Statistical antenna modelling

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Abstract

The present work is a “concept paper”, addressing the non traditional idea that antenna properties embedded in their device casing and under the perturbing influence of close objects or bodies, may be statistically described. The benefit of this approach is similar to other statistical descriptions of the radio link such as the radio channel, intending to provide a more realistic description of the antenna part of this channel. Statistical antenna models might be included in standards, or in radio system simulators. The paper tackles a few possible methods, which could be tried towards the definition of such models.

1. Introduction

It is commonplace to support the development of radio access networks through radio planning tools, which help optimize the placement of base stations. Such tools rely on radio propagation modeling, which is unfortunately heavily dependent on the local terrain and building characteristics, as well as specific parameters as antenna height. The large randomness of the propagation environment has led researchers and engineers to introduce a statistical part in these models, in order to account for shadow fading or a number of other effects which are not easily described by deterministic approaches. Even when physically based tools are used, such as ray-tracing which exploits detailed 3D maps of the environment, residual propagation computation uncertainties and insufficiencies in the description of the environment inhibit a perfect agreement between true and modeled channels, and require statistical modelling to account for the difference. This is quite well known, and the parameters of these statistical models (such as the variance of a lognormal distribution for shadow fading) are part of the propagation model itself.

One of the problems of propagation models is that they are derived from extensive channel measurement campaigns, which are often carried out with generic antennas such as dipoles, bicones, discones etc, in an attempt to measure a “pure channel” fully rid of antenna particularities. These instrumental antennas are quasi perfectly omnidirectional, very well impedance matched to the transmitter or receiver, placed on a tripod or mast at a good distance from any electromagnetic perturbation etc. Thus they indeed provide effectively data dominated by electromagnetic interactions away from the antennas, but they by no means account for effects and imperfections due to the antennas themselves, or close scatterers.

Surprisingly enough, the analysis and modelling effort carried out for the radio channel has no equivalent for antennas and their close environment. This is all the more astonishing as evidently putting a radio terminal antenna on the side of a laptop, or in full contact with a head, or attached at a man’s belt will significantly impact the quality of the radio link. Probably one reason is that while the propagation environment does not change and is of universal character (place de la Concorde in Paris has existed long before GSM), this is not true of radio terminals and of the way they are used. Significant variations in antenna characteristics are to be expected, according to the engineering efforts made by manufacturers, and by the way the terminals are handled. Nevertheless, many commonalities could probably be found among manufacturers and designers, as the terminals can be classified into categories according to their functionality and their geometry. In addition even though some antenna/terminals may behave better than others, it is not a consideration we should stress at the early stages of definition of a new standard, where the realistic evaluation of the system performance must be addressed. Thus, the incorporation of statistical variations at the terminal level in a more refined manner than a given standard deviation of path loss, will bring further insight into this performance, especially when the statistical models and parameters can be explicitly related to a local status of the terminal and its environment. An example of the importance of properly taking into account antenna and channel characteristics jointly is the demonstration that the effective performance of an ultra wide band (UWB) radio link depends sensitively on the way these characteristics “interfere”, and this is best treated in a statistical framework [1]. Obviously this is not an easy task to define such statistical models, to relate them to the local status of the terminal and its environment, and to specify values for the model parameters. In the present paper, we address a few ideas into this direction, and support our views by a few example cases.

2. Randomness in antennas

The randomness related to antennas in the context of radio access networks can be classified by three origins:

- randomness in the antenna itself. This comes form the complexities inherent to antenna design methods, which favor small form factors, easy integration into a terminal casing, low cost etc. These constraints often imply a number of degradations with respect to ideal characteristics, which considerably vary from one antenna type to another. Actually this variability has increased in the last years, as the result of the trend to accommodate more frequency bands, which induces complicated geometries with several slots, shorts, plates etc.
- randomness in the terminal, due to the fact that the antenna has to be adequately mounted on the PCB, that it has to find enough place in the casing etc. All these elements, some of them being conducting, have a strong electromagnetic influence on the antenna matching and radiation [2].
- randomness in the immediate environment of the terminal. This can be the head in close contact with a handset, whose influence is enormous due to the very high dielectric constant of the biological tissues, or the hand around a smartphone [3], or the screen of a laptop to which an antenna is attached etc. We will consider such electromagnetic perturbations as within the antenna surrounding whenever they are in its near field, and in principle cannot be factored as it is the case in the far field. In the latter case, we consider the perturbations to be part of the radio channel, where they can be dealt with through methods such as ray-tracing.

