Sub-THz Spectrum as Enabler for 6G Wireless Communications up to 1 Tbit/s

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***Abstract*— The radio spectrum above 90GHz offers opportunities for huge signal bandwidths, and thus unprecedented increase in the wireless network capacity, beyond the performance defined for the 5G technology. Today this spectrum is essentially exploited for scientific services, but attracts nowadays much interest within the wireless telecommunications research community, following the same trend as in previous network generations. The aim of this work is to discuss the elaboration of new waveforms able to efficiently operate in the 90–200 GHz spectrum. The researches rely on three complementary works: the definition of relevant communications scenarios (spectrum usage, application, environment, etc); the development of realistic models for the physical layer (propagation channel and RF equipments); and the elaboration of efficient single-carrier modulations.**

Keywords—Sub-THz, 6G communications

I. Introduction

Alongside the well-known 5G initiatives, the scientific community has recently launched many investigations on the beyond 5G (B5G) as well as 6G services and communications systems, thereby is considering more stringent application requirements, higher number of devices, and even denser networks. 6G might go further in the expected network virtualisation and softwarization w.r.t 5G. It aims at ultra-high capacity, and throughputs in the order of several hundreds of Gbit/s up to few Tbit/s. The effort for achieving these requirements must be done at the same pace on the user access and transport segments to avoid any bottleneck effect.

In this work, we introduce and evaluate new radio technologies that would operate in the 90-200 GHz spectrum and support 6G performance. This paper will contribute to the migration of 5G networks towards radio access systems that support several hundreds of Gbit/s. Ultimate goal is the definition of a solution that would reach 1 Tbit/s. Taking into account the adversary nature of a communications channels in frequencies above 90 GHz, the paper focusses on scenarios in which the connected nodes (end user, relay, access point, gateway) are in line-of-sight (LoS) or nearly LoS (i.e. only light obstruction).

We propose to revisit the PHY-layer by looking back on single-carrier (SC) modulations, thus allowing for improved spectral efficiency and reduced power consumption (i.e. from lower PAPR). Indeed LoS transmission and the use of large antenna arrays make the propagation channel favourable to SC. Besides, the propagation and RF impairments at frequencies above 90 GHz are investigated and modelled. This will serve three objectives: 1) implement realistic link- and system-level simulators; 2) design the new air interface based on well-understood physical constraints; 3) evaluate and demonstrate 6G scenarios.

Based on the motivation and first results, this paper gives in Section II an overview on the above-90GHz opportunities and target applications. Section III, briefly introduces the current research activities for a realistic modelling of the Physical layer (propagation channel and RF impairments), and for definition of single-carrier waveforms and modulation schemes that are expected to offer improved spectral and energy efficiency, while being compliant with sub-THz physical constraints.

II. Promising Opportunities

The sub-THz radio spectrum above 90 GHz is today essentially known for being used by scientific services e.g. astronomy observation, earth exploration and satellite services, meteorology, etc. It has never been effectively used for radio wireless communications purposes [1]. Yet, the radio regulations have already allocated several frequency bands above 90 GHz to the fixed and mobile services. More specifically, the following frequency bands might be considered for future terrestrial communication systems: 92-94 GHz, 94.1-100 GHz, 102-109.5 GHz, 111.8-114.25 GHz, 122.25-123 GHz, 130-134 GHz, 141-148.5 GHz, 151.5-164 GHz, 167-174.5 GHz, 174.5-174.8 GHz and 191.8-200 GHz. There is today some ongoing work within the CEPT organization (European Conference of Postal and Telecommunications Administrations) to facilitate the deployment of fixed services links in the frequency ranges 92 - 115 GHz and 130 - 175 GHz.

Wireless data rates are increasing over time, and will require a Tbps in the future. This is mainly driven by the need for having to move files of ever-increasing size, as well as for downloading streaming\podcast services. Following use cases have been identified [2] [3]:

- Data kiosk application: very short-range for very-high downlink data rate link, with possibly connection of several simultaneous users (Fig. 1).
- Inter/Intra-chip communication,
- Resolution of congestion issues in server farms,
- Small range hot-spots delivering high-speed data to demanding applications such as augmented or virtual reality,
- High-capacity wireless mesh backhauling for dense mobile access networks, hotspot, connected cities and fixed broadband access at user premises.

The envisioned ultra-dense network topology in urban areas with the extreme data rate, capacity and latency requirements makes the fiber-based backhauling highly desirable, but sometimes complicated due to current fiber networks penetration (variable from one country to the other) and related extension cost. The wireless infrastructure must an alternative option to avoid any bottleneck in the dense mobile network backhaul (or xhaul), at lower cost and possibly with lower deployment constraints.

