Exposure Optimization in Indoor Wireless Networks: Application to Heterogeneous WiFi-LTE Case

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INTRODUCTION

The popularity of indoor wireless networks has greatly increased in recent years. Many software tools have been developed for the prediction of the received signal quality and the network performance. The enormous increase of wireless communication makes it necessary to characterize the exposure of people due to electromagnetic fields at RF (radiofrequency) frequencies and to investigate the exposure of the general public to wireless telecommunication systems. International guidelines such as the ones of ICNIRP [1] have been developed and authorities and countries have implemented laws and norms to limit human exposure. Some cities (e.g., Salzburg, Brussels, Paris,...) even have their own specific guidelines. This indicates the need for accurate exposure calculations. Therefore, this paper presents an exposure prediction and optimization algorithm that has been developed and integrated in the WiCa Heuristic Indoor Propagation Prediction (WHIPP) tool [2]. The field exposure minimization algorithm will be applied to an indoor heterogeneous Long Term Evolution (LTE) femtocell and WiFi network.

MATERIALS AND METHODS

The WHIPP planner consists of a set of heuristic planning algorithms, developed and experimentally validated for network planning in indoor environments [2]. The path loss prediction algorithm takes into account the effect of the environment on the wireless propagation channel and bases its calculations on the determination of the dominant path between transmitter and receiver, i.e., the path along which the signal encounters the lowest obstruction. This approach is justified by the fact that more than 95% of the energy received is contained in only 2 or 3 paths. The dominant path is determined with a multidimensional optimization algorithm that searches the lowest total path loss, consisting of a distance loss (taking into account the length of the propagation path), a cumulated wall loss (taking into account the walls penetrated along the propagation path), and an interaction loss (taking into account the propagation direction changes of the path, e.g., around corners). The model has been constructed for the 1.8 - 2.6 GHz band and its performance has been validated with a large set of measurements in various buildings [2]. In contrary to what has been done for many existing network planning tools, no tuning of the tool's parameters is performed for the validation. Excellent correspondence between measurements and predictions is obtained, even for other buildings. The WHIPP tool is designed for optimal network planning with a minimal number of access points or for a limited or minimized (downlink) exposure [3].
Figure 1 shows the ground plan of an office building, for which we will optimize the human exposure. As receiver, a 4G mobile phone, able to receive LTE and WiFi, will be considered. We will design a network that provides a certain required throughput in the different rooms

of the building, but where the *global exposure* will at the same time be minimal. To assess the global exposure, an optimization metric reflecting the degree of human exposure on the building floor is needed. Different metrics exist to assess, limit, or minimize the exposure on a building floor, e.g., [3]. Here, we will use E_M, the average of the median electric-field strength E_{50} in the entire building, and the 95%-percentile value E_{95} of the field strengths in the building.

$$E_M = \frac{w_1 E_{50} + w_2 E_{95}}{w_1 + w_2} \quad (1)$$

with w_1 and w_2 weighting factors for the 50%-percentile value E_{50} and the 95%-percentile E_{95} respectively. We choose to include E_{50} into the metric to account for the median exposure on the building floor, and also E_{95}, to account for the maximal exposure values. Here, we will assume an equal impact of E_{50} and E_{95} on the metric and set both $_{w1}$ and w_2 at a value of 0.5. When evaluating and optimizing the different networks for a low exposure, the given coverage requirement always has to be met, using the 90% shadowing margin and 95% fading margin. The WHIPP tool allows choosing a separate coverage requirement for each room [3].

Traditionally, network designers try to provide coverage with the least amount of access points possible. In the considered building and for a traditional network deployment a network with several access points with an equivalent isotropic radiated power (EIRP) of 20 dBm is designed. The gain factor G [-] of using an exposure-optimized network instead of a traditional deployment is defined as the ratio of E_M for a traditional deployment (E_{M_TRAD} [V/m]) and E_M for the exposure-optimized deployment (E_{M_OPT} [V/m]).

$$G = \frac{E_{M\_TRAD}}{E_{M\_OPT}} \quad (2)$$

A value of G greater than 1 thus means that the exposure-optimized network has better exposure characteristics than the traditional deployment.

Two optimization phases are developed to minimize exposure while maintaining a certain coverage requirement. In phase 1, the WHIPP optimization module places access points with an EIRP of 1 dBm on the ground plan, with the empty ground plan of the considered building floor and the coverage requirement in the different rooms as an input to the algorithm. After that, access point pairs are merged into one access point (with possibly a higher EIRP) if this reduces E_M. In the second phase, it is investigated if access points can be removed by increasing the transmit power of the surrounding access points in an optimal way. If removal of an access point is impossible, its transmit power is lowered, if possible without losing coverage.

RESULTS AND DISCUSSION

We consider the following (heterogeneous) scenario, shown in Figure 1. *One* LTE femtocell at 2600 MHz is present in the building, with an EIRP of 10 dBm, a bandwidth of 20 MHz and a 3:1 downlink-uplink ratio (top right of building plan in Fig. 1). The femtocell is indicated with a hexagon with the EIRP value inside. Femtocell downlink traffic may cause significant exposure values. In this scenario, the femtocell EIRP cannot be decreased and is assumed to be fixed at 10 dBm. The femtocell has a fixed location and WiFi access points are added to provide a throughput of 18 Mbps. For this heterogeneous scenario, we assume a 4G receiver (WiFi and LTE) that is able to automatically switch to the transmitter (access point or femtocell) that provides it with the best capacity.

Figure 1 (a) shows the result of the traditional deployment where a network with one access point with an EIRP of 20 dBm is designed additionally to the present LTE base station. E_{50}- and E_{95}-values of 0.051 V/m and 0.316 V/m respectively are obtained. The standard deviation is 0.184 V/m.

