OUTAGE PROBABILITIES AND HANDOVER CHARACTERISTICS OF SIMULCAST CELLULAR MOBILE RADIO SYSTEMS

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Abstract — Recently, a new mobile radio cell architecture was proposed employing macro diversity and overlapping cells [2, 8]. Simulcast transmission is used in the downlink. Due to multiple propagation paths between the base stations and a single mobile station the transmission impairments caused by fading are reduced significantly. Therefore, macro diversity cell structures show substantially smaller outage probabilities. The essential effects of the explicit cell overlapping on the outage probability and the handover reliablility are evaluated.

I. INTRODUCTION

Digital cellular mobile radio networks show rapidly increasing subscriber numbers, especially in Europe. Due to this high local capacity requirements must be met for the so-called *hot spots* such as railway stations, airports, congress centres and dense urban areas in general. In addition to that a large part of this traffic is generated within buildings, so that good in-house supplying must be achieved.

The investigated simulcast architectures offer a promising alternative to micro-cell structures to meet the requirements of hot spots while leaving the handover rates low. For the GSM-System the regarded simulcast architectures with two or three base station sites per cell *and cell overlapping* allow frequency re-use factors of three, therefore increasing the traffic capacity while maintaining rather large cell areas compared to micro-cell networks. [2, 7, 8].

Considering radio transmission under the influence of log-normal fading due to shadowing and diffraction, the redundant supply of a mobile station by multiple base stations at distant sites is especially advantageous. In comparison to conventional approaches using a single base station per cell or sector the probability that all paths to or from the mobile station are shadowed at the same time is reduced significantly.

In this contribution two different simulcast structures are presented. They are compared to conventional networks regarding their traffic capacities and outage probabilities, taking different power control schemes into consideration. The vital influence of cell overlapping on the outage probability is discussed. The improved handover properties of this structure are proven in the last section.

II. SIMULCAST CELLULAR STRUCTURES

The considered radio cell architectures are based on the two fundamental properties ***multiple supply*** with simulcast and *cell overlapping* of neighboring cells. Both properties are shown in Fig. 1 as an example with threefold supply of each cell [2, 8].

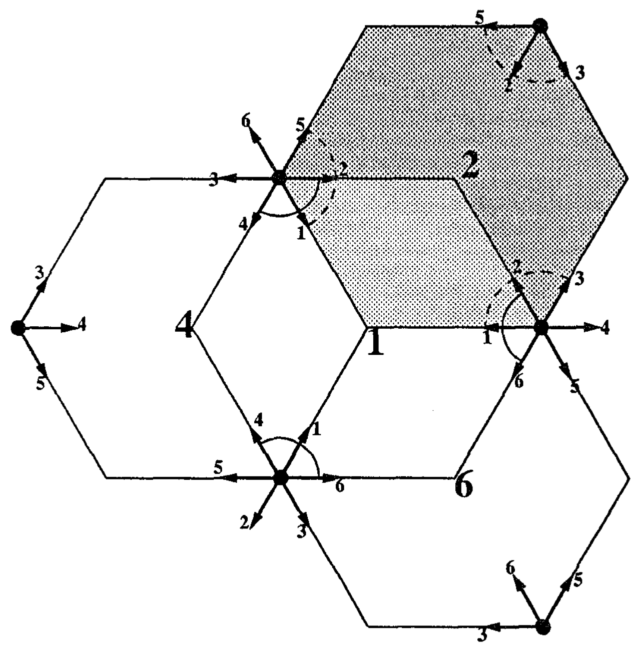

Fig.1 Cell arrangement for simulcast with threefold supply and cell overlapping

Each of the four depicted cells is supplied by three base stations at every other corner of a regular hexagon that indicates the theoretical bounds of the cell. Each base station site carries six sector antennas with e.g. 120° horizontal opening angle which are directed into the respective cells. Thus the antennas of cell 1 at the three corner base stations are directed towards the centre of cell 1.

