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Review

Toward 6G Communication Networks: Terahertz Frequency Challenges and Open Research Issues

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Abstract: Future networks communication scenarios by the 2030s will include notable applications are three-dimensional (3D) calls, haptics communications, unmanned mobility, tele-operated driving, bio-internet of things, and the Nano-internet of things. Unlike the current scenario in which megahertz bandwidth are sufficient to drive the audio and video components of user applications, the future networks of the 2030s will require bandwidths in several gigahertzes (GHz) (from tens of gigahertz to 1 terahertz [THz]) to perform optimally. Based on the current radio frequency allocation chart, it is not possible to obtain such a wide contiguous radio spectrum below 90 GHz (0.09 THz). Interestingly, these contiguous blocks of radio spectrum are readily available in the higher electromagnetic spectrum, specifically in the Terahertz (THz) frequency band. The major contribution of this study is discussing the substantial issues and key features of THz waves, which include (i) key features and significance of THz frequency; (ii) recent regulatory; (iii) the most promising applications; and (iv) possible open research issues. These research topics were deeply investigated with the aim of providing a specific, synopsis, and encompassing conclusion. Thus, this article will be as a catalyst towards exploring new frontiers for future networks of the 2030s.

Keywords: Wireless networks; beyond 5G; 6G communications; terahertz waves; terahertz frequency; terahertz communications

1 Introduction

The standardization of 5G has been completed and deployment commenced in many cities across the globe [1]. However, the exponential increase in data traffic due to the growing number of connected devices, which it is foreseen that may leapfrog hundred(s) of connected devices per cubic meter. In addition, future uses and novel applications such as virtual reality (VR), augmented reality (AR), 4K/8K UHD video, 3D communications, autonomous driving, and other applications and scenarios that have not been currently imagined yet in existence [2]. The present deployed 5G communications will find it difficult to satisfy the data rates and ultra-low latency requirements of these applications. These challenges are considered a critical driver toward the development of communication systems to a new era of wireless network, sixth generation (6G). Given into 5G networks and its foreseeable evolution and the tremendous potentials that will be provided compared to previous generations networks, what should there be in 6G that is not in 5G or in its long-term evolution? Academic, industrial and research communities are already started working on identifying, defining and evaluating the key relevant enabling technologies that will shape 6G [3,4]; which are expected to be deployed by 2030 [5].

The vision of 6G communications is an improve performance of the data rate and latency limitations and permit ubiquitous connectivity. In addition, 6G communications will adopt a novel strategies enabling new communication experiences with virtual existence and universal presence will be readily available anywhere. Moreover, 6G communications will use notable applications, such as holographic calls, flying networks, and tele-operated driving [6]. Further, 6G is expected to provide high reliability and more security comparing with conventional wireless networks. However, among all technological works pertaining to 6G, THz and Artificial Intelligence (AI) are the most promising. These technologies are considered as revolutionary technologies in the area of wireless networks [7]. For these novel technologies to be incorporated in the future networks, a radical change is required in the design principles by the industry practitioners.

The first 6G wireless summit was launched in March 2019, and its vision statement was "ubiquitous wireless intelligence" [8]. It is expected that 6G wireless networks will witness a radical transformation making it substantially different from the previous generations and will revolutionize the wireless evolution from "connected things" to "connected intelligence." Not only that, 6G communications will offer services that are beyond just mobile Internet but as well support ubiquitous AI services from the core network comprising the data centres through the transmission backhauls and finally to the end devices. In other words, the transformation will not be limited to domain but will usher in an era of interdisciplinary cooperation between information technology and wireless communication. Meanwhile, AI will be crucial towards the design and optimization of 6G networks, configurations, topology, protocols, and operations [5,9]. To address the spectrum crunch in 4G communications, the millimeter wave (mmWave) spectrum was proposed and adopted. Unfortunately, this new spectrum bandwidth is incapable of meeting the bandwidth requirement of holographic videos. Obviously, this presents difficult issues such as spatial spectral efficiency and the required frequency bands for connectivity. Hence, a large bandwidth will be required, which can be found at THz bands, known as a gap band between the microwave and optical spectra (Fig. 1), which it is the subject of this study, Terahertz waves.

