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Measurement Based Cell Bandwidth Allocation in Cellular Mobile Radio Networks using Power-Bandwidth Characteristics

Philipp P. Hasselbach[1], Anja Klein[1] and Ingo Gaspard[2]
1. Technische Universität Darmstadt, Institut für Nachrichtentechnik, Fachgebiet Kommunikationstechnik, Merckstr. 25, 64283 Darmstadt, Germany
2. Deutsche Telekom Laboratories, Darmstadt, Germany
Phone: +49 6151 16 5353
Fax: +49 6151 16 5348
Email: p.hasselbach@nt.tu-darmstadt.de

Abstract

Future mobile radio networks are expected to witness increasing capacity demands. In order to be able to provide more and more capacity with the limited spectrum available to mobile communication, the spectrum efficiency of future mobile radio networks has to be increased. In this scope, the adaptation of the assignment of the resources power and bandwidth to the time-varying demands of the users is an important topic. Power-Bandwidth Characteristics represent the interdependence of transmit power and cell bandwidth considering behaviour and environment of cells and users. They therefore provide important information required for the efficient assignment of resources. The application of Power-Bandwidth Characteristics for resource assignment, however, has so far not yet been shown. In this paper, the allocation of bandwidth to the cells of a cellular mobile radio network using Power-Bandwidth Characteristics is presented. An efficient approach using convex optimisation techniques is introduced and a distributed implementation is proposed. The approach is shown to be capable of significantly increasing the spectrum efficiency, and thus also the system capacity, of a cellular mobile radio network. Due to the use of convex optimisation and since Power-Bandwidth Characteristics can be derived from system measurements, the presented method is suited for self-organising optimisation which is of great interest for future mobile radio networks. [1] [2]

1 Introduction

As mobile radio technology evolves, the introduction of new services and the growing needs of the users lead to higher data rate requirements and thus rising capacity demands. The spectrum suited for mobile communication, however, is limited. In order to be able to fulfil the increasing capacity demands, the spectrum efficiency therefore has to be increased.

Cellular mobile radio networks are able to achieve high system capacity since the cellular concept allows to use the same resources several times. Due to this so called reuse of resources, however, inter-cell interference arises between cells that use the same resources. This interference impacts signal quality and in order to reliably achieve sufficient signal quality, the assignment of resources to the cells of a cellular mobile radio network has to be carried out carefully. Furthermore, since the behaviour of the users and thus the capacity demand vary over time, the resource assignment has to be dynamically adapted to the capacity demand in order to achieve high spectrum efficiency.

Two main approaches exist for that purpose. First, each user is assigned a certain bandwidth from the totally available bandwidth. This assignment is done based on measurements of the signal quality as in [1-3], for example. Since propagation conditions, and with this approach also interference strength, vary quickly, the assignment of frequencies to users has to be carried out in timescales of milliseconds, leading to very high effort in signalling and strong dependence on quick and reliable signal quality measurements.

Alternatively, chunks of bandwidth are assigned to the cells and the users of a cell are assigned bandwidth from these chunks. Since the assignment of chunks of bandwidth is carried out observing a certain minimum spatial separation between cells that use the same frequencies, a certain signal quality is assured without further control while the high signalling overhead of the first approach is avoided. Several general work as well as several heuristic approaches regarding this approach have been proposed, such as [4-9], for example.

In [10], Power-Bandwidth Characteristics have been proposed for resource assignment. They represent the interdependence of transmit power and cell bandwidth considering behaviour and

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environment of cells and users and thus reveal important information for efficient resource assignments. The application of Power-Bandwidth Characteristics for the assignment of resources, however, has not been shown yet.

In this paper, the application of Power-Bandwidth Characteristics for the allocation of bandwidth to the cells of a cellular mobile radio network is introduced. An approach using convex optimisation techniques to efficiently provide optimum results is presented and a distributed implementation proposed. Since Power-Bandwidth Characteristics can be derived from system measurements and since convex optimisation techniques are used, the presented approach is suited for self-organising optimisation which is of great interest for future mobile radio networks.

