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Transmit Power Allocation for Self-organising Future Cellular Mobile Radio Networks

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***Abstract*—Future mobile radio networks are expected to witness an increase in capacity demand. Since the spectrum suited for mobile radio application is scarce, the spectrum efficiency of future mobile radio networks has to be increased in order to be able to meet the capacity demand. In networks applying adaptive modulation and coding, both, transmit power and bandwidth can be considered as resources. In order to achieve high spectrum efficiency, the adaptation of the allocation of transmit power and bandwidth to the time-varying capacity demand is an important topic. In this paper, an approach that adjusts the allocation of transmit power to the cells in order to adapt the network to changing capacity demands is proposed. A mathematical model that relates transmit power and the probability of outage in the cells is presented and used in an approach for the minimsation of the outage probability in the cells using convex optimisation techniques. The performance of the presented approach is evaluated and its suitability for the adaptation of the network to capacity hotspots is shown. Due to the use of a mathematical model and convex optimisation techniques, the presented approach is suited for self-organising optimisation.**

I. INTRODUCTION

Future mobile radio networks are expected to witness an increase in capacity demand as mobile radio technology evolves and new services are introduced. Since the spectrum available for mobile radio application is limited, a key issue in meeting these increased capacity demands is the increase of the spectrum efficiency of future mobile radio networks.

Additionally, the environment of a cellular mobile radio network is changing due to the mobility of the users. The capacity demands made on the cells therefore vary over time and space. In order to increase the spectrum efficiency while assuring reliable and efficient operation of the network, the assignment of resources to the cells has to be adapted dynamically and according to the actual capacity demand.

In cellular mobile radio networks applying adaptive modulation and coding, the resources transmit power and bandwidth are both parameters suited to adjust the capacity of a cell. Several approaches concerning the adjustment of the bandwidth allocation in order to adapt the network to changing capacity demands exist. Earlier works, mainly for circuit switched networks, propose the borrowing of channels based on rules [1] or using different heuristic approaches, such as neural networks or genetic algorithms [2, 3]. Concerning modern packet switched networks applying adaptive transmission techniques, approaches that allocate bandwidth either based on signal quality measurements or based on user densities have been proposed [4-6].

This paper introduces an approach that adjusts the allocation of transmit power to the cells in order to adapt a network applying adaptive transmission techniques to changing capacity demands. The cell borders are fixed and the allocated cell bandwidth is kept constant. The transmit power, however, is adjusted such that cells experiencing higher capacity demands are allocated more transmit power than cells experiencing lower capacity demands. This approach decreases the signal to interference and noise ratio (SINR) in areas of the network where little capacity is demanded and increases the SINR in areas with high capacity demand. The spectrum efficiencies of the cells and also the capacities provided by the cells can thus be adjusted according to the capacity demand.

For this purpose, an analytic model of the relation of transmit power and outage probability in the cells is derived. The model is then used in a convex optimisation problem for the allocation of transmit power to the cells. Since a mathematical model and convex optimisation techniques are used, the presented approach is suited for self-organising optimisation, such as self-organising radio resource management (RRM) for example.

The paper is organised as follows. The system model is presented in Section II. Section III introduces an analytic approach to model the relation of transmit power and outage probability in the cells, which is used in Section IV to formulate a convex optimisation problem for the allocation of transmit power to the cells of a cellular mobile radio network. Section V analyses the performance of the proposed approach and Section VI concludes the paper.

II. SYSTEM MODEL

The downlink of a cellular mobile radio network with N_C cells of radius R is considered. The system bandwidth B_sys is divided into r_f equal parts of bandwidth $\frac{B_\mathrm{sys}}{r_\mathrm{f}}$, with r_f the frequency reuse factor. The bandwidth parts are allocated to the cells such that all cells that are located at a distance of $D = \sqrt{3 r_\mathrm{f}} \cdot R$ use the same part of the bandwidth [7, 8].