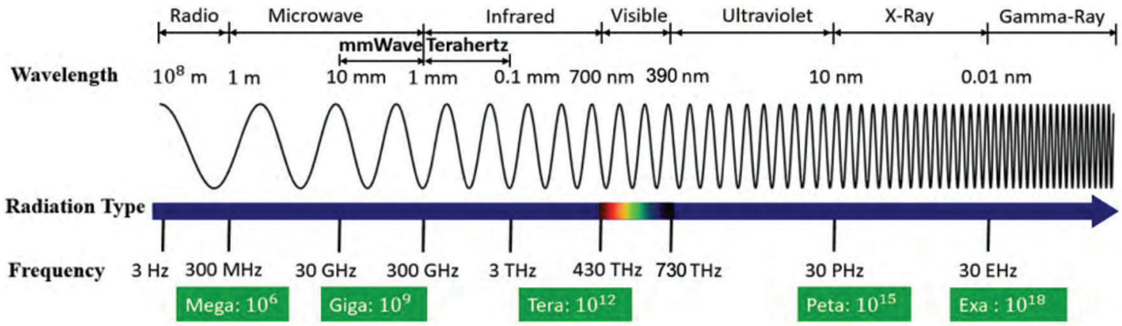

Figure 1: Electromagnetic spectrum and wavelength of terahertz waves

This study set out to present and discuss the unique properties of Terahertz waves. The key contributions are summarised as follows:

- This study presents a comprehensive overview of controversial research topics on THz waves and covers recent industry developments in the context of the main areas of application and challenges. We summarize the major areas of research topics into (i) key features and significance of THz frequency; (ii) recent regulatory; (iii) the most promising applications; and (iv) possible open research issues.

- This article will provide several new references for researchers, which could be opening new horizons for future research directions and support the pursuit of enabling Terahertz waves.

The rest of the article is organized as follows. The key features and significance of THz frequency is provided in Section 2. Then, the paper described recent regulatory and activities in Section 3. In Section 4, We demonstrated a number of promising applications. The open research issues are discussed in Section 5. Section 6 concludes the work.

2 Key Features and Significance of Terahertz Waves

In the electromagnetic (EM) spectrum chart, the frequency bands located beneath and over THz frequency band (namely, the µWave, mm Wave, and infrared) are fully allocated and are maximally occupied. Despite this spectrum crunch in the µWave, mmWave, and infrared, little efforts have been made to study and understand the THz band. This section explores the THz frequency bands exposing its peculiarity.

The notion "THz waves," also known as sub-millimeter radiation, denotes the frequency band between 0.1 and 10 THz which corresponds wavelength of 3 and 0.03 mm, respectively [10]. Basically, these bands could be referred as extremely small wavelength bands as the number of oscillations per section is extremely high. The THz band is accurately located between the frequency regions of oscillator-based electronic and emitter based photonic approaches to generate the EM signal, which leads to difficulty of signal generation at THz frequencies, loosely referred as the "THz gap" [11], as shown in Fig. 1.

THz waves are high frequency waves with extremely short wavelength. When compared to the mm Wave, the THz waves possess higher frequencies. As a result, THz waves will convey data more quickly, at the expense of limited signal propagation distance. Obviously, when THz waves are fully introduced and deployed into wireless networks, it will overcome the issue of low data throughput or low latency that 5G may not solve [12]. Accordingly, THz waves will be embraced by service providers as a vehicle to overcome the spectrum crunch currently being witnessed in the lower electromagnetic spectrum. As technology diffuse into massive connected devices era, plethora of devices will be connected resulting in large amounts of data especially with the rise of smart society. 6G is expected to provide massive capacity and reliable wireless link to human to machine (H2M) and machine to machine (M2M) communications, especially with the development of robotic and autonomous drone systems. In the future, there will be a migration from the present Internet of Things (IoT) concept to Internet of Everything (IoE) paradigm. Thus, it can be said that 6G will be an ultra-dense network with more flexibility, which can aptly integrate various technologies to adopt and satisfy various service orchestration request. Furthermore, THz band communication has the capacity to instantly support diverse applications such as macro and micro scale applications [13]. Transporting videos require huge bandwidth and this is one of the reasons why online video streaming applications were delayed in the legacy wireless generations. Lately, with the massive demand for mobile data (i.e., up to 24 Gbps for an uncompressed ultrahigh definition [UHD] video and up to 100 Gbps for uncompressed 3D UHD video [14,15]). Existing high-rate technologies such as mm Wave Wi-Fi (60 GHz IEEE 802.11ad) can reach only up to 6.8 Gbps, with a typical average of 1 Gbps [16]. In other words, capacity for existing channels have been exhausted and therefore, new spectrum must be explored. Certainly, the only feasible option is to explore the THz bands which is capable of providing multi-gigahertz contiguous bandwidths required to support the multi Gbps and Tbps data rates for uncompressed videos [14]. On the other hand, using Radar at THz frequencies is advantageous when compared to light or infrared-based imaging such as

