Beamforming for 3G base stations antennas

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***Abstract*—The electric field produced within the sectoral coverage area of mobile telecom base stations is very inhomogeneous. In this paper we investigate how beamforming can be applied to homogeneize the electric field, thereby better distributing the power density to mobile users.**

I. Introduction

A macrocell antenna for 2G, 3G and 4G cellular mobile telephony networks is covering a 120° sectoral area extending up to 3km in front of the antenna location [1]. The vast majority of those antennas consist of a Nx2 array of $\lambda/2$ dipoles backed by a reflector plane, where N ranges between 5 and 10, mechanically tilted downwards by around 5° [2]. To ensure optimal coverage throughout and at the limits of the cell the antennas are usually elevated between 20 and 40m above ground level and the power delivered to the array ranges between 20 and 80W, depending on the relief, vegetation and urbanization. In Belgium, especially in the capital district, very strict radiation hazard limits do apply : any mobile telecommunication operator is not allowed to illuminate public areas with more than a total electric field $|E|$ of 3V/m. In some cases, operators are forced to reduce the power fed to the antenna to maintain the total electric field below this limit anywhere within the cell, thereby reducing the quality of service within the coverage area.

The only way-around envisaged by the operators is to add new base stations where the coverage becomes poor. In this paper we present the results and conclusions of an alternative and potentially less expensive beamforming approach.

II. Non optimized solution

The radiation pattern of the macrocell antenna arrays, obtained by feeding all the antennas in phase and with the same amplitude, produces a high gain main lobe and a few side lobes. Considering the ground reflection, the electric field at ear height (1,5m above ground) is distributed in a very inhomogeneous way throughout the cell, as shown in Fig.1.

In this two-ray propagation scheme (direct and ground reflected rays), the E-field at a height h_{Rx} above ground exhibits spatial oscillations due to both the interaction between the two rays and the radiation pattern of the antenna. Beyond a ground distance to the antenna $d_{FF} = 4h_{Tx}h_{Rx}/\lambda$ this oscillatory region ceases and the electric field invariably decreases, converging at even larger distance to a d^{-2} decay law instead of the d^{-1} law encountered in free space conditions. For the parameters used to obtain Fig. 1, detailed further in section III, d_{FF} =1225m.

For an (untilted) antenna 30m above a flat dielectric ground (ε_r=2 to 15, $\tan\delta$=0,005 to 0,5), the ratio $|E|_{max}/|E|_{min}$ throughout the sectoral cell ranges between 20 (ϕ=60°) and 60 (ϕ=0°), as shown in Fig.1. Keeping the maximum electric field below 3V/m implies that the minimum electric field can be pushed as low down as 50mV/m. Knowing that operators consider a no coverage threshold limit around 0,3mV/m for 2G and 3mV/m for 4G, this gives only 25 to 45dB of margin to cope with a non free space real environment (shadow areas, indoor propagation).

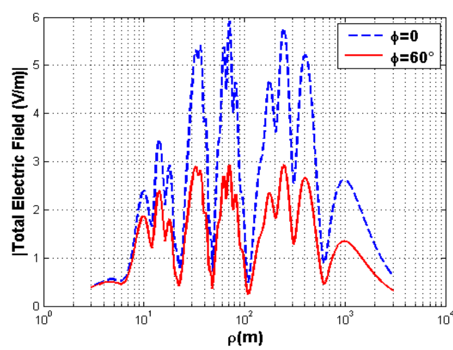

Fig. 1. E-field distribution within a 3G cell.

III. Optimized solution

Feeding the vertical dipoles with appropriate amplitudes and phases should reduce the large variations of the electric field within the oscillatory region. It is well known that a cosecant squared power radiation pattern is the perfect solution to this problem [3], but only in free space. It is applicable for a radar looking to the sky, but not for a constant illumination above ground, owing to the ground reflection. A more complex optimization scheme has therefore been developed in this work.

