Factsheet 04 | Sub-THz systems coping with an elephant in the room: strengthen first, standardize next

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1. Highlights: the sub-THz highway is a slippery road

- Sub-THz systems have been advocated for high-speed wireless access, precise localization, and advanced sensing applications, owing to the high bandwidth available at these frequencies. However, there has been and is a proverbial 'elephant in the room': **sub-THz links are fragile.** Propagation and hardware at these frequencies do not behave as one would expect extrapolating from systems operating at 'conventional' < 10GHz frequencies. **The complications** have remained underexposed. They **make the sub-THz highway a slippery road**.
- **New paradigms** for the deployment of sub-THz systems are **needed to offer reliable services**.
- The recommendation is hence to first develop and validate novel concepts for the deployment and operation of sub-THz systems to **strengthen them** [1], and then to standardize them. Otherwise, we risk commercial failures.
- A more philosophical observation of technological R&D learns that it is tempting to fall into the trap of only considering positive outcomes as a success. Rigorous research [2] requires a critical approach that formulates hypotheses and challenges these rather than searching for confirmation.
- Europe should **proceed cautiously with sub-THz standardization**. Despite solid progress in R&D and better understanding of propagation and hardware constraints, the technology is still far from being reliable, scalable, affordable, or sustainable at system level.

2. Context: Sub-THz systems and the elephant in the room

In the quest for increased-capacity wireless networks, the high bandwidth available at mmWave and sub-THz bands presents an attractive direction. However, providing reliable coverage and consistent connectivity to non-static terminals at these frequencies is extremely difficult when compared to operation in sub-10 GHz bands. These frequencies must cope with an elephant in the room: they can get fully blocked by relatively small objects, and even slow movements can have a detrimental effect.

Consider a coffee mug with a diameter of 7 cm versus an African elephant that gets 4m long. These have similar sizes when expressed in number of wavelengths for the 140 GHz and 2.4 GHz bands, respectively. The liquid in the cup behaves at sub-THz frequencies as an almost perfect reflector. Suppose someone holding a cup of coffee at 1 m on the line to the access point from a terminal, equipped with a narrow beam antenna array typically proposed for these frequencies, as illustrated in Figure 1. The cup effectively becomes like an elephant in the room, breaking the link completely. Humans are probable to create huge blockers at sub-THz frequencies. Another vulnerability of sub-THz links concerns the impact of varying circumstances. Mobility that is trivial at lower bands becomes a fundamental reliability challenge in the sub-THz regime. Consider a person walking to the coffee machine at 5 km/h. When communicating using sub-THz frequencies, this person will experience a similar Doppler as sub-10 GHz communication does in high-speed trains moving at 300 km/h.

Beyond the propagation challenges, integrated hardware at sub-THz frequencies remains a major bottleneck. High-frequency components introduce signal distortions, they suffer from reduced efficiency and have a limited output power. Tight co-integration of antennas with RF circuitry further is needed yet limits achievable link budgets and system scalability.

At the same time, record-setting demonstrations of transmission beyond 100 Gbit/s are documented in the literature [7, 8]. These results convincingly show that very high throughputs are achievable in sub-THz bands, particularly for static, highly aligned links under controlled laboratory conditions. However, translating these point demonstrations into deployable, mobile, and scalable systems remains an open challenge precisely due to the combined propagation and hardware limitations outlined above.

Figure 1: Sub-THz links are fragile, for example a coffee cup can block the connection

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3. Policy recommendations: strengthen first, standardize next

Contributions to standards based on EU-funded R&D initiatives are considered a very important outcome. And rightfully so: global wireless standards have been a huge success over the last decades. This has resulted in impressive operability – taken for granted nowadays. Standard essential patents (SEPs) protecting innovation and owned by European companies provide strategic benefits.

