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6–100 GHz Channel Modelling for 5G: Measurement and Modelling Plans in mmMAGIC

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Abstract

This white paper presents an overview of the propagation measurement and modelling plans as a first step of the mmMAGIC project. One of final goals of the project is to provide adequate propagation and channel models in the frequency range 6–100 GHz to be used as inputs for 5G radio communications standardization in 3GPP and ITU.

Keywords

5G channel model, mm-wave propagation, channel measurement plan, channel modelling methodology

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1 Introduction

Mobile communication systems operating at millimetre-wave (mm-wave) frequencies are drawing tremendous attention in industry as a very promising solution to significantly boost capacity in 5G systems due to its potential to provide much larger transmission bandwidth. The availability of suitable channel models is crucial for 5G mm-wave developments and deployments. However, despite the experimental results and modelling attempts so far, knowledge of mm-wave channel characteristics for the relevant frequencies and scenarios is insufficient.

One of the key ambitions of the mmMAGIC (mm-wave Based Mobile Radio Access Network for Fifth Generation Integrated Communications) project [MMM15] is to develop comprehensive advanced propagation and channel models within the entire range from 6–100 GHz covering relevant 5G deployment scenarios. In the initial stage of the work, channel measurement activities have been planned and modelling methodologies are being explored, based on a study of the state-of-the-art below and above 6 GHz. This white paper presents an overview of the propagation measurement and modelling plans in the project. One of final goals of the project is to provide adequate propagation and channel models in the frequency range 6–100 GHz to be used as inputs for 5G radio communications standardization in 3GPP and ITU.

2 mmMAGIC Scope

The main objective of mmMAGIC is to develop and design new concepts for mobile radio access technology (RAT) for deployment in the frequency range 6–100 GHz. One of the integral parts of the project is to carry out comprehensive channel measurement and modelling work. Corresponding plans and initial considerations are introduced in this document. Overall, more than 60 (single-frequency equivalent) measurement campaigns will be performed by seven project partners within the whole frequency range of 6–100 GHz. By using the massive amount of measurement data collected for multiple sub-bands and complementing simulation data, the development of a unified system-level channel model covering the entire frequency range is targeted. The initial channel model based on early available data will be proposed in March 2016. Finally in March 2017, mmMAGIC will provide the final model that will also be available as an open source software implementation following the approach of [JRB+14].

3 Deployment Scenarios for Channel Modelling

The list of deployment scenarios for channel modelling considered in the mmMAGIC project is given in Table 1. In addition to urban micro-cellular (UMi) scenarios (street canyon, open square), indoor (office, shopping mall, airport), and outdoor-to-indoor (O2I), two more scenarios of stadium and metro station are considered as environments with very high user densities. Urban macro-cellular (UMa) scenario is taken into account in the channel model, however, it's not explicitly mentioned in the table since frequency spectrum above 6 GHz is expected to be used for small cell base stations (BS).

Table 1: Deployment scenarios considered in the mmMAGIC project

Scenario	Definition/Specifications	BS/UE deployment
UMi Street canyon	▪ Urban environment with high user density. ▪ Users are pedestrians or slow vehicular users. ▪ Buildings of 4-7 storeys on both sides. ▪ The length of the street is at least 100 m. ▪ The street canyon typically includes street furniture (lamp posts and/or traffic signs) and may include trees.	BS is installed on the lamp posts, walls or at the rooftop of buildings. $1.5 \le \mathrm{h}_{\mathrm{UE}} \le 3\ \mathrm{m}$, $3 \le \mathrm{h}_{\mathrm{BS}} \le 10\ \mathrm{m}$

