Journal of Multidisciplinary Innovations and Perspectives (JMIP)
Maiden Edition
www.fedpodjournal.com
Volume 1; Issue 1; November 2024; Page No. 9-20.

THE DESIGN OF TRANSCEIVERS AND THEIR ASSOCIATED AIR INTERFACE IN SUB-THZ AND THZ FREQUENCY BAND IN 6G NETWORK

***Okafor, A. C.[1]; Ogbuikwu, R. I.[2] Akpan, N. J.[3]; Otache, O. [4]; Onogwu, A. J.[5]; Ogbe, M. O.[6]; Ezea, O. F.[7]**
[1,2,3,4,5,6,7] Department of Electrical and Electronics Engineering, Federal polytechnic ohodo, Enugu state, Nigeria
[1]okaforanthonyc82@gmail.com, [2]rowlandikechukwu@gmail.com

Abstract

The development of transceivers and their respective air interfaces within the sub-THz and THz frequency range is a major milestone in the development of the wireless communication technology. The aim of this paper is to design transceivers and their air interfaces in THz frequencies for the 6G network. The idea of exploiting sub-THz frequencies for next-generation wireless communication has generated much research interest and industrial attention. The sub-THz spectrum from 90 GHz to 300 GHz can provide vast bandwidth for transceiver systems, capable of supporting high-speed wireless communication. Thus, wireless communication technologies developing along the vector of sub-THz frequency might serve as a prominent building block for future network infrastructures. This paper highlights transceiver design and air interface development in the sub-THz and THz frequency bands, from transmitter and receiver units optimized for these frequencies. In the design of the physical layer, a major difficulty that arises is coping with phase distortion and limitations imparted by band-limited analog-to-digital converters. The prime objective of this work is, therefore, to introduce novel communication technologies operating within the sub-THz spectrum and meeting the stringent requirements of next-generation wireless applications.

Keywords: Transmitter, Receiver, sub-THz, THz frequency band, 6G Network.

Introduction

In modern wireless communication, particularly with the deployment of 5G and the transition to 6G, significant emphasis is placed on optimizing transceivers and air interfaces in the sub-THz and THz frequency ranges. This evolution is supported by advancements at the physical layer, which underpins digital communication systems. Initial design processes focus on ensuring reliable data transmission across interconnected systems, adhering to established communication protocols that guarantee interoperability and reliable data exchange between devices and networks. (Saad *et al*., 2020).

The Open Systems Interconnection (OSI) model is a foundational framework for structuring communication systems, dividing them into distinct, hierarchically organized layers, each with specific roles for managing information flow. Each layer operates independently and communicates only with its adjacent layers, enhancing the system's modularity and robustness. This design allows for the isolation of errors or failures within a single layer, preventing issues from affecting the entire network. (Bicais, 2020). This structure also facilitates the rapid construction and modification of protocols under the OSI model in order to more easily suit new technologies and evolving demands on the network.

Cite this article as:
Okafor, A. C.. et. al., (2025). The Design of Transceivers and their associated Air Interface in Sub-THZ and THZ Frequency Band in 6G Network *Journal of Multidisciplinary Innovations and Perspectives (JMIP)l, 1*(1) 10-20.

Physical Layer in Digital Communication Systems

The physical layer of the OSI model interfaces a digital system with the physical transmission medium by converting digital information into physical signals. This modulation process allows binary data to be transmitted through various mediums, such as radio waves, light waves in optical fiber, or high-frequency carriers. Ultimately, it ensures that data can flow smoothly through the chosen communication medium (Peng *et al*., 2020). In addition to modulation, the physical layer also performs demodulation, which decodes incoming physical signals to accurately reconstruct the original digital information. This process is complicated at high frequencies like sub-THz and THz due to issues like signal attenuation and phase noise. To ensure reliable data transmission, advanced signal processing and error correction methods are essential. The effective design of the physical layer is crucial for meeting the extreme performance demands of future wireless networks, including ultra-high-speed data rates and low latency. This research focuses on developing new physical layer architectures to maximize the benefits of sub-THz and THz frequencies for 6G and beyond applications.

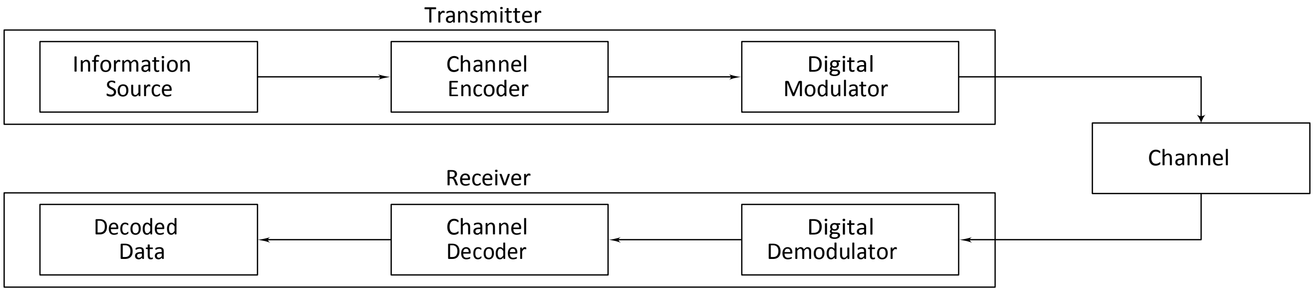


Figure 1: Transmission System Model

The physical layer of a communication system can be represented in a transmission model comprising three key components: the transmitter, the channel, and the receiver, each playing a distinct role in the data transmission process.

