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Self-organising Radio Resource Management for Cellular Mobile Radio Networks using Power-Bandwidth Characteristics

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Abstract: Future mobile radio networks are expected to witness increasing capacity demands. At the same time, operational expenditures are expected to rise due to increasing network complexity. In order to be able to operate future mobile radio networks in a commercially successful way, the spectrum efficiency of future mobile radio networks has to be increased while operational costs have to be kept low. In this scope, the autonomous, self-organising adaptation of the assignment of the resources power and bandwidth according to the time-varying capacity 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. In this paper, the application of Power-Bandwidth Characteristics for adaptive allocation of bandwidth and transmit power to the cells of a cellular mobile radio network 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 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.

Keywords: Radio Resource Management, Radio Resource Assignment, Self-organising, Self-optimising, Self-management

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. At the same time, operational expenditures are expected to rise due to the high complexity of future cellular mobile radio networks. Both factors increase the costs of network operators. As a consequence, techniques that lower operational costs and that increase the spectrum efficiency of future cellular mobile radio networks are of great importance in order to ensure the economic success of future cellular mobile radio networks. In this scope, autonomous, self-organising operation and optimization of the network is of great relevance, since self-organising networks are expected to run more efficient while requiring less man power, thus lowering operator costs.

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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 [1].

Furthermore, the resource assignment has to be adapted dynamically since the capacity demand varies over time and space.This adaptive assignment can be done on a per user basis, assigning resources to individual users from the totally available pool of resources, for example. In order to assure signal quality, the assignment has to be done based on measurements of the signal quality, leading to very high effort in signalling and strong dependence on quick and reliable signal quality measurements [2, 3]. Alternatively, chunks of resources are assigned to the cells and the individual users of a cell are assigned resources from these chunks. This assures a certain signal quality since the assignment of chunks of resources is carried out observing a certain minimum spatial separation between cells that use the same resources. The high signalling overhead of the first approach is thus avoided [4-6].

In this paper, Power-Bandwidth Characteristics, which represent the interdependence of transmit power and cell bandwidth considering behaviour and environment of cells and users, are applied for adaptive allocation of resources to the cells of a cellular mobile radio network. 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. The algorithm can be implemented in base stations (BSs) or in dedicated nodes. Standard system measurement data is used and only little communication between the BSs or dedicated nodes, respectively, is required. A rapid implementation of the presented approach is thus possible.

The paper is organised as follows. Section 2. presents the system model. Section 3. derives a convex optimisation problem for the allocation of bandwidth and transmit power to the cells of a cellular mobile radio network. Section 4. presents a distributed implementation of the algorithm, Section 5. investigates the performance of the proposed approach using simulations and Section 6. concludes the paper.

2. System Model

A cellular mobile radio network with N_C cells is considered. Every cell i, $i = 1 \dots N_\mathrm{C}$, supports a number of K_i users with certain bit rate requirements $R_{\mathrm{bit},i,k}$, $k = 1 \dots K_i$. Several cells of the network can use the same resources simultaneously. Due to this reuse of resources, inter-cell interference arises between cells that use the same resources. In order to control inter-cell interference and to assure sufficient signal quality, the available resources are assigned such that two cells that use the same resources 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 [1].

A Neighbourhood Group is defined as a group of exactly r cells that are all mutually located within the reuse distance D [7]. 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 $d(i_l, i_m) < D$, $l, m = 1 \dots r$, 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 $\mathbb{G} := \{\{i_1, \dots, i_r\} \subseteq \mathbb{I} | d(i_l, i_m) < D\}$, $l, m = 1 \dots r$. Since all cells of a Neighbourhood Group are located within the reuse distance, each resource can not be used by more than a single cell within each Neighbourhood Group and

$$\sum_{n \in \{i_1,\dots,i_r\}} B_{\text{cell},n} \leq B_{\text{sys}} \quad \forall \ \{i_1, \dots, i_r\} \in \mathbb{G} \tag{1}$$

holds, as shown in [7], 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 [1, 7].

