A Review on Integrating Native-AI and Edge Computing for THz Communication in 6G: Key Advancements, Limitations and Future Prospects

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Abstract: The next-generation cellular technology is often referred to as Sixth Generation (6G) networks that are established to ensure better network sensing ability and efficiency. When compared to existing applications, Terahertz (THz) communication is considered the most effective approach for 6G networks because of its greater efficiency to assist terabit per second communication among advanced applications. The THz communication band is considered the primary factor for 6G networks because of its huge and unused frequency bands with high spatial resolution, huge bandwidth, and short signal wavelength. At present, numerous investigations have been conducted to analyze the performance of THz communication on 6G networks. This research presents a review of recent studies related to THz communication in 6G networks and focuses on the incorporation of native-AI and edge computing technology for THz communication within 6G networks. This article also presents a novel architecture overview and technical mapping, which combines native AI protocol with THz communication operations for analyzing how scalability, synchronization, and resilience are attained by intent-based orchestration and distributed coordination. Along with the architectural overview, this review discusses the practical and implementation factors. In addition, the analysis of existing research trends across conventional approaches is also discussed in this review. Finally, the future outlooks are also analyzed to improve THz communication in 6G networks.

Keywords: Sixth Generation networks; THz Communication; Native-AI; Edge Computing; Practical Limitations and Future Prospects

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Nomenclature

Abbreviation	Description
6G	Sixth Generation
5G	Fifth Generation
THz	Terahertz
AI	Artificial Intelligence
Native-AI	Native Artificial Intelligence
BS	Base Station
RIS	Reconfigurable Intelligent Surface
UAV	Unmanned Aerial Vehicle
IoT	Internet of Things
XR	Extended Reality
URLLC	Ultra-Reliable Low-Latency Communication
CSI	Channel State Information
RL	Reinforcement Learning
DRL	Deep Reinforcement Learning
MIMO	Multiple Input Multiple Output
UM-MIMO	Ultra-Massive Multiple Input Multiple Output
LoS	Line of Sight
NLoS	Non-Line of Sight
ISAC	Integrated Sensing and Communication
V2X	Vehicle-to-Everything
RSU	Roadside Unit
SON	Self-Organizing Network
ZSM	Zero Touch Service Management
QoS	Quality of Service
MAC	Medium Access Control
LEO	Low Earth Orbit
ITU	International Telecommunication Union
ITU-T	ITU Telecommunication Standardization Sector
3GPP	3rd Generation Partnership Project

1. Introduction

The evolution of wireless applications towards 6G technology has promoted the rapid growth of advanced technologies, including digital twin, holographic communication, tactile internet, and XR [1]. THz communication is considered a prime factor of 6G networks. It presents better bandwidth when compared to other applications. Yet, it still face certain limitations due to greater path loss, environmental sensitivity, molecular absorption, and narrow beams [2]. To tackle these obstacles, recent studies have concentrated on embedding the strength of native-AI across every layer of the 6G network. Instead of functioning as a supporting application, the AI integration assists in analyzing and boosting the functions of the system even in real-world cases [3]. Furthermore, edge computing is another core application of 6G, which performs the computational function near the user with the intent to minimize communication latency and to boost the reliability and competence. Moreover, it aims to enhance the resource allocation procedure even in dynamic THz circumstances [4].

In THz networks, the integration of native AI permits accurate channel estimation and modeling, predictive mobility, dynamic spectrum and power allocation, beamforming and tracking. Moreover, it promotes real-world management of RIS, edge intelligence, as well as federated learning for distributed networks, monitoring anomalous actions and boosting the privacy of the communication channel [5]. Thus, the incorporation of native AI and edge computing technology into 6G networks ensures a rapid, reliable and intelligent model for secure communication.

1.1 Motivations and Contributions

Existing studies on THz communication bands have concentrated on particular domains, including beamforming, antennas, measurements, hardware, and channel modelling. The core motive behind this review is to present a detailed description of the THz communication networks in 6G [6]. Most of the recent investigations have explained the overview of THz communication but lack in providing its applications and functions in the 6G environment. Moreover, existing research often analyzes the THz communication bands on conventional wireless applications and ignores their sensing abilities and demands on 6G devices [7].