The two exposure minimization phases will be applied to a *heterogeneous* (WiFi and LTE) network (see Section method). During the successive optimization phases, the femtocell settings are fixed; only the EIRP of the WiFi APs is assumed to be adaptable. Since the requested capacity (18 Mbps throughput) cannot be provided by only the femtocell, WiFi access points will have to be added accordingly. Table 1 summarizes the different steps of the exposure optimization of the heterogeneous WiFi-LTE network and makes a comparison with the traditional deployment.
In the first optimization phase (Table 1), three WiFi access points with an EIRP of 1 dBm are added (see Fig. 1 (b)) to provide the necessary capacity on the building floor. Due to the small number of WiFi access points (three) and their optimal location, no merge operations are possible. For this network, E_{50} equals 0.021 V/m, E_{95} equals 0.135 V/m, and E_M equals 0.079 V/m. In phase 2, no access points can be removed, but the EIRP of two of the three WiFi access points (circled in Fig. 1 (b)) can be lowered to 0 dBm, resulting in final E_{50}- and E_{95}-values of 0.020 V/m and 0.135 V/m respectively (E_M = 0.077 V/m). The standard deviation is 0.066 V/m.

The global exposure E_M is of course much lower for the optimized network than for the traditional deployment: 0.077 V/m versus 0.184 V/m: a gain of a factor G = 2.39 is obtained. Also, the standard deviation of the optimized network (0.066 V/m) is lower than the one of the traditional deployment (0.184 V/m), resulting in a more homogeneous field distribution with lower local maxima (see Fig. 1 (a) versus Fig. 1 (b)). This is due to the higher number of Aps and lower EIRPs of the APs. The number of access points in the optimized network (1 LTE femtocell and 3 WiFi APs) is indeed substantially higher than for the traditional deployment (1 LTE femtocell and 1 WiFi AP) due to the much lower EIRP values. The traditional deployment will thus have a lower cost compared to the optimized network.

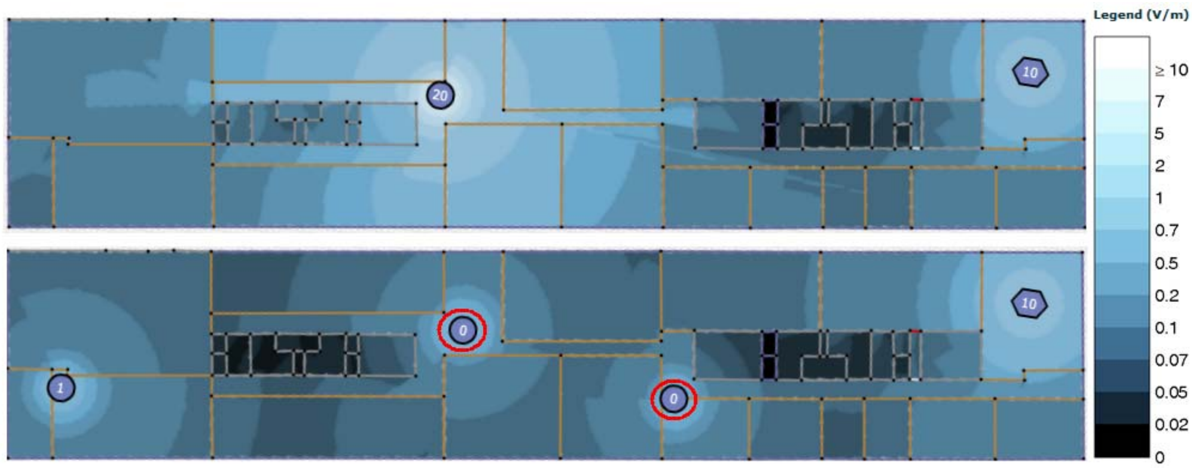

Figure 1: Network layout and resulting electric-field strength for (a) top: traditional deployment and (b) bottom: after the two exposure minimization phases (WiFi AP = dot, LTE femtocell = hexagon, EIRP in dBm is

indicated within dot or hexagon, circles around APs indicate access points for which EIRP is lowered to 0 dBm in minimization phase 2).

Case	#APs [-]	EIRP [dBm]	E_{50} [V/m]	E_{95} [V/m]	σ [V/m]	E_M [V/m]	G [-]
After phase 1	1 LTE 3 WiFi	10 (femto) 1 (WiFi)	0.021	0.135	0.068	0.079	2.33
After phase 2	1 LTE 3 WiFi	10 (femto) 0 or 1 (WiFi)	0.020	0.135	0.066	0.077	2.39
Traditional	1 LTE 1 WiFi	10 (femto) 20 (WiFi)	0.051	0.316	0.184	0.184	1

TABLE 1: Number of access points (#aps), their EIRP needed to cover the building floor of Fig. 1 with the required throughput, the resulting median (E_{50}) and 95%-percentile (E_{95}) exposure values, the standard deviation σ of the field values, the E_M value, and the gain G with respect to a traditional network deployment for the two optimization phases for a heterogeneous network providing a throughput of 18 Mbps.

CONCLUSIONS

A heuristic indoor network planner for exposure calculation and optimization in wireless homogeneous and heterogeneous networks is developed: networks are automatically jointly optimized for both capacity and electromagnetic exposure.
An exposure minimization algorithm is presented and applied to a heterogeneous WiFi-LTE network, using a new metric that is simple but accurate. Compared to a traditional network deployment, a field strength reduction of a factor 2.4 for the considered case and a higher homogeneity of the field strength distribution on the building floor are obtained.
Future research may investigate more complex metrics, where different locations in the optimized building have different weights, depending on the expected distribution of the human presence at the different locations.

ACKNOWLEDGMENTS

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