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(Draft version)

Prospects and Technologies for Mobile Terahertz 6G Communications

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(invited talk)

Abstract: Prospects and challenges for mobile 6G communications using terahertz frequencies are discussed. For the first time, THz wireless communications with 15 Gbps to multiple mobile users employing a photonic-assisted beam steering antennas is experimentally demonstrated.

1. Introduction

The successor of the current 5G new radio infrastructure is named 6G. Approximately every ten years, a new mobile generation is developed, as illustrated in Fig. 1. Starting in the late 70s, when first commercial networks were installed, over first mobile phones developed by Motorola in 1983, mobile communications has evolved a lot ever since. While 5G is widely considered as foundation of mobile machine to machine (M2M) communications, 6G may become the mobile generation for hyper connectivity besides providing improved key performance indicator such as higher cell capacities.

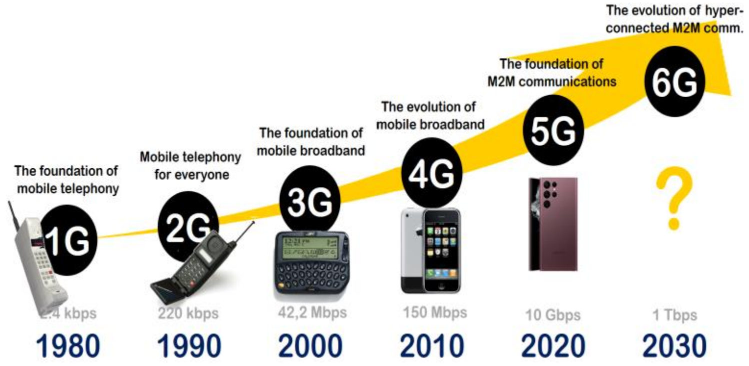

Fig. 1. The evolution of mobile generations. Almost every 10 years a new mobile generation is introduced.

THz THz communications is seen as a potential candidate for one of the 6G PHY layers. For example, the 6G flagship project emphasizes that THz communications is an enabler to achieve wireless data rates beyond 100 Gbps up to 1 Tbps [1]. Indeed, since the beginning of the current decade, THz communications is no longer a pure research topic but has reached regulatory and standardization bodies. In 2019, the world radio communication conference (WRC 19) has identified 137 GHz spectrum in the frequency range between 275-450 GHz for THz communication services. Together with a previously identified bandwidth of 23 GHz between 252-450 GHz, there is now a total spectrum of 160 GHz identified. Besides these regulatory aspects, also first standards were created recently. In 2017, both, IEEE and ITU-R created standards (IEEE 802.15.3d and ITU-R F.2416-0, respectively) for fixed wireless access (FWA) with PHY data rates of 100 Gbps for wireless distances from a few centimeter up to several 100 m including fallback options [2,3]. A major drawback of using THz frequencies is the high free-space path loss (FSPL). In line-of-sight (LOS) FWA applications, the FSPL is mitigated by using high-gain antennas. Already available commercial (sub-) THz FWA front-ends operating, e.g., in the E-band (71-76 GHz and 81-86 GHz) are capable to provide 10 Gbps over more than 3 km by using high gain antennas with 40 dBi directivity and more. In recent research works, THz FWA links were demonstrated for much higher data rates of 100 Gbps and more (see e.g. [4-6]). Challenges coming with mobility include user equipment (UE) localization during link set-up, beam tracking in case of at least one mobile UE and beam handover in dense UE scenarios to name a few. A key advantage of using THz frequencies is the antenna size which can be even smaller than a Euro coin [7]. Due to the small size and large available bandwidth, it is expected to enable new applications including short range intrasystem communications or high throughput hot spots. However, the advantage of having small antennas comes with some technological challenges. Among them is the comparably low THz output power available from photonic (PIC) or electronic radio frequency integrated circuits (RFIC). This basically limits the wireless distance. In addition, scalable photonic or electronic THz beam steering technologies are required to support mobility.

2. Terahertz Beam Steering Technologies

Despite Despite THz technologies are not yet as mature as microwave/mm-wave technologies, there is an increasing number of recent technological achievements enabling THz beam steering using PICs or RFICs. Besides classical approaches utilizing RF phased arrays, true time delays (TTD) or reflectarrays also novel photonic technologies for THz phase shifters or TTDs have been successfully demonstrated. Table I summarizes some of the recent achievements using materials such as CMOS, SiGe BiCMOS, liquid crystals, Graphene but also InP and hybrid SiN/InP for PICs. A review describing most of these antenna technologies can be found in [8]. The beam steering antennas reported in [7, 10] were already exploited for proof-of-concept mobile THz 6G communications as will be discussed in the next section. Photonic and photonic assisted beam steering antennas have been used in first proofof-concept experiments. 2D THz steering with maximu [5].

Table I . Recently developed Terahertz beam steering antenna arrays.

Frequency [GHz]	Array size	Technology	Steering angle	Gain [dBi]	Bandwidth [GHz]	Antenna type	Ref.
115	39x39 cells	Liquid crystal	20°	16	7	Reflectarray	[9]
140	8x16 array	**45 nm CMOS**[2]	80°	21	2	Patch antenna	[10]
230-245	600 elements	Metallic	48°	28.5	0.8	LWA[4]	[11]
230-330	32 elements	**Photonic (InP)**[2]	88°	11	12	LWA[4]	[7]
230-330	108 elements	Photonic (InP)	92°/69° [1]	15	8.7	LWA[4]	[12]
300	1x4 array	Photonic (SiO_2/Si_3N_4/InP)	62°	10	N/A	BTA[5]	[13]
320	1x4 array	130 nm SiGe BiCMOS	24°	12	20	Patch antenna	[14]
338	4x4 array	65 nm CMOS	45°/50° [1]	18[3]	N/A	Microstrip	[15]
586	6x6 array	40 nm CMOS	30°	24	N/A	Microstrip	[16]
1100	2x2 array	Graphene	60°	7	N/A	Patch antenna	[17]

[1]2D steering in elevation and azimuth, [2]**antenna successfully employed for mobile THz 6G communications**, [3]directivity, [4]leaky-wave antenna (LWA), [5]bow-tie antenna (BTA).

