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# 6G Enabled Unmanned Aerial Vehicle Traffic Management: A Perspective

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**ABSTRACT** Unmanned aerial vehicles (UAVs) and UAV traffic management (UTM) have drawn attention for applications such as parcel delivery, aerial mapping, agriculture, and surveillance based on line-of-sight (LoS) links. UTM is essential to operate multiple fully autonomous UAVs safely beyond the visual line of sight (BVLoS) in the future dense UAV traffic environment. Various research and development teams globally take UTM initiatives and work on platform testing with different industrial partners. In the future, urban airspace will be congested with various types of autonomous aerial vehicles, thereby resulting in complex air-traffic management caused by communication issues. The UTM requires an efficient communication backbone to handle all airborne communication services. Existing cellular networks are suitable only for terrestrial communication and have limitations in supporting aerial communications. These issues motivate the investigation of an appropriate communication technology for advanced UTM systems. Thus, in this study, we present a future perspective of 6G-enabled UTM ecosystems in a very dense and urban air-traffic scenario focusing on non-terrestrial features, including aerial and satellite communication. We also introduce several urban airspace segmentations and discuss a strategic management framework for dynamic airspace traffic management and conflict-free UAV operations. The UTM enhances the adaptive use of the airspace by shaping the airspace with the overall aim of maximizing the capability and efficiency of the network. We also discuss the 6G multi-layer parameters, i.e., space, air, and terrestrial, for safe and efficient urban air transportation in three-dimensional space. Moreover, we discuss the issues and challenges faced by future UTM systems and provide tentative solutions. We subsequently extend the vision of the UTM system and design an advanced and fully autonomous 6G-based UTM system.

**INDEX TERMS** Unmanned Aerial Vehicle, Personalized Aerial Vehicle, UTM system, 6G, traffic management

## I. INTRODUCTION

THE UAV has been known for centuries and is commonly known as drones, aerial vehicles, flying cars, etc. The UAVs are flying robots, which can fly autonomously or are operated by human pilots. The massive boom of UAVs is due to their high aerial mobility, sophisticated battery technology, rotors, gyroscopes, GPS, cameras, sensors, low production costs, and a broad range of applications. The UAVs provide new potential for business in civil and non-civil applications such as parcel delivery, aerial mapping, agriculture, wildlife conservation, and surveillance. A previous study [1] classified the different types of drones/UAVs based on their platforms such as commercial, military, or civilian, and based on their characteristics such as capabilities, length, size, maximum altitude, speed, payload, weight, and flight time. The basic UAV classifications are personalized aerial vehicles (PAVs), cargo aerial vehicles (CAVs), small unmanned aerial vehicles (sUAVs), micro aerial vehicles (MAVs), nanoaerial vehicles (NAVs), and picoaerial vehicles (PAVs). Figure 1 shows the classification of various types of aerial vehicles based on the above-mentioned characteristics [2].

In the coming years, the production of UAVs and PAVs will increase and evolve with their technical capabilities; consequently, there is an immense need for airspace management. The Federal Aviation Administration (FAA) in the US, European Aviation Safety Agency (EASA) in Europe, Global UTM Association (GUTMA) including industry actors such as Google, Amazon, and several drone manufacturers and au-

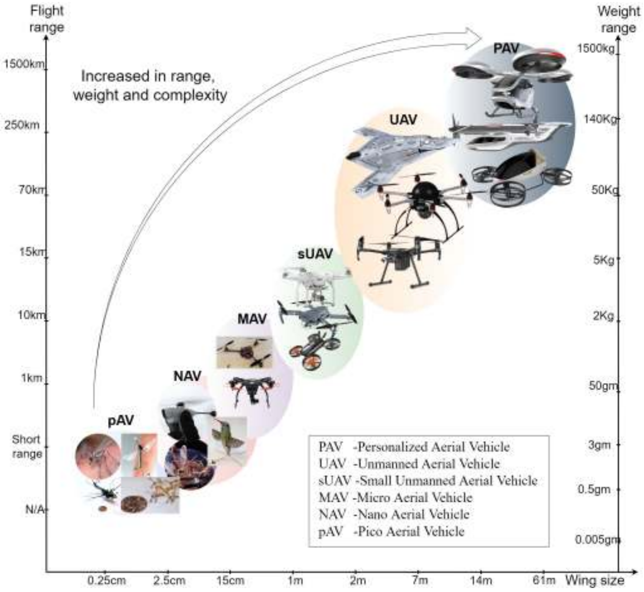

**FIGURE 1.** Comparison of different types of aerial vehicles based on various parameters

thorities from many countries around the globe are working effortlessly to create an efficient and safe UAV traffic management (UTM) system. Most UAV traffic management systems have similar functions, operations, and goals, as mentioned in US-UTM and EU U-Space [3]. Several UTM Concept of Operations (ConOps) are based on service-oriented, distributed, or federated architecture. The aforementioned traffic management concepts offer infrastructure and some conflict-free airspace operational concepts. Unmanned aerial system (UAS) service providers (USPs), also known as UAS service suppliers (USSs) in Europe, provide services to UAV operators and other regulated entities. UAVs and PAVs flying in low-and high-altitude airspaces represent a future breakthrough in urban air mobility (UAM) with the ability to move goods and humans from congested roads into the open air space in high-density urban cities [4]. UAM provides for fast, easy, and smooth journeys at a lower cost, while minimizing congestion, reducing pollution, and opening new economic opportunities. UAM includes different types of passengers and logistic aircraft such as air taxis and air cargo vehicles that operate independently in a number of settings, including major metropolitan areas and urban cities. UAM activities involve increasing levels of autonomy. Thus, the airspace will be swarming with various types of UAVs and UAM. The current UTM focuses only on the VLL airspace and supports BVLoS at some levels. The current UTM system is shown in Figure 2. However, for a smooth operation of BVLoS at both VLL and higher altitudes, the cooperation and harmonization of manned and unmanned airspaces is necessary. The current UTM does not fully consider an autonomous UAV, and there is no seamless connectivity for UAVs. We might use UAVs and PAVs interchangeably, depending upon the situation in the paper.

To access the UTM, the UAV needs to connect to the USS cloud service through the infrastructure to obtain critical information. UAVs can use existing infrastructures such as cellular base stations (BSs) or access points (APs). If an existing terrestrial network (i.e., 4G, 5G, V2X, C-V2X) is used, there are issues with UAV-to-Infrastructure (U2I) connectivity as the cellular BS uses a directional antenna for the ground vehicles only. It is also expensive to use a dedicated antenna in all BSs for aerial vehicles. Air-to-air (A2A) or air-to-ground (A2G) communication is currently used in commercial aircraft. If A2A and A2G are used, then it does not fully consider the dense aerial UAV transportation system, unlike the UTM system. The communication support for UTM requires three levels of connectivity, i.e. satellites operating at low-earth orbits, ground stations (such as cellular networks), and flying aerial vehicles. 6G is expected to integrate with terrestrial, non-terrestrial, and aerial networks to provide super ubiquitous connectivity and global connectivity. When integrated with satellite communication, 6G communication provides ultra-high speed with low-latency communications (uHSLLC), ubiquitous mobile ultra-broadband (uMUB), ultra-high data density (uHDD), and seamless connectivity. Hence, 6G is an appropriate technology for UTM systems. Research on UAV and aerial communication is gaining pace by leveraging research advancements in 6G technologies, including edge-cloud computing and machine learning [5]. As soon as 6G is launched and implemented, UTM will adopt 6G for its ecosystem, which might be in the mid-2030s if everything goes right.

The motivation for this study is based on the fact that there will be an exponential growth of advanced and autonomous aerial vehicles in the future. The low- and high-altitude airspace will be congested with various types of aerial vehicles in the coming decades, and air-traffic management will be more complex. It is obvious that there is an urgent requirement for an air-traffic management system, such as UTM, to handle high-and low-altitude aerial vehicles. UTM requires an efficient communication backbone to handle all airborne communication services. The existing terrestrial networks such as 4G and 5G New Radio (NR) have limitations in supporting aerial communications because wireless networks are exclusively tailored for terrestrial users. While the non-terrestrial-based 6G networks that integrate satellite, air, and terrestrial networks are appropriate candidates for future UTM systems. Therefore, for the smooth operation of UAVs and other air vehicles, advanced, multifaceted, multidimensional air-traffic management enabled by 6G is required. In this study, an advanced UTM architecture is designed that is intelligent and assists different types of aircraft operations in controlled and uncontrolled airspaces. It supports emerging technologies that evolve and scale as the density of aircraft increases. It offers safety for manned and unmanned aircraft, including terrestrial cars and buildings, by facilitating real-time situational awareness, dynamic flight management, and traffic density management to adjust scheduled operational activities based on 6G communication.