Furthermore a large and well-defined overlapping area exists between neighboring cells, indicated in Fig. 1 by the

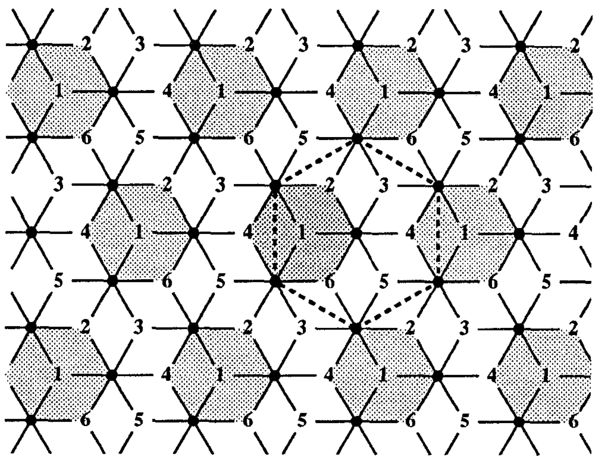

Fig.2 Regular cell layout for simulcast with threefold supply and cell overlapping with frequency re-use 3

light shaded overlapping area of cell 1 and cell 2. In a geometric regular network this overlapping can be found for all pairs of neighboring cells. Each point in the plane belongs to two different neighboring cells. It should be noted that no additional base station sites are required in comparison with conventional omnidirectional or sectorized cellular layouts that use the same cell radii.

The frequency group numbers shown in Fig. 1 are valid for a regular cluster with a frequency re-use factor of three, which is shown in Fig. 2. Due to the cell overlapping six frequency groups are required to form two hexagonal cell clusters with re-use 3 that are shifted against each other.

A second structure employing multiple supply by simulcast is shown in Fig. 3 [7]. In this case *two* base stations are positioned at opposite corners of a hexagonal cell. In order to achieve a regular hexagonal base station grid, again

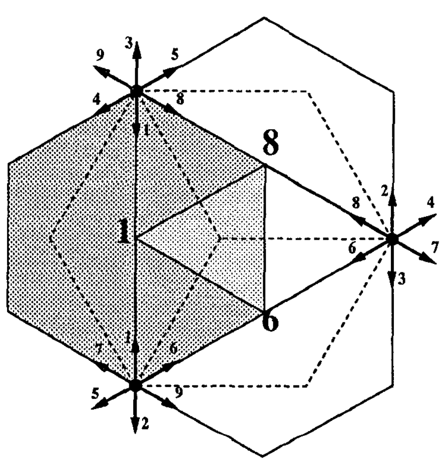

Fig.3 Cell arrangement for simulcast with twofold supply and cell overlapping

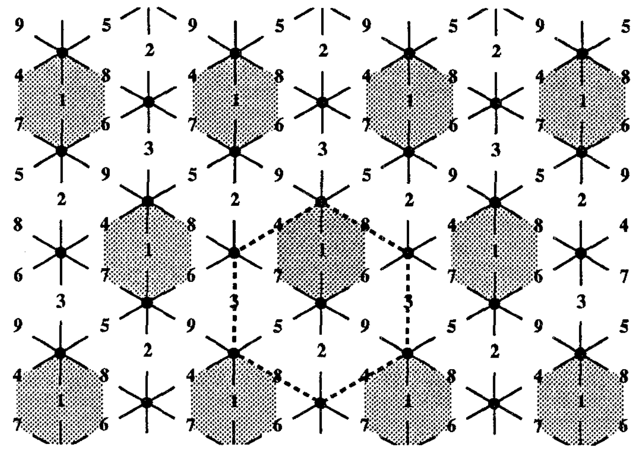

Fig.4 Regular cell layout for simulcast with twofold supply and cell overlapping with frequency re-use 3

large cell overlapping areas are deliberately obtained for neighboring cells, being shaped as rhombs. Most parts of the plane belong to at least two different cells, the centre triangular area in Fig. 3 is even assigned to the three different cells 1, 6, and 8. Fig. 4 shows a regular cell arrangement for this structure with frequency re-use of 3. For a regular layout $\frac{3}{4}$ of the plane are assigned to 2 cells, and $\frac{1}{4}$ is assigned to 3 cells. The areas of the individual cells are reduced to $\frac{3}{4}$ when compared with the threefold supply of Fig. 1 if the same base station grid is used. Nine frequency groups are required to establish the cluster with a re-use factor of 3.

III. PROPAGATION MODEL

In order to calculate the outage probabilities of the presented cell architectures, models of the radio propagation and the mobile station distribution are required as well as algorithms for power control and handover. The outage probability is considered with respect to a required carrier-to-interference power ratio C/I, since interference limited networks are assumed. This means that the received *powers* are sufficient at arbitrary positions. The transmission is only degraded by interference from other cells operating in the same frequency band.