Each cell i, $i = 1 \ldots N_\mathrm{C}$, provides service to K_i users. The distribution of the K_i users over the area of cell i follows the probability density function (pdf) $p^{(i)}_{\mathbf{r},\varphi}(r, \varphi)$ of the user position with r the distance and φ the angle relative to the base station (BS) of cell i.

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The signal to interference and noise ratio (SINR) of user k, $k = 1 \dots K_i$, of cell i is given by

$$\gamma_{i,k} = \frac{P_{\mathrm{tx},i}}{a_{i,k} \cdot (P_{\mathrm{I},i} + P_{\mathrm{N}})} \tag{1}$$

with $P_{\mathrm{tx},i}$ the transmit power of the BS of cell i, $a_{i,k}$ the attenuation between the BS of cell i and user k of cell i and P_{N} the receiver noise power. Inter-cell interference is in (1) represented by term $P_{\mathrm{I},i}$ which is given by the expectation value of the inter-cell interference over the cell area according to

$$P_{\mathrm{I},i} = \int_0^R \int_0^{2\pi} \sum_{\substack{j=0,\\ j\neq i}}^{N_{\mathrm{C}}} \frac{P_{\mathrm{tx},j}}{a_j^{(i)}(r,\varphi)} p_{\mathbf{r},\varphi}^{(i)}(r,\varphi)\, d\varphi dr, \tag{2}$$

where $a_j^{(i)}(r,\varphi)$ is the attenuation between location (r,φ) in cell i and BS j.

Since the change of the capacity demand on the cells can be assumed to be significantly slower than the change of the mobile radio channel, fast fading can be neglected and the attenuation $a_{i,k}$ can be divided into a term $a_{\mathrm{PL},i,k}$ due to path loss and a term a_{sh} due to shadow fading. The path loss in dB is given according to [9] by

$$a_{\mathrm{PL},i,k} = a_0 + 10\log_{10}\left(\left(r_{i,k}^2 + \Delta h_{i,k}^2\right)^{\frac{\alpha}{2}}\right) \tag{3}$$

with a_0 the attenuation at 1 meter of the antenna, $r_{i,k}$ the distance between the BS of cell i and user k of cell i, $\Delta h_{i,k}$ the difference in the heights of the antennas of the BS of cell i and terminal k of cell i and α the propagation coefficient. The shadow fading has zero mean and is log-normal distributed, i.e. the shadow fading in dB has the pdf [8]

$$p_{a_{\mathrm{sh}}}(a_{\mathrm{sh}}) = \frac{1}{\sigma_{\mathrm{sh}}\sqrt{2\pi}} \cdot e^{-\frac{a_{\mathrm{sh}}^2}{2\sigma_{\mathrm{sh}}^2}} \tag{4}$$

with σ_{sh}^2 the variance of the fading process.

Each user has a certain bit rate requirement $R_{\mathrm{bit},i,k}$. Adaptive transmission is applied and the bandwidth required to provide the required bit rate to a user is according to [10, 11] given by

$$B_{\mathrm{user},i,k} = R_{\mathrm{bit},i,k}\left[\log_2\left(1+\gamma_{i,k}\right)\right]^{-1}. \tag{5}$$

The bandwidth required to provide service to a user thus depends on the SINR at the receiver.

III. CELL OUTAGE PROBABILITY MODEL

In this section, a model to express the relation between the transmit power of a cell, the cell bandwidth and the probability that outage occurs in the cell, called cell outage probability, is derived. At first, the bandwidth required by a single user that follows the position probability function $p_{\mathbf{r},\varphi}^{(i)}(r,\varphi)$ is determined. Then, the pdf of the bandwidth required by the cell to provide service to all its users is derived. Finally, the cell outage probability is defined and it is pointed out how the model is used to relate transmit power to cell outage probability.