UMi Open square	▪ Urban environment with high user density. ▪ Users are pedestrians or slow vehicular users. ▪ (semi-) flat areas in the shape of a square or circle usually surrounded by buildings of 4-7 storeys. The main elements inside an open square are lamp posts, vegetation (e.g. trees), etc. ▪ The width of open squares is usually between 50 and 100 meters.	BS is placed below the rooftop level of the surrounding buildings. $1.5 \leq \mathrm{h_{UE}} \leq 3\ \mathrm{m},$ $3 \leq \mathrm{h_{BS}} \leq 10\ \mathrm{m}$
Indoor Office	▪ Traditional office (private office): An enclosed work space for (usually) one to four people. These offices are enclosed by doors and walls. ▪ Cubicle: A semi-enclosed work space for one person. Typically, these working spaces are in partitioned rows with dividers which may or may not reach the ceiling. Rows are usually separated by aisles for workers to pass by along the cubicles. ▪ Open-office: An open work space for more than ten people. There are no walls or cubicles to separate staff's working space. ▪ The entire office, including traditional office, cubicle, and open-office, can typically have the dimension from 25 to 100 meters, while the ceiling height is 3 to 5 m.	BS can be placed at the ceiling or on the walls. $1 \leq \mathrm{h_{UE}} \leq 1.5\ \mathrm{m},$ $1 \leq \mathrm{h_{BS}} \leq 5\ \mathrm{m}$ (from floor level)
Indoor Shopping mall	▪ A large enclosed shopping area in form of multi-storey buildings, usually with open ceiling (atrium) in the middle of the building ▪ Shops are arranged next to the outer walls of the building; corridors provide a walking area for the pedestrians. ▪ The shopping mall including shops can typically have the dimension from 50 to 200 m. ▪ Ceiling height in the corridors and individual shops: 3–5 m (typically 3 m). ▪ Ceiling above open space (atrium): 9–18 m. ▪ High user density depending on the time of day.	BS is positioned at the ceiling. $\mathrm{h_{UE}} = 1.5\ \mathrm{m},$ $3 \leq \mathrm{h_{BS}} \leq 5\ \mathrm{m}$ (from floor level)
Indoor Airport	▪ Gate area: A gate, or gatehouse, is an area of an airport that provides a waiting area for passengers before boarding their flight. Most gates consist of seating, a counter, an aircraft entry or exit doorway, and a jet bridge. Ceiling height is usually between 4 to 6 meters. The gate is connected to a corridor with or without walls. Typical width of the gate area can vary from 20 m to 50 m, while its length along the corridor can stretch up to 100 m. ▪ Check-in area: The area before the security check-point where check-in counters are placed. The ceiling height is about 4–9 m. Airline and service offices are located in the multi-storey walls. The user density varies depending on the time and airport. Typical dimension can be from 50 to 200 m.	BS should be installed near the ceiling. $\mathrm{h_{UE}} = 1.5\ \mathrm{m},$ $4 \leq \mathrm{h_{BS}} \leq 9\ \mathrm{m}$ (from floor level)
O2I	▪ UE is located in an indoor environment, either following office, shopping mall or airport, and the building is surrounded by UMi street canyon or open square scenario. ▪ Dimensions and antenna heights of the outdoor and indoor environments can follow those of street canyon, open square, office, shopping mall and airport.	BS is positioned at neighbouring building exterior wall, a lamp post or similar. $\mathrm{h_{UE}} = 1.5\ \mathrm{m},$ $3 \leq \mathrm{h_{BS}} \leq 10\ \mathrm{m}$ (from ground level)
Stadium	▪ A place or venue for sports, concerts, or other events. ▪ Consists of a field or stage either partly or completely surrounded by a tiered structure designed to allow spectators to stand or sit and view the event. ▪ Can be roofed or unroofed. ▪ Typical width can be from 100 to 150 m. ▪ Very high user density.	BS is put on higher levels of spectators' area. $\mathrm{h_{UE}} = 1.5\ \mathrm{m},$ $3 \leq \mathrm{h_{BS}} \leq 10\ \mathrm{m}$ (from floor level in spectators' area)
Metro station	▪ A railway station for rapid transit system. ▪ The station can be above the ground level or underground. ▪ There are entrances/exits at the ground level. ▪ The metro station can be a junction of two or more metro lines in different floors. These floors are connected to each other and to the exits/entrances via stairs, escalators and lifts. ▪ Typical dimensions of underground stations are: width: approx. 20–	BS can be put near the ceiling of the station or on the walls. $\mathrm{h_{UE}} = 1.5\ \mathrm{m},$ $3 \leq \mathrm{h_{BS}} \leq 10\ \mathrm{m}$ (from floor level)

	50 m, length: approx. 60–150 m, ceiling height: approx. 6–15 m. ▪ High to very high user density depending on the time of day.	

4 Measurement Plan

In mmMAGIC, more than twenty measurement campaigns in more than eight frequency bands from 6 to 100 GHz will be performed by seven project partners, namely Aalto University (Aalto), CEA-Leti (CEA), Ericsson (EAB), Fraunhofer HHI (HHI), Orange (Orange), University of Bristol (UoB) and Rohde & Schwarz (R&S). The campaigns involve channel sounder setups with multi-frequency (up to four bands in parallel) and ultra-wideband capabilities (up to 4 GHz bandwidth). Overall, more than 60 single-frequency equivalent measurement campaigns have been planned. Details are listed in Table 2 with the acronym of the partners, timeline and centre frequency of each measurement.