Light Detection and Ranging (LIDAR), because weather and ambient light have negligible effects on Radar at THz frequencies. In terms of image resolution, LIDAR performs optimally but suffers in the presence of natural phenomenon of fogs, rain, and clouds [7]. However, these natural phenomena do not inhibit using THz radar in driving or flying in such adverse weather conditions [17,18]. The operational frequency of HD video resolution radar is at several hundred gigahertzes and it is capable of provisioning a TV-like picture quality and will augment radars at lower frequencies (below 12.5 GHz) that provides extended range recognition but with low image resolution [17,19]. When dual-frequency radar systems are fully integrated into a system, it will facilitate driving or flying in severe fog or rain environment [17]. From technical perspective, THz communication will enable 6G to achieve the follows as indicated:

- mmWave and THz will provide massive spatial multiplexing, as well as provisioning of precise sensing and other applications [17]. Using the THz band, it will be extremely difficult to launch passive cyber-attack, man-in-the middle attacks especially in the frequency range of 100 GHz through 3 THz. This is due to the fact that frequency range of 100 GHz–3 THz are attributed with extremely small wavelengths thus, enabling extremely high gain antennas to be made in extremely small physical dimensions [18]. This will create a platform for provisioning of secured communication.
- Ultra-high data rates per device 1000–10000x data rate realization with sufficient transmission distance in complex network environments involving heterogeneous platforms. Undoubtedly, wireless communications have witnessed massive data rate thanks MIMO and massive MIMO technology with associated diversity techniques. These improved data rate propagated with MIMO technology which exploits the fading channel coefficients have limitations because of its high computational complexities. Therefore, this technique is not sustainable on the long run and THz wave is the solution.
- Ultra-high data rates per connection density in the range of 1000x more devices compared to 5G proposition. Increased capacity can be realized using highly directional beam in which signal beams are steered to the desired mobile device without causing interference. Beam steering is easy to implement in the higher electromagnetic spectrum as being witness in the mmWave currently.
- Ultra-reliable connectivity to support various critical applications in mobility environments. Given the high atmospheric attenuation in THz band frequencies, highly directional beam antennas will be used to compensate for the increased path loss [20]. Thus, THz signals will be very tough to capture or eavesdrop [21].
- Very high energy efficiency (EE) is crucial in 6G communications considering that there would be many apps running on the device and each conveying data arising from massive data hungry applications. THz waves has advantages to directional beam communication with MIMO antenna arrays. This technique has the potential to supply sufficient energy to devices under the network coverage. Moreover, consumption factor (CF) theory (with a metric measured in bit per second per watt [bps/W]). According to [22], the electronic components closest to the transmitter antenna such as antenna, analogue-to-digital converter play crucial on CF [23,24]. As bandwidth increases, power efficiency also increases when most of the power used by components that are "off," for example, ancillary, to the signal path (e.g., the baseband processor, oscillator, or a display) is much greater than the power consumed by the components that are in line with the transmission signal path (e.g., power amplifier, mixer, antenna) [22]. A case in hand will the radio transmitter often deployed in low cost IoT application. In this configuration, power needed to function by the ancillary baseband processor and oscillator is negligible comparison to the received emitted power, the power efficiency is independent of the bandwidth [7]. The CF theory has consistently showed that communication antennas with a given physical design, energy efficiency improves as moving

up to mmWave and THz frequencies. These two bands have bigger bandwidth and hence, superior power efficiency when analysed on a bps/W.

Expectedly, wireless terabit-per-second is set to attract more research efforts from the industry and academic in the next decade. The current physical layer must be improved upon resulting to superior physical layer to support these bands and, more importantly, novel spectral frequencies will be needed to sustain these very high data rates [12].