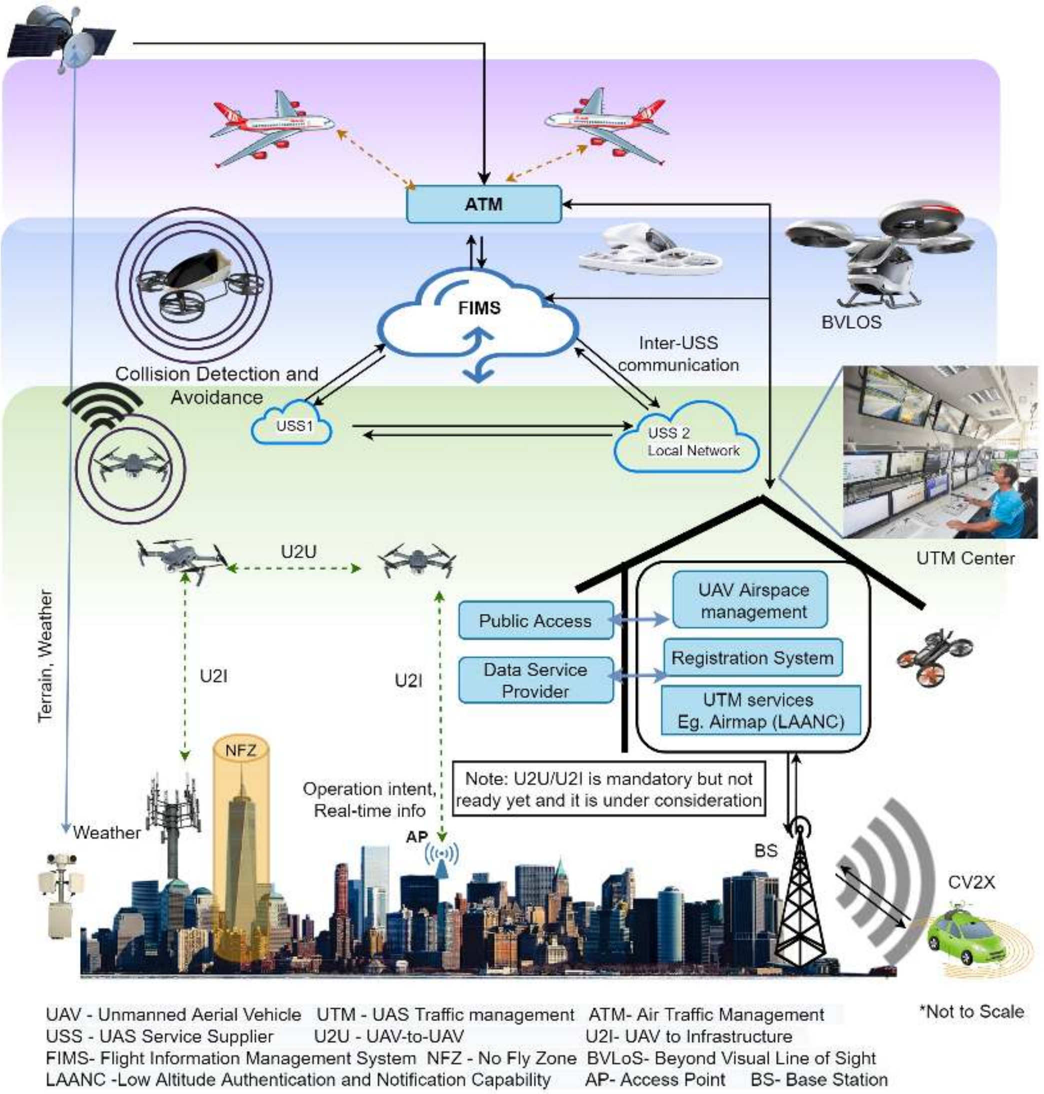

**FIGURE 2.** Current perspective of unmanned aerial vehicle traffic management (UTM) system

The key contributions of this paper are as follows:

- In this study, we aim to design an advanced UTM system enabled by 6G technology utilizing non-terrestrial networks (NTNs) for future air transportation.
- We discuss the multilayer, i.e., air, satellite, and terrestrial network integration for ultra-wide coverage in UTM ecosystem along with air-traffic automation based on machine learning techniques to optimize the urban air traffic and mobility system.
- We introduce various urban airspace segmentation and airspace traffic management suitable for UAVs and PAVs.
- We present the capabilities, and role of 6G in UTM and its support for UTM Ecosystems.
- We discuss how 6G communication technology can be used for advanced and fully autonomous UTM systems for safe and efficient future aerial traffic management.

The remainder of this paper is organized as follows. Section II presents the background of the airspace segmentation and air-traffic management system. Section III presents dynamic air-traffic management and its adoption in UAVs and PAVs. In Section IV, we present various communication technologies for UTM and discuss the communication requirements of UTM and the role of 6G in UTM systems. Section V presents the 6G communication support for the UTM ecosystem and discusses the space, air, and terrestrial design. Section VI discusses the design of an advanced and fully autonomous UTM system based on the 6G technology. Section VII presents the issues and challenges of UAV traffic management systems. Section VIII presents the discussion and research directions for the use of non-terrestrial-based 6G communication in UTM systems. Finally, Section IX provides concluding statements. A list of acronyms is provided in Table 1 for ease of reading and understanding.

**TABLE 1.** List of Acronyms

| | |
|---|---|
| A2A- Air-to-Air | MR- Mixed Reality |
| A2G- Air-to-Ground | MIMO- Multiple Input Multiple Output |
| AAN- Aerial Access Network | NAS -National Airspace System |
| ADS-B- Automatic Dependent Surveillance Broadcast | NAV- Nano Air Vehicle |
| AP- Access Point | NR- New Radio |
| AR- Augment Reality | NTN- Non Terrestrial Network |
| ASB- Aircraft Safety Bounds | OWC- Optical Wireless Communication |
| AF- Amplify and Forward | PAV- personalized air vehicles |
| AI- Artificial Intelligence | pAV- Pico Aerial Vehicle |
| BRLoS- Beyond Radio Line of Sight | RAN- Radio Access Network |
| BS- Base Station | RID- Remote ID |
| BVLoS- Beyond Visual Line Of Sight | RRC- Realtime Remote Control |
| CAV- Cargo Aerial Vehicle | SNR- Signal-to-Noise Ratio |
| CNN- Convolutional Neural Network | SDN-Software Defined Networking |
| CNS- Communication, Navigation and Surveillance | sUAV- Small Unmanned Aerial Vehicle |
| ConOps- Concept of Operation | SAT- Satellite Air Terrestrial |
| DAA- Detect and Avoid | U2I- UAV-to-Infrastructure |
| DRL- Deep Reinforcement Learning | U2U- UAV-to-UAV |
| D2D- Device-to-Device | UAM- Urban Air Mobility |
| EASA- European Aviation Safety Agency | UAS- Unmanned Aircraft Systems |
| EIRP- Effective Isotropic Radiated Power | UAV- Unmanned aerial vehicles |
| FAA- Federal Aviation Administration | uHDD- ultra high data density |
| FANET- Flying Ad-Hoc Network | uHSLLC- ultra high-speed-with low-latency communications |
| GEO- Geostationary Satellites | uMUB- ubiquitous mobile ultra-broadband |
| GUTMA- Global UTM Association | USP- UAS Service Providers |
| HAPS- High Altitude Platform Station | U Space- Urban Space |
| IoE- Internet of Everything | USS- UAS Service Suppliers |
| LAANC- Low Altitude Authorization and Notification Capability | UTM- UAV Traffic Management |
| LEO- Low-Earth-orbit Satellites | VLL- Very Low-Level |
| LoS- Line of Sight | VNF- Virtualization Network Functions |
| MAV- Micro Aerial Vehicle | VR- Virtual Reality |
| MAPF- Multi-Agent Path Finding | NUTM- National UTM |
| NFV- Network Function Virtualization | RUTM- Regional UTM |
| LAPS- Low Altitude Platform Station | WBCI- Wireless Brain Computer Interaction |
| MEC- Mobile Edge Cloud | XR-Extended Reality |

## II. BACKGROUND

Future UAVs and PAVs might need to share certain parts of airspace with commercial aircraft so that the UAVs and PAVs can fly in their designated airspace. This requires efficient airspace management so that different types of aircraft can access airspace equally. The airspace management enhances the adaptive use of the airspace concept by shaping the airspace into a range that is flexible and adaptive to changes in the needs of airspace users, with the overall aim of maximizing the capability and efficiency of the network. The airspace management system consists of two parts, i.e. airspace segmentation and airspace traffic management. The airspace management concept focuses on the integration of new airspace users (i.e. autonomous UAVs and PAVs) in an uncontrolled airspace (i.e., Class G) into commercial airspace users in the controller airspace. The advantage of the airspace management concept is that it opens up the airspace equally for various aircraft with both low and high levels of technical capabilities. Dynamic airspace adoption based on aircraft specific flight approval, technical capabilities, and performance parameters enable specific aircraft to operate in particular airspace layers.

### A. URBAN AIRSPACE SEGMENTATION

The concept of airspace segmentation assumes that airspace is segmented into multi-dimensional interactive map based on (a) 3D coordinates (x, y and z), (b) segment characteristics based on obstacles, geo-fences, weather, and (c) segment based on performance parameters such as detect and avoid (DAA), Communication, Navigation, Surveillance (CNS), etc. Depending on the particular aircraft authorization, technological capability and performance criteria, UAVs are permitted to operate in those airspaces wherein their specific characteristics comply with those required in that particular location. UTM monitors airspace requirements, UAV flight schedules and updates the paths over time accordingly. Besides, static geo-fences (e.g. buildings, towers, no-fly zones) and dynamic geo-fences (e.g. crime/accident scene, changing weather situations) are required to be inserted into the UTM system to avoid unseen risks for UAV and other aircraft. Further, the spatial and temporal separation between UAVs along with aircraft safety bounds (ASBs) should be considered for safe operation. ABS is an ellipsoid or complex polygon area surrounding each individual aircraft. ASB can be applied depending on the aircraft performance such as type, size, speed, technical capabilities, and applications. [6]. In the future, there will be a high density of UAVs/PAVs flying in different

