THE IMPACT OF EMF EXPOSURE LIMITS REDUCTION ON AN EXISTING UMTS NETWORK

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In this paper it was evaluated the impact of introducing a new EMF exposure regulation, based on the model of the Brussels Region in Belgium, in an existing UMTS network. In the results of the performed simulations, an important decrease was observed in the area of service availability and, as well, in network capacity.

Keywords: EMF, UMTS, coverage, capacity, exposure, limit, Brussels

1. Introduction

The current electromagnetic field (EMF) exposure limits in force in most EU countries were published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) in 1998 [1]. They have been reviewed in 2009 [2], taking into consideration the more recent studies in this field, but ICNIRP could not find any scientifically backed reason to modify them. However, the rampant growth of mobile telephony in the past decade has also led to greater concern among the public opinion regarding the potential health hazards linked to non-ionizing electromagnetic radiation and especially to that generated by the base stations of the mobile phone networks. Despite sufficient evidence that the current EMF exposure of the general public linked to the base stations is very low [3], the pressure on the political authorities has caused, in some cases, the arbitrary adoption of much more drastic limits than those calculated by ICNIRP.

The potential benefits, if any, of such measures on the health protection of the respective communities are hard to quantify at this moment, but one of the most direct effects is the decrease of the current quality of service (QoS) provided by the mobile network operators. One of the first proposals for very low limits of exposure within the EU was that of the City of Salzburg, which wanted in 2001 to impose the maximum value of the measured power density at 1 mW/m^2, more than 4500 times less than the lowest ICNIRP limit for the mobile telephony frequency bands. The proposal was rejected by the Austrian federal parliament. However, the Swiss Federal Communications Commission asked the Swiss Office of Communications to make a feasibility study on the possibility of implementing such a model. The ensuing report concluded that the proposed limit could not be achieved through the existing network in Salzburg [4].

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In 2007, the Brussels region parliament passed a law that imposed a strict limit of 3 V/m on the electric field generated by the base stations of the mobile phone networks. This value is roughly 200 times smaller than the lowest ICNIRP limit for the mobile telephony frequency bands and, in order to respect it, the operators needed to reduce the transmit power of the base stations. In turn, reducing the output power would decrease the network coverage and QoS, which could only be maintained by building 400 new base stations [5]. Thus, the new exposure limit would increase the number of existing base stations by 40%.

In the ensuing lawsuit between the Belgian mobile operators and the federal government, on one side, and the Brussels region, on the other side, the Belgian Constitutional Court ruled in 2009 in favor of the latter. This decision led to the slow deployment of Universal Mobile Telephony System (UMTS) networks (better known as 3G) in Brussels, due to the fact that the operators risked to surpass the new limit by adding UMTS, a new source of EMF, on the same site with the already existing GSM (Global System for Mobile Communications) base station. More recently, for similar reasons, the introduction of the Long Term Evolution (LTE) technology, commercially known as 4G, is hampered by the 3 V/m limit. This is why the debate is still going on and the Belgian Institute for Postal Services and Telecommunication is pushing for the relaxation of this limit, which it considers is halting the development of new technologies [6].

From a pure technical perspective, such a situation poses some interesting problems. The purpose of this paper is to evaluate them from the point of view of an existing UMTS network, because the reduction in output power means both a reduction in coverage and in performance of the data services. Furthermore, in the medium term, UMTS will replace GSM as the main mobile technology and the implications of such regulations need to be evaluated.

2. The equivalence of the proposed limits to the received signal power

UMTS is generally deployed in the 2100 MHz frequency band, for which ICNIRP limits the measured power density to 10 W/m^2. A 200-fold reduction leads to a value of 50 mW/m^2. To simplify the evaluation process, the power density will be transformed into the received signal power, a more familiar notion to the mobile communications technical domain. Equation (1) defines the relation between the received power P_R, the power density S and the antenna aperture A.

$$P_R = S \cdot A = S \cdot \frac{\lambda^2 \cdot G_R}{4\pi} \tag{1}$$

For a frequency of 2140 MHz, the wavelength λ is 14 cm and, considering the reception antenna as omnidirectional, the gain G_R is 1. The power density of 50 mW/m^2 is equivalent with a received power $P_{R\_tot\_max}$ of 78 µW (-11.077 dBm).