To overcome these obstacles, this article aims to offer a comprehensive review of THz communication bands and their sensing ability in 6G networks. Further, it describes the significance of THz band frequency over classical communication bands, explores the role of THz bands in 6G networks, along with specific elements like propagation, beamforming, channel modeling, etc. Additionally, this review describes the significance of embedding advanced methods like native AI and edge computing for better communication.

The major contributions of this review are listed below.

- To explain the need for the THz spectrum for emerging 6G applications. Examining the necessity of THz bands for 6G networks helps to resolve the limitations faced by the mmWave and optical frequency bands during the communication phase.
- To analyze the impacts of 6G networks and THz band's sensing ability for secure communication. Analyzing the short wavelength and high resolution characteristics of THz bands enables the 6G networks to improve physical layer security.
- To examine the properties of the THz communication channel and its effects on signal propagation for allowing short-range communication with better security and minimum communication latency.
- To explore the inclusion of advanced techniques like native AI and edge computing with 6G networks. This analysis assists to resolve the challenges faced by 5G networks by transforming the communication network from a passive pipeline to an intelligent architecture.
- To discuss the limitations and future scope for enhancing THz communication in 6G networks and guiding the researchers to boost the reliability and efficiency of the 6G wireless communication network.

This review is organized into four major parts with a summary. Part I discusses the introduction and the motive behind this review. The overview and application of THz communication in 6G networks are explained in Part II. Part III describes the integration of edge computing and native AI technology with 6G networks. Part IV explains the comprehensive study of existing models and the future direction for increasing THz communication in 6G networks. Finally, the summary of the review is offered in Part V.

2. THz Communication in 6G: Global View, Need and Applications

2.1 Global View of 6G Development

Globally, the development of 6G networks is a major research topic. These developments have concentrated on integrating innovative frameworks for ensuring better communication.
The emergence of 5G network started in mid-2019 in the mid of 2019 in South Korea and the US. The evolution of the 5G network has extended mobile communication beyond human-centric services to create a massive communication model by combining IoT applications and multiple industrial devices [8]. Moreover, the Covid-19 outbreak has increased the social value of modern communications for guaranteeing better healthcare, education, work, and other services by highlighting the significance of a proper communication framework, which has been the primary motive behind the development of 6G networks.

The research behind 6G development began in 2018 by the ITU-T's Technologies for Network 2030, which concentrated on examining the role of the communication network in 2030. Moreover, the European Commission established its 6G flagship project named Hexa-X in 2021 and Hexa-X Phase II in 2023 [9]. Additionally, the Next Generation Mobile Networks (NGMN) has begun its research on 6G vision and trends to offer proper guidelines for the global functioning of 6G networks.

Additionally, in 2018, Finland began its 6Genesis Flagship campaign for analyzing the 6G devices and their impacts. Later, Northern states of the US have introduced the Next G Alliance to speed up the development of 6G networks. In addition, France has introduced a France 2030 plan and PEPR-NF Campaign for exploring the significance of sub-THz as well as THz bands for upcoming wireless applications. This campaign concentrates on improving the 5G technology by considering its effects on security and the environment. At the same time, the Large-scale LEO satellite program, including SpaceX's Starlink, has concentrated on offering better internet access throughout the nation [10]. In addition, these groups complement the terrestrial mobile networks, which influence the design and functions of upcoming 6G networks without eliminating the traditional 5G networks. The diagrammatic view to describe the global view of 6G development is given in Fig. 1.

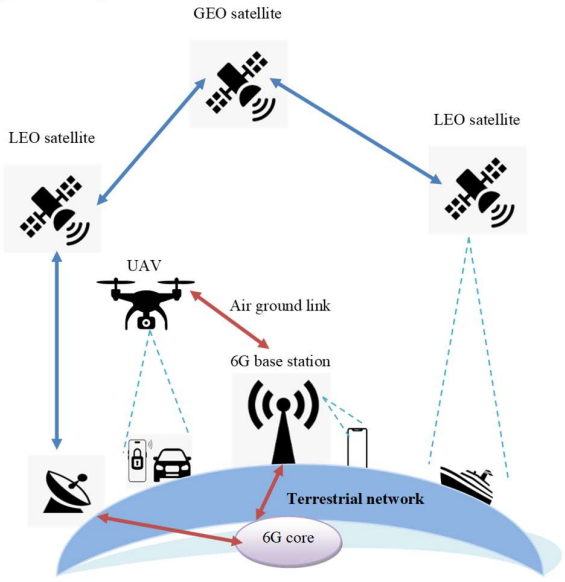


Fig. 1. Global View of 6G Development

2.2 Need of THz band in 6G

In recent days, THz bands have been widely employed as the key element in wireless communication models. Generally, 6G networks often demand advanced frequency bands with rapid communication and sensing ability, which is much lower in existing sub-6 GHz and mmWave frequency bands. To overcome this limitation, recent studies have recommended the integration of THz bands in 6G networks, which results in effective communication and sensing throughout the communication phase. The basic functions of THz bands in wireless communication are described below.