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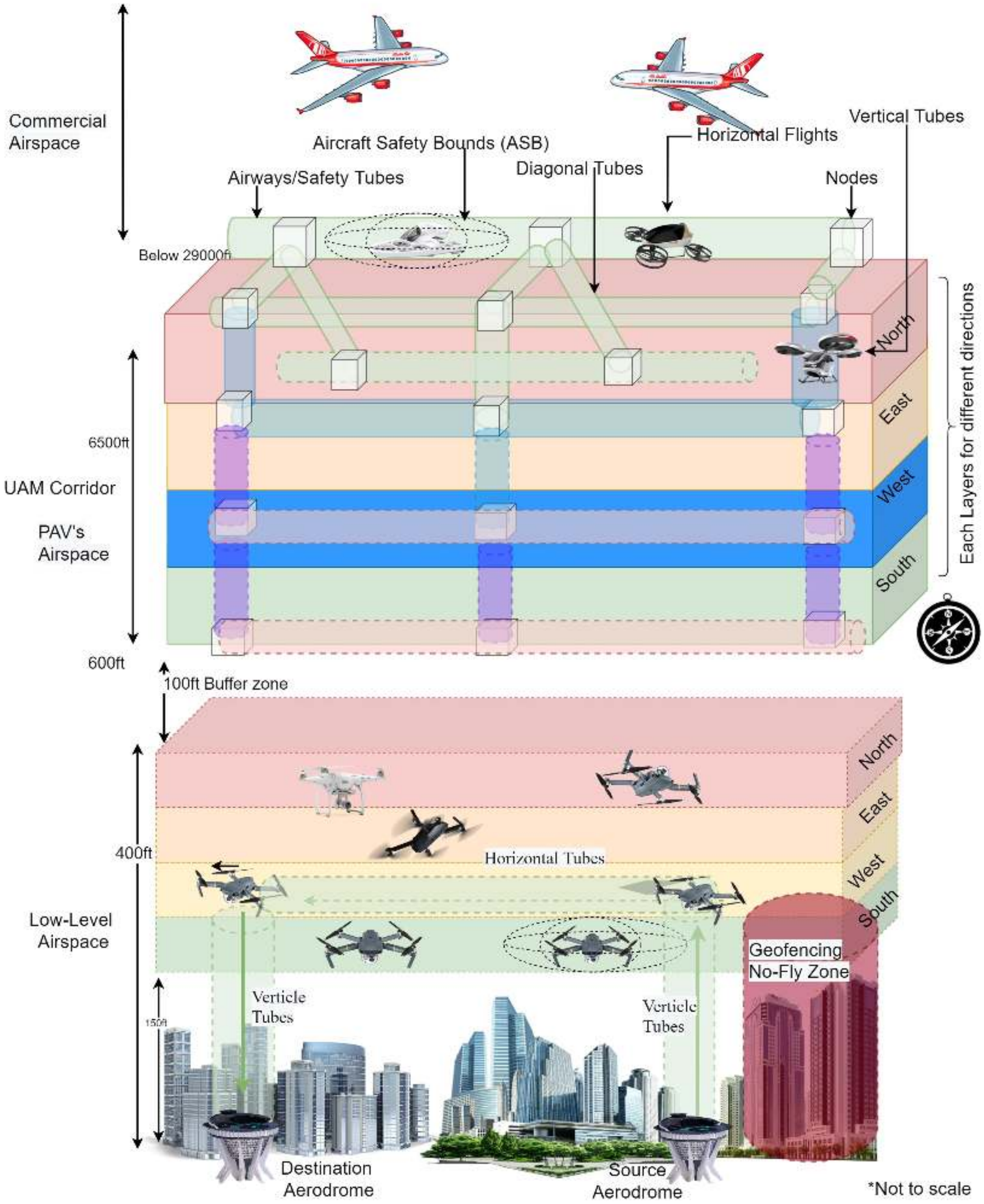

**FIGURE 3.** Proposed urban airspace segmentation and multilayer airspace model

layers of airspace, so it advisable to not involve humans in UTM monitoring and operation as human intervention would slow the UTM operation. It is safer and more efficient if the UTM system is autonomous without humans on the loop because it can minimize the accident or loss caused by the pilot erroneous behaviour like distraction [7]. As such, UTM should have complete awareness of all airspace users at all times to handle airspace hazards successfully.

### 1) Multilayer Airspace Model

The uncontrolled airspace, i.e., class G, can be divided into horizontal layers at various operational altitudes with specific separation, allowing safe flights for different types of aircraft. We present a perspective model for urban airspace segmentation and multilayer airspace, as shown in Figure3. In each layer, airways (or safety tubes) and nodes are designed such that the aircraft can operate in the specified layers for mobility [8]. The airways are aircraft corridors linked with nodes at each intersection within a layer horizontally or between layers vertically or even diagonally. The airways are configured to enable UAVs/PAVs to travel based on guided airway regulations (e.g. speed, flight directions and overall traffic volume). The cross-sectional size of airways/safety tubes is defined by the ABS of the UAVs, while their lengths are determined by the presence or absence of static-obstacles, airway-intersections or nodes. The aircraft route is a complete path from source to the destination that travels through several airways and nodes. The UAVs/PAVs communicates with other aircraft based on ad-hoc communication without directly communicating with UTM. This reduces latency and enables UAVs to make instant routing decisions. The different layers allow various aircraft to fly in the designated layers at varying speed levels. The aircraft speed increases with altitude as there will be few or no static obstacles at higher altitudes; hence, airway highways are feasible [8]. Thus, UAVs and PAVs can fly at different attitudes and destinations at various speeds in their designated safety tubes minimizing collisions between aircraft. A detailed description of low-altitude airspace management can be obtained in [9].

### B. AIRSPACE TRAFFIC MANAGEMENT

Urban airspace traffic management is accountable for managing different levels of airspace and traffic flows at tactical and strategic levels. At a strategic level, UTM requires efficient operation and optimum coordination of aircraft movements so that airspace is used more efficiently. It is strategically responsible for the segmentation and planning of the available airspace for optimal use. At a tactical level, UTM is accountable for observing, tracking, and surveillance of the airspace [9]. In order to provide tactical or situational awareness, the embedded data management system gathers all available traffic information (position, heading, and speed), weather, and geo-fencing information, and sends warnings to aircraft when required.

## III. DYNAMIC AIR TRAFFIC MANAGEMENT AND ADOPTION

The UTM is capable of enabling dynamic airspace segmentation and traffic management. The UTM can split the airspace into distinct segments, as discussed previously. It establishes a strategic management framework that approves UAV operation requests dynamically within the same air segment based on actual traffic and expected demands. If full capacity is reached or a proximity-warning alert is received, UTM revises the flight plans. Moreover, a dynamic notification can be automatically launched to abort or interrupt UAV flights in case of emergencies such as rescue helicopters, crime squads, and disasters. The UTM can guarantee optimum flight management and conflict-free aircraft operational activities based on strategic management, and it provides dynamic geofencing and conflict avoidance management. However, aircrafts are accountable for deviation, operation improvement, and rescheduling of flights based on weather conditions, static topography, and dynamic obstacles. Moreover, the dynamic air- traffic management includes technological aspects such as performance-related restrictions on the CNS and DAA, and operating criteria or permission for UAVs to operate in a particular layer.

Path planning is one of the techniques used in UAV air-traffic management. Optimum path planning for efficient decisions during critical flight has become a prime concern for UTM systems. The objective of path planning strategies is not only to find the best and fastest path to reach the final destination but also to prevent unseen collisions and ensure the safety of the UAVs by providing a collision-free zone. This helps the UAVs decide the optimal path themselves, thereby improving their performance [11]. A previous study [12] used an enhanced genetic algorithm and A* algorithm to guarantee that the UAVs cover the shortest path from the source to the destination with fewer error corrections. However, another study [13] proposed a multi-agent path finding (MAPF) based on an enhanced conflict-based search mechanism for UTM that performs better and has more time efficiency than incremental planning based on Cooperative A*, and it can satisfy timely response on the delivery request to UTM service users. Several other studies have been conducted to improve the path planning for UAV systems [14], [15], [16], [15], [17], and [18].

## IV. COMMUNICATION TECHNOLOGIES FOR UTM

The existing 4G and 5G-NR technologies used for V2X communication in autonomous vehicles can be candidates for UAV communication. While driving on the road, the autonomous vehicles use various sensors and AI technology for localization, sensing, collision detection, maintaining 2-D lane detection, lane change, safe distance, and critical message exchange between other vehicles etc. The 5G NR can connect autonomous vehicles and infrastructures based on sidelinks (mode 1 and mode 2) [19] providing NLoS visibility and a greater degree of predictability for improved traffic safety and autonomous driving. The benchmarks from 5G NR for V2X can be used for PAVs/UAVs and UTM ecosystem. In PAVs, the specifications are similar to terrestrial autonomous vehicles but with additional requirements for aerial 3-D space connectivity, where the aerial vehicles need precise aerial location information for collision avoidance, flight in 3-D lanes, exchange status and other information with neighboring aerial vehicles. The horizontal separation distance between the PAVs for collision detection and avoidance were 250m, while the vertical safe distance was 50m [20]. Similar to the terrestrial vehicles traveling on their designated lanes, the PAVs fly at the designated safety tubes in the airspace to minimize collisions with other aircraft. However, the PAVs/UAVs wireless communication in the airspace poses new design issues owing to high mobility, battery constraints, frequent handovers, uHSLLC, LoS and downlink interference from cells compared to terrestrial mobile users. The use of 4G, and 5G NR may provide the communication links such as U2U and U2I but they do not guarantee full network coverage, because wireless networks are tailored exclusively for terrestrial mobile users. The 6G can overcome several limitations of previous generation wireless communication for aerial communication. The 6G communication integrates non-terrestrial network to provide 3-Dimensional (3D) connectivity, ubiquitous services based on AI in the 3D space that is suitable for the aerial communi-

**TABLE 2.** Comparison of implemented 4G, 5G NR and proposed 6G cellular communication [10]

| Major Features | 4G | 5G NR | Proposed 6G for UTM |
|---|---|---|---|
| Peak data rate/device | 1Gbps | 10 Gbps | 1Tbps |
| Mobility support | up to 350km/hr | up to 500km/hr | >1000Km/hr |
| Satellite integration | No | No | Fully |
| Artificial Intelligence | No | Partial | Fully |
| Extended Reality (XR) | No | Partial | Fully |
| End-to-end (E2E) latency | 100ms | 10ms | <1ms |
| Autonomous Vehicle | No | Partial | Fully |
| High precision positioning | 10m | 1m | cm level |
| Connection density | 100,000//km$^2$ | >1million/km$^2$ | >10million/km$^2$ |
| Reliability | <99% | About 99.9% | >99.999% |
| THz communication | No | Very limited | Extensive |

cation. It provides seamless connectivity, high precision positioning, ultra-high bandwidth, real-time remote controlling features in a very high density of aerial vehicle scenarios. We discuss different types of wireless communication technologies suitable for the UTM ecosystem.

