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Map–Based Channel Model for 5G Wireless Communications

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Abstract

This paper introduces a type of channel models especially suitable for demanding air interface evaluations like the case in many 5G communication systems will be. The map–based channel model is based on the digital information of the environment and uses a deterministic method to search for the propagation links. Most often used link calculation method is ray–tracing. Also here the examples are covered with ray–tracing. However, it is practically impossible to have all the environment information stated deterministically leading thus either to simplifications in the modelling or in the use of hybrid modelling methods. The hybrid modelling here means to add stochastic add–ons on top of the deterministic path search. The model evaluations are reflected to the corresponding geometry based stochastic channel model (GSCM).

1 Introduction

The main goal of channel modelling is to generate the radio propagation coefficients in time–space–frequency domains as accurately as possible for the applications of link–level and system–level simulations under acceptable computational complexity. The model used should be consistent across wide range of environments, network topologies and frequencies. Moreover, channel models should be able to illustrate the key characteristics of the propagation under different circumstances and requirements. For 5G communications, promising techniques such as high–frequency, massive MIMO, beam–forming/tracking enhance the capacity of the communication system. Therefore, the important features of propagation channel such as spatial/temporal consistency, large bandwidth, large antenna array human/object blockage should be taken into considerations during the channel modelling for 5G use cases. See references [1, 2, 3] for more detailed discussion on the new requirements to channel modelling.

The main stream in spatial channel modelling has been on GSCMs [4]. They model spatial radio channel with randomly drawn directional and propagation parameters, without any particular definition of the environment in form of, e.g., maps or layout in a coordinate system. Jaeckel at al. [3] gives a clear overview on 3D state–of–the–art GSCMs and reflects their capabilities with respect to the new requirements. To the line of considered models must be added the recently specified 3GPP channel model for frequencies up to 100 GHz [5]. There the previous 3GPP 3D model [6] is updated. The same technical report includes also as an alternative model the hybrid model that is a combination of deterministic and stochastic modelling principles. Ideas of combinations close to that standardized model are presented also in the literature. The motivation lies, e.g., to speed–up the calculation or to model stochastically missing environmental information.

2 Why to Use A Deterministic Model?

There are several reasons why a deterministic model is considered to be more suitable for 5G wireless communications.

Accuracy — real world correspondence is better. In the deterministic model, the real world propagation mechanisms involving Line–of–Sight (LoS), reflection and penetration on smooth surface/slab, diffraction on wedge and diffuse scattering on rough surface can be accurately emulated via ray–tracing approach that is based on the proven propagation theories such as geometric optics and uniform theory of diffraction, with acceptable computation complexity [1, 7].

Site specific simulations — inherently guaranteed by the maps imported. In the map–based model, which is a deterministic procedure to emulate channels in a specific and determinant scenario, the properties of each ray, such as path loss, propagation delay, angle of arrival and angle of departure, are directly calculated by applying ray–tracing principle to a well-defined deployment/environment layout map. The effects of shadowing and blockage are also inherently guaranteed.

Spatial & temporal consistency — inherently guaranteed in map-based models. According to the propagation theories, the channel coefficient of each path is calculated mainly based on the traveling distance, incident angle, reflected/diffracted/scattered angle as well as the electromagnetic property of the corresponding material. When *Tx/Rx* node or the surrounding object moves, the smooth transition of the parameters leads to a consistent change on the channel coefficients, i.e., spatial and temporal consistency, can be achieved naturally.

Mesh networks & D2D & massive/distributed MIMO, & CoMP — correlation between links inherently guaranteed in map-based models. Similar with the ability to fulfill spatial consistency, map–based model can simulate the correlation between any two communication links whose transmitters or receivers are either the same or nearby, where the correlation exists in both large scale fading and small scale fading. This feature is crucial to support some of the 5G use cases such as mesh networks, D2D, massive/distributed MIMO or CoMP.

Frequency dependency & large bandwidth — interaction formulas physics based. There is no need to have additional bandwidth handling in ray–tracing tool as long as the bandwidth is up to 10% of carrier frequency. The calculation based on centre frequency can be representative for the whole bandwidth. If extremely large channel bandwidth (>10%) is needed, the bandwidth can be partitioned into several bins and ray–tracing is applied separately to each bandwidth bin to obtain the frequency response, i.e., channel transfer function. A discrete Fourier transformation is achievable to get the channel impulse response from the channel transfer function.

