Mobility Management of Unmanned Aerial Vehicles

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Contributor: W. T. Alshaibani, Ibraheem Shayea, Ramazan Caglar, Jafri Din, Yousef Ibrahim Daradkeh

The rapid growth of mobile data traffic will lead to the deployment of Ultra–Dense Networks (UDN) in the near future. Various networks must overlap to meet the massive demands of mobile data traffic, causing an increase in the number of handover scenarios. This will subsequently affect the connectivity, stability, and reliability of communication between mobile and serving networks. The inclusion of Unmanned Aerial Vehicles (UAVs)—based networks will create more complex challenges due to different mobility characterizations.

Keywords: connected drones ; 5G networks ; UAV ; machine learning ; handover

1. Introduction

The rapid growth of wireless technology has caused a dramatic shift in people's daily lives. Mobile–connected devices, connected applications, Machine to Machine (M2M), Internet of Things (IoT), and other services are steadily increasing. IoT connects almost everything throughout numerous environments. With its evolution, it will be the most utilized technology and the largest telecom market. IoT marks a new era of total automation and offers efficient solutions for several fields. Since it has become extremely simple to connect several devices in different locations, its impact on daily life has been tremendous. Various industries are currently demanding wide–area communication, especially for numerous operations that are performed indoors [1][2][3][4][5]. These factors will further lead to the massive growth of mobile data traffic.

The transmission and reception of signals by antenna systems are critical components of wireless technology (such as IoT, autonomous aerial vehicles, and wireless communication systems). Antenna systems are used for transmitting and receiving signals in wireless communication systems. Tiny miniature antennas are now in high demand for various applications, including communication systems, radio sensors, etc. Several studies have been conducted in this field. For instance, in ref. [6], a strategy was suggested for reducing the size of planar antennas by integrating loaded cell (LC) elements. The planar transmission model can then be applied to analyze two different antenna configurations. This model enables preliminary design research and enhances the comprehension of parametric structural relationships. In ref. [7], a new printed leaky–wave antenna (LWA) was also designed, produced, and characterized with beam routing. The antenna design procedure was based on the placement of an appropriate number of E–shaped arms on printed circuit boards, resulting in an operating bandwidth of 118.7 GHz. This topic generated a wide range of valuable research results. Although this research cannot discuss all outcomes, a link is provided for researchers to access the most significant studies in this field [8][9][10][11][12][13][14][15].

In recent years, the urgent need to apply large frequency bands to enable quick and smooth data transfers has emerged, especially in light of the advanced technology provided by the fifth generation (5G) and sixth generation (6G) networks. Establishing airborne communication will mark the advanced stage of development for communication networks. The number of obstacles and scattered objects impeding data transmission will significantly reduce. This network type is typically employed in emergency scenarios, for instance, when communication infrastructure is unavailable, during natural disasters, or in areas where conventional communication networks are too expensive [16][17]. Other high mobility–based emergency services are also required, such as for provision of medical assistance to patients in ambulances struggling with life–threatening situations before they reach a hospital where competent medical care is available. Real–time consultations with specialists in remote hospitals should also be made possible. These services are urgently needed, especially in the current pandemic scenario [18][19].

New telecommunications seek faster data rates, lower latency, higher quality benefits, and increased user capacity [20]. When viewing cellular service maps, cellular coverage is unavailable in more than 60% of locations to several reasons. Firstly, it would be inefficient to deploy fixed base stations (BSs) in remote areas where there is limited human activity, and, although greater human activity requires remote management, complex terrains may hinder BS deployment. Stationary BSs may struggle to handle excess information traffic, especially when distant requests arrive in an unanticipated or unpredictable manner [21][22]. Future telecommunication generations and beyond must establish additional coverage alternatives to provide on–demand and remote services for increasing gadget use. Cellular networks supplemented with UAVs are referred to as UAV–supported cellular systems [23]. The next generation of UAV–BS have generated considerable interest due to their rapid deployment, mobility, extensive opportunities for unobstructed propagation channel, and resilient features. UAVs will therefore play a significant role in future mobile communication networks, serving as BSs and mobile users in the sky. UAVs can be categorized into two classes: those that operate autonomously, and those that supplement or assist overcrowded BSs [24][25][26][27]. Determining the optimum technology for UAV deployment is a critical and challenging issue that must be addressed. To resolve this issue, the first step is to provide on–demand services to geographically dispersed UEs. Given the probability of disaster and the necessity for UEs to have end–to–end communication, a powerful UAV spine network is required. Secondly, UAVs must also maintain connectivity to established BSs for backhaul connections and global data interchange. Overcoming these obstacles must be the first priority, particularly in the area of mobility management.