### A. 4G/5G NR COMMUNICATION

The 4G and 5G-NR communication may be used for very low-altitude UAV communications based on U2U and U2I modes. However, they have limited coverage, while the UAVs and PAVs fly in a 3D environment and at a much higher altitude, i.e., beyond 150 m to 2 km, further enhancing mobility issues. The UAVs can also be used as BSs to provide 4G and 5G cellular networks in remote locations that have limited coverage due to natural disasters [21]. We will not discuss the UAV-based cellular base station because it is beyond the scope of this study. The existing 4G and 5G NR terrestrial networks (TNs) are fixed at a particular location and can support ground users or vehicles that move on fixed routes. However, UAVs are capable of randomly and sporadically moving in any 3D direction in space at a very high speed. 5G can resolve the two-dimensional position but not the 3D position and can have issues in solving the occlusion. In TNs, occlusion occurs frequently, which is challenging to handle owing to its similar structures and colors. 5G has limited connectivity and incurs frequent handovers for high-mobility UAVs due to the use of directional antennas in the BS. It has a limited coverage range, which is unsuitable for PAVs and UAVs flying BVLoS. It is necessary to install additional antennas in the entire BS to cover high-density UAVs in the sky, which might be expensive. The cellular V2X and 5G communication cannot handle dynamic handover management in such a high-mobility scenario and cannot provide reliable communication with route planning, which is critical for autonomous UAVs/PAVs flying in the airspace. Moreover, cell interactions at higher altitudes are very different from those of TNs. There are issues with high-altitude propagation that result in higher downlink interference owing to the risk of LoS propagation of interfering BS [22]. Some issues with existing cellular networks suffer from interference owing to the high density of UAVs in an urban scenario. The highest speed of mobile devices increased from 350 km/h in 4G to 500 km/h in 5G for terrestrial vehicles. The average speed of PAVs is expected to reach more than 350 km/h, while 6G can support speeds of more than 1000 km/h, which is very high compared to 4G and 5G [23]. Latency, navigation, and collision detection play an important role in highly dense and urban air mobility scenarios, which require uHSLLC requirements, energy-aware deployment, and efficient channel models for UAV/PAV communication. In 5G networks, the research is focused on solutions for NR and radio access networks (RAN) to integrate high-altitude platforms to provide ubiquitous, low-latency, and broadband services [24]. 5G provides enhancement of 2D terrestrial connectivity and services as compared to its previous generations; however, it cannot fully satisfy all requirements of 3D aerial communication and mobility management. Observing the prospects of emerging technology and services for the next decade, there is a strong need to go beyond 2D infrastructure coverage to fully 3D native services.

### B. 6G COMMUNICATION

One of the revolutionary trends for 6G networking is having "connectivity from the sky." The integration of NTN is considered to be a prospective feature of 6G communication. NTN refers to networks operating through the airspace for aerial vehicle communication that provides large global and ubiquitous connectivity [25]. A2A and A2G are used for commercial aircraft that do not support a high density of aerial vehicles, whereas existing TNs can support ground subscribers but have limited connectivity for high-mobility UAVs. Thus, 6G is an appropriate and enabling technology for UTM systems. Table 2 lists the differences between existing 4G, 5G NR, and the proposed 6G technology [10], including future vision and characteristics. It includes uHSLLC, uMUB, uHDD, seamless connectivity, ultra-high-speed data transfer rate, AI, smart sensors, integrated radar, precision positioning, and wide network connectivity. Prospective 6G communication is expected to be a global connectivity (GlobCon) service that provides smart automation and integrates AI to provide additional new services such as ultra-smart cities, XR (including AR, VR, and MR), autonomous connectivity (such as autonomous vehicles and UAV connection), wireless brain–computer interaction (WBCI), and AI-based Internet of Everything (IoE) [26]. 6G is expected to provide 100 times higher wireless connectivity and increased

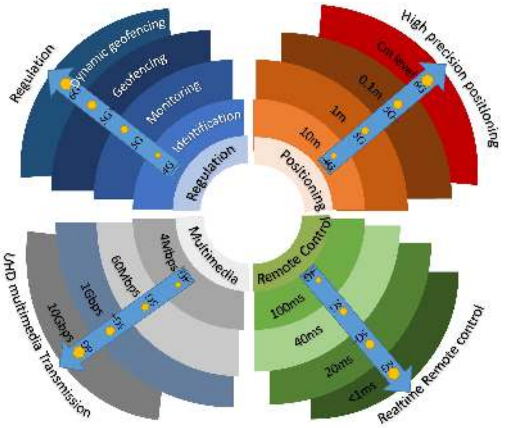

**FIGURE 4.** 6G technology for UAV communication and applications

performance by several times compared to its 5G counterpart. The most important innovations that will be the leading factor for 6G are the inclusion of UAVs, satellite connectivity, terahertz (THz) band, connected intelligence with machine learning (ML), optical wireless communication (OWC), 3D networking, and wireless power transfer [27] [28].

Thus, satellite integration in 6G communication provides a peak data rate of 1 Tbps per device with high-mobility support of 1000 km/h flying in autonomous mode in a very dense urban aerial scenario. It has the capability of high-precision positioning at the centimeter level.

### C. COMMUNICATION REQUIREMENTS AND ROLE OF 6G IN UTM

The communication requirements of the UAV and UTM, along with its capabilities and role of 6G in the UTM ecosystem are as follows:

- High-precision positioning and seamless coverage: The UAVs flying in different layers of airspace require high-precision positioning and seamless coverage, which are both essential for network development and planning. A secure connection along with a broad coverage of the network guarantees seamless connectivity, while the UAVs are flying autonomously. For 4G/5G cellular networks, enveloping a wide range of coverage at various altitudes and seamless connectivity is a significant challenge.
  6G integrates radar technology, which provides high-precision localization and positioning. The construction of dynamic maps and 3D positioning in the sky with the help of several high-tech sensors provides high-precision positioning of the UAVs as well as dynamic objects. In 6G, multi-level networks (3D) comprising ultra-dense heterogeneous networks can increase the number of connected UAVs in high-density environments by approximately $10^7$ devices/km$^2$, which is ten times greater than the 5G connection density. A systematic, high-quality, and secure wireless connection with broad 6G coverage offers robust, affordable, and seamless aircraft connectivity beyond BVLoS. The high-capacity backhaul connectivity provided by the high-speed OWC system supports a large volume of UAV traffic information.

- Remote and real-time control (RRC): Remote and real-time connections rely on real-time flight status reports from UAVs such as geo-coordinates and equipment status. RRC allows a remote controller to issue command and control orders in real time. Specific data rates and latency requirements must be fulfilled to allow remote control and tracking of the UAVs.
  With 6G, numerous UAVs can be operated outside the VLoS or operate independently (i.e., autonomously in BVLoS) without direct pilot control. 6G communications integrated with satellites can provide connectivity over infinite distances and provide near real-time control with less than 1-ms latency. If UAVs have 6G connectivity, they can effectively be operated from anywhere in the world with the help of UTM system.

- Multimedia transmission: Some UAV-based systems involve the transfer of data to ground stations such as live multimedia/video streaming or data analysis to save time. In the future, advanced multimedia services such as truly immersive XR, 3D holograms, 360° ultra-high image/video quality shoots (4K and 8K videos) need to be realized. Moreover, extended reality (XR) experiences, which include AR, VR, and MR services, require higher data rates at higher Gbps levels.
  A large bandwidth data connection requirement in the UTM can be fulfilled by the 6G network. An adequate bandwidth should be guaranteed for improved data traffic capabilities that come with the 6G technology so that the UAVs do not continuously drop connectivity and can transmit high-quality live videos. 6G is expected to provide a 10-Gbps peak data rate to support multimedia transmission [29].

- Aircraft Identification and Regulation: In the future, the use of automatic dependent surveillance broadcast (ADS-B) for detecting commercial aircraft might saturate its frequencies owing to the large volume of UAVs. Thus, a new identification mechanism is required. The remote ID information can be used based on 6G, which acts as license plates similar to license plates in vehicles. The remote ID is transmitted using radio waves. The Aircraft registration, identification, tracking, and regulation require efficient cellular network connectivity. By tracking and monitoring UAV positions and path information, UAV traffic conditions can be automatically measured, and early detection of geofencing and possible threats can be rendered accordingly.
  The UTM ecosystem implements low altitude authorization and notification capability (LAANC) for UAVs so that UAV operators can access the controlled airspace

near the airport locations through real-time validation of airspace authorization below permitted altitudes and manage dynamic geofencing [30].

Figure 4 shows the solution for the communication requirements and role of 6G technology for UTM systems that provide advanced features compared to the previous generation of wireless communications.

## V. 6G COMMUNICATION SUPPORT FOR UTM ECOSYSTEM

The 6G communication integrates the terrestrial, aerial and non-terrestrial network that provides 3D connectivity, and ubiquitous services in 3D space. The implementation of an aerial access network (AAN) using NTN including satellites as well as low-and high-altitude platform stations (i.e. LAPS and HAPS) complementing heterogeneous terrestrial networking provides communication, computation, and caching (C3) for the UTM ecosystem [5]. Communication support for UTM ecosystem has three levels, 1) satellites operating at geostationary and low-earth-orbit satellites (GEO/LEO), 2) dedicated ground stations (cellular networks), and 3) Flying ad-hoc networks (FANET) [39] operating in midair as shown in Figure 5.

In the UTM ecosystem, one of the greatest problems in the future will be mobility management of UAV traffic and its integration with commercial aviation. Additionally, UAVs suffer from difficulties in wide-aerial network coverage, BVLoS communication, connectivity, and interference. If UAVs lose communication through cellular networks, then solutions for handling such scenarios need to be established. Space or NTN is a 3-D hierarchical and heterogeneous architecture that includes UAVs, HAPS/LAPS, and constellations of LEO/GEO satellites. It provides continuous global tracking and surveillance of the aircraft. It also integrates with terrestrial networks via a service links.

