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Overview of Drone Communication Requirements in 5G

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Abstract. The ease of use and flexibility provided by drones or Unmanned Aerial vehicles (UAV) is attracting different industries and researchers across domains (e.g., delivery, agriculture, security, etc.). Although maintaining a reliable and secure command and control communication channel is still an open challenge and primary limitation for using drones. Satellite and 5G are considered viable solutions for drone communication. In this survey paper, we have explored specifications and proposed enhancements in cellular technology specified by 3GPP to command and control UAVs. It also describes the required network Quality of Service (QoS) parameters for drone communication. Such as end-to-end latency to send and receive a command and control message (C2), reliability, and message size. Along with these, it also emphasizes defining the reliability in terms of communication and navigation of UAVs, based on cellular technology 5G additional investigation and standardization should be executed.

Keywords: 5G Cellular technology, Unmanned Aerial vehicle, Drones, Latency, Coverage, 3GPP, etc..

1 Introduction

We live in a technological era and try to develop a world where essential services can be operated and controlled autonomously—for example, autonomous cars, buses, trains, etc.. Researchers, educational institutes, and some giant tech companies are attentively looking into the field related to UAVs, in general, known as drones. Drones are prominently emerging technology and attracting people to develop some usage scenario. This technology is still in the developing phase in terms of mass acquiescence for formulating and implementing, but drones have already broken the conventional obstacles and proved their importance in several fields. For instance, delivering a parcel and medical help where a human can not reach or is incapable of performing in a timely manner, along with these it has been used to keep an eye on the military area. Several use cases are there, where unmanned aerial vehicles are considered as feasible tools [1][2].

Acceptance of UAVs applications and innovations across the industries hopped from sluggish level to active level, because gradually businesses have started to see the potential, comprehensive scope, and worldwide reach in drone based applications. Drones can be operated and controlled remotely via an application installed on smartphones or autonomously. They can provide services and support with or without manpower and conserve efforts, energy, and, most importantly, time. All these points are very attractive to the industries and research groups to invest their time and resources to get the profitable business based on drones[3].

As we know, drones or UAVs can be used for a variety of applications such as surveillance, data gathering, environment monitoring, aerial photography, delivery, etc.. Along with these, it provides real-time data to help the industry design real-time operations. A report published in "Fortune Business Insights" about unmanned aerial vehicles or drones shows that the global service market based on drones was 7.12 billion USD in 2020. An unfortunate situation like COVID-19 boosted the market and allowed further investigation related to applications based on UAVs. The drone-based market is projected to escalate from 9.56 billion USD to 134.89 billion USD by 2028 [4]. A Germany-based company, "Drone Industry Insights," has forecasted that the drone market will be 41.3 billion USD by 2026. Figure 1 shows the commercial drone scale and business forecast by 2026. They have also divided the drone business market into three segments[5].

1. **Hardware:-** This segment includes the industries which are generating the revenue from providing the tools, components, hardware, and systems associated with unmanned aerial vehicles. This sector acquires 16.4% revenue of total drone business sector [5].
2. **Software:-** This segment holds the 4.3% revenue of the drone market. This revenue is generated from providing the software for drone communication, navigation, fleet planning, computer vision, control, and management system [5].
3. **Drone based Services:-** The drone-based service sector produces a huge part of the revenue. This segment generates 79.3% revenue for the drone business market [5].

This survey paper aims to find out the supporting capability of cellular technology, primarily of 5G for the drones or UAVs based applications. Along with this, it will also fill the gap between the researcher in academia and on going trends in giant tech industries by providing a comprehensive analysis. In this survey paper, the following questions are investigated and attempted to address with appropriate answers.

- What are the near-future potential applications of drones and which are the giant tech companies exploring this field?
- What are the requirements for drone based applications?
- What are the technical enhancements executed or proposed by the 3rd Generation Partnership Project (3GPP) standards, especially for the UAVs based applications?
- How 5G cellular technology can support and contribute to enhance drone communications and applications?