According to [8], the power ratio Γ_i of cell i is defined as

$$\Gamma_i = P_{\text{tx},i} \left(P_{\text{N}} + P_{\text{I},i}\right)^{-1} \tag{2}$$

with $P_{\text{tx},i}$ the transmit power of cell i, P_{N} the receiver noise power and $P_{\text{I},i}$ the inter-cell interference power of cell i, which is assumed to be constant over the whole area of the cell and given by

$$P_{\text{I},i} = \sum_{j=1}^{N_{\text{C}}} \frac{P_{\text{tx},j}}{a_{i,j}^{(BS)}} b_{i,j}, \tag{3}$$

with $a_{i,j}^{(BS)}$ the attenuation between the BS of cell j and the centre of cell i. Factor $b_{i,j}$ denotes the fraction of the bandwidth of cell j that is also used by cell i.

The signal to interference and noise ratio (SINR) $\gamma_{i,k}$ of user k of cell i is given by $\gamma_{i,k} = \Gamma_i \cdot a_{i,k}^{-1}$ with $a_{i,k}$ the attenuation between user k and its base station. In each cell, a Power-Bandwidth Characteristic, which considers the distribution of the users over the cell area and stochastically models the bandwidth required by cell i to support all its users with their required bit rates $R_{\text{bit},i,k}$, is maintained based on the measurements of the user SINR $\gamma_{i,k}$ [8]. Using this Power-Bandwidth Characteristic, the probability that the bandwidth $B_{\text{cell},i}$ assigned to cell i is not sufficient to provide all users of the cell their required bit rates is according to [7, 8] defined by

$$p_{\text{cell},i}\left(B_{\text{cell},i}, \Gamma_i\right) = 1 - \Phi\left(\frac{B_{\text{cell},i} - \mu_{\text{cell},i}(\Gamma_i)}{\sigma_{\text{cell},i}(\Gamma_i)}\right), \tag{4}$$

with Φ the CDF of a Normal distributed random variable with zero mean and a variance of one and $\mu_{\text{cell},i}(\Gamma_i)$ and $\sigma_{\text{cell},i}(\Gamma_i)$ mean and standard deviation of the bandwidth required by cell i to support all its users with their required bit rate. Probability $p_{\text{cell},i}$ of (4) is called cell outage probability [7, 8].

3. Convex Radio Resource Allocation

Since cells that are located within a spatial distance of less than the reuse distance D cannot use the same resources, (1) has to be observed and the allocation of bandwidth to a cell has effect on the surrounding cells. Furthermore, inter-cell interference is influenced by the allocated transmit power and the amount of allocated bandwidth, according to (3). As a consequence, a large number of dependencies have to be considered in the allocation of radio resources to the cells of a cellular mobile radio network.

Mathematical optimisation is an optimisation technique capable of observing large number of dependencies. In this scope, the identification of an objective function capable of quantifying the quality of a resource assignment is an important aspect. The Power-Bandwidth Characteristic of [8] relates the assigned cell bandwidth $B_{\text{cell},i}$ and the power ratio Γ_i with the probability that the assigned resources are not sufficient to support the users of cell i with their requested quality of service (QoS). Furthermore, it is capable of considering the different situations of the cells in terms of inter-cell interference, number of users, user distribution and user behaviour [7, 8]. As a consequence, the cell outage probability of (4) is proposed as a measure of the quality of a resource assignment.

The allocation of bandwidth can then be carried out by the optimisation problem

$$\begin{aligned} \min_{B_{\text{cell},i}} \quad & \max_i \left\{ p_{\text{cell},i} \left(B_{\text{cell},i}, \Gamma_i \right) \right\} \\ \text{s. t.} \quad & B_{\min,i} \leq B_{\text{cell},i} \leq B_{\max,i} \\ & \sum_{n \in \{i_1,\ldots,i_r\}} B_{\text{cell},n} \leq B_{\text{sys}} \quad \forall \ \{i_1, \ldots, i_r\} \in \mathbb{G} \end{aligned} \tag{5}$$

with $B_{\min,i}$ and $B_{\max,i}$ lower and upper bounds for the assigned cell bandwidths, respectively, and the second side condition the constraint concerning the sum bandwidth of all cells within a Neighbourhood Group as given by (1).