3 Standardization of Terahertz Spectrum for Communication Systems

The electromagnetic spectrum is not personal property but rather, it is being controlled by the government through special regulatory agencies. These regulatory bodies have allocated the sub 6GHz bands to many agencies and institutions leaving behind frequencies from 100 GHz to 3 THz. These frequencies are yet to be explored and have swatches of contiguous bands capable of provisioning high data rates [25,26]. Developing a strategic spectrum roadmap toward 6G in terms of the THz band will be a valid and valuable research challenge in the coming years. The following section highlights on recent regulatory and standard body rulings about using THz frequencies [7].

Consortium of global spectrum regulatory and management entities in collaboration with other radio Standardization entities such as the Federal Communications Commission (FCC) [27], the European Telecommunication Standards Institute [28], and the International Telecommunication Union [29], have commenced process of allocating electromagnetic beyond 95 GHz to be used for point-to point/direct line of sight communications, broadcast services, and other use cases [14]. Just recently, in March 2019, the FCC unanimously agreed to lift the restriction on electromagnetic beyond 95 GHz, and making available 21.2 GHz of spectrum for unlicensed use shown in Tab. 1, and allowed investigational activities in the electromagnetic spectrum up to 3 THz [30]. Similarly, National Telecommunications and Information Administration (NTIA) has set up a policy motion towards efficient spectrum policy for America's future, and encouraged NTIA to lessen the restrictions place on spectrum beyond 95 GHz [31]. The IEEE formed the IEEE 802.15.3d [32] task force in 2017 for global Wi-Fi use at frequencies from 252–325 GHz, creating the first worldwide wireless communications standard for the 250–350 GHz frequency range, with a nominal new physical layer (PHY) data rate of 100 Gbps and channel bandwidths from 2 to 70 GHz [7]. In addition, the European Commission established the Radio Spectrum Policy Group [33] to address THz-band communication management matters.

Table 1: Operation frequency proposed by the FCC [27]

Frequency band (GHz)	Bandwidth (GHz)
116–123	7
174.8–182	7.2
185–190	5
244–246	2

4 Potential Emerging Applications of Terahertz Band Communication

Two main types of applications are envisioned for the THz system: THz applications on the (i) macroscale and (ii) the micro/nanoscale [11,14]. These two types of applications can be divided into automotive, indoor networking, aerospace, healthcare, location-based services, high-definition holographic communications, and underwater communication categories. In the following we discuss the main expected applications aligned with THz band communication.

(i) Holographic communications: This strand of wireless communications will render the transmission of 3-D images with voice inadequate when conveying in-person presence. To address this need, one might be tempted to explore the possibility of transmitting reconfigurable three-dimensional video with stereo audio which can mimic numerous physical attributes in the same area. Holographic videos consume more data bandwidth than the 4K/8K UHD video formats that 5G will support. In this situation what can we do. A benign approach might be devising a strategy to interact with the received holographic data in video format with the goal of modifying if needed. The holographic videos are bandwidth intensive applications must be transmitted over a reliable communications system [34].

(ii) Tactile communications: After using holographic communication to transfer a virtual vision of close-to-real sights of people, events, and environments, remote physical interaction through the tactile Internet in real time will be beneficial [35,36]. The following analysis shows that THz frequencies will provide real-time computations needed for wireless application of human cognition [37].

The human brain includes around 10^{11} neurons, each of neuron can fire 200 times per second (5 ms), beside that each neuron is connected to approximately 1,000 others, resulting in a computation speed of 20×10^{15} floating-point operations per second (*flops*) [7]. Accordingly, speed of human brain can compute as follow:

$$\begin{aligned} Computation\,Speed\,of\,Human\,Brain &= 10^{11}\,neurons \times 200\,flops\,per\,second \times 10^{3}\,per\,neuron \\ &= 20 \times 10^{15}\,flops/second = 20\,peta\,flops\,per\,second \times 1\,bit\,per\,flop \\ &= 20{,}000\,Tbps \end{aligned} \tag{1}$$

Each neuron has write access to 1,000 bytes, thus a memory size can compute as follow [37]:

$$Storage = 10^{11}\ neurons \times 10^{3}\ bytes\ per\ neuron = 10^{14}\ bytes = 100\ TB \tag{2}$$

