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Review

Technological Bibliography Study on UAV and IoT Wireless Communication Specification Through 5G Cellular Networks

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Abstract: The growth of Information and Communication Technologies (ICTs) involvement in our daily life elicits currently a reliable network connection at anytime and anywhere. Robust cellular network is required for the approval of demand users' demand. In the late of last century, noticeable studies were invested in the ICT infrastructure development to meet the public and industrial needs. The evolution of mobile telecommunication has transitioned through multiple phases, from early voice-centric First-Generation (1G) systems to the data-heavy Fourth-Generation (4G) era. Currently, Fifth-Generation (5G) technology has emerged as a superior standard, prioritizing enhanced security protocols and high-speed data transmission according to nomad users. The global rollout of 5G frameworks is inherently linked to the integration of Internet-of-Things (IoT) ecosystems. Then, the design of relevant Base Stations (BSs) for communication during the urban social events constitutes a challenging problem of IoT infrastructures. Scholars have identified Unmanned Aerial Vehicles (UAVs) as a versatile solution for supplementing BS infrastructure, particularly for broadening the reach and throughput of 5G deployments. In scenarios involving public safety, UAV-integrated networks function as airborne base stations, facilitating advanced technologies such as millimeter-wave signaling, IoT connectivity, and 3D Multiple-Input-Multiple-Output (MIMO) arrays. The review on UAV-based wireless communication system modelling by taking into account the different classes and specification with respect to the regulation of technology is synthesized. The synthesis review of UAV cellular network planning for the urban cities is reported by stating about the experiment and performance evaluation. The research works highlight the technical challenge on the UAV-BS deployed for urban social events. It can be emphasized that the study of the UAV wireless communication necessitates the modeling consideration of channel from air transmission to ground BS reception, optimal deployment and the optimization of trajectory. To guarantee the

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communication quality, the analysis of system performance using UAVs is based on the energy efficiency and resource management.

Keywords: Fifth Generation (5G) network, Aerial Base Station (ABS), cellular network, Information and Communication Technology (ICT), Internet-of-Things (IoT) solution, Unmanned Aerial Vehicle (UAV), UAV deployment planning, wireless communication

1. Introduction

Since the last twenty first century, the mobile communication devices have played a very important role for the modern civilization way of life [1, 2]. Every day, the mobile devices are used for the satisfaction of the users' demand. In more practical speaking, different types of mobile devices must be available for everyday human services, such as smartphones, laptops, wearables, sensors and vehicles [3, 4]. Today, these mobile devices communicate over the world with each other in wireless configuration via Wi-Fi, Bluetooth, Zig-Bee, Near-Field Communication (NFC) platforms … [3, 4]. To reach such a successful development, the Information and Communication Technology (ICT) must evolve under convenable infrastructures with respect to the users' demand [5, 6]. Wireless secure connection and architecture satisfying the interaction between the portable connected devices anytime are expected with ideally efficient and perfect network system [7–9]. One of key challenges behind the communication networks dedicated to mobile devices is the ability to support numerous user efficient and safeguard connections [10, 11]. Wireless cellular network available to operate correctly anywhere and anytime constitutes the ideal solution to face up such technical challenges [12–14].

Nevertheless, the increase of the users of mobile devices and the significant demands stimulate ICT engineers to develop cellular network technology guaranteeing higher performances [15, 16]. Cooperative communication infrastructures and devices should allow to transmit multimedia data as sessions of streaming in live located in diverse places with a single phone, and numerous types of apps to be a reality [17, 18]. The different software applications force traditional wireless communication systems to be centered on low-data-rate voice transmission to shift their attention to multimedia transmissions at a high data rate which require better performance in terms of error with respect to Quality of Service (QoS) standards [19–21].

The raw-strength way of providing ubiquitous broadband coverage notably for Internet-of-Things (IoT) [22, 23] is particularly popular by deploying a complex network including Base Station (BS). However, that solution is not always feasible for some particular services as Capital Expenditures (CAPEX) and Operating Expenditures (OPEX) especially under the case temporary events [24, 25]. This situation may appear because significant parts of BSs is slightly charged or does not have a charge in any space-time position. Besides, changes in user density and application rates can lead to unpredictable traffic patterns [26, 27]. The rollout of aerial BS constitutes an attractive solution for such scenarios [28, 29]. During excessive demand saturating unintentionally the allocated communication space and time, Unmanned Aerial Vehicle (UAV), frequently known as drones can help the ground BS to provide high data rate coverage [30–33]. While the aerial BS OPEX is better than the OPEX for ground-based small cell BS, if correctly designed, the drone-BS could significantly save the entire network deployment cost [34].

To deal with such a technological challenge, the Fifth-Generation (5G) wireless networks promise a great evolution in the areas of communications [4, 5, 16, 35]. The 5G ICT aims to serve network users anytime and everywhere as required for very dense data transmission [8, 9, 12–14]. The 5G ICT enables to communicate smart objects via IoT service by handling interaction between different domains [24, 26, 27, 36]. To achieve these goals, different communication system parameters must be taken into account in each type of network [37, 38]. The BS deployment in the wireless cellular networks [39–43] depends more on the environment, users' density and the implementation cost.

Due to the overload or probable destruction of hardware system, the ground BS becomes less and less enough to constitute the technological solution in certain emergency situations like temporary social events [44–47]. However, the UAV-BS deployment can be a solution against such problems if they are correctly deployed in the expected environment

[31, 45, 48–51]. Furthermore, the aerial BSs bring a lot of advantages because they can be easily adjusted in term of altitude, to deal with obstacles by establishing Line-of-Sight (LoS) communication links to users located on the ground position [52–57]. Innovative network planning, for example, with 5G cellular systems should be developed in order to increase the UAV-BS communication performance [58–60].

To literally synthesize more efficiently the progress of IoT [36] and UAV-BS solution by means of the ICT development for the high-density user communication, a review study considering notable specifications, rollout and planning by means of 5G network overview is proposed in the present study. The present paper is structured in seven different sections including the introduction:

- Section 2 overviews the different generations of ICT system toward the first- to Fifth-Generation (1G to 5G) technical specifications. The historical progress of mobile phone communication services is synthesized.
- Section 3 describes the today particular applications of UAV wireless communication network. The necessity to use connected devices to operate with IoT solution in the wireless communication is discussed.
- Section 4 focuses on the technical background related to the necessity of using the UAVs in the public scenario. The specification, regulation and safety of the UAV communication terminals are discussed.
- Section 5 reports briefly the UAV mobile terminal and wireless networking including the reliability under 3D Multiple-Input Multiple-Output (MIMO). Then, Millimeter Wave (mmW) communications are also considered.
- Section 6 investigates on the literature review including the technical challenges about the deployment, design and planning of UAV cellular network as an aerial BS for urban city social events. Moreover, recent works on the UAV-BS beamforming control by avoiding Electromagnetic Interference (EMI) including coding, algorithmic approach and Reconfigurable Intelligent Surface (RIS) technology will be overviewed.
- Finally, Section 7 presents the conclusion of the paper.

2. Overview on mobile phone or cellular network

The technological needs to our daily life dependence and specifications of mobile devices operating under cellular network are overviewed in this section.

2.1 *Ubiquity for mobile network in the moderncivilization*

The cellular network allows many portables devices such as tablets, mobile phones and also laptops playing transmitter and receiver roles to communicate with each other via BSs [3, 4]. In the urban city, such a communication network enables the simultaneous use of millions of wireless phones, whether fixed or mobile, including high-speed and long-distance travel [41–48, 58, 59]. This type of network is distributed in a terrestrial area called cells. To do this, each cell is covered by at least one BS. The mobile communication became extraordinarily popular this last time because of the fast infrastructure development from 1G to 5G in mobile technology [3, 4, 15, 16].

The wireless communication users' demand for compatibility of transmission service technology increases due to the reasons of historical development of terminals as mobile phones during the last four decades as stated in the next subsection.

2.2 *Brief history of mobile phone wireless technology*

The last and present centuries are literally particular compared to the previous ones by the involvement of information technology. Historically, the evolution of mobile phone infrastructure can be technologically differentiated with the operation signal characteristics, data rates and the allocated frequency spectrum. In a nutshell, Table 1 summarizes the main specifications enabling to quantify the evolution of mobile network technology.

