Perspectives of Geometry Based Deterministic Reference Channel Models for 5G Applications

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***Abstract*—Geometry based reference channel models (GBRCM) have been one of key topics of radio channel modelling for years. Their development and applications have been bringing the academy, industry and standardization bodies together in several large projects, such are 3GPP, WINNER, METIS, etc. With 5G as an ongoing process, it is important to continue and adapt GBRCM research to new arriving technologies and applications. This paper discusses perspectives of geometry based deterministic reference channel models (GBDRCM), a subset of GBRCM, for 5G reference channel models, focusing on some key concepts of 5G: massive MIMO, Internet of Things and resources. The main hypothesis lies on the concept of deterministic reference channel models as an alternative for the commonly accepted stochastically based geometry based RCMs. The proposed solution is based on the concept of ray entity delivered from ray tracing simulations.**

***Keywords*—deterministic reference channel model; 5G; massive MIMO**

I. INTRODUCTION

5G today is more than just a buzz word. Regulatory and standardization bodies, as well as industry, have been pushing the concept forward, targeting years 2019/2020 for the final launch. The technology brings not only another increase of traffic throughput in mobile networks, but also new applications such as machine-to-machine (M2M) communication and internet-of-things (IoT) technology. In other words, 5G is not merely a continuation of the existing technologies, but a new platform that introduces some new concepts, highly reliable and intelligent systems, and new business models.

Implementing new technology, as well as all kinds of different (new) services, requires careful planning, along with large number of different tests and measurements in order to assure necessary capacity and reliability of a given service. Reference channel models (RCM) have been one of the crucial tools in this area, as they are in fact a platform which allows testing and verifying new techniques, coding schemes, antenna designs, etc. Geometry based stochastic reference channel models (GBSRCM) are commonly accepted concept for all mainstream standards, such as 3GPP [1], METIS [2], [3] or WINNER [4] model. All of them cover large number of typical scenarios and provide good approximation of typical propagation conditions, but often lack adequate parameterization, hence lose their accuracy and/or link with a real scenario.

This paper presents perspectives of a different approach to radio channel modelling for 5G applications. Deterministic reference channel models (DRCM) are not a novel approach and they have been investigated by many researchers, but they are usually considered too complex, time consuming and, in the end, too expensive. However, with available storage and processors' capacity and reasonable prices, this has become a feasible option, which can provide very accurate real-life like radio channel realizations.

The proposed solution is based on the concept of ray entities delivered from the exhaustive ray tracing simulations. Ray entities preserve all properties of raw data, thus keeping their high accuracy, while at the same time they enable easy data manipulation, thus providing the deployment of the mobility and different antenna patterns into the model. This has a wide range of applications, including several key parts of 5G, such are massive MIMO or IoT/M2M/D2D communications.

The paper is organized as follows. In Section II a brief overview of 5G technology is given, whereas Section III gives some basic information about the existing reference channel models. Section IV describes the proposed deterministic reference channel model based on ray entity concept, and provides possible applications for 5G systems. Section V includes some concluding remarks and future work.

II. 5G OVERVIEW

The definition of 5G has been somewhat loose, since its standardization is still an ongoing process, but as a general consensus, it includes advanced radio access schemes and conceptually new applications. Several key concepts are linked with 5G: deployment of massive MIMO, massive intelligent non-human communications (e.g. IoT, M2M), highly reliable low latency devices, core network on cloud, etc. Also, there is a question of appropriate resources that could accommodate all current and future needs, which is why European Commission (and other international bodies) have been allocating more and more radiofrequency (RF) spectrum for 5G applications.

