Reuse1. MCP, improving edge user's SINR, is less affected by the shadowing and can use macro-diversity as an advantage.

VI. Conclusion and Future Work

The uniform capacity appears to be a useful criterion to design and evaluate the wireless network: in a given propagation environment the density of users defines the data rate offered to every user. It can be used as a design tool for a provider to perform a network service provisioning in terms of target capacity.

The studied optimal MCP transmission method was shown to be efficient to reduce the total resource consumption and thus improving the uniform capacity compared to other classical methods. Moreover, it is more resistant to shadowing phenomenon, and reduces the impact of worst SINR users on uniform capacity.

We plan to extend our results to more realistic time-varying fading channels, as well as to provide and analyse scheduling algorithms and impact of various parameters, such as availability and quality of feedback information on their performance.

Acknowledgment

The authors would like to thank Laurent Thomas (Alcatel-Lucent) for sharing his ideas and for his valuable remarks.

References

[1] Sheng Jing, David N. C. Tse, Joseph B. Soriaga, Jilei Hou, John E. Smee, and Roberto Padovani. Multicell downlink capacity with coordinated processing. *EURASIP Journal on Wireless Comm. Networks*, 2008(5):1–19, 2008.

[2] Saad G. Kiani, Geir E. Øien, and David Gesbert. Maximizing multicell capacity using distributed power allocation and scheduling. In *WCNC*, 2007.

[3] M. C. Necker. Local interference coordination in cellular ofdma networks. *Vehicular Technology Conference, 2007. VTC-2007 Fall. 2007 IEEE 66th*, pages 1741–1746, 30 2007-Oct. 3 2007.

[4] A. Alsawah and I. Fijalkow. Optimal frequency-reuse partitioning for ubiquitous coverage in cellular systems. In *15th European Signal Processing Conference (EUSIPCO)*, 2008.

[5] IEEE 802.16e-2005: Air interface for fixed and mobile broadband wireless access systems, 2005.

[6] A. Goldsmith. *Wireless Communications*. Cambridge, U.K., 2004.

[7] M. K. Karakayali, G. J. Foschini, and R. A. Valenzuela. Network coordination for spectrally efficient communications in cellular systems. 13(4):56–61, Aug. 2006.

[8] A. D. Wyner. Shannon-theoretic approach to a gaussian cellular multiple-access channel. *Information Theory, IEEE Transactions on*, 40(6):1713–1727, Nov. 1994.

[9] S. Chatzinotas, M. A. Imran, and C. Tzaras. The effect of user distribution on a linear cellular multiple-access channel. In *Proc. Third International Conference on Communications and Networking in China (ChinaCom) 2008*, pages 95–99, Aug. 25–27 2008.

[10] X. Cai and G.B. Giannakis. A two dimensional channel simulation model for shadow fading processes. In *IEEE Transactions on Vehicular Technology*, volume 52, 2003.

[11] 3GPP TR 25.996: Spatial channel model for multiple input multiple output (MIMO) simulations (Release 8), December 2008.