As of writing this paper, there are several research works related to aerial vehicle communication based on cellular technology while very few articles are available related to UTM and other UAV traffic management utilizing cellular technology. We compared and discussed the existing schemes along with their advantages and disadvantages in detail in Table 4.

In [31], LTE was used with the UTM to provide updates regarding situational awareness such as geo-fences, weather conditions, traffic information, among others, to the UAVs. LTE was used to provide tracking and surveillance systems using various sensors that enhance the air-traffic control in U-Space. However, the LTE had a limited vertical coverage due to the direction of the antenna and was unsuitable for high UAVs/PAVs flying beyond the VLL altitude.

The authors in [32] introduced regional UTM (RUTM) with a concept similar to ATM, which was managed by local government and National UTM (NUTM) in Taiwan. They integrated 4G/LTE connectivity in UTM so that the UAVs can fly BVLoS to a distance of 8km in suburban locations. In their paper, 4G assisted as a reliable solution for detect and avoid system. However, 4G was only used for sUAVs and for limited distance and vertical altitude.

The authors in [33] presented a spatial temporal routing algorithm for UTM that minimized route planning and allowed small UAVs to avoid static as well as dynamic obstacles in an urban air traffic environment. The authors simulated their proposed scheme and showed that their routing algorithm can substantially decrease the route planning time. They discussed about the communication model for the UTM system but did not clearly mention which cellular technology they were using in their UTM.

The authors in [34] proposed a service orchestration in network function virtualization (NFV) and edge computing utilizing 5G network for UAVs. They evaluated their scheme by simulating 5 to 25 number of UAVs with a maximum of 20 BSs. They claimed that their scheme demonstrated effectiveness to achieve the design goals; however, they have not given any details of the 5G communication parameters. Moreover, they used only few UAVs to validate their systems.

In [35], the authors leveraged the 5G MEC enabled by SDN to provide an efficient UAV traffic control and management system. The authors evaluated the impact of scalability, reliability and network delay on the UAV flight control. In their scheme, MEC helped to reduce the communication latency in UAVs so that the UAVs could fly reliably within the defined geo-fences or geo-restricted location. However, the disadvantage of this paper is that the emulated performance result was based on only one UAV and a single edge node and did not discuss about NTN connectivity.

The authors in [36] provided a high-level research on aerial experimentation, and research platform for advance wireless (AERPAW) infrastructure for UAV based on 5G and beyond 5G (B5G) communication. It delivered advance wireless system research that supported UAS applications, development and testing including policies, regulations and other technological systems. This paper mainly focused on 5G standardization, research challenges and architecture for UAVs but they neither discussed on how the 5G can be used in UTM systems nor any non-terrestrial connectivity.

The authors in [37] enhanced the safety and security of the UTM and UAVs in urban scenarios by using 6G network integrated with AI technology. The authors integrated the urban air mobility with the 6G cellular networks that could handle extremely dynamic airspace topology as well as it could help in efficient identification, positioning and performance management. The AI techniques at the edge-node helped in reducing latency and provided real-time applications such as route change, audio and video transmission from UAVs, etc. However, this paper lacks the real-life capability of UTM applications such as NTN integration, network security, energy efficiency and reliability.

The authors in [38] utilized 6G in UAVs and UTM based on NTN to extend broadband connectivity beyond low-altitude coverage. They also integrated ML technology in the UAVs to design and optimize cellular-connected UAV networks and enhanced their features. However,they did not

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**TABLE 3.** Comparison of existing UTM schemes based on cellular networks

| Ref. | Connect-ivity Type | Network Scenario | Objective | Advantages | Disadvantages |
|---|---|---|---|---|---|
| [31] | LTE | Air-Ground | LTE is used in UTM service to provide situational awareness | LTE provides tracking and monitoring that enhances the air traffic control system | LTE has a limited vertical coverage beyond VLL altitude |
| [32] | 4G/LTE | Air-Ground | Regional UTM integrates 4G/LTE connectivity in UTM so that the UAVs can fly BVLoS. | 4G could assist as a reliable solution for detect and avoid system | 4G is used for limited UAV distance and altitude |
| [33] | – | Air-Ground | Proposed a spatial temporal routing algorithm for UTM to minimize route planning and allowed sUAVs to avoid obstacles | The UAV routing algorithm can decrease the route planning time significantly. | They did not clearly mention the type of cellular technology used in UTM. |
| [34] | 5G | Air-Ground | Proposed a UTM based Service orchestration in NFV and MEC utilizing 5G network for UAVs | They integrated edge cloud computing, NFV with 5G technology in the UTM system. | Their result was based on a very few numbers of UAVs and have not provided enough information on 5G based UTM. |
| [35] | 5G | Air-Ground | Presented efficient UTM framework based on 5G MEC utilizing SDN for high reliability and low latency in UAV communication. | 5G MEC helped to reduce communication latency in UAVs that provided reliability to fly UAV within the geo-fence boundary. | The emulated performance result was based on only one UAV and a single edge node and did not include NTN connectivity. |
| [36] | 5G/B5G | Air-Ground | Provided a high-level research on AERPAW for UAV based on both 5G and B5G communication and discussed UAV applications. | Provided support for UAS applications, development and testing including policies, regulations. | No discussion related to implementation of 5G in UTM system nor any NTN connectivity. |
| [37] | 6G | Air - Ground | 6G based UTM powered by AI for safe and reliable UAVs operation by virtually sharing radio resources between aerial/terrestrial platforms. | Integration of urban air mobility in UTM | Does not include NTN communication, network security and reliability. |
| [38] | 6G | Space-Air-Ground | Use of 6G and NTN in UAVs and UTM to provide broad band connectivity beyond VLL coverage | Integration of 6G and AI in UAVs and UTM to enhance their features. | No discussion regarding utilization and connectivity of Satellite in UTM system. |

discuss in detail the connectivity and utilization of NTN networks such as different types of satellites or HAPS in UTM systems.

The integration of UTM architecture with 6G cellular networks seems to be a mandatory technical requirement ahead of deploying UAVs at urban areas. Therefore, UAV service may just become a new service slices within 6G to share the database required for UAV identification, localization and performance management.

### A. SPACE-AIR-TERRESTRIAL COMMUNICATION PARAMETERS

In multi-layer space-air-terrestrial (SAT) architecture, any entity of a multilayered network is a node that can be used to provide a variety of services to other subsystems through communication links. Any network connection may be either unidirectional or bidirectional. Various SAT nodes are located at different layers of airspace as shown in Figure 5. The 3GPP recommends a set of parameters that need to be taken into account while evaluating and performing satellite scenarios [40]. The SAT system design parameters are given in Table 3 based on the 3GPP ITU guidelines [40] for integrating SAT communication in the UTM ecosystem. The space, aerial and terrestrial communication designs are discussed below.

#### 1) Space Design

The GEO and LEO satellites can operate in both the S-bands and Ka-bands. For downlink transmission, GEO and LEO operate at 2 GHz in S-bands and 20 GHz in the Ka-bands, while for uplink transmissions, GEO and LEO operate at 2 GHz in S-bands and at 30 GHz in the Ka-bands represented by S and Ka in Table 3. The GEO satellites have a fixed orbit at an altitude of 36,000 km from the Earth's equator whereas the LEO satellites can be operated at two altitudes,600 km and 1200 km. The LEO satellites operating at 1200 Km altitude provides the system Bandwidth (BW) of 30 MHz for downlink and uplink in S-bands. While LEO satellites operating at 600 km provide BW of 400 MHz for downlink and uplink in Ka-bands as shown in Table 3. The GEO satellites can sustain an extremely high effective isotropic radiated power (EIRP) of 73.8 dBW while the LEO satellites have a maximum EIRP of 54 dBW. The EIPR is responsible for antenna transmit power, the cable loss, and the transmit antenna gain. The LEO satellites (such as Starlink from SpaceX [41]) use energy-efficient components; provide better signal strength, wide coverage, very low latency, and super-accurate positioning than GEO satellites. The integration of LEO in 6G is expected to be 100 times faster than its 5G counterpart as they provide precise information on spatial, and temporal coverage. The satellite internet technology operates in THz frequency, indicating that it has a high-data rate, uHSLLC, uMUB as compared to mmWave and fiber networks [29]. In 6G, highly directional antennas will be used and narrow