Note that the optimisation problem of (5) 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, (5) can be treated as a continuous optimisation problem. The assignment of certain frequencies or chunks of bandwidth, e. g. subcarriers or subsets of subcarriers, may be carried out based on the solution of (5) using efficient heuristics, as proposed in [7], for example. After frequencies have been assigned to the cells, the transmit powers $P_{\text{tx},i}$ of the cells will be calculated by combining (2) and (3) using the power ratios Γ_i of the cells, which are set prior to the optimisation.

In order to use convex optimisation techniques for the solution of (5), objective function and constraints have to be convex, according to [9]. For the constraints of (5), this holds true. The Gaussian CDF, however, is neither convex nor concave, consequently also the cell outage probability as defined by (4), and thus the objective function of (5), is neither convex nor concave. To resolve this problem, the utility function

$$u_i \left(B_{\text{cell},i}, \Gamma_i \right) = -\log \left(1 - p_{\text{cell},i} \left(B_{\text{cell},i}, \Gamma_i \right) \right) \tag{6}$$

is defined. Since the Gaussian CDF is a log-concave function [9], the utility function of (6) is convex and the objective function in (5) can now be replaced by (6) to achieve a convex problem formulation.

Several solutions to the optimisation problem of (5) may exist, however, even though the largest cell outage probability is minimised. The reason for this is that several bandwidth allocations are possible for all cells that can achieve better cell outage probability than the maximum. To assure a single solution, an auxiliary variable t is introduced and using (6), the optimisation problem of (5) is extended to

$$\begin{array}{lll} \min\limits_{B_{\text{cell},i}} & t + \beta \cdot \sum\limits_{i=1}^{N_{\text{C}}} u_i\left(B_{\text{cell},i}, \Gamma_i\right) & \\ \text{s. t.} & B_{\min,i} \leq B_{\text{cell},i} \leq B_{\max,i} & \\ & \sum\limits_{n \in \{i_1,\ldots,i_r\}} B_{\text{cell},n} \leq B_{\text{sys}} \quad \forall \ \{i_1,\ldots,i_r\} \in \mathbb{G} & \\ & u_i\left(B_{\text{cell},i}, \Gamma_i\right) \leq t & \end{array} \tag{7}$$

with $\beta \geq 0$. The optimisation problem of (7) carries out two tasks. First, it minimises auxiliary variable t. Since the third constraint assures that the utility function $u\left(B_{\text{cell},i}, \Gamma_i\right)$ is smaller than t for each cell, the largest cell outage probability is minimised, as in the initial optimisation problem of (5). 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 (7) is equivalent to the one of (5).

4. Distributed Implementation

The distributed implementation of resource allocation algorithms is of large practical importance. In order to derive a distributed bandwidth allocation algorithm, the global minimax-problem of (5) can be divided into several local optimisation problems by carrying out the optimisation problem of (5) for every Neighbourhood Group individually. Since a cell in general belongs to several Neighbourhood Groups, several bandwidth allocations result for each cell. In order to always fulfil the constraint on the sum bandwidth of a Neighbourhood Group as given by (1), 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, a cell j determines the set $\mathbb{G}(j)$ of all Neighbourhood Groups it belongs to. It then carries out (7) for each Neighbourhood Group in $\mathbb{G}(j)$. 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 (1).