Table 1. Evolution of mobile technology

Generation	Operation signal or data	Data rates	Frequency
1G	AMPS, TACS	2 kbps	800 MHz–900 MHz
2G	GSM, EDGE, CDMA	14.4 kbps–64 kbps	850 MHz–1,900 MHz
3G	WCDMA, CDMA-2000	144 kbps–2 Mbps	1.6 GHz–2.5 GHz
4G	WIMAX, LTE-A	100 Mbps–1 Gbps	2 GHz–8 GHz
5G	WWWW, BDMA, CDMA	>1 Gbps	3 GHz–300 GHz

Over the history, the main specifications of each mobile phone generation can be noticed as follows:

- In the 1980s, the First-Generation (1G) of cellular technology was initially proposed in [3, 4]. The 1G communication was also called the Nordic Mobile Telephone (NMT) because at the beginning of modern telecommunication platform, one can only ensure voice services. The 1G mobile system was based on a technology called Advanced Mobile Phone System (AMPS) [4]. The Total Access Communication System (TACS) as a variant of AMPS was also considered. In all, the 1G system is limited to work with low data rate and dedicated to only voice services.
- Second-generation (2G) operates with the Global System for Mobile (GSM) Communication technology. The 2G communication system was launched in 1990. The 2G technology offers more services, such as voice service, Short Messaging Service (SMS) and Multimedia Messaging Service (MMS). The General Package Radio Service (GPRS) was a variant of 2G technology that allows users to access Internet services [3]. The EDGE (Enhanced Data Rate for GSM Evolution) was also considered as a superset to GPRS and can function on any network with GPRS deployed on it, provided the carrier implements the necessary upgrade. The 2G system suffers of its data transmission slow speed.
- In 2000, the third generation (3G) technology was introduced with objectives to bring faster services of voice, SMS, Video chat, Multimedia Messaging Service (MMS) and internet services. There was an improvement in data bandwidth and the data rate speed [15].
- In 2010, the Fourth-Generation (4G) represents the implementation of Long-Term Evolution (LTE) [21, 25, 32] used today was inaugurated in 2010. The WiMAX (Worldwide Interoperability of Microwave Access) is based on modern communications technologies such as MIMO. Compared to the precedent generation, the 4G technology is more advanced because of its large bandwidth and throughput [3].
- Then, the 5G technology [35] promises far better levels in a wireless network experience that supports the Wireless World Wide Web (WWWW) according to its deployment from early 2020s. The 5G communication system is explored based on Beam Division Multiple Access (BDMA) and Code Division Multiple Access (CDMA) technologies. The 5G ICT high-speed data transmission was extended to Wideband CDMA (WCDMA). It will provide different additional services like online gaming services, ultra-High Definition (HD) video streaming, mobile full HD television (TV), telemedicine and secure online banking transaction [16].

2.3 *5G cellular network*

To fulfill the requirements of the user and to address the cellular network deployment solution, a change in design strategy is needed for the 5G wireless system architecture [35]. Typical heterogeneous architecture must include macro-, micro- and small cells, and relays. The 5G cellular network considers small cells as an integral part [11]. However, the concepts of mobile relays and small cells will be the partial part [11]. According to [37], the architecture of the 5G cellular network contains logical different layers, such as cloud and Radio Network (RN). In fact, the RN is constituted by various components that perform different roles. The Network Function Virtualization (NFV) cloud is constituted by two respective elements, such as user and control plane entities. The important roles of NFV are related to the user and the control plane. The connection between the RN and the cloud network is provided by a functionality dedicated to special network as a service known as XaaS [8].

3. Brief review on iot solutions in 5g wireless system

The IoT [36] solution involvement to 5G wireless communication system is briefly reviewed in the present section.

3.1 *Preliminary on the expectation of 5G wireless cellular communication*

Recent applications of wireless communications rely primarily on large amounts of data and end-users [7, 18, 19]. Therefore, a new set of requirements compared to previous network architectures with specifications such as low latency, range of frequency and especially data high-rates should be taken into account. Decades have passed since the creation of the 1G cellular communications where data transmission was limited to voice usually specified by very low-rate data. Since then, necessary improvements have been made to the existing system and the 5G wireless networks for example in order to respect the expected standard requirements allocated to Device-to-Device (D2D) communication [13, 14].

3.2 *IoT solution application diversity*

In 2000s, the 4G cellular network systems were expected to process large quantity of data that are communicated through billions of mobile devices. However, the 4G system applications are particularly limited due to the lack of suitable services. The introduction of new applications including Device-to-Device (D2D), IoT systems, Virtual Reality (VR) and Vehicle-to-Vehicle (V2V) communications increased to satisfy the diversity aspect. For these remarkable services, the 5G IoT communication systems can be:

• Defined by the connection between a large number of mobile devices surrounds us the network explored in our daily life.

• And assumed as embedded platform that generates and transmits large amounts of data intending to make life easier and smarter.

However, in these cases, the improvement of existing cellular systems to meet these application requirements is expected. In short, these IoT applications connect many objects and devices to smart intelligence operating in different areas, including healthcare, agriculture, industry and wearable. The IoT-based approach is launched by developing ideas, detecting data from your environment, analyzing data and ultimately connecting devices or objects to system development.

A global diagram illustrating applications of IoT and end-users that are classified according to the services as seen in Figure 1. These IoT systems require more devices connected per cell with a huge demand for network traffic that 4G LTE-A can handle even with large number of connected objects in certain scenarios [14]. The 5G network operates under high rate of date and requirement related to low latency [10]. For the satisfaction of these requirements, the 5G networks need to increase the rate of transmission data and bandwidth higher than the LTE, connect a large number of devices over long periods and reduce latency.

Figure 1. Application domains of IoT

3.3 *Goals of 5G technology*

Figure 2 illustrates the evolution versus technical architecture diagram of a 5G technology network provided in [12] organized by layers. The adjacent legend clarifies the 5G service category acronyms for contextual reference.

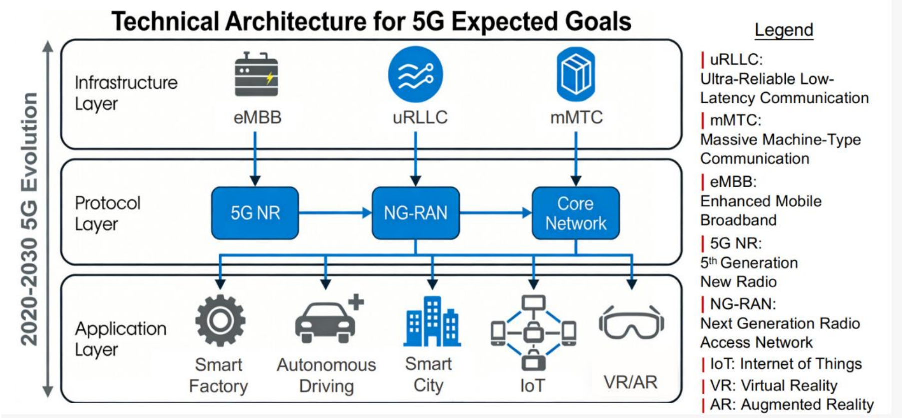

Figure 2. Expected goals of 5G technology (C-RAN: Cloud Radio Access Network)

This diagram outlines the tiered technical framework aligning with 5G's core expected performance and application objectives (spanning 2020–2030 5G evolution), organized across three interconnected layers. At the infrastructure layer, the foundational 5G service categories are defined by the overarching network goals:

- Enhanced Mobile Broadband (eMBB) for high-bandwidth connectivity,
- for time-critical by deploying Ultra-Reliable Low-Latency Communication (uRLLC),
- fail-safe operations with Massive Machine-Type Communication (mMTC) for large-scale IoT device connectivity.

These goals are enabled by:

- The Protocol Layer as 5G New Radio (NR) for the air interface supporting eMBB's throughput,
- The Next Generation Radio Access Network (NG-RAN) unifying radio resources to deliver uRLLC's low-latency reliability,
- And the density and end-to-end network management of 5G Core Network orchestrating mMTC's massive device.

The application layer translates these technical capabilities for use cases in the real-world:

- Virtual Reality (VR) and Augmented Reality (AR) tied to eMBB via 5G NR,
- autonomous driving/smart factories leveraging uRLLC via NG-RAN,
- IoT deployments supported by mMTC via the Core Network,
- And smart cities integrating all three 5G services.

In the 5G technology, a better utilization of frequency planning and resource in cellular networks will be required for D2D communications because this type of engineering allows to involve ultra-dense small cell and wireless data transmission operating with mmW. In the backhaul, interference, overall network modeling, ultra-dense small cellular networks and mmW wireless communication constitute the principal practical challenges. Similarly, mmW communications are subject to blocking because of its high dependence on the LoS target to work with certain performances as high speed and low-latency. To overcome some of these technological challenges, the use of aerial BSs is considered an inevitable solution in particular for the certain cases of heterogeneous 5G environments [14].