Remembering that the users are distributed over the area of the cell according to $p_{\mathbf{r},\varphi}^{(i)}(r,\varphi)$, the pdf $p_{a_{\mathrm{PL},i,k}}(a_{\mathrm{PL},i,k})$ of the path loss experienced by a user can be determined from $p_{\mathbf{r},\varphi}^{(i)}(r,\varphi)$ by using (3) in a random variable (RV) transformation [12]. Since path loss and shadow fading can be considered independent, the pdf $p_{a_{i,k}}(a_{i,k})$ of the total attenuation is given by the convolution of the pdf $p_{a_{\mathrm{PL},i,k}}(a_{\mathrm{PL},i,k})$ of the path loss and the pdf $p_{a_{\mathrm{sh}}}(a_{\mathrm{sh}})$ of the shadow fading [12]. Using now (1) and (5) in a RV transformation, the pdf $p_{B_{\mathrm{user},i,k}}(B_{\mathrm{user},i,k})$ of the bandwidth required by a user that follows the position probability $p_{\mathbf{r},\varphi}^{(i)}(r,\varphi)$ is determined.

Assuming uniform position probability of the users over the cell area, i.e. $p_{\mathbf{r},\varphi}^{(i)}(r,\varphi) = \frac{r}{\pi R^2}$, where $0 \le r < R$ and $0 \le \varphi < 2\pi$, the pdf of the path loss $a_{\mathrm{PL},i,k}$ can be determined to yield

$$p_{a_{\mathrm{PL},i,k}}(a_{\mathrm{PL},i,k}) = \frac{\ln(10)}{5\alpha R^2 a_0^{\frac{2}{\alpha}}} \cdot e^{\frac{\ln(10)}{10} a_{\mathrm{PL},i,k}}, \tag{6}$$

and the pdf of the total attenuation $a_{i,k}$ results to

$$\begin{aligned} p_{a_{i,k}}(a_{i,k}) \quad = & \frac{\ln(10)}{10\alpha R^2 a_0^{\frac{2}{\alpha}}} \cdot e^{\frac{c_1^2}{4c_2} + c_1 a_{i,k}} \cdot \\ & \left[\mathrm{erf}\left(\frac{c_1 + 2c_2(a_{i,k} - a_{\mathrm{PL},\min,i})}{2\sqrt{c_2}}\right)\right. \\ & \left. -\mathrm{erf}\left(\frac{c_1 + 2c_2(a_{i,k} - a_{\mathrm{PL},\max,i})}{2\sqrt{c_2}}\right)\right] \end{aligned} \tag{7}$$

with $c_1 = \frac{\ln(10)}{5\alpha}$, $c_2 = \frac{1}{2\sigma_{\mathrm{sh,dB}}^2}$ and $a_{\mathrm{PL},\min,i}$ and $a_{\mathrm{PL},\max,i}$ the smallest and largest pathloss of the cell i in dB, respectively. The pdf $p_{B_{\mathrm{user},i,k}}(B_{\mathrm{user},i,k})$ of the bandwidth $B_{\mathrm{user},i,k}$ required by a single user to transmit at its data rate requirement $R_{\mathrm{bit},i,k}$ results to

$$\begin{aligned} p_{B_{\mathrm{user},i,k}}(B_{\mathrm{user},i,k}) \quad = & \frac{R_{\mathrm{bit},i,k} \cdot \ln(2) \cdot 2^{\frac{R_{\mathrm{bit},i,k}}{B_{\mathrm{user},i,k}}} \cdot e^{\frac{c_1^2}{4c_2} + c_1 x}}{\alpha R^2 \left(2^{\frac{R_{\mathrm{bit},i,k}}{B_{\mathrm{user},i,k}}} - 1\right) B_{\mathrm{user},i,k}^2} \\ & \cdot \left[\mathrm{erf}\left(\frac{c_1 + 2c_2(x - a_{\mathrm{PL},\min,i})}{2\sqrt{c_2}}\right)\right. \\ & \left. -\mathrm{erf}\left(\frac{c_1 + 2c_2(x - a_{\mathrm{PL},\max,i})}{2\sqrt{c_2}}\right)\right] \end{aligned} \tag{8}$$

with $x = 10\log_{10}\left(\Gamma_i\left(2^{\frac{R_{\mathrm{bit},i,k}}{B_{\mathrm{user},i,k}}} - 1\right)^{-1}\right)$ where the power ratio

$$\Gamma_i = \frac{P_{\mathrm{tx},i}}{P_{\mathrm{I},i} + P_{\mathrm{N}}} \tag{9}$$

is used. Fig. 1 shows for both, the pdf of the path loss and the pdf of the total attenuation considering shadow fading, the result of the analytic model in comparison to numerical simulation results. Fig. 2 shows analytically and numerically obtained results for the pdf of the bandwidth required by a single user and for both scenarios of Fig. 1.

