Channel Modelling for the Fifth Generation Mobile Communications

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***Abstract*—The main objective of this paper is to present major challenges regarding the fifth generation (5G) mobile communications propagation modelling work in the European 7th framework project METIS (Mobile and wireless communications Enablers for the Twenty-twenty Information Society). The goal of the propagation work in METIS is to provide adequate propagation models for 5G. For this purpose corresponding deficiencies of present commonly used models are identified. Further, the lack of available channel models for several propagation scenarios has been assessed. Based on this assessment the framework of 5G channel modelling is sketched. A crucial part of this work is propagation measurement campaigns which are illustrated by a few examples.**

I. INTRODUCTION

This paper summarizes the first phase of the propagation modelling work performed in the European 7th framework project METIS (Mobile and wireless communications Enablers for the Twenty-twenty Information Society) [1]. The overall goal of the METIS project is to lay the foundation of the fifth generation (5G) mobile and wireless communication systems, targeting beyond 2020, by providing the technical enablers needed to address the requirements foreseen for this time frame.

The first phase of the METIS propagation modelling work consists of a definition of propagation scenarios, a survey of existing channel models and identification of extensions and/or modifications needed to meet the propagation modelling requirements of the 5G mobile communications. To meet the exceptional expected growth of wireless communications traffic both efficient transmission schemes and additional spectrum allocation are needed. Envisioned transmission schemes, like very large MIMO and ultra-dense networks (UDN), put radically new requirements on the channel modelling in the spatial domain. Further, as substantially higher frequencies in the millimetre wave range have the most promising prospects for providing additional spectrum, corresponding extensions of propagation modelling are needed.

II. 5G PROPAGATION SCENARIOS

The METIS work is specified in five generic scenarios each addressing at least one specific challenge of the coming 5G mobile systems:

- “Amazingly fast” to reflect the very high data rate challenge
- “Great service in a crowd” to address the challenge of very dense crowds of users
- “Ubiquitous things communicating” to represent very low energy, cost, and a massive number of devices challenge
- “Best experience follows you” to address the mobility challenge
- “Super real-time and reliable connections” to set the very low latency challenge

Out of these scenarios twelve detailed test cases (TCs) are defined to cover the practical applications of 5G system and simulation needs in METIS [2, 3].

Herein a few important propagation scenarios based on the METIS test cases are briefly explained to address 5G specific modelling requirements.

A. *Virtual Reality Office*

In this TC huge amounts of data are exchanged to enable interactive work among people in remote locations (such as high-resolution 3D data that gives the amazing experience “as if you were there”). It is assumed that the users can rely on getting bitrates higher than 1 Gbps.

The propagation challenge is to characterize higher frequencies (in the millimetre band), larger bandwidth and higher antenna directivity.

B. *Dense urban information society*

In this TC the challenge is to ensure connectivity at any place and at any time in dense urban areas for the traffic between humans and between human and the cloud. Here bitrates in the range 50-300 Mbps will be guaranteed for almost all users.

The main propagation challenge here is to improve the 3D channel and path loss modelling. Moreover, full large scale mobility providing realistic correlations characteristic between different links is needed.

C. *Traffic efficiency and safety*

This TC addresses super real-time and reliable connections as illustrated in Fig. 1 where traffic accidents will be avoided by cooperative intelligent traffic systems that require timely and reliable exchange of information of less than 5ms end-to-end (E2E) latency.

The corresponding propagation challenge is to model the device to device (D2D) channel allowing for mobility in both ends of the link.

III. AVAILABLE MODELS

The METIS propagation modelling needed for developing the 5G mobile communications technology is largely based on existing and widely used geometry based stochastic channel models (GSCM) [4,5,8]. These models are popular partly because of their scalability and reasonable complexity. Some of the most important models are briefly described below.

A. *WINNER/IMT-Advanced*

These models [4,5,8] describe a versatile set of environments, ranging from indoor to a variety of indoor-to-outdoor and outdoor. The parameterizations of the models are based on a fair number of channel measurement campaigns. The modelling framework supports three-dimensional description of environments. Early implementations [4,5] have 2D parameterization only while [8] contains an extension to elevation dimension. Channel realizations are generated by superimposing plane waves with certain characteristic parameters. Small scale parameters of rays are: departure and arriving angles, propagation delay and power. A continuous evolution of these parameters is not accounted for as the sub-paths (plane waves) are not based on geometric locations of scattering clusters. Instead, the parameters are chosen randomly from appropriate probability distributions. Large scale characteristics like rms delay spread may however evolve smoothly.