The paper is organised as follows. Section 2 presents the system model. Section 3 gives a summary on Power-Bandwidth Characteristics which are used in Section 4 to set up a convex optimisation problem for the allocation of bandwidth to the cells of a cellular mobile radio network. Section 5 presents a distributed implementation of the algorithm, Section 6 investigates the performance of the proposed approach using simulations and Section 7 concludes the paper.

2 System Model

A cellular mobile radio network with N_{C} cells of radius R with the base stations (BSs) located in the centre of the cells is considered. Every cell i, $i = 1 \dots N_{\mathrm{C}}$, supports a number of K_i users with certain bit rate requirements $R_{\mathrm{bit},i,k}$, $k = 1 \dots K_i$. The distribution of the users over the area of a cell is given by the probability density function (PDF) $p_{\mathbf{r},\varphi}(r,\varphi)$ with r the distance and φ the angle relative to the BS.

Several cells of the network can use the same part of the spectrum simultaneously. Due to this reuse of resources, inter-cell interference arises between cells that use the same frequencies. Assuming exponential power loss propagation [11], the signal to interference and noise ratio (SINR) $\gamma_{i,k}$ of user k of cell i is given by

$$\gamma_{i,k} = P_{\mathrm{tx}} \left(P_{\mathrm{N}} + P_{\mathrm{I}}\right)^{-1} \cdot d_{i,k}^{-\alpha} \tag{1}$$

with P_{tx} the transmit power spectral density (PSD), P_{N} the noise PSD of the receiver, P_{I} the inter-cell interference PSD, $d_{i,k}$ the distance between between user k and its BS i and α the pathloss coefficient. The inter-cell interference is assumed to be constant over the whole area of the cell. Assuming Gaussian Signalling, the bandwidth $\tilde{B}_{i,k}$ required by user k of cell i to transmit at data rate $R_{\mathrm{bit},i,k}$ over a radio link is according to [12] given by

$$\tilde{B}_{i,k} = R_{\mathrm{bit},i,k} \left[\log_2\left(1 + \gamma_{i,k}\right)\right]^{-1}. \tag{2}$$

The bandwidth $\tilde{B}_{\mathrm{cell},i}$ required by cell i to support all its K_i users with their bit rate requirements is given by the sum of the bandwidths required by the K_i users:

$$\tilde{B}_{\mathrm{cell},i} = \sum_{k=1}^{K_i} \tilde{B}_{k,i}. \tag{3}$$

In order to control inter-cell interference and to assure sufficient signal quality, the available frequencies are assigned such that two cells that use the same frequencies are separated by a certain minimum distance D, called reuse distance. The reuse distance is related to the cell radius R by $D = \sqrt{3r} \cdot R$, where r is a rhombic number [13]. A Neighbourhood Group is defined as a group of exactly r cells that are all mutually located within the reuse distance D [14]. Variable r is therefore called Neighbourhood Group size. With $\mathbb{I} = [1, \dots, N_{\mathrm{C}}] \subset \mathbb{N}$, the set of cells $\{i_1, \dots, i_r\} \subseteq \mathbb{I}$

consequently forms a Neighbourhood Group if and only if $d(i_l, i_m) < D, \quad l, m = 1 \dots r$, holds, where $d(i_l, i_m)$ is the distance between the centres of cell i_l and cell i_m. The set of all Neighbourhood Groups $\mathbb{G}$ is thus defined by

$$\mathbb{G} := \{\{i_1, \dots, i_r\} \subseteq \mathbb{I} | d(i_l, i_m) < D\}, \quad l, m = 1 \dots r. \tag{4}$$

Since all cells of a Neighbourhood Group are located within the reuse distance, each frequency can not be used by more than a single cell within each Neighbourhood Group and

$$\sum_{n \in \{i_1, \dots, i_r\}} B_{\text{cell},n} \leq B_{\text{sys}} \quad \forall \ \{i_1, \dots, i_r\} \in \mathbb{G} \tag{5}$$

holds, as shown in [14], where $B_{\text{cell},i}$ and B_{sys} are the bandwidth assigned to cell i and the totally available bandwidth, respectively. Note that the difference between Neighbourhood Groups and clusters, as they are usually defined in the context of cellular networks, is that Neighbourhood Groups may have several different shapes and can overlap each other [13, 14].