THz communications: The existing Sub-6 GHz as well as mmWave frequency bands struggle due to spectrum scarcity as well as hardware limitations, which make Tbps-level connections unfeasible. Moreover, optical frequency bands present abundant spectrum [11]. Yet, they face certain limitations due to the requirement of line-of-sight elements, propagation, and security issues. On the other hand, the THz frequency bands present rich, non-ionizing spectral resources over a wide range of frequencies. Recently, advanced techniques including UM-MIMO, lens antenna arrays, and grapheme-aided elements permit better beamforming performance and compensate for free-space loss, climatic changes, and make Tbps links more viable.

THz sensing: THz sensing utilizes the minimum wavelength for attaining images with better resolution, exact localization, as well as spectroscopic material evaluation [12]. Moreover, its non-ionizing characteristics permit it to effectively penetrate non-conductive materials and identify the hidden objects and chemical particles securely. The THz bands can be adapted to climatic interferences, including ambient light, fog, etc., which expand their utilization in diverse applications, including process tracking, remote sensing and security monitoring.

Combination of THz Communications and Sensing: The THz frequency band assists ISAC, in which the sensing process aids to increasing communication through rapid beam alignment, elimination of connection blockage, and predictive beamforming [13]. At the same time, the communication models promote collaborative sensing by performing data fusion. This hybrid fusion enhances the convergence, sensing rate, and propagation predictability by reducing the measurement uncertainties, which makes the THz bands more effective for 6G networks.

2.3 Applications of THz Communications

The primary applications of THz communication bands are listed below.

Terabit Cellular Hotspots: In dense urban regions and high-demand areas, including industrial sites, the THz frequency permits the deployment of small cells with better bandwidth and short-range LoS connections for enabling terabit communication among networks. Furthermore, these hotspots allow devices, including immersive virtual reality, holographic links, and ultra-high-resolution video streaming, to ensure better performance during the communication phase [14]. Moreover, when combined with existing low-frequency cellular systems within the heterogeneous networks, these hotspots attain flawless links, global roaming and superior 6G efficiency.

Terabit Campus or Private Systems: The THz frequency can offer better and more reliable performance with minimum latency when linked with the private or campus networks. Moreover, it supports devices, including Tactile Internet as well as Industry 4.0, which enable the wireless connections to reach optical fiber speeds, better throughput, machine interactions, large-scale sensor-actuator systems, real-world automation within industries and logistics units.

Terabit Device-to-Device as well as V2X: THz communication bands enable a direct terabit connection among nearby applications that assist rapid data transmission in homes, offices, or commercial circumstances [15]. This link can be frequently employed for rapid personal device transmission, high-resolution video streaming, multimedia kiosks, and brain-computer interfaces. Moreover, THz links can assist V2X communication to provide minimum latency with greater throughput connections among vehicles and infrastructure.

Secure Wireless Connectivity: Sparsity of the THz channel and directional beams provide intrinsic privacy by mitigating eavesdropping. A huge antenna array with accurate beam forming assists in resolving the free-space loss as well as climatic impact by limiting the transmissions towards the narrow routes [16]. Yet, it demands additional countermeasures to avoid interception and ensure better security during communication.

Terabit Wireless Backhaul: Implementation of fiber optics is expensive and challenging in specific regions. THz connection acts as a rapid wireless fronthaul or backhaul among the system components, including small cells, distributed antennas, macro BS and relays. This connection results in better system deployment, offers ubiquitous service to both rural and remote regions, and ensures better 6G connectivity by reducing the impacts caused by the digital divide.