Quadriga [11] is an extension of the WINNER II/+ models. It is a full 3D model with geometric polarization and it can be used for terrestrial as well as satellite communications. Continuous time evolution for links with a single base station is supported with environment transitions and small and large scale fading between segments.

The GSCMs are not spatially consistent meaning that they don't fully support continuous motion beyond stationary intervals. The plane wave assumption (inherent in angular description) sets the following requirement: antenna arrays are assumed to be small enough such that all elements experience the same large scale parameters. This assumption may not be valid with 5G requirements. Another characteristic of GSCM is that they are mostly developed for cellular deployment with fixed base stations. Thus the models are not parameterized for peer-to-peer (D2D) links. Also the range of frequencies covered by the existing parameterizations is in the range of present cellular networks.

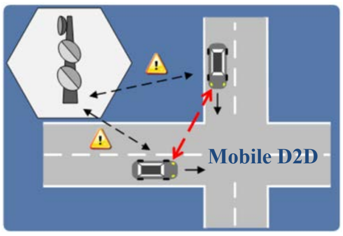

Fig. 1. Traffic safety test case illustrating collision avoidance.

B. *COST 2100*

The COST 2100 model [6] is closely related to the WINNER model as both have common origin. The COST 2100 model is however not restricted to the drop concept with short independent segments of motion. By modelling spatially located scattering clusters and their corresponding visibility regions the COST 2100 model supports non-stationary and continuous evolution of the radio channel. If a UE is within a visibility region of a cluster the signal propagates via that cluster. Two UEs close to each other are likely to see partly the same clusters, and thus are likely to have similar angular characteristics. There are two basic types of clusters: 1) single bounce clusters, and, 2) twin clusters that enable multi-bounce modelling with specific last and first bounce cluster co-ordinates.

The COST model supports spherical wave modelling and also spatial consistency by means of geographically located clusters and their corresponding visibility regions. However, the COST does not account for mobility of both ends of the link and is thus is not applicable in D2D. Also parameterizing the COST model to different environments according to measurements is a challenge, because input parameters like cluster properties are not straightforward to extract from measurements.

C. *IEEE 802.11 for 60 GHz*

The IEEE 802.11ad channel model is intended for 60 GHz Wireless Local Area Networks (WLANs) where very high data rates are required [7]. The model is cluster-based and describes the channel by providing accurate space-time characteristics including polarization and supports both beamforming and non-stationary characteristics of the channel. As a result of experimental measurements and ray-tracing simulations, the model is parameterized for three indoor scenarios, namely a conference room, a cubicle and a living room. However, since the model parameters are determined deterministically, the parameterization for each scenario is site-specific and may not be valid for other similar environments.

IV. 5G CHANNEL MODELLING CHALLENGES

There are two main factors determining requirements on the propagation modelling. The first is the scenarios from the environment and user perspective and the second is the technology components envisaged to provide the required end user services. The scenarios were briefly described in section II. From a technology perspective, the propagation challenge is mainly higher frequencies and wider bandwidths, together with much larger antenna arrays in terms of number of elements and in terms of physical size with respect to the wavelength. Combining these two factors the following main challenges have been identified.

A. *Spatial consistency and mobility*

The current most commonly used channel models [4,5] are drop based, meaning that the scattering environment is randomly created for each link. The corresponding performance of spatial techniques like MU-MIMO is exaggerated, because even close-by mobiles see independent scatterers, which is not the case in reality. As the importance of spatial techniques, as well as the density of links is expected to increase, it is increasingly important to model these links in a consistent manner. A spatially consistent model can also inherently support mobility of users.

To create a consistent model, geometric locations of the scatterers of the first and last hop of each path (transmitter-to-scatterer and scatterer-to-receiver) have to be defined. Moreover, a death and birth process of rays has to be defined according to the visibility of the scatterers. No known model can describe this dual mobility in a consistent manner.