3 Power-Bandwidth Characteristics

3.1 Analytic Derivation

Assuming that each user of a cell follows the user position probability $p_{\mathbf{r},\varphi}(r, \varphi)$, the PDF of the distance $d_{i,k}$ between user and BS can be derived with random variable (RV) transformation [15]. Using the PDF of $d_{i,k}$ and (1), the PDF of the SINR $\gamma_{i,k}$ can be derived and from the PDF of the SINR and using (2), the PDF of the bandwidth $\tilde{B}_{i,k}$ required by a single user to transmit at bit rate $R_{\text{bit},i,k}$ can be derived, both using RV transformations [16]. The PDF of the bandwidth $\tilde{B}_{i,k}$ and its mean $\mu_{i,k}$ and variance $\sigma^2_{i,k}$ are consequently functions of the transmit PSD P_{tx}, the interference PSD P_{I} and the bit rate $R_{\text{bit},i,k}$.

The bandwidth $\tilde{B}_{\text{cell},i}$ required by the whole cell is according to (3) given by the sum of the bandwidths $\tilde{B}_{i,k}$ required by the individual users of the cell. Assuming independent users, the PDF of the required cell bandwidth $\tilde{B}_{\text{cell},i}$ of cell i can be derived using the Central Limit Theorem. Since the Central Limit Theorem only holds if none of the distributions is dominant, the bit rate requirements $R_{\text{bit},i,k}$ have to be of comparable order, since only they determine, due to the assumption that each user follows the user position probability $p_{\mathbf{r},\varphi}(r, \varphi)$, the differences of the bandwidth demands of different users. The PDF of the required cell bandwidth $\tilde{B}_{\text{cell},i}$ is, thus, Gaussian distributed and its cumulative distribution function (CDF) given by

$$p\left(\tilde{B}_{\text{cell},i} < B_{\text{cell},i}\right) = \Phi\left(\frac{B_{\text{cell},i} - \mu_{\text{cell},i}}{\sigma_{\text{cell},i}}\right) \tag{6}$$

with Φ the CDF of a Normal distributed random variable with zero mean and a variance of one [15] and $\mu_{\text{cell},i} = \sum_{k=1}^{K_i} \mu_{i,k}$ and $\sigma^2_{\text{cell},i} = \sum_{k=1}^{K_i} \sigma^2_{i,k}$ mean and variance of the PDF of the required cell bandwidth $\tilde{B}_{\text{cell},i}$, respectively. Mean and variance of the required cell bandwidth are consequently functions of the transmit PSD P_{tx}, the interference PSD P_{I} and the bit rates $R_{\text{bit},i,k}$, and (6) thus relates assigned cell bandwidth $B_{\text{cell},i}$, transmit power P_{tx} and interference power P_{I} considering the user distribution and the propagation conditions.

The left side of (6) gives the probability that the required cell bandwidth $\tilde{B}_{\text{cell},i}$ is less than the assigned cell bandwidth $B_{\text{cell},i}$. It is thus the probability that the assigned cell bandwidth $B_{\text{cell},i}$ is sufficient to provide the required bit rates to all users of cell i. Consequently, the probability

$$p_{\text{cell},i}\left(B_{\text{cell}}\right) = 1 - p\left(\tilde{B}_{\text{cell},i} < B_{\text{cell}}\right) \tag{7}$$

is the probability that the bandwidth B_{cell} is not sufficient to provide the required bit rates to all users of cell i, which means that outage will occur in cell i. Probability $p_{\text{cell},i}$ of (7) is therefore called cell outage probability.

Considering the derivation of (6), it can be easily seen that (6) reflects user distribution, the attenuation between users and BS as well as inter-cell interference. Equation (6) thus describes the cell with its environment and the behaviour of its users from the point of view of resource use. Mean and variance $\mu_{\text{cell},i}$ and $\sigma^2_{\text{cell},i}$, respectively, of the CDF of (6) depend on the transmit power and interference power and are specific to the cell. The CDF consequently is characteristic for the interdependence of transmit power and cell bandwidth of the cell and (6) is therefore also called Power-Bandwidth Characteristic. Power-Bandwidth Characteristics thus represent the interdependence of transmit power and cell bandwidth for a certain cell outage probability.

3.2 Measurement of Power-Bandwidth Characteristics

In practice, the distribution of the users over the area of a cell and size and shape of a cell are not exactly known. Also, the analytic calculations of Section 3.1 are in general not possible with realistic user distributions.