THz Nano-Networks: Nano-technology permits the nanoscale applications to execute diverse operations on multiple domains, including biomedical, industrial, and military applications [17]. The THz frequencies are more effective for nono communication, since they can resolve the impacts caused by the RF as well as optical transceivers on the nanoscale. Moreover, the development of plasmonic transceivers, microchip emitters, and graphene-aided nano-antennas boosts the efficiency of THz-aided nano-systems [18]. Additionally, the early

nanosensing application assists in determining the chemical elements in regions with low concentrations and increases the ability of nano-scale applications.

The pictorial view to describe the applications of THz communication is depicted in Fig.2.

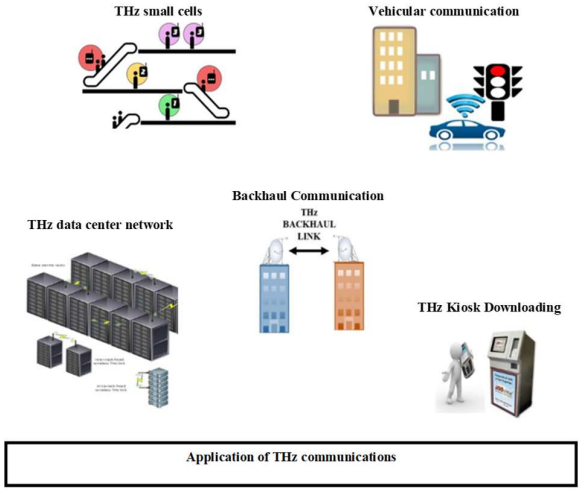


Fig. 2. Applications of THz Communication

3 Integration of Native-AI and Edge Computing for THz Communication in 6G: Detailed View

3.1. Native AI and Its Key Functionalities in 6G

In THz communication, the incorporation of AI technology holds a primary role in attaining minimum latency, better reliability and intelligent system behavior. In a communication network, native AI is openly incorporated into the BS of the THz channel, RIS controllers, edge nodes, user applications, and UAV relays [19]. This integration reduces the dependence on cloud applications and suggests appropriate decisions with minimum latency for ensuring better holographic communication within 6G networks.

The major functions of native AI in 6G THz networks are discussed below.

- The integration of deep learning techniques within the communication network assists in determining the highly dynamic and sparse THz channels within the network [20]. Further, generative approaches assist to generating real-time synthetic channel information for enhancing communication robustness as well as reducing measurement overload, which is significant for ensuring better robustness during the communication phase.
- By employing the strength of RL technologies, native AI presents adaptive and predictive beam alignment within the ultra-narrow THz channel [21]. It enables the communication channel to adapt to blockages, ecological, and mobility variations by minimizing beam recovery duration and satisfying the URLLC requirements.
- Native AI effectively processes the prior CSI trends, mobility, as well as multi-modal sensor data on the edge to effectively guide the channel beams, to rearrange the RIS and UAV paths [22]. Moreover, the edge AI models utilize the hardware accelerators to determine anomalous actions within the network in real-time scenarios.
- The integration of RL and advanced optimization techniques improves the ability of the model to accurately assign power and other resources to communication channels. Moreover, the AI-assisted RIS, as well as metasurface beamforming models, enhance propagation routes even in undefined channel circumstances.
- Native AI approaches assist in determining the anomaly actions on the communication channel [23]. Furthermore, the RL agents automatically reconfigure the system elements, communication routes, and beams to ensure predictive maintenance and zero-touch opimization.

3.2. Integration of Native AI and Edge Computing in 6G

The inclusion of native AI and edge computing in 6G communication channels is characterized as follows. This architecture contains THz BS, edge computing units, RIS controllers, federated learning coordinators, a UAV and an orchestration layer. The primary units of 6G communication systems are described below.

THz BSs: These BSs operate on high-frequency transmission bands by employing massive MIMO and hybrid beamforming units [24]. Moreover, the AI processors on the BS garner real-time information for beam control and estimating the communication channel. Furthermore, in 6G communication frameworks, this layer functions as an autonomous controller.

Edge computing units: These computing elements offer distributed intelligence and minimum latency during processing. This unit concentrates on safeguarding the privacy of the model during aggregation [25]. Moreover, these elements reduce cloud latency by ensuring security and scalability throughout the communication phase.

RIS controllers: These controller dynamically control the THz signal propagation process by employing programmable meta-atoms [26]. RIS converts the wireless framework into a controllable unit for increasing the network reliability, performance, and convergence.