This represents the maximum value that could be received in case there was only one radio signal is transmitted. However, this is not the case in real life and it needs to be adjusted by some factors, as it is presented in (2). All the values between brackets are logarithmic.

$$[P_{R\_CPICH}] = [P_{R\_tot\_\max}] + 10 \cdot \lg\left(F_{tech} \cdot F_{band} \cdot F_{op} \cdot F_{cell} \cdot F_{carrier} \cdot F_{CPICH} \right) \quad (2)$$

where:

- F_{tech} represents the percentage of the total EMF exposure owed to mobile telephony systems, which was found to be 0.37 [7]
- F_{band} is used to model the contribution of each of the five major frequency bands used by mobile telephony in Europe: 800, 900, 1800, 2100 and 2600 MHz and is 0.2
- F_{op} takes into account the contribution of all operators that have base stations in a region and, in the case of Romania, it is 0,25
- F_{cell} takes into account the contribution of neighboring serving cells and, considering the worst-case scenario in which all seven have equal contributions, should be 0.14
- $F_{carrier}$ models the typical maximum number of UMTS carriers that can be deployed by four operators in the 2100 MHz band and is 0.33
- F_{CPICH} represents the percentage of the total cell power that is transmitted on the Common Pilot Channel (C-PICH) and is 0.1

Thus, after calculating (2) with the above values, the received power on the C-PICH of the serving UMTS cell should not surpass –51.758 dBm.

3. The impact of the proposed limits on UMTS coverage

The UMTS network of Orange Romania SA in the city of Craiova was chosen for the coverage simulations. A total of 102 cells from 35 base stations were selected, both inside the city and in its immediate vicinity. A larger city and network would have increased the simulation time beyond reasonable values, without having a decisive influence on the results.

The coverage was simulated in the professional network planning software Aircom ASSET 6.2. A deterministic propagation model, Myriad, was used in order to take advantage of the detailed map of the city's buildings that is included in ASSET. Thus a more accurate propagation prediction could be achieved compared to a classical statistical model, like, for example, COST231-Hata. The base stations were modeled to reflect the actual situation in the field in terms of positioning, antenna type, azimuth, tilt, feeders and output power.

The result of the simulation is a geographically referenced array, with the resolution of 5 m, containing the maximum calculated received power from the dominant C-PICH in each array element.

In order to determine the current service availability, a coverage threshold was first established. This threshold value for the received power is determined in (3) by subtracting the maximum allowable pathloss from the effective isotropically radiated power of the cell.

$$[P_{thresh}] = [P_{CPICH}] + [G_A] - [L_F] - [MAPL] \tag{3}$$

The power transmitted on C-PICH P_{CPICH} is typically 33 dBm. The antenna gain and feeder losses are irrelevant for reasons that will be seen below and the maximum allowable pathloss represents the propagation losses value above which communication between the base station and the mobile phone is no longer possible. Since in UMTS usually the uplink is the limiting factor, the MAPL can be expressed as the difference between the effective isotropically radiated power of the mobile phone and the base station's sensitivity.

$$[MAPL] = [P_{Tx\_MS}] - [L_B] - [S_{UMTS}] \tag{4}$$

The maximum transmit power of the UMTS terminal is 21 dBm and the attenuation induced by the contact with the human body (the hand, the head etc.) L_B is 5 dB. The sensitivity of the base station is presented in (5), based on the standard equation of the minimum detectable signal by a radio receiver [8] and on the main factors that influence the power budget of the UMTS radio link [9].

