CHANNEL MODELS AND MEASUREMENTS FOR 5G













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ome years ago, the late Larry Greenstein, known also as the father of radio propagation, published a beautiful article where he quotes Don Cox: "Before we can build a new radio system, we have to understand the propagation." In the 1970s, when AMPS was first introduced, Don Cox did pioneering studies in understanding of mobile radio propagation — mainly in the 850 MHz band. Since then, wireless mobile communication is well developed from first to fourth generation supported by plenty of channel studies in microwave bands (below about 6 GHz).

The fifth generation (5G) is expected to include new requirements, applications, and scenarios, and it will need massive and 3D multiple-input multiple output (MIMO), and increased spectrum via the use of millimeter-wave (mmWave) bands. The emerging techniques also pose new challenges to channel models. For example, 28 GHz is some 33 times higher in frequency relative to 850 MHz, and the channel bandwidth is 8000 times more than that of AMPS. These differences will increase even more when the operating frequency further increases. Reduced cell range, increased building penetration loss, human blocking, spatial consistency of some impulse response parameters, and so on are new properties that must be studied. Suffice it to say that propagation studies are time consuming and "not for the impatient as nature often reveals her secrets on a time table different from ours," as quoted by Larry in his article on 100 years of radio. It is therefore clear that more efforts are needed to understand propagation characteristics, especially in mmWave bands, and to demonstrate their impact on system design and deployment.

This main objective of this Feature Topic is to identify differences between propagation characteristics at microwave bands and at mmWave bands, summarize the current status of the 5G wireless channel modeling, and demonstrate the performance impact of channel models on system design and deployment. These considerations will enable simulation, evaluation, performance optimization, and network deployment of future 5G systems. We present eight articles that have been accepted after a rigorous peer review process.

The first contribution, "Microwave vs. Millimeter-Wave Propagation Channels: Key Differences and Impact on 5G Cellular Systems" by M. Shafi *et al.*, explains key differences in the propagation characteristics between the microwave

and mmWave bands, including the large-scale propagation, bandwidth dependency of propagation parameters, the multipath cluster number differences, and spatial consistency, and also gives examples of how these differences impact 5G system design. The second article, "Recent Research on Massive MIMO Propagation Channels: A Survey" by P. Zhang et al., summarizes the recent activities in massive MIMO channel research and identifies key propagation characteristics of the massive MIMO channel as well as their influence on massive MIMO systems. Several open issues for massive MIMO propagation modeling are also pointed out. The third article, "Millimeter-Wave Channel Measurement and Modeling: A NIST Perspective" by C. Gentile et al., provides an overview of mmWave channel sounding through three types of systems: switched array, virtual array, and phased array at 28, 60, and 83 GHz, respectively. The authors describe how mmWave channel models - for path loss, dispersion, multipath tracking, Doppler spread, and blockage - differ from sub-6 GHz models.

The fourth article, "Spatial and Temporal Channel Characteristics of 5G 3D Channel Model with Beamforming for User Mobility Investigations" by U. Karabulut et al., shows that a simplified and computationally efficient channel model is needed to evaluate when beamforming is applied to users connecting and switching between beams of the same or different cells. Most measurement campaigns measure the propagation channel between transmit and receive antennas that are (at least in the near field) free from surrounding obstacles. In reality, the UE is held by a person, which distorts the electromagnetic field and thus further changes the characteristics of the channel. The fifth article, "Spatio-Temporal Impact of Hand and Body Blockage for Millimeter-Wave User Equipment Design at 28 GHz" by V. Raghavan et al., gives a description of the underlying effects, measurement results, and implications for the system design of this important aspect. Considering that high-gain narrow-beam antennas or beamformed antenna arrays will likely be used in mmWave bands, beamwidth, orientation, and shape of the narrow beam will impact channel properties. The sixth article, "Millimeter-Wave Radio Channels vs. Synthetic Beamwidth" by R.Y. Sun et al., proposes a procedure to measure and model the channels vs. synthetic beamwidth and validate it by measure results.

Based on phased array transmitters and receivers operating at 60 GHz, the seventh article, "Empirical Effects of Dynamic Human-Body Blockage in Millimeter-Wave Communications" by C. Slezak *et al.*, presents a spatial dynamic channel sounding system, and the human-body statistical dynamic models are empirically studied by utilizing it. The last article, "A Channel Sounder for Massive MIMO and mmWave Channels" by J. Nielsen *et al.*, uses a setup with parallel receiver chains so that the device can measure in the sub-6 GHz range up to 128 antenna elements in 1.3 ms. Extending the frequency range through upconverters to the mmWave range, the > 6 GHz bands of interest in many 5G applications can also be measured.

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