UAV: This unit acts as a mobile THz relay as well as a flying edge module [27]. It permits effective positioning, connectivity, and NLoS improvement.

Federated learning coordinators: This server organizes distributed AI training by accumulating the network updates over BS, edge nodes, user applications, and UAVs [28]. Further, it assists in ensuring better privacy during the learning phase and boosts the network efficiency by hiding the sensitive information.

Orchestration layer: This layer manages every element within the network to offer dynamic slice generation as well as the scaling process [29]. Moreover, the fairness-aware learning procedure guarantees effective resource allocation within the network with the aid of Jain's fairness index.

The pictorial view of the integrated 6G communication model is displayed in Fig. 3.

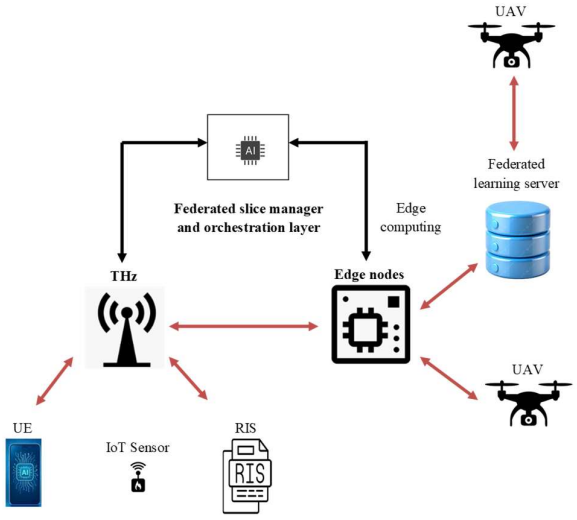


Fig.3. Integrated 6G Communication Model

4 A Comprehensive View of Existing Works, Challenges and Future Directions for Improving THz Communication in 6G

4.1 Discussion on Related Work

At present, numerous studies have been conducted to analyze the competence of integrating the emerging techniques like native AI for enhancing THz communication in 6G networks [30]. These investigations aim to establish diverse practical use cases for resolving the limitations faced by the THz spectrum, including path loss, highly dynamic communication channels, and narrow beams for increasing the performance of 6G wireless networks. Holographic telepresence and immersive XR demands Tbps information rates as well as minimum latency,

which can be attained through integrating neural architectures along with edge computing for accomplishing real-world THz channel estimation, local inferences, and beamforming, which assist in minimizing communication latency and synchronizing interactions with rendering [31]. Autonomous V2X systems highlight the significance of native AI by employing RL for determining vehicle trajectories and dynamically adjusting beam directions, which assist in resolving LoS blockages in the system by ensuring URLLC connectivity. Moreover, AI agents permits the selection of RIS routes, promoting RSU handovers and transforming to a hybrid THz-mmWave fallback connection [32]. AI-driven RIS within indoor THz configurations employs neural architecture to analyze spatial link among users, obstacles, as well as reflectors, which improves the predictive beam steering and minimizes overhead during channel estimation.

Edge-aided real-world resource allocation utilizes the strength of DRL for dynamically adapting spectrum, power, as well as beam directions. Moreover, they employ unique techniques such as EARAPO for tuning network energy consumption while satisfying QoS constraints [33]. Furthermore, self-healing THz systems employ native AI-aided Self-Optimizing Networks (SON) operations to accomplish automatic failure and anomaly detection, zero-touch reconfiguration, and predictive maintenance processes for guaranteeing better network performance by addressing problems associated with connection blockage and hardware failure.

Moreover, UAV-aided THz mesh frameworks expand their efficiency in rural, urban, and disaster scenarios, in which coordinated multi-agent RL permits UAVs to fine-tune flight route, energy utilization with respect to ground BS and RIS [34]. Furthermore, the ITU's IMT-2030 models identify the sub-THz as well as THz frequency bands as 6G elements, and 3GPP expands radio specifications over 100 GHz, and describes connectivity among short-range THz bands. Moreover, existing studies have concentrated on prototypes, spectrum distribution, and feasibility analysis along with commercial applications. The deployment of native AI–based THz systems visualizes intelligence integrated across the physical layer, management units and MAC, which enables real-world self learning and proactive self healing [35]. Additionally, the inclusion of Al technique helps manage predictive handovers, autonomous energy management, and proactive beam steering.