Several studies have been conducted on the use of UAVs as flying BSs. Various objectives were discussed, such as reducing the number of UAVs at different user densities to provide maximum coverage with the least amount of transmission control [28][29][30][31]. These studies overlooked the network and/or strength of the UAV spine organization, which is crucial in a complex environment. UAVs are regularly dispatched near established BSs to increase capability and enhance user satisfaction [32][33][34]. Most studies did not consider the links between UAVs and fixed BSs, which are crucial for providing backhaul connections. In conclusion, previous research [28][29][30][31][32][33][34] did not thoroughly examine the issue of UAV organization in cellular networks.

UAVs are aircraft that can autonomously fly without human guidance. This type of aircraft employs radio waves to navigate and present a route map. UAVs range in size, weight, shape, and engine. They are employed for specific purposes such as surveillance, gaming, spying, warfare, and presentations. As a result, they are furnished with technical gadgets such as cameras and Global Positioning System (GPS) sensors, both of which are necessary for monitoring and tracking. UAVs have a significant advantage in this area since they can immediately register and monitor any region or item without requiring additional infrastructure.

Based on the 3rd Generation Partnership Project (3GPP) TS 22–261, governments and corporate sectors are expected to use UAVs in a wide range of applications. The key issues of the future 6G network will be latency and dependability. UAVs will require more precise position information as well as protection against theft and fraud. The information transferred between UAVs and their control units must be secure. The next–generation mobile network must also be resistant to spoofing and non–repudiation to fully integrate UAVs. Unmanned Aerial System Traffic Management (UTM) is a centralized system for identifying, tracking, and authorizing UAVs and controllers. The UTM stores all identifications and metadata for UAVs and UAV controllers. The data interchange protocols used by UTM and mobile network centers, particularly Allied Telesis Management Framework (AMF), have permitted the confirmation and authorization of UAVs within the zone. Including UAVs in this flexible network will increase the AMF's computational load. The use of UAV–mounted BS (UxNB) to extend the scope range is specified in 3GPP references. The UxNB may connect to a 5G core as a BS on the ground via a wireless backhaul link. The UxNB can be used in various situations (such as in emergencies, the temporary scope for UEs, and hotspot events) due to its quick setup and vast range of capabilities. When acting as a BS, the UxNBs must be validated by the center setup. Since UAVs have limited power, one condition for utilizing a BS is to consume as little energy as possible. The use of UAVs is limited due to their flying time and energy requirements. In conveyance administrations, for instance, using a single UAV results in a waiting period for the vehicle to return to base. As a result, UAVs should be used in swarm mode. Group management is the most basic requirement for a swarm of UAVs. Group management entails collecting confirmation and guaranteeing secure communication within a group.

This research focuses on the HO of UAV communication through wireless communication. A smooth HO is difficult to achieve while using traditional wireless networks. When compared to cellular networks, UAV wireless communications have less communication coverage and a longer HO procedure. The conventional HO technique further assumes that the coverage area for different cells is the same, which is not the case with UAVs due to their varying heights. The HO of UAVs should be more closely and efficiently monitored than that of terrestrial UEs. The use of traditional HO methods and strategies may not be suitable for UAVs. Although numerous relevant arrangements have been discussed throughout the literature, the problem remains unaddressed. Since future mobile networks are expected to be self–sufficient, node mobility forecasting may be a critical technique for optimizing the benefits of UAV systems. A large number of contemporary arrangements follow distance–based assumptions [2][35].

2. UAV Technology in Wireless Communication

Connected UAVs will be a revolutionary invention that will provide a wide range of services throughout various settings. The requirement for constant connection while on the move is a key issue that must be addressed. Defining the concept of UAVs and HO management is essential. This section provides an overview of UAVs, UAV communication networks, the HO concept, and 3D parameters. The following subsections present an extensive summary of the various subtopics.

2.1. Overview of UAVs

The use of UAVs has skyrocketed in recent years and continues to do so across multiple industries and services. UAVs present low–cost solutions in several industries, such as healthcare and marketing. They can provide a wide range of solutions for different scenarios. At this stage, it is crucial to employ cutting–edge technology to ensure the safe functioning and administration of this developing innovation. For decades, billions of devices have been linked together on the ground. Now, they are ready to be linked in the sky. Currently, UAVs can serve as wireless communication BSs to connect mobile users. However, several challenges will arise with connected UAVs before achieving reduced latency, enhanced connection dependability, real–time data transfer, and remote installations. The widespread adoption of contemporary developments, such as IoT and machine–to–machine communication (MTC), has significantly increased the number of UEs and MTC devices that interfere with mobile systems. As the number of UEs inside a BS scope increases, the quality of service (QoS) decreases. UxNB can be a viable solution in regions with a high concentration of UEs, such as stadiums. UxNB is a promising technology that can be applied in future for capacity injection due to its fast transmission. However, this new technology also possesses several security risks. When using UxNB for capacity injection, common verification, the development of a communication link between terrestrial BS and UxNB, and quick HO procedures may all raise security problems. This new protocol also suggests that the UE transition from earthbound to UxNB should be accomplished in groups.