Table 2: Channel measurement plan in mmMAGIC

Category	**Scenario**	**Frequency range**					
		Lower range		**Middle range**		**Upper range**	
		6–10GHz	**10–20GHz**	**20–35GHz**	**35–50GHz**	**50–70GHz**	**70–100GHz**
UMi	Street canyon	EAB/end-2015/5.8GHz	Aalto/end-2015/14.25GHz] HHI/end-2015/10.25GHz] Orange/early-2016/10GHz & 17GHz] EAB/end-2015/14.8GHz	Aalto/end-2015/27.45GHz HHI/end-2015/28.5GHz EAB/early-2016/28GHz	HHI/end-2015/41.5GHz	Aalto/end-2015/61GHz EAB/end-2015/60GHz	Aalto/mid-2015/82.5GH HHI/end-2015/82.5GHz
	Open square		Aalto/end-2015/14.25GHz Orange/ early-2016/10 GHz & 17GHz R&S/early-2016/17GHz	Aalto/ end-2015/27.45GHz		Aalto/early-2016/61GHz Orange/early-2016/60GHz UoB/early-2016/60GHz	Aalto/mid-2016/82.5GHz UoB/early-2016/70 or 80GHz
Indoor	Office	EAB/mid-2015/5.8GHz	EAB/mid-2015/14.8GHz HHI/early-2016/10.25GHz	EAB/early-2016/28GHz HHI/early-2016/28.5GHz CEA/early-2016/28GHz	HHI/early-2016/41.5GHz	EAB/mid-2015/60GHz UoB/end-2015/60GHz CEA/early-2016/60GHz	HHI/early-2016/82.5GHz (& 100 GHz) UoB/early-2016/70GHz or 80GHz CEA/early-2016/82.5GHz
	Shopping mall		HHI/early-2016/10.25GHz	HHI/early-2016/28.5GHz	HHI/early-2016/41.5GHz	UoB/end-2015/60GHz]	HHI/early-2016/82.5GHz (& 100 GHz) UoB/Jan-2016/70, 80GHz
	Airport		Aalto/end-2015/14.25GHz HHI/mid-2016/10.25GHz	Aalto/end-2015/27.45GHz HHI/mid-2016/28.5GHz	HHI/mid-2016/41.5GHz	Aalto/end-2015/61GHz	HHI/mid-2016/82.5GHz (100 GHz)
O2I	O2I	EAB/mid-2015/5.8GHz	HHI/end-2015/10.25GHz EAB/mid-2015/14.8GHz Orange/early-2016/10GHz/17 GHz R&S/early-2016/17GHz	HHI/end-2015/28.5GHz EAB/early-2016/28GHz	HHI/end-2015/41.5GHz	EAB/mid-2015/60GHz	HHI/end-2015/82.5GHz
Dense	Stadium (optional)		HHI/mid-2016/10.25GHz	HHI/mid-2016/28.5GHz	HHI/mid-2016/41.5GHz		HHI/mid-2016/82.5GHz (100 GHz)
Mobility	Metro station / metro		HHI/early-2016/10.25GHz	HHI/early-2016/28.5GHz	HHI/early-2016/41.5GHz		HHI/early-2016/82.5GHz (&100 GHz)

Two measurement approaches are pursued – one using steered directional antennas and one with omnidirectional antennas. The measurement campaigns are complemented by map-based simulations based on ray tracing and point cloud models as well as by available data from previous projects. The massive amount of data provides a solid base for accurate channel characterization over the full range of the parameter space. The determined channel characteristics are used to assess the modelling requirements, develop new model features and provide a unified channel model for the whole range of 6–100 GHz including corresponding parameter tables.

Figure 1 illustrates the measurement bands on a frequency bar in conjunction with the scenarios. It can be seen that the sample frequencies are well distributed over the whole range. The edge frequencies, i.e. 6 and 100 GHz, are explicitly included.