THz wireless generations are expected that use RF channels up to 10 GHz for each user. By assuming that each user is able to exploit 10 bits/symbol modulation methods and 1,000 times increase in channel capacity, and addition to using massive MIMO, data rates is expected up to 100 Tbps.

$$Data\ rate = 10\ GHz \times 10\ bits\ per\ (sec.\ Hz) \times 10^{3} = 100\ Tbps$$

Eqs. (1) and (2) show that a data rate up to 100 Tbps with use RF channels up to 10 GHz for each user, which providing 0.5% of real-time human computational power. Ambitiously, if RF channels up to100 GHz are used, then 1 petabit per second of information or 5% of real-time human computational power [37].

However, efficient PHY and cross-layer communication system design needs to be conducted to meet the stringent requirements of these applications [38].

(iii) Human bond communications: Essentially, 6G will drive the human-centric communication concept, where humans can have access to physical data and/or share physical features. When fully developed, this communication will create a platform in which the human five senses can be conveyed via the Internet [39]. Recently, the concept has gained traction because of ‘communication through breath’ scheme which permits acquiring the human bio-profile via exhaled breath, and even communicate with the human body by inhaling through volatile organic compounds [40]. Consequently, it is feasible to analyze diseases, detect emotions, gather biological attributes, and relate with the human body remotely. In general, developing communication systems that can imitate the human senses and human biological attributes is a hot topic research area and need more investigations in future.

5 Challenges and Open Research Issues

6G being a new frontier in wireless communications, some the issues are expected and must be addressed. The notable issues are such as impact of atmospheric and water absorption on the signal propagation [26]. Unless, these issues are addressed, the goal of realizing cost effective, efficient, and pragmatic THz band communication for 6G communication systems will be a mirage. These challenges require both the novel policy adjustment and the advancement of present solution-set which cut across the various communication stacks, including the physical layer, through the protocol stacks, to the applications and lastly, user interface. It should be noted that is not possible to satisfy all features; however, should be trade-offs between these features with raising all features in a balanced way. This section highlights a set of crucial challenges in THz band communication.

5.1 Transceiver Design and THz Signal Generators

One of the greatest concern towards the use of THz spectrum is how to design a new transceiver module because the current designs are not suited for THz band frequencies [12]. In this regard, on-going efforts are in offing to tackle this issue. For instance, the DARPA T-MUSIC program is researching on SiGe HBT, CMOS/SOI and BiCMOS circuit integration, and are optimistic of attaining the power amplifier threshold frequencies 500–750 GHz [41]. The semiconductor industry will solve these challenges, however, the novel designs for highly dense antenna arrays will be needed, to overcome the relative minute wavelengths and physical size of RF transistors comparable to element spacing in THz arrays. In addition, a great deal of innovation is needed to suppress the excessive propagation attenuation common at THz band frequencies. Other extra issues such as high power, high sensitivity, and low noise figure should not be neglected during the fabrication of THz enabled transceivers. Furthermore, the THz transceivers are performance-constrained, from the viewpoint of transmission power (and distance). Silicon germanium (SiGe), gallium nitride (GaN), gallium arsenide (GaAs), and indium phosphide (InP) are among the popular option for THz signal generators and detectors [11,14]. Equally, the transmission distance for GaN, GaAs, and InP based transceivers are bounded. Designing a novel THz band transceiver architecture has become a necessity. The issue of imperfect hardware features, including nonlinear amplifier, phase noise, limited modulation index [42], and so on, can severely mar the quality of transmitted signals. It is also possible that issues may arise in the design of antennas and waveforms, and energy efficient signal processing. Therefore, novel transceiver technologies have become essential towards fabrication of state of the art THz sources (hardware), especially for the medium- to high-end part of THz bands (>300 GHz) [11,26]. Both the conventional CMOS technology and the recently introduced nanomaterials, such as Graphene, can be used for new transceiver designs for THz-enabled devices [14]. However, analytical testing should be supported by real experimentation to re-assess the performance of any proposed design.