4. Specifications, classification and safety of UAV technology owing to the wireless communication system

The needs, specifications, regulation and classification of UAV for wireless communication system is synthesized in the present section.

4.1 *Terrestrial and aerial BS*

In a geographical area with limited cellular infrastructure, deploying Low-Aptitude Platform (LAP) UAV is a cost-effective way to provide wireless connectivity. During the temporary urban events like sports, live concerts, public meeting, symposia, work places, student schools and festivities, UAVs can be used as BSs to deploy small cells. For rural environments, High-Aptitude Platform (HAP) UAVs are able to provide solution in longer-term. Furthermore, if planned and operated well, the combination of UAVs with potentially massive MIMO technology working in mmW is able to create a novel type of cellular network with dynamic flight to provide a good quality of wireless services.

Table 2 shows the characteristic and network configuration parameters illustrating the differences between the terrestrial- and aerial- BSs. Nevertheless, aerial BSs have different key applications in 5G technology, like the safety of public scenarios, take in charge terrestrial networks for information dissemination, and the enhancement of connectivity due to their mobility and LoS opportunities [42, 60]. In 3D MIMO and mmW communications, the consideration of Three-Dimensional (3D) beams allows the separation of beams in 3D space at the same time [29]. Such a beamforming solution reduces the inter-cellular interference [29].

Table 2. Terrestrial- versus aerial- BS

Parameters	Terrestrial BS	UAV-BS
Characteristics	• Deployment is generally Two-Dimensional (2D) • Usually long-term and permanent deployments • Rare and designated locations • Static and fixed	• Deployment is Three-Dimensional (3D) • Short-term and often varying deployments • Positions are generally unlimited • The dimension of mobility is available
Networks	• The deployment space is too limited and somehow confined • Models and energy constraints definite • Mostly static association • BS constantly there, no schedule constraints	• Large range of deployment space • Severe energy constraints and models • Variable cellular association • Hovering and flight time constraints

In an IoT-centric scenario, drones are deployed as aerial BSs to operate efficiently and reliably in upstream IoT communications [28] and in cache-enabled UAVs.

4.2 *Classification and specifications of UAVs*

Unlike conventional portable hardware, the UAVs possess unique mobility features that facilitate the rapid field deployment. In the wake of natural catastrophes where terrestrial networks are compromised, or within high-traffic hot spots, the UAV-aided systems can be implemented [41] to bolster connectivity for mobile subscribers. The selection of an appropriate drone platform is contingent upon the specific operational requirements and research goals.

A comprehensive taxonomy of UAV classifications along with their respective technical specifications is presented in Figure 3. The optimization of QoS necessitates a thorough analysis of environmental variables and operational constraints. Generally, the UAV categorization follows two primary frameworks: operational altitude and flight mechanics. The aerial units functioning at heights under 17 km are termed Low-Altitude Platforms (LAPs), whereas those operating in the stratosphere above the 17 km threshold are designated as High-Altitude Platforms (HAPs). Furthermore, the UAVs are distinguished by their aerodynamic configuration, primarily categorized into fixed-wing or rotary-wing architectures based on their propulsion and lifting mechanisms:

- Fixed-wing drones expects a motion in high-speed and to be located in the sky,
- And rotary-wing drones keeps a position to be fixed [41].

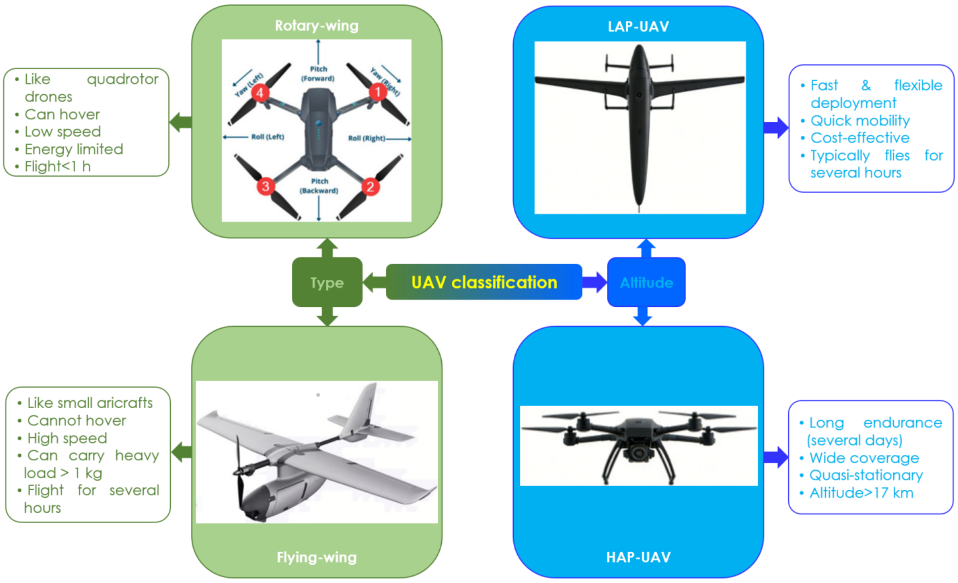

Figure 3. UAV classification and specifications

4.3 *UAV technology regulation*

The integration of UAVs into wireless architectures offers significant potential, several critical challenges persist, including data confidentiality, public welfare, cybersecurity and obstacle sensing. Currently, regulatory frameworks represent a primary constraint on the widespread implementation of UAV-based communication. Consequently, governance policies are undergoing constant refinement, focusing on parameters such as vehicle classification, spectral allocation, altitude thresholds, and velocity limits. The evolution of these regulations [20] is typically guided by five fundamental pillars: scope of applicability, flight constraints, management protocols, technical standards, and the enforcement of ethical guidelines. For a comparative overview of these technical mandates, Table 3 summarizes the regulatory landscapes across six international jurisdictions.

Table 3. Regulations of UAV deployment

Country	Maximum altitude	Minimum distance to people	Minimum distance to Airport
US	400 ft	N/A	8 km
China	394 ft	50 m	N/A
Australia	394 ft	30 m	5.5 km
South Africa	151 ft	50 m	10 km
UK	400 ft	50 m	N/A
Chile	427 ft	36 m	N/A

These regulations are different for each country and each type of geographical area such as rural and urban ones:

- In the United States, the regulatory operations of UAV are assigned by Federal Aviation Authority (FAA) and National Aeronautics and Space Administration (NASA).
- In China, the UAV regulations are provided by the Civil Aviation Administration of China (CAAC).

4.4 *UAVs exploited as aerial BSs for public safety*

Globally, the catastrophic environmental events ranging from inundations and cyclonic storms to intense blizzards frequently compromise the integrity of telecommunication frameworks. In the aftermath of such events, the physical destruction of terrestrial nodes often leads to a cascading traffic surge on surviving base stations, a phenomenon notably documented during the Sandy and Irma hurricanes [44]. Maintaining connectivity is paramount for public welfare in these scenarios, as emergency personnel rely heavily on robust networks to coordinate search and rescue efforts. Given that UAVs circumvent the need for costly, static infrastructure, their capacity for dynamic repositioning and rapid deployment makes them ideal for restoring emergency services. Consequently, the integration of airborne network architectures serves as a highly effective strategy [49], as illustrated in Figure 4, for establishing resilient and adaptable wireless coverage.

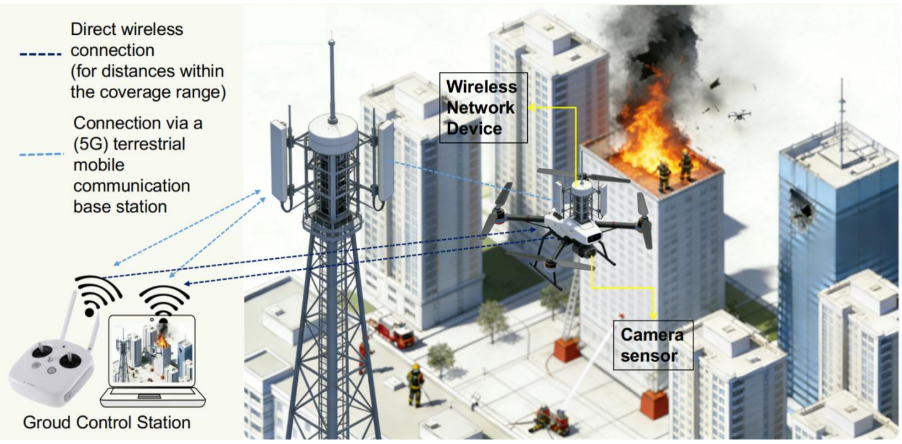

Figure 4. UAV in public safety scenario

Thus, UAVs can be used as aerial BSs. This solution enables to broaden the connectivity especially to the zones with damaged terrestrial wireless infrastructure. Meanwhile, the UAV-BSs is clearly appropriate to public safety scenarios for delivering a robust communication system.