Based on ITU M.2083 [5], 5G should fulfill the following requirements:

- Peak data rate: tens of Gbit/s

- User experienced data rate: 100 Mbit/s to 1 Gbit/s
- Connection density: 1 million connections per km^2
- End-to-end latency: millisecond level
- Traffic volume density: 10 Mbit/s per m^2
- Mobility: up to 500 km/h

On the international level (ITU, CEPT, etc.) several frequency bands have been discussed in order to accommodate all users, devices and new applications. The first set of frequency bands and the main candidates at this point include 3.6 GHz (3400 MHz -3800 MHz) and 26 GHz (24.25-27.5 GHz), according to CEPT roadmap [6], but many other have also been discussed. While most other candidate frequency bands are in higher frequency ranges, it is reasonable to expect that 5G will be implemented also in the band of 700 MHz (694-790 MHz) or in the area of "second digital dividend".

Apart from the resource requirements for higher capacities, there are additional needs for the deployment of new applications. That is why some advanced solutions have been proposed on the all layers, including physical. One of them is the application of massive MIMO in 5G [7]. There is no strict definition what massive MIMO is, but it generally refers to a very large antenna arrays, or more simply, MIMO system with a huge number of antenna elements (Figure 1).

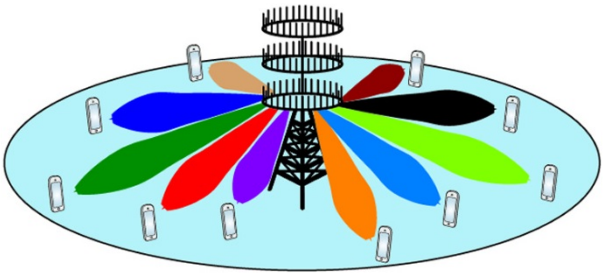

Figure 1 Massive MIMO scheme [7]

Leading manufactures (e.g. Ericsson, Huawei, etc. [8], [9]) have demonstrated solutions with tens and hundreds of antennas. But regardless of their number, it is important to stress that MIMO uses the same RF resource, i.e. the same radio channel, hence provides high capacity and spectrum efficiency. Also, massive MIMO is based on beamforming rather than sharing the whole spectrum between users, thus allowing intelligent and highly efficient communication with each user.

However, in order to properly exploit all given benefits of both massive MIMO and beamforming, it is important to have an adequate model. The proposed DRCM enables the deployment of an arbitrary MIMO antenna geometry into the model, as elaborated in the following sections.

Communication between machines is conceptually novel approach that will be introduced by 5G. IoT and M2M are applications that are expected to be cornerstones of the 5G (and beyond). Whereas many of the available literature about IoT addresses only the expected number of devices, energy consumption or expected revenues, researchers still need to deal with open issues regarding the physical layer where all of them will operate.

The proposed DRSCM will provide simple tracking of each user or device in a real-life propagation scenario. It should be noted that our model allows following the device/user with a very fine resolution, thus enabling the implementation of mobility into the model. Also, any kind of antenna pattern can be applied, which makes it possible to model radio channel for IoT with massive MIMO.

III. STANDARD REFERENCE CHANNEL MODELS

With so many new and heterogeneous applications of wireless communications, it is no wonder that standardization bodies have a handful of work in order to provide general documents with some general guidelines.

Currently agreed 5G new radio specifications are available in 3GPP Release 15 [10]. Other significant projects which provided some deeper insights into propagation effects and delivered appropriate advanced reference channel models are METIS [2], [3], WINNER [4] and COST [11-13], as well as the most prominent international standardization bodies IEEE ETSI and ITU. An overview of the current 5G models, including reports and other deliverables by IEEE, ETSI and ITU, can be found in [14]. All of them belong into a group of GBRCMs.

As mentioned before, reference channel models (RCM) enable realistic performance comparison and testing for new wireless communication systems. Recent requirements impose, among other things, the implementation of MIMO air interfaces and mobility into the model. The purpose of RCM is to simulate typical radio environment properties, which can then become a platform for testing and verification of new generations of radios, modulation and coding techniques, new applications, different antenna designs, etc.

Typical procedure of creating a RCM is shown Figure 2 and elaborated more thoroughly in [15].