$$[S_{UMTS}] = 10\lg(KTB) + [NF] + \left[\frac{E_B}{N_O}\right] - [G_A] + [L_F] - [G_{RxD}] - [G_{\Pr}] - [G_{SHO}] + [M_I] + [M_S] + [M_F] \tag{5}$$

The terms are explained below:

- B is the 3.84 MHz bandwidth of the UMTS carrier.
- NF is the noise figure of the base station that is usually around 2 dB.
- E_B/N_o is the energy per bit per noise ratio and the required value for the voice service is 5.6 dB.
- G_{Pr} represents the processing gain and it is calculated as the ratio between the maximum chip rate (3.84 Mcps) and the bit rate of the voice service (12.2 kbps). It is 25 dB.
- G_{SHO}, the soft handover gain, is usually considered to be around 3 dB.
- M_I is the interference margin, also known as the uplink noise rise, and depends on the uplink load in the cell. The system is typically designed taking into account a 50% load in order to

leave room for the cell breathing effect that occurs when the load rises. For the chosen load of 50%, the margin is 3 dB.

- M_S represents the saturation margin, which is meant to preserve a headroom for the transmit power when the mobile is in poor radio coverage conditions. Because the power control algorithm is changing the transmit power with a frequency of 1500 Hz in order to compensate the fast fading, it requires a safety margin to avoid entering saturation when there isn't enough power available for allocation. The value of this margin is 3dB.

By inserting (4) and (5) into (3), together with the above-mentioned values, it is possible to determine the received C-PICH power coverage threshold for the voice service in UMTS. The value of this threshold is –101.4 dBm.

In Fig. 1, with light blue is displayed the area in the city of Craiova where there is UMTS voice service coverage (the received C-PICH power is at least –101 dBm) and with white is displayed the area with no coverage. The red represents the areas where the received C-PICH power exceeds the limit of –52 dBm.

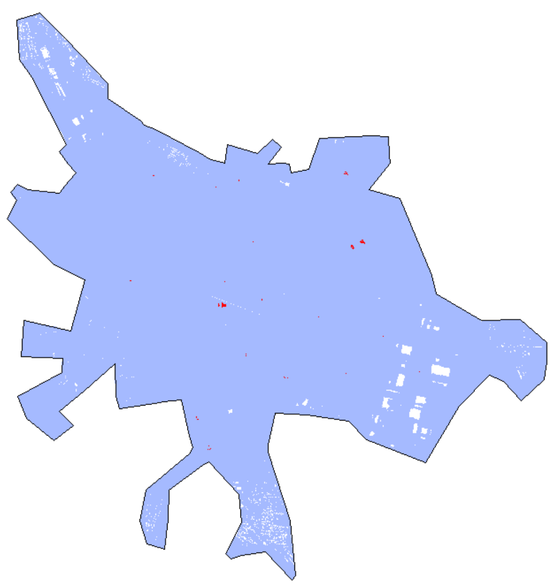

Fig. 1. UMTS coverage simulation in the city of Craiova

With the help of the MapInfo Professional 8.0 software, it was possible to extract the surface covered by each area. The results are listed in Table 1. They are presented also as a percentage of the city's total surface of 39.527 km^2. The overall voice service coverage is of 98.55% of the city's surface and the area where the exposure limit would be surpassed is relatively small, only 0.05%, but it must be completely eliminated.

Table 1

Surface covered by UMTS 2100 signal

$P_{R\_C\text{-}PICH}$ [dBm]	Surface [km^2]	Percentage of the total surface [%]
> -52	0.019	0.052
[-52, -101)	35.98	98.502
< -101	0.528	1.446

The most straightforward way to accomplish this is to reduce the output power of the base stations. In order to determine the extent of this reduction, the current coverage was exported from ASSET for each received C-PICH power level between –30 and –101 dBm. The corresponding surfaces were then processed with MapInfo to determine the distribution of the received power throughput the city.

