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Interdependence of Transmit Power and Cell Bandwidth in Cellular Mobile Radio Networks

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***Abstract*—The assignment of resources to the cells of a cellular mobile radio network is usually done by assigning certain parts of the total bandwidth to the cells. With the use of adaptive transmission, power can be considered as a resource and taking power into account in the assignment of resources to cells offers additional flexibility, especially in achieving efficient assignments and in adapting the network to varying capacity demands. Considering power and bandwidth jointly requires the knowledge of their interdependence since they are exchangeable. Concerning a single link, this interdependence has been stated by Shannon and is well known. For the assignment of resources to cells, however, this interdependence has to be known for the whole cell. In this paper, an analytic approach to modelling the interdependence of transmit power and cell bandwidth considering outage probability is presented. The ΓB-Characteristic, where Γ is a term considering the power of signal, noise and interference, is introduced as a representation of this interdependence and a method for the on-line measurement of ΓB-Characteristics for practical application is presented. The applicability of the proposed approach is validated using simulations and a broad spectrum of applications for operation and optimisation of mobile radio networks based on ΓB-Characteristics is proposed.**

I. Introduction

Cellular mobile radio networks are able to deliver high system capacity using limited resources due to the ability to use the same resources in several cells. This reuse of resources leads to interference between cells using the same resources, the so called inter-cell interference, and the assignment of resources to cells has to be done carefully [1], [2].

In adaptive transmission, the modulation and coding scheme (MCS) is adapted to the signal to interference and noise ratio (SINR) at the receiver in order to exploit the channel capacity as much as possible [2]. If the SINR at the receiver is larger, less bandwidth is required for a transmission with given data rate. Since the transmit power influences the SINR at the receiver, transmit power can be considered as a resource. According to [3], power can be exchanged for bandwidth, and power and bandwidth thus have to be assigned jointly.

The joint assignment of power and bandwidth offers increased flexibility in achieving efficient resource assignments and in adapting the network to varying capacity demands, for example, but the interdependence of power and bandwidth has to be known. For a single link, this interdependence has been stated by Shannon [3]. For the assignment of resources to cells in a cellular network, however, the interdependence of power and bandwidth considering the whole cell with all its links has to be known. The interdependence of transmit power and cell bandwidth is therefore required.

Several work related to the assignment of bandwidth to cells in a cellular network has been carried out in [4]–[6], for example, and the modelling of intercell interference allowing to evaluate the effect of transmit power assignment has been treated in [7], [8], for example. The outage probability of OFDMA has been investigated in [9]–[11].

In this paper, the topics of bandwidth and power assignment, inter-cell interference and outage probability are considered jointly using the interdependence of transmit power and cell bandwidth considering outage probability. A model of this interdependence is derived by extending the bandwidth demand model introduced in [12]. The ΓB-Characteristic, a representation of the interdependence of transmit power and cell bandwidth, and an efficient approach to its measurement on-line, during operation of the network, is presented and validated. Finally, a broad range of applications of ΓB-Characteristics for evaluative tasks, resource assignment and user accommodation is proposed.

The paper is organised as follows. Section II presents the system model and gives a description of the problem. Section III derives a model of the interdependence of transmit power and cell bandwidth considering outage and introduces the ΓB-Characteristic. Section IV presents an efficient approach to the measurement of ΓB-Characteristics, which is validated in Section V using simulations. Section VI gives an outlook on a broad range of applications of ΓB-Characteristics for operation and optimisation of mobile radio networks, and Section VII concludes the paper.

II. System Model and Problem Description

A cellular mobile radio network with N_C hexagonally shaped cells of radius R is considered. The base stations (BSs) are located in the centre of the cells and are equipped with omnidirectional antennas. Groups of r cells form clusters, where the cluster size r is a rhombic number. Two cells of different clusters may use the same resource which leads to inter-cell interference. The minimum distance between two cells that use the same resources is called the reuse distance D and is given by $D = \sqrt{3r} \cdot R$ [1], [2].