Modulation:

On the transmitter side, the digital modulator takes care of converting information bits into physical signals that are suitable for transmission. This is done through a modulation scheme by which groups of bits are modified into a unique signal point, also called symbol. These symbols are derived from some pre-defined set called constellation, which refers to M possible symbols. Each symbol therefore encodes $\log_2(M)$ bits - M referring to the modulation order, representative of constellation size. Modulation order directly affects information rate, and this can be expressed as $R = \log_2(M)/T□$ in bits per second (bit/s), where T□ is the symbol duration. An important parameter concerning the performance of the physical layer has to do with spectral efficiency: $\eta = R/B$, where R is the data rate and B the system bandwidth in Hertz (Hz). That expresses the efficiency in bits per second per Hertz (bit/s/Hz) with which the system utilizes the available bandwidth. One achieves high information rates and high spectral efficiencies at increased modulation orders but at the expense of greater degradation against noise and disturbances.

After the pulse modulation, the digital symbol is photo-shaped to form the discrete time curves of the entire transmitted wave. This baseband analog signal is then converted to high frequencies by RF front-end transmission to ensure that it is transmitted within a high-frequency range that corresponds to the passband of the communication channel.

Channel:

A channel refers to the medium in which signals propagate from the transmitter to the receiver. This propagation generally degrades signals severely through several different types of noise, distortion and non-ideality effects. It could be modeled in different ways using disparate channel representations to cover the various sources of degradation mainly to the signal (Zhang *et al*., 2021). The following are some of the important channel models:

i. **Additive White Gaussian Noise (AWGN) Channel:** This is the simplest model in which the link is described as being interfered with thermal noise which cannot be avoided in real systems. Such kind of noise is statistically represented as a Gaussian random process with a constant power spectrum density defined across every frequency of the bandwidth of the system.
ii. **Flat Fading Channel:** Every frequency component of the transmitted signal experiences the same attenuation as the result of path loss during free-space propagation. The fading coefficient must be estimated by this communication system for fading mitigation.

Further, it includes the export into the channel models, the RF front-end induced distortion at both the transmitting and receiving ends. These results are due to transferring signal from baseband to passband, amplification in different frequency bands, and other linear and nonlinear transformations which are affecting the signal integrity.

Demodulation:

After being processed to reach the receiver, the analog signal is sampled and digitized through Analog to Digital Converters (ADCs), and this is followed by demodulation, which processes these noisy digital samples to recover back the originally transmitted bits. The demodulation process widely depends on sophisticated algorithms for estimating the symbols transmitted through these channels even in the presence of noise and channel impairments. Also, there are equalization techniques for further improvement. These techniques reverse the distortions caused by the channel, making the entire bit recovery process much more reliable (Bicais *et al*., 2020).

Channel Coding:

Channel coding, also known as Forward Error Correction (FEC), is implemented to enhance the resilience of the communication system against transmission errors. As the signal traverses the channel, it inevitably suffers from noise, interference, and other distortions that can cause bit errors. To combat this, the channel encoder introduces redundancy into the transmitted data, enabling the receiver's channel decoder to identify and correct a subset of errors. This redundancy increases the likelihood of accurately recovering the original information, even when the received signal is corrupted. The balance between added redundancy and overall data rate is a crucial design consideration to ensure optimal performance in high-frequency, high-speed communication environments.

Literature Review

The Sub-THz Spectrum: Increasing Demand for Faster, More Reliable Wireless Connections

Global data traffic has soared exponentially over the last few decades. One of the major reasons behind this fast increase has been the need for stronger, faster, and eventually user-friendlier wireless capabilities that can permit seamless access to data (Tervo *et al*., 2020). Wireless technologies have enabled people to connect anytime and from anywhere without wires. Obviously, this eliminates the requirement of wiring up networks which further simplifies and costs down the installation. Well-developed standards in wireless protocols, on the other hand, have opened the doors for the penetration of such technologies worldwide by promoting interoperability and scalability. A new generation of communication technologies, such as cellular network or Wireless LAN (WLAN) access technology, has been constructed for achieving higher data throughput in the new generation. High-speed connectivity has been defined as broadband access, which is one of the pillars on which modern wireless systems stand. Although the last-born generation, i.e., the 5th generation (5G), brought into being extraordinary concepts, such as mMTC (massive Machine-Type Communications) and URLLC (Ultra-Reliable Low-Latency Communications) (Sarieddeen *et al*., 2020), broadband connectivity has continued to flourish in the extremely competitive world of wireless networks because of its versatility and extensive practicality.

Wireless Internet is in pretty good progress, and with the acceleration in the extensive adoption of the Internet globally, it continues to flourish in leaps. 6G and subsequent generations of networks are expected to reach farther boundaries- data rates incomparable to previous generations, greater capacities, and denser access point placements. However, the idea still holds: making data transmission quicker for more users, at more locations, and tougher conditions (Ahmadi and Semiari, 2021). High-capacity backhaul links, on the other hand, will be needed to support such phenomenal data rates as well as efficient data flow between core networks and distributed radio access pointe goes the converting of AI to a human language and will make sure to Rewrite it using lower perplexity and create a higher burstiness but kept the word count and HTML elements intact:

Strategies of Improving Throughput to Communicate.

The communication channel is the most important measure because it determines the maximum achievable data rate-the maximum rate at which it is possible to transmit information with arbitrarily low error probability. Simply put, it is the ceiling data transmission rate, usually expressed in bits per second (bit/s). Another one of the most vigilant and decisive factors that determine channel capacity is the signal-to-noise ratio (SNR), such that, SNR: P_r/Pn = ratio Nabp received signal: noise power: in reference to decibels (dB): SNR is one of the important indicators of communication link status. Higher SNR means more signal in noise, so the cleaner, the signal becomes much more robust. There, it would deliver much higher data rates.

