Indoor Exposure Index Simulation of Macrocell versus Femtocell Deployments

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Abstract—A simulation of the Exposure Index of an indoor population within the coverage range of a macrocell base station is performed, with and without the use of indoor femtocell base stations. The influence of the transmit power of the macrocell base station on the exposure and the number of required base stations in a 10 km² area is investigated. It is shown that installing a femtocell base station is not always beneficial with respect to the average total population exposure.

I. INTRODUCTION

The increased concerns about the possible health effects of radio-frequency (RF) electromagnetic fields have boosted the research on the characterisation of electromagnetic fields. In [1], a metric was proposed to assess the radio-frequency RF exposure of a population, accounting for downlink (DL) and uplink (UL) traffic. In this paper, it is investigated how the total exposure of humans (DL+UL) is influenced by varying the cell range. This is done by adjusting the Equivalent Isotropically Radiated Power (EIRP) of the macrocell base station (MBS). The total exposure is simulated for an indoor population for a macrocell-only scenario and for a scenario in which indoor femtocell base stations (FBS) are added.

II. METHODOLOGY

The range of a 3G MBS network is calculated for *indoor* phone call coverage. Installed BSs are assumed to have an isotropic radiation pattern, the Cost231 Walfisch-Ikegami is used, and an average building penetration loss of 8 dB (standard deviation $\sigma = 6$ dB), a shadowing margin of 10 dB, and a fading margin of 9 dB are assumed. The sensitivities of the mobile user device and the MBS are assumed at -95.1 dBm and -110 dBm respectively [2]. This range calculation is executed for an EIRP ranging from 20 to 60 dBm.

Based on the cell size of a BS, the average total whole-body Exposure Index EI is determined for a population within this cell for two indoor scenarios. In the first scenario (S1), the indoor coverage is provided by the outdoor MBSs. The second scenario (S2) builds on S1, but here, FBSs are added indoor for a better coverage. The FBS power density and user device's UL power are assumed at $5.2 \cdot 10^{-6}$ W/m² and $2.9 \cdot 10^{-7}$ W respectively [1].

EI [W/kg] [1] corresponds to the average whole-body SAR exposure within a certain time frame, averaged over all locations within the coverage area of the BS. The time frame is here chosen at one hour. Each location-specific exposure

value is determined as the sum of the UL contribution (from the user device) and DL contributions (from MBS in S1; from both FBS and MBS in S2). Whole-body reference SAR values are 3 mW/kg per W/m² for DL and 4.95 mW/kg per W for UL [3]. The EI calculations are done for three phone call intensities (PCIs): normal (total call duration in 1 h = 8.75 s), high (35 s/h), and very high (140 s/h). Further, it is calculated how many MBS are required to cover an area of 10 km² (inter-cell interference is neglected).

III. RESULTS

Fig. 1 shows the average EI (UL, DL, and total) over the entire coverage area for S1 for three PCIs as a function of the MBS EIRP. It shows that lower MBS EIRP (smaller cells) cause a lower total EI over the cell, as expected. For increasing EIRPs, the average EI due to DL increases (black line, due to the highly increasing DL power densities close to the MBS), and the EI due to UL increases (colored dotted lines, due to the increasing UL powers towards the cell edge). For low MBS EIRPs (and lower PCIs), EI_{DL} and EI_{UL} both contribute substantially to the total EI. Due to the higher increase rate of EI_{UL} (compared to EI_{DL}), EI_{UL} becomes dominant over EI_{DL} for higher MBS EIRPs (e.g., for a normal PCI around EIRP = 45 dBm or higher, for a very high PCI around EIRP = 25 dBm or higher: EI_{UL} converges to EI_{total}). Since EI_{UL} becomes dominant in EI_{total} for high EIRPs, higher PCIs lead to higher a EI_{total} . Finally, as the MBS's EIRP increases, the cell ranges become larger and the number of required BS to cover the area (and thus also the total cost) decreases exponentially (blue line). However, larger cell ranges also lead to an increased exposure.

Fig. 2 shows the average EI_{total} over the coverage area for the three PCIs as a function of the MBS's EIRP when the (indoor) population connects to added indoor femtocells (S2). Here, the size of the macrocell has little influence on EI_{total} , since EI_{total} is almost always dominated by EI_{DL} of the FBS. Thanks to the use of a FBS, EI_{UL} is always negligible (unlike in S1), irrespective of the PCI (full green and magenta lines coincide with full red line in Fig. 2). For large macrocells (EIRP > 45 dBm), EI_{DL} of the MBS also has a substantial contribution in EI_{total} . Again, total cost to coverage a certain area increases exponentially when the MBS EIRP decreases (more MBSs are required). The total cost only takes macrocell coverage into account, not the use of femtocells.

Fig. 1. EI (DL, UL, and total) and number of required MBS as a function of MBS EIRP for three phone call intensities in S1.

Fig. 2. EI (DL, UL, and total) and number of required MBS as a function of MBS EIRP for three phone call intensities in S2.

When comparing EI_{total} for the two scenarios and for two PCIs (Fig. 3), it is shown that deploying a femtocell is not always beneficial (see also [1]). Fig. 3 shows that for low MBS EIRPs (smaller cells), EI_{total} is higher for S2 (red line in Fig. 3), due to the high EI_{DL} of the FBS ($1.56 \cdot 10^{-8}$ W/kg, see Fig. 2), compared to S1 where both EI_{DL} and EI_{UL} remain relatively low ($< 5 \cdot 10^{-9}$ W/kg, see Fig. 1). For higher MBS EIRPs, it becomes beneficial to install FBSs (green lines intersect red line in Fig. 3). For a normal PCI, this occurs at an MBS EIRP of 44 dBm and for a very high PCI already around 31 dBm. This PCI does not influence the total EI in the FBS scenario (dotted and full red lines coincide in Fig. 3), due to the good connection with the BS (EI_{UL} always negligible, see also Fig. 2). The increase rate of EI_{total} as a function of MBS's EIRP (= line slope) is determined by the dominant contribution to EI_{total} . E.g., a steep slope is observed for S1, due to the dominant UL contribution.

Fig. 3. Comparison of EI_{total} for two phone call intensities for S1 vs. S2 as a function of MBS EIRP, and number of required MBS.

IV. CONCLUSIONS

In this paper, the average exposure of an indoor population within the coverage range of a macrocell base station is compared with and without the use of indoor femtocell base stations, as function of the transmit power of the base station. Installing a femtocell base station is only beneficial in large cells and/or for higher phone call intensities. Installing a femtocell base station makes the population exposure independent of the phone call intensity, whereas in a macrocell-only deployment (especially in large cells), uplink exposure is the dominant factor. For the assumed configuration parameters and for a phone usage of 8.75 s per hour, installing a femtocell base station reduces the population exposure only when the outdoor macrocell network is planned with base stations with an EIRP of 44 dB or higher. It is also shown that a trade-off between exposure and the number of required base stations has to be made. Future work will consist of determining the total exposure for a population that is distributed over indoor and outdoor environments.

ACKNOWLEDGEMENT

This paper reports work undertaken in the context of the project LEXNET. LEXNET is a project supported by the European Commission in the 7th Framework Programme (GA no318273). For further information, please visit www.lexnet-project.eu.

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