Spherical wave & large antenna arrays beyond consistency interval — inherently guaranteed in map–based models. Under the assumption of plane wave, the same modeling principle and procedure as in the stochastic modeling for the normal antenna array can be reused. In addition, for the large antenna arrays beyond consistency interval, spherical wave calculation should be taken into consideration, where the ray–tracing can support it by calculating the propagation parameters such as deterministic delays and arrival/departure angles per each pair of *Tx/Rx* antenna element.

2.1 What Is a Map?

The map is the basis for the deterministic type of simulation. The map is defined here as digital information of the environment. The environment is understood as the total of all surroundings, which provide an impact in the wireless propagation. They are objects like buildings or vehicles that have electromagnetically an effect on the propagation. Usual examples of the map are the city maps or floor layouts of the buildings like illustrated in Fig. 1. The level of details in the maps vary. In some cases it is necessary to process the map information to leave only the relevant information. The same map as used for the simulation is possible to use also to the result visualization. It helps non–experts to understand better the simulated results.

Figure 1. Screenshot of map–importing tool.

2.2 Speed

Ray–tracing calculation methodologies have existed already for decades but they have not been used widely. The highest problem has been traditionally the computation time; to find the propagation paths from the map is often the most time consuming task. To overcome this bottleneck intelligent methods have been implemented. Furthermore, HW acceleration has been also utilized. These advances have made already the speed to be on an acceptable level.

3 Map–Based Model

The map–based models are most often based on ray–tracing; digital description of the propagation environment and deterministic modelling of propagation in terms of rays. The environment, i.e. the map is discussed in section 2.1. The deterministic, physics based propagation mechanisms like penetration, diffraction, specular reflection, diffuse scattering blocking, etc. are accounted for. Thus the frequency dependency is inheritably included in the formulation. For each specific link between *Tx* and *Rx* there are a number of pathways, which contribute to the received power. Example block diagrams of map–based model with minor variations are presented in [1, 4, 5]. In all these diagrams the procedure is divided to four main operations: creation of the environment, determination of propagation pathways, determination of propagation channel matrices for path segments, and composition of the radio channel transfer function. Note that a so–called hybrid map–based model is presented separately in section 4.

3.1 Creation of Environment

The map is produced by some means where the importing functionalities for complex environments are preferred. Any necessary simplification or modification including case reduction is applied. It is possible also to add random objects here like pedestrians — moving or static — or other blocking objects. The creation of random objects is implementation dependent and may occur also in later phases. The transceiver locations are defined here also. A note here is given that if the transceiver locations are drawn randomly the simulation case corresponds to drop simulations of GSCMs.

3.2 Determination of Pathways

The determination of pathways is usually computationally the highest workload. The search of the pathways is started from *Tx* or *Rx* and all possible nodes visible to *Tx/Rx* are identified. This procedure is repeated using the previous step's nodes as the *Tx/Rx* to get any number of physical interactions. The desired accuracy or the computational effort may be used as the limiting factor. After the paths are determined the corresponding path lengths and arrival and departure directions are calculated. The directions are used later in the radiation patterns of *Tx* and *Rx* antennas.

3.3 Determination of Propagation Matrices

Propagation matrices are determined for the interactions. They are complex 2×2 matrices describing the gains of polarization components. The examples to calculate them are through the Fresnel reflection coefficient for the specular reflections and through the uniform theory of diffraction (UTD) in case of diffractions. See for more details in specific cases in [4].

3.4 Composition of the Radio Channel Transfer Function

The last operation is to compose the radio channel transfer function by embedding the antenna radiation patterns to the losses and to the composite propagation matrices. The composed transfer function is time dependent because of the motion of *Tx/Rx* or the environment.