For practical application, the measurement of Power-Bandwidth Characteristics is therefore proposed. It is assumed that at BS i, a set of $N_{\gamma,i}$ SINR measurements from the users assigned to the BS is available. The data set is denoted by $\gamma_{i,m}$, $m = 1 \ldots N_{\gamma,i}$. This set is then transformed into a set of bandwidth values required for the transmission of a bit rate equal to a certain bit rate unit $R_{\text{bit,unit}}$. Regarding (2), the transformation is done according to

$$\tilde{B}_{\text{unit},i,m} = \frac{R_{\text{bit,unit}}}{\log_2\left(1+\gamma_{i,m}\right)}. \tag{8}$$

For this set of bandwidth values, the empirical distribution and its mean $\mu_{\text{unit},i}$ and variance $\sigma^2_{\text{unit},i}$ are calculated which are used to calculate estimates of mean and variance of the required cell bandwidth $\tilde{B}_{\text{cell},i}$ using [10]

$$\hat{\mu}_{\text{cell},i} = \mu_{\text{unit},i} \cdot \sum_{k=1}^{K_i} \frac{R_{\text{bit},i,k}}{R_{\text{bit,unit}}}, \tag{9}$$

$$\hat{\sigma}^2_{\text{cell},i} = \sigma^2_{\text{unit},i} \cdot \sum_{k=1}^{K_i} \left(\frac{R_{\text{bit},i,k}}{R_{\text{bit,unit}}}\right)^2. \tag{10}$$

The estimates $\hat{\mu}_{\text{cell},i}$ and $\hat{\sigma}^2_{\text{cell},i}$ of mean and variance of the required cell bandwidth as given by (9) and (10), respectively, can now be used in the Power-Bandwidth Characteristic of (6) to replace the analytically derived mean $\mu_{\text{cell},i}$ and variance $\sigma^2_{\text{cell},i}$ of the required cell bandwidth.

4 Convex Cell Bandwidth Allocation

An important aspect of the assignment of resources to the cells of a cellular mobile radio network is the determination of how much bandwidth is actually required by a cell. The Power-Bandwidth Characteristic of (6) can be used for this purpose, since assuming fixed transmit power, it relates the assigned cell bandwidth $B_{\text{cell},i}$ to the cell outage probability $p_{\text{cell},i}$.

Since cells that are located within a spatial distance of less than the reuse distance D can not use the same resources, (5) has to be observed and the allocation of bandwidth to a cell has effect on the surrounding cells. Large number of dependencies therefore have to be considered in the allocation of bandwidth to the cells of a cellular mobile radio network. Furthermore, as each cell may encounter a different situation in terms of inter-cell interference, number of users, user distribution and user behaviour, each cell will have different requirements concerning the cell bandwidth, and the allocation of a certain amount of bandwidth will in generally have different effect on each cell and its users.

These different situations and different requirements on the cell bandwidth addressed above, however, are reflected by the Power-Bandwidth Characteristics. In order to carry out a good bandwidth allocation, the cell outage probability of (7) is therefore proposed as a measure of the quality of a resource assignment. The goal of the bandwidth allocation is to assure the lowest possible cell outage probability in each cell for a given totally available bandwidth B_{sys}. The bandwidth allocation can thus be expressed by the optimisation problem

$$\begin{array}{ll} \min\limits_{B_{\mathrm{cell},i}} & \max\limits_{i} \left\{ p_{\mathrm{cell},i} \left(B_{\mathrm{cell},i} \right) \right\} \\ \text{s. t.} & B_{\min,i} \leq B_{\mathrm{cell},i} \leq B_{\max,i} \\ & \sum\limits_{n \in \{i_1,\ldots,i_r\}} B_{\mathrm{cell},n} \leq B_{\mathrm{sys}} \quad \forall \ \{i_1,\ldots,i_r\} \in \mathbb{G} \end{array} \tag{11}$$

with $B_{\min,i}$ and $B_{\max,i}$ lower and upper bounds for the assigned cell bandwidths, respectively. The second side condition is the constraint concerning the sum bandwidth of all cells within a Neighbourhood Group as given by (5).