For the further derivation of the model, the approach of [13] is pursued. It is pointed out that the bandwidth $B_{\mathrm{cell},i}$ required by cell i is given by the sum of the bandwidths required by the users according to $B_{\mathrm{cell},i} = \sum_{k=1}^{K_i} B_{\mathrm{user},i,k}$. Assuming independent users, the central limit theorem can be applied to determine the pdf of the bandwidth required by the

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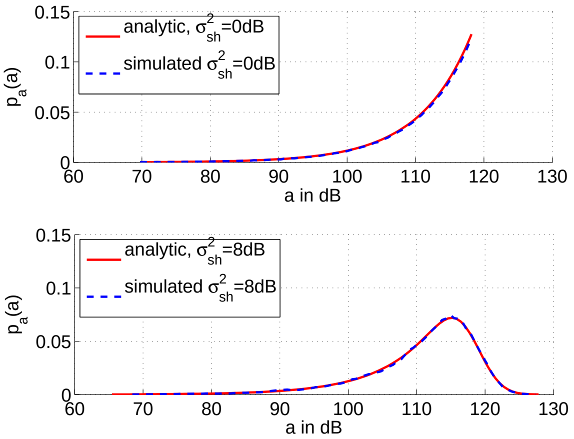

Fig. 1. Comparison of the pdfs of path loss and total attenuation considering shadow fading in a 3GPP urban macro cell scenario for uniform position probability over the cell area. $R = 250$ m, $a_0 = 34.5$ dB, $\alpha = 3.5$.

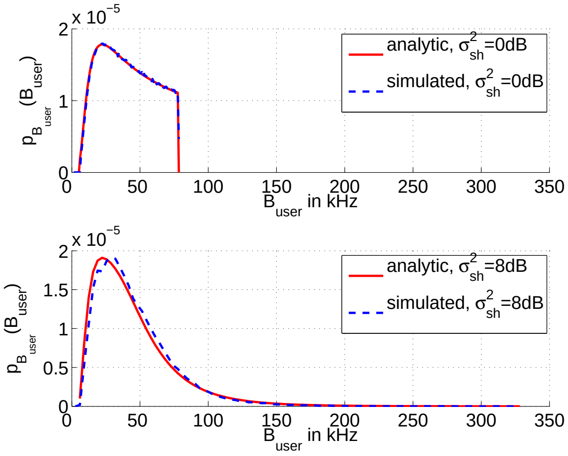

Fig. 2. Comparison of the pdfs of the bandwidth required by a single user in a 3GPP urban macro cell scenario for uniform position probability over the cell area. $R = 250$ m, , $a_0 = 34.5$ dB, $\alpha = 3.5$, $\Gamma = 120$ dB, $R_{\mathrm{bit}} = 100$ kbit/s.

cell. The pdf of the required cell bandwidth $B_{\mathrm{cell},i}$ is, thus, Gaussian distributed and its cumulative distribution function (cdf) is given by $\Phi\left(\frac{B_{\mathrm{cell},i}-\mu_{\mathrm{cell},i}(\Gamma_i)}{\sigma_{\mathrm{cell},i}(\Gamma_i)}\right)$, with $\Phi(\cdot)$ the cdf of a Normal distributed random variable with zero mean and a variance of one [12]. Mean $\mu_{\mathrm{cell},i}(\Gamma_i)$ and variance $\sigma^2_{\mathrm{cell},i}(\Gamma_i)$ of the required cell bandwidth $B_{\mathrm{cell},i}$ are given by the sums of the means and variances of the bandwidths required by the active users of cell i, respectively, and are therefore according to (8) functions of Γ_i.