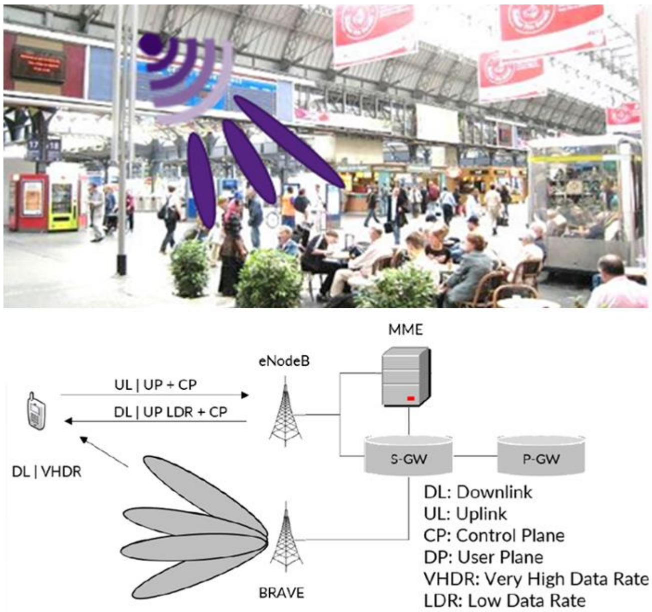

Fig. 1. Kiosk application in an offloading scenario coupled with cellular network.

High data rate wireless backhauling is a valuable competitive technology, which benefits from lower deployment costs and constraints.

Some of the mentioned use cases are defined by the IEEE 802.15 standard in the band between 250-325 GHz, IEEE 802.11ad in the 60 GHz, and by others at 60-300 GHz where the targeted rate is up to 100 Gbps. However, the foreseen required rate in the near future will extend towards Tbps. As for example, the 100 Gbps rate is enough for virtual\augmented reality and kiosk for a single user, but not sufficient for multiple simultaneous users and large file downloads.

In general, the scenarios of interest constraints to static or nomadic use cases (low mobility) with short-range communication due to beam tracking issues and high propagation losses at high frequencies.

III. Research on Physical layer modelling, waveform and modulation schemes

Most propagation and model characteristics established for 5G mmW bands are expected to remain valid above 90 GHz, however the current models are not yet fulfilling all requirements, and (as always) adjustments are mandatory. The modelling of sub-THz radio propagation is gaining interest today. Indoor measurements highlight that the predominance of LoS still increases compared to sub-100GHz. However the most powerful multi-paths remain quite similar (in terms of delay and angle) at 28 and 140 GHz. Current investigations mainly relies on ray-based multi-channel simulations [3], in both indoor and outdoor scenarios, along with highly detailed representation of the environment, from LiDAR in particular.

High-frequency systems are also critically impacted by the RF impairments, such as non-linearity, IQ imbalance and phase noise. The nonlinearity of analogue components used in RF front ends gives increased challenges in the modelling of circuits and in anticipating the compensation measures. The Power Amplifier (PA) efficiency and achievable output power decreases are important challenges to meet. The tone of the local oscillator (LO) is modulated and phase noise is introduced, this last causes significant degradation in the performance and reduces the effective signal-to-noise ratio (SNR) at the receiver. Besides, the digitalization of a large amount of bandwidth with power and integration constraints is still an open research topic to solve.

The definition of a B5G sub-THz system requires the identification of waveforms, channelization and modulation/demodulation schemes that offer optimal performance under those physical layer impairments. We are currently investigating the following topics [3]: phase noise estimation and compensation ; robust modulation scheme for phase noise channel; near-constant envelope modulation ; or implementation of Peak-To-Average Power ratio (PAPR) reduction schemes at baseband level.

The poor performance of high frequency oscillators as well the need of power efficiency motivates the studies of new baseband processing, including the revisit of single carrier modulation. Moreover, the current methodology for high data rate wireless communication that keep increasing the M-ary modulation schemes and the order of MIMO spatial multiplexing cannot be a solution for a power efficient Tbps system with the current hardware and technology limitations.

The key points for our methodology are based on using power efficient modulation like constant or near-constant envelope modulation (CPM and (D)QPSK) then increase the system spectral efficiency by means of Index Modulation (IM) as Generalized Spatial Modulation (GSM) or any other efficient IM. SC-IM approaches are a balanced trade-off between system performance/power efficiency and hardware cost/detector computational complexity [4]. Non-coherent transmission schemes have also a particular interest in the sub-THz context. Designing waveforms, modulations and coding scheme remains an open and complex problem to fulfil the sub-THz requirements.

IV. Acknowledgement

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