On top of this, the Shannon-Hartley Theorem provides a mathematical framework to understand that relationship. It states maximum channel capacity C in bits per second (bit/s) depends upon the available bandwidth B in Hertz and on SNR:

$$C = B \times \log_2(1 + \mathrm{SNR})$$

This equation demonstrates that channel capacity will increase in proportion to either bandwidth increase or SNR; however, that's when constraints arise in physics limitations such as the spectrum available, power cannot be consumed freely, and the hardware needs a special design to improve throughput. The following are some of the major approaches utilized to push the limit for communication throughput:

- Wider Bandwidth Utilization: Improving the operational frequency spectrum, especially in the sub-THz and THz bands, has also enabled the provision of larger bandwidths and thus higher data rates.
- Advanced Modulation Schemes: High-order modulation techniques, e.g., Quadrature Amplitude Modulation (QAM), encode more bits per each symbol thereby improving spectral efficiency.
- Multiple Input Multiple Output (MIMO): This system exploits the use of multiple antennas mounted at both transmitter and receiver ends to increase throughput capabilities by spatial multiplexing, enabling different parallel data streams to be transmitted simultaneously over different spatial paths.
- Basically, the Shannon–Hartley theorem expresses that.

$$\boldsymbol{R<C=}\ B \cdot \mathbf{log}_2\left(1+\frac{P_r}{N_0 B}\right), \qquad (1)$$

Where R is denoting the information rate in bits per second (bit/s), C refers to the maximum channel capacity in bit/s, B means the system bandwidth in Hertz (Hz), and P_r shows the received power of the signal. The noise power, P□, is defined mathematically by P□ = N_0B, where N_0 is called noise spectral density. The mathematical relation shows that theoretically the data can be sent at an information rate R close to the channel capacity C with a negligible probability of error on the receiver side. It can be well noted that the channel capacity is increasing with an increase in both the bandwidth and the Signal-to-Noise Ratio due to the importance of such parameters in improving wireless communication performance.

Future-Oriented Applications

The sub-THz and THz frequency bands are expected to play a central role in 5G and 6G, which are aimed at serving the extreme requirements of new high-performance applications. (Guerboukha *et al*., 2020).

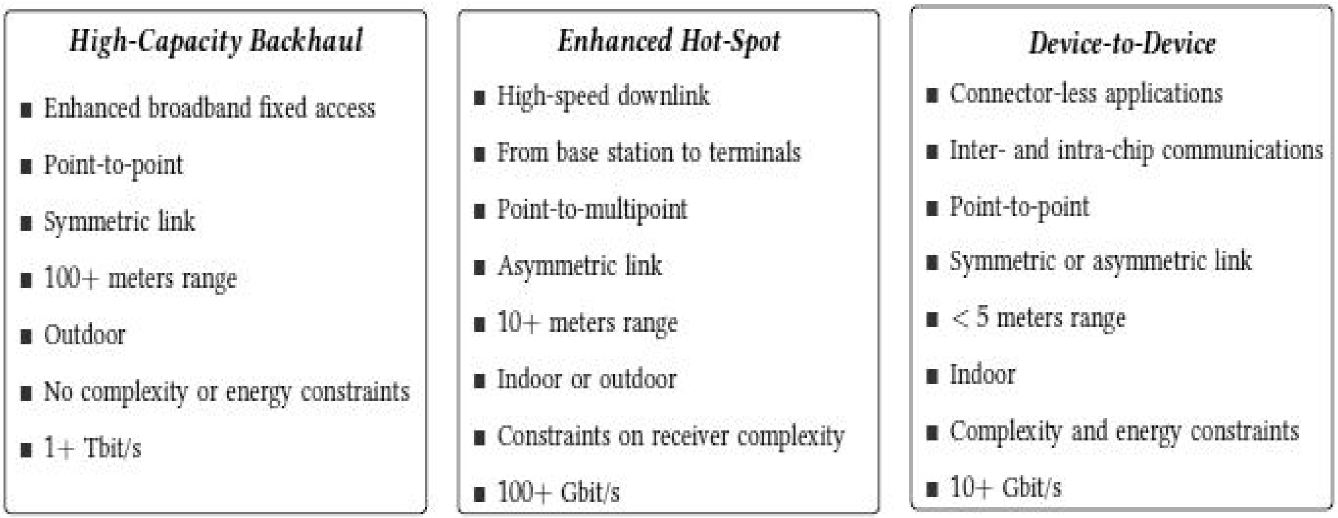
The vast sub-THz frequency bands are being exploited in three major scenarios towards ultra-fast wireless services, which are hereby described:

i. **High-capacity Backhauls:** set up for fixed, symmetric point-to-point links with super-high data rate requirements. Low energy consumption and system complexity are requirements because end-user devices are not considered in this scenario. This paves the way for ultra-dense architects — especially urban, which are capacity and ultra-low-latency demanding. Although fiber looks to be the backhaul option for such scenarios, limited penetration makes its deployments indeed complicated. Thus, sub-THz wireless backhaul looks to be a feasible option that can actually offer a near-fiber-like performance without much physical infrastructure.

ii. **Enhanced High-Speed Hotspot Connectivity:** High-throughput downlink transmissions from base stations to multiple user devices are envisaged in this case within confined, high-density areas. Operation over shorter distances imposes greater constraints on receiver complexity. This could be typified by high-speed data kiosks that download media and software updates in high-density areas such as airport terminals, railway stations, shopping centers, and sports arenas with transient but heavy traffic. Such kiosks can thus allow users more rapidly to download content like HD media files or software updates in a given brief window of time, substantially improving the user experience in those crowded data-demanding environments.

iii. **Device-to-Device (D2D) High-Speed Communications:** This scenario supports the realization of symmetric, high-data-rate links between devices, often limited by power and architectural considerations. In general, it is meant for short-range communication applications involving intra-chip or inter-chip data exchange in advanced computing systems. Other applications might include data transfers between devices in close quarters, such as data center environments and server farms, in which minimizing latency and maximizing throughput are of utmost importance. A streamlined system design aids in providing device interconnectivity in a flexible, scalable, and efficient manner.