5. Brief review on UAV wireless networking

The UAVs is generally used as aerial BSs for several circumstances in the wireless networking field. The UAV-BSs are able to operate with hotspot coverage in public scenarios by caching apparatus. As discussed in the present section, the UAVs are particularly useful as an outstanding mobile equipment to ensure the wireless communication.

5.1 *Reliability of UAV-assisted ground networks*

Nowadays, despite the ICT spectacular development, the communication device users suffer of performance limitation related to the coverage failure [30, 32, 33] because of the communication short range and the undesirable interference which becomes more and more significant [31]. To deal with such a drastic situation, the UAV wireless communication systems assist ground networks [45–47] to increase their QoS in multitude of different scenarios. One can cite different situations adopting more and more the UAV-assistance such as the reliability enhancement [29] of:

- The intelligent broadcasting of multimedia common files between the ground communication devices via improvement of data transmission capacity and network coverage,
- The information dissemination through high densification terrestrial networks such as crowds of User Equipment (UE),
- The D2D connectivity and limitation by offering an effective solution to the communication networks,
- And the information safety [44] by contributing in terms of offloading cellular data traffic constituting the communication networks of Vehicle-to-Vehicle (V2V) and also Vehicle-to-Infrastructure (V2I).

As global illustration of UAV assistance of ground networks, the drones are utilized as explained in Figure 5 to operate as aerial BSs. As dissemination of information, the UAV-BSs can support the D2D network or ad hoc mobile network.

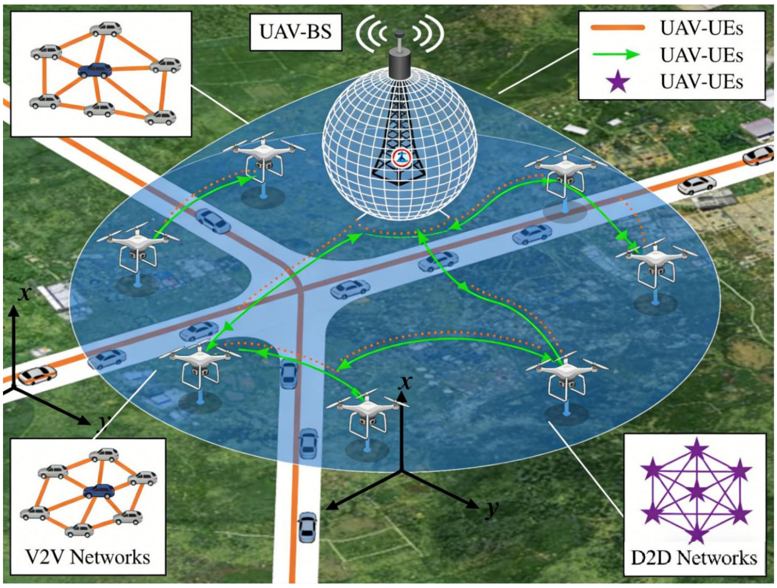

Figure 5. UAV-assisted terrestrial networks

In other words, due to the fact related to the mobility and the good probability to operate by guarantying the LoS, the UAVs allows to improve any connectivity between ground network terminals [42].

5.2 *3D MIMO and mmW communications with UAVs*

From a modeling perspective, UAVs function as airborne antenna arrays capable of implementing massive MIMO architectures [54–58]. Their inherent mobility and elevated positioning make them ideal for leveraging mmW signaling and 3D beamforming. Current research [42] has shifted focus toward Full-Dimension (FD) MIMO, which integrates both vertical and horizontal planes to surpass the limitations of legacy terrestrial networks. By utilizing 3D MIMO, systems can achieve superior throughput and broader coverage, effectively mitigating signal attenuation for User Equipment (UE). Specifically, UAV-based stations facilitate the dynamic optimization of LoS paths and accommodate a higher density of subscribers than traditional 2D systems. Given the spatial distribution of users across varying altitudes and angles, 3D MIMO remains the most effective framework. Consequently, UAV platforms represent the most viable candidates for 3D MIMO-based data transport, enabling the concurrent generation of distinct spatial beams as depicted in Figure 6.

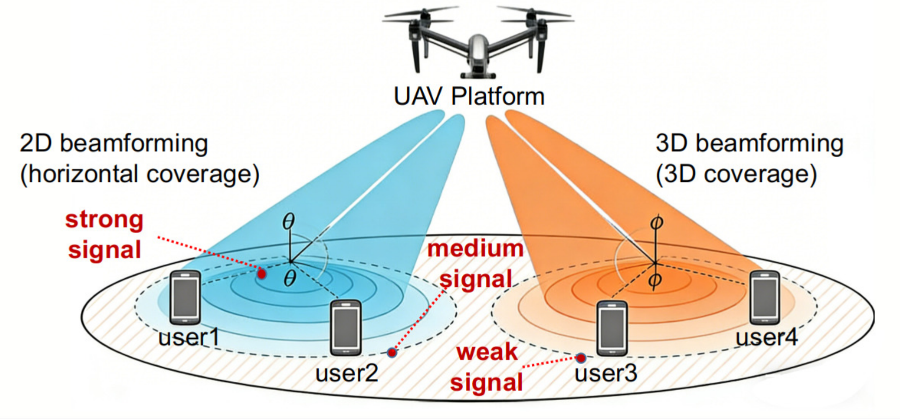

Figure 6. UAV-based 3D beamforming

In this diagram, we have the following functioning:

(1) The blue 2D beam (horizontal coverage) spreads energy across the ground plane:

- User 1 (at the beam's core) gets a strong signal,
- And while User 2 (near the core) receives a medium signal.

(2) And the orange 3D beam (precise 3D-focused coverage) concentrates energy on a specific 3D zone:

- User 3 (on the beam's edge/outside the focus) has a weak signal since 3D beamforming avoids wasting energy on non-targeted areas, but User 4 (inside this targeted area) gets a strong signal.

5.3 *IoT communications and cache-enabled UAVs*

The swift integration of wireless protocols within the IoT ecosystem encompasses a diverse array of hardware, including mobile handsets, vehicular systems, remote sensors and aerial units. Deploying IoT frameworks for smart urban planning, medical monitoring and logistics [36] necessitates high-density wireless synchronization. The achievement of low latency and reliable uplink speeds is technically feasible, the primary hurdles in cellular architectures reside within specific use-case scenarios [43]. Notably, many IoT nodes suffer from severe power limitations and restricting long-range transmissions. Furthermore, these devices are frequently situated in remote topographies, such as mountainous or arid regions, where terrestrial infrastructure is absent. The utilization of mobile UAVs serves as a strategic remedy to these connectivity gaps. By positioning UAV-BSs in proximity to ground clusters, the mobile devices can maintain network access while minimizing energy expenditure.

To augment data throughput and minimize latency, the content caching at small BSs has emerged as a vital technique [18]. However, the static caching often fails to accommodate high-mobility subscribers, particularly during frequent handovers in ultra-dense environments. In traditional setups, a user transitioning to a new cell may encounter a 'cache miss,' where the requested data is unavailable at the target BS. While multi-node redundant caching could mitigate this, it introduces prohibitive storage costs and signaling overhead. Consequently, the deployment of agile UAV-BSs offers a superior alternative for content delivery. Their ability to dynamically follow user trajectories significantly enhances caching efficiency and ensures seamless service continuity [46].

5.4 *UAVs as UE in Flying Ad-hoc NETwork (FANET)*

When functioning as UE, the UAVs are utilized across diverse sectors including environmental monitoring, logistics, and spatial sensing. Industry leaders like Amazon® have integrated these platforms for various commercial logistics and critical medical transport, such as the autonomous delivery of life-saving pharmaceuticals [61]. The cellular-connected UAVs represent a vital component for optimizing the efficiency of IoT terminals. Their primary strengths as UAV-users lie in their high mobility and capacity for real-time trajectory adjustment. For successful integration, these aerial units require robust, low-latency links with terrestrial base stations. Furthermore, the UAVs utilized in reconnaissance missions necessitate high-throughput uplink capabilities from the supporting ground infrastructure. It is important to note that legacy cellular networks, primarily engineered for terrestrial subscribers, may struggle to accommodate the distinct mobility patterns and traffic demands of airborne users.