With $P_{\mathrm{tx},i}$ the transmit power of cell i, $i = 1 \ldots N_\mathrm{C}$, P_N the noise power of the receiver and $P_{\mathrm{I},i}$ the inter-cell interference power at a certain reference point of cell i, the power ratio

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Γ_i, an artificial parameter used for calculation and modelling purposes, is defined by

$$\Gamma_i = \frac{P_{\text{tx},i}}{P_\text{N} + P_{\text{I},i}}. \quad (1)$$

Note that Γ_i does not occur in reality since $P_{\text{tx},i}$ is the transmit power at the antenna of cell i. Assuming inter-cell interference power to be constant over the whole area of cell i and equal to the interference power $P_{\text{I},i}$ at the reference point, the SINR $\gamma_{k,i}$ at the receiver of user k of cell i can be calculated from (1) by

$$\gamma_{k,i} = \Gamma_i \cdot a_{k,i}^{-1}, \quad k = 1 \dots K_i, \quad (2)$$

with $a_{k,i}$ the attenuation between user k and the BS of cell i and K_i the number of users of cell i. The assumption of constant interference power level is acceptable unless very small reuse distances are used [1]. A perfect adaptation to the SINR at the receiver is assumed, such that the link bandwidth $B_{k,i}$ required by user k of cell i to transmit a data rate $\eta_{k,i}$ is given by [3]

$$B_{k,i} = \eta_{k,i} \cdot (\log_2(1 + \gamma_{k,i}))^{-1}. \quad (3)$$

The link bandwidth required to provide a certain link data rate therefore depends on the SINR at the receiver and with $B_{\text{cell},i} = \sum_{k=1}^{K_i} B_{k,i}$, the cell bandwidth $B_{\text{cell},i}$ of cell i depends on the SINRs of all K_i users of cell i.

In this paper, Quality of Service (QoS) is expressed in terms of the link data rate. A user is in outage, if the demanded link data rate $\eta_{k,i}$ is not achieved. Outage probability concerning a user is the probability that a user does not get the demanded link data rate. The cell outage probability $p_{\text{cell},i}$ is defined as the probability that cell i can not give to all its K_i users the demanded link data rates.

The problem addressed in this paper is the modelling of the mutual influence of transmit power $P_{\text{tx},i}$ and cell bandwidth $B_{\text{cell},i}$ in a cellular network applying adaptive transmission and accommodating several simultaneously active users with different link qualities. Due to the adaptive transmission, the bandwidth $B_{k,i}$ required by user k of cell i to achieve a fixed data rate $\eta_{k,i}$ varies. The more bandwidth a user requires, the less bandwidth is available for the remaining users, such that each user has effect on the data rate and, thus, service quality of the remaining users. Additionally, by changing the transmit power $P_{\text{tx},i}$, the SINR $\gamma_{k,i}$ and therefore the bandwidth $B_{k,i}$ required by user k of cell i is influenced. According to (3), the change of the required bandwidth depends on the SINR and is therefore usually different for the users.

III. Introduction to ΓB-Characteristics

In this section, the bandwidth demand model from [12] is extended to derive a model of the interdependence of transmit power and cell bandwidth.

As a generalisation of [12], the bandwidth $B_{\text{cell},i}$ required by cell i in order to provide sufficient QoS to all its users can be modelled using a random variable (RV) approach. The modelling is carried out in two steps. First, RV $\mathbf{B}_{k,i}$ representing the link bandwidth $B_{k,i}$ required by user k of cell i is derived using a chain of RV transformations [13]. Then, RV $\mathbf{B}_{\text{cell},i}$ representing the bandwidth $B_{\text{cell},i}$ required by cell i is calculated by summing up the required link bandwidths $B_{k,i}$ of all users of the cell. Assuming independent users, the central limit theorem can be applied and $\mathbf{B}_{\text{cell},i}$ follows a Gaussian distribution [13].