The radio propagation is modelled as a distance dependent attenuation with an addditional log-normally distributed random component modelling the shadowing process. In the logarithmic domain the average path loss $\overline{L_{BM}}$ between the base station location z_B and the mobile station position z_M is calculated as [3]

$$\overline{L_{BM}} = L_0 - 10\,\mathrm{dB} \cdot \gamma \log_{10} |z_M - z_B| \,. \qquad (1)$$

Here a layout within a flat area is assumed, therefore complex numbers z_B and z_M can be used to describe the mobile and base station positions. The propagation coefficient γ

is assumed to be constant over the plane. L_0 is the path loss at the unit distance. The *actual* propagation loss is modelled as a log-normal random variable L_{BM} describing the statistical effects of local shadowing [3]. L_{BM} posesses a pdf. of the from

$$p_{L_{BM}}(L_{BM}) = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-(L_{BM}-\overline{LBM})^2/2\sigma^2} \qquad (2)$$

in the dB domain. The standard deviation σ is also assumed to be constant. It is further assumed that the random path losses for all *different* pairs of mobile and base station positions are uncorrelated.

The mobile station positions are equally distributed within the serving cells, thus cell architectures with different cell shapes or sizes can be compared. The full load case is considered, where in all co-channel cells interfering transmitters are active. With respect to the outage probability analysis it is assumed that the mobile station is always assigned to the cell with the closest base station distances.

IV. OUTAGE PROBABILITY RESULTS

For comparison of simulcast architectures with conventional omnidirectional or sectorized structures, geometrically regular cell patterns are regarded which are theoretically continued periodically to infinity. The carrier-to-interference ratio distributions and the outage probabilities under influence of co-channel interference and log-normal fading are calculated, regarding only interferers with a distance of less than 10 cell radii. This leads to three tiers of interfering cells containing 36 cells in the case of a 3 cell cluster. The standard deviation σ of the shadowing process is assumed to be 6 dB and the propagation coefficient is $\gamma = 3.5$. The results were determined using Monte Carlo simulations. For each time instance all mobile station positions and fading values were generated independently.

The uplink outage probabilities due to co-channel interference and log-normal fading are shown in Fig. 5. A power control algorithm is assumed which controls the transmission power of the mobile station such that the maximum power that is received at one of the base stations of a cell is maintained constant. This applies to simulcast architectures. For the conventional architectures with only one base station per cell or sector the algorithm does the corresponding by keeping the received power at the single base station constant.

Fig. 5 shows that the outage probability of the simulcast architecture is reduced significantly in comparison to conventional structures, leading to a gain of about 5 dB. It can also be seen that threefold supplied cells perform somewhat better than twofold supplied cells. Table 1 lists the used cluster abbreviations. It should be noted that the traffic capacities of the examined architectures differ. They are proportional to the reciprocal value of the cluster size, so that e.g. the 3t cluster has capacity gains with respect to the 4 and 7 cell clusters, in addition to the outage probability improvements.

