Exposure Reduction in GSM Networks by Cell Splitting

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Abstract—Spectrum for mobile communications is limited. With increasing number of customers the resources have to be used more efficient. Therefore, there is a trend to implement a higher density of base stations. Since the exposures of wireless techniques are more and more under consideration the question arises how denser network structures will change the exposure. It is shown that increasing the number of base stations will not generally raise the exposure but can rather help to lower it significantly.

Index Terms—exposure, network planning, cell splitting

I. INTRODUCTION

With the increasing number of users the precious resources in a mobile radio network have to be deployed more efficient. Reusing the available channels in spatially separated areas increases the efficiency. This leads to a higher density of access points i.e. a larger number of base stations is required to cover the same area. Although the exposure at places where people usually stay is well below the limit values, part of the people claims that there is still an evidence for a risk. The fear is the more and the closer the base stations are the higher is the potential risk.

It is well known that decreasing the cell range leads to lower a transmit power per base station. Furthermore, the total network power can be lowered [1]. This yields a reduction of emissions. But decreasing the cell size will in general also lead to lower antenna heights resulting in smaller separations between persons and radiating antennas. Therefore, the question arises what effect the emission reduction in combination with modified antenna heights has on the exposure.

Absorption of the electromagnetic fields in the frequency ranges used in mobile communications results in a temperature increase in the human body. A measure of the absorbed energy is the specific absorption rate which is proportional to the square of the electric field in the body. Therefore, the power density, which is in the far field of a source and outside any media proportional to the square of the electric field, is a measure of the exposure.

II. RADIO NETWORK PLANNING

In order to satisfy their customers a mobile radio network has to cover all area where users can be with a good quality. This can be achieved by providing a required signal to noise ratio (SNR). Noise is due to the noise generated in the receiving device and the interference caused by other signals lying within the bandwidth of the receiver. In a system where no relevant interference occurs radio planning can be based simply on a calculation of signal levels.

Conventional cell planning is done considering the following main constraints:

– assure desired quality
– allocate needed resources
– minimize costs

The emerging exposure within and beyond the coverage area is usually not considered in conventional cell planning since the resultant field values are well below the limit values.

III. THE MODEL

The main elements in the presented model are:

– network layout
– wave propagation model
– base station’s technical data and configuration
– mobile station’s technical data and configuration
– additional propagation losses
– user distribution

These items and their modeling will be described in detail in the following sections.

As GSM is the most popular system the calculations are presented for this system. Interference can be neglected as long as the spacings of the carrier frequencies used in nearby cells are large.

A. Network Layout

A homogenous area is subdivided into hexagonal cells (cf. Fig. 1). Two rings of hexagons are added around a center hexagon to take the impact of surrounding cells into account. Base stations are placed in the center of the hexagons. All cells are identical concerning the number of active users and technical configurations of the terminals. The exposure is determined for the center cell. Simulations have shown that adding further two rings around the center cell will increase the exposure only by some tenth of a dB, which is negligible. Therefore, it is sufficient to limit the number of neighboring hexagons around a considered center hexagon to two rings.

In the middle of Fig. 1 the definition of the cell radius and the orientation of the considered sector antennas are shown. On the right hand side the notation of the angles in the spherical coordinate system is depicted.
A very popular model to describe the path loss in mobile communications, which is also quite simple, is the COST-Hata model [2]. The model is COST-231’s extension of Hata’s model [3] for frequencies in the range from 1.5 GHz to 2 GHz. The COST-Hata model gives the path loss $L$ between a transmitter and receiver depending on the antenna heights of the base station $h_{\text{BS}}$ and mobile station $h_{\text{MS}}$, the distance $R$ between both and their operating frequency $f$. The model is completely empirical since it is based solely on measurements.

According to the COST-Hata model the path loss $L$ in an urban area is given by [2]:

$$
L_{\text{urban}}^{\text{dB}} = 46.3 + 33.9 \log \left( \frac{f}{\text{MHz}} \right) - 13.82 \log \left( \frac{h_{\text{BS}}}{\text{m}} \right) \\
- \left( 1.1 \log \left( \frac{f}{\text{MHz}} \right) - 0.7 \right) \frac{h_{\text{MS}}}{\text{m}} \\
- \left( 1.56 \log \left( \frac{f}{\text{MHz}} \right) - 0.8 \right) \\
+ \left( 44.9 - 6.55 \log \left( \frac{h_{\text{BS}}}{\text{m}} \right) \right) \log \left( \frac{R}{\text{km}} \right) + C_m
$$

(1)

The logarithm is to the base 10. For metropolitan centers the path loss $L_{\text{urban}}$ is increased by $C_m = 3$ dB. In the following $C_m = 0$ dB, which holds for medium sized cities and suburban centers with medium tree density [2]. As frequency $f = 2$ GHz is considered. No difference is made between uplink and downlink frequency since the frequency difference would produce only negligible deviation in signal attenuation compared to the range of the overall attenuation.

