Some Important Antenna Design Aspects for the 5th Generation mmWave User Device

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Abstract—**The major issues related to antenna system designs in user devices for the next-generation cellular network at millimeter-wave frequencies are addressed. The array topology, packaging, spatial coverage, human body effect and human body exposure are discussed.**

Keywords—5G, mmWave, user device, antenna array, user body effect, exposure.

I. Introduction

The next-generation mobile technology (5G) aims to provide an improved experience through higher data-rates, lower latency, and stronger link robustness. The mobile industry has deployed all spectrum available below 3 GHz for cellular systems from the First Generation (1G) to the Fourth Generation (4G), and will further deploy possible spectrum up to 6 GHz. In order to implement wider bandwidth for 5G cellular networks, the frequency bands above 6 GHz and into the millimeter-wave (mmWave) band has been chosen as carrier frequencies for 5G communications, where a large number of free spectra can be potentially used. In the last few years, a lot of work was carried out for modeling mmWave mobile channels and also designing antennas for base stations and user devices [1]-[3]. In this paper, we will discuss some 5G mmWave antenna design aspects, such as beamforming, mobile coverage, human body effects, and electromagnetic field (EMF) design issue etc.

II. Antenna Array Beamforming

The beamforming technologies include analog beamforming, digital beamforming, and hybrid beamforming [4]. The digital beam forming offers a better performance but with increased complexity and cost, particularly in the mmWave analog-to-digital converter (ADC) and the digital-to-analog converter (DAC), which will cost more power due to wide bandwidth. On the other hand, the analog beamforming is a simpler method but with less flexibility. The hybrid beamforming aims to reduce the number of radio-frequency (RF) chains but still offer certain flexibility in the system, which is a promising solution for 5G mobile communication systems. Beamforming technologies and array topology in user devices will play a vital role in the capacity of 5G mmWave channels, which has been discussed in [5]-[6].

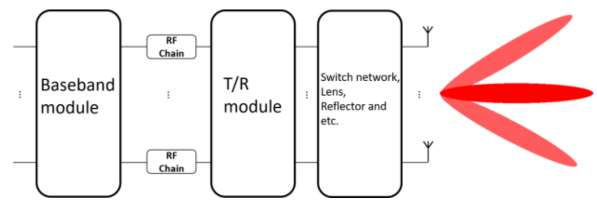

Fig. 1. Beamforming architectures with the switch function.

In addition to a phased array system, passive multi-port beam steering antenna systems are particularly interesting in the user device case as well (Fig. 1), as it has a simpler structure and lower insertion loss. Passive multi-port beam steering antenna systems can be realized using lens, reflectors, or passive feeding networks [7]. The bulky dimension of such a system is the major issue when they need to be integrated into a compact user device.

III. MmWave Antenna Design and Package

MmWave antenna design technologies have been under development for decades in other industries, for example in radar and military applications [3]. Still, there are many challenges in mobile devices, such as multiple bands, dual-polarization, wide coverage, improving efficiency, reducing mutual coupling and other losses, package and signal process.

IV. Antenna Array Coverage and User Body Effects

Due to the mobility, omnidirectional spatial coverage is required for antenna systems in user devices. The spatial coverage is particularly going to be a critical issue for 5G mmWave antenna systems since highly directional antenna systems will be used. In addition, the propagation channel is likely to be sparser due to the higher loss of transmission and diffraction. Therefore, it is necessary for the antenna systems in user devices to have a wide beam steering angle to ensure a stable performance of 5G cellular networks (Fig. 2(a)).

In [7], the concept of the total scan pattern and a parameter named the coverage efficiency are introduced to evaluate the spatial coverage of antenna array system in a user device. The total scan pattern is obtained by extracting the highest gain at every solid angular point with all possible patterns from beam steering. The coverage efficiency is a quantitative description of the spatial coverage for an array system; it is the ratio between the covered solid angle with respect to a threshold gain level in the total scan pattern and the whole sphere. The coverage efficiency and the total scan pattern offer an intuitive insight of the spatial coverage that an array system can offer, which is critical for evaluating and optimizing the array topology in the user device.

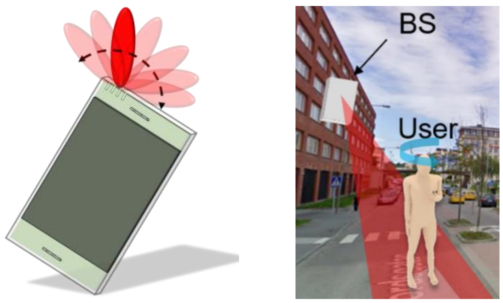

Fig. 2. (a) A phased array in a user device. (b) User body blockage in the mmWave channel.

Another challenge is the complex propagation environments including user body effects, such as orientation and blockage uncertainty [8]-[9]. The presence of a user body will introduce a shadowing region in mmWave bands (Fig. 2 (b)), which must be taken into consideration in 5G cellular system designs [10].

V. EMF Aspect in mmWave Frequency

EMF exposure limits have huge impacts on the wireless network and device antenna design. People are now quite familiar with the SAR limits for below-6-GHz devices, however, in the mmWave range, there are many challenges for the mobile industry: the absorption of electromagnetic waves in the human tissue becomes more superficial, and the basic restrictions for compliance test change from SAR to incident power density. Current regulations are not well defined for the application of mmWave user devices. In addition, the usage of array systems in user devices will lead to a more complicated evaluation process [12]-[15]. With the ongoing standardization of 5G cellular systems, there is a clear need to define the corresponding compliance boundaries and develop RF EMF exposure assessment methods.

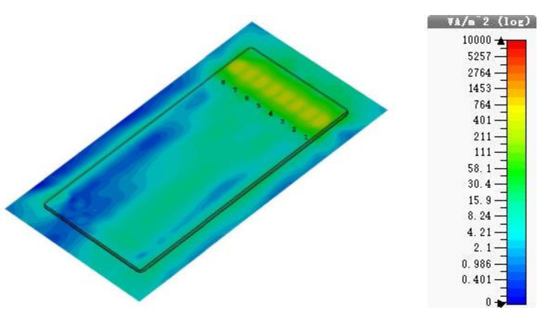

Fig. 3. The simulated power density of a patch array in a user device (adapted from [13]).

VI. Conclusion

The antenna system related issues in user devices for 5G cellular systems are reviewed in this paper. Antenna systems in user devices should be able to achieve omnidirectional coverage, and the corresponding array topology will be a critical factor for the channel capacity. The user body interaction with user device antenna systems includes the user body blockage and human exposure to EMFs, which must also be further investigated.

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