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

Require: $\mathbb{G}(j) := \{\{i_1,\ldots,i_r\} \in \mathbb{G} | j \in \{i_1,\ldots,i_r\}\}$
  $B_{\text{cell},j} = B_{\text{sys}}$
  for all $\{\{i_1,\ldots,i_r\} \in \mathbb{G}(j)\}$ **do**
    solve (7) for Neighbourhood Group $\{i_1,\ldots,i_r\}$ to calculate new $\hat{B}_{\text{cell},j}$
    if $\hat{B}_{\text{cell},j} < B_{\text{cell},j}$ **then**
      $B_{\text{cell},j} = \hat{B}_{\text{cell},j}$
    end if
  end for

5. 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 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 technique of [1], which extends the scenario to infinite size using only the N_{C} cells under consideration. The total number of users in the scenario is fixed, but the distribution of the users to the cells varies randomly. The simulation parameters are summarised in Table 1.

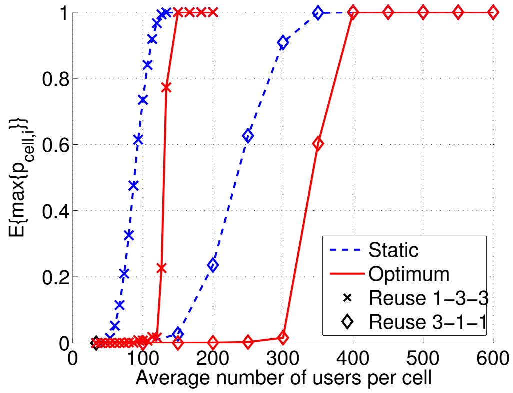
Table 1: Common simulation parameters.

Cell radius R	250 m	Shadow fading variance	8dB
Height of the BSs/users	32 m/1.5 m	Power ratio Γ_i	137 dB
User distribution	uniform	User data rate $R_{\mathrm{bit},i,k}$	100 $\frac{\mathrm{kbit}}{\mathrm{s}}$
Operation frequency	1.9 GHz	Total bandwidth B_{sys}	10 MHz
Propagation model	3GPP Urban Macro	Noise PSD P_{N}	-167 $\frac{\mathrm{dBm}}{\mathrm{Hz}}$

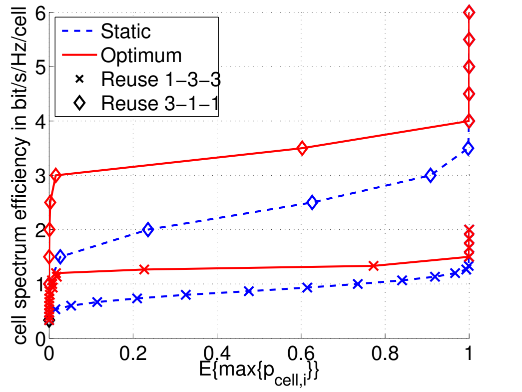
For the simulations, two scenario with frequency reuse patterns 3-1-1 and 1-3-3 are used, resulting in Neighbourhood Group sizes of $r = 3$ and $r = 1$, respectively [10]. Applying convex optimisation tools, the optimisation problem of (7) is solved with $\beta = 0.01$, $B_{\mathrm{min},i} = 0$ and $B_{\mathrm{max},i} = B_{\mathrm{sys}}$ 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 $\frac{B_{\mathrm{sys}}}{r}$.

Figure 1(a) shows the expectation value of the largest cell outage probability in the simulated scenarios as a function of the average number of users per cell. As expected, the figure shows that the capacity of a system applying Reuse 1-3-3 is almost three times as high as the capacity of a system applying Reuse 3-1-1. Furthermore, it can be seen that the application of the optimum bandwidth allocation approach proposed in Chapter 8 increases the capacity of the system in both scenarios significantly. The reason for this increase is the ability of the optimum approach to allocate bandwidth according to the requirements of the cells. While for the static bandwidth allocation a cell with few users can have more bandwidth allocated than it requires, another cell with many users might lack bandwidth in order to provide their users with the demanded QoS. With the optimum bandwidth allocation, bandwidth would in this case be moved away from the cell with few users to the cell with many users. The limiting factor of the optimum bandwidth allocation is consequently more the total number of users in a Neighbourhood Group, rather than the number of users in a cell, as it is with the static allocation.