We will quantify the beneficial effect of the optimized beamforming by the homogenization factor (HF) defined as :

$$HF_{dB} = 20Log_{10} \frac{\{|E|_{max}/|E|_{min}\}_{Before\ Optimization}}{\{|E|_{max}/|E|_{min}\}_{After\ Optimization}} \quad (1)$$

Considering the large amount of parameters at stake in this optimization problem, the pragmatic approach in this feasibility study was to preset some of those parameters to an average value, thereby reducing the degrees of freedom to the sole phases and amplitudes feeding the array. Afterwards, a sensitivity analysis has been conducted separately on each of those parameters. In this paper we present only the frequency and height above ground sensitivity analyses.

We focused on the Belgian 3G uplink and downlink bands (1885 to 2200 MHz). The beamforming optimization has been performed at the central frequency (2042 MHz). The antenna is a 5x2 array of vertical $\lambda/2$ dipoles, optimally matched to 50Ω. No mechanical downtilt is applied, as it will be included in the beamforming process. The array center of gravity is located 30m above the ground. The dipoles vertical and horizontal spacings in the array are set to a uniform value of 0,75λ and 0,25λ respectively, while the distance to the backplane is set to 0,15λ. The backplane is 15x75cm, or approximately λx5λ at 2042MHz.

The electric field homogenization optimization has been performed at 1,5m above ground throughout the macrocell coverage sector extending up to 3km away from the antenna. Considering now that a feeding symmetrical with regard to the vertical axis is constrained to ensure symmetrical illumination of the -60/+60° sector, the highest field variations always occur on the ϕ=0° symmetry axis, as illustrated in Fig 1.

The cost function to minimize in the optimization stage is the difference between $|E_{max}|$ and $|E_{min}|$ on the ϕ=0° axis for a given value of the active power fed to the array. The 5 amplitudes and 5 phases producing the most homogeneous electric field distribution are obtained as follows: we discretize the ϕ=0° axis in ten equally spaced sampling points along ρ and we impose that the cost function must equal zero at these points. The obtained system of ten equations with ten unknowns is resolvable. In the next iteration, we double the number of samples by dichotomy. This system of 20 equations is now resolved in the least squares sense by taking as a starting point the solution obtained in the previous iteration. We continue this way until the norm of the difference between the solution obtained at a given iteration and that obtained at the previous iteration becomes smaller than 10^{-4}.

For a soil characterized by (ε_r=2 to 15, tanδ=0,005 to 0,5), a base station antenna located 30m above this ground, the result of this optimization, conducted with the full wave software FEKO and the Nelder Mead algorithm, yields the tapered complex feeding coefficients of Fig.2, the lowest (highest) ones corresponding to the lowest (highest) horizontal dipoles pair in the array. The current distribution on the backplane is also represented.

The ratios E_{max}/E_{min} before and after optimization are respectively 24,6 and 11,8 corresponding to a HF≈6,4dB. This improvement is illustrated in Fig.3, along with a sensitivity analysis through the whole 3G band : applying to the lowest and highest frequencies of the 3G band a unique feeding, optimized for its central frequency, shows that the homogeneization degrades only for the shortest distances (ρ < 20m) to the base station antenna.

C_{mn} [A]
3,33∠213°
4,84∠251°
5,57∠294°
4,95∠331°
2,76∠355°

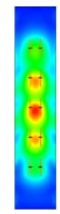

Fig. 2. Optimized feeding.

Finally we also observe in Fig. 3 that the solution optimized for a height of 30m above ground improves (degrades) for a higher (lower) elevation.

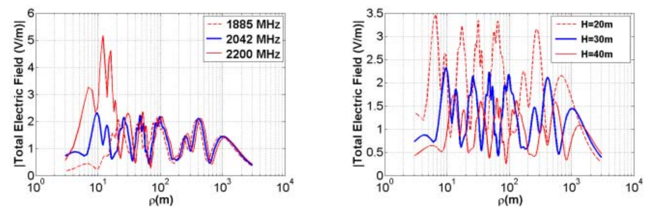

Fig. 3. Optimized solution and sensitivity analysis.

Conclusions

It was shown how the electric field homogeneity can be improved by more than 6dB throughout a 3G macrocell by a simple beamfoming, optimization without any hardware changes to the array, but feeding it with tailored amplitudes and phases to properly account for the direct and ground reflected rays.

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