B. *Diffuse vs. specular scattering*

Commonly used channel models assume scattering by geographically fixed clusters. This assumption is appropriate for diffuse scattering and diffraction. Literature [9] and measurements performed in METIS (Fig. 4) indicate, however, that specular paths may dominate in many scenarios. The characteristics of specular paths are very different from diffuse paths regarding apparent scatterer locations which are not fixed for specular propagation. As 5G transmission schemes are expected to utilize steerable highly directive and/or very large MIMO antennas the channel modelling should take into account realistic modelling of specular paths.

C. *Very large antenna arrays*

An important technology component of 5G mobile communications is the use of very large antenna arrays (which even may extend over large scale fading regions) for e.g. massive MIMO and pencil beamforming as illustrated in Fig. 2. For these highly directive antennas or large antenna arrays substantially non-realistic performance will be achieved using present modelling. Transmission schemes based on antenna arrays extending over many wavelengths (which does not imply a large physical array size at millimetre wavelengths) exploit super-resolved channel properties. Current channel modelling needs corresponding improvement in angular resolution as well as sub-path amplitude distribution. Further, these large arrays require spherical wave modelling replacing the commonly used plane wave approximation.

D. *Millimetre wave frequencies*

The millimetre wave frequencies have very promising prospects of providing substantial additional amount of both spectrum and spatial multiplexing capacity. Though millimetre propagation has been investigated quite extensively, particularly at 60 GHz, crucial characteristics such as highly resolved angular properties and NLOS path loss are not well known.

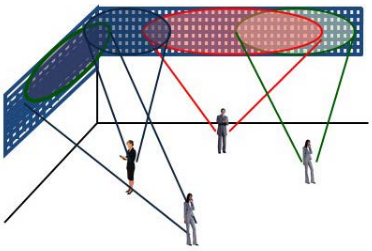

Fig. 2. Scenario using very large wall mounted antenna arrays.

V. THE METIS CHANNEL MODEL

The final METIS channel model will be based on the previous European 6th framework project WINNER II [5], and Celtic project WINNER+ [8] channel models to as large extent as possible. Required extensions and modifications are based on METIS measurement campaigns and literature. The main extensions/modifications concern frequency range, spatial consistency, 3D (elevation) and spherical waves. This work is on-going and an interim version of the METIS models will be available in May 2014, and the final model is expected to be ready by March 2015.

A. *Frequency range*

WINNER II/+ and IMT-Advanced models have been designed for frequency range below 6 GHz. The METIS model should cover frequencies from 380 MHz up to 86 GHz [13]. Due to the extremely large frequency range and limited availability of channel sounders, only some “snapshots” from the range can be measured within METIS. The gaps between those snapshots are filled based on a literature review, software simulations, and interpolation. Our assumption is that the GSCM principle is applicable to the millimetre waves as well, but many parameter values depend on the frequency.

B. *Spatial consistency*

For obtaining the spatial consistency, it is necessary to define the geographical cluster location (x, y, z coordinates) and visibility region/cluster lifetime. For the single bounce case, the delay, Angle of Arrival and Departure (AoA, AoD) depend on each other according to the geometry (Fig. 3). However, in the case of multiple bounces, AoA, AoD, and delay are assumed to be independent.

When the transmitter and/or receiver moves a short distance, the AoA, AoD and delay are adjusted based on the geometry. In a longer movement, cluster locations need to be updated depending on corresponding cluster visibility regions.

When a device is moving, the clusters are updated individually according to their visibility regions. For the single bounce case the receiver and transmitter are within the same visibility region. For multi-bounce each end of the link has its own visibility region.

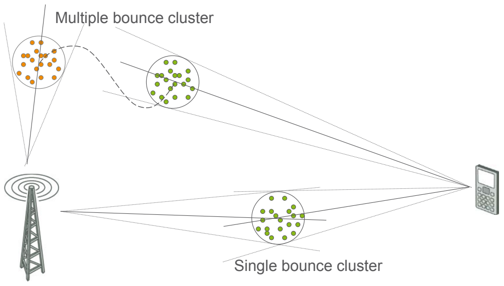

Fig. 3. Illustration of METIS single- and multi-bounce clusters.

This approach enables both single mobility and dual mobility (moving BSs, D2D), smooth time evolution of small scale and large scale parameters.

Additionally, it has been discussed whether clusters can be located according to the physical environment, e.g. Manhattan grid. This could be done either by defining each building as a cluster (or a group of clusters) or using almost rectangular type statistical distributions of angular parameters/cluster locations.

