
Exploring Terahertz (THz) Communication in 6G Wireless Networks

Hussein A. Jasim¹, Hikmat Z. Neima¹, Dhuha Habeeb², Nazik K. Aljbur¹

¹*Computer Sciences Department, College of CSIT, University of Basrah, Basrah, Iraq*

²*Department of Laser and Optoelectronics Technical Engineering, Shatt Al-Arab
University College, Basrah, Iraq*

*hussein.jasim@uobasrah.edu.iq, hikmat.taher@uobasrah.edu.iq, dhuha.hahu@gmail.com,
nazik.obaid@uobastah.edu.iq*

Abstract. The sixth generation (6G) of wireless networks targets terabit-per-second data rates, sub-millisecond latency and pervasive sensing, requirements that the sub-6 GHz and millimeter-wave (mmWave) bands used by 4G/5G cannot sustain because of their limited contiguous bandwidth. The Terahertz (THz) band (0.1–10 THz) offers tens of gigahertz of largely unused spectrum and is therefore regarded as a key physical-layer enabler of 6G. This paper explores THz communication for 6G: it reviews the dominant channel impairments – spreading loss and molecular absorption – and develops a link-budget and Shannon-capacity analysis quantifying how carrier frequency, bandwidth and distance determine achievable data rate. Results show a 10 GHz-wide THz channel can sustain over 100 Gbps at 1 m and still exceeds 40 Gbps at 10 m, but usable range shrinks quickly as frequency and distance increase. Key 6G use cases and open challenges of THz communication are also discussed.

Keywords. Terahertz communication, 6G wireless networks, THz channel modeling, path loss, Shannon capacity, ultra-massive MIMO.

1. INTRODUCTION

Mobile data traffic keeps growing faster than fifth-generation (5G) networks, built mainly on sub-6 GHz and millimeter-wave (mmWave, 24–100 GHz) spectrum, can sustain. Sixth-generation (6G) targets push peak data rates toward the terabit-per-second range, latency below one millisecond, and native integration of sensing with communication, requirements that call for far more contiguous bandwidth than sub-6 GHz or mmWave can offer. The Terahertz (THz) band, loosely defined as 0.1–10 THz, sits between mmWave and infrared and remains largely unlicensed, providing tens of gigahertz of usable spectrum in a single channel [1]. Early THz research targeted nanoscale and short-range links [2], but the band is now a leading candidate for 6G access, backhaul and joint communication-sensing

systems [3]–[6], [8], with the first sub-THz standard, IEEE 802.15.3d, already ratified for the 252–325 GHz range [7].

This paper explores THz communication for 6G along two lines: it reviews the propagation characteristics that distinguish the THz channel from lower-frequency bands, and it develops a link-budget and capacity analysis, presented as numerical results, quantifying how carrier frequency, bandwidth and distance jointly determine achievable data rate. Section 2 discusses THz channel characteristics; Section 3 presents the numerical results; Section 4 discusses 6G use cases and open challenges; Section 5 concludes the paper.

2. THZ BAND CHARACTERISTICS FOR 6G

The THz band (0.1–10 THz) provides orders of magnitude more bandwidth than sub-6 GHz or mmWave spectrum, at the cost of a harsher channel. Two impairments dominate: spreading loss, which grows with the square of frequency, and molecular absorption from water-vapor and oxygen resonances, which carves the band into narrow, low-loss “transparency windows” (e.g., near 140, 220, 300, 350 and 410 GHz) separated by high-absorption peaks [1], [2]. The free-space spreading loss between an isotropic transmitter and receiver separated by distance d at frequency f is

$$PL(f, d) = 20 \log_{10}(4\pi f d / c) \quad (1)$$

where c is the speed of light and PL is expressed in dB. Figure 1 plots (1) for 1, 5 and 10 m links across 0.1–1 THz: spreading loss alone already reaches nearly 96 dB at 300 GHz for a 5 m link, and molecular absorption adds further loss outside the transparency windows [1]. Because present THz devices deliver only modest transmit power, this loss must be compensated with high-gain, steerable ultra-massive MIMO antenna arrays rather than by raising transmit power [1], [9].