Referring to [12] and considering (1), RV $\mathbf{B}_{k,i}$ depends on the power ratio Γ_i, and mean and variance of $\mathbf{B}_{k,i}$ can be expressed in dependence of Γ_i. According to the central limit theorem [13], mean and variance of $\mathbf{B}_{\text{cell},i}$ are given by

$$\mu_{\text{cell},i}(\Gamma_i) = \sum_{k=1}^{K_i} \mu_{k,i}(\Gamma_i), \quad \sigma^2_{\text{cell},i}(\Gamma_i) = \sum_{k=1}^{K_i} \sigma^2_{k,i}(\Gamma_i), \quad (4)$$

with $\mu_{k,i}(\Gamma_i)$ and $\sigma^2_{k,i}(\Gamma_i)$ mean and variance of the link bandwidth $B_{k,i}$ required by user k of cell i, respectively.

Using (4) with different power ratios Γ_i, a set of cumulative distribution functions (CDFs) of the bandwidth $B_{\text{cell},i}$ required by cell i can be calculated. Extracting from each of the CDFs the bandwidth $B_{\text{cell},i}$ corresponding to the probability $1 - p_{\text{cell},i}$ and plotting it against Γ_i, a graph illustrating the interdependence of the power ratio Γ_i and the required cell bandwidth $B_{\text{cell},i}$ for a cell outage probability of $p_{\text{cell},i}$ is constructed. This graph will in the following be called ΓB-Characteristic. Since Γ_i depends on the transmit power $P_{\text{tx},i}$, the ΓB-Characteristic is a representation of the interdependence of transmit power and cell bandwidth.

For a general approach, a data rate unit η_unit is defined and regarding (3), mean and variance of the cell bandwidth $B_{\text{cell},i}$ are now given by

$$\mu_{\text{cell},i}(\Gamma_i) = \mu_{\text{unit},i}(\Gamma_i) \cdot \sum_{k=1}^{K_i} \frac{\eta_{k,i}}{\eta_\text{unit}}, \quad (5)$$

$$\sigma^2_{\text{cell},i}(\Gamma_i) = \sigma^2_{\text{unit},i}(\Gamma_i) \cdot \sum_{k=1}^{K_i} \left(\frac{\eta_{k,i}}{\eta_\text{unit}}\right)^2, \quad (6)$$

with $\mu_{\text{unit},i}$ and $\sigma^2_{\text{unit},i}$ mean and variance of the link bandwidth required by a single user of cell i for the transmission of a data rate equal to the data rate unit η_unit. The bandwidth $B_{\text{cell},i}^{(\tilde{p}_\text{cell})}$ required by cell i to achieve a certain cell outage probability target $\tilde{p}_\text{cell}$ is given by

$$B_{\text{cell},i}^{(\tilde{p}_\text{cell})}(\Gamma_i) = \text{erf}^{-1}(1 - 2\tilde{p}_\text{cell}) \sqrt{2\sigma^2_{\text{cell},i}(\Gamma_i)} + \mu_{\text{cell},i}(\Gamma_i), \quad (7)$$

with erf^{-1} the inverse error function [13]. Using (5), (6) and (7), the ΓB-Characteristic can be calculated for any number of users and combinations of different data rate requirements of the users and for any cell outage probability target $\tilde{p}_\text{cell}$ from just the two parameters $\mu_{\text{unit},i}$ and $\sigma^2_{\text{unit},i}$. The ΓB-Characteristic can therefore be represented, stored and processed in a very efficient and compact form.

Note that the presented approach is valid for the downlink as well as the uplink of a cellular mobile radio network. Since the central limit theorem is applied in the presented model, the data rates of the users have to be comparable in magnitude [12]. If users with largely deviating data rates are simultaneously active, different ΓB-Characteristics have to be applied. As a consequence, different ΓB-Characteristics might have to be maintained for different service classes.

IV. Measurement of ΓB-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 III are in general not possible with realistic user distributions. For practical application, the measurement of ΓB-Characteristics is therefore proposed.

Two methods are introduced. Both follow the theoretical approach presented in Section III but instead of working with RVs and RV transformation, measurement data is used to empirically calculate the distribution of the required link bandwidth and its mean and variance.