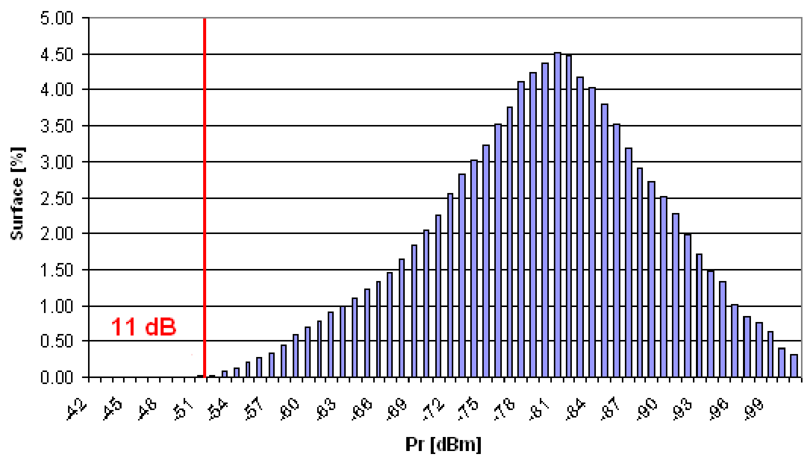

Fig. 2. Distribution of the received C-PICH power according to the surface covered by each level

Fig. 2 contains the distribution of the received C-PICH power, starting from –42 dBm, the highest power level calculated. In order to be absolutely sure that the exposure limit is not reached, the maximum received C-PICH power should be –53 dBm. Thus the output power has to be reduced by 11 dB. The resulting surface with UMTS voice service coverage represents only 85.85% of the city. However, most of the areas where the coverage is lost are buildings, places where the potential users of the network are usually located and thus the impact in service availability perception is actually higher.

In Fig. 3, the loss of coverage is illustrated with red. There are 13 large areas in the city were significant gaps have appeared and, in order to restore the quality of service, 13 new base stations need to be installed.

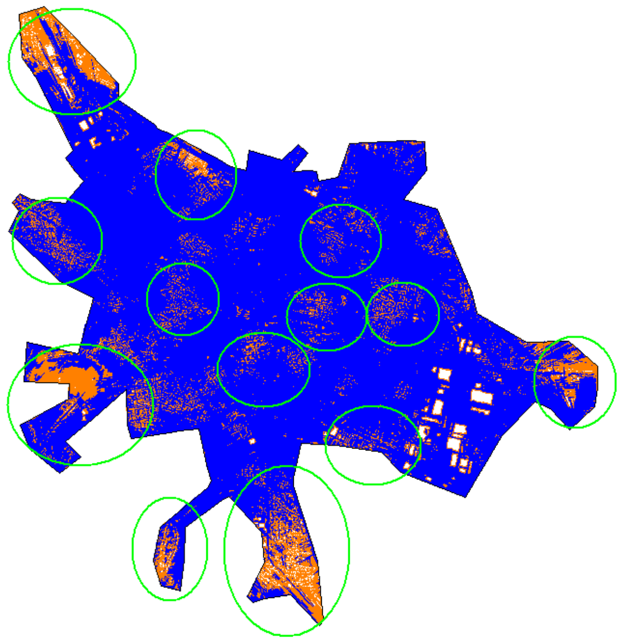

Fig. 3. Evaluation of the decrease in coverage after the reduction of output power by 11 dB

The coverage simulation was run again to include the 13 new base stations, while preserving the output power reduction by 11 dB. The area of coverage for the UMTS voice service in Craiova was increased from 85.85% of the city's surface, as it was in the case of the output power reduction, to 95.60%. Although significantly higher, this value is still smaller than the initial coverage of 98.55%. A further 14th base station was added and, following a new simulation, the coverage percentage increased to 95.83%. The process was continued. Due the 15th extra base station the coverage reached 96.04% and due to the 16th it increased to 96.25%. At this moment, the efficiency of adding further base stations, from the coverage point of view, is low and it was decided to stop the process. The initial network of 26 UMTS base stations inside the city's administrative boundary was increased to 42 base stations in order to compensate de 11 dB output power reduction. The network grew by 61.53%, but the coverage decreased from 98.55% to 96.25%. The final coverage is presented with dark blue in Fig. 4.