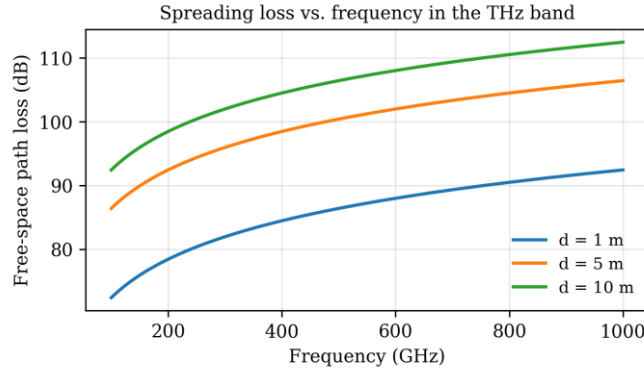


Figure 1. Free-space spreading loss vs. frequency for 1, 5 and 10 m links

3. NUMERICAL RESULTS AND DISCUSSION

Table 1 summarizes how the THz band compares with sub-6 GHz and mmWave spectrum in terms of typical bandwidth, range and representative 6G use cases.

Table 1. Comparison of sub-6 GHz, mmWave and THz spectrum for 6G

Band	Frequency range	Typical channel BW	Typical range	Representative 6G use case
Sub-6 GHz	< 6 GHz	Up to ~100s MHz	Several km	Wide-area mobile broadband, massive IoT
mmWave	24-100 GHz	Up to ~2 GHz	Tens-100s of m (LOS)	Dense urban 5G/6G access, fixed wireless
THz	0.1-10 THz	Tens of GHz	< 10-100 m (LOS)	Ultra-high-rate backhaul, kiosk download, joint sensing-communication

To quantify the resulting data rate, we combine (1) with a link budget and the Shannon capacity bound. For transmit power P_t , antenna gains G_t and G_r , bandwidth B and receiver noise figure NF , the received SNR is $SNR(f,d) = P_t + G_t + G_r - PL(f,d) - (-174 + 10\log_{10} B + NF)$, all in dB, and the achievable capacity follows the Shannon bound:

$$C = B \log_2(1 + SNR) \quad (2)$$

We evaluate (2) for two representative transparency-window carriers, 140 GHz and 300 GHz, with $P_t = 0$ dBm, $G_t = G_r = 25$ dBi, $B = 10$ GHz and $NF = 10$ dB, parameters consistent with present THz front-end capability [1], [9]. Figure 2 plots the resulting capacity against distance: at 1 m both carriers exceed 100 Gbps (129 Gbps at 140 GHz, 107 Gbps at 300 GHz); at 10 m capacity falls to 62 Gbps and 41 Gbps. Capacity always decreases with distance because spreading loss grows with d , and at a fixed distance the lower carrier outperforms the higher one for the same reason, even though both lie in low-absorption windows.

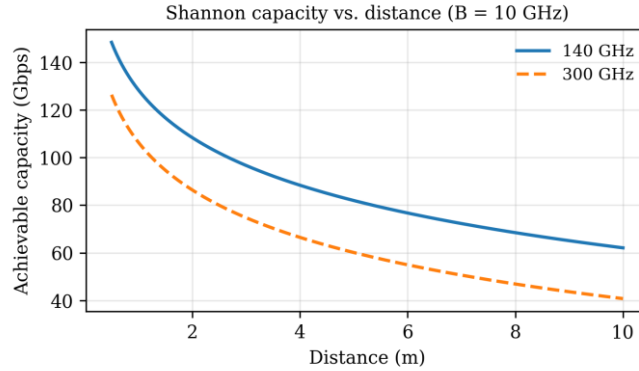


Figure 2. Shannon capacity vs. distance at 140 GHz and 300 GHz ($B = 10$ GHz)

In practice, additional impairments not captured here – molecular absorption outside the chosen windows, multipath, and beam-misalignment – would further reduce the usable range, reinforcing the need for the ultra-massive MIMO beamforming and beam-tracking discussed in Section 2.