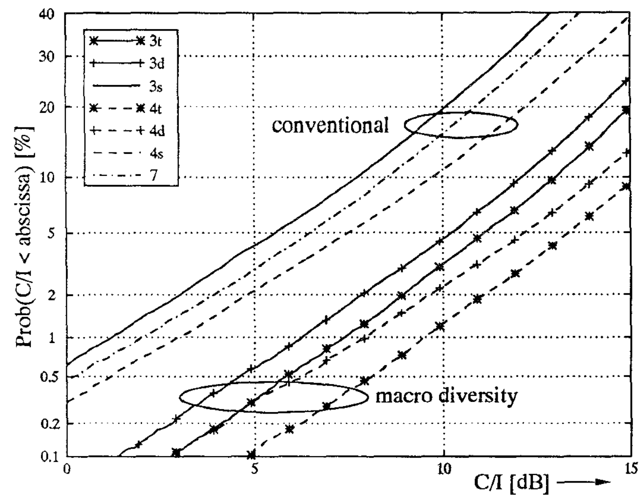

Fig.5 Uplink outage probabilities at $\sigma = 6$ dB

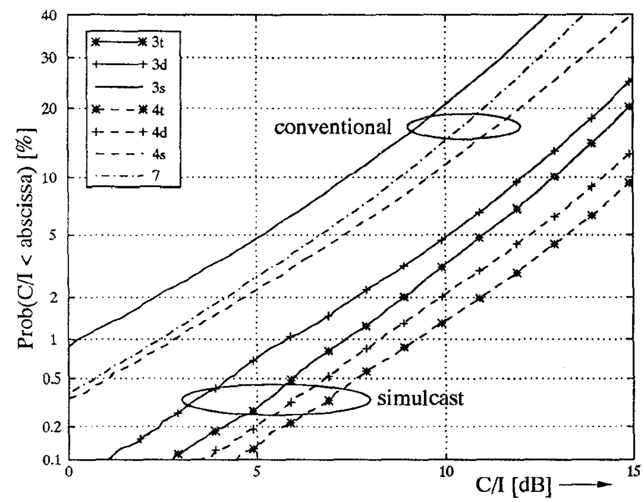

Fig.6 Downlink outage probabilities at $\sigma = 6$ dB

Table 1 Cluster abbreviations

3t:	3 cell cluster with threefold supply and overlapping
3d:	3 cell cluster with dual supply and overlapping
3s:	conventional sectorized 3 cell cluster (9 frequencies)
4t:	4 cell cluster with threefold supply and overlapping
4d:	4 cell cluster with dual supply and overlapping
4s:	conventional sectorized 4 cell cluster (12 frequenies)
7:	7 cell cluster with omnidirectional cells

The sub-optimum selection combining scheme was applied for the uplink macro-diversity combination. Additional gains are achieved if better combination schemes such as maximal ratio combining are used [5].

In the downlink a similar power control algorithm is assumed. It allows only the currently best serving base sta-

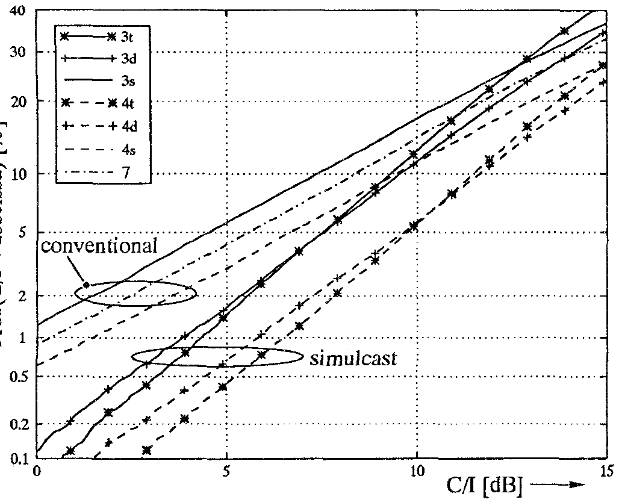

Fig.7 Downlink outage probabilities at $\sigma = 6\,\mathrm{dB}$ with constant transmission powers

tion of the cell to transmit a power that keeps the power received at the mobile station constant. In simulcast structures the transmission powers of the other base stations of the cell are reduced to zero. The results are almost the same as in the uplink, as shown in Fig. 6.

An alternative downlink power assignment scheme is examined that performs no power control but lets all base stations transmit continuously with equal powers. The results for this case are depicted in Fig. 7 and show only slight differences w.r.t. Fig. 6 for conventional cell architectures. The simulcast structures, however, lose partly the outage probability improvements.

A third, more sophisticated distribution scheme for the downlink transmitter powers of a 3t cluster is considered. It keeps the received power R_M at the mobile station con-

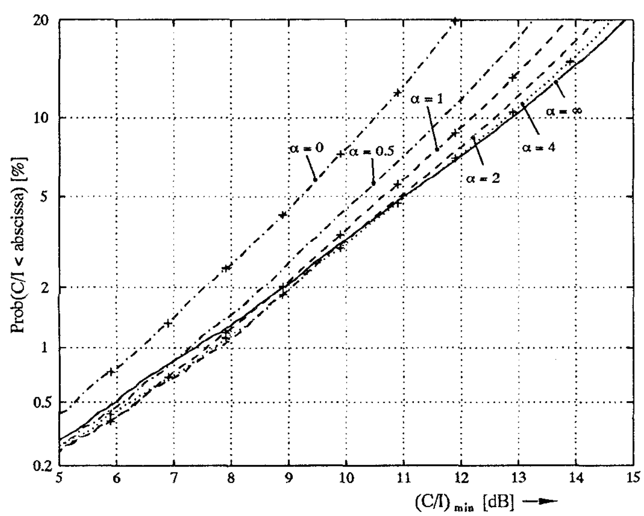

Fig.8 Downlink outage probabilities at $\sigma = 6\,\mathrm{dB}$ for cluster 3t employing power distribution according to (3)

