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Key Enabling Technologies for 5G: Millimeter-Wave and Massive MIMO

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5G wireless networks are expected to operate with orders of magnitude higher performance than the current 4G deployments. The demand for 5000 times higher data rates leads to the necessity of finding new techniques to increase spectral efficiency and of exploring new frequency bands above 6 GHz.

It has been proved that from UHF up to C band, a significant increase in system spectral efficiency can be reached through various techniques, such as Coordinated Multi-Point (CoMP), Massive Multiple-Input-Multiple-Output (MIMO), and interference management and cancellation; still, the resulting performance will not cope with the full expectations of IMT-2020 and 5G-PPP requirements for 5G networks, mainly in terms of offering 10 Gbps peak data rates with connection densities of 100 k–1 M devices/km^2. To overcome this limitation, the future architecture of such 5G networks is being defined to be deployed on small cells and to use higher frequency bands, such as super high frequency (SHF, 3–30 GHz) or extremely high frequency (EHF, 30–300 GHz), also referred as to centimeter and millimeter wave bands, respectively.

The drawback of high propagation losses in mm-wave bands is expected to be compensated by using large blocks of continuous spectrum, which makes possible in early deployments to trade off spectral efficiency for bandwidth, where high data rates are achieved even with low-order modulation schemes requiring lower powers, lower complexity, and lower cost. The World Radiocommunications Conference in 2015 (WRC15) identified some candidate frequency bands for 5G mobile radio services, ranging between 24 and 86 GHz, with significant bandwidths up to 10 GHz in the 66–76 GHz band.

Developing models for mm-wave propagation is crucial for the development of 5G radio access technologies, as such models are used for the definition and test of physical and higher layer components, link and system level feasibility studies, and spectrum management and regulatory issues. Although there are many published works about cm- and mm-wave propagation and radio channel modelling, like the COST IC1004 models published in "Co-operative Radio Communications for Green and Smart Environments" (River Publishers), or the specific models for mm-wave channels compiled in "Channel Measurements and Modeling for 5G Networks in the Frequency Bands above 6 GHz"(IC1004 white paper), there are still open challenges for the development of technologies in such bands for 5G, being of outmost importance the appropriate measurements and models for 5G scenarios, including indoor, outdoor, and vehicular environments.

In this sense, ITU recommendations contain detailed information on gaseous and rain attenuation, mainly in ITU-R P.676-10 and ITU-R P.530-16, but the channel path loss coefficients and wideband parameters, like the RMS delay spread, are very briefly stated in the reports on propagation data and prediction methods for the planning of outdoor short-range radio-communication systems (ITU-R P.1411-8) and radio local area networks in the frequency range 0.3–100 GHz (ITU-R P.1238-8).

Most of the propagation and channel modelling studies published so far for mm-wave bands were made for static or quasi-static environments, and were aimed to determine the path-loss, the angle of arrival and the delay-spread of the radio channel. Among those parameters, the angle of

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arrival is of special interest, as getting the angular information allows to optimize beamforming, one of the key enabling technologies for 5G.

In addition to the above-mentioned advantage of having available large continuous blocks of spectrum, at cm- and mm-wave bands the wavelength, and consequently the antenna elements, are smaller, which facilitates the implementation of large antenna arrays. On this basis, Massive MIMO has been identified as one of the pillars of future 5G radio access networks. Massive MIMO uses configurations with hundreds of antenna elements, which enables the use of the spatial dimension via e.g., beamforming, reaching high antenna gains and spatial multiplexing capability, compensating for the severe propagation losses, and significantly improving system performance.

The implementation of Massive MIMO has been widely studied under two possible approaches: fully digital and hybrid analog–digital configurations. Fully digital massive MIMO requires a large-scale digital signal processing unit and one digital-to-analog converter per antenna element. High power consumption, and implementation and computational costs of fully digital configurations are balanced with the high flexibility that these configurations offer. The alternative of hybrid analog–digital systems, which combine analog beamforming and digital MIMO signal processing, reduces the number of digital-to-analog converter elements. Hybrid beamforming may be of full connection type or subarray type, in which the latter can reduce the complexity of RF circuits while reasonably maintaining performance compared to the former one.

For this special issue of the International Journal of Wireless Information Networks, three works presented in the IEEE PIMRC 2016 Symposium were selected, which have been extended and reviewed for this purpose. The three papers deal with the key aspects of 5G radio access networks in mm-wave bands: propagation modelling and massive MIMO implementation.

The paper “Channel Sounding System for mm-Wave Bands and Characterization of Indoor Propagation at 28 GHz”, by Wei Fan et al., describes a measurement campaign in an indoor environment preformed at 26–30 GHz, using both a directional horn antenna and a virtual uniform circular array at the same time. This allows for comparative studies of measured channels with two different antennas in a simultaneous way, conducted in both line-of-sight and non-line-of-sight scenarios. The measurements show good agreement between the measurement data collected with the horn antenna and the data collected with the uniform circular array, and the paper gives details on how propagation environment was found to be sparse both in delay and angular domains for the given scenario.

In the paper “Millimeter-Wave Beam Multiplexing Method Using Subarray Type Hybrid Beamforming of Interleaved Configuration with Inter-subarray Coding”, by Masahiko Shimizu et al., the challenges related to mm-wave beam multiplexing methods using hybrid beamforming configurations of interleaved subarray type is studied, and a solution based on sub-array coding is proposed. The method can reduce inter-beam interference and create multiple beams of a theoretical maximum gain that an array antenna can generate. As shown in detail in the paper, the channel capacity of the interleaved configuration with inter-subarray coding is larger than that of the localized configuration, with even better performance in high user density environments.

Finally, the work entitled ‘‘Performance Evaluation of NL-BMD Precoding over Analog–Digital Hybrid Beamforming for High SHF Wide-Band Massive MIMO in 5G’’, by Hiroshi Nishimoto et al., focuses on multi-user Massive MIMO systems and evaluates the performance of nonlinear block multi-diagonalization precoding, an intermediate solution between the conventional linear precoder and nonlinear precoder, for analog–digital hybrid beamforming. Their simulation results in an indoor scenario show that the nonlinear block multi-diagonalization precoding has a better performance than linear precoder and around half the complexity of nonlinear precoder.

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