Beyond standard cellular connections, FANETs facilitate decentralized communication between multiple aerial nodes. The dynamic nature of FANETs allows for expanded network reach in remote zones lacking fixed infrastructure [62]. These decentralized systems are fundamental to various domains, including metropolitan traffic oversight, border security, precision agriculture, and emergency response management. In particular, the utilization of UAVs as relay nodes ensures stable connectivity between the distant transceivers separated by physical barriers or geographic gaps.

6. Review on the main roadblocks of UAV-BS deployment in urban cities

The deployment of UAVs in the urban cities [48–50] constitutes one of popular ICT applications of this twenty-first century. The present section overviews the main challenges on the UAV-BS design wireless communication and its potential deployment for the smart cities [32, 36, 63].

6.1 *UAVs as aerial Backhaul for terrestrial and broadband networks and its diverse rural and urban utilities*

Nowadays, the UAVs work as airborne embedded systems with diverse utilities in rural and urban sectors such as reconnaissance, telecommunications, precision farming and emergency logistics. Over the past ten years, the adoption of UAV-BS platforms has surged, driven by their operational autonomy, spatial mobility and versatile altitude control. Within the context of wireless networks, UAV-integrated solutions provide a reliable and economically viable alternative to static infrastructure when effectively optimized. The primary benefit of employing an UAV-BS is the substantial expansion of network footprint [31]. Crucially, the elevated position of a UAV-BS significantly increases the probability of establishing a robust LoS connection with ground-level subscribers. The UAV exploration can be literally afforded in two sides:

- On one side, the UAVs can be employed as aerial BSs. They can work with the existing terrestrial wireless network like cellular and broadband networks.
- And on the other side, they can be used as aerial user equipment also known as cellular-connected UAVs.

6.2 *Benefits of using UAVs for ground networks and application for smart cities*

For the ground network application scenarios, the most familiar approach to connect the core and the BSs is generally the wired backhauling. Nevertheless, such a terrestrial wired communication is not feasible in ultra-dense cellular networks. Furthermore, the wired connections are expensive, permanently facing up expensive geographical constraints [35]. Despite the cost-effective and viable solution of wireless backhauling, the ground network may suffer because of the blocking and interference that decrease the radio access network performance [59]. To overcome these technical limitations, the UAV-BS wireless network is particularly an attractive solution because:

- For terrestrial network, it enables to operate in high-speed wireless backhaul connectivity with reliable and cost-effective.
- It enables to minimize the influences of obstacles and also establishing communication links with good reliability.
- It can be exploited with respect to the locations of the users.
- It can be used with high data rate wireless backhauling for high traffic demands in congested areas. The UAVs have capabilities to communicate efficiently in mmW.
- And the possibility of enhancement of operation cost, relatability and capacity of backhaul networks flexibility when operating as ground networks.

The realization of comprehensive blueprint for interconnected urban environments remains a formidable technical undertaking. The modern smart cities require the seamless convergence of multiple service layers, including pervasive IoT ecosystems, robust mobile telecommunication frameworks, disaster recovery protocols, and big data analytics [64]. The UAVs are capable to operate in the smart cities by:

- Providing multiple wireless application use cases,
- Delivering cloud units for the big data analytics center,
- Collecting large amounts of data emitted from various geographic regions of a city,
- Deploying to improve the coverage of cellular network in the considered city [31],
- And used as mobile cloud computing systems [47].

In brief, thanks to the operational prospects and the flexibility of deployment, the UAV-BS solution is able to significantly contribute to the improvement of wireless communication in the smart cities.

6.3 *Challenges on UAV-BS design*

Despite all the benefits of using UAV-BS in telecommunication region, further constraints have to be overcome by the design and fabrication engineers. According to the literature [39], the UAV wireless communication technology present two fundamental challenges:

(1) The first problem is multiple reflection of Electromagnetic (EM) waves caused by:

- The time-varying characteristics of the channel,
- The wireless communication link obstacles,
- And the pre-optimization of distance which guarantees the transmitter-receiver reliable communication [52, 54–56, 65].

(2) The EMI between the transmission signals is the second problem because, in wireless communication. This problem is related to the lack of transmitter-received direct and isolated links.

So far, open challenges of UAV-BS deployment beyond the deep technological aspect notably to operate in the urban cities are:

- In existence of terrestrial network and joint 3D beamforming communication, the deployment of UAV-BS must take into account the resource allocation,
- The autonomy by being aware to the energy constraints and during the transmission of power optimization,
- The channel modeling under imperfections as small-scale fading, air-to-air and air-to-ground channel path loss,
- The planning of cellular network path and backhaul-aware cell by optimizing UAV number and also traffic-based cell association,
- The evaluation of performance under mobility considerations by considering heterogeneous aerial-terrestrial networks, signaling and overhead relevant analysis and for capturing spatial and temporal correlations,
- The resource management with bandwidth and flight time optimization and with multi-dimensional communication spectrum shared by cellular networks,
- And the optimization of trajectory by ensuring the energy-efficient and delay issues to reach reliable communication with path planning.

6.4 *Methodology of UAV-BS design for urban social events*

Among the potential applications of UAVs explored in the literatures [28, 30, 34, 41, 50], the urban social events associated to crowding activities that can be attended by numerous people. The quantity of participants to such urban social events varies depending on the geographical or local physical constraints. Before deploying BSs to serve the users, relevant planning of cellular network is needed. Thanks to the optimal locations, the UAV-BS enables to target different areas with cheap technological solution.

The network dimensioning and planning strategies for terrestrial BSs differ significantly from their aerial counterparts due to distinct operational parameters. The design of UAV-integrated communication frameworks entails greater complexity than traditional ground-based cellular planning, primarily due to dynamic spatial variables. Nevertheless, the UAV-BSs offer superior performance in terms of signal reach and QoS, largely attributed to the increased likelihood of establishing LoS links. Consequently, the rollout of airborne base stations provides a strategic advantage in specific networking scenarios where terrestrial infrastructure is insufficient or impractical. These numbers vary depending on the organization place logistics [51] and most of them are using mobile devices. To meet these needs of users, the deployment of ground-BS does not enable to overcome the communication problem. Recent research works [48, 51] stated about the UAV wireless communication challenges for urban social events. The main focus of UAV solution is stated as follows:

- First, the knowledge of the architecture constituting the wireless cellular network representing the social event,
- Second, the understanding of how the UAV contributes to the communication performance improvement,
- Third, the development of an optimization problem to select the UAV-BS better locations adapted to the social event.
- And then, the implementation of right algorithm dedicated to solve the UAV positioning problem.

6.5 *Recent work including UAV-BS exploring certain ICT framework integrating sensing RIS*

In addition to the IoT and UAV progress, the wireless communication evolves with physical improvement based on the innovative EM and wave transmission processing algorithms. Among the existing research works, one can cite the following ones:

- A communication framework operating with joint source-channel coding architecture enabling to achieve simultaneous sensing decoding and transmission was developed [66]. The proposed communication framework is based on the semantic-driven multimodal sensing [66]. It was reported that the semantic-driven multimodal sensing communication framework overcomes notable limitations of the accuracy and capability of traditional single-modality wireless communication sensing.
- Furthermore, a MIMO wireless transmission method with adaptive beamforming as a key direction in Vehicle-to-Everything (V2X) networks was developed [67]. The adaptive beamforming schemes investigated in this study are compatible to NR and V2X. Moreover, the proposed method allows to reach significant gain compared to conventional MIMO communication ones. The adaptive beamforming is expected to operate for extended target with perspective of predictive error ellipse.
- Another recent communication scheme for BS with feedback integrating the ability of RIS sensing control was introduced to replace the communication process based on traditional Channel State Information (CSI) [68]. The RIS forwards the transmission with algorithm designed for EM wave transmission Direction of Arrival (DOA) estimation and also allowing the identification recognition via RF. The RIS sensing scheme is expected in the future to assist and to enhance communication system by suppression of near-field EMI by playing smartly on the DOA.