stant, but distributes the transmission powers T_i to the base stations according to $T_i \sim H_i^\alpha$, taking into account the link losses $1/H_i$ of the respective base to mobile station links. For base station i this leads to the transmission power

$$T_i = R_M \frac{H_i^\alpha}{\sum_j H_j^{\alpha+1}} \quad . \tag{3}$$

The individual link losses $1/H_i$ can be measured on the uplink. The transmission powers are distributed the more to the best link, the larger α is. In case of $\alpha = 0$ the transmission power is distributed equally between the three base stations and with $\alpha = \infty$ all power is transmitted by the best serving base station (same as for Fig. 6). Fig. 8 depicts the outage results for different values of α. It shows that values of $\alpha = 1 \ldots 2$ lead to slightly better results than $\alpha = \infty$, but all α values above 1 perform nearly the same.

Fig. 9 shows the differences in the uplink outage probabilities for clusters employing cell overlapping as in Fig. 1 and simulcast clusters that do not employ overlapping, as proposed in the literature, mainly for analogue cellular radio [1, 4, 6]. The assumed power control algorithm keeps the power received at the best served base station of a cell constant, as for Fig. 5. It can be recognized that the overlapping scheme reduces the outage probability substantially. An overlapped 3 cell cluster performs nearly the same as a non-overlapped 4 cell cluster. It should be noted that both structures use the same base station sites. For the downlink similar results are achieved.

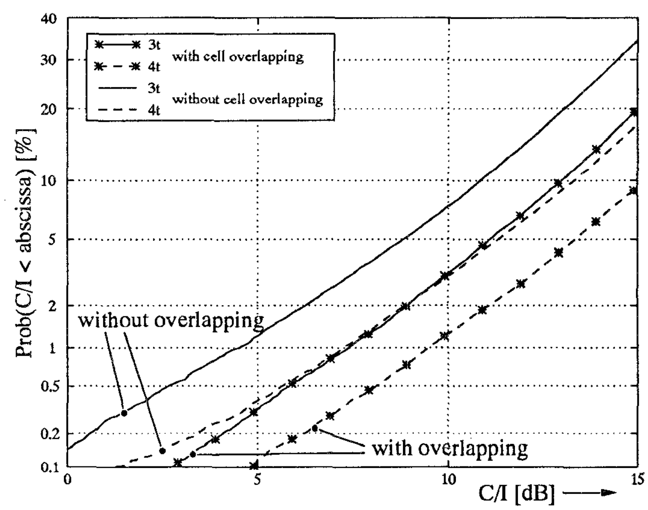

Fig.9 Uplink outage probabilities at $\sigma = 6\,\mathrm{dB}$

V. HANDOVER

In comparison to conventional cell architectures the handover between the overlapping cells of a threefold supply simulcast cluster with cell overlapping (Fig. 1) is more reliable since a large handover area with good reception conditions for both cells can be found in the overlapping zone

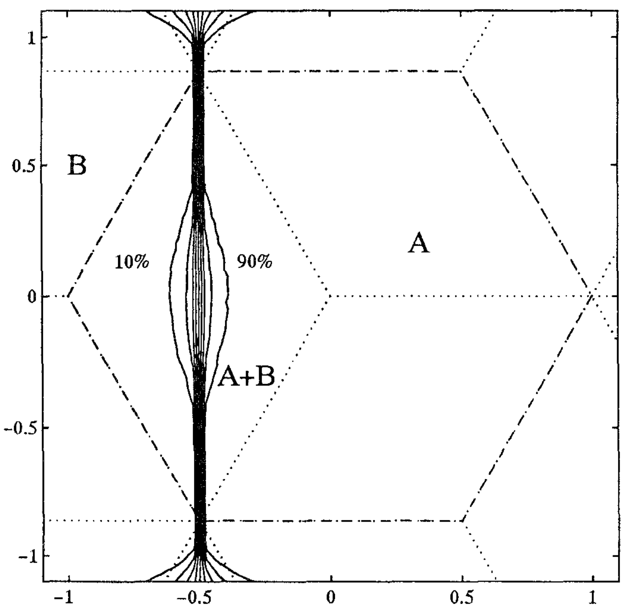

Fig.10 Cell **A** assignment decision probability when deciding between cells **A** and **B**: Prob$\{P_A(z) > P_B(z)\}$