In an open area the path loss $L$ is smaller due to the very limited impact of obstacles, which might have an influence on the wave propagation. Therefore, a correction term has to be added to (1) when considering an open area [3]:

$$
\Delta L_{\text{open}}^{\text{dB}} = -4.78 \left( \log \left( \frac{f}{\text{MHz}} \right) \right)^2 \\
+ 18.33 \log \left( \frac{f}{\text{MHz}} \right) - 40.94
$$

(2)

At 2 GHz (2) computes to $-32.5$ dB and is, thus, very different from (1), which holds for an urban area.

In order to assess the influence of building heights easily the path loss for a built up area is calculated here by

$$
\frac{L}{\text{dB}} = \frac{L_{\text{urban}}}{\text{dB}} + \frac{\Delta L_{\text{open}}}{\text{dB}} \left( 1 - \frac{h_b}{h_{b,\text{ref}}} \right)
$$

(3)

$h_b/h_{b,\text{ref}}$ is an empirical correction factor which resembles the degree of the building development. $h_b$ can be thought to be the average building height and $h_{b,\text{ref}}$ a reference building height for which the path loss $L$ is given by (1).

The path loss according to the COST-Hata model is shown in Fig. 2 for different building developments $h_b/h_{b,\text{ref}}$. For distances where the path loss according to the COST-Hata model would yield values smaller than the free space value the path loss is set to the free space value (bright solid line).

The path loss according to the free space model decreases by 20 dB per decade. The clear bending for small distances suggesting a smaller decrease is due to the fact that for small separations the direct line of sight distance is much larger than the horizontal distance $R$, which measured in the $(x, y)$-plane. This horizontal distance is used as abscissa in Fig. 2.

C. Base Station

The base station serves as an air interface of the mobile radio network. The equipment and configuration are chosen in order to provide mobile services to customers within a limited area. In the following the most important parameters, which have an influence on the exposure, are explained.

1) Antenna Height: Whereas for large cells it is practicable to build antennas on high towers for smaller cell sizes only lower mounted antennas seem to be feasible. Therefore, changing the cell size will modify also the antenna height. Assuming an antenna height that will increase with increasing cell size takes this dependency into account. The simulation results presented here assume at a cell radius of $R_C = 500$ m
an antenna height of \( h_{\text{BS}} = 10 \text{ m} \) increasing linearly to \( h_{\text{BS}} = 60 \text{ m} \) at a cell radius of \( R_C = 10 \text{ km} \).

Regarding solely macro cells the antenna height is assumed to be always above the height of buildings close to the base station.

2) Antenna Type and Downtilt: A typical base station antenna type with a gain of \( G_{\text{BS}} \approx 18 \text{ dBi} \) is chosen. The pattern data is available as text file on a CD [4].

Due to the impact of reflections the elevation pattern is smoothed (cf. Fig. 3). The usually smooth azimuth pattern remains unchanged. The three dimensional pattern \( C_{\text{BS}}(\theta, \psi) \) is calculated by multiplying the azimuth and elevation pattern

\[
C_{\text{BS}}(\theta, \psi) = C_{\text{BS}}(\theta) C_{\text{BS}}(\psi),
\]

which is commonly done when no three dimensional data is available.

The considered sector antennas are slightly tilted down. The downtilt angle is chosen in such a manner that the direction where the antenna has its half power beamwidth above the main beam direction is directed at the height of the mobile station’s antenna at the cell radius \( R_C \).

A three sector configuration with main beam directions of \( \psi = \{90^\circ, 210^\circ, 330^\circ\} \), is chosen for Kathrein’s 742212 (cf. Fig. 1).

3) Transmit Power: The calculated minimum path loss from all possible locations of the mobile stations to any base station determines the power which is necessary to transmit the mandatory broadcast control channel (BCCH) in every sector independent of the number of active users in the cell.

For time slots which are not transmitted on the BCCH carrier an optional power control is possible. According to the specifications [5] a maximum power reduction of 30 dB compared to the transmit power of the BCCH carrier is allowed in time slots serving users at positions where the smaller path losses allow a reduction of transmit power.