Systems capable of exploiting GHz bandwidth at mmWave have been standardized and on the market for Wi-Fi for more than a decade. These systems have remained underutilized so far. 5G systems operating in FR2 (24-52 GHz) spectrum have been launched with great expectations – and taken out of the air again in certain regions of the world . The reasons for the disappointing commercial results are to be found in fundamental reasons relating to wave propagation and hardware implementation. These are experienced by the users in poor link stability, unreliable services , and energy-hungry and costly hardware of terminals with high-frequency capabilities

Hence, caution is recommended in the standardization of sub-THz system. A hasty approach bears significant risks and should be avoided, despite the large R&D investments that have already been made in the technology. Adequate access-infrastructure topologies, operation procedures, and integrated hardware solutions are needed to mitigate the obstacles to the sub-THz highway.

Conventional deployments do not suffice to provide reliable services and consistent coverage. The 6GTandem project proposes a distributed deployment and dual-frequency operation [1] to cope with the propagation challenges at sub-THz. Previous studies have also proposed solutions to cope with blockage [4]. Other R&D projects investigate protocols and hardware solutions [5] to unleash the application-level potential of sub-THz frequencies and push the boundaries of sub-THz integrated circuits [6].

In conclusion, impressive progress has been made in R&D, and efforts are continuing – especially in academia - ranging from transmission concepts to hardware design. At the same time, it is clear that major equipment vendors and leading operators have become more prudent in promoting very high frequencies for 6G when compared to the advent of 5G – and the little positive experience with the exploitation of FR2 spectrum so far. It is important to understand, recognize, and cope with the complications of >10GHz systems prior to targeted standardization.

In the broader sense, it should also be encouraged to share negative outcomes of R&D activities. Understanding why promising ideas are not (yet) confirmed may be as valuable as a success story.

4. Evidence and analysis: throughput demonstrated in friendly conditions, yet the complex reality requires diversity in space and frequency

Demonstrations of transmission at sub-THz frequencies achieving beyond 100 Gbit/s have been reported in controlled laboratory environments [7, 8]. These results confirm the potential of sub-THz bands for extreme throughput, yet the validation remains confined to highly favourable, blocker-free, static links. The reality of wireless access is far more complex: objects and people move unpredictably, scenes are dynamic, sub-THz signals are blocked by small obstacles. The combination of blockage, Doppler, and rapid channel variability, make standalone sub-THz access fundamentally brittle.

This gap between laboratory demonstrations and operational reality motivates a dual-frequency tandem architecture proposed in 6GTandem [1], as illustrated in Figure 2:

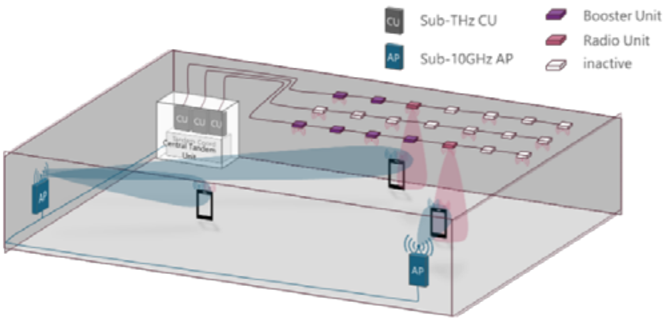

Figure 2: Distributed deployment and dual-frequency operation can strengthen sub-THz systems

By tightly integrating a robust sub-10 GHz layer with the fragile but high-capacity sub-THz layer, the system gains both spatial and frequency diversity. The lower band provides resilient coverage, stable control-plane connectivity, and a dependable fallback path, while the sub-THz layer opportunistically delivers extreme throughput whenever conditions allow. A low-complexity distributed deployment of Radio Units connected with radio-over-fibre segments aims to lower the cost of deployment. While R&D results confirm the feasibility of the concepts, implementation challenges remain: distortions and losses accumulate along the path of the signals.

In conclusion, experts on wireless transmission systems, propagation, antennas, and integrated hardware implementation should team up to jointly tackle the obstacles encountered towards the sub-THz highway. The 6GTandem project and other initiatives have embarked on such a journey, achieving progress yet also recognizing that technology is not quite at the level that justifies standardization of the systems to start in the short term.

Sources

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5 Countries

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