Since the proposed optimum bandwidth allocation increases the user capacity of the system for a constant total system bandwidth, the spectrum efficiency must be increased by the optimum bandwidth allocation. The performance of the proposed approach in terms of cell spectrum efficiency of the system as a function of the expectation value of the maximum cell outage probability is therefore shown for both scenarios in Figure 1(b). Again, the approximate performance increase by factor three comparing Reuse 3-1-1 and Reuse 1-3-3 can be seen, as well as the significant performance increase due to the use of the proposed optimum bandwidth allocation algorithm.



(a) Maximum cell outage probability in dependence of the average number of users per cell for both, static bandwidth allocation and optimum bandwidth allocation.



(b) Cell spectrum efficiency in dependence of the maximum cell outage probability for both, static bandwidth allocation and optimum bandwidth allocation.

6. Conclusion

In this paper, a new approach for the self-organising optimisation of the radio resource allocation of cellular mobile radio networks is presented. The approach is based on the use of Power-Bandwidth Characteristics. An efficient convex problem formulation is introduced and a distributed implementation proposed. The performance of the presented approach is evaluated using simulations and it is shown that the proposed optimum bandwidth allocation increases the cell spectrum efficiency significantly. Since Power-Bandwidth Characteristics can be determined from system measurements and due to the use of convex optimisation techniques, the presented approach is suited for autonomous self-organising operation. As a consequence, the presented self-organising radio resource management approach is capable of increasing the spectrum efficiency while enabling automatic operation. The presented approach is thus capable of lowering operational costs while increasing the income of network operators, thus fulfilling key requirements for the economic success of future mobile radio networks.

References

[1] J. Zander and S.-L. Kim, *Radio Resource Management for Wireless Networks*. Artech House, April 2001.

[2] M. Feng, L. Chen, and X. She, “Uplink adaptive resource allocation mitigating inter-cell interference fluctuation for future cellular systems,” in *Proc. 2007 IEEE International Conference on Communications*, pp. 5519–5524, June 2007.

[3] K. B. Letaief and Y. J. Zhang, “Dynamic multiuser resource allocation and adaptation for wireless systems,” *IEEE Wireless Communications Magazine*, vol. 13, pp. 38–47, Aug. 2006.

[4] W. K. Hale, “Frequency assignment: Theory and applications,” *Proc. IEEE, Vol. 68*, pp. 1497–1514, Dec. 1980.

[5] A. Gamst, “Some lower bounds for a class of frequency assignment problems,” *IEEE Transactions on Vehicular Technology*, vol. 35, pp. 8–14, Feb. 1986.

[6] K. I. Aardal, S. P. M. van Hoesel, A. M. C. A. Koster, C. Mannino, and A. Sassano, "Models and solution techniques for frequency assignment problems," Tech. Rep. ZIB-Report 01-40, Konrad-Zuse-Zentrum für Informationstechnik Berlin, Dec. 2001.

[7] P. P. Hasselbach, A. Klein, and I. Gaspard, "Dynamic resource assignment (DRA) with minimum outage in cellular mobile radio networks," in *Proc. 2008 IEEE 67th Vehicular Technology Conference: VTC2008-Spring*, May 2008.

[8] P. P. Hasselbach, A. Klein, and M. Siebert, "Interdependence of transmit power and cell bandwidth in cellular mobile radio networks," in *Proc. 2008 IEEE* 19$^{\text{th}}$ *International Symposium on Personal, Indoor and Mobile Communications (PIMRC08)*, 2008.

[9] S. Boyd and L. Vandenberghe, *Convex Optimization*. Cambridge University Press, 6th ed., 2008.

[10] K. Ramadas and R. Jain, "WiMAX system evaluation methodology," tech. rep., WiMAX Forum, 2007.