As a consequence, the probability that the required cell bandwidth $B_{\mathrm{cell},i}$ is larger than a certain bandwidth B is given by

$$p\left(B_{\mathrm{cell},i} > B, \Gamma_i\right) = 1 - \Phi\left(\frac{B - \mu_{\mathrm{cell},i}\left(\Gamma_i\right)}{\sigma_{\mathrm{cell},i}\left(\Gamma_i\right)}\right), \qquad (10)$$

which gives the probability that not all users of cell i can be served with their required bit rate $R_{\mathrm{bit},i,k}$ if cell i is allocated a bandwidth of B and a power ratio of Γ_i. As a consequence, outage will occur among some or all of the users of cell i with probability $p\left(B_{\mathrm{cell},i} > B, \Gamma_i\right)$, which is therefore called cell outage probability $p_{\mathrm{cell},i}\left(B, \Gamma_i\right)$.

Note that (10) relates cell bandwidth, transmit power or power ratio Γ_i, respectively, and cell outage probability. In the further discussion, the cell bandwidth is according to Section II set to a constant value, such that (10) provides information on the cell outage probability in dependence of the transmit power or power ratio, respectively.

In [13], it is shown that the approximation of the pdf of the required cell bandwidth by a Normal distribution is valid even for small number of users. Note, however, that the pdfs $p_{B_{\mathrm{user},i,k}}\left(B_{\mathrm{user},i,k}\right)$ of the bandwidth required by the single users have to be comparable, without one or few dominating the others [12, 13].

IV. CONVEX TRANSMIT POWER ALLOCATION

In this section, a convex optimisation problem that minimises the largest cell outage probability by adapting the allocation of transmit power to the cells of a cellular mobile radio network is derived. It is assumed that for each cell, the relation between cell outage probability and transmit power is modeled by (10). Note that $\mu_{\mathrm{cell},i}\left(\Gamma_i\right)$ and $\sigma^2_{\mathrm{cell},i}\left(\Gamma_i\right)$ can be different for each cell, depending on the number of active users and the user position probability $p^{(i)}_{\mathbf{r},\varphi}\left(r,\varphi\right)$ of the cell.

Instead of directly allocating transmit powers $P_{\mathrm{tx},i}$ to the cells, the allocation of the ratio between transmit power and average interference plus noise power, as expressed by the power ratio Γ_i of (9), is pursued. This allows a convex formulation of the optimisation problem. The power ratios Γ_i are then used to determine the transmit powers $P_{\mathrm{tx},i}$ of the cells.

For this purpose, a matrix representation of the network that models the dependence of the power ratios Γ_i and the transmit powers $P_{\mathrm{tx},i}$ is derived. Resolving (9) for $P_{\mathrm{tx},i}$ and substituting (2), the linear system of equations

$$\mathbf{P}_{\mathrm{tx}} = \mathrm{diag}\left(\mathbf{\Gamma}\right) \cdot \left(\mathbf{G} \cdot \mathbf{P}_{\mathrm{tx}} + \mathbf{P}_{\mathrm{N}}\right) \qquad (11)$$

is formulated, with $\mathbf{P}_{\mathrm{tx}} = \left[P_{\mathrm{tx},1}\,,\,\ldots\,,\,P_{\mathrm{tx},N_{\mathrm{C}}}\right]^{\mathrm{T}}$, $\mathbf{\Gamma} = \left[\Gamma_1\,,\,\ldots\,,\,\Gamma_{N_{\mathrm{C}}}\right]^{\mathrm{T}}$, $\mathrm{diag}\left(\mathbf{\Gamma}\right)$ a $N_{\mathrm{C}} \times N_{\mathrm{C}}$ matrix with the elements of vector $\mathbf{\Gamma}$ on the diagonal and zeros elsewhere, $\mathbf{G}$ a $N_{\mathrm{C}} \times N_{\mathrm{C}}$ matrix with elements