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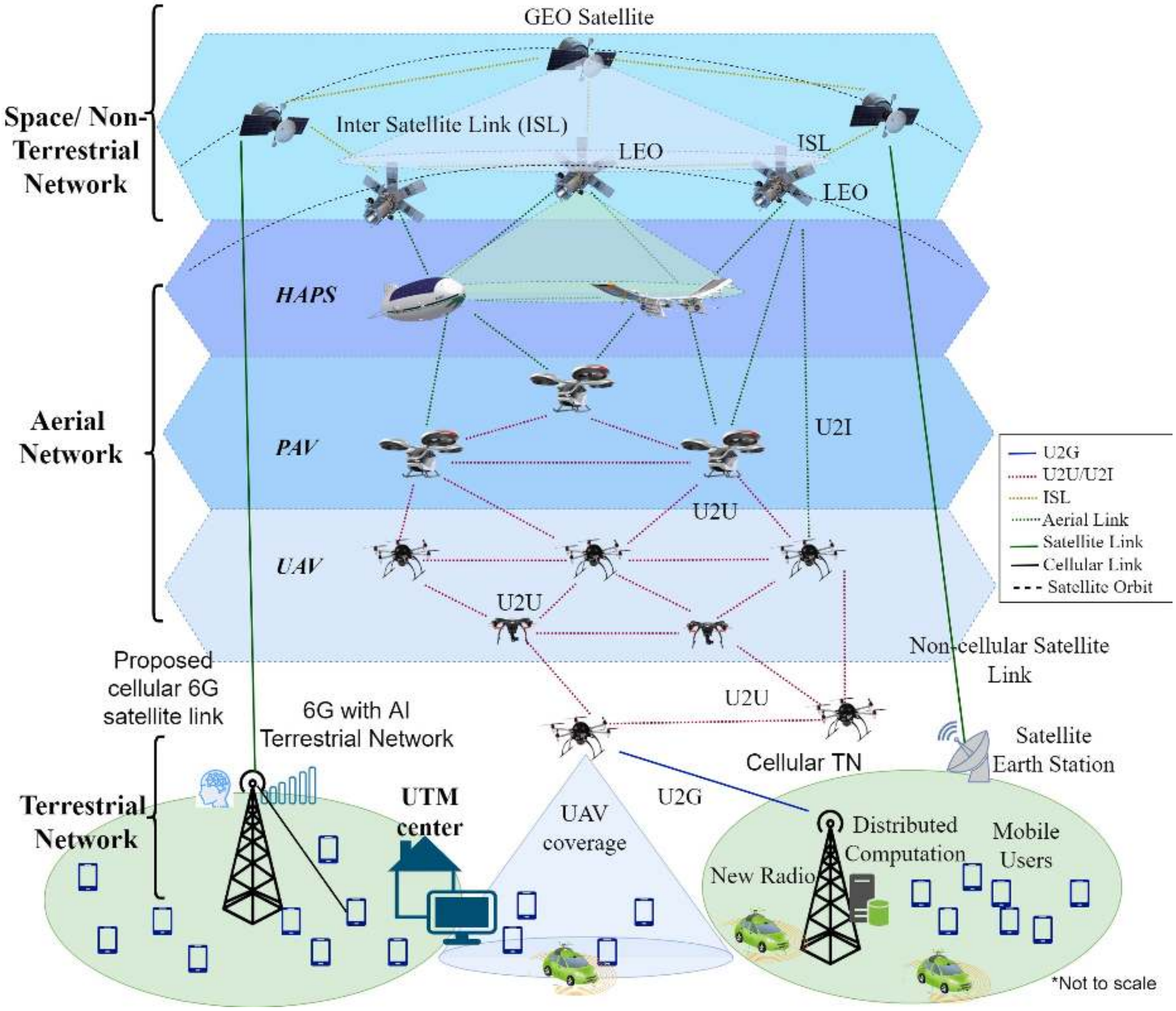

**FIGURE 5.** 6G communication support for UTM ecosystem

beam-width introduced by directional antennas reduces interference for the UTM communication system.

### 2) Aerial Design

The HAPSs deliver a wide coverage area providing low-cost deployment of wireless services, re-usability, lower delays, and signal attenuation as compared with satellites. HAPS can provide continuous coverage for long term and HAPS with greater payload capabilities are expected by 2023. The low-altitude HAPS operate at 38 GHz with a BW of 400 MHz based on the ITU-R guidelines [42]. The HAPSs offer antenna gains up to 27.7 dB/K without considering satellite infrastructures as shown in Table 3.

### 3) Terrestrial Design

Similarly, the terrestrial cellular BSs are installed at an altitude of approximately 30m above the ground and usually operates on mmWaves. It also operates on the 2GHz and 20GHz frequency bands. The receiving antenna gain temperature for the terrestrial network is 39.7 dBi and omnidirectional antenna unit gains need to be considered at sub 6 GHz according to [42]. The TN will be integrated with ubiquitous intelligence through AI so that the networks can optimize themselves on their own. The AI approach can also be used to build complicated system models in an autonomous manner. The TN communicates with the satellites based on the 6G satellite links.

## B. MULTI-LAYER SAT NETWORKS

The multi-layer SAT networks can integrate all or a combination of nodes from space, air, and ground networks to provide an efficient 3D communication paradigm for UTM ecosystems. The GEO and LEO satellites communicate with each other using inter-satellite links, while the satellites within the same layer communicate based on intra-satellite links. The different integrations primarily based on NTN can be GEO-LEO integration, GEO-HAPS integration, and GEO-LEO-HAP integration. Multilayer integration provides (a) service ubiquity: it provides global coverage or cross-country wide geographical coverage through space–air links; (b) scalable

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**TABLE 4.** Space-air-terrestrial communication parameters [42]

| Parameters | Space (Satellites) | | | | | | | | Aerial (HAPS) | Terrestrial Base Station(BS) |
|---|---|---|---|---|---|---|---|---|---|---|
| | GEO | | | | LEO | | | | | |
| | Downlink | | Uplink | | Downlink | | Uplink | | | |
| Height (h) [Km] | 36,000 | | 36,000 | | 1200 | 600 | 1200 | 600 | 20 | 0.03 |
| Bandwidth (B) [MHz] | 30 | | 400 | | 30 | 400 | 30 | 400 | 400 | N.D |
| Frequency (fc) [GHz] [S & Ka-band] | 2(S) | 20 (Ka) | 2(S) | 30(Ka) | 2(S) | 20 (Ka) | 2(S) | 30(Ka) | 38 | 2 20 |
| Max. EIRP [dBW] | 73.8 | 66 | 73.8 | 46.2 | 54 | 48.6 | 36 | 46.2 | 27.9 | N.D |
| Rx. Ant. gain Temp. (G/t) [dB/K] | -36.6 | 19 | 15.9 | 28 | -31.6 | 1.1 | 15.9 | 13 | 27.7 | 0 [dBi], 39.7 [dBi] |

service: it helps in offloading data traffic from congested or low-computing terrestrial nodes to space–air nodes with high computation power; and (c) connected service: it provides connection services when the TNs are congested with high network traffic during peak times or in an emergency situation.

The authors in [43] improved the SAT networks system, evaluated the performance of different multilayered SATs, and compared the network performance with the baseline deployment. The authors used a downlink system model for the SAT networks where the intermediate nodes in each air/space layer use cooperative Amplify and Forward (AF) relay protocol. In SAT networks, the signal travels from GEO, LEO, HAPS, and Terrestrial (GLHT) network to the target nodes through N-hops. The signal-to-noise ratio (SNR) $\varphi_{i,j}^{(n)}, i, j \in G, L, H, T$ at the nth hop between source,$i$, and target $j$ is calculated as

$$\varphi_{i,j}^{(n)} = EIRP_i + \frac{G_j}{t} - PL_{i,j} + \delta_{i,j} - k - B - N \quad (1)$$

where PL is the path loss, $\frac{G_j}{t}$ is the receiver antenna gain-to-noise temperature, $\delta$ is the fading, B is channel bandwidth, k is Boltzmann constant and N is the noise. The end to end SNR for a fully cooperative AF system is given as

$$\varphi_{\mathrm{AF}} = \left[ \Pi_{n=1}^{N} (1 + \frac{1}{\varphi_{i,j}^{(n)}}) - 1 \right]^{-1} \quad (2)$$

The average channel capacity that is related to the end-to-end SNR given in equation (2) can be calculated. The authors in [43] compared the average capacity obtained by different multi-layer integration with GEO only configuration as a function of the carrier frequency, elevation angle, etc. from the Table 3. The HAPS amplifies the signal from the upstream satellites and forward towards the terrestrial network. They showed that the GEO-HAPS integration performs better than other types of integration. Moreover, the Ka-bands transmission provides a higher coverage capacity. It achieved six times higher capacity than the standalone GEO-only configuration, while full integration of GLH only resulted in more complexity without any significant increase in capacity.

Besides, large-scale UAV communication will have an advanced 3D infrastructure consisting of U2U, U2I, and U2G communications. The U2U or the side link communication can be realized by leveraging the device-to-device (D2D) communication used in the previous generation of cellular communication such as 5G. The direct discovery and connection between UAVs are accomplished through the side link radios.

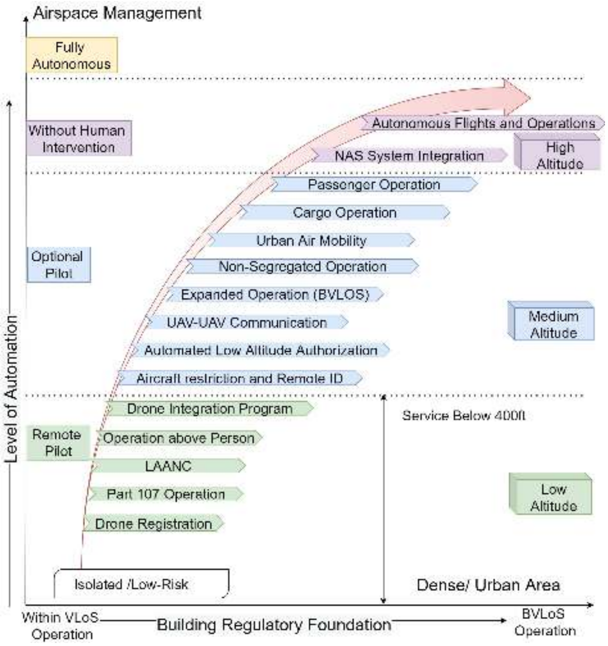

**FIGURE 6.** Full automation and integration path of UTM

## VI. ADVANCED AND FULLY AUTONOMOUS UTM DESIGN

The responsibilities of UTM systems are (a) Information management: management of critical information to enable safe air traffic operation, (b) Airspace management: smooth cooperation with other airspace layers and (c) Traffic management: strategic and tactical control of airspace activities. The NASA's integration pilot program is near to completion that demonstrates the gradual progress of UAV integration into the National Air Space (NAS). Several UAV traffic management systems are being developed around the globe; however, we will compare two major low-altitude traffic

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**TABLE 5.** Comparison between UTM and U-Space along with their advantages and disadvantage

| UTM | U-Space | Advantages | Disadvantages |
|---|---|---|---|
| Very Low Level (VLL) airspace | Very Low Level (VLL) airspace | Harmonized approach to integrated small UAVs (sUAVs) into VLL airspace at 122m above ground to achieve safety and public acceptance | Not yet suitable for large UAVs, PAVs and CAVs flying at higher altitude |
| Centralized UTM architecture | Not specific centralized or federated U-space architecture, but depends on service by service | Both UTM and U-space have similar architecture and operation strategy. | The centralized architecture might have a single point of failure, thus future UTM system should be decentralized. |
| Technical Capability Levels (TCL) from TCL1 to TCL4. Complexity and automation increases with levels | U-space Levels i.e. from U1 to U4 and complexity and autonomous operation increases with levels | At each level, sUAVs have defined functions, operation capabilities, confliction management based on range, density, and mobility or sUAVs. | In future UTM, all the UAVs should be able to adopt dynamic capability depending upon situations. |
| FAA maintains regulatory, authority and traffic operation for airspace | CAA and local regulatory authorities evaluates gives authority for UAVs operation | Certified government body looks after the UAV traffic management system | Global and distributed consensus mechanism might be required such as GUTMA |
| Existing UTM system does not have a web-based portal for access | U-space has web-based portal for easy access via accessible gateway for the architects | The registered users of the U-space system from closed community can login to the system and use the U-Space. | The future UTM system should be open source and accessible to the legitimate global users. |

management for UAV system in detail. The first one was developed by NASA in US called UAS Traffic Management (UTM). And the other one was developed by Concept of Operation for EuRopean UTM systems (CORUS) research group in Europe called U-Space. A detailed comparison between existing UTM and U-Space along with their advantages and disadvantages [9] are given in Table 5.