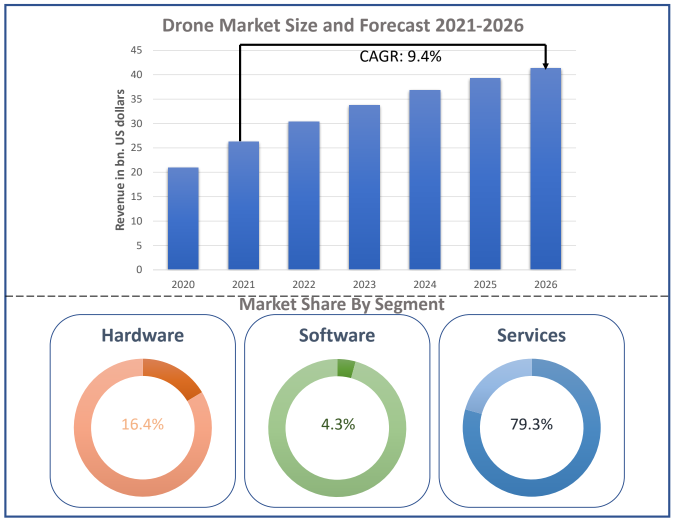

Fig. 1. Drone Market Projection 2021-2026[5]

The structure of this paper is as follows, section 2 gives the information about the drone based applications and which multinational companies are looking into the drone based business. Essential parameters for drone based communication are explored in section 3. These parameters include the government's rules and regulation along with technical requirements for drone based applications. Information about some previous research works, challenges, and findings in reference to drones or UAVs are given in section 4. Section 5 demonstrates the role of 5G cellular technology for drones or UAVs. The conclusion of this survey paper is given in section 6.

2 Applications of Drones

This section will explore the applications of drones and which corporations are investing their time, money, and resources to design and develop a potential application using drones or UAVs. Drone or UAV based applications can be deployed in several sectors. Based on some ongoing developments and used cases, we have divided drone based applications into the following sectors-

1. **Delivery of Products:-** Since 2013 Amazon has created a research and development team to leverage the drones for delivering their packages. Amazon has now a drone based application that can deliver packages in the range of 24 Km and the delivery drone is capable to deliver a package of approximately 2.5 Kilograms. In 2018 Amazon is awarded a patent for its UAVs application by US patent [6]. Google's parent company Alphabet is working in the field of UAVs based package delivery applications under the project

name "Wing". Alphabet executed its first UAVs flight test in Australia in the year 2014[8]. In the year 2021, Wing has delivered more than 140,000 packages to customers [7].

Uber has published a white paper to investigate the future on-demand air transportation, and they were more anxious to design and developed an autonomous air travel[10]. But in the year 2018 company has shifted its interest to develop a more efficient drone based application for the food delivery business. DHL is working on UAVs since 2013 to use a quadcopter to deliver small packages[9]. Like Amazon, Walmart is also exploring this field and has opened an incubator in Austin, Texas in 2018. The central objective of this tech incubator is to develop drone or UAV based applications. JD.com China's one of the largest e-commerce retailers is testing drones since 2016 to deliver the products. In the year 2019 company has delivered its first product in Indonesia [8].

2. **Security and Inspection:-** Drones are considered as one of the feasible solutions for the sectors where security and inspection of a site or product are necessary. FedEx is using UAVs to deliver the aircraft's parts to the ground engineers and along with this, the drone will inspect the runways at the airports. Since 2016, IBM is developing an application to visualize natural disasters in real-time, using IBM's Cloud, drones, and cognitive computing technologies[11]. GE provides UAVs to inspect the tools and equipment installed in the field of energy and manufacturing sector [12]. A British-based airline enterprise easyJet is using UAVs since 2015 to perform an inspection of aircraft to detect damages [8].
3. **Entertainment:-** Drones are making the entertainment sector more realistic. To shoot a movie's scene a drone with a high-resolution camera is used by the movie craters. Intel has designed and developed light-weighted fleets of UAVs. Which are used in concerts, sports opening ceremony events, and for the entertainment purpose [13]. The UK-based broadcasting company British Broadcasting Corporation (BBC) is using drones for news broadcasting since 2013 [8].
4. **Internet Connectivity:-** In 2014 Facebook announced a project "Aquila". The objective of this project is to provide internet connectivity using lightweight UAVs. Based on the estimation given by a telecom company Otelco installing fiber optic cables costs 22000 USD per mile. This was the reason behind deploying UAVs for internet connectivity, which is less expensive than installing fiber optic cables [8]. Facebook had carried out a successful test flight of Aquila in the year 2017 at an altitude of 3000 feet, but in the year 2018 Facebook terminated this project [14].
5. **Maps and Navigation:-** In the year 2012 Apple created its maps, but it disappointed Apple's customers because the maps were imprecision and they were not competent to show the location directions. Apple uses drone technology to improve the gathering and transmitting of visual and geographical real-time data [15]. In this way Apple eliminated the flaws from the Apple maps [8].