The first method is based on the measurement of the attenuation between the users and the BS of cell i. A set of $N_{\mathrm{a},i}$ attenuation measurements is given by $a_{i,m}$, $m = 1 \dots N_{\mathrm{a},i}$. This data set is transformed into several sets of bandwidth values required for the transmission of a data rate equal to the data rate unit η_{unit} and for different values of Γ_i. Regarding (2) and (3), the transformation is done according to

$$B_{i,m}^{(\mathrm{a})}(\Gamma_i) = \frac{\eta_{\mathrm{unit}}}{\log_2\left(1 + \frac{\Gamma_i}{a_{i,m}}\right)}. \tag{8}$$

For each of the sets of bandwidth values, an empirical distribution and their means $\mu_{\mathrm{unit},i}(\Gamma_i)$ and variances $\sigma^2_{\mathrm{unit},i}(\Gamma_i)$ are calculated. The ΓB-Characteristic is then constructed as described in Section III using (5), (6) and (7).

The second method is similar to the first but based on the measurement of the SINR experienced by the users of cell i. A set of $N_{\gamma,i}$ SINR measurements is given by $\gamma_{i,n}$, $n = 1 \dots N_{\gamma,i}$. The transformation of the SINR measurements is derived similar to (8), but the power ratio $\tilde{\Gamma}_{i,n}$ at the time of measurement n has to be taken into account:

$$B_{i,n}^{(\gamma)}(\Gamma_i) = \frac{\eta_{\mathrm{unit}}}{\log_2\left(1 + \gamma_{i,n}\frac{\Gamma_i}{\tilde{\Gamma}_{i,n}}\right)}. \tag{9}$$

As before, $\mu_{\mathrm{unit},i}(\Gamma_i)$ and $\sigma^2_{\mathrm{unit},i}(\Gamma_i)$ are calculated from the data sets, from which the ΓB-Characteristic is constructed.

Note that the effort for measuring ΓB-Characteristics using SINR measurements is higher, compared to using attenuation measurements, since the power ratios $\tilde{\Gamma}_{i,n}$ at the time of the measurements have to be known. On the other hand, an attenuation based ΓB-Characteristic describes the environment of the BS and the users as well as the distribution and the behaviour of the users, while a SINR based ΓB-Characteristic also regards inter-cell interference and therefore additionally considers the environment of the cell as well as the distribution and the behaviour of the interferers.

In order to determine Γ_i, the reference interference power $P_{\mathrm{I},i}$ has to be measured or calculated from several measurements. $P_{\mathrm{I},i}$ is also required in the assignment of resources for determining which transmit power corresponds to a certain value of Γ_i that has to be achieved.

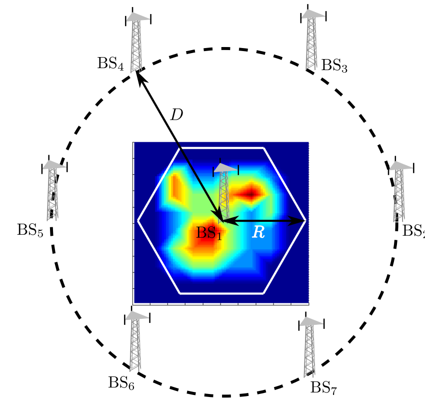

Fig. 1. Simulation scenario.

V. Simulation Results

In order to show that ΓB-Characteristics are suited for the joint assignment of transmit power $P_{\mathrm{tx},i}$ and cell bandwidth $B_{\mathrm{cell},i}$ such that the cell achieves a certain target cell outage probability $\tilde{p}_{\mathrm{cell}}$, the downlink of a scenario with a cell and its six closest interferers as shown in Fig. 1 is considered. The user distribution of the considered cell is given by the coloured background of Fig. 1, with blue colour for low and red colour for high user density, and the reference interference power $P_{\mathrm{I},i}$ is measured at the centre of the cell. The simulation parameters are summarised in Table I.

TABLE I
Simulation parameters.