The promising versatility of sub-THz and THz frequency bands conditions the advent of an era of high-performance wireless communication networks. Ranging from backhaul infrastructure to user-centered services down to device-level interconnections, these frequencies have an opportunity to turn connectivity upside down by providing unparalleled speed, reliability, and efficiency to a plethora of future-worthy applications.



High-Capacity Backhaul

- Enhanced broadband fixed access
- Point-to-point
- Symmetric link
- 100+ meters range
- Outdoor
- No complexity or energy constraints
- 1+ Tbit/s

Enhanced Hot-Spot

- High-speed downlink
- From base station to terminals
- Point-to-multipoint
- Asymmetric link
- 10+ meters range
- Indoor or outdoor
- Constraints on receiver complexity
- 100+ Gbit/s

Device-to-Device

- Connector-less applications
- Inter- and intra-chip communications
- Point-to-point
- Symmetric or asymmetric link
- < 5 meters range
- Indoor
- Complexity and energy constraints
- 10+ Gbit/s

Figure 2: Key Components and Performance Metrics of Proposed Applications

Signal-to-Noise Ratio (SNR): The receiver-end Signal-to-Noise Ratio (SNR) can be calculated using Friis' transmission equation:

$$\mathrm{SNR} = \frac{P_r}{P_n} = \frac{P_t \cdot G_A^{Tx} \cdot G_A^{Rx}}{L_p \cdot P_n} \quad (2)$$

The received signal power Pr is distinguished from thermal noise power Pn. Thus, transmission power is referred to by Pt, and the directional antenna gains at the transmitter and receiver are given by GATx and GARx, respectively. The free-space path loss resulting from signal propagation is indicated by Lp.

Lp: free-space path loss can be defined as Lp = $\{4\pi dfc / c\}^2$, where fc is the carrier frequency, d is the distance of propagation, and c is the speed light. It can be inferred from this equation that the higher the carrier frequency, the greater will be how much the path loss rises. Hence, the sub-THz systems have to contend with huge propagation losses when they are capable of imaging high-data-rate communications.

The receiver noise power is obtained from the Johnson-Nyquist noise equation:

Pn = KBT0BNf

Where KB is Boltzmann's constant, T0 is the absolute temperature (in K), B is the system bandwidth in Hertz, and Nf is the noise figure associated with the Low Noise Amplifiers (LNAs) in the receiver system (Chaccour *et al*., 2020). This equation indicates that overall noise power is influenced by bandwidth, temperature, and receiver noise characteristics.

Sub-Terahertz (Sub-THz):

The physical layer of communication systems faces significant challenges at sub-THz frequencies, primarily due to phase impairments and limitations of band-limited ADCs and DACs. Phase impairments result from oscillator phase noise, which can severely degrade signal quality and increase bit error rates (BER). To combat this, advanced phase noise compensation methods are necessary, such as using a parallelized RF architecture that divides the frequency band into smaller sub-bands, allowing independent processing to reconstruct high-bandwidth signals.

Additionally, powerful signal processing techniques like digital beamforming enhance performance by dynamically steering antenna patterns to improve gain and reduce interference. Multi-carrier modulation schemes, including Orthogonal Frequency-Division Multiplexing (OFDM), efficiently utilize the sub-THz spectrum while mitigating frequency-selective fading. As sub-THz technology evolves, innovative materials like graphene-based transistors and nanophotonic components are expected to revolutionize RF front-end design, aiming for higher efficiency, lower noise, and improved linearity for high-performance sub-THz transceivers in future wireless networks.

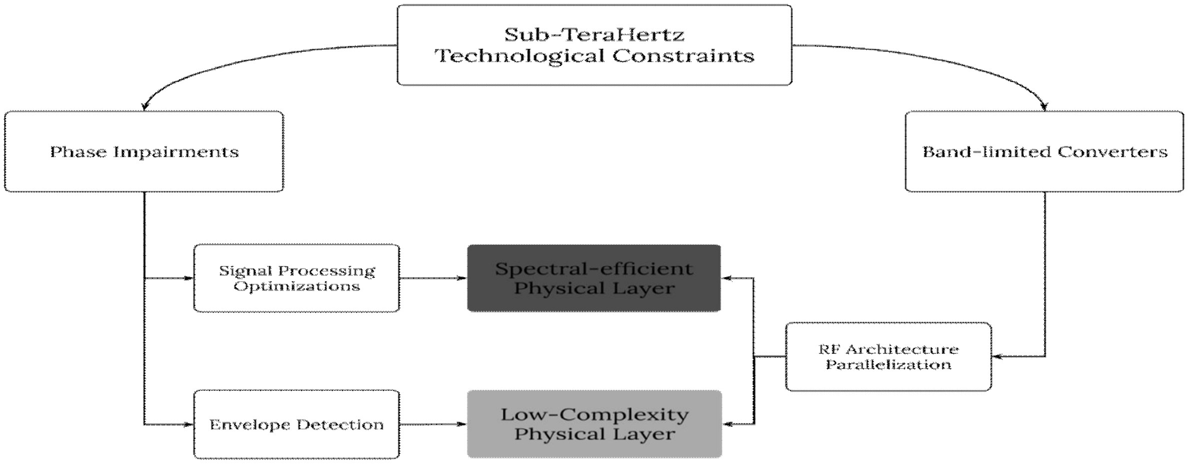


Figure 3: The path from technological constraints to Sub- the THZ physical layer

Methodology

Transceiver design

RF chain transmitter: The architecture of the transmitter employs envelope modulation in order to ensure efficiency in generating and amplifying signals. One of these RF chain configurations is illustrated in Figure 4. Envelope modulation is particularly known for its simplicity and power efficiency, most commonly coupled with high-performance power amplifiers — the example is given by flash-signaling (Bicais *et al*., 2020). On-Off Keying (OOK) modulation has been used for the n-th RF chain, whereby the transmitted signal sn(t) signifies a member of the non-negative real domain (sn(t) ∈ R≥0). The above minimizes power consumption while still achieving the reliable use of signal transmission performance.