5.2 Propagation Modelling and Path Losses

Another strategy to assist the research community to explore the THz spectrum can be in the form of arranging THz sub-domains based on their absorption and reflection coefficients. Explicitly, this approach serves as a guide on the suitability or otherwise of using any of THz spectrum for communications and other applications purposes. Another issue that demands investigation is how to address scenarios supporting multiple applications. In this case the ensuing harmonic overlaps can be mitigated by careful frequency planning. Furthermore, the sensitivity of weak signal suffers signal depreciation making detection one of the major limitations impeding the versatility of this band. The THz electromagnetic spectrum is roughly categorized into favorable spectrum windows atmospheric below 500 GHz and above 500 GHz (Fig. 2) [43]. It is obvious as we move the THz region from 30 GHz onwards, there is increase in free space path loss, molecular atmospheric absorption and total signal loss. The high free space path loss can be compensated by the high antenna obtainable in this region because of the high signal directivity components. Apart from the adverse impact of the free space loss, higher frequencies transmission increase complication and parallelism in RF hardware and the decrease beam width leading to problem of signal acquisition and beam tracking in mobile applications [44]. In addition to technological boundaries, penetration through various materials and reflections from surfaces are other factors to be considered when categorizing the radio spectrum.

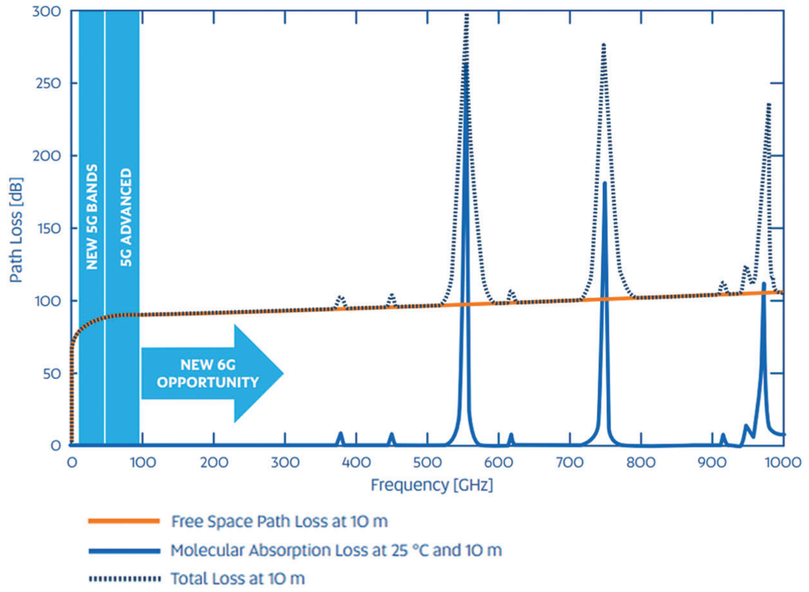

Figure 2: Spectral windows, the effect of free space loss, and water vapor absorption at a distance of 10 m [45]

Identifying the issue of high path loss at THz frequencies is important. More important is proposing strategies to mitigates these abnormalities. A plausible solution set will be the deployment of highly directional dynamic massive MIMO antennas. These antennas are equipped with narrow beam width array and, hence minimizing interference. This approach is currently proposed in 5G communication as a strategy towards increasing spectral efficiency. When fully explored, the signal-to-interference-ratio will increase resulting to massive data rate per communication density. Thought highly directional antenna can increase system data rate, there are other structural issues that must be address before deploying THz communications in wireless communications. For instance, till this moment, no channel model has been proposed and suggested the THz band with exception to those within 300 GHz for stationary indoor scenarios [46]. Moreover, ultra-high rates are attributable to ultra-high energy utilization. This implies that, energy-efficient communications are unavoidable both at the digital signal processing and radio interface levels [44].

Basically, the upcoming ultra-fast THz communication systems will support holographic call, researchers should explore the desirability of stochastic approach as a solution set towards 3D channel model to design 6G deployment scenarios, including 3D beamforming. 3D channel modelling is an interesting research area with rich potential both in 5G communications and unmanned aerial vehicle communications. In a bid to increase the confidence level, any analytical channel characterization simulation is expected to be subjected to real world deployment scenario either in the form of testbed before receiving approval. Mobility support within a multiuser THz cellular environment must be receive attention as well and must support different kinds of mobility scenarios experience in wireless communication environment. Any analysis in mobility is expected to consider the issue of handover simultaneously. THz cellular environment will witness excessive handover issues because of the small cell topology and consequently, a unique solution is required.

