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Base Station Antenna Systems for mm-Waves

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Abstract – Lower efficiencies of power amplifiers and increased path loss at higher frequencies are two reasons why utilizing millimeter-wave frequencies for future wireless communications systems is challenging. In this paper, two distinct antenna systems are presented which address this challenge by using high antenna gain. This allows lower transmit power levels, compared to conventional phased array antennas, while still providing high effective isotropic radiated power.

Keywords — Antennas, focal plane arrays, switched-beam arrays, reflectors, lens horns, mm-wave, 5G, beyond-5G, base stations, wireless communications.

I. INTRODUCTION

The continuously growing need for higher data rates in wireless communications drives new applications into the upper microwave and millimeter-wave frequency domains, where large bandwidths are available that can serve the needs of these demanding applications [1]. To exploit the spectrum efficiently and to achieve the required data-rate objectives, advanced multi-antenna systems, such as systems employing MIMO (multiple-input, multiple-output), will be used. Advanced multi-beam antenna systems for wireless communication are conventionally implemented using dense, regular array antennas, viz. vertical linear arrays or planar arrays, which employ analog, digital, or hybrid beamforming [2] in the elevation domain or in both the azimuth and elevation domains, respectively.

While dense array solutions are conceptually applicable in general, they also present challenges at higher frequencies. Due to the increasing path loss with increasing frequency [3], and decreasing available transmit power of active electronics [4], antenna systems may require larger apertures in order to provide desired EIRP (effective isotropic radiated power) and SNR, resulting in challenges with respect to integration, signal routing, efficiency, thermal performance, and cost for array-based solutions. Various alternative antenna solutions, nonconventional in wireless communications systems, have been considered for base station applications, such as irregular sparse arrays [5] and dielectric lenses [6].

This paper presents novel implementations of two further antenna technologies, lens horn antennas and phased array-fed (PAF) reflector antennas, which can overcome some of the challenges facing dense array-based solutions. These antenna systems have been developed within the European Union Horizon 2020 project “SILIKA” [7], a project aiming to create a breakthrough towards millimeter-wave multi-antenna systems for energy-efficient and low-cost base

stations for 5G wireless infrastructure within the framework of a doctoral student training network with leading R&D labs from European industries, universities, and technology institutes. The presentation will include an overview of the achievements of the SILIKA project.

II. NONCONVENTIONAL BASE-STATION ANTENNA SYSTEMS FOR MM-WAVES

A common use case for the presented antenna systems is as replacements for a dense array antenna system, that employs digital beamforming, by more power-efficient, high-gain, non-conventional antenna architectures. To this end, they exploit low-loss beamforming techniques avoiding long routing solutions based on transmission lines make use of large antenna apertures for high gain.

Both implemented antenna systems operate in the 26.5-29.5 GHz band and the application systems focus is on high gain solutions for full cell coverage, one of the main challenges for mm-wave systems. The presented solutions are both designed for a 60-degree sector hexagonal cell plan and configured for a base station height of 10 m and a cell radius of 150 m, see Fig. 1.

Fig. 1 Considered scenario with 150-meter cell range.

A. Multi-Lens-Horn Antenna System

A fixed-beam antenna system is presented, consisting of 16 dual-polarized lens-horn antennas, oriented such that they together provide the desired sector coverage, see Fig. 2. The horns are equipped with lenses to allow shorter horn lengths ($D = 18.5$ cm for the largest horn) while still providing a uniform aperture phase distribution and corresponding high gain and low side-lobes. The antenna system consists of three unique horn configurations, with 15 dBi, 25 dBi, and 30 dBi gain, respectively. The higher gain horns are configured for outer cell edge coverage, while the lower gain horns serve the cell region closer to the base station antenna, effectively canceling out the distance-dependent path loss difference over the cell. Sample radiation patterns for the 25 dBi horn are presented in Fig. 3, showing excellent agreement between simulations and measurements [8].

Fig. 2. Lens-horn antenna array system.

Fig. 3. 25-dBi horn elevation radiation pattern at 28 GHz.

B. Phased-Array-Fed Torus Reflector Antenna System

A PAF reflector antenna system is presented, with a torus reflector surface based on a swept parabola with an active array feed in the focal region, see Fig. 4. Such systems offer both the flexibility of an array antenna and the robustness, low loss, and high gain of a reflector antenna, making them interesting candidates for cellular systems at mm-waves. With the feed array configured to allow beams being generated over the entire cell, only a small fraction of the array elements is needed for generating a given beam. This means that the antenna system can support multiple simultaneous beams with maintained EIRP if the beams are sufficiently isolated, since the amplifiers (one per element) are then not shared between beams. Sample torus reflector radiation patterns (gain 37 dBi), for a beam pointing along the cell center direction, are presented in Fig.5 showing good agreement between simulation and measurement.

Fig. 4. Phased-array-fed torus reflector antenna system.

Fig. 5. Torus reflector azimuth radiation pattern.

III. CONCLUSION

Two base station-oriented antenna systems, with high-gain energy-efficient beamforming solutions suitable for mm-waves, have been presented. Measured performance agrees well with simulations and the antennas will now be tested in outdoor coverage measurements. The dimensions of these antennas are larger than those of standard array antennas, hence their high gain, and this may be a drawback from a deployment point-of-view. However, for the frequency bands near and above 100 GHz now being investigated for use in wireless communications, this point may become moot.

The presentation will include performance evaluations with respect to coverage for the presented antenna systems and comparisons with dense array-based systems.

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