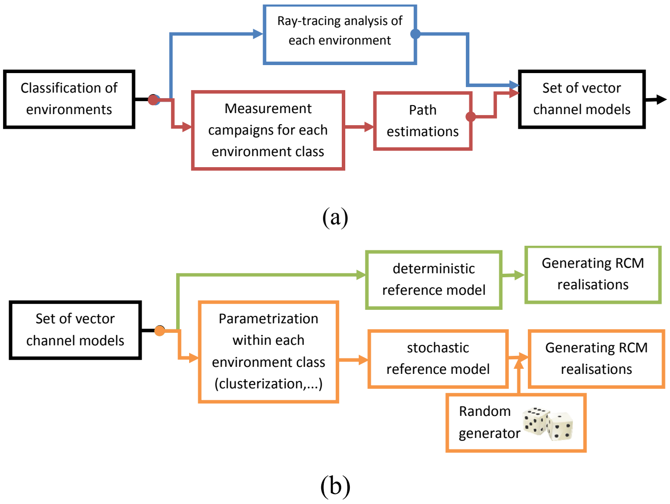

Figure 2 Processes for creating Reference Channel Models (a); Deterministic and stochastic RCM (b)

Fig 2.a depicts the process of obtaining information about representative channels. This is usually statistically sufficient number of cases per environment gathered either numerically (blue) or by measurements (red). The second part, depicted in Figure 2.b, represents two possible options for building RCM: either by directly using “raw data”, i.e. already determined set of vector channel models (upper branch in green) or by delivering a stochastic model through parameterization of the available data (lower branch in orange). In the latter case all future radio channel realizations are subject to a given stochastic model and basically random and potentially discrepant from realistic scenarios.

IV. RAY ENTITY DETERMINSTIC RADIO CHANNEL MODEL AS A REALISTIC CANDIDATE FOR 5G DEVELOPMENT

As elaborated in chapter III, DRCMs have a potential to offer more realistic descriptions of environments and thus more realistic emulation/simulation of 5G radio channels, regardless of the applied bandwidth.

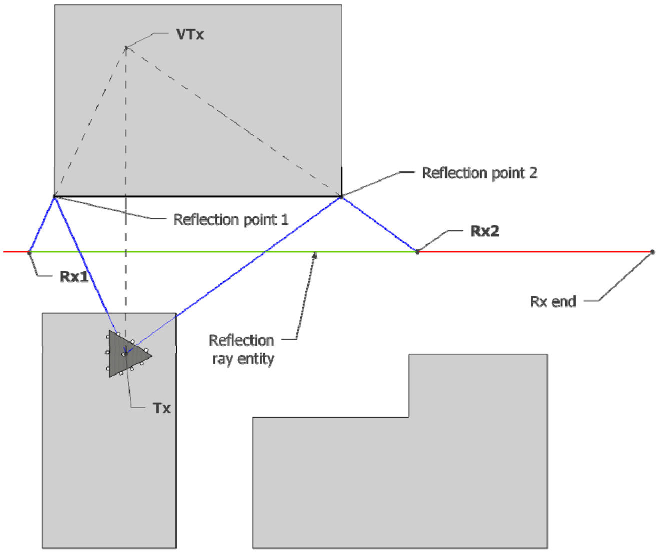

Figure 3 Top view illustrating visibility of receiver route, reflection ray entity and location of virtual source

The main challenges of DRCMs lie in their realization at minimum memory and computational burden. The idea of compressing and interpolating RT data, based on the concept of ray entity (RE), was derived previously [16]. In principle, RE is a set of rays that underwent same series of propagation phenomena (direct ray, diffraction, reflection or scattering) on the same objects (building walls or edges). Rays are generated by exhaustive RT simulations on a given route, sampled in an arbitrary resolution, although the concept allows that input data come also from measurements. For each RE a visibility region (VR) is also defined, which represents the area where a certain RE is present or not. This way, raw data are significantly reduced, while at the same time the main properties of the real-life radio channel have been preserved, which enables interpolating at non-simulated locations with minimum accuracy loss. Figure 3 shows RE and VR for the case of reflection.

While RE, combined with VR, provides an efficient solution for implementing the mobility into the model, with the reduction of computational complexity and storage requirements, there is still an issue of implementing MIMO air interface and different antenna designs into the model.