The latency plays important role for air-traffic management. However, both the existing UTM and U-space architecture does not connect with edge-cloud computing to reduce latency. It is not clear if both the architecture will operate in a distributed manner in future due to the risk of single point of failure in centralized based architecture. Due to the limitation in the existing UAV traffic management system, we need to design an advanced UTM architecture based on 6G technology.

Figure 6 shows the progress and future projection of UAV innovation, human interaction, level of autonomy and social acceptance based on regulatory foundation. We are approaching a complete automation level of the UAV and UTM by integrating the NAS system with efficient airspace management and flying BVLoS in accordance with the rules and regulations provided by the regulatory body [44].

### 1) Machine learning techniques to enhance UTM

There are several ML techniques to enhance the overall performance of the UTM system. During operation planning, RL techniques can be used for dynamic trajectory planning in an unseen situation where there are no prior data available or environmental change information. For situational awareness functionality such as bad weather forecasting or obstacle awareness, RL, deep learning (DL) or convolutional neural network (CNN) techniques can be implemented for dynamic obstacle sensing, detection and avoidance [45]. Similarly, for UAV internal equipment and communication network failure, supervised learning can be utilized for future failure prediction based on past datasets, and RL can be used for optimal fault tolerance and failure recovery against various unavoidable failures and attacks. Deep RL (DRL) can be used for dynamic flight optimization in the presence of a large number of data and parameters. By integrating RL and unsupervised learning, it is possible to run the network in a fully autonomous way based on quantum communication.

### 2) Advanced UTM Design

The advanced UTM system dynamically and autonomously regulates the air traffic. The autonomous UTM supports U2X, U2U, U2I and higher levels of multimodal communication and integration with urban intelligent mobility based on 6G communication. The advanced UTM architecture is designed to be intelligent and long-term-proof to assist different types of aircraft operations in controlled and uncontrolled airspaces. It supports emerging technologies that evolve and scale as the density of aircraft increases. It provides safety for manned/unmanned aircraft, terrestrial vehicles and properties by facilitating real-time situational awareness, collision avoidance, dynamic flight management, and traffic density management to adjust scheduled operational activities based on 6G communication. The advanced UTM integrates human, information technologies and services supported by aerial and ground-based communications, monitoring and navigation systems. UTM should be an open-source cloud-based architecture interoperable with manned/unmanned airspace along with USS. The interoperability protocol should ensure the communication, timeliness, integrity of critical information, and seamless exchange of information between different entities to operate in a harmonious manner. Its database can be designed for a super-fast speed, fault tolerance and distributed architecture. This architecture has the capability to scale up very easily and accommodate a huge number of aircraft maintaining safety requirements. The design or the advanced UTM system is shown in Figure 7.

The main principle of an advanced UTM system is information sharing among all participating entities to make

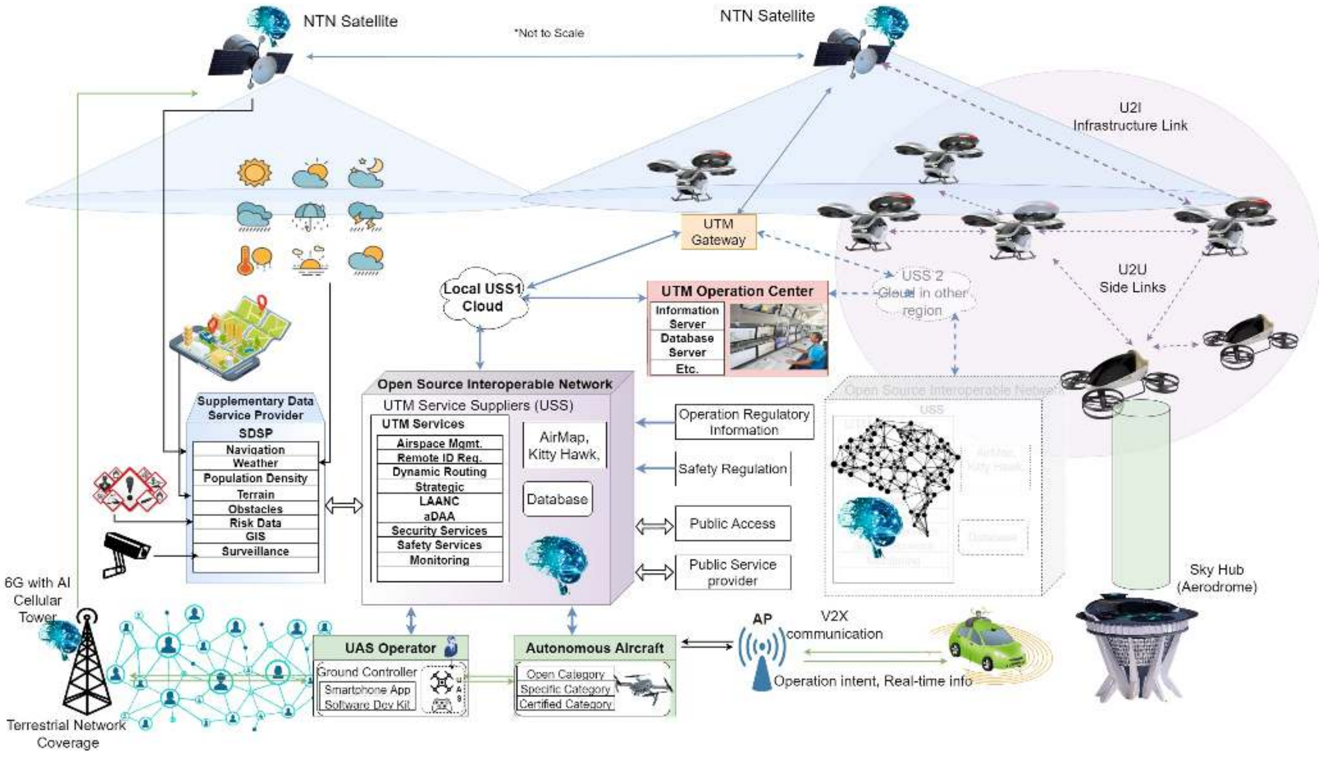

FIGURE 7. Proposed advanced UTM architecture design

airspace equitable. In an advanced UTM system, a fully autonomous aircraft can determine its own path and destination. Thus, all UTM operations should manage air traffic autonomously based on 6G communication. In addition, advanced UTM based on 6G communication will provide uHSLLC, uMUB, and uHDD due to integration with NTN. As mentioned in the previous sections regarding the capabilities and role of 6G in UTM ecosystems, advanced UTM is capable of handling complicated operations in high-density, strictly controlled airspace over dense urban cities, with challenging requirements of aircraft performance and functionality. Moreover, it provides surveillance and monitoring real-time aircraft traffic to guarantee situational awareness and facilitate de-confliction strategies using advanced 6G communication technology. It provides features such as safety tubes, strategic de-conflict, tactical de-conflict, emergency management, etc. In strategic de-conflict, advanced UTM system calculates the pre-flights plan and segmentation of usable airspace with the goal of optimizing the airspace. In tactical de-conflict, the advanced UTM system monitors the airspace for possible conflicts based on the collected air-traffic information from other entities and provides situational awareness such as weather, geofencing, collision alerts, etc. In emergency management, critical information regarding aircraft's internal sensor failures or external incidents is reported and managed efficiently.

In summary, the 6G enabled advanced UTM conceptual design is capable of adapting to emerging technological advances, including space, aerial and terrestrial communication. The advanced UTM system is capable of airspace automation, data exchange automation, and flight automation, and utilizes most of the features mentioned in Table 2. The ML techniques in UTM help automate the UTM system fully without any human intervention. Moreover, it provides reliable operations based on dynamic route planning while avoiding conflicts with other aircraft. The implementation of multi-layer SAT networks based on 6G as discussed in Section V supports and enhances the advanced UTM ecosystem. Thus, the advanced UTM ecosystem promotes automated, safe, and secure information exchange, and ensures equal and fair access to global airspace.

## VII. ISSUES AND CHALLENGES IN UAV TRAFFIC MANAGEMENT

As the UTM evolves, the safe and efficient incorporation of UAVs and PAVs into current controlled and uncontrolled airspace faces several issues and challenges in its path. It must encounter new challenges while integrating the manned and unmanned aircraft in UTM ecosystem systems. The policies, laws and strategies specific to fair airspace access must be established. The European Union has started to examine policies on fair airspace access [46]. Some of the issues and challenges faced by UTM are listed below:

- The integration of TN with NTN (e.g., satellite and air access networks) is complected and introduces new issues and challenges such as routing, load balancing, and node association. A key solution to overcome these issues is to adopt network virtualization, cloud computing, cloud-based caching among others.