UAV operations are primarily conducted at low altitudes in uncontrolled airspace. This airspace, which is regularly used for a range of existing flying exercises, contains critical infrastructure and is susceptible to changing conditions. In 5BG, the AMF, the radio access network (RAN), and the UE are the most important components. The AMF is in charge of registration, managing connections, ensuring that UEs can be reached, and managing their mobility. With 5G networks, the speed can reach up to 500 km/h, and with 6G networks, it will be even faster. This network function makes it possible to handle the mobility of nodes. Radio transceivers are used by RAN to connect to cellular networks. The BSs connect the UE to the New Radio (NR) user plane and control plane protocols.

3GPP defines UE as a device used by an end user to communicate with another user or service.

Most pilots employ Visual Flight Rules (VFR) when flying in low–altitude airspace, as shown in **Figure 1**. Under VFR, each pilot is responsible for avoiding other aircraft or obstructions by maintaining a steady view of the region and other airspace users. Significant dangers associated with UAV movements are present in unclassified airspace if airframes are not monitored and human pilots are not present. The risk of bird collisions, building collisions, or accidents with other unmanned vehicles can cause significant issues among national aviation authorities. Collision avoidance frameworks will enhance the safety of unmanned aircraft. However, they are not designed to handle complex activities or movements of other planes and objects within the area. A new perspective is required to organize and monitor activities in low–altitude and unclassified airspaces. Several researchers are currently examining various methods to tackle the UTM challenge. **Figure 1** presents the problem that administrative authorities must confront as well as the tasks required for a complete UTM framework. UTM is a traffic management ecosystem for movements that are not monitored by the Federal Aviation Administration's (FAA) Air Traffic Management (ATM) system. The UTM will be improved and developed to define the services and responsibilities assigned to UAV operations when flying at low altitudes without supervision. Information exchange protocols and other technical details will also be specified in control and communication operations.

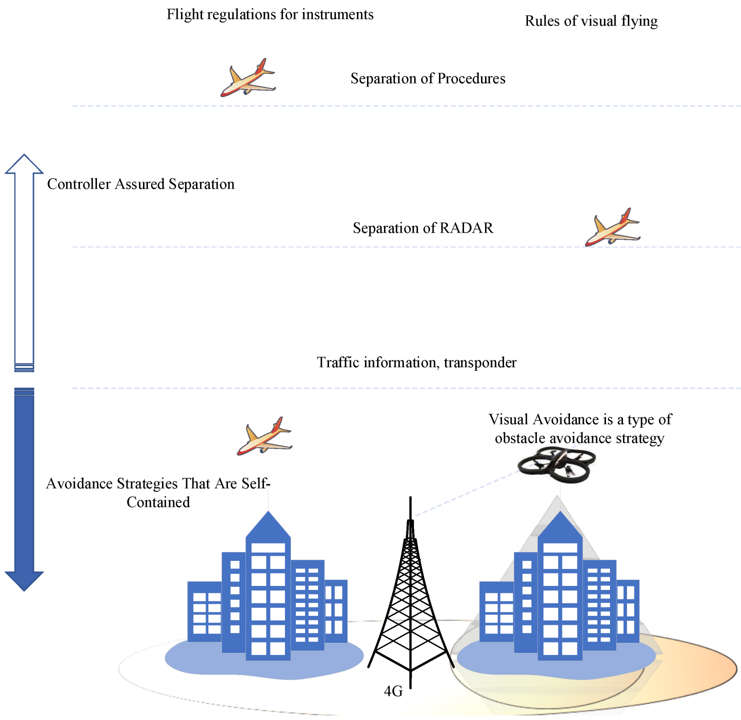

Figure 1. Details of the task confronting administrative bodies and the activity required for a comprehensive UTM framework.

UTM is the mechanism that manages airspace to facilitate and permit UAV operations performed outside the beyond visual line of sight (BVLoS) where standard air services are unavailable. As a result, UAV operators and the FAA will work together to determine and report the state of the airspace in real–time. The FAA now imposes several restrictions on UAV operators to ensure safe management operations. FAA and UAV operators mostly communicate through a distributed network of highly automated systems via the Application Programming Interfaces (APIs). They do not coordinate through verbal communication, as pilots and air traffic controllers do.

2.2. UAV Communication Network

The IEEE 802.11 Wireless Local Area Network (WLAN) and radio technology both conduct command and control activities for most commercial UAVs. However, due to the UAV's speed and fluctuating altitudes, IEEE 802.11 is unable to meet the required conditions. Command and control activities can be accomplished in a non–licensed range; however, numerous security and reliability issues would arise. Cellular networks are the only option. Cellular networks are stable, secure, and capable of covering wide areas with acceptable data speeds. However, they are not designed to support flying devices despite substantial standardization efforts. The most pressing issues continue to be interference and radio coverage. Certain limits must be met when a cellular network is linked with a UAV to improve coverage and capacity. UAVs are used as relays or mobile BSs to enhance coverage, connectivity, and capacity. RANs are also simple to install in regions where no established network architecture is available. This implementation is a configuration style that can be set up in the event of a disaster to avoid investing time and money on new infrastructure. It is also beneficial for increasing capacity and coverage during significantly crowded gatherings, such as concerts and sporting events [2][36][37][38].