Cell radius R	250m
Height of the MSs/BSs	1.5m/32m
Average number of active users K_1	50
Data rate requirement per user $\eta_{k,i}$	$10\frac{\mathrm{kbit}}{\mathrm{s}}$
Data rate unit η_{unit}	$1\frac{\mathrm{bit}}{\mathrm{s}}$
Propagation model	3GPP SCM Urban Macro
Carrier frequency	1.9GHz
Pathloss exponent	3.5
Lognormal shadow fading variance	8dB
Shadow fading correlation distance	40m
Noise power spectral density (PSD) P_{N}	$-167\frac{\mathrm{dBm}}{\mathrm{Hz}}$
Cell outage probability target $\tilde{p}_{\mathrm{cell}}$	0.05

At first, the ΓB-Characteristic of the centre cell is determined. Both methods for measuring ΓB-Characteristics introduced in Section IV are applied. The power spectral densities of the transmitted signals (TxPSDs) of all seven BSs are set to $P_{\mathrm{tx},i} = -30\frac{\mathrm{dBm}}{\mathrm{Hz}}$, $i = 1 \dots 7$.

Fig. 2 shows for both measurement methods and different reuse factors r the ΓB-Characteristic of the centre cell for $K_1 = 50$ simultaneously active users with a data rate requirement of $\eta_{k,i} = 10\frac{\mathrm{kbit}}{\mathrm{s}}$ each. As expected, the attenuation based ΓB-Characteristic is independent of the reuse factor r since the reuse distance does not have influence on the attenuation. Concerning the SINR based ΓB-Characteristic, a small dependence on the reuse factor r can be observed, since the SINR increases with increasing reuse factor [1], and the required bandwidth $B_{\mathrm{cell},1}^{(\tilde{p}_{\mathrm{cell}})}$ therefore decreases with

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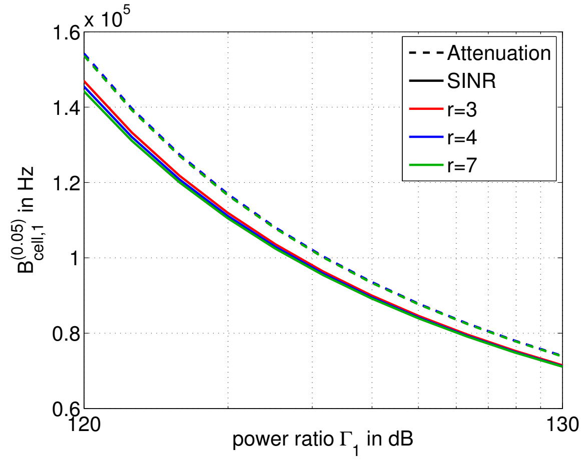

Fig. 2. ΓB-Characteristic of the considered cell for both measurement methods and different reuse factors r and for $K_1 = 50$ simultaneously active users, each one requiring a data rate of $\eta_{k,i} = 10\frac{\mathrm{kbit}}{\mathrm{s}}$.

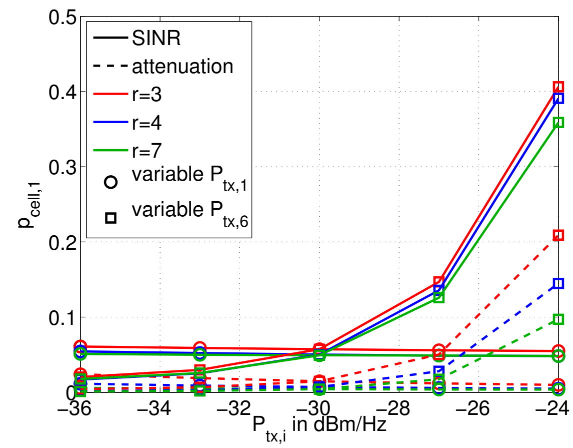

Fig. 3. Cell outage probability $p_{\mathrm{cell},1}$ of the centre cell for different reuse factors r. The case of constant interference power and variable signal power $P_{\mathrm{tx},1}$ and the case of constant signal power and variable interference due to variable transmit power $P_{\mathrm{tx},6}$ are shown.

increasing r.