- Along with the integration of NTN features with the UTM system, there is an increase in ubiquitous broadband connectivity such as LEO satellites and HAPS. The integration of LEO constellation networks still poses many challenges within the network and its convergence with other networks in many aspects. Increased satellites, for example, would make the network topology more complex. A key technique is to adopt efficient wireless routing methods that can be adapted to the complex characteristics of the system.
- It is essential to address the safety and integrity of the UTM system through an efficient failure-alerting system. The UTM operational procedures such as normal scenarios, emergency situations, and contingency situations. These operational procedures need to be addressed efficiently. As the response to emergency situations is critical and needs a rapidly action to prevent any calamities in the airspace, a tactical and strategic level for emergency management is expected in air traffic management.
- One of the issues in UTM is, data recording capabilities, storage and regulations. Adequate data standards are necessary to ensure UTM safety and cybersecurity. One possible solution is to use related services such as commercial flight data storage that helps to prevent events such as aircraft crashes, misbehavior, accidents, among others, as well as provide information during accident investigations [3]. An embedded data management system can be used in the UTM system that gathers all critical traffic data (such as location, velocity, weather, geofence, etc.) and sends alerts to the UAVs to provide situational awareness.
- In the near future, the UTM and ATM need to be interconnected with each other using an interface to exchange critical information such as information related to the separation distance between manned and unmanned aircraft at a specific airspace level. However, there are issues related to operation compatibility, reliability, and responsibility between manned and unmanned aircraft. One possible solution is to develop tools and protocols to ensure compatibility and consistent exchange of critical information between the two systems.
- It is very critical for the aircraft to identify, detect and then avoid other flying vehicles, birds, or any obstacles (dynamic or static) to prevent aerial crashes. The development of a perfect detection and avoidance system is a major issue. However, creating a reliable automatic DAA and conflict avoidance system using various modern sensor technologies embedded in the aircraft and an efficient communication interface is possible.
- If the density of urban aircraft such as low-and high-altitude aircraft increases, congestion will occur in the low-level airspace. This will create issues related to airspace layer classification, such as moving from Class G to D airspace. One solution is to use different types of airspace concepts such as layered, zonal, or tube airspace concepts to manage and redesign the higher airspace layers so that the manned and unmanned aircraft can fly and coexist in certain airspace layers [9].
- Similar to cybersecurity issues in autonomous vehicles, safety, cybersecurity risks, and vulnerabilities must be considered in UTM systems [47] [48] [49]. With the increasing number of UAVs in the sky, protecting civilians from falling UAVs or causing harm to the humans is important. On the contrary, UAVs often pose various security threats, such as injecting fake messages, hackers exploiting ECUs, and attempting to reverse engineer the micro-controllers, software attacks, etc [50]. The attacks on UAVs as well as the UTM system are a serious challenge and pose serious threats. Some of the threats to the UTM ecosystem are discussed below:

  1) Signal jamming: The hackers will send out jamming signals on the same radio frequency as the operators to disrupt connectivity between the operators and the UAVs or even between UAVs and the UTM, resulting in accidents and casualties. Increased signal-to-noise ratio is one approach to jamming attacks; however, there is a restriction on the transmitter side to maximize transmitting power as well as restriction to minimize noise at the receiver side.
  2) Spoofing and eavesdropping: Another common type of attack is eavesdropping and spoofing, which occurs when hackers gain confidential information by eavesdropping on the communication between the sender and receiver UAVs through spoofing address resolution protocol (ARP) packets. The hacker can eavesdrop and intercept sensitive information via an open communication channel. Thus, encrypting sensitive data and securing a communication channel using a strong encryption mechanism is beneficial.
  3) Hijacking: The hijacker hijacks the wireless links between UAVs and UTM by de-authenticating the management frames, as a consequence the hijacker would take control of the UAVs, which may cause it to malfunction or cause serious damage. One way to solve this issue is by employing an identification method in conjunction with encryption of transmitting messages, shielding SSID as well as limiting MAC addresses.
  4) DoS: In case of DoS attack, the hackers overwhelm the UTM system with several messages, creating network congestion and exhaustion of the UAV's bandwidth and energy by using Telnet tools. One way to solve this issue is to provide a strong cryptographic mechanism to UAVs and

UTM system to evade this type of attack.

Similarly, there are several other types of attacks on UAV and UTM systems such as physical attacks. In physical attacks, the adversaries might perform drone napping to detain the air vehicles to obtain sensitive data by using various vulnerable interfaces such as Bluetooth, USB, etc. They might also destroy the air vehicles by using physical force or external equipment that increases the risk of collision. To avoid this type of physical attack, various external sensors can be used to identify the invaders, or self-destruction techniques can be used when a significant threat is detected to prevent critical information from being stolen.

## VIII. DISCUSSION AND RESEARCH DIRECTIONS

In previous sections, we have presented communication technologies focusing on NTN features of 6G communication for dynamic air traffic management in UTM systems. We emphasized on space, air and terrestrial-based multi-layer communication for urban air transportation, their issues and challenges. In this section, we will further discuss on the future UTM systems and future research directions. Some of the UTM discussions are given below.

- One of the features of the 6G networks is the use of NTN to provide coverage even in the geographic areas where there are no terrestrial networks. The 6G supports Terahertz (THz) frequency band (i.e., 0.1-10 THz), which is a sandwich between the mmWave and infrared bands. It aims to provide hundreds of Gbps data rates, huge bandwidth, massive connectivity, and extremely secure bandwidth that is suitable for UTM ecosystems. However, several unique problems need to be resolved to reach the full potential of THz communications. Some of the problems in THz bands are
    1) Critical free space path-loss and atmospheric absorption. This issue can be solved by using ultra massive multiple-input multiple-output (MIMO). The possible approach to overcome this issue is to use focused beams that can reduce the path loss.
    2) THz have large wavelengths, consequently the size of the THz supporting UAV nodes increases resulting in the application of the devices to be inefficient. A possible approach to overcome this issue is to implement new semiconductor technologies, which helps to minimize the size of the devices and at the same time enables the devices to work at a low THz band [29].
- Several types of research have been conducted on the UTM communication standards, and among which is the research, which was performed by IEEE aerial network group. The IEEE aerial communication-working group is developing two standards for UAV aerial communications that provide a safe, secure, and enhanced aerial vehicle tracking system. These standards are still in progress and very little information is available as of the time of writing this paper. The two standards are as follows:
    1) IEEE P1920.1 standard: It defines aerial ad-hoc communication for self-organized manned/unmanned and commercial aerial vehicles based on wireless, cellular or other communication, and networking standard by exchanging advanced collision avoidance information directly among all aircraft.
    2) IEEE P1920.2 standard: It is a U2U communication protocol for UAVs designed for information exchange (e.g. command, control, and navigation) facilitating BVLoS and beyond radio line of sight (BRLoS) communications [51].
- The UTM provides autonomous flight provisions including automatic takeoff and landing through a range of predetermined flight operation modes and navigation systems. A possible approach, which is similar to 5G NR, the concept of a side link mode (such as PC5 and Uu for uplink and downlink) for air interface required to be developed for dense and urban aerial traffic. A feedback beacon from the UAVs is required for periodic positioning and tracking purposes.
- According to 3GPP TS [52], for UAV to operate in VLoS, it requires a 2Mbps data rate for processing 480p video size with 30 frames per second (fps) within a latency of 1s. While the requirements to operate in BVLoS are more stringent, and it requires twice the data rate, i.e. 4Mbps for processing a 720p video size with 30fps with a minimum latency of 140ms.
- Similarly, the recommended technical specifications provided by 3GPP [52] [53] for the UAVs flying with a speed of 300km/hr is that the command and control message size should be less than 10K bytes with a message interval of 1s with a minimum latency of 5s. However, in the future, the UAVs and PAVs will be capable of flying at a speed higher than 330 km/hr, thus it should have significantly lower latency, i.e. less than 10ms for autonomous flight; and the vehicle positioning should be at cm level. We believe that these requirements can be satisfied by 6G communication.

This is just the beginning of future aerial vehicles, and many fundamental problems still need to be resolved. As for the future research direction, both the theoretical and experimental realms must be overcome before the advanced UTM system can take off. Some of the future research directions are as follows:

- The data exchange protocols and components for UTM and ATM must be taken into account according to the state data privacy policy. The data standards used for UTM and ATM must be interoperable and consistent. Future research is needed to facilitate the establishment of interoperable standards and protocols for data exchange.
- A futuristic UTM ecosystem requires a reliable, cooperative, and real-time advanced DAA (ADAA) system.

In ADAA, onboard equipment based on 360 degree computer vision technology must be installed on the UAVs for dynamic obstacle detection. The ADAA system must support multi-communication technologies like wireless, satellite, optical, U2X etc.

- In future UAVs, an elliptical-shaped safety bound encircling the UAVs will be required. This safety bound should be based on UAVs shape, size velocity, technical potential among others. It should be capable of monitoring and detecting all the neighboring aircraft and make strategic decisions for safe operation and collision avoidance.
- For future research, the proposed advanced UTM system needs to be applied and evaluated in real-world scenarios. Simulations or experiments will be performed in diverse modes of operation that capture real data in the presence and absence of vulnerabilities. These data need to be made available for research and development as benchmarks, for the reproduction of real use cases to evaluate research developments.

## IX. CONCLUSION

In this article, we discussed urban airspace segmentation and airspace traffic management with multilayer airspace model. We discussed the dynamic air-traffic management, adoption, and enabling technologies in the UTM. Subsequently, we discussed the communication requirements of UAV and UTM systems and presented the capabilities and role of 6G in the UTM ecosystems. We introduced 6G as an enabling technology for UTM and focused on 6G-communication support for UTM ecosystems as a future perspective. We also presented some of the issues and challenges in UAV traffic management systems. We extended the vision of the UTM systems and designed an advanced urban traffic management system for future air transportation through automation to maximize its impact based on 6G. In future work, we plan to simulate and evaluate the proposed advanced UTM system across diverse real-world scenarios.

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