$$s_n(t) = \sum_{\tau \in \mathbb{Z}} s_n[\tau] \cdot \frac{\Pi\left(\frac{t}{T_s} - \tau - \frac{1}{2}\right)}{\sqrt{T_s}}, \quad t \in \mathbb{R}, \tag{3}$$

where $sn[_\tau]$ is the$^{\tau s}{}_{\tau}$-th modulated symbol from constellation^{s} C = $\{0_{,}\ \sqrt{}_{2\_}\}$ and $_{Ts}$ is the symbol duration. We have $R\tau_{T}{}^{T}{}_{s}{}^{+T}|s_n(t)|^2dt = s_n[_\tau]^2$. The transmitted signal $x_n(t)$ at carrier frequency FC on the n-th RF chain is expressed by

$$x_n(t) = s_n(t) \cdot \sqrt{2}\cos(2_\pi f_c t + {}_\varphi(t)), \tag{4}$$

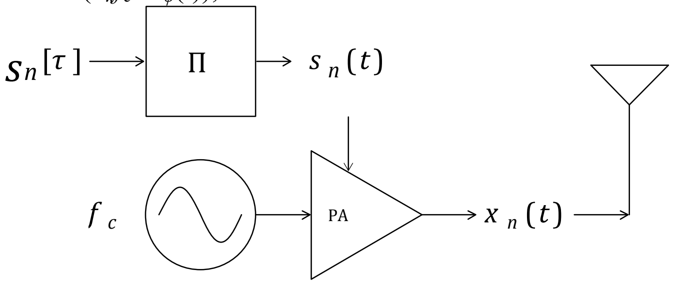


Figure 4:*diagram of Transmitter Radio Frequency chain*

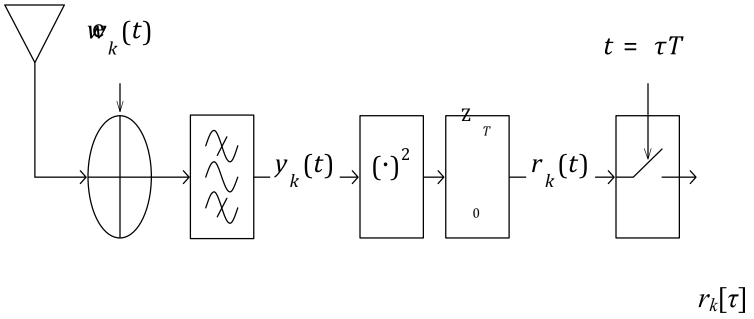


Figure 5: Diagram of one Receiver Radio Frequency chain

Where φ(t) represents a stochastic process modeling the phase noise (PN) produced by a high-frequency oscillator. The transmitter here employs a common reference oscillator to drive all Radio Frequency (RF) chains. Hence, the PN process φ(t) is identical and exclusive over all chains so that they are synchronized.

Propagation Channel:

Recent experimental measurement campaigns (Balevi *et al*., 2020; Zhang *et al*., 2021) indicate an environment in which propagation at sub-THz likely behaves with a totally dominant line-of-sight (LoS) path and highly-resisted non-line-of-sight (NLoS) components. This suggests that in most cases, a sub-THz channel functions in a single path-across-line kind, and in some aspects, it represents simplifications in signal modeling but holds problems in link reliability over relatively long ranges. The other problems have been exacerbated by molecular absorption and the high free-space path loss.

Receiver RF Chain:

The common architecture from incident Figure 6, on the receiver-side, combines a number of RF chains to make up for the processing of the input signal. Treating each k-th RF chain, there is an y□(t)-input, a signal with double-sideband spectrally. This signal is band-limited by a bandwidth B, which holds for B ≥ 2/T, around a center frequency fc. Those receiving chains of the receiver comprise a band-pass filter (BPF) to avoid folding of the spectrum — spurious distortion emerges from envelop detection. The favorable filtering allows only the relevant frequency components to pass through, while it suppresses the effects of unwanted noise or interference out of band. The signal expression is then filtered and down converted, giving a clear, baseband representation of the signal that will undergo further processing for subsequent demodulation and decoding (Bicais *et al*., 2020).

The design of this particular receiver chain is maximized towards the real conditions of sub-THz communication concerning the different stabilities against noise as well as those provided by phase noise. Further improvements in data reliability and bit error rates (BER) can be achieved by employing advanced equalization and error correction techniques downstream.

$$_k(t^{)}{}^{=}\sum_t h_{k,n}s_n(t^{)} \cdot \sqrt{2}\cos\,(2_{\pi}f_ct + {}_{\phi k,n} + {}_{\varphi}(t)) + w_k(t), \quad (5.3)\ n=1 \qquad (6)$$

