5G: The next generation of Wireless Communications Technology

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***Abstract*—Satisfying the increasing demand for higher data rates, lower latency, energy efficiency, and an expected 50 billion new devices by 2020, 5G will need a number of breakthroughs in wireless communications, software defined networking, and big data cloud computing to be realized [1]. The bottleneck in spectrum bandwidth will push the new technology to the milimeter wave spectrum bringing with it a number of challenges [2], [3]. With extremely large path-loss expected in this spectrum, the necessity for Massive Multiple Input Multiple Output (MIMO) is evident to overcome the power limitations of modern compact solid-state THz transceivers [2], [4]–[6]. In this paper, we discuss the current scope of challenges in the THz spectrum and the primary technologies that are expected to make 5G possible, focusing primarily on existing path-loss models for the band and on UM-MIMO and its promise to make communications efficient and feasible.**

I. Introduction

Today, at the dawn of the Internet of Things, 50 billion new internet connected devices are expected by 2020 [1], [7]. Current technologies will quickly consume all available spectral bandwidth pushing 5G to consider utilizing the THz spectrum and its promise for an exponential increase in bandwidth to satisfy the demand. Utilizing this spectrum for Line of Sight (LOS) in particular due to its high loss all technologies will need to work together in places theyre most suited for. With the help of Wireless Software Defined Networking (WSDN) and Network Function Virtualization (NFV), 5G networks will dynamically adapt to their environment.

While LTE technology is already here and WSDN is just an extension of SDN, efficient antennas for the THz band have yet to be invented to support Tbps data rates. In this paper we look at these antennas and the Ultra-Massive Multiple Input Multiple Output (UM-MIMO) technology needed to make it efficient and feasible in dense spectral environments [1]. We also look at the expected performance of this system in this spectral environment for different communication cases.

II. Ultra-Massive MIMO

Despite heavy investigation in the 30-300 GHz range and opportunities with such systems, a bandwidth of less than 10 GHz would require spectral efficiency to be almost 100bits / s / Hz to support Tbps speeds; this seems improbable, and has pushed research into the THz Band (0.06 10 THz) [2]. The enormous bandwidth this band provides is at the cost of very high propagation loss, and with a constraint on output power of THz transceivers, antenna arrays must be utilized to increase communication distances by means of beamforming [2].

While typical modern MIMO systems use up to 8 antennas, the concept of Massive MIMO was introduced, utilizing 2D arrays of antennas to increase spectral efficiency by enabling signal radiation in specific elevations and direction [2]. A number of research efforts have been made to make beamforming more capable in [2], [5] and to use those new capabilities efficiently for greater overall performance [4], [7].

III. Antennas for mmWaves

The MmWave, from 30 GHz 300GHz would bring more bandwidth and allow large scale antennas to be packed into smaller form factors, higher MIMO gains will be essential to make up for the higher path loss with the smaller wavelength [5]. With more antennas, the amount of interference between neighboring users increase. A pre-coding algorithm is necessary for interference alignment, ultimately determined in the uplink and supplied to the downlink for use in beamforming; the pre-coding algorithm seeks to maximize the signal-to-leakage plus-noise ratio (SLNR) and performs marginally better than existing algorithms [4].

An hybrid system designed to take advantage of both digital and analog approaches to minimizing interference was proposed. Using both a baseband provided pre-coding algorithm and analog-determined frequency that optimizes SLNR, the new system demonstrates similar results with a less sophisticated approach [5].

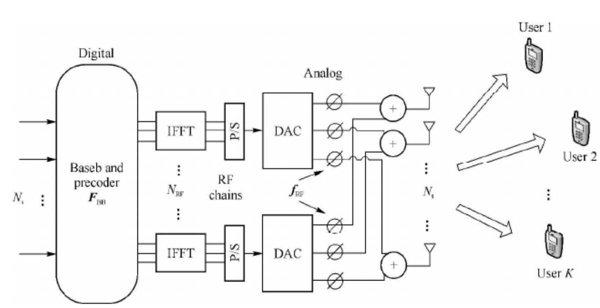

Fig. 1. mmW block diagram [5]

IV. Antenna for THz Band

Though MIMO requires a large amount of antennas, the THz bands small wavelength makes it possible to embed thousands of antennas in a few square centimeters. Unique properties of novel plasmonic materials such as graphene and metamaterials can be utilized to build miniature nano-antennas and nano-transceivers; in the 1-10 THz band, graphene-based plasmonic nano-antenna arrays with thousands of elements can be embedded in $1mm^2$ at 1 THz [2].