C. 3D Extension

The 3D extension of METIS model follows the principles described in WINNER+ [8] and 3GPP. Additionally over the rooftop diffraction in macro-cell cases could be modelled more accurately.

D. Spherical waves

To account for spherical waves the channel model may be formulated in a similar way as for plane waves [4,5,9] by

$$\begin{aligned} H_{mn} &= \sum_{l=1}^{N} \mathbf{g}_{m}^{\mathrm{rx}}\left(-\mathbf{k}_{lmn}^{\mathrm{rx}}\right)^{\mathrm{T}} \cdot \mathbf{A}_{l} \cdot \mathbf{g}_{n}^{\mathrm{tx}}\left(\mathbf{k}_{lmn}^{\mathrm{tx}}\right) \\ &\cdot \exp\left[i\left(\mathbf{k}_{lmn}^{\mathrm{rx}} \cdot \left[\mathbf{r}_{m}^{\mathrm{rx}} + t \cdot \mathbf{v}^{\mathrm{rx}}\right] - \mathbf{k}_{lmn}^{\mathrm{tx}} \cdot \left[\mathbf{r}_{m}^{\mathrm{tx}} + t \cdot \mathbf{v}^{\mathrm{tx}}\right] + \left[\omega + \omega_{lmn}^{\mathrm{D}}\right]\tau_{lmn} \right)\right] \end{aligned} \tag{1}$$

where H_{mn} is the channel between transmit (Tx) antenna n and receive (Rx) antenna m, $\mathbf{A}_l$ is the complex polarimetric amplitude matrix of the l^{th} of totally N spherical waves, $\mathbf{g}_m^{\mathrm{rx}}\left(-\mathbf{k}_l^{\mathrm{rx}}\right)$ and $\mathbf{g}_n^{\mathrm{tx}}\left(\mathbf{k}_l^{\mathrm{tx}}\right)$ are the complex polarimetric antenna pattern vectors for the corresponding wave vectors $\mathbf{k}_{lmn}^{\mathrm{rx}}$ and $\mathbf{k}_{lmn}^{\mathrm{tx}}$, $\mathbf{r}_m^{\mathrm{rx}}$ and $\mathbf{r}_n^{\mathrm{tx}}$ are the position vectors of the receive and transmit antenna elements relative to corresponding antenna reference points, ω is the angular frequency, $\omega_{lmn}^{\mathrm{D}}$ is the Doppler frequency and τ_{lmn} is the wave propagation delay between the Tx and Rx antenna elements. This formulation allows, for each single path, different delays and directions depending on the locations of the corresponding receive and transmit antenna elements thus allowing for any non-planar type of wave including spherical waves.

VI. MEASUREMENTS

METIS is currently in an intensive phase regarding propagation measurements. Corresponding measurement data are crucial for the needed extensions/modifications of available channel modelling. Presently the effort is focused on 60 GHz, D2D and 3D channel properties. A few illustrative examples of this work are presented below.

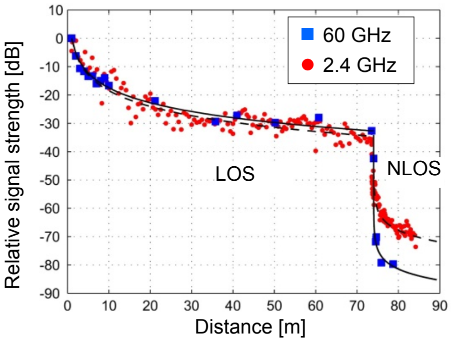

Fig. 4. Signal strength measured and modelled at 2.4 GHz and 60 GHz in a corridor of an indoor office scenario.

A. Millimetre waves

One example on the frequency dependency of indoor path-loss is shown in Fig. 4. It is clear that the propagation characteristics are very similar at 2.4 GHz and 60 GHz for LOS conditions in a corridor of an indoor office environment. However, after a turn of 90 degrees around a corner of the corridor the shadowing loss at 60 GHz is around 50 dB which is 15 dB more than at 2.4 GHz. The used Berg recursive model [10] fits the data very well at both frequencies.