2.3. Antenna Tilting and Cell Association

To provide the best service to ground users, cellular BS antennas are tilted downwards. Aerial coverage has recently received significant attention, mostly for connecting airline passengers on domestic flights. Only a small number of BSs with upgraded antennas are necessary to ensure extensive coverage and continuous connectivity during the flight. However, due to construction and regulatory constraints, these methods cannot be used for commercial UAVs which frequently fly at lower altitudes, such as 50–300 m, as illustrated in **Figure 2**. UAVs are fundamentally different from terrestrial users since the assumptions that apply to terrestrial users are not applicable to aerial users. Consider the following example, two BSs (A and B) have antennas tilted downwards with the primary lobes facing down towards the earth. The ground user connects to the BS. If the signal strength from both BSs is equal, the user will stay connected to the previous one. In the case of UAVs, side–lobe antennas are useful. **Figure 3** shows that despite being closer to BS A than BS B, the UAV at Y1 is served by BS B. This will cause excessive HOs and ping–pong effects. This issue also applies to horizontal locations.

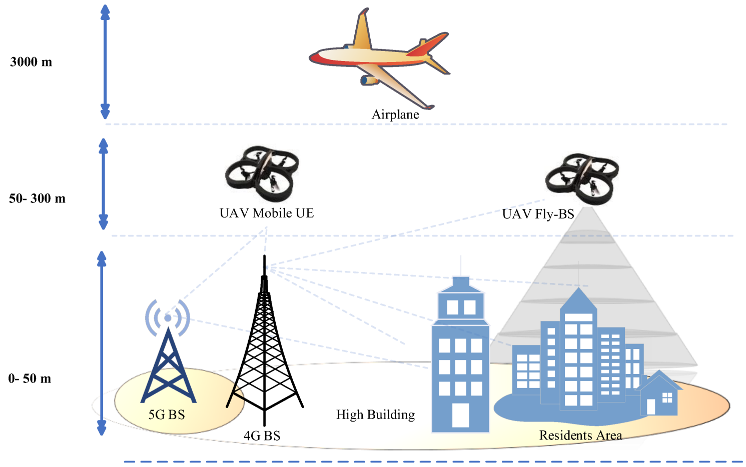

Figure 2. UAV base station (UBS) and normal BSs in a future ultra–dens heterogenous network.

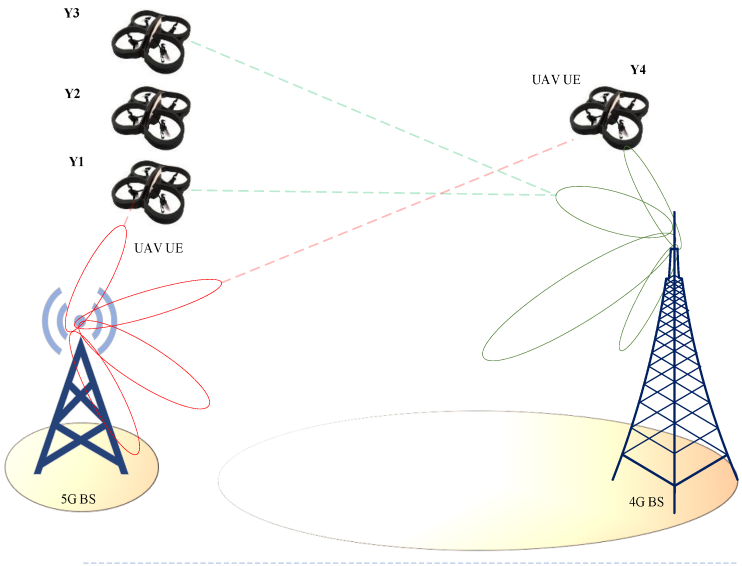

Figure 3. UAV connection via side lobes in a future ultra–dens heterogenous network.

For locations Y2 and Y4 in **Figure 3**, the picture can be expanded to include a large number of BS s, signifying that the rate of HO for UAVs will be more excessive than conventional or traditional networks. Increasing the UAV's height will decrease the competitiveness of its service via the main lobes as long as the terrestrial BS antennas are slanted downwards. As a result, the service given to UAVs at high altitudes will be via the side lobes, which is not at the same level offered by the main lobes. Due to the increased potential of line–of–sight (LoS) at such high altitudes, UAV communication will suffer from uplink (UL) and downlink interference. This will create severe interference and navigation management issues. Increasing the altitude will allow the side lobes of the BS antennas to have more than one connection possibility depending on the location of the UAV. This raises the possibility of LoS communication links, which increases interference in neighboring cells when compared to UE ground equipment [39][40][41][42][43].