The larger number of base stations inside the city has as a possible consequence the increase of interference, which leads to the decrease of signal quality. In UMTS the signal quality is measured by using the signal to interference ratio E_C/I_O, which can also be exported from the ASSET simulation.

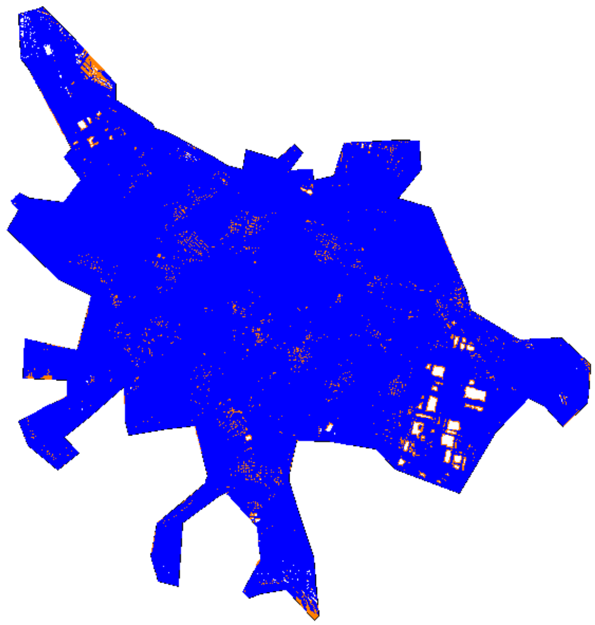

Fig. 4. Final UMTS coverage after output power reduction and addition of 16 new base stations

Each type of UMTS radio bearer (voice, video telephony, data traffic) requires a minimal value of the signal to interference ratio in order to function and can be determined with the help of (6) [10].

$$\left[\left.\frac{E_C}{I_O}\right|_{\min}\right]=\left[\left.\frac{E_B}{N_O}\right|_{t\arg et}\right]-\left[G_{\Pr}\right] \tag{6}$$

The target energy per bit per noise ratio is known for a given bit error rate or block error rate and the processing gain is the ratio between the channel width and the data rate of the requested service. In Table 2 were synthesized the required E_C/I_O values for different services.

Table 2

Required E_C/I_O

Service	Target E_B/N_O [dB]	Processing gain [dB]	Required E_C/I_O [dB]
Voice – 12.2 kbps	8	24.98	-16.98
Video telephony – 64 kbps	5	17.78	-12.78
Data – 128 kbps	5	14.77	-9.77
Data – 384 kbps	5.1	10	-4.9

The rounded values from Table 2 were used as thresholds in the ASSET simulations. The areas corresponding to each interval were extracted with the help of MapInfo Professional. In Fig. 5 are illustrated the results for the three scenarios.