These three origins require a different treatment.

The first can be tackled through the listing and the analysis of characteristics of the various types of antennas concerned by a given class of applications. For instance if we are interested in omnidirectional antennas for WIFI indoor networking, we may use the traditional $\lambda/4$ monopole to be place vertically, but for compactness reasons (e.g. for incorporation into a USB dongle) we may prefer a planar meandered radiator, with a radiation pattern significantly deviating from perfect circular symmetry. If we are interested in a sectored antenna with a fixed directivity gain (e.g. 6 dBi), we know that there will be certain deviations from one antenna to another in terms of beam width, and sidelobe levels, or front to back ratios. All these deviations may be modeled by a suitable statistical description.

The second origin is more difficult to deal with, as there is a strong electromagnetic interaction between the antenna and the casing, and we can expect much variability due to the changing geometry and characteristics of materials. Again it may be possible to define classes of terminals (depending on their size, their mode of operation with a clamshell or a compact casing etc), and to define range of geometrical and material parameters for theses classes. Obviously it will not be a simple task while being representative of the variety of existing terminal types.

The third origin also represents a large variability of electromagnetic environmental situations which can affect the effective antenna properties. However due to a slightly larger distance than for the previous one, it is expected that the main influence will be on radiation patterns rather than on the antenna impedance. It will be necessary to identify the most typical environments which can experience an antenna with respect to the way it is employed and the nature of the terminal, and find ways to describe this variability on radiation patterns in a statistically valid way.

3. Methods and models

The problem pertaining to statistical models for antennas can be formulated as follows :

Find the minimal set of parameters for describing the statistical part of antenna characteristics, allowing to achieve a given accuracy on the considered output quantities.

This formulation is quite general, however what it means here is that we should limit the model complexity with respect to what we want to obtain. One central consideration is that the model predictions should be valid in a statistical sense only, i.e. we do not want to reproduce accurately a well defined situation of a given antenna, a given terminal and a given environment, but we want that the lowest moments of a statistical distribution were reasonably approached through the adjustment of very few model parameters. However it is clear that the choice of the ”output quantity” will affect the relevance of the statistical model, in the sense that the more this quantity will be sensitive to the details of the antenna characteristics and its environment, the more the model will have to be able to properly render these characteristics.

In other words the validity of the model will, this is not surprising, depend on what we will do with it. At this stage we will have to decide whether we want a model of sufficient wide applicability to cover the most relevant cases, or we want models that will be specific of the use we have in mind for them. The former are of broader interest, but they may be more complex than needed for many uses, the latter will be more optimized for a given use, but need to be redefined for each new use.

One solution to mitigate both approaches is through scalability, i.e. with models which lend themselves easily to enrichment by increasing the number of parameters. Series expansions are especially appropriate in this respect. Statistical models can be physically based, i.e. based on the real physical structure of the antenna and its environment, which is modeled in a simplified way for the purpose expressed above. They can also be empirical, i.e. purely based on the reproduction of output quantities without any relation to the physical origin of the randomness. Finally they can be hybrid, or inspired by the physical origin of the randomness, although the mathematical aspects are constructed empirically. This distinction between models bears strong similarities with radio channel modeling. The quantities to model are twofold :

- the antenna impedance, which affects the efficiency of the energy transfer between the transceiver and the antenna
- the radiation pattern, in both its directional character and its overall gain.

Another distinction need be done, with respect to frequency. The antenna can be single band (narrow band), or multiband, or very wide band / ultra wide band. The first case is the simplest, as the statistical model may reduce to a single frequency, or to a few frequency values. The second is not a simple addition of independent models for the different bands, as correlations may occur between the statistical variations of these bands. Finally the third is the most demanding, since we need a statistical model over a large frequency band. Alternatively we may choose to model the statistical variations in the time domain in this case. Naturally both are in principle related through the Fourier transform. However in practice it may turn out more relevant to construct a model directly in the time domain with few parameters, while many more would be necessary in the frequency domain, and vice-versa.