4. 6G USE CASES AND OPEN CHALLENGES

The short-range, high-rate links in Section 3 suit several 6G scenarios: ultra-high-speed wireless backhaul/fronthaul between small cells, “kiosk downloading” of large files in seconds, intra-data-center and chip-to-chip wireless links, and joint communication-radar-imaging systems that reuse the same THz front-end for sensing [1], [9].

Realizing these use cases still faces open challenges. THz power amplifiers, low-noise receivers and antenna arrays remain immature compared with mmWave counterparts [3], [6]. The short range and near-optical propagation of THz signals make links sensitive to blockage and require fast beam-tracking for mobility [1], [4]. Standardization is still early: IEEE 802.15.3d covers only fixed point-to-point links in the 252–325 GHz window [7], and channel-measurement campaigns across the wider 0.1–10 THz range remain limited [3].

5. CONCLUSION

THz communication offers the huge, largely unused bandwidth that 6G needs for terabit-level data rates, and the link-budget analysis here confirms that a single 10 GHz THz channel can already sustain 40–130 Gbps over 1–10 m links. This capacity is only realizable, however, if the band's severe spreading and molecular-absorption losses are compensated through ultra-massive MIMO beamforming, and if THz hardware, mobility management and standardization mature accordingly. THz communication is thus best viewed not as a replacement for sub-6 GHz and mmWave layers, but as a short-range, ultra-high-rate complement within 6G.

6. REFERENCES

- [1] I. F. Akyildiz, J. M. Jornet, C. Han, “Terahertz band: Next frontier for wireless communications,” *Physical Communication*, vol. 12, pp. 16–32, 2014.
- [2] J. M. Jornet, I. F. Akyildiz, “Channel modeling and capacity analysis for electromagnetic wireless nanonetworks in the terahertz band,” *IEEE Trans. Wireless Commun.*, vol. 10, no. 10, pp. 3211–3221, Oct. 2011.
- [3] T. S. Rappaport, Y. Xing, O. Kanhere, S. Ju, A. Madanayake, S. Mandal, A. Alkhateeb, G. C. Trichopoulos, “Wireless communications and applications above 100 GHz: Opportunities and challenges for 6G and beyond,” *IEEE Access*, vol. 7, pp. 78729–78757, 2019.
- [4] K. M. S. Huq, S. A. Busari, J. Rodriguez, V. Frasca, W. Bazzi, D. C. Sicker, “Terahertz-enabled wireless system for beyond-5G ultra-fast networks: A brief survey,” *IEEE Network*, vol. 33, no. 4, pp. 89–95, 2019.
- [5] H. Elayan, O. Amin, B. Shihada, R. M. Shubair, M.-S. Alouini, “Terahertz band: The last piece of RF spectrum puzzle for communication systems,” *IEEE Open Journal of the Communications Society*, vol. 1, pp. 1–32, 2020.
- [6] K. Tekbıyık, A. R. Ekti, G. K. Kurt, A. Görçin, “Terahertz band communication systems: Challenges, novelties and standardization efforts,” *Physical Communication*, vol. 35, Art. 100700, 2019.
- [7] V. Petrov, T. Kürner, I. Hosako, “IEEE 802.15.3d: First standardization efforts for sub-terahertz band communications toward 6G,” *IEEE Communications Magazine*, vol. 58, no. 11, pp. 28–33, 2020.
- [8] Z. Chen et al., “A survey on terahertz communications,” *China Communications*, vol. 16, no. 2, pp. 1–35, Feb. 2019.
- [9] H. Saeed et al., “Next generation terahertz communications: A rendezvous of sensing, imaging, and localization,” *IEEE Communications Magazine*, vol. 58, no. 5, pp. 69–75, 2020.