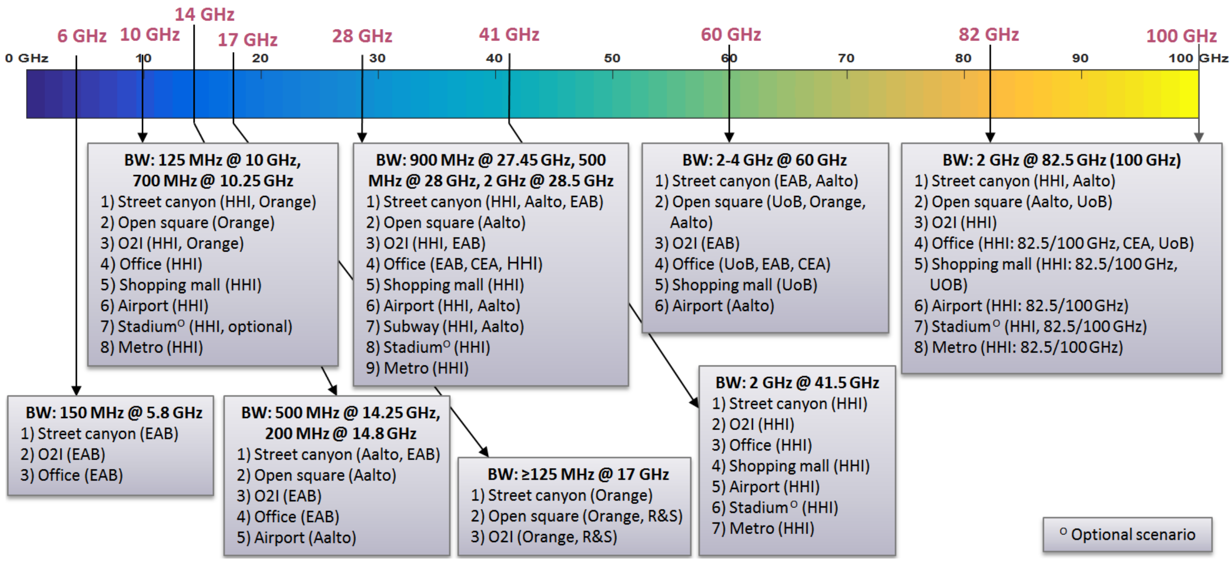

Figure 1: mmMAGIC measurement frequencies and scenarios.

5 Channel Modelling Methodology

State-of-the-art three-dimensional (3D) geometry-based stochastic channel models (GSCMs), which basically involve a quasi-deterministic modelling, will form the basis of an advanced mmMAGIC channel model. The geometry-based 3D approach is essential to support antenna arrays with a large number of elements and/or large size, while the stochastic approach is chosen to keep the model complexity at an acceptable level, which might not be possible with map-based approaches. The evolution of channel models up to recent 3D GSCMs is illustrated in Figure 2.

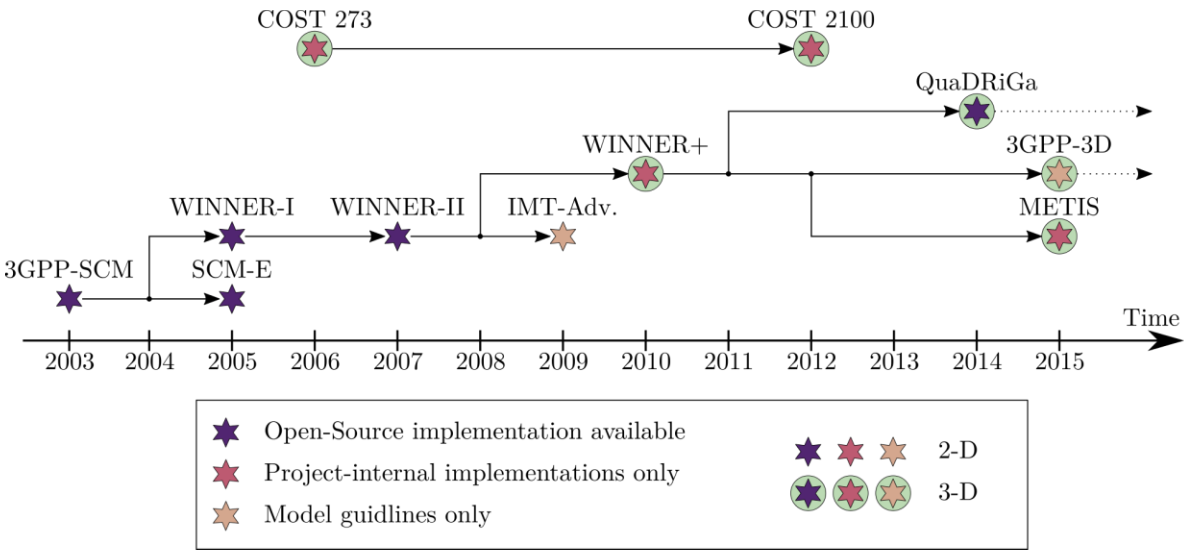

Figure 2: Channel models for cellular networks and their family history.