Note that the power ratio Γ_1 increases with increasing r since $P_{\mathrm{I},1}$ in (1) decreases with increasing r. If no noise is present, the increase in Γ_1 is proportional to the decrease in required bandwidth $B_{\mathrm{cell},1}^{(\tilde{p}_{\mathrm{cell}})}$, such that the possible combinations of bandwidth $B_{\mathrm{cell},1}^{(\tilde{p}_{\mathrm{cell}})}$ and power ratio Γ_1 are independent of r. In the noise free case, consequently, the SINR based ΓB-Characteristic is independent of the reuse factor. In the interference free case, ΓB-Characteristics are independent of the measurement method and independent of r.

Since the attenuation based ΓB-Characteristic neglects inter-cell interference, it generally assigns less bandwidth for a certain Γ_i than the SINR based ΓB-Characteristic. Fig. 2, however, shows the opposite behaviour due to normalising the SINR measurements to $\tilde{\Gamma}_{i,n}$ in (9), which shifts the SINR based ΓB-Characteristic downwards if shadowing in the interference reference power $P_{\mathrm{I},i}$ is below average.

Note that in practice, ΓB-Characteristics would be stored using the parameters $\mu_{\mathrm{unit},i}(\Gamma_i)$ and $\sigma^2_{\mathrm{unit},i}(\Gamma_i)$ since they enable a very compact representation, see Section III. Also the curves of Fig. 2 are gained from $\mu_{\mathrm{unit},1}(\Gamma_1)$ and $\sigma^2_{\mathrm{unit},1}(\Gamma_1)$ using (5), (6) and (7).

In order to verify the applicability of the ΓB-Characteristic as described in Section III, it is applied to estimate the bandwidth required by the centre cell to provide sufficient QoS to all its active users observing the target cell outage probability $\tilde{p}_{\mathrm{cell}}$. Different values of Γ_1 are used, which are achieved by varying the TxPSDs of different cells. Using Monte Carlo Simulations, the cell outage probability $p_{\mathrm{cell},1}$ of the centre cell is evaluated by comparing the actually required cell bandwidth, which depends on the number of active users K_1, their data rate requirements $\eta_{k,i}$ and their reception situation, to the estimate $B_{\mathrm{cell},1}^{(\tilde{p}_{\mathrm{cell}})}$ of the required cell bandwidth gained from the ΓB-Characteristic.

For the first simulation, the signal power in the centre cell is varied by varying the TxPSD of the centre cell. The TxPSDs of the interferers are set to $-30\frac{\mathrm{dBm}}{\mathrm{Hz}}$. The simulation results of the cell outage probability $p_{\mathrm{cell},1}$ are shown in Fig. 3, marked with circles. The figure shows that the target cell outage probability $\tilde{p}_{\mathrm{cell}}$ is acceptably well achieved over the whole dynamic range of 12 dB using the SINR based ΓB-Characteristic, but using the attenuation based ΓB-Characteristic, it is clearly undercut. The reason is that shadowing in the interference reference power $P_{\mathrm{I},1}$ is below average, which causes a too large estimation of the required bandwidth, using attenuation based ΓB-Characteristics, since interference is overestimated. This effect could be mitigated by calculating $P_{\mathrm{I},1}$ from interference measurements at several points in the cell since this would average shadow fading. Using SINR based ΓB-Characteristics, the shadowing effect is cancelled due to the normalisation of the SINR measurements to $\tilde{\Gamma}_{i,n}$ in (9).