4 Hybrid Model

Based on the well-defined propagation theories, the map–based model based on ray–tracing can simulate well the mechanisms of free-space propagation, reflection and diffraction given the digitized map of deployed scenario [7]. The accuracy of map–based model is directly relative to the resolution of digitized map, which is also relative to the modeling complexity. Meanwhile, for the other important part of radio propagation, i.e. diffuse scattering, the propagation theory is not that mature. Also the modeling of (multiple–bounces of) diffuse scattering requires a huge computational effort.

Recently, several channel modelling methods which combine the idea of stochastic and deterministic approaches have been proposed to ease the modeling complexity of diffuse scattering and meanwhile maintain the modeling accuracy of scenario-specific propagation paths, such as METIS hybrid model [1], quasi-deterministic model [8], semi-deterministic or hybrid model based on ray–tracing and propagation graph [9, 10, 11] and point–cloud model [12]. These promising models are mainly proposed based on new frameworks, and many of the parameters involved in these models are needed to be calibrated through measurement data in different scenarios.

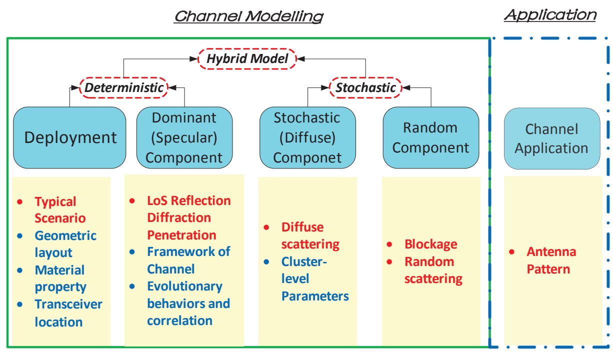

Figure 2. Framework of map–based hybrid model.

A so–called map–based hybrid model has been endorsed as an alternative modelling methodology in 3GPP New Radio (NR) [5]. As illustrated in Figure 2, it takes the advantages of both ray-tracing (i.e. to calculate the dominant propagation paths through a few number of reflection and diffraction bounces) and stochastic approach (i.e. to expand the paths to clusters by calculating the diffuse scattering from rough surfaces, and complement the channel response by calculating the random scattering from the small objects which are hard to be included in digitized maps). The dominant paths calculated from RT naturally support the additional features required by 5G high–frequency channel modelling as mentioned in section 2, and the stochastic part of this hybrid model is compatible with the standardized stochastic models (e.g. 3GPP 3D model [6] or NR high–frequency model [5]). The novelty of this map–based hybrid model is that the statistical parameters in the standardized stochastic models can be fully reused. Therefore, there is no barrier for large–scale applications in various scenarios as long as the digital maps are available. Recently, this map–based hybrid model has also been recommended in IMT–2020 (5G) technology evaluation report.

5 Simulations

Both map–based and stochastic implementations are capable of generating the same set of output parameters. The channel matrix, angle of arrival and departure, spreads, etc. are the normal parameters. There is, however, an advantage for the map–based; the user can take out intermediate results. If interested in a node in between the user can look at all the usual parameters also for that specific node only. It is then easy to play what–if analysis by changing environmental details. Single path is possible to consider only or to compare two or more paths from *Tx* to *Rx*. Visualization is also an example that is more natural for the map–based methods because the result visualization is brought back to the same map where the simulation was started from.

The user may have the possibility to make the decision on the criteria to halt the calculation. The condition may be energy, which means that the rays below (sometimes above) the certain level are excluded. This is reasonable when the simulation is targeting to, e.g., network functionality. The condition might be also the number of interactions included; for example, how many reflections and diffractions are calculated no matter what is the energy of the rays. This is sometimes reasonable because it simplifies the implementation.

Because of lack of space this summary paper does not present numerical simulation results. These are expected to be displayed in the meeting presentation.

6 Summary

This paper has overviewed the map–based model. It is a deterministic modelling methodology using ray–tracing calculation. The reasons to use it and benefits were walked through. Also the hybrid option has been studied. It offers additional advantages like speed or modelling stochastically missing environmental info. The simulation section covered that the same set of output parameters as the main stream stochastic methods are given but there are some options that can be utilized to get even more out of the simulations. It was concluded that the map–based model provides consistency in frequency, time, and space domains as well as supports many novel 5G use cases.

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