Note that the optimisation problem of (11) determines the optimum cell bandwidths without carrying out the actual assignment of frequencies to the cells. The bandwidth allocation is therefore not limited to the allocation of discrete portions of bandwidth. Instead, (11) can be treated as a continuous optimisation problem. The assignment of certain frequencies or chunks of bandwidth, e. g. subcarriers, may be carried out based on the solution of (11) using efficient heuristics, as proposed in [14], for example.

In order to use convex optimisation techniques for the solution of (11), objective function and constraints have to be convex, according to [17]. For the constraints of (11), this holds true. The Gaussian CDF, however, is neither convex nor concave, consequently also the cell outage probability as defined by (7), and thus the objective function of (11), is neither convex nor concave. To resolve this problem, the utility function

$$u_i \left(B_{\mathrm{cell}} \right) = - \log \left(1 - p_{\mathrm{cell},i} \left(B_{\mathrm{cell}} \right) \right) \tag{12}$$

is defined. Since the Gaussian CDF is a log-concave function [17], the utility function of (12) is convex.

The cell outage probability of (7) can in (11) now be replaced by (12) to achieve a convex problem formulation. However, several solutions to the optimisation problem of (11) may exist even though the largest cell outage probability is minimised since several bandwidth allocations are possible for all cells that achieve better cell outage probability than the maximum. To assure a single solution, an auxiliary variable t is introduced and using (12), the optimisation problem of (11) is extended to

$$\begin{array}{ll} \min\limits_{B_{\mathrm{cell},i}} & t + \beta \cdot \sum\limits_{i=1}^{N_{\mathrm{C}}} u_i \left(B_{\mathrm{cell},i} \right) \\ \text{s. t.} & B_{\min,i} \leq B_{\mathrm{cell},i} \leq B_{\max,i} \\ & \sum\limits_{n \in \{i_1,\ldots,i_r\}} B_{\mathrm{cell},n} \leq B_{\mathrm{sys}} \quad \forall \ \{i_1,\ldots,i_r\} \in \mathbb{G} \\ & u_i \left(B_{\mathrm{cell},i} \right) \leq t \end{array} \tag{13}$$

with $\beta \geq 0$. The optimisation problem of (13) carries out two tasks. First, it minimises auxiliary variable t. Since the third constraint assures that the utility function $u\left(B_{\text{cell},i}\right)$ is smaller than t for each cell, the largest cell outage probability is minimised, as in the initial optimisation problem of (11). Additionally, the sum of the cell outage probabilities of all cells is minimised, which assures a single solution with the smallest possible cell outage probabilities for each cell. Factor β adjusts the weight of the sum of the cell outage probabilities in the optimisation. For $\beta = 0$, the optimisation problem of (13) is thus equivalent to the one of (11).

5 Distributed Implementation

The distributed implementation of resource allocation algorithms is of large practical importance. In order to derive a distributed bandwidth allocation algorithm, the minimax-problem of (11) can be divided into several local optimisation problems by carrying out the optimisation problem of (11) for every Neighbourhood Group individually. Since a cell in general belongs to several Neighbourhood Groups, several bandwidth allocations exist for each cell. In order to always fulfil the constraint on the sum bandwidth of a Neighbourhood Group as given by (5), the smallest cell bandwidth allocation is chosen for each cell. Algorithm 1 shows an algorithm that has to be run by each cell for minimising the maximum cell outage probability. In the first step, each cell j determines the set $\mathbb{G}\left(j\right)$ of all Neighbourhood Groups it belongs to. It then carries out (11) in the convex formulation of (13) for each Neighbourhood Group in $\mathbb{G}\left(j\right)$. The if-condition assures a cell bandwidth allocation such that the sum bandwidth of each Neighbourhood Group is never larger than the totally available bandwidth, as required by (5).