4) Channel Configuration: Each active user in a cell occupies one time slot for speech transmission. Within the BCCH carrier one time slot contains cell specific information which is necessary for mobile terminals to find a cell. The remaining timeslots of the BCCH carrier can be filled with users. If not all time slots are needed for users or signalling information they are transmitted anyway containing dummy bursts.

The simulations are done assuming that the BCCH carrier should be kept clear of user data and all signalling is handled by this carrier.

5) Sensitivity: The sensitivity level as minimum received power of the base station is assumed to be \( P_{\text{R,BS,min}} = -104 \text{ dBm} \) independent of the cell size.

D. Mobile Station

The mobile station’s antenna height is chosen to be \( 1.5 \text{ m} \) above the ground. As antenna an isotropic radiator is regarded. The sensitivity level is assumed to be \( P_{\text{R,MS,min}} = -102 \text{ dBm} \) [5].

Only speech calls are considered where one time slot is used by an active user. The transmit power in a time slot can be adjusted from 0 dBm up to 30 dBm in dependence on the path loss. The average transmit power is one eighth of the power per time slot. Discontinuous transmission (DTX), which would lead to a lower average power, is not considered.

E. Additional Damping

Choosing the transmit powers to be minimum received power plus the path loss will yield just the minimum received power at the other end. In order to assure good quality further losses have to be considered. To allow a connection a 3 dB loss due to the user and 7 dB due to signal fading are taken into account. There is a high probability that these losses occur. For this reason the signal levels and, therefore, the transmit powers need to be at least 10 dB higher than what is predicted from the path loss model.

To further increase signal quality and to take into account that part of the active users might be situated in buildings further 10 dB are added to the transmit powers of the base and mobile station. For the calculation of the coverage this quality improvement is not considered.

F. User Distribution

Mobiles are assumed to be equally distributed. Three cases are considered:

- network without load — no active user
- very low loaded network — 1 active user per \( \text{km}^2 \)
- medium loaded network — 100 active users per \( \text{km}^2 \)

IV. RESULTS

To evaluate the influence of a change of the cell size on the exposure the power density at the height of the mobile station \( h_{\text{BS}} = 1.5 \text{ m} \) is calculated for the modelled center hexagon (cf. Fig. 1). The statistical relevant values considered here are the average and median value of the power density. All calculations are performed with Matlab.
Fig. 4 shows the run of the average power density $S_{\text{avg}}$ in dependence on the cell radius $R_C$ for different building developments assuming a network with no active users.

Fig. 4 shows the run of the average power density $S_{\text{avg}}$ in dependence on the cell radius $R_C$: assuming a mobile network without users. Due to the higher path loss for higher building developments $h_b/h_{b,\text{ref}}$ the maximum achievable cell radius gets smaller.

The average power densities for larger building developments are higher. The (not shown) transmit powers are by some 12 dB larger when increasing $h_b/h_{b,\text{ref}}$ from 0 to 0.4. This is due to the increase of the path loss when increasing the building development (cf. Fig. 2). For all building developments decreasing the cell size generally yields slightly smaller values of $S_{\text{avg}}$. The slight but abrupt increase around a cell radius of $R_C = 800$ m is due to a integer change of the downtilt angle from $3^\circ$ to $4^\circ$.

Fig. 5 shows that increasing the number of users in a cell will increase the average power density $S_{\text{avg}}$, since a higher transmit power is needed to serve the customers. Decreasing the cell size shows that the curves get closer together, which is due to the dominant contribution of the compulsory BCCH carrier to the transmit power in smaller cells containing fewer active users.

Since the resources are limited the case of 100 active users per square kilometer typically can’t be realized with a cell size of 10 km. Depending on the number of available frequencies and reuse factor of them the cell size might be smaller e.g. around 1 km.

The median power density $S_{\text{med}}$ differs from the average power density $S_{\text{avg}}$, but the general results are the same (cf. Fig. 6). There is almost no change of $S_{\text{med}}$ when there are no users in the cell. Increasing the number of active users shows clearly a lower exposure for smaller cell sizes.

V. CONCLUSION

It is shown that decreasing the cell sizes in mobile cellular networks can help to lower the exposure. This is mainly due to the reduction of the number of active users in smaller cells.

Building up more base stations in areas where no users are will not change the exposure significantly. Concerning the exposure there is no reason to limit the number of base stations.

REFERENCES