FUTURE NETWORKS: 5G AND BEYOND

Estimation of network densification impact on EMF exposure using stochastic geometry

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Abstract:
EMF exposure in Brussels, Belgium, is studied in the framework of stochastic geometry. Poisson point processes with realistic intensity are randomly generated to model base stations. Electric field level at random location is deduced from a simple path loss law. Statistical results are compared to experimental data's in order to optimize the model. The impact of network densification is analyzed and probabilities of exceeding exposure thresholds are derived.

1 Introduction

Electro-Magnetic Field (EMF) level due to cellular networks is difficult to calculate deterministically in a reasonable time, and it is subject to many uncertainties (due to the number of base stations in operation, the environment geometry, the presence of people and vehicles causing shadowing...). Instead, it is preferable to look for statistical values over a representative area P where the base stations (BS) density $\lambda[\frac{\text{BS}}{\text{km}^2}]$ can be considered uniform. In the stochastic geometry approach [1] considered here, the BS pattern is modeled as an homogeneous Poisson Point Process (PPP). In section II, it is shown that exposure at an arbitrary location, for a given PPP, can then be deduced from an attenuation model for the electric field. By comparing simulated and experimental data's for the centre of Brussels, optimal values for the model parameters are found in Section III. Finally, in section IV, the impact of network densification is deduced from the stochastic approach.

2 Method

We focus on modeling exposure in the centre of Brussels, also known as the Pentagon area. This region P is chosen because the BS intensity can be considered uniform, and because experimental values of the equivalent 900MHz electric field are available (see [4] experimental set-up). The equivalent 900MHz electric field is defined as the total electric field summed up over the cellular bands with weights depending on frequency according to ICNIRP reference levels [4]. In P, the BS intensity for the whole set of services and providers is $\lambda = 25.8 \pm 2.5\ \frac{\text{BS}}{\text{km}^2}$.
Knowing λ, realizations of an homogeneous PPP can be generated to serve as basis to evaluate the statistical properties of the equivalent 900MHz E-field. The area where the PP is generated is a square of 1km^2, as seen in Fig.1, and the calculation point u is at the centre of the square, without lost of generality.
To estimate exposure, a model for the amplitude of the equivalent 900MHz electric field E at distance d from the computation point $u \in P$ to a given BS is needed. Single-slope and multi-slope models were tested. The one that gave the best results when compared to the experimental data's is a generalized Friis law:

$$E(d) = A\ \frac{\sqrt{30\ \text{EIRP}}}{(d^2 + h^2)^{\frac{n}{4}}} \tag{1}$$

where n the *path loss exponent*, equal to 2 in free-space, and h the height of the BS antenna, assumed the same for all BS. A is a scaling factor with dimensions $[\text{m}^{\frac{n}{2}-1}]$, and EIRP is set to 61dBm, to initiate the model with a realistic value without losing generality (through fitting of A in the next section).
At this point, we can consider two cases. Given a calculation point u, either (a) we consider only the electric field due to the nearest BS or (b) we consider the quadratic sum of the electric fields emitted by all BS present in a disc of radius R to be defined, assuming that the BS are uncorrelated.

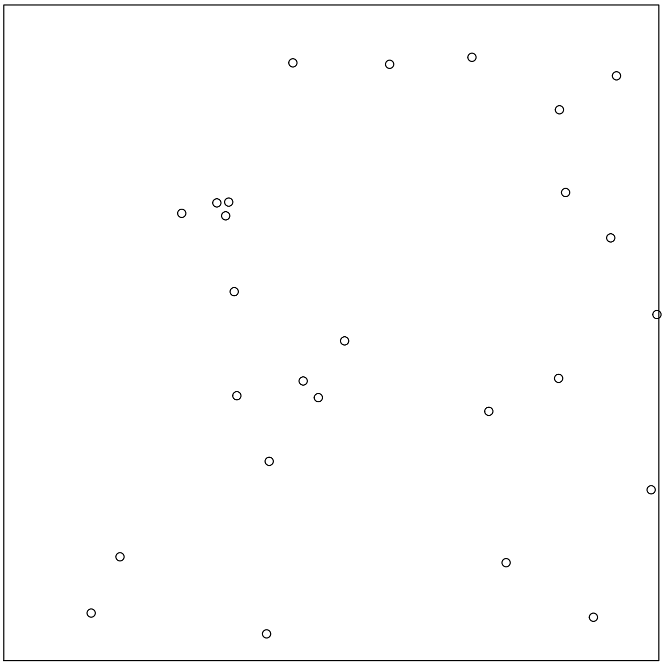

Figure 1 – Example of PPP generated on a square of 1km^2 with intensity $\lambda = 25\ \frac{\text{BS}}{\text{km}^2}$