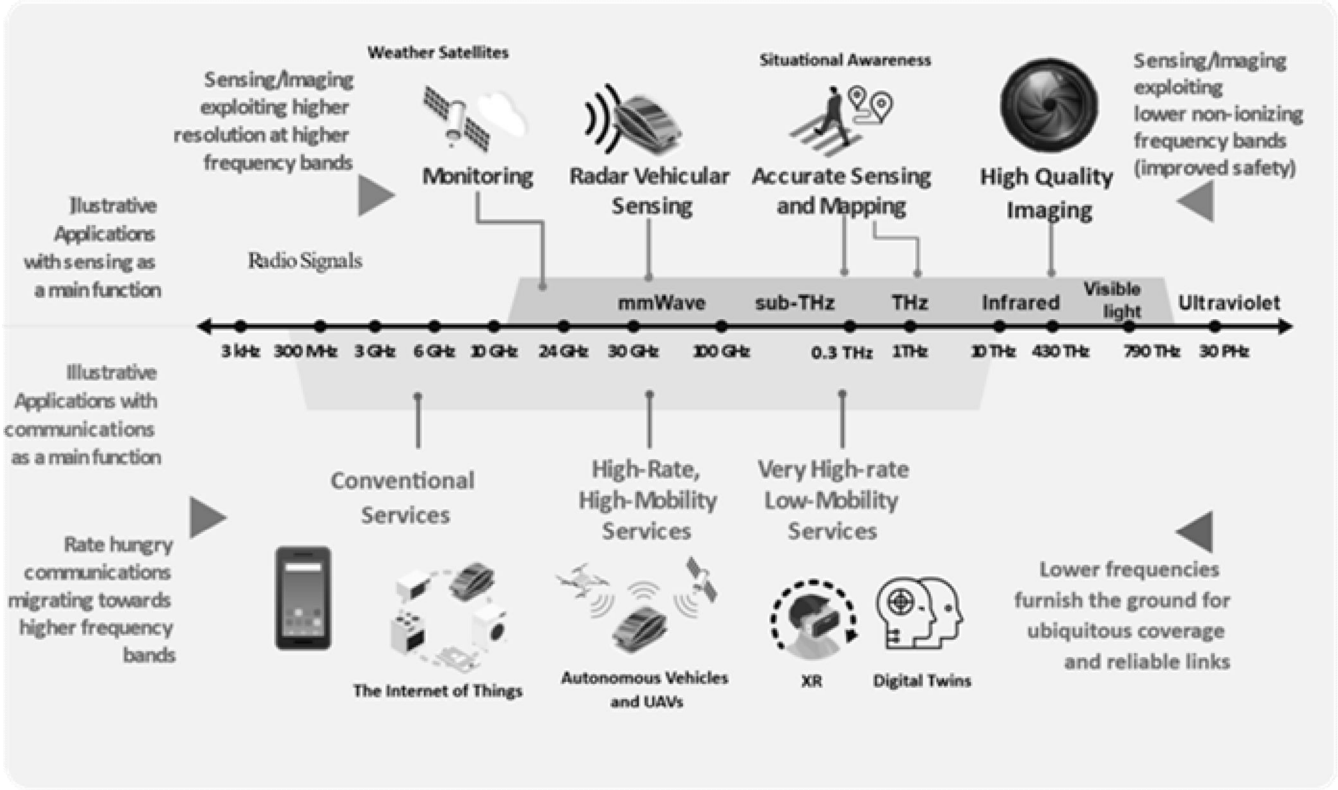


Figure 6: The frequency spectrum transition showcasing the shared utilization of the sub-6GHz to THz range for both communication and sensing capabilities.

Progression of transceiver performance limitations is being progressively surpassed by advances in plasmonic technology and graphene-based architectures (Farsi *et al*., 2020). Unlike conventional systems that rely on electron flow or photon transmission, plasmonic devices leverage electromagnetic excitation occurring on metal surfaces at optical frequencies. Moreover, the impressive electrical and optical properties offered by graphene-based designs resulted in much flexible, small, fast, and energy-efficient transceivers. These were first adopted into the area of nano-networks, where it was generally easier to build a transceiver since ultra-short pulse generation and low-power factors could create ultra-short femtosecond pulses — an exciting prospect for using such devices for short-range communication within nanoscale environments.

Nano-machine, nano-sensor, and nano-actuator interconnection constitute an unobstructed link between devices functioning at the molecular level, with biological systems and microchip architectures. This is the foundation place for the concept of the Internet of Nano-Things (IoNT), a new paradigm that is expected to change wireless technologies very soon. Such a vision will have nano-devices interconnecting and opening up innovations in various fields, from intra-chip exchange of data to advanced biosensors, which can monitor human physiology and organ function through THz frequencies.

The Shift Towards THz for 6G and the Internet of Everything (IoE): During recent years, advances in transceiver design have begun to initiate the vertical takeoff of THz communications, bringing such systems from the previous more confined applications in the Internet of Things to a much larger stage as the Internet of Everything (IoE) and future 6G wireless setup. While this trend is promising and holds great potential, large-scale THz deployment in an IoE environment for integrated communication and sensing services poses a long list of challenges in modeling, network analysis, design, and optimization (Tataria *et al*., 2020).

In the first place, the fact that THz signals are not just low-frequency signals demands a complete restructuring of wireless network infrastructure. It is especially important to cater to the highly dynamic behavior of the THz channel, signal-short-range characteristics of THz links, and narrow-beam, line of sight (LOS) pathways to offer a way out for a stable connection (Giordani *et al*., 2020).

Secondly, it will require emerging new system architectures-including a distributed and heterogeneous definition of Small Base Stations (SBSs) to facilitate potential THz network deployment. Therefore, new approaches for efficient THz channel estimation, better optimized network coverage, and seamless resource synchronization across multiple frequency bands that will ensure interoperability with current sub-6GHz and mm Wave infrastructure will need to be evaluated for the new SBS installations.