For generalization of SISO ray tracing data into ray tracing data for arbitrary MIMO antenna geometry application, such as massive MIMO antennas, a planar wave assumption would be a reasonable approximation [17]. Rigorous modeling should also include issues like polarization, arbitrary antennas (not just dipoles) at both sides of communication channel, and frequency. Straightforward formulation is possible, that parses impacts of the antenna elements from impact of multipath environment and MIMO antenna location shifts to the final elements of the MIMO transfer matrix. The challenge of rotating an arbitrary radiation pattern for arbitrary angle in 3D that arises in such an approach is somewhat tackled in [18] and [19].

Beside the model itself, it is worth considering methods and ways for its application. As usages for 5G applications would stretch across many bands, DRCM database should be created surely for each band separately, even if identical urban geometry database is used, taking into account different propagation properties at different frequencies.

Methods of applications could include final statistical analysis of obtained propagation data and also feed to some laboratory simulators/emulators such as [20] or [21]. References in [21] list more of similar hardware platforms under development. Such hardware simulators/emulators enable real-time and real-equipment network testing in a limited bandwidth, where geometric propagation models can be applied to real signals of a real network equipment. Figure 4. gives a principal scheme of such an hardware device:

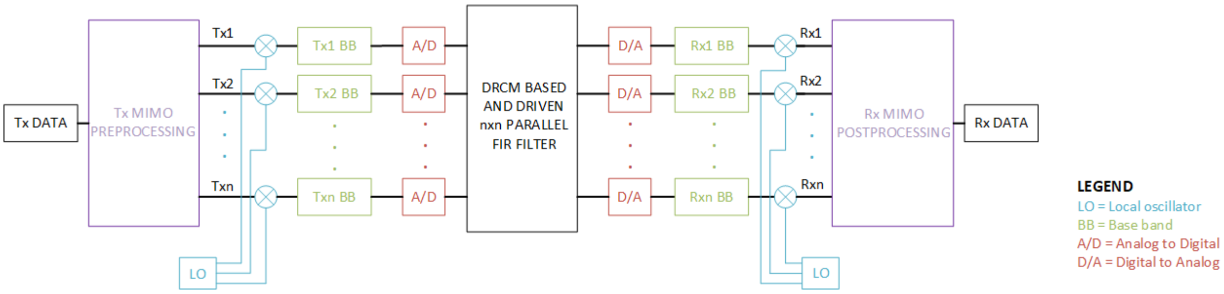

Figure 4 Principal scheme of a hardware propagation simulator for MIMO systems

This approach saves a lot of system fine-tuning otherwise performed using field trials and exhaustive measurement campaigns. Usage of DRCMs in such realistic laboratory tests would provide realistic performance results of the prospective network solutions for 5G, yet with a benefit of standardization - repeatability and fairness of their comparison.

V. CONCLUSION

The paper discusses perspectives of applying deterministic approach for delivering a reference channel model for 5G applications. The paper provided a brief overview of 5G technology, as well as the existing RCMs, and focused on the proposed solution – DRSCM based on the concept of ray entity.

In the context of perspectives of the proposed DRSCM model for 5G applications, there are many possibilities and challenges. As elaborated in this work and in other relevant papers, the model enables the deployment of multiple arbitrary antenna elements on both sides of the radio channel, which makes it suitable for massive MIMO simulations/emulations. The model also provides simple and straightforward implementation of mobility, with high accuracy and arbitrary fine resolution, thus being suitable for modelling and keeping track of the behavior of both users and devices even in highly congested areas. Another advantage of the model comes from the fact that it is not frequency dependent, i.e. it can be easily upgraded for an arbitrary frequency band, which is very important for 5G since it will use different frequency bands in order to fulfill the capacity requirements.

It should be stressed however that the proposed model is still in its early phase and there are still many open issues for the future work.

VI. ACKNOWLEDGMENT

This work has been fully supported by Croatian Science Foundation under the projects 6198 Textile Antennas for Smart Environment.

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