7. Conclusion

Today, any sector of public and industrial activities cannot be imagined in the large megalopolis without wireless ICTs. For the technical comprehension, it is particularly interesting to point out about the backstage of communication system. Through the present study, an investigation on the ICT evolution with the dependance of communication mobile devices and reliable cellular network is reviewed. The ICT progress from the last century to today is reported with the specifications of different generations (1G to 5G) of mobile phones. The different generations of 1G-to-5G wireless communication cellular system were recapitulated. The relevance of wireless communication infrastructure depends on the deployment and BS enabling to data transmission between terminals as IoT and UAVs.

The main focus on the technological review study of smart infrastructures enabling the wireless communication for urban social event is addressed. The research contributions and challenges notably with respect to portable and smart devices are indicated. It is emphasized that the resilience and the flexibility is required for upcoming cellular networks with respect to the increase of communication users. As the ground BSs cannot fulfill correctly the requirements to reach the communication reliability, the technological solution with the IoT and UAV. It was noticed that the UAV allows to communicate with each over different portable devices via BSs. The main goals of 5G technology and the challenges on UAV-BS design are indicated. The overview of UAVs in flying ad-hoc network and as aerial backhaul for terrestrial networks in the smart objects and smart cities are underlined. In the event of a crisis or natural catastrophe, the UAV platforms serve as viable BS when the terrestrial infrastructure is incapacitated or service gaps emerge. Additionally, the

UAVs work effectively as backhaul trunks to augment the efficiency of established networks. The implementation of UAVs as wireless nodes, either as relays or BS units, can significantly lower operational expenditures. The present work also details the fundamental ICT specifications and 5G network dimensioning strategies required for high-density scenarios, such as large-scale urban gatherings. Recently, the integration of UAV technologies into wireless communication frameworks has become a focal point of extensive research and industrial interest. The UAV cache-enabled, user equipment's and regulations are reported.

Despite the spectacular progress of technologies, different challenges have to be solved during the UAV-BS deployment in urban cities. For example, open challenges as cellular network planning, optimization of trajectory, modeling of communication channel, energy efficiency and resource management on the UAV-BS design to reach significant performance of large cellular system remain to overcome. An innovative method of cellular planning is expected as direction of future research on the UAV-BS deployment and investigation by improving the backhaul perception, joint optimization of energy efficiency and trajectory, and the incompleteness of air-ground channel modeling.

Confilict of interest

The authors declare no competing financial interest.

Abbreviation

1G/2G/3G/4G/5G	First/Second/Third/Fourth/Fifth Generation
2D/3D	Two-/Three-Dimensional
AMPS	Advanced Mobile Phone System
AR	Augmented Reality
BS	Base Station
BDMA	Beam Division Multiple Access
CAAC	Civil Aviation Administration of China
CAPEX	Capital Expenditures
CDMA	Code Division Multiple Access
CSI	Channel State Information
D2D	Device-to-Device
DOA	Direction of Arrival
EM	Electromagnetic
eMBB	Enhanced Mobile Broadband
EMI	Electromagnetic Interference
FAA	Federal Aviation Authority
FANET	Flying ad-hoc Network
GSM	Global System for Mobile Communication
GPRS	General Package Radio Service
HAP-UAV	High Altitude Platform Unmanned Aerial Vehicles
HD	High-Definition
HD TV	High-Definition Television
ICT	Information and Communication Technology
IoT	Internet of Thing
LAP-UAV	Low Altitude Platform Unmanned Aerial Vehicles
LoS	Line-of-Sight
LTE	Long-Term Evolution
MIMO	Multiple Input Multiple Output

MMS	Multimedia Messaging Service
mMTC	Massive Machine-Type Communication
mmW	Millimeter Wave
NASA	National Aeronautics and Space Administration
NFC	Near-Field Communication
NFV	Network Function Virtualization
NG-RAN	Next Generation Radio Access Network
NMT	Nordic Mobile Telephone
NR	New Radio
OPEX	Operating Expenditures
QoS	Quality of Service
RN	Radio Network
RIS	Reconfigurable Intelligent Surface
SBS	Small Base Station
SMS	Short Messaging Service
TACS	Total Access Communication System
UAV	Unmanned Aerial Vehicle
UE	User Equipment
uRLLC	Ultra-Reliable Low-Latency Communication
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VR	Virtual Reality
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperability of Microwave Access
WWWW	Wireless World Wide Web

References

[1] Q. Bi, G. L. Zysman, and H. Menkes, “Wireless mobile communications at the start of the 21st century,” *IEEE Communications Magazine*, vol. 39, no. 1, pp. 110-116, 2001. https://doi.org/10.1109/35.894384.

[2] A. Singh, “A review of different generations of mobile technology,” *International Journal of Advanced Research in Computer Engineering and Technology*, vol. 4, no. 8, pp. 3404-3408, 2015.

[3] B. Kalra and D. K. Chauhan, “A comparative study of mobile wireless communication network: 1G to 5G,” *International Journal of Computer Science and Information Technology Research*, vol. 2, no. 3, pp. 430-433, 2014.

[4] P. Sharma, “Evolution of mobile wireless communication networks-1G to 5G as well as future prospective of next generation communication network,” *International Journal of Computer Science and Mobile Computing*, vol. 2, no. 8, pp. 47-53, August 2013.

[5] I. Petkovics, Á. Petkovics, and J. Simon, “A survey of ICT: Evolution of architectures, models and layers,” In Proc. IEEE 14th International Symposium on Intelligent Systems and Informatics, Subotica, Serbia, Aug. 29-31, 2016, pp. 215-220. https://doi.org/10.1109/SISY.2016.7601500.

[6] D. N. Molokomme, C. S. Chabalala, and P. Bokoro, “A survey on information and communications technology infrastructure for smart grids,” In Proc. IEEE 2nd Wireless Africa Conference, Pretoria, South Africa, Aug. 18-20, 2019, pp. 1-6. https://doi.org/10.1109/AFRICA.2019.8843419.

[7] C. Y. Lee and H. G. Kang, “Cell planning with capacity expansion in mobile communications: a tabu search approach,” *IEEE Transactions on Vehicular Technology*, vol. 49, no. 5, pp. 1678-1691, September 2000. https://doi.org/10.1109/25.892573.

[8] P. K. Agyapong, M. Iwamura, D. Staehle, W. Kiess, and A. Benjebbour, “Design considerations for a 5G network architecture,” *IEEE Communications Magazine*, vol. 52, no. 11, pp. 65-72, November 2014. https://doi.org/10.1109/MCOM.2014.6957145.

[9] A. Gupta, “A survey of 5G network: architecture and emerging technologies,” *IEEE Access*, vol. 3, pp. 1206-1232, 2015. https://doi.org/10.1109/ACCESS.2015.2461602.

[10] N. Yang, L. Wang, G. Geraci, M. Elkashlan, J. Yuan, and M. Di Renzo, “Safeguarding 5G wireless communication networks using physical layer security,” *IEEE Communications Magazine*, vol. 53, no. 4, pp. 20-27, 2015. https://doi.org/10.1109/MCOM.2015.7081071.

[11] F. Haider, C.-X. Wang, H. Haas, D. Yuan, H. Wang, X. Gao, et al., “Spectral efficiency analysis of mobile femtocell based cellular systems,” In Proc. IEEE 13th International Conference on Communication Technology, Jinan, China, Sep. 25-28, 2011, pp. 347-351. https://doi.org/10.1109/ICCT.2011.6157894.

[12] D. Liu, L. Wang, Y. Chen, M. Elkashlan, K. Wong, R. Schober, et al., “User association in 5G networks: a survey and an outlook,” *IEEE Communications Surveys and Tutorials*, vol. 18, no. 2, pp. 1018-1044, 2016. https://doi.org/10.1109/COMST.2016.2516538.

[13] A. Gupta and R. K. Jha, “A survey of 5G network: architecture and emerging technologies,” *IEEE Access*, vol. 3, pp. 1206-1232, 2015. https://doi.org/10.1109/ACCESS.2015.2461602.

[14] M. Agiwal, A. Roy, and N. Saxena, “Next generation 5G wireless networks: a comprehensive survey,” *IEEE Communications Surveys and Tutorials*, vol. 18, no. 3, pp. 1617-1655, 2016. https://doi.org/10.1109/COMST.2016.2532458.

[15] A. Jain, E. Lopez-Aguilera, and I. Demirkol, ”Evolutionary 4G/5G network architecture assisted efficient handover signaling,” *IEEE Access*, vol. 7, pp. 256-283, 2019. https://doi.org/10.1109/ACCESS.2018.2885344.

[16] M. M. ud in Mir and S. Kumar, “Evolution of mobile wireless technology from 0G to 5G,” *International Journal of Computer Science and Information Technologies*, vol. 6, no. 3, pp. 2545-12551, 2015.