3. Mobile Terahertz 6G Communications

Although prototype THz beam steering antennas exist, there are only very few experimental studies demonstrating mobile THz 6G communications yet. A first experiment showing THz connectivity to a mobile UE was reported by the authors in [7]. This work exploited a 50 µm thin InP on Si leaky-wave antenna (LWA) with 32 radiating stubs which was fed by a THz photodiode in the transmitter (Tx). For a single UE, short-range (6 cm) wireless data transmission of 24 Gbps in the 300 GHz band with was successfully demonstrated. The maximum steering angle and gain of the fabricated THz LWA are 33° and ~14 dBi, respectively. Almost at the same time, another impressive proof-of-concept demonstration for end-to-end mobile THz 6G communications was reported in [10]. In this work, a 45nm CMOS RFICs antenna array with 128 radiating elements was used to up-convert and down-convert a baseband signal to 140 GHz. Here, beam steering was performed in the digital domain. The realized antenna gain is ~22 dBi within a maximum steering angle of 80°. The channel bandwidths of 2 GHz enabled data transmission at 140 GHz to a single UE at 15 meter distance with a maximum throughput of 6 Gbps.

In this work, we report the first multi-user (two UE) mobile THz 6G communications within the 300 GHz band using multiple steerable directive THz beams generated from a InP-on-Si LWA. To reach longer wireless distances compared to our previous work [7], a THz medium power amplifier (IAF M260AMPH) is employed. First, single UE THz transmission is experimentally studied. Fig. 2(a) shows the measured bit error rate (BER) for a single UE THz transmission at 20 GBd and 25 GBd using PAM2. As can be seen, 25 Gbps was transmitted to UEs at BER below the soft decision forward error correction (SD-FEC) limit for wireless distances up to 90 cm. For the first time, to the authors knowledge, THz transmission to multiple independent UEs is experimentally demonstrated in this work. The photo in Fig. 2(b) shows the set-up with a single fiber-coupled transmitter and two THz receiver UEs located at beam angles of 20° and 6° w.r.t. the transmitter chip. A cylindrical lens is integrated with the transmit antenna to increase directivity. In the experiment, the LWA was used to simultaneously generate two THz beams carrying individual data. The 1st beam at 300 GHz points at a steering angle of 20° and transmitted 5 Gbps over a wireless distance of 50 cm to UE_1, while the second beam at 280 GHz points at 6° and transmitted 10 Gbps over 70 cm wireless distance to UE_2. The measured BER for both UEs is below SD-FEC level.

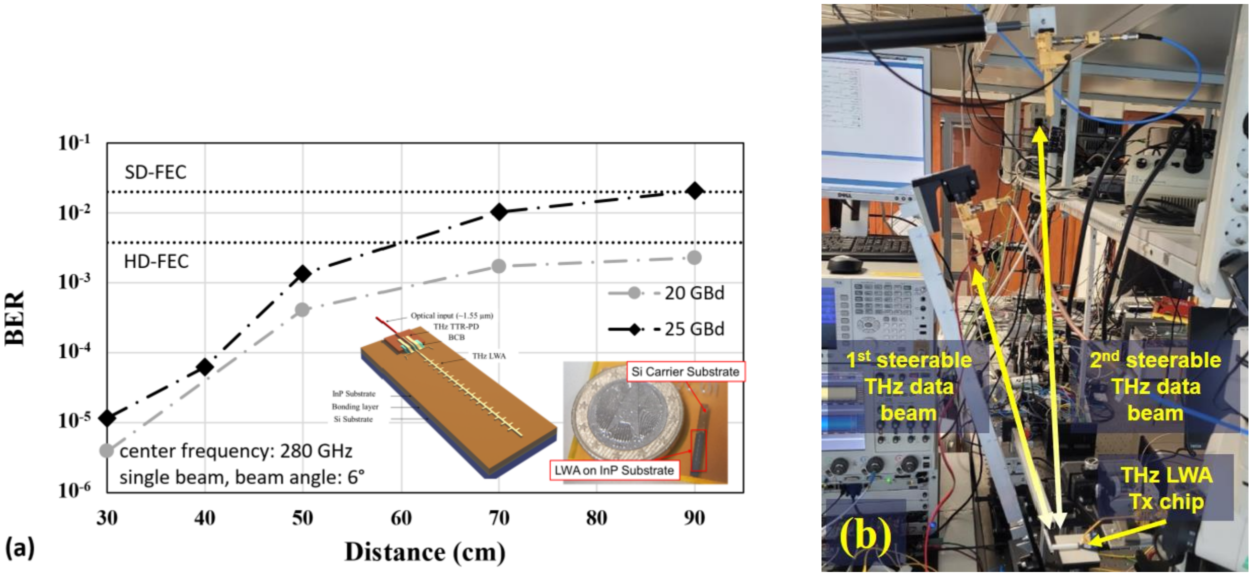

Fig. 2. Measured BER vs. distance for single THz beam. Insets show schematic and photo of fabricated photonic assisted LWA (a). Multi-beam operation with two THz Rx at 6° and 20° with distances of 70 cm and 50 cm (b).

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