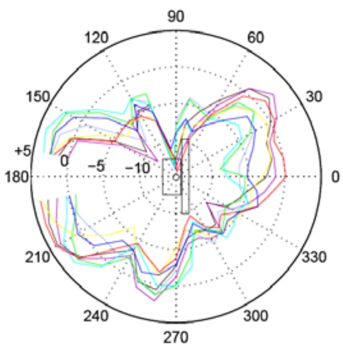

Fig. 1: radiation pattern of an antenna at various positions on a computer flat screen (from [4]).

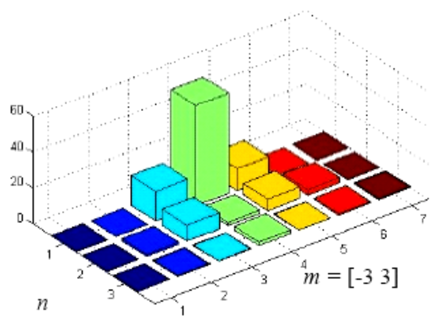

Fig. 2: modal energies for an UWB bicone (from [5]).

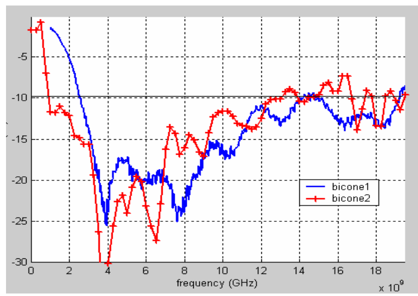

Fig. 3: variation in return loss between two slightly differing UWB bicones.

4. Examples

Figs. 1-4 illustrate the type of variabilities which can deserve a statistical description. Fig. 1 is an example of variation of an antenna radiation pattern on its close environment. In this case the antenna was placed at various positions on the foot of a PC flat screen. The main characteristics of the pattern are preserved, however significant amplitude differences are seen according to the position. Fig. 2 shows the distribution of the radiation pattern modal powers for a bicone, after decomposing the radiation pattern over spherical modes. Fig. 3 shows the variation of antenna return loss for UWB bicones of slightly differing geometries.

Fig. 4 shows the modification of the impulse response of a UWB planar bicone when integrated on the casing of a personal digital assistant (PDA). In a case where the main radiation pattern characteristics are preserved, the statistical variability can be expressed on the modal energies, assuming a suitable statistical distribution (Figs 1-2). On the other hand it may be considered more efficient to fabricate randomness directly on the characteristics (e.g. Figs 3-4), by incorporating a suitable parameterized function with a statistical distribution for the parameters. Regarding the temporal response (Fig. 4), a statistical distribution of additive impulses may suffice provided the perturbations are of limited importance. One of the major difficulties is the randomness complexity. Concentrating im near field effects by using radar cross sections for the characterization of scatterers [7]. This has the advantage that the distance between the antenna and scatterers enters only through the far field approximation $\exp(-jkr)/r)$, which is simple and fully deterministic. Another simplification is an additivity principle, whereby the effects of several scatterers may approximately be obtained by the sum of the effect of single scatterers. These ideas will be investigated in the near future.

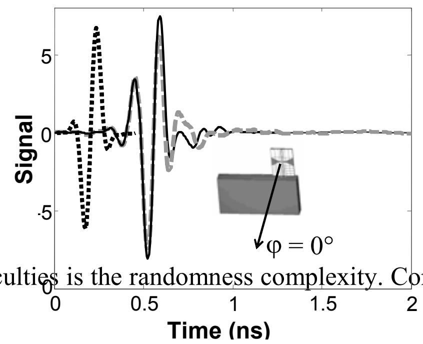

Fig. 4: radiated impulse for an ideal UWB antenna (dots), an isolated planar bicone (solid black), and the same on a PDA casing (dashed gray) (from [6]).

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6. References

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