5.3 3D Networking Reliability-Deployment Fundamentals

6G must support communications in 3D space. This requires concerted research on various fronts. (i) Measurement and (data-driven) modelling of the 3D propagation environment. (ii) New approaches for 3D frequency and network planning. (iii) new network optimizations for mobility management, routing, and resource management in 3D. In addition, fundamental 3D performance, in terms of rate-reliability-latency trade-offs and SE, is needed. Such analysis must quantify the spectrum, energy, and communication requirements that 6G needs to support the identified driving applications. Recent works in [47,48] provide a first step in this direction.

On the other hand, the Poisson point process (PPP) is a widely used mathematical tool to model the randomness obtainable in real network deployment and coverage probability scenario. Nevertheless, the fundamental assumptions commonly used in PPP is that objects are distributed randomly in space and hence unpredictable. This model is not entirely correct because in both mono and multi-tier heterogeneous networks, transmitter deployment is static in contrast to mobile devices that exhibit random distributions. In studying base station location, a pattern has emerged in which some base stations attract more traffic while others don't. In small cell networks will witness more users, signifying user-centric hotspot areas, while there will be repulsion (low traffic) observed at the macrocell level to signifying rural and urban deployments. This assumption is in consonant with the issue of excessive handover as described earlier. Due to the imperfection of the PPP techniques, it will not adequately model the 6G networking environment. Furthermore, PPP has shown versatility in the 2D plane until now and has been extended the 2.5D domain. If this same model must be deployed to derive the 3D channel model of the emerging network, there is need to address this issue.

5.4 Network Architecture

In [16], the authors proposed the next generation system network topology, in which mmWave, THz, and conventional microwave bands function jointly, and proposed a medium access control (MAC) protocol that switches among the various bands for data transmissions. However, this model may be unrealizable for THz-only ultra-dense system networks. The reason being that the THz frequency band is massive (i.e., roughly 10 THz in total), the attributes of diverse carrier frequency windows are quite different, particularly from the context of transmission distance. In furtherance to the goal of provisioning of pervasive ultra-high-rate access in complex environments, over-hauling the currently deployed MAC protocols and network deployment schemes are imperative. From the MAC design, a critical issue that needs further research is the channel coding scheme to be deployed. Are the current error detecting and error correcting codes sufficient to work in these frequencies. Which of the forward error correcting codes will result to optimal performance when considered from the view point of high path loss and weak diffusion signals. Highly directional signals are easily blocked and hard for mobility applications. Recall that in the presence of excessive path loss the transmission distance becomes small. Thus, new error control mechanisms should be proposed, and new networking strategies should be developed to improve the coverage and support the seamless connection. Undoubtedly, Tbps per link wireless networks has tremendous potential to enhance, the aggregated traffic flowing through the network and the Internet dramatically. Thus, the upper layers such as transport layer protocols compromising TCP and UDP will undergo morphological changes to be able to deal with upper layer issues such as congestion control.

5.5 Health and Safety Issues

The photon energy THz radiation is between 0.1 to 12.4 meV, which is a less than three times of ionizing photon energy levels. Thus, THz radiation is considered as a non-ionizing photon energy [49,50]. Accordingly, the concern source with THz frequencies is a heating which is considered the main reason for cancer risk [51]. However, the principle of thermal hazards and standards for non-ionizing radiation are designed by FCC and International Commission as given in [52]. Moreover, electromotive-force transmission should be a novel concept to be introduced in 6G to mitigate health concerns.

6 Conclusion

The exponential increase in data traffic due to the growing number of connected devices, which it is foreseen that may leapfrog hundred(s) of connected devices per cubic meter. In addition, future uses and novel applications. Thus, the future networks will require bandwidths in several gigahertzes; accordingly, THz is considered one of the most promising technology for future networks to perform optimally. In this paper, we covered various aspects of THz technology for 6G networks with different perspectives. We provided a vision for key features and significance of THz frequency, and recent regulatory activities. Furthermore, a way out is discussed promising applications that future THz frequencies will support. Finally, the opportunities and research challenges for THz technology on the way to the commercialization of next generation communication network are presented.

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