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THz Communications for Wireless Links in a Digital World

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The possibility of using frequencies between 100 GHz and 1 THz for wireless communications—the so-called THz communications—has been discussed for almost two decades. The first concepts were published in 2007. Especially the spectrum above 275 GHz allows the use of bandwidth in the order of several tens of GHz, which enable data rates of 100 Gbits and beyond with transmission schemes of moderate complexity and spectral efficiencies. In the context of the development of the sixth generation (6G) of wireless communications, THz communications are discussed as an enabler to realize wireless links with 1 Tbps.

Challenges of THz communications

To realize a radio system at ultra-high frequencies comes with challenges, which need to be met. These include path loss and generating output power levels at the transmitter.

Research has shown that path loss increases with frequency. The free space loss (in linear scale) is a factor of 1000 to 6000 higher compared to the “traditional” carrier frequencies below 6 GHz. In addition, atmospheric attenuation and the impact of weather reduces the link distance significantly. This has to be compensated by highly directive antennas, which makes it challenging for transceivers to find each other and to track the signal, especially when at least one of the transceivers is moving. On the other hand, the small wavelength enables the realization of antenna arrays with small form factors, which are in turn a prerequisite to master the device discovery and tracking problems.

At the frequency range of interest, generating enough output power levels at the transmitter is challenging. Two principal methods to generate THz signals exist. Electronic approaches transform the methods used at millimeter wave systems to higher frequencies. In this case, output power levels decrease with increasing frequencies. The other approach uses photonic waves, where the output power levels decrease with decreasing frequencies. Both trends meet between 0.1 and 1 THz and the effect is called “the THz gap.” In recent years, semiconductor technology has made significant progress both in III-V and silicon-based realization of integrated RF circuits, yielding numerous demonstrations of THz communications with moderate output power levels in the order of 10 to 20 dBm.

Applications of THz communications

The above-mentioned chances and limitations make it obvious that THz communications will be able to provide powerful solutions to a specific set of applications rather than enabling a full-fledged cellular communication system. In this sense, THz communications can be used as a data pipeline enabling ultra-high data rates. Early applications of THz communication probably will be fixed point-to-point applications, where the locations of the antenna positions at both ends of the link are completely known. Examples for such applications include:

- Wireless backhaul links connecting access points with the backbone network. These wireless links can complement fiber links when they are not available or too expensive to deploy.
- Wireless links in data centers complementing fiber links, increasing the flexibility of reconfiguring connectivity in data centers.
- Wireless links within devices like computers, cameras, and video projectors. Here, ultra-high data rates can be provided, avoiding a connector and increase the flexibility in terms of reconfiguration.
- Close-proximity communications between wireless devices to allow quick data exchange of a large amount of data without the need for cabling.

Further development of THz antenna arrays solving the device discovery and tracking problem will also enable the creation of solutions for mobility. This includes both solutions to provide ultra-high data rates for users in public transportation, such as trains or airplanes, and solutions for vehicle-to-vehicle-communication. The latter will benefit from the imaging, sensing, and localization capabilities of THz communications in Integrated Sensing and Communication (ISAC) applications. For example, a radar system operating beyond 300 GHz can exploit a bandwidth of several GHz providing

high resolution, which can be used to improve the communication system. The capability of THz to sense the environment by THz imaging or THz spectroscopy is another interesting aspect. Mobiles can sense the environment THz frequencies and the THz data link can be used to transmit the potentially ultra-high data volume within a short period. Other potential mobile applications with high data rate requirements are, for example, virtual and augmented reality.

Demonstrating the feasibility of THz communications

In recent decades, numerous research groups have demonstrated that THz communications are feasible. For example, in 2013 a group at KIT in Germany demonstrated the first 100 Gbps link over a distance of 20m in a lab environment using combination of electronic and photonic approaches, setting a world record. A recent demonstration has achieved link distances of more than 320m in an outdoor environment in the frequency range 155 to 175 GHz. In June 2022, the EU-Japan Horizon 2020 project ThoR demonstrated the first bi-directional backhaul transmission of real data at 300 GHz with a net data rate of 2x20 Gbps over a distance of 160m using 8.64 GHz of spectrum.

European research projects

In Europe, THz communications have made significant progress in several large collaborative research projects—for example in the Beyond 5G cluster carried out within the Horizon 2020 framework. On January 1, 2023, three projects (Tera6G, TIMES and TERRAMETA) exclusively dedicated to THz communications were launched within the Smart Networks and Services Joint Undertaking 6G Initiative, These initiatives are complemented by national initiatives, for example the 6G Flagship project in Finland or the 6G Hub projects in Germany, which also comprise significant portions of THz research activities.

Standardization and regulation

The first initiatives toward standardization were already underway in 2008 when the IEEE 802.15 THz Interest Group (now Standing Committee THz) was established. This group was the nucleus, which triggered the development of IEEE Std 802.15.3d-2017, the first worldwide standard for wireless communications in the frequency range 252-321 GHz. The applications addressed by this standard are the above-mentioned point-to-point applications. Currently a revision of this standard is ongoing, which targets extending the frequency range up to 450 GHz, among other objectives.

Intensive regulatory activities have been performed in the framework of the World Radiocommunications Conference (WRC) 2019. The activities contained sharing studies with passive services like Earth Exploration Satellite Service (EESS) and Radio Astronomy Service. As a result of WRC 2019, the radio regulations contain 160 GHz of spectrum, which can be used on the frequency range between 252 and 450 GHz. This includes an allocation of 23 GHz below 275 GHz to FIXED and MOBILE Service and the identification of 137 GHz above 275 GHz, where no harmful interference to passive services has been revealed.

ETSI ISG THZ

The above-mentioned research initiatives and the regulatory boundary conditions form a sound basis to consider THz in 6G standardization activities also in 3GPP. It is expected that these activities will start in 2025. As a preparation for these standardization activities, ETSI recently launched its Industry Specification Group on Terahertz (ISG THz) to coordinate pre-standards research efforts on THz technology across various European collaborative projects, extended with relevant global initiatives.

This is a move toward paving the way for future standardization of the technology, for this candidate technology for 6G. The ETSI group will initially focus on two categories of use cases. The first one will include mobile applications with high data rate requirements, such as virtual and augmented reality, applications for in-flight and in-train entertainment, and vehicular and satellite communications. The second category includes applications requiring both communication and sensing functionalities, such as holographic telepresence, and interactive and cooperative robotics. Apart from identifying use cases and frequency bands of interest, ETSI ISG THz will focus on modelling aspects such as channel modelling and the modelling of the RF system.