2.4. UAV Communication Scenarios

From a wireless perspective, a UAV in a 3D environment could potentially act as a mobile BS and mobile EU. Detailed consideration of both of these scenarios is provided below.

2.4.1. Flying Base Stations

A flying BS that connects backhaul and access networks can be a UxNB. The so–called fly ad–hoc network (FANET) is formed when more than one UAV is included in a transmitting apparatus. FANETs are air–borne frames for remote wireless ad hoc networks (WANETs) or mobile ad hoc networks (MANETs). An innovative aspect of the 5G network is "network from the sky". UAV have the ability to provide on–demand systems to specific regions due to their built–in mobility features, flexibility in three–dimensional space, adaptive elevation, and symmetric revolution. Ground users can benefit from premium services such as high–quality wireless connections, seamless connection, large data capacity, and low degradations thanks to these unique characteristics. UAV integration with distant cellular systems serving as aerial communication platforms will open up previously unconsidered foundations, new perspectives, and numerous possibilities [44].

When compared to their earthly counterparts, several differences are unquestionably present. The average height of earthbound BSs in an urban setting is about 10–20 m. UAVs can hover up to 100–120 m. This allows the UAV to have a longer range than traditional terrestrial BS s, further reducing interference from nearby terminals. Ground terminals are easily visible from various measured altitudes and points with the UAV. UAVs can track users in 3D with high mobility. Traditional ground–to–ground communications suffer from higher route loss attenuation and blurring. UAV s can provide a better LoS channel probability. In such situations, a few key areas must be considered. Millimeter waves (mm–wave), for instance, are used in 5G systems. LoS is essential for delivering high recurrent transmission capacity to the network. Since the LoS condition allows for effective beamforming in 3D space, UAVs are good candidates for 3D Multiple Input Multiple Output (MIMO). The idea of using UAVs as BSs is represented in **Figure 4**.

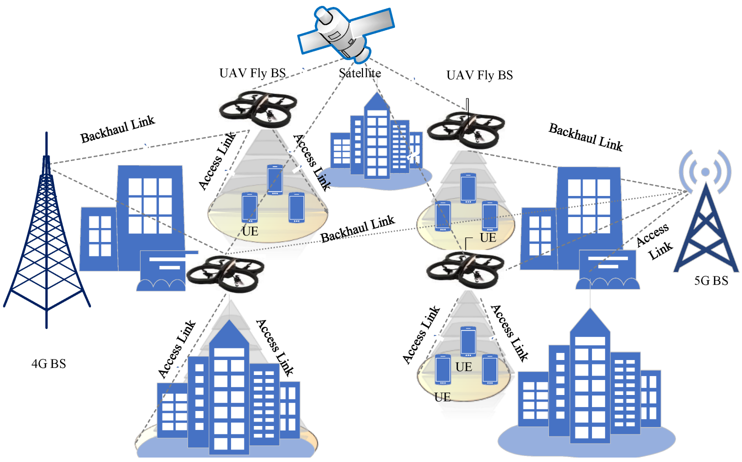

Figure 4. UAVs as base stations in a future ultra–dens heterogenous network.

2.4.2. Normal User

Due to obstacles in the coordinate LoS path, the signal to and from the BS for a terrestrial UE is regularly deflected or diffracted. As a result, the UE's gained signal quality will be significantly reduced. BSs are typically located at high elevations, such as cell towers or building tops. The likelihood of obstacles obstructing the LoS path dramatically decreases as the UE ascends to a higher altitude, as in the case of a hovering UAV. The signal quality improves as the path loss decreases since signal propagation through the sky is close to free–space propagation. The UAV can have LoS access to a number of nearby non–serving BSs. The increased likelihood of LoS paths to numerous non–serving cells will increase the UAV's obstacles since the cells share the same radio assets. The signal–to–interference–plus–noise ratio (SINR) may be low due to the high number of obstacles, making it difficult for the roaming UE to quickly receive and translate adaptable management–related signals (for instance, HO commands). **Figure 5** presents the normal user scenario of UAVs in wireless communication.

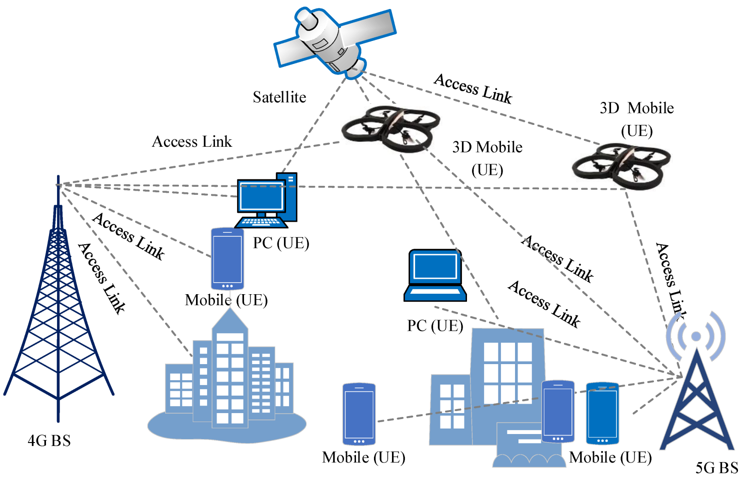

Figure 5. UAVs as normal users in a future ultra–dense heterogenous network.