of two neighboring cells. Fig. 10 shows the best server cell assignment decision for such a cell structure according to single downlink power measurements of frequencies **A** and **B** by the mobile station. Highly correlated shadowing components have to be assumed between the path losses of the signals of cell **A** and cell **B** from any of the two common base station sites to the mobile station, since the physical propagation paths are the same for the two

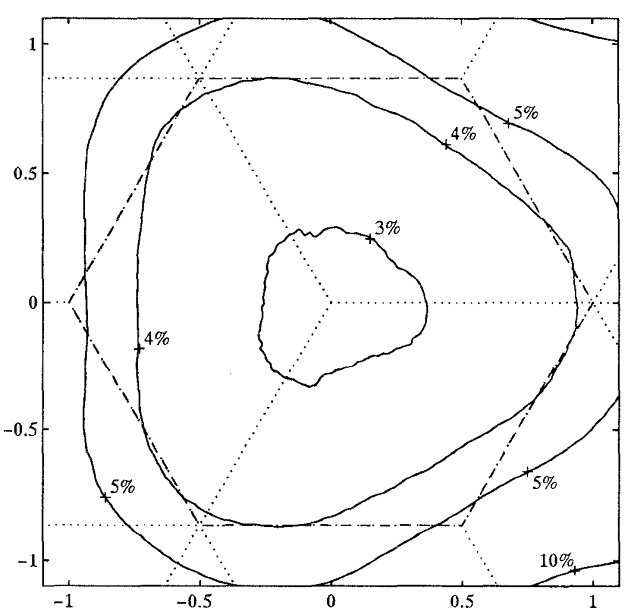

Fig.11 3t cluster downlink outage prob. $(C/I < 10\,\text{dB})$ with power control as function of mobile station position

signals. Thus the cell assignment decision is rather certain even within the overlapping zone. The shape of the cell can be controlled easily by using a biased assignment decision threshold for the reception powers of both cells.

On the other hand Fig. 11 shows the outage probability in a 3t cluster (Fig. 2) as a function of the mobile station position. When compared to Fig. 10, it is found that high supply reliability is achieved even outside the handover limits of the cell.

VI. CONCLUSION

Macro diversity cell architectures using simulcast show pronounced outage probability improvements in comparison to conventional networks with equal cluster sizes. Traffic capacity can be gained if the outage probability is kept constant. Cell overlapping and adaptive power control are essential means to gain this improvements. Handover reliability is increased by the overlapped structure since both involved cells provide good supply conditions in the handover zone.

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REFERENCES

[1] R. C. Bernhardt. Macroscopic diversity in frequency reuse radio systems. *IEEE Journal on Selected Areas in Communications*, 5(5):862–870, June 1987.

[2] German Patent DE 41 41 398 A1. *A method to improve cell illumination for a cellular mobile radio system and equipment to apply the method.* DETECON GmbH, Bonn, June 1993.

[3] W. C. Jakes. *Microwave Mobile Communications.* Wiley, New York, 1974.

[4] W. C. Y. Lee. Smaller cells for greater performance. *IEEE Communications Magazine*, 29(11):19–23, Nov. 1991.

[5] W. Papen. Improved soft handoff and macro-diversity for mobile radio. In *Proceedings ICC '95*, pages 1828–1833, Seattle, June 1995.

[6] Y.-S. Yeh, J. C. Wilson, and S. C. Schwartz. Outage probability in mobile telephony with directive antennas and macrodiversity. *IEEE Transactions on Vehicular Technology*, 33(3):123–127, Aug. 1984.

[7] S. Zürbes and W. Papen. Versorgungswahrscheinlichkeit und Signalkombination in zellularen Mobilfunksystemen mit Makrodiversität. In *Proceedings ITG Fachtagung Mobile Kommunikation '95*, Sept. 1995. In German.

[8] S. Zürbes, W. Papen, and W. Schmidt. A new architecture for mobile radio with macroscopic diversity and overlapping cells. In *Proceedings PIMRC '94*, pages 640–644, Den Haag, Sept. 1994.