$$g_{lm} = \begin{cases} 0 & \text{if } \; l = m \\ \int\limits_0^R \int\limits_0^{2\pi} \frac{1}{a^{(l)}_m\left(r,\varphi\right)} p^{(l)}_{\mathbf{r},\varphi}\left(r,\varphi\right) d\varphi dr & \text{else} \end{cases} \qquad (12)$$

and $\mathbf{P}_{\mathrm{N}}$ a vector of size N_{C} containing the receiver noise power. Resolving (11) for $\mathbf{P}_{\mathrm{tx}}$ yields

$$\mathbf{P}_{\mathrm{tx}} = \left(\mathbf{I} - \mathrm{diag}\left(\mathbf{\Gamma}\right) \cdot \mathbf{G}\right)^{-1} \cdot \mathrm{diag}\left(\mathbf{\Gamma}\right) \cdot \mathbf{P}_{\mathrm{N}}, \qquad (13)$$

with $\mathbf{I}$ the $N_{\mathrm{C}} \times N_{\mathrm{C}}$ unity matrix with ones on its diagonal and zeros elsewhere. Equation (13) can be used to calculate the transmit powers $P_{\mathrm{tx},i}$ from the power ratios Γ_i. Note, however, that (13) always has a solution, but only positive solutions have

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physical meaning. According to [14], the solution of (13) is always positive if

$$\rho\left(\operatorname{diag}\left(\mathbf{x}\left(\boldsymbol{\Gamma}\right)\right)\cdot\mathbf{G}\right)<1 \tag{14}$$

holds, with $\mathbf{x}\left(\boldsymbol{\Gamma}\right)=\left[x_1(\Gamma_1)\,,\,\ldots\,,\,x_{N_\mathrm{C}}(\Gamma_{N_\mathrm{C}})\right]^\mathrm{T}$, $x_i(\Gamma_i)$ an arbitrary function of Γ_i and the spectral radius $\rho\left(\mathbf{M}\right)=\max_p\left\{\left|\lambda_p\left(\mathbf{M}\right)\right|\right\}$, where $\lambda_p\left(\mathbf{M}\right)$ are the eigenvalues of matrix $\mathbf{M}$. If (14) is met, the result of (13) is positive and the allocation of the power ratios Γ_i is called a feasible allocation.

Using above matrix representation of the network, the optimisation problem

$$\begin{array}{ll} \underset{\Gamma_i}{\min} & \underset{i}{\max}\left\{p_{\mathrm{cell},i}\left(\frac{B_\mathrm{sys}}{r},\Gamma_i\right)\right\} \\ \text{s. t.} & \rho\left(\operatorname{diag}\left(\mathbf{x}\left(\boldsymbol{\Gamma}\right)\right)\cdot\mathbf{G}\right)<1 \end{array} \tag{15}$$

is formulated. This optimisation problem allocates power ratios Γ_i to the cells such that the largest cell outage probability is minimised while only feasible power ratio allocations are taken into account, according to the side condition. After the optimum power ratio allocation is found, the transmit powers $P_{\mathrm{tx},i}$ are determined using (13).

In order to solve (15) using convex optimisation techniques, objective function and constraint have to be convex [15]. According to [14], (14) is convex if the elements $x_i(\Gamma_i)$ of vector $\mathbf{x}\left(\boldsymbol{\Gamma}\right)$ are log-convex functions. This is not fulfilled in the constraint of (15), since $x_i=\Gamma_i$ holds in (15). For this reason, the modified power ratio vector

$$\tilde{\boldsymbol{\Gamma}}=\left[\ln(\Gamma_1)\,,\,\ldots\,,\,\ln(\Gamma_{N_\mathrm{C}})\right]^\mathrm{T} \tag{16}$$

is defined. Substituting $\tilde{\boldsymbol{\Gamma}}$ for $\boldsymbol{\Gamma}$ in (14) leads to $x_i=e^{\tilde{\Gamma}_i}$ which is a log-convex function. Using the modified power ratio $\tilde{\Gamma}_i$, the constraint of the optimisation problem is thus convex.