2.5. UAVs in 5G Networks

As commonly known, 5G will transform multiple aspects of society. UAVs will likely be a significant tool used to demonstrate the full potential of 5G technology. UAV connection may even be possible with 4th generation (4G) LTE, which would be advantageous. UAVs are currently used as flying sensors linked to 4G networks. These sensors can convey data over great distances while remaining securely outside the pilot's line of sight.

The International Telecommunication Union (ITU) provided an overview of the differences between 4G and 5G networks. This agency developed the capabilities that differentiate broadband cellular network generations. When discussing wireless networks, two definitions must be highlighted: upward and Verizon. In 2009, telecommunication operators deployed 4G and continued its management until 2019. During that time, 4G was widely employed, allowing users to download movies and use the GPS in cars. In 2019, Verizon pioneered 5G, launching a commercial 5G ultra–wideband mobile network in different sections of two cities. 5G enables rapid data transmission speeds due to the massive amounts of data acquired from simulating linked devices. Overall, 5G includes high data rates, low latency, energy, cost efficiency, increased system capacity, and widespread device connectivity.

The rate at which data is successfully transmitted across a network is referred to as throughput. Peak data rates of up to 10 Gbps can be achievable with 5G. At this level, driverless vehicles, fabrication, and virtual reality (VR) can rapidly advance. This further indicates that UAVs will be capable of transmitting large volumes of data. 5G technology allows devices to communicate at speeds of up to 500 km/h. Commercial UAVs will be able to inspect vast lengths of highways in minutes while maintaining network connection in such a way that data can be promptly transmitted. The 5G network can service millions of devices in a single square kilometer. Numerous organizations can be completely transformed and developed, ranging from home parcel delivery to search and rescue operations. The energy efficiency of 5G ultra–wideband will also be enhanced. Delays will further reduce, signifying the impact of lower latency. It is not uncommon that audio and visual images lag from time to time. 5G data transmission speeds will be at much faster magnitudes than the blink of an eye, with an end–to–end reaction time of roughly 10 milliseconds. This process provides UAVs and sensor operators with a near–real–time experience. With low latency, autonomous UAVs can navigate with tremendous precision due to instant communication.

References

1. Henry, P.S.; Luo, H. WiFi: What's next? IEEE Commun. Mag. 2002, 40, 66–72.
2. Sandhu, S.S.D.M.K. A Review Over Existing Handover Decision Systems For Drones In Wireless Network. Int. J. Sci. Technol. Res. 2020, 9, 5.
3. Laghari, A.A.; Wu, K.; Laghari, R.A.; Ali, M.; Khan, A.A. A review and state of art of Internet of Things (IoT). Arch. Comput. Methods Eng. 2021, 29, 1395–1413.
4. Waqas, M.; Kumar, K.; Laghari, A.A.; Saeed, U.; Rind, M.M.; Shaikh, A.A.; Hussain, F.; Rai, A.; Qazi, A.Q. Botnet attack detection in Internet of Things devices over cloud environment via machine learning. Concurr. Comput. Pract. Exp. 2022, 34, e6662.
5. Mohsan, S.A.H.; Khan, M.A.; Alsharif, M.H.; Uthansakul, P.; Solyman, A.A.A. Intelligent Reflecting Surfaces Assisted UAV Communications for Massive Networks: Current Trends, Challenges, and Research Directions. Sensors 2022, 22, 5278.
6. Alibakhshi Kenari, M. Design and modeling of new UWB metamaterial planar cavity antennas with shrinking of the physical size for modern transceivers. Int. J. Antennas Propag. 2013, 2013, 1–12.
7. Alibakhshi-Kenari, M.; Andújar, A.; Anguera, J. New compact printed leaky-wave antenna with beam steering. Microw. Opt. Technol. Lett. 2016, 58, 215–217.
8. Alibakhshikenari, M.; Virdee, B.S.; See, C.H.; Abd-Alhameed, R.A.; Falcone, F.; Limiti, E. Super-wide impedance bandwidth planar antenna for microwave and millimeter-wave applications. Sensors 2019, 19, 2306.
9. Alibakhshi-Kenari, M.; Naser-Moghadasi, M.; Sadeghzadeh, R.A.; Virdee, B.S.; Limiti, E. New CRLH-based planar slotted antennas with helical inductors for wireless communication systems, RF-circuits and microwave devices at UHF–SHF bands. Wirel. Pers. Commun. 2017, 92, 1029–1038.
10. Alibakhshikenari, M.; Virdee, B.S.; Althuwayb, A.A.; Aïssa, S.; See, C.H.; Abd-Alhameed, R.A.; Falcone, F.; Limiti, E. Study on on-chip antenna design based on metamaterial-inspired and substrate-integrated waveguide properties for millimetre-wave and THz integrated-circuit applications. J. Infrared Millim. Terahertz Waves 2021, 42, 17–28.
11. Alibakhshi-Kenari, M.; Movahhedi, M.; Naderian, H. A new miniature ultra wide band planar microstrip antenna based on the metamaterial transmission line. In Proceedings of the 2012 IEEE Asia-Pacific Conference on Applied Electromagnetics (APACE), Melaka, Malaysia, 11–13 December 2012; pp. 293–297.