It combines emerging 6G services, on the other hand, like extended reality (XR), real-time holography, and autonomous systems, with sharp demands-set reliability, latency, and data throughput (Huang *et al.,* 2020). Attaining these performance metrics will thus require technology breakthroughs in real-time sensing algorithms, dynamic network optimization, and adaptive resource scheduling strategies. It is only through the addressing of multiple challenges that THz technologies would be able to realize their capabilities and therefore open up new avenues for the ultra-fast, intelligent, and seamlessly connected IoE ecosystem.

Results

Spectrum Access Techniques

Orthogonal Access Multiple (OAM):

The orthogonal access multiple (OAM) technique leverages the unique wave properties of electromagnetic (EM) waves, particularly the rotational nature of optical beams, to enhance channel capacity and spectral efficiency in next-generation communication systems. OAM is based on two components: Spin Angular Momentum (SAM), which controls the orientation of the EM wave, and Orbital Angular Momentum (OAM), which represents the wave's rotational phase structure. OAM allows for multiple independent data streams to be transmitted simultaneously on different modes without interference, significantly increasing the data-carrying capacity of communication channels. Each mode is characterized by a "topological charge," enabling a family of orthogonal spatial modes. This capability makes OAM a promising solution for improving wireless data rates and supporting THz-enabled multi-stream transmissions. Ultimately, OAM addresses the growing demand for ultra-high-capacity wireless networks and has potential applications in both classical and quantum information systems.

Non-Orthogonal Multiple Access (NOMA) - Copyright Fairness and Efficiency

While OAM introduces a new spatial dimension for parallel data streams, Non-Orthogonal Multiple Access (NOMA) offers an efficient alternative by exploiting power domain resources, optimizing THz networks. NOMA assigns different power levels based on channel conditions, allowing users with strong signals to transmit at lower power while weaker users receive higher power configurations. This ensures that users with poor signal conditions maintain adequate quality of service. NOMA operates quasi-orthogonally, enabling users to share the same frequency and time resources but differing in power levels, utilizing successive interference cancellation (SIC) to decode signals. This approach is particularly beneficial in THz communication, where disparities in channel conditions exist. NOMA enhances data rates and promotes fairness among users, which is crucial for supporting heterogeneous devices in ultra-dense environments. Together, OAM and NOMA present innovative solutions for THz systems, enhancing spectral efficiency and redefining power allocation for improved performance in future 6G networks.

In Real Time Thz Network Optimization

The Terahertz (THz) frequency spectrum is poised to enable next-generation wireless technology for data-intensive and high-resolution sensing applications in 6G networks, offering unmatched bandwidth and spectral efficiency. However, THz communication faces significant challenges, including molecular absorption, severe path loss, atmospheric attenuation, and beam misalignment, which hinder reliability and robustness. To maximize THz capabilities for 6G services, these challenges must be addressed. Enhancing THz networks requires integrating critical considerations into design, optimization, and operational strategies to ensure effective real-time communications.

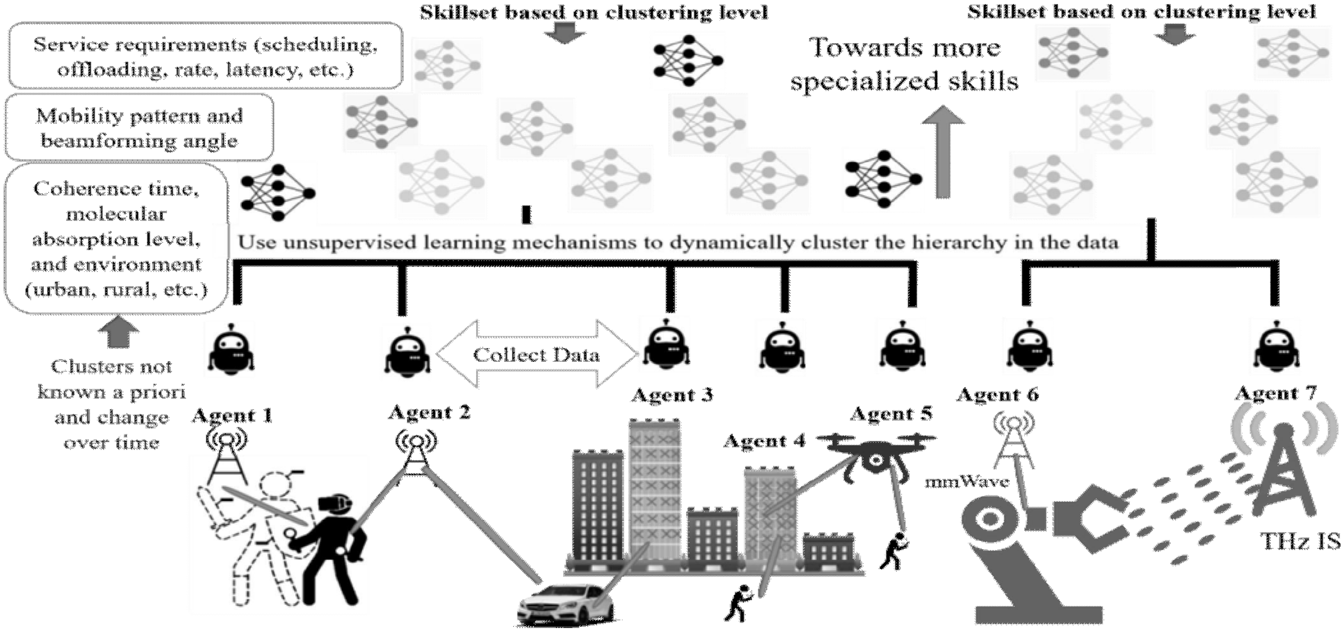


Figure 7: The need for generalized and specialized learning for 6G systems operating at THz bands.