Algorithm 1 Distributed maximum cell outage probability minimsation algorithm for cell j, $j = 1 \ldots N - \mathrm{C}$.

```
Require: $\mathbb{G}\left(j\right) := \left\{\left\{i_1, \ldots, i_r\right\} \in \mathbb{G} | j \in \left\{i_1, \ldots, i_r\right\}\right\}$
  $B_{\text{cell},j} = B_{\text{sys}}$
  for all $\left\{\left\{i_1, \ldots, i_r\right\} \in \mathbb{G}(j)\right\}$ do
      $\min_{\hat{B}_{\text{cell},n},\ n=i_1,\ldots,i_r} \quad t$
      s. t. $B_{\min,n} \leq \hat{B}_{\text{cell},n} \leq B_{\max,n}$
            $\sum_{n \in \{i_1,\ldots,i_r\}} \hat{B}_{\text{cell},n} \leq B_{\text{sys}}$
            $u_n\left(\hat{B}_{\text{cell},n}\right) \leq t$
    if $\hat{B}_{\text{cell},j} < B_{\text{cell},j}$ then
      $B_{\text{cell},j} = \hat{B}_{\text{cell},j}$
    end if
  end for
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6 Simulation Results

In order to evaluate the performance of the proposed approach, a scenario of the size of a Neighbourhood Group has been chosen, such that $N_{\mathrm{C}} = r$. This can be done since the resource assignment problem is the same for each Neighbourhood Group in a cellular network, such that instead of

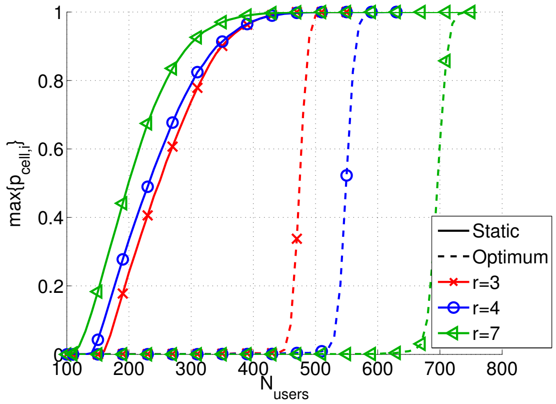

Figure 1: Maximum cell outage probability for different Neighbourhood Group sizes r in dependence of the total number of users N_{users} per Neighbourhood Group for both, static bandwidth allocation and optimum bandwidth allocation.

having several resource assignment problems side by side when simulating a large network, several resource assignment problems are simulated one after another for $N_{\mathrm{C}} = r$. In order to consider inter-cell interference, the scenario is constructed using the wraparound of [11], which extends the scenario to infinite size using only the N_{C} cells under consideration. For the inter-cell interference PSD P_{I} of (1), the interference caused by the first tier of interferers at the centre of a cell is considered, such that $P_{\mathrm{I}} = 6 \cdot \frac{P_{\mathrm{tx}}}{D^{\alpha}}$ holds. The total number of users in the scenario is fixed, but the distribution of the users to the cells varies randomly. The user distribution within each cell is characterised by mean and standard deviation $\mu_{i,k}$ and $\sigma_{i,k}$, respectively, of the bandwidth $\tilde{B}_{i,k}$ required by a single user. The simulation parameters are summarised by Table 1, the values of $\mu_{i,k}$ and $\sigma_{i,k}$ correspond to a uniform distribution $p_{\mathbf{r},\varphi}(r,\varphi)$ of users over the cell area.

Table 1: Common simulation parameters.

Cell radius R	250 m
Height of the BSs	32 m
Antenna height of the users	1.5 m
Pathloss coefficient α	3.5
Data rate requirement per user $R_{\mathrm{bit},i,k}$	$10\ \frac{\mathrm{kbit}}{\mathrm{s}}$
Total available bandwidth B_{sys}	1 MHz
$\mu_{i,k}$	1.44 kHz
$\sigma_{i,k}$	337 Hz
Transmit PSD P_{tx}	$-30\ \frac{\mathrm{dBm}}{\mathrm{Hz}}$
Interference PSD P_{I}	$-123\ \frac{\mathrm{dBm}}{\mathrm{Hz}}$
Noise PSD P_{N}	$-167\ \frac{\mathrm{dBm}}{\mathrm{Hz}}$

Using convex optimisation tools, the optimisation problem of (13) is solved with $\beta = 0.01$, $B_{\min,i} = 0$ and $B_{\max,i} = B_{\mathrm{sys}}$ to obtain optimum allocations of bandwidth to the cells of the scenario. All results of the optimum bandwidth allocation are compared to a static bandwidth allocation in which every cell is allocated a bandwidth of $\frac{B_{\mathrm{sys}}}{r}$.

Fig. 1 shows the maximum cell outage probability as a function of the number of users N_{users} per Neighbourhood Group for different values of r. As expected, the figure shows that the optimum

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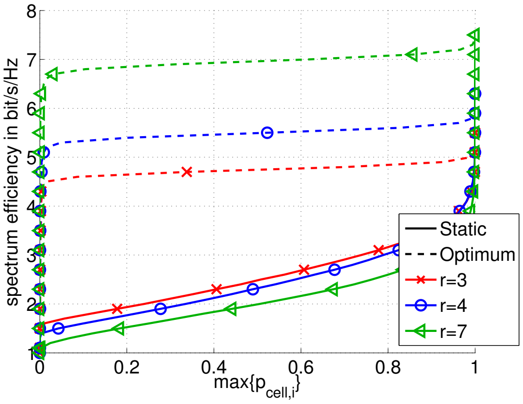

Figure 2: Spectral efficiency of a Neighbourhood Group for different Neighbourhood Group sizes r in dependence of the maximum cell outage probability for both, static bandwidth allocation and optimum bandwidth allocation.