12. Alibakhshikenari, M.; Virdee, B.S.; Shukla, P.; Parchin, N.O.; Azpilicueta, L.; See, C.H.; Abd-Alhameed, R.A.; Falcone, F.; Huynen, I.; Denidni, T.A. Metamaterial-inspired antenna array for application in microwave breast imaging systems for tumor detection. IEEE Access 2020, 8, 174667–174678.

13. Alibakhshikenari, M.; Virdee, B.S.; Limiti, E. Study on isolation and radiation behaviours of a 34× 34 array-antennas based on SIW and metasurface properties for applications in terahertz band over 125–300 GHz. Optik 2020, 206, 163222.

14. Alibakhshikenari, M.; Virdee, B.S.; See, C.H.; Abd-Alhameed, R.A.; Falcone, F.; Limiti, E. Surface wave reduction in antenna arrays using metasurface inclusion for MIMO and SAR systems. Radio Sci. 2019, 54, 1067–1075.

15. Dicandia, F.A.; Fonseca, N.J.G.; Bacco, M.; Mugnaini, S.; Genovesi, S. Space-Air-Ground Integrated 6G Wireless Communication Networks: A Review of Antenna Technologies and Application Scenarios. Sensors 2022, 22, 3136.

16. Lum, C.; Gauksheim, K.; Deseure, C.; Vagners, J.; McGeer, T. Assessing and estimating risk of operating unmanned aerial systems in populated areas. In Proceedings of the 11th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, including the AIAA Balloon Systems Conference and 19th AIAA Lighter-Than, Virginia Beach, VA, USA, 20–22 September 2011; p. 6918.

17. Kardasz, P.; Doskocz, J.; Hejduk, M.; Wiejkut, P.; Zarzycki, H. Drones and possibilities of their using. J. Civ. Environ. Eng. 2016, 6, 1–7.

18. Usman, M.A.; Philip, N.Y.; Politis, C. 5G enabled mobile healthcare for ambulances. In Proceedings of the 2019 IEEE Globecom Workshops (GC Wkshps), Waikoloa, HI, USA, 9–13 December 2019; pp. 1–6.

19. Abubakar, A.I.; Omeke, K.G.; Öztürk, M.; Hussain, S.; Imran, M.A. The role of artificial intelligence driven 5G networks in COVID-19 outbreak: Opportunities, challenges, and future outlook. Front. Commun. Netw. 2020, 1, 575065.

20. Andrews, J.G.; Buzzi, S.; Choi, W.; Hanly, S.V.; Lozano, A.; Soong, A.C.K.; Zhang, J.C. What will 5G be? IEEE J. Sel. Areas Commun. 2014, 32, 1065–1082.

21. Maps., C.C. Cellular Coverage Maps. Available online: https://www.fleetistics.com/resources/misc-fleet-management/cellular-network-coverage-maps (accessed on 17 June 2020).

22. Li, B.; Fei, Z.; Zhang, Y. UAV communications for 5G and beyond: Recent advances and future trends. IEEE Internet Things J. 2018, 6, 2241–2263.

23. Zeng, Y.; Zhang, R.; Lim, T.J. Wireless communications with unmanned aerial vehicles: Opportunities and challenges. IEEE Commun. Mag. 2016, 54, 36–42.

24. Wu, H.; Tao, X.; Zhang, N.; Shen, X. Cooperative UAV cluster-assisted terrestrial cellular networks for ubiquitous coverage. IEEE J. Sel. Areas Commun. 2018, 36, 2045–2058.

25. Zhang, J.; Hu, X.; Ning, Z.; Ngai, E.C.H.; Zhou, L.; Wei, J.; Cheng, J.; Hu, B.; Leung, V.C.M. Joint resource allocation for latency-sensitive services over mobile edge computing networks with caching. IEEE Internet Things J. 2018, 6, 4283–4294.

26. Zhang, J.; Zhou, L.; Tang, Q.; Ngai, E.C.H.; Hu, X.; Zhao, H.; Wei, J. Stochastic computation offloading and trajectory scheduling for UAV-assisted mobile edge computing. IEEE Internet Things J. 2018, 6, 3688–3699.