[17] T. X. Tran, A. Hajisami, and D. Pompili, “Cooperative hierarchical caching in 5G cloud radio access networks,” *IEEE Network*, vol. 31, pp. 35-41, July 2017. https://doi.org/10.1109/MNET.2017.1600307.

[18] J. Qiao, Y. He, and X. S. Shen, “Proactive caching for mobile video streaming in millimeter wave 5G networks,” *IEEE Transactions on Wireless Communications*, vol. 15, no. 10, pp. 7187-7198, October 2016. https://doi.org/10.1109/TWC.2016.2598748.

[19] M. Vandana and H. D. Kallinatha, “Quality of service enhancement for multimedia applications using scalable video coding,” In Proc. Second International Conference on Intelligent Computing and Control Systems, Madurai, India, Jun. 14-15, 2018, pp. 394-399. https://doi.org/10.1109/ICCONS.2018.8663244.

[20] A. Fotouhi, H. Qiang, M. Ding, M. Hassan, L. G. Giordano, A. Garcia-Rodriguez, et al., “Survey on UAV cellular communications: practical aspects, standardization advancements, regulation, and security challenges,” *IEEE Communications Surveys and Tutorials*, vol. 21, no. 4, pp. 3417-3442, 2019. https://doi.org/10.1109/COMST.2019.2906228.

[21] F. Gordejuela-Sanchez and J. Zhang, “LTE access network planning and optimization: a service-oriented and technology-specific perspective,” In Proc. GLOBECOM 2009-2009 IEEE Global Telecommunications Conference, Honolulu, HI, USA, Nov. 30-Dec. 4, 2009, pp. 1-5. https://doi.org/10.1109/GLOCOM.2009.5425478.

[22] F. T. El-Hassan and D. Ionescu, “Design and implementation of a hardware versatile publish-subscribe architecture for the internet of things,” *IEEE Access*, vol. 6, pp. 31872-31890, 2018. https://doi.org/10.1109/ACCESS.2018.2842706.

[23] Y. Wang and Y. Yang, “A novel secure and energy-efficient routing method for the agricultural internet of things using whale optimization algorithm,” *Journal of Cyber Security and Mobility*, vol. 13, no. 4, pp. 725-749, July 2024. https://doi.org/10.13052/jcsm2245-1439.1347.

[24] Zabeehullah, Q. M. u. Haq, F. Arif, N. A. Khan, M. S. Anwar, and W. Alhalabi, “A secure AI framework for intelligent traffic prediction and routing in SDN-based consumer internet of things,” *IEEE Transactions on Consumer Electronics*, vol. 71, no. 2, pp. 6294-6306, May 2025. https://doi.org/10.1109/TCE.2025.3552609.

[25] H. Ghazzai, E. Yaacoub, M. Alouini, Z. Dawy, and A. Abu-Dayya, “Optimized LTE cell planning with varying spatial and temporal user densities,” *IEEE Transactions on Vehicular Technology*, vol. 65, no. 3, pp. 1575-1589, 2016. https://doi.org/10.1109/TVT.2015.2411579.

[26] H. Wang, L. Meng, Y. Liu, X. Yin, J. Wang, Z. Wang, et al., “An intelligent optimization for the vehicle routing of multi-commodity and multi-trip supply chain logistics in the internet of things,” *IEEE Internet of Things Journal*, 2025. https://doi.org/10.1109/JIOT.2025.3619495.

[27] R. Arora and R. B. Damarla, “Generative AI-augmented federated learning for vehicle routing in supply chain management with human resource management and low-carbon emission in IIoT,” *IEEE Internet of Things Journal*, vol. 12, no. 18, pp. 39061-39076, 2025. https://doi.org/10.1109/JIOT.2025.3588189.

[28] M. Mozaffari, W. Saad, M. Bennis, and M. Debbah, "Mobile unmanned aerial vehicles (UAVs) for energy efficient internet of things communications," *IEEE Transactions on Wireless Communications*, vol. 16, no. 11, pp. 7574-7589, 2017. https://doi.org/10.1109/TWC.2017.2751045.

[29] H. C. Nguyen, R. Amorim, J. Wigard, I. Z. Kovács, T. B. Sørensen, and P. E. Mogensen, "How to ensure reliable connectivity for aerial vehicles over cellular networks," *IEEE Access*, vol. 6, pp. 12304-12317, 2018. https://doi.org/10.1109/ACCESS.2018.2808998.

[30] M. Mozaffari, W. Saad, M. Bennis, and M. Debbah, "Efficient deployment of multiple unmanned aerial vehicles for optimal wireless coverage," *IEEE Communications Letters*, vol. 20, no. 8, pp. 1647-1650, 2016. https://doi.org/10.1109/LCOMM.2016.2578312.

[31] A. A. Khuwaja, G. Zheng, W. Feng, and Y. Chen, "Coverage area performance for multiple interfering UAVs," In Proc. IEEE Global Communications Conference, Waikoloa, HI, USA, Dec. 9-13, 2019, pp. 1-6. https://doi.org/10.1109/GLOBECOM38437.2019.9014242.

[32] A. Colpaert, E. Vinogradov, and S. Pollin, "Aerial coverage analysis of cellular systems at LTE and mmwave frequencies using 3D city models," *Sensors*, vol. 18, no. 12, pp. 1-15, 2018. https://doi.org/https://doi.org/10.3390/s18124311.

[33] S. Javed, Y. Chen, M.-S. Alouini, and C.-X. Wang, "Optimizing air-borne network-in-a-box deployment for efficient remote coverage," *IEEE Internet of Things Journal*, vol. 11, no. 23, pp. 38728-38743, 2024. https://doi.org/10.1109/JIOT.2024.3455439.

[34] R. A. C. da Silva, N. L. S. da Fonseca, and R. Boutaba, "Evaluation of the employment of UAVs as fog nodes," *IEEE Wireless Communications*, vol. 28, no. 5, pp. 20-27, 2021. https://doi.org/10.1109/MWC.101.2100018.

[35] N. Bhushan, J. Li, D. Malladi, R. Gilmore, D. Brenner, A. Damnjanovic, et al., "Network densification: the dominant theme for wireless evolution into 5G," *IEEE Communications Magazine*, vol. 52, no. 2, pp. 82-89, 2014. https://doi.org/10.1109/MCOM.2014.6736747.

[36] A. Zanella, N. Bui, A. Castellani, L. Vangelista, and M. Zorzi, "Internet of things for smart cities," *IEEE Internet of Things Journal*, vol. 1, no. 1, pp. 22-32, 2014. https://doi.org/10.1109/JIOT.2014.2306328.

[37] C.-X. Wang, F. Haider, X. Gao, X.-H. You, Y. Yang, and D. Yuan, "Cellular architecture and key technologies for 5G wireless communication networks," *IEEE Communications Magazine*, vol. 52, no. 2, pp. 122-130, 2014. https://doi.org/10.1109/MCOM.2014.6736752.

[38] A. Guo and M. Haenggi, "Spatial stochastic models and metrics for the structure of base stations in cellular networks," *IEEE Transactions on Wireless Communications*, vol. 12, no. 11, pp. 5800-5812, 2013. https://doi.org/10.1109/TWC.2013.100113.130220.

[39] A. Goldsmith, *Wireless Communications*. Cambridge university press, 2005.

[40] Y.-H. Nam, B. L. Ng, K. Sayana, Y. Li, J. Zhang, and Y. Kim, "Full-dimension MIMO (FD-MIMO) for next generation cellular technology," *IEEE Communications Magazine*, vol. 51, no. 6, pp. 172-179, 2013. https://doi.org/10.1109/MCOM.2013.6525612.

[41] M. Mozaffari, W. Saad, M. Bennis, Y.-H. Nam, and M. Debbah, "A tutorial on UAVs for wireless networks: applications, challenges, and open problems," *IEEE Communications Surveys and Tutorials*, vol. 21, no. 3, pp. 2334-2360, 2019. https://doi.org/10.1109/COMST.2019.2902862.

[42] Y. Zeng, R. Zhang, and T. J. Lim, "Wireless communications with unmanned aerial vehicles: opportunities and challenges," *IEEE Communications Magazine*, vol. 54, no. 5, pp. 36-42, 2016. https://doi.org/10.1109/MCOM.2016.7470933.