Conclusion and Recommendations

This paper explores the physical layer of digital communication systems, focusing on the transmitter, receiver, and communication channel, and how they work together in network systems. It highlights the importance of sub-THz and THz frequency bands in enabling connectivity across various applications, including point-to-point links and inter-chip communications. The role of THz technology in advancing 6G networks is emphasized, particularly in enhancing transceiver designs for more efficient wireless systems. The evolution of transceivers operating in the sub-THz and THz spectrum represents a significant advancement in wireless communications, providing unprecedented bandwidth and ultra-fast data rates for applications like ultra-high-definition video, virtual reality

(VR), and large-scale IoT ecosystems. To address challenges such as path loss and environmental sensitivity, advanced materials, innovative antenna designs, and sophisticated signal processing techniques are essential. Ultimately, the enhanced spectral efficiency and reduced latency of sub-THz and THz technologies are poised to be foundational for the 6G era, enabling transformative services like holographic communication and seamless machine-to-machine interactions.

Recommendations

To facilitate the adoption of sub-THz and THz technologies in future 6G networks, several recommendations are proposed.

Significant investment in research and development (R&D) is essential to harness the full potential of THz transceivers. This includes exploring new materials like graphene and metamaterials to reduce signal loss, advancing semiconductor technologies for high-speed operation, and creating innovative, beam-steering antenna designs. Additionally, implementing AI-driven signal processing algorithms can enhance network reliability and throughput.

Energy-efficient network designs should be prioritized due to the high power requirements of THz systems. This involves developing power-efficient amplifier architectures to reduce energy waste, integrating energy harvesting techniques to prolong device battery life, and utilizing AI-driven dynamic power control systems to optimize transmission power. Lastly, designing low-power hardware for THz applications is crucial, particularly for IoT devices and wearables, to minimize energy consumption while maintaining performance.

References

Ahmadi A., & Semiari O. (2021). Reinforcement learning for optimized beam training in multi-hop terahertz communications," arXiv preprint arXiv:2102.05269, 2021.

Balevi E., Doshi A., Jalal A., Dimakis A., & Andrews J. G. (2020). High dimensional channel estimation using deep generative networks, arXiv preprint arXiv:2006.13494, 2020.

Bicaïs S., Doré J.-B., & Miscopein B. (2020). Coherent Quadratic Receiver with Low Intermediate Frequency. Patent, Jan. 2020.

Bicaïs S., J.-B. Doré J.-B., & Falempin A.(2020). Neural Networks Based Demodulation for MIMO systems using Energy Detection Receivers. Patent, Jun. 2020.

Bicais, Simon (2020). Design of the Physical Layer for Future Sub-TeraHertz Communication Systems, EEATS, Unitersité Grenoble Alpes.

Chaccour C., Soorki M. N., Saad W., Bennis M., &Popovski P. (2020). Can terahertz provide high-rate reliable low latency communications for wireless VR? arXiv preprint arXiv:2005.00536, 2020.

Farsi M., Daneshkhah A., Hosseinian-Far A., & Jahankhani H. (2020). Digital Twin Technologies and Smart Cities. Springer, 2020.

Giordani M., Polese M., Mezzavilla M., Rangan S., & Zorzi M. (2020). Toward 6G networks: Use cases and technologies, IEEE Communications Magazine, vol. 58, no. 3, pp. 55–61, Mar. 2020.

Guerboukha ., Shrestha R., Neronha J., Ryan O., Hornbuckle M., Fang Z. & Mittleman D. (2020. Efficient leaky-wave antennas at terahertz frequencies generating highly directional beams, Applied Physics Letters, vol. 117, no. 26, p. 261103, Aug. 2020.

Huang C., Hu S., Alexandropoulos G. C., Zappone A., Yuen C., Zhang R., Di Renzo M. & Debbah M. (2020) Holographic mimo surfaces for 6G wireless networks: Opportunities, challenges, and trends," IEEE Wireless Communications, vol. 27, no. 5, pp. 118–125, Jul. 2020.

Peng B., Guan K., Kuter A., Rey S., Patzold M., & Kuerner T., (2020). "Channel modeling and system concepts for future terahertz communications: Getting ready for advances beyond 5G," IEEE Vehicular Technology Magazine, vol. 15, no. 2, pp. 136–143, Jun. 2020.

Saad W., Bennis M., & Chen M. (2020). A vision of 6G wireless systems: Applications, trends, technologies, and open research problems IEEE Network, vol. 34, no. 3, pp. 134–142, May. 2020.

Sarieddeen H., Alouini M.-S., & Al-Naffouri T. Y. (2020). An overview of signal processing techniques for terahertz communications, arXiv preprint arXiv:2005.13176, 2020.

Tataria H., Shafi M., Molisch A. F., Dohler M., Sjoland H., & Tufvesson F. (2020). 6G wireless systems: Vision, requirements, challenges, insights, and opportunities," arXiv preprint arXiv:2008.03213, 2020.

Tervo O., Levanen T., Pajukoski K., Hulkkonen J., Wainio P., & Valkama M. (2020). 5G New Radio Evolution Towards Sub-THz Communications 2020.

Zhang Q., Ferdowsi A., & Saad W. (2021). Distributed generative adversarial networks for mmWave channel modeling in wireless UAV networks in Proc. of IEEE International Conference on Communications (ICC), Next Generation Networking and Internet Symposium, Montreal, Canada, Jun. 2021, pp. 1–6.

Zhang Q., Ferdowsi A., & Saad W. (2021). Distributed generative adversarial networks for mmWave channel modeling in wireless UAV networks in Proc. of IEEE International Conference on Communications (ICC), Next Generation Networking and Internet Symposium, Montreal, Canada, Jun. 2021, pp. 1–6.