Since the 3GPP-3D channel model [3GPP15-36873], the QuaDRiGa model [JRB+14], and the METIS stochastic model [MET15-D14] are evolutions from the 3D WINNER+ channel model [WIN+10-D53], they can use the same set of parameters for channel simulation. The modelling work in mmMAGIC will build heavily on these state-of-the-art 3D GSCMs, related knowledge and implementations. However, based on preliminary analyses on the measurement data at higher frequencies, it turned out that new additional features will potentially be required to enhance the accuracy in view of their application to mm-wave frequencies. In concrete, the following features will be studied and evaluated. Some of them are overlapped with contemporary works of 5G channel modelling in [ABC+15].

- Blockage and time variance

  At lower BS heights and higher frequencies, pedestrians or vehicles can (randomly) block the direct path or strong multi-path components, especially when large antenna arrays are used with narrow beamwidth, with the effect that the signal power drops significantly and rapidly. Additional time variance can be introduced by dynamic scatterers. In order to model this kind of phenomena accurately, a channel model supporting large-scale time variability is needed.

- Explicit modelling of the ground/floor reflection

  Another effect observed in measurements is the strong influence of the ground/floor reflection. At higher frequencies even small differences in angle and in length between the line of sight and reflected paths can cause strong and regular spatial fading up to a breakpoint distance. Hence, it might be needed to model the reflection from the ground or the floor (and strong reflections from building walls) in a deterministic manner, e.g. as proposed in [MIW14-D51].

- Distance- and frequency dependence of large scale parameters (LSPs)

  The advanced model should be applicable to a frequency range of 6–100 GHz and even beyond. Therefore, assuming fixed values for the LSPs is not realistic anymore. For example, diffraction coefficients, diffuse scattering coefficients and penetration losses are very different between 6 and 100 GHz, which leads to different propagation characteristics. Path loss exponents can depend on both frequency and distance since the breakpoint may be located in between the inter-site distance (ISD) in this frequency range. Overall, the path loss exponents, delay-spreads, angular-spreads, and Ricean K-factors will have a frequency and distance dependency. Therefore, it is important to improve the modelling approach for the LSPs in order to reflect such frequency and distance dependency.

- Coherent small-scale fading for different frequencies

  In 5G systems, UEs might be connected to a BS at multiple frequencies (e.g. at 2 GHz for control plane and mm-wave for data plane). Both channels may be constituted by the same propagation paths, but with divergent power values due to e.g. different diffraction and penetration losses. Therefore, new approaches are needed to map angles, powers, and delays for different frequencies with appropriate coherence that will create partially correlated small-scale fading in the different frequency bands.

- Realistic high resolution spatial properties

  Advanced multi-antenna techniques are needed to compensate for the increased link loss due to a reduced (omnidirectional) antenna aperture for higher frequencies in the mm-wave range. Antenna techniques such as massive MIMO (multiple-input multiple output) and pencil beamforming utilize critically highly resolved spatial/directional characteristics of the radio propagation channel. For this purpose the spatial accuracy regarding path and sub-path distributions in angle and amplitude need substantial improvement relative to present widely used 3GPP and ITU models as shown in section 5.11 of the METIS channel model deliverable [MET15-D14].

- New model for intra-cluster delay spread and power

  In the currently available GSCMs, intra-cluster delay spread is omitted to simplify the models. The main assumption for the simplification is that the intra-cluster delay spread is smaller than the time resolution of the legacy system. However, in the mm-wave band, this assumption is not valid because of the high time resolution at GHz bandwidths. Therefore, sub-paths should be introduced to create intra-cluster delay spread based on measurements like [SR15]. The number of sub-paths within a cluster may be generated similarly with the current GSCM models, while the power of each sub-path may not be equal in different frequency bands. The distribution of sub-path power within a cluster was omitted in the 3D WINNER+ channel model. This needs to be considered in the newly developed mmMAGIC channel model.

- Frequency-dependent canonical antenna modelling

  The current GSCMs use the same antenna model for the full system bandwidth. However, at GHz bandwidths and different carrier frequencies (e.g. a UE being served at 28 GHz and 60 GHz simultaneously from the same BS), antenna characteristics will be frequency dependent. Hence, frequency-dependent canonical antenna models might be important to evaluate the multi-frequency multi-antenna radio channels appropriately.

6 Conclusion

In the mmMAGIC project, the elaboration of an advanced channel model for the frequency range of 6–100 GHz is aimed to support 5G radio communications standardization in 3GPP and ITU. In this paper, measurement and modelling plans have been introduced. The mmMAGIC initial channel model recommendations based on early available measurement data will be published in March 2016.

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