THz Communications: A Catalyst for the Wireless Future


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As the wireless world moves toward 6G, radio Tbit/s communications and the supporting access and backhaul network infrastructures are expected to become a predominant technology trend. However, certain severe limitations affect the capability of future wireless communications systems to meet the joint requirements of high data rate, near-zero latency, and high spectral and energy efficiency. In this context, utilizing THz frequency bands for wireless transmissions, as an extension to optical fiber, is a promising enabler to bridge this gap and provide ubiquitous high-speed Internet access beyond 5G. Moreover, an increasing number of mobile and fixed users in the private and industry sectors will require hundreds of Gbit/s for connectivity to or between cell towers (backhaul) or between cell towers and remote radio heads (fronthaul). In such scenarios, critical parameters, apart from the data rates in the order of Tbit/s, are the communications range and the achievable spectral and energy efficiency at reasonable capital and operational expenditures.

Utilizing the THz frequency bands for access and backhaul connectivity brings unique and novel challenges that make it necessary to rethink several conventional communications and networking mechanisms. The root cause of these challenges is the ultra-wideband and highly directional nature of THz radio links and other THz communications peculiarities, in terms of signal and antenna design, channel and interference modeling, and hardware constraints. The fundamentally different structure of radio interference due to narrow beams calls for a thorough characterization and detailed modeling of interference. Building on past propagation and channel modeling studies, contributions of the line-of-sight and non-line-of-sight reflected and scattered components should be considered, as should be the inherent molecular noise, misalignment impairments, and blockage probability. Medium access control and radio resource management protocols need to operate with pencil beams and must therefore be based on radically new principles. Fast handover procedures need to incorporate the time required for discovery, localization, and tracking functionalities. The Tbit/s data rates create significant challenges in transceiver processing, which include algorithm and architecture design as well as hardware implementation.

Motivated by the potential of THz technologies to shape the future of wireless communications, this feature topic seeks to identify the critical technology gaps and the feasible enablers in terms of baseband processing. These include radio frequency frontend and antenna design; propagation and channel modeling; waveforms, signals, and coding; beamforming and (ultra-massive) MIMO; as well as resource management and medium access control schemes. Most importantly, this feature topic aims to shed light on the potential accelerators or showstoppers in the adoption of THz communications as viewed by the various stakeholders, both incumbents and newcomers. In doing so, it provides insights on prototyping, implementation challenges, and standardization and regulatory matters in the THz regime.

The first article, "A Holistic Investigation of Terahertz Propagation and Channel Modeling toward Vertical Heterogeneous Networks," by Kürşat Tekbıyık, Ali Rıza Ekti, Güneş Karabulut Kurt, Ali Görçin, and Halim Yanikomeroglu, presents a recently proposed vertical heterogeneous network architecture for backhaul/fronthaul in the case of a large number of small cells of different communications technologies, including geostationary Earth orbit and low Earth orbit satellites and networked flying platforms, along with terrestrial communications links. THz communications are proposed to enable this heterogeneous system concept. As THz links offer large bandwidth, leading to ultra-high data rates, this solution is suitable for backhauling and fronthauling of small cells that support numerous applications from inter-satellite links to in-vivo nanonetworks. Accurate channel modeling is considered key for the feasibility of such system concepts. To this end, measurement campaign findings are reported to reveal the true potential of THz communications in vertical heterogeneous network architectures.

The article entitled "THz Radio Communication: Link Budget Analysis toward 6G," by Kari Rikkinen, Pekka Kyösti, Marko E. Leinonen, Markus Berg, and Aarno Pärssinen, assesses and quantifies the potential of THz radio by considering antenna and radio frequency hardware technologies and radio propagation challenges, by means of link budget evaluations. The achievable or required noise figure, transmit power, and antenna gain are the main parameters of interest. From the RF viewpoint, the observed bottlenecks occur in the generation of sufficiently high transmit power and low noise with the support of very high antenna gains. For example, the authors analyze the case of 300 GHz frequency to support 100 Gbit/s data rate at 30 GHz bandwidth on 10 m link distance for different kinds of devices.

The article entitled "IEEE 802.15.3d: First Standardization Efforts for Sub-Terahertz Band Communications toward 6G" by Vitaly Petrov, Thomas Kürner, and Iwao Hosako, presents the standardization activities within IEEE 802.15.3d, an amendment to 802.15.3 established to facilitate standardization of consumer wireless communications in the sub-THz frequency band. IEEE 802.15.3d addresses switched point-to-point connectivity with data rates of 100 Gbit/s and higher at distances ranging from tens of centimeters up to a few hundred meters. Target applications and usage scenarios and key design principles for the physical and the medium access layers are presented, along with initial performance results. These results indicate substantial improvements over fifth-generation wireless systems, thus paving the way toward sixth generation THz networks.

"Beyond 100 Gbit/s Optoelectronic Terahertz Communications: Key Technologies and Directions," by Lu Zhang, Xiaodan Pang, Shi Jia, Shiwei Wang, and Xianbin Yu, addresses enabling technologies for optoelectronic THz communications. The authors propose a multicarrier signal processing routine with high noise tolerance, which is verified by experiments in a 500 Gbit/s net rate THz communications system. This work shows the technology potential of optoelectronic THz communications, discusses research directions in the fields of optoelectronic THz devices and advanced optoelectronic THz systems, and suggests that the optical domain is of great importance for realizing high-speed THz communications.

In the article "Experimental Demonstrations of High-Capacity THz-Wireless Transmission Systems for Beyond 5G," Carlos Castro, Robert Elschner, Thomas Merkle, Colja Schubert, and Ronald Freund present the concept of a "THz-wireless fiber extender," which combines the flexibility of wireless networks with the high capacity of fiber optic communication. The availability of a large, contiguous bandwidth in the frequency band around 300 GHz offers a unique opportunity to seamlessly interconnect coherent THz-wireless and fiber optic transceiver frontends using a transparent, analog baseband interface. This concept has been materialized in a real-time demonstrator, implementing a short-range THz-wireless fiber extender with 100 Gbit/s net capacity. This combined fiber optic/THz-wireless transmission system was operated by a high-speed fiber optic real-time modem capable of compensating the channel impairments of both the optical and THz-wireless links. Moreover, the article analyzes the potential of THz-wireless links to achieve long-range transmission by reporting, first, on the operation of a 500-m-long line-of-sight THz-wireless outdoor link in Berlin, Germany and the effect of weather conditions, and second, on a 1-km-long THz transmission field trial performance merits, compared against theoretical limits and performance figures achieved in the laboratory.

Finally, in "Toward End-to-End, Full-Stack 6G Terahertz Networks," Michele Polese, Josep Jornet, Tommaso Melodia, and Michele Zorzi emphasize that in order to integrate THz communications in complex mobile networks, it is necessary to design the full communications stack and address link-level and system-level challenges. These challenges are related to network setup, management, coordination, energy efficiency, and end-to-end connectivity. To this end, the work provides an overview of design issues at the medium access control, network, and transport layers, with considerations on the end-to-end data flows over THz connections. This holistic perspective is useful because it helps identify important questions for future research, including questions related to beam management, medium access schemes, deployment strategies, and spectrum policies.

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