4.2 Practical Limitations and Mitigation

The integration of native AI and edge computing in THz-enabled 6G networks offers transformative capabilities, but several practical challenges must be resolved. Severe path loss and obstructions limit THz coverage, since the signals are easily blocked by walls or obstacles. Moreover, AI-powered beam prediction, dynamic beamforming, and RIS can proactively maintain a reliable connection. Additionally, high energy consumption arises from running advanced AI models at the edge, which can be mitigated through lightweight models such as TinyML, hardware accelerators, and edge offloading. Hardware limitations in high-precision THz transceivers can be partially offset by AI-based channel prediction and synthetic modeling that reduce exhaustive measurements. Privacy and security concerns increase when distributing AI across edge devices and solutions such as federated learning and privacy-preserving AI-enable model updates without exposing raw user data.

Beyond these generic challenges, implementing ZSM in federated and distributed 6G networks introduces additional complexities. Unlike centralized systems, ZSM can operate across heterogeneous edge domains with differing compute and energy capabilities, while coordinating non-IID data can slow model convergence and cause straggler effects. Employing intent-driven orchestration may introduce hidden misconfigurations and continuous cross-node signaling for ZSM and expose the network to adversarial manipulation. To address these challenges, approaches such as Byzantine-resilient aggregation, hierarchical federated learning, and lightweight intent verification can be used. Moreover, native AI-driven orchestration further enhances these strategies by embedding anomaly-aware zero-touch controllers and privacy-preserving aggregation protocols, enabling secure, scalable, and fully automated operation in federated THz 6G environments.

4.3 Future Prospects

Future research focuses on improving the scalability and fairness of federated learning in highly heterogeneous edge networks, in which each device within the network varies in computation, memory, energy, and communication capabilities. This helps address challenges associated with straggler nodes, non-uniform data distributions, and uneven update rates. Moreover, the

integration of potential solutions such as asynchronous training, adaptive client selection, hierarchical federated learning, and personalized federated models into an AI-native orchestration layer would enable resilient, scalable, and resource-aware federated learning, optimizing learning efficiency across dense THz-enabled 6G networks.

Additionally, future studies should perform ablation studies to measure the individual and combined effects of AI modules in the proposed architecture. Isolating DRL for adaptive beamforming and graph neural networks for topology-aware resource allocation can reveal their separate contributions to throughput, latency, and link reliability. Simulations using environments like DeepMIMO or THz-specific channel emulators enable selective activation of modules, while hardware-in-the-loop and real-world test beds provide empirical validation. These studies guide prioritization and deployment of AI functions in resource-constrained networks, ensuring that processing and energy resources are allocated to the most impactful modules.

5 Summary

A detailed review of existing studies related to THz communication in 6G networks is presented in this article. Further, this review explains the inclusion of native-AI and edge computing technology for THz communication within 6G networks and discusses the analysis of current research trends over conventional approaches. Finally, the future scope is also analyzed to improve THz communication in 6G networks. The summary table is presented in Table 1.

Table 1. Summary table

Elements	Role in 6G network	Enabling technique	Advantages	Disadvantages
Native AI	❖ Permits intelligent management of the network fibre.	➢ Neural networks	☑ Resource allocation and channel estimation	☒ Beam misalignment, fault detection and channel dynamics
RIS	❖ Modify the propagation circumstances	➢ Beam reflection and AI-tuned phase control	☑ Better convergence, low power utilization	☒ Low propagation and blockages
Federated learning	❖ Trains the AI techniques over distributed nodes	➢ Safe aggregation and differential privacy	☑ Scalability and privacy-aware AI	☒ Communication overhead and information heterogeneity
THz communication	❖ Presents ultra bandwidth for 6G applications	➢ Antennas, sub THz and THz bands	☑ Greater capacity connection for XR and digital twin	☒ Loss of server path and high absorption with a poor range
Edge nodes	❖ Offers low latency during implementation	➢ Federated learning, edge AI inference	☑ Local decision making and privacy preservation	☒ Struggles due to latency and backhaul bottleneck issues
UAVs	❖ Presents mobile and on-demand frameworks for THz connections	➢ Ai-aided flight controlling, dynamic locationing and network relays	☑ Better mobility and adaptive backhaul	☒ Energy constraints and minimum LoS

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