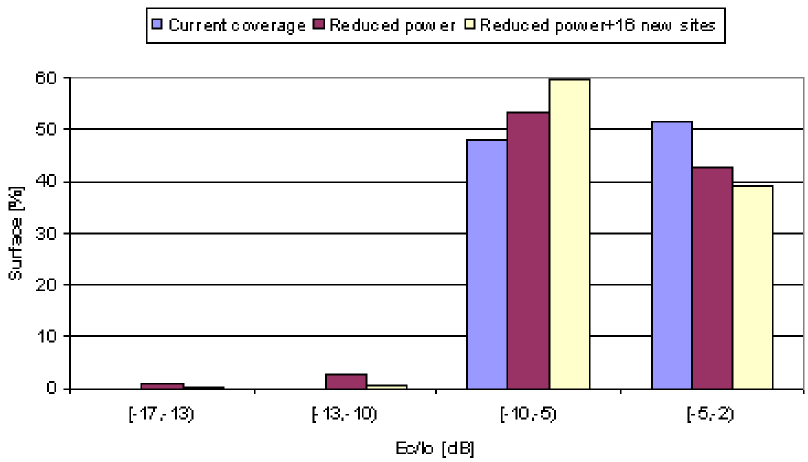

Fig. 5. Distribution of the E_C/I_O for the three coverage scenarios

It can be easily observed that mostly the 384 kbps data service is affected, because the coverage of this service decreases from 51.54% to 39.21% of the city's surface. Because of the interference, the quality of the signal is worse in the scenario with the new sites than in the one in which only the output power is reduced. For the other services the changes are relatively small from the point of view of the signal to interference ratio.

3. The impact of the proposed limits on HSDPA performance

In UMTS, the base station's output power gives an indication not only on the estimated coverage, but also on the capacity and performance. By reducing the output power, it is expected to have also a decrease in the latter aspect as well.

The High Speed Downlink Packet Access (HSDPA) evolution of UMTS offers the possibility to achieve data throughputs in excess of several Mbps in downlink and is, after voice, the second UMTS service in terms of actual usage. The power is allocated to the users served by the HSDPA cell by the base station's scheduling algorithm, which has several different possible implementations. In order to eliminate the impact of the algorithm on the results, it was decided to simulate the cell's throughput when serving only one user. Thus the entire traffic power can be allocated on the High Speed Data Shared Channel

(HS-DSCH), which is used to transport the requested data. Equation (7) describes how to calculate the available power for this channel.

$$P_{HS-DSCH} = P_T - P_{CCH} - P_{HS-SCCH} - P_{A-DCH} - P_{Backoff} \quad (7)$$

The terms are explained below:

- P_T is the total power of the cell;
- *PCCH* represents the power of the UMTS control channels, which is usually around 20% of the total cell power;
- $P_{HS\text{-}SCCH}$ is the power transmitted on the high speed shared common channel and, in the worst case, amounts for 10% of the total cell power;
- $P_{A\text{-}DCH}$ is the power reserved for the associated dedicated channel, which serves as an emergency channel on which voice traffic could be carried simultaneously with the HSDPA data traffic for the same user. It is usually 3.16% of the total cell power;
- $P_{backoff}$ represents the power reserved for the power control algorithm's overhead and is 5% of the total cell power.

Considering a total power of 20 W, the maximum value of the $P_{HS\text{-}DSCH}$ is 12,368 W. In order to simplify the simulation, only one user will be scheduled by the base station each time interval and the entire HS-DSCH power will be reserved for this user. The power is transmitted through feeders, which have losses L_F of 0.5 dB, into an antenna that has a gain G_A. The gain is variable, according to the relative angle between the main direction of radiation of the antenna and the line connecting the base station and the user's position in the horizontal plane. The maximum value of G_A is 17.76 dB and the minimum is 0.09 dB at a relative angle of 60 degrees.

The received signal power P_{RX} is defined in equation (8).

$$[P_{RX}] = [P_{HS-DSCH}] - [L_F] + [G_A(a)] - [PL(d)] \quad (8)$$

PL represents the propagation losses, which can be determined using the COST 231-Hata model (see equation (9) [11]), where *F* is the carrier frequency of 2100 MHz, H_b is the height of the base station antenna of 30 m and H_m the height of the mobile phone of 1.7 m.

$$[PL(d)] = 46.3 + 33.9\lg F - 13.82\lg H_b - aH_m + (44.9 - 6.55\lg H_b)\lg d + 3 \quad (9)$$