bandwidth allocation proposed in this paper achieves significantly lower cell outage probabilities over a wide range of total number of users per Neighbourhood Group than the static allocation. It further shows that for the static allocation, the maximum cell outage probability increases with increasing r. The reason is that for larger r, less bandwidth per cell is available, leading to a higher probability of outage in the cells. For the case of the optimum bandwidth allocation, however, the opposite result can be seen in Fig. 1. This is due to the fact that when using the optimum allocation, the bandwidth can be allocated according to the capacity demands of the cells, such that the limiting effect of the static allocation does not apply. Outage in the cells therefore only arises if the total number of users in the scenario is too large. As a consequence, the cell outage probability decreases for increasing values of r since inter-cell interference decreases for increasing r such that less cell bandwidth is required for larger values of r.

The results of Fig. 1 can also be interpreted in terms of total number of users that can be supported per Neighbourhood Group for a certain cell outage probability. As expected, the capacity of the system significantly increases using the presented optimum bandwidth allocation, compared to the static bandwidth allocation.

Furthermore, when using the optimum allocation, more users can be served per Neighbourhood Group using a certain bandwidth if r is increased, as shown by Fig. 1. In order to show this effect more clearly, the spectrum efficiency of a Neighbourhood Group is plotted by Fig. 2 as a function of the maximum cell outage probability and for different values of r. The figure shows that if r increases, the spectrum efficiency and therefore the capacity per Neighbourhood Group increases. The number of users per cell, however, decreases, as can be easily calculated from Fig. 1. As a consequence, if the cell size is kept constant, the capacity per area decreases for increasing r, in contrast to the spectrum efficiency and the capacity per Neighbourhood Group. If the capacity per area is supposed to stay constant, the cell size has to be decreased for increasing values of r.

Fig. 2 further shows the large increase of the spectrum efficiency of the network over a wide range of cell outage probabilities, compared to the static allocation. For a cell outage probability of 0.05, for example, the optimum bandwidth allocation leads to an increase in the spectral efficiency by factor 2.7, 3.5 and 5.3 for $r = 3$, 4 and 7, respectively. The proposed bandwidth allocation approach is thus capable of significantly increasing the system capacity of a cellular mobile radio network.

7 Conclusion

Power-Bandwidth Characteristics represent the interdependence of transmit power and cell bandwidth of the cells in a cellular mobile radio network considering behaviour and environment of cells and users. They therefore reveal important information for the efficient assignment of resources. In this paper, the application of Power-Bandwidth Characteristics for the allocation of bandwidth to the cells of a cellular mobile radio network is introduced. The transmit power is assumed to be fixed. A bandwidth allocation approach minimising the largest cell outage probability is proposed and a convex problem formulation as well as a distributed implementation is derived. The performance of the presented approach is evaluated using simulations and it is shown that the proposed optimum bandwidth allocation increases the spectral efficiency several fold, leading to a significant increase in system capacity of a cellular mobile radio network. The possibility to determine Power-Bandwidth Characteristics from system measurements and the use of convex optimisation techniques enable the application of the presented approach for self-organising system optimisation.

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