Concerning the objective function, convexity can be achieved by introducing the utility function

$$u_i\left(\tilde{\Gamma}_i\right)=-\log\left(1-p_{\mathrm{cell},i}\left(\frac{B_\mathrm{sys}}{r},e^{\tilde{\Gamma}_i}\right)\right), \tag{17}$$

which can be shown empirically to be convex. The optimisation problem of (15) can now be expressed in the convex formulation

$$\begin{array}{ll} \underset{\tilde{\Gamma}_i}{\min} & \underset{i}{\max}\left\{u_i\left(\tilde{\Gamma}_i\right)\right\} \\ \text{s. t.} & \rho\left(\operatorname{diag}\left(e^{\tilde{\boldsymbol{\Gamma}}}\right)\cdot\mathbf{G}\right)<1 \end{array} \tag{18}$$

Note that the optimisation problems of (15) and its convex formulation of (18) lead to a balancing of the cell outage probabilities $p_{\mathrm{cell},i}$ of all cells.

V. PERFORMANCE RESULTS

According to the system model of Section II, the cells of the network are divided into r_f different groups with orthogonal bandwidth allocations. Within each group, all cells use the same part of the system bandwidth. As a consequence, there exists no mutual influence between cells of different groups and in order to gain performance results, it is sufficient to consider a subnetwork that consists of the cells of a single group.

TABLE I
COMMON PERFORMANCE ANALYSIS PARAMETERS.

Cell radius R	250 m
Height of the BSs/users	32 m/1.5 m
User distribution over cell area	uniform
Carrier frequency	1.9 GHz
Propagation model, a_0, α	3GPP Urban Macro, 34.5 dB, 3.5
Shadow fading variance σ^2_sh	8 dB
Frequency reuse factor r_f	3
System bandwidth B_sys	10 MHz
User data rate $R_{\mathrm{bit},i,k}$	100 $\frac{\mathrm{kbit}}{\mathrm{s}}$
Cell bandwidth	3.33 MHz
Noise power P_N	-102 dBm

For performance analysis of the proposed approach, two different urban scenarios with high data rate requirements are used. The common performance analysis parameters are summarised in Table I.

The first scenario is a symmetric scenario with $N_\mathrm{C}=13\cdot r_\mathrm{f}$ cells. The considered subnetwork therefore has size $\tilde{N}_\mathrm{C}=13$ and consists of the cells of one group, cf. Fig. 3. A wrap-around technique [7] that wraps the scenario on a torus is applied such that for each cell, two tiers of interferers are considered. One cell supports a variable number N_hs of users, the remaining cells support a constant number N_0 of users, as shown in Fig. 3. A hotspot is thus created by adjusting the number N_hs of users of the centre cell.

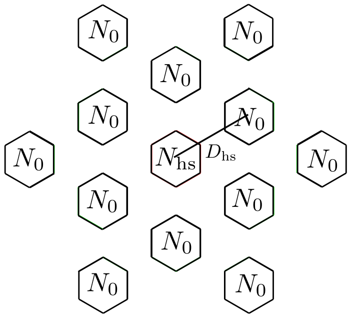

Fig. 3. Performance analysis scenario.

Fig. 4 shows the cell outage probability of the first scenario as a function of the number N_hs of users in the hotspot cell and for different values of N_0. The figure shows that up to a certain strength of the hotspot, the proposed approach is capable of allocating the transmit power to the cells according to the different demand distributions such that low cell outage probability is achieved. The proposed approach is thus capable of concentrating the capacity of a cellular mobile radio network at a hotspot. The point where the cell outage probability of the first scenario increases significantly depends on the number N_0 of users in the cells surrounding the hotspot and the number N_hs of users in the hotspot. Note that for constant cell outage probability, the capacity of the whole network decreases if the strength of the hotspot increases.