The power of the signal received by the mobile can also be determined by taking into account the standard equation of the minimum detectable signal by a radio receiver [8] and the main factors that influence the power budget of the UMTS radio link [9].

$$[P_{RX}] = 10\lg(KTB) + [NF] + [SNR] - [G_{Pr}] + [L_B] + [M_F] \quad (10)$$

Because the mobile phone is a poorer receiver than the base station, the noise figure *NF* will be 8 dB instead of 2 dB. The processing gain G_{Pr} is only 12 dB, the difference from the value in (5) being owed to the larger bandwidth consumed by the HSDPA. The body loss L_B is considered to be 4 dB in case the mobile phone is held in the hand in front of the body (a typical usage scenario for data traffic) and the fading margin M_F is 4.2 dB.

From (8) and (10) it is possible to arrive at equation (11) with which the signal to noise ratio *SNR* can be calculated.

$$\begin{aligned}[SNR]=&[P_{HS-DSCH}]-[L_F]+[G_A(a)]-10\lg(KTB)-[NF]+[G_{\mathrm{Pr}}]\\&-[L_B]-[M_F]-[PL(d)]\end{aligned} \quad (11)$$

The signal to noise ratio is a good indication of the theoretical data throughput that the base station ca transmit to the user. In [12] several curves that show the dependence between the throughput and the SNR are given for different types of HSDPA terminals. For the purpose of this simulation, a class 10 terminal was chosen. This terminal can achieve a maximum theoretical downlink data throughput of 14.4 Mbps.

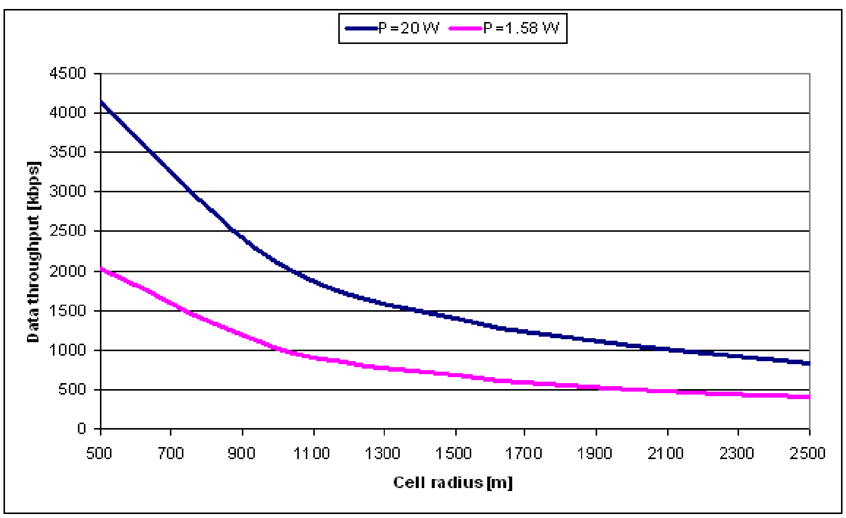

Fig. 6. Comparison of average cell data throughput depending on cell radius and output power

Equation (11) and the related values were implemented in MATLAB. A total of 100,000 random positions for the user were generated. These positions consisted of a distance *d* between the base station and the user and an angle *a* relative to the antenna's main radiation direction. The simulation was run for a cell radius varying from 500 to 2500 m. The resulting average cell data throughput is displayed in Fig. 6, both for a normal cell with the total output power of 20 W and for a cell with the output power reduced by 11 dB to 1.58 W.

As it can easily be observed, the average data throughput decreases with 48.9% if the output power is reduced by 11 dB.

4. Conclusions

The simulations performed in this paper show a considerable decrease in both service coverage and system capacity of an UMTS network, which is forced to decrease output power due to harsher electromagnetic field exposure regulations. These side effects must be carefully taken into consideration before new regulations are introduced and a balance between quality of service and decreased EMF exposure must be found.

R E F E R E N C E S

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