3 Comparison with experimental data's

Sets of unknown parameters $\{A, h, n\}$ in (1) were tested for fitting. For each given set, 10^5 PPP with $\lambda = 25\ \frac{\text{BS}}{\text{km}^2}$ were generated in order to obtain a simulated distribution of E using equation (1), for cases (a) and (b). Then, statistical values such as the mean $\mathbb{E}[E] = \mu$, the median $Q_2(E)$, the quartiles Q_1 and Q_3 and the standard deviation $\sigma(E)$ were computed but also the parameters μ_{LN} and σ_{LN} of the log-normal approximation of the distribution of E. These values were compared to the drive-test (DT) experimental values in order to find the set $\{A, h, n\}$ that fits best.
Optimal values of the parameters are listed in table 1. For case (b), R was chosen equal to $400m$. This value is large enough to contain at least one BS, but also not too large to avoid prohibitive computation times. BS outside this disk actually have a very small impact on E as compared to the BS inside. The probabilities of reaching some thresholds for E are also added in this table. Method (b) gives slightly better results and has so to be preferred to assess exposure.

Table 1 – Numerical and experimental values of the total equivalent 900MHz electric field.

	Case (a)	Case (b)	DT
h	15	15	
n	2.35	2.95	
A	0.39	0.90	
Q_1 [V/m]	0.24	0.25	0.24
Q_2 [V/m]	0.36	0.35	0.45
μ [V/m]	0.50	0.50	0.51
Q_3 [V/m]	0.58	0.56	0.66
Max [V/m]	3.14	3.30	3.33
σ [V/m]	0.44	0.44	0.35
μ_{LN} [dBV/m]	-8.16	-8.08	-7.92
σ_{LN} [dBV/m]	5.82	5.56	6.19
$\mathbb{P}[E > 1V/m\ [\%]$	10.05	7.59	8.08
$\mathbb{P}[E > 3V/m\ [\%]$	0.17	0.25	0.02
$\mathbb{P}[E > 6V/m\ [\%]$	0.00	0.00	0.00

4 Impact of network densification

Let us consider an increasing value of λ, which can for instance simulate the expansion of current networks such as for the release of 5G. Table 2 lists the probabilities to reach the thresholds if the BS intensity increases. It can be concluded that, even by tripling the BS density, the probability of reaching the threshold 6 V/m imposed by the city of Brussels is negligible.

Table 2 – Evolution of the probabilities with the increase of the intensity

λ $[\frac{\mathrm{BS}}{\mathrm{km}^2}]$		25	40	75
Case (a)	$\mathbb{P}[E > 1V/m$ [%]	10.05	15.65	27.27
	$\mathbb{P}[E > 3V/m$ [%]	0.17	0.21	0.44
	$\mathbb{P}[E > 6V/m$ [%]	0.00	0.00	0.00
Case (b)	$\mathbb{P}[E > 1V/m$ [%]	7.59	12.94	27.05
	$\mathbb{P}[E > 3V/m$ [%]	0.25	0.40	1.08
	$\mathbb{P}[E > 6V/m$ [%]	0.00	0.00	0.00
DT	$\mathbb{P}[E > 1V/m$ [%]	8.08		
	$\mathbb{P}[E > 3V/m$ [%]	0.02		
	$\mathbb{P}[E > 6V/m$ [%]	0.00		

5 Conclusions

Knowing the intensity of base stations inside Brussels, $\lambda = 25.8 \pm 2.5 \ \frac{\mathrm{BS}}{\mathrm{km}^2}$, and fitting a model giving the magnitude of the equivalent 900 MHz E-field as a function of distance to the transmitting BS, PPP were used to model exposure to EMF. Statistical results were compared with experimental values. The agreement between stochastic geometry and measurements is very good showing the potentiality of this method to assess exposure.

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6 References

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