[43] Z. Dawy, W. Saad, A. Ghosh, J. G. Andrews, and E. Yaacoub, "Toward massive machine type cellular communications," *IEEE Wireless Communications*, vol. 24, no. 1, pp. 120-128, 2017. https://doi.org/10.1109/MWC.2016.1500284WC.

[44] K. Gomez, A. Hourani, L. Goratti, R. Riggio, S. Kandeepan, and I. Bucaille, "Capacity evaluation of aerial LTE base-stations for public safety communications," In Proc. 2015 European Conference on Networks and Communications, Paris, France, Jun. 29-Jul. 2, 2015, pp. 133-138. https://doi.org/10.1109/EuCNC.2015.7194055.

[45] A. Merwaday and I. Guvenc, "UAV assisted heterogeneous networks for public safety communications," In Proc. 2015 IEEE Wireless Communications and Networking Conference Workshops, New Orleans, LA, USA, Mar. 9-12, 2015, pp. 329-334. https://doi.org/10.1109/WCNCW.2015.7122576.

[46] M. Chen, M. Mozaffari, W. Saad, C. Yin, M. Debbah, and C. S. Hong, “Caching in the sky: proactive deployment of cache-enabled unmanned aerial vehicles for optimized quality-of-experience,” *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 5, pp. 1046-1061, 2017. https://doi.org/10.1109/10.1109/JSAC.2017.2680898.

[47] S. Jeong, O. Simeone, and J. Kang, “Mobile edge computing via a UAV-mounted cloudlet: optimization of bit allocation and path planning,” *IEEE Transactions on Vehicular Technology*, vol. 67, no. 3, pp. 2049-2063, 2018. https://doi.org/10.1109/TVT.2017.2706308.

[48] V. Lala, W. Desheng, L. Rajaoarisoa, G. F. Filho, G. Fontgalland, P. Thakur, et al., “Overview on bandpass NGD based signal propagation delay suppression for UAV base station cellular,” in *Smart systems: Theory and Advances*, G. Fontgalland, Ed. Campina Grande-Brazil: Amplla Editora, 2022, pp. 37-56.

[49] V. Lala, W. Desheng, J. A. Ndombasi Diakusala, F. H. Rabevohitra, N. M. Murad, G. F. Fontgalland, et al., “UAV base-station design method and optimization for urban environment communication with 5G cellular network,” *Computer Networks and Communications*, vol. 3, no. 2, pp. 82-110, 2025. https://doi.org/10.37256/cnc.3220257142.

[50] V. Lala, W. Desheng, N. B. Gurgel, F. H. Rabevohitra, G. Fontgalland, N. M. Murad, et al., “Investigation on deployment planning of 5G cellular network UAV base stations for stadium sports events,” *COJ Electronics and Communications*, vol. 3, no. 3, pp. 1-10, 2025. https://doi.org/10.31031/COJEC.2025.03.000562.

[51] V. Lala, A. F. Ndreveloarisoa, W. Desheng, R. F. Heriniaina, G. Fontgalland, N. M. Murad, and B. Ravelo, “Channel modelling for UAV air-to-ground communication,” In Proc. 5th International Conference on Emerging Trends in Electrical, Electronic and Communications Engineering, Balaclava, Mauritius, Nov. 20-22, 2024, pp. 1-5. https://doi.org/10.1109/ELECOM63163.2024.10892167.

[52] M. Mozaffari, W. Saad, M. Bennis, and M. Debbah, “Efficient deployment of multiple unmanned aerial vehicles for optimal wireless coverage,” *IEEE Communications Letters*, vol. 20, no. 8, pp. 1647-1650, 2016. https://doi.org/10.1109/LCOMM.2016.2578312.

[53] I. Bor-Yaliniz and H. Yanikomeroglu, “The new frontier in RAN heterogeneity: multi-tier drone cells,” *IEEE Communications Magazine*, vol. 54, no. 11, pp. 48-55, 2016. https://doi.org/10.1109/MCOM.2016.1600178CM.

[54] Q. Feng, E. K. Tameh, A. R. Nix, and J. McGeehan, “Modelling the likelihood of line-of-sight for air-to-ground radio propagation in urban environments,” In Proc. IEEE Globecom 2006, San Francisco, CA, USA, Nov. 27-Dec. 1, 2006, pp. 1-5. https://doi.org/10.1109/GLOCOM.2006.917.

[55] V. Sharma, M. Bennis, and R. Kumar, “UAV-assisted heterogeneous networks for capacity enhancement,” *IEEE Communications Letters*, vol. 20, no. 6, pp. 1207-1210, 2016. https://doi.org/10.1109/LCOMM.2016.2553103.

[56] M. Mozaffari, W. Saad, M. Bennis, and M. Debbah, “Optimal transport theory for cell association in UAV-enabled cellular networks,” *IEEE Communications Letters*, vol. 21, no. 9, pp. 2053-2056, 2017. https://doi.org/10.1109/LCOMM.2017.2710306.

[57] Y. Huang, M. Cui, G. Zhang, and W. Chen, “Bandwidth, power and trajectory optimization for UAV base station networks with backhaul and user QoS constraints,” *IEEE Access*, vol. 8, pp. 67625-67634, 2020. https://doi.org/10.1109/ACCESS.2020.2986075.

[58] T. Bauschert, C. Büsing, F. D’Andreagiovanni, A. M. C. A. Koster, M. Kutschka, and U. Steglich, “Network planning under demand uncertainty with robust optimization,” *IEEE Communications Magazine*, vol. 52, no. 2, pp. 178-185, 2014. https://doi.org/10.1109/MCOM.2014.6736760.

[59] U. Siddique, H. Tabassum, E. Hossain, and D. I. Kim, “Wireless backhauling of 5G small cells: challenges and solution approaches,” *IEEE Wireless Communications*, vol. 22, no. 5, pp. 22-31, 2015. https://doi.org/10.1109/MWC.2015.7306534.

[60] A. Orsino, A. Ometov, G. Fodor, D. Moltchanov, L. Militano, S. Andreev, et al., “Effects of heterogeneous mobility on D2D and drone-assisted mission-critical MTC in 5G,” *IEEE Communications Magazine*, vol. 55, no. 2, pp. 79-87, 2017. https://doi.org/10.1109/MCOM.2017.1600443CM.

[61] D. Bamburry, “Drones: designed for product delivery,” *Design Management Review*, vol. 26, no. 1, pp. 40-48, 2015. https://doi.org/10.1111/drev.10313.

[62] I. Bekmezci, O. K. Sahingoz, and S. Temel, “Flying ad-hoc networks (FANETs): a survey,” *Ad Hoc Networks*, vol. 11, no. 3, pp. 1254-1270, 2013. https://doi.org/10.1016/j.adhoc.2012.12.004.

[63] A. M. Hayajneh, S. A. R. Zaidi, D. C. McLernon, and M. Ghogho, “Drone empowered small cellular disaster recovery networks for resilient smart cities,” In Proc. 2016 IEEE International Conference on Sensing, Communication and Networking Workshops, London, UK, Jun. 27, 2016, pp. 1-6. https://doi.org/10.1109/SECONW.2016.7746806.

[64] A. Ferdowsi, W. Saad, and N. B. Mandayam, “Colonel blotto game for secure state estimation in interdependent critical infrastructure,” [online]. Available: https://arxiv.org/abs/1709.09768. [Accessed Feb. 10, 2026].

[65] Z. Kong, E. M. Yeh, and E. Soljanin, “Coding improves the throughput-delay tradeoff in mobile wireless networks,” *IEEE Transactions on Information Theory*, vol. 58, no. 11, pp. 6894-6906, 2012. https://doi.org/10.1109/TIT.2012.2208573.

[66] Y. Peng, L. Xiang, K. Yang, F. Jiang, K. Wang, and D. O. Wu, “SIMAC: a semantic-driven integrated multimodal sensing and communication framework,” *IEEE Journal on Selected Areas in Communications* , vol. 44, p. 673-688. https://doi.org/10.1109/JSAC.2025.3610398.

[67] S. Zhou, L. Xiang, Y. Wang, K. Yang, K. K. Wong, and C.-B. Chae, “Extended target adaptive beamforming for ISAC: a perspective of predictive error ellipse,” *IEEE Transactions on Wireless Communications*, vol. 25, pp. 10604-10617, 2026. https://doi.org/10.1109/TWC.2026.3652714.

[68] C. Luo, L. Xiang, J. Hu, and K. Yang, “Algorithm design and prototype validation for reconfigurable intelligent sensing surface: forward-only transmission,” [online]. Available: https://arxiv.org/abs/2503.23883. [Accessed Feb. 10, 2026].