Another 60 GHz measurement campaign was conducted in a modern large open shopping mall. Fig. 5 presents a power angular delay profile (PADP) from a non-line-of-sight measurement where the Rx was placed behind a pillar and the Tx was placed in an open corridor. We see that only a few paths can be identified in the azimuth directions 45°, 180° and 320°. These distinct paths are explained as specular reflections off the interior walls of the mall. The large empty regions in the PADP suggest that there are no significant diffuse scatterers in this environment.

B. Crowded areas

A MIMO channel measurement campaign was conducted at 2 GHz in the vicinities of an urban railway station (Shibuya, Tokyo) which is very crowded in daytime. The mobile station (MS) antenna height was set to 1.5 m and the base (BS) antenna heights for small cell and D2D scenarios were set to 3 and 1.5 m, respectively. Fig. 6 shows the reception power distributions for the small cell and D2D scenarios. The average reception power in daytime is about 5dB lower than that in midnight-time. The difference is due to different amount of shadowing by pedestrians in night- and daytime.

C. Vehicle to vehicle

Fig. 7 presents the measured path loss at 5.25 GHz for a vehicle to vehicle (V2V) propagation scenario. The Tx and the Rx antennas were placed on the roofs of two cars. The cars were moving in the opposite directions on the same street. The black dots indicate the measured loss, solid red line presents the expected PL and dashed blue line is the free space loss. The expected path loss was derived using a linear fit of the measured path loss using logarithmic link distance.

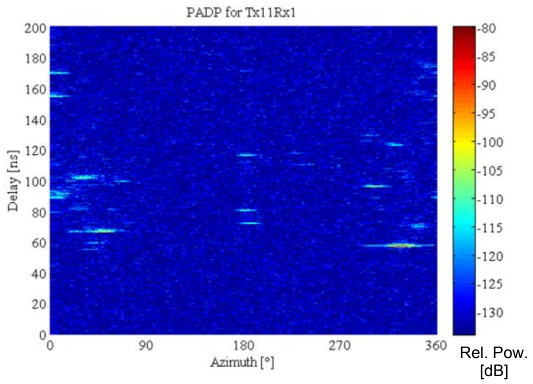

Fig. 5. Power angular delay profile from 60 GHz NLOS measurements in a modern shopping mall.

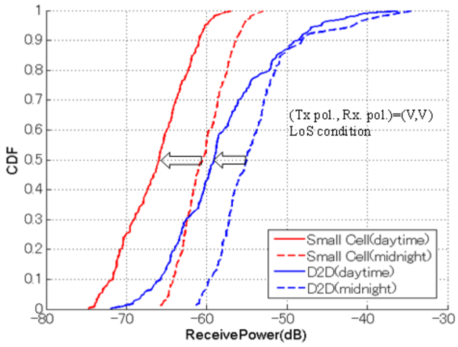

Fig. 6. Received power distributions measured at 2 GHz in Shibuya, Tokyo in daytime and night-time.

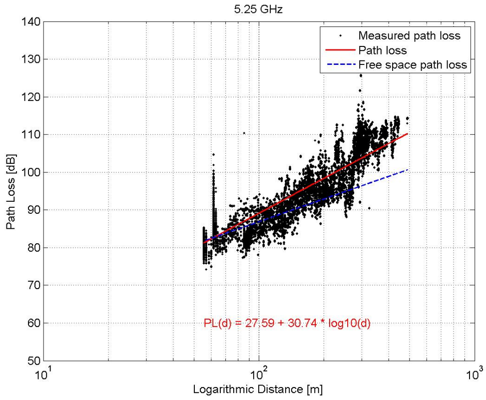

Fig. 7. Path loss measured at 5.25 GHz in an urban street V2V scenario in Oulu, Finland.

The measured loss is greater than free space loss due to other vehicles blocking the LOS condition. The large variation of measured path loss at the distance around 60 m was caused by traffic flow when the measurement cars were standing at the traffic lights.

VII. SUMMARY AND CONCLUSIONS

This paper reports on the European 7th framework project METIS' propagation modelling work. The 5G propagation scenarios and main propagation modelling challenges are described. Moreover, the main needed extensions and modifications of current available and widely used models for providing the final METIS model are assessed. This is ongoing work which is in an intensive phase. Much effort is put on finding solutions for the most critical problems like how to ensure spatial consistency for the dual mobility case (D2D) and how to model super resolved waves in a realistic way. This paper reports also on the current achievements including preliminary measurement results. The final METIS channel model is expected in April 2015.

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