For the second simulation, the interference power in the centre cell is varied by varying the TxPSD of BS 6. The TxPSDs of the remaining BSs are set to $-30\frac{\mathrm{dBm}}{\mathrm{Hz}}$. The simulation results of the cell outage probability $p_{\mathrm{cell},1}$ of the centre cell are marked with squares in Fig. 3. As before, the figure shows that when using the attenuation based ΓB-Characteristic, the cell outage probability $p_{\mathrm{cell},1}$ is significantly lower than when using the SINR based ΓB-Characteristic. The robustness against varying interference is in both cases not always given, in particular for large TxPSDs of BS 6, the estimate $B_{\mathrm{cell},1}^{(\tilde{p}_{\mathrm{cell}})}$ of the required cell bandwidth is too small, resulting in high cell outage probabilities. The reason for the incorrect bandwidth estimation is the change in the distribution of the interference power over the cell area, which is caused by varying the TxPSD of just one interferer. Varying the TxPSDs of all six interferers uniformly, the same performance as in the first simulation is expected, since this corresponds to varying the TxPSD of the centre cell. A possibility to improve the robustness against changes in the distribution of the interference is again to calculate $P_{\mathrm{I},1}$ from measurements

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at several points in the cell since this would reflect the changes in the distribution.

In all simulations, the cell outage probability $p_{\mathrm{cell},1}$ is lower for larger reuse factors r, since for larger reuse distances, the variations in the interference power over the cell area are smaller, such that the reference interference power $P_{\mathrm{I},1}$ is closer to the interference power actually experienced by a user. The estimation of the required bandwidth is thus more accurate for larger r.

Note that according to Fig. 1, BS 6 is the main interferer of the area with the most users of the centre cell. Varying the TxPSD of any of the remaining interferers is therefore expected to have less impact on the centre cell. The presented results can thus be considered to be a worst case for the considered scenario.

VI. Application of ΓB-Characteristics

The applications enabled by the knowledge of the interdependence of transmit power and cell bandwidth, and by the ΓB-Characteristic in particular, can be divided into the fields of evaluative tasks, resource assignment and user accommodation. An overview is given in the following.

Evaluative tasks: ΓB-Characteristics consider the environment of BS and cell, as well as the users and interferers including their behaviour, as stated in Section IV. They thus represent complex relations of a large number of different parameters that have influence on the behaviour and the performance of a cell. ΓB-Characteristics are therefore suited to efficiently evaluate and identify the states and operation conditions of the cells, including the detection of weakly covered areas.

The compact representation presented in Section III additionally enables an efficient processing of the data. In particular, transmission and storage of the states and operation conditions of the cells can be realised very efficiently, and profiles of the cells concerning their states and operation conditions can be established.

Resource assignment: Every point on a ΓB-Characteristic identifies a resource assignment that assures the observation of the target cell outage probability. The ΓB-Characteristic can thus be used for the assignment of transmit power and cell bandwidth to the cells of a cellular network.

Due to the in general non-linear interdependence of transmit power and cell bandwidth, different combinations of the resources are more efficient for different cells, depending on the environment, the users and the interferers. The efficient combinations could be identified using ΓB-Characteristics and the optimisation of the resource assignment could thus be carried out based on ΓB-Characteristics.

The same way, antenna patterns that are efficient from the point of view of the resource assignment could be identified using ΓB-Characteristics.

User accommodation: The location of the users in the environment and their behaviour influence the shape of the ΓB-Characteristics, which determines efficient resource assignments. Users could therefore be assigned to cells with the goal of changing the shape of the ΓB-Characteristic such that the efficiency of the current resource assignment is increased.

This directly proposes to use ΓB-Characteristics for tasks such as self-healing, hand over (HO) parameter optimisation, load balancing and neighbour cell list optimisation, for example. For self-healing, in particular, ΓB-Characteristics promise an efficient approach since they enable the accommodation of users that lost coverage due to a failing BS while maintaining an efficient resource assignment.

VII. Conclusion

In this paper, the ΓB-Characteristic, a representation of the interdependence of transmit power and cell bandwidth considering outage probability, is introduced. An analytic derivation of the ΓB-Characteristic is presented and an efficient method for its representation is shown. For practical application, two methods for the on-line measurement of ΓB-Characteristics are proposed. The applicability of the proposed approaches is validated using simulations, the effect of shadow fading is shown and an approach to overcome the problems imposed by shadow fading is proposed. Finally, an outlook to a broad range of applications for operation and optimisation of cellular mobile radio networks enabled by ΓB-Characteristics is given.

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