These small sizes can be achieved by leveraging a unique property of plasmonic materials known as Surface Plasmon Polariton (SPP) waves. The waves appear at the interface between metal and a dialectric as a result of oscillations of electrical charges. SPP waves propagate much slower than EM waves in free space allowing plasmonic antennas to resonate at much smaller sizes. Graphene-based plasmonic nano-antennas need only be a few micrometers long to operate on the THz band enabling much smaller antennas that achieve a finer ability to beamform.

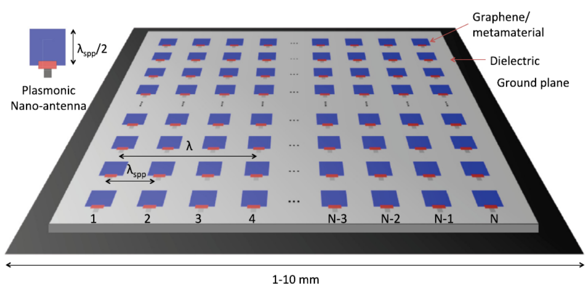

Fig. 2. Proposed Plasmonic Nano-Antenna Array [2]

While these nano-antennas will achieve much higher gains, the ability to create independent separate links between different users and efficiently supporting a wide range of frequencies might only be possible with the advent of a new technology, Software Defined Material (SDM). Leveraging ideas from Meta-materials and Nano-networking, SDMs promise to allow materials that could modify the confinement factor of SPP waves enabling resonance at different frequencies with the same fundamental antennas [2]. While still highly theoretical, both Meta-materials and Nano-networking have shown promising progress in that respect.

V. Massive MIMO Efficiency Schemes

Massive MIMO requires a high ratio of number of base station antennas to number of users to bring reliability, this eventually results in high power consumption. Technologies for 5G are expected to be more efficient than ever on top of bringing new speeds, in this effort thought has been put into bringing reliability without the cost of power consumption [7]. With capacity for so many devices, it is expected that much of the infrastructure will not be used at all times. Whether it be location or spectral distribution, it is possible to turn antennas on and off to meet the reliability demands of the current system load [7]. It has been shown under certain simplifying assumptions that such an adaptive system could save up to 50% of consumed energy [7].

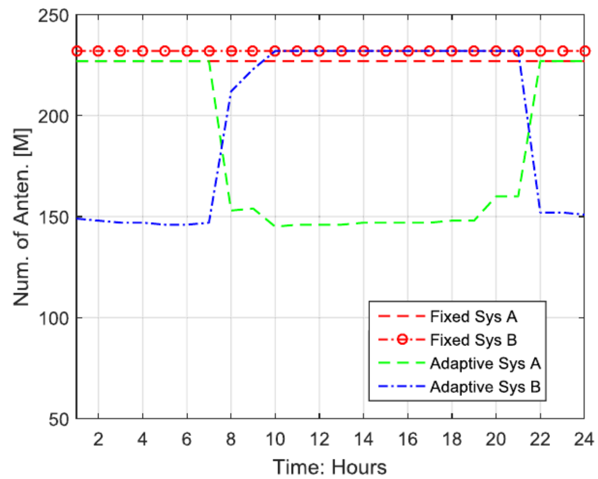

Fig. 3. Proposed adaptive system state for decreasing power [7]

VI. Conclusion

At the dawn of the Internet of Things and the accommodation of 50 billion new internet connected devices by 2020, technologies to bring that capacity along with new Tbps throughput have yet to be invented. With many software technologies already well into development, physical antennas to take advantage of the THz band are lagging behind because of the evidently high loss of such channels.

With plenty of research on milimeter waves and their channels, the necessity of Massive MIMO systems and their related algorithms for minimizing interfere is evident. Beyond mmW, it will be necessary to move to the THz band if we truly hope to bring Tbps to 50 billion devices. Perhaps the only way it will even be possible is with the advent of software defined materials, the culmination of two very new fields, meta-materials and nano-networks. With a focus on efficiency both with the spectrum and with power consumption, 5G still has many open problems but it is well understood where things need to be improved.

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