In the second scenario, several hotspots are considered. To quantify the density of the hotspots, the hotspot reuse factor r_hs, which is defined similar to the frequency reuse factor

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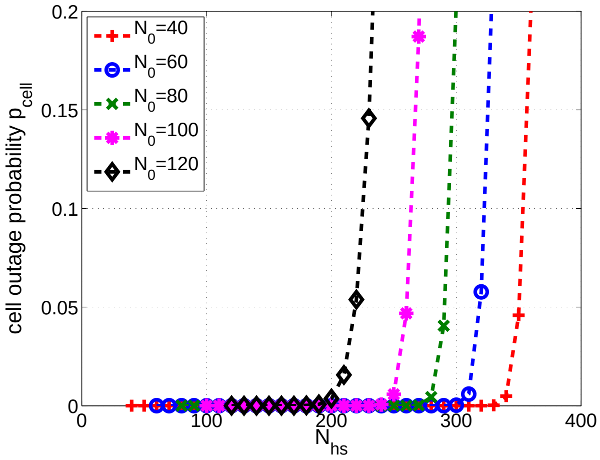

Fig. 4. Cell outage probability of the first scenario in dependence of the number N_{hs} of users in the hotspot cell and for different user densities N_0.

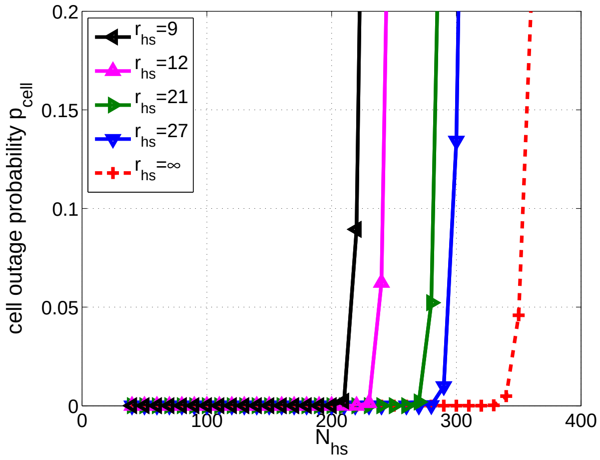

Fig. 5. Cell outage probability of the second scenario in dependence of the number N_{hs} of users in the hotspot cell and for different r_{hs}. $N_0 = 40$.

r_{f}, is introduced. The smallest distance between two hotspots is given by $D_{\mathrm{hs}} = \sqrt{3 r_{\mathrm{hs}}} \cdot R$ and the size of the network required to achieve two tiers of interfering hotspots is given by $N_{\mathrm{C}} = 13 \cdot r_{\mathrm{hs}}$. Again, a subnetwork of size $\tilde{N}_{\mathrm{C}} = 13 \cdot \frac{r_{\mathrm{hs}}}{r_{\mathrm{f}}}$ consisting of all cells that use the same part of the system bandwidth is considered and the wrap around technique is applied, such that each hotspot has two tiers of interfering hotspots.

Fig. 5 shows the cell outage probability of the second scenario as a function of the number N_{hs} of users in the hotspot cell and for different r_{hs}. As expected, the cell outage probability decreases with increasing hotspot reuse factor, since the hotspot density decreases with increasing r_{hs}. Since in the first scenario, no interfering hotspots exist, the hotspot reuse distance in the first scenario is infinite such that the performance of the first scenario as shown in Fig. 4 is the lower border for the performance of the second scenario.

VI. CONCLUSION

In this paper, a new approach for the adaptation of a cellular mobile radio network to the dynamically changing capacity demands in the network is introduced. The bandwidth allocated to the cells is fixed, but the transmit power allocated to the cells is adjusted in order to adapt the capacities of the cells according to the demand. A mathematical model of transmit power and outage probability in the cells is derived and used to formulate a convex transmit power allocation problem for the minimisation of the outage probability in the cells. The optimisation problem is solved using convex optimisation techniques and it is shown that the presented approach is capable of effectively concentrating the capacity of the network at points where high capacity is demanded. The proposed approach is thus able to assure maximum Quality of Service (QoS) to the users while providing high network capacity. Since a mathematical model and convex optimisation techniques are applied, the presented approach is applicable for self-organising optimisation, such as self-organising radio resource management (RRM) for example, which is of great interest for the operation of future cellular mobile radio networks.

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