27. Gures, E.; Shayea, I.; Alhammadi, A.; Ergen, M.; Mohamad, H. A comprehensive survey on mobility management in 5g heterogeneous networks: Architectures, challenges and solutions. IEEE Access 2020, 8, 195883–195913.

28. Kalantari, E.; Yanikomeroglu, H.; Yongacoglu, A. On the number and 3D placement of drone base stations in wireless cellular networks. IEEE Internet Things J. 2018, 6, 3688–3699.

29. Lyu, J.; Zeng, Y.; Zhang, R.; Lim, T.J. Placement optimization of UAV-mounted mobile base stations. IEEE Commun. Lett. 2016, 21, 604–607.

30. Zhao, H.; Wang, H.; Wu, W.; Wei, J. Deployment algorithms for UAV airborne networks toward on-demand coverage. IEEE J. Sel. Areas Commun. 2018, 36, 2015–2031.

31. Mozaffari, M.; Saad, W.; Bennis, M.; Debbah, M. Efficient deployment of multiple unmanned aerial vehicles for optimal wireless coverage. IEEE Commun. Lett. 2016, 20, 1647–1650.

32. Sharma, V.; Bennis, M.; Kumar, R. UAV-assisted heterogeneous networks for capacity enhancement. IEEE Commun. Lett. 2016, 20, 1207–1210.

33. Savkin, A.V.; Huang, H. Deployment of unmanned aerial vehicle base stations for optimal quality of coverage. IEEE Wirel. Commun. Lett. 2018, 8, 321–324.

34. Chen, M.; Mozaffari, M.; Saad, W.; Yin, C.; Debbah, M.; Hong, C.S. Caching in the sky: Proactive deployment of cache-enabled unmanned aerial vehicles for optimized quality-of-experience. IEEE J. Sel. Areas Commun. 2017, 35, 1046–1061.

35. Yan, X.; Şekercioğlu, Y.A.; Narayanan, S. A survey of vertical handover decision algorithms in Fourth Generation hetero geneous wireless networks. Comput. Netw. 2010, 54, 1848–1863.

36. 3GPP TR 36.777. Enhanced LTE Support for Aerial Vehicles; 3GPP: Sophia Antipolis, France, 2017.

37. Zeng, Y.; Lyu, J.; Zhang, R. Cellular-connected UAV: Potential, challenges, and promising technologies. IEEE Wirel. Co mmun. 2018, 26, 120–127.

38. Cabrera-Castellanos, D.F.; Aragón-Zavala, A.; Castañón-Ávila, G. Closing Connectivity Gap: An Overview of Mobile Co verage Solutions for Not-Spots in Rural Zones. Sensors 2021, 21, 8037.

39. Alibakhshikenari, M.; Virdee, B.S.; Azpilicueta, L.; Naser-Moghadasi, M.; Akinsolu, M.O.; See, C.H.; Liu, B.; Abd-Alham eed, R.A.; Falcone, F.; Huynen, I. A comprehensive survey of “metamaterial transmission-line based antennas: Design, challenges, and applications”. IEEE Access 2020, 8, 144778–144808.

40. Nadeem, I.; Alibakhshikenari, M.; Babaeian, F.; Althuwayb, A.; Virdee, B.S.; Azpilicueta, L.; Khan, S.; Huynen, I.; Falcon e, F.J.; Denidni, T.A. A comprehensive survey on" Circular Polarized Antennas" for existing and emerging wireless com munication technologies. J. Phys. D Appl. Phys. 2021, 55, 033002.

41. Alibakhshikenari, M.; Ali, E.M.; Soruri, M.; Dalarsson, M.; Naser-Moghadasi, M.; Virdee, B.S.; Stefanovic, C.; Pietrenko-Dabrowska, A.; Koziel, S.; Szczepanski, S. A comprehensive survey on antennas on-chip based on metamaterial, meta surface, and substrate integrated waveguide principles for millimeter-waves and terahertz integrated circuits and syste ms. IEEE Access 2022, 10, 3668–3692.

42. Alibakhshikenari, M.; Babaeian, F.; Virdee, B.S.; Aïssa, S.; Azpilicueta, L.; See, C.H.; Althuwayb, A.A.; Huynen, I.; Abd-Alhameed, R.A.; Falcone, F. A comprehensive survey on “Various decoupling mechanisms with focus on metamaterial and metasurface principles applicable to SAR and MIMO antenna systems”. IEEE Access 2020, 8, 192965–193004.

43. Alibakhshikenari, M.; Moghaddam, S.M.; Zaman, A.U.; Yang, J.; Virdee, B.S.; Limiti, E. Wideband sub-6 GHz self-groun ded bow-tie antenna with new feeding mechanism for 5G communication systems. In Proceedings of the 2019 13th Eu ropean Conference on Antennas and Propagation (EuCAP), Krakow, Poland, 31 March–5 April 2019; pp. 1–4.

44. Guillen-Perez, A.; Cano, M.-D. Flying ad hoc networks: A new domain for network communications. Sensors 2018, 18, 3571.