6. **Agriculture:-** Microsoft and DJI are working together on a project "Farm-Beast" since 2015. The purpose of this project is to gather agricultural data such as soil moisture, temperature, infected crops, and other important parameters which could help to increase crop productions [8].

Table 1. Drone Based Applications [8]

Application Sector	Company	Drone Based Application	Starting Year of R&D	Application is Developed / Under Development
Delivery	Amazon	Home deliveries of products with in 24 KM of range	2013	Developed
	Alphabet	For delivery	2014	Application is developed got the air-carrier certification from FAA and have legal permission to deliver the products
	Uber	For foods delivery	2018	Under Development
	JD.com	For delivery	n/a	Developed
	UPS	For delivery the vaccines	2016	Developed
	Walmart	For delivery	2016	Under Development
	DHL	For delivery	2013	Under Development
Security and Inspection	FedEx	Drones for maintaining aircraft and inspecting runway	n/a	Application is developed, soon FedEx will use UAVs at Memphis International Airport
	GE	Inspection of manufacturing sectors	2014	Developed
	easyJet	To inspect the aircrafts	2015	Under Development
	IBM	To Visualize the natural disaster in real-time	2016	Under Development
Entertainment	Intel	For entertainment purposes like light shows, dancing drones, etc..	n/a	Application is developed, used for the sports, concerts and entertainment
	BBC	Real-time news brodcasting	2013	Developed
Maps and Navigation	Apple	To enhance the maps and navigation	2012	Developed
Internet Connectivity	Facebook/Meta	To provide internet connectivity	2014	Terminated the program in the year 2018
Agriculture	Microsoft and DJI	To gather the agricultural data	2015	Under Development

3 Essential Parameters for Drone Communication & Navigation

To fly a drone for any kind of application there are some specific rules and regulations, and they are applied on both hobbyist applications as well as commercial operations. European Aviation Safety Agency (EASA) has developed these rules to make drone operations more secure and regulated. This section will discuss the EASA rules for drone flights. Along with this, it will also elaborate on the technical parameters that are essential for drone communication and navigation based on 5G cellular technology.

3.1 Government Rules and Regulations

Following are brief information about EASA regulations which are followed by the European Union member states along with Norway, Iceland Liechtenstein and United Kingdom [16].

- Drone should not be flown above 120 m or 400 ft above the ground surface.
- Drones operations are prohibited under 150 m of a crowded area.
- Drones having weight less than 250g (A1 Drones), can be operated over the people. Drones having a weight of more than 250g but less than 2 Kg (A2-Drones) must have to operate at least 50m away from people. Drones having more than 2kg weights should be operated well away from people.

- Drone operators should have a license to operate the drones.
- No drones operations inside 1 km perimeter of airbase without permission.
- While flying the drones operators have to look always at the drones to avoid any kind of incursions. They should look at the screen to just adjust the frame to capture the shot or to check battery [17]. If the operator is flying drones in line-of-site in that case operating distance should not be more than 500 m.

Depending upon the countries and regions there are more other rules. Drone operations in Beyond Visual Line of Sight (BVLOS) have more strict rules and regulations. Government officials are still looking thoroughly into this, to develop a secure infrastructure for UAVs applications.

3.2 Technical Parameters

To achieve secure and reliable communication for drones using a cellular communication system, drones have to exchange the information with the pilot, nearby other drones or UAVs, and principally with the air traffic control system. This mechanism is called UAV Control and Non-payload Communication (CNPC)[19]. simultaneously, depending upon the applications, a drone has to transmit or receive information on a timely basis related to the assigned task, such that images, videos, and data packets from ground entities to the drone and vice-versa. This operation is known as payload communication [20]. To deploy the UAVs application on a large scale the International Telecommunication Union (ITU) has categorized the CNPC in the following section:

1. **UAV Command and Control Communication (C2)**:- This type of communication includes UAV or drone's status, a real-time control signal from pilot to UAV, and flight command updates.
2. **Air Traffic Control (ATC) Relay Communication**:-Communication between the air traffic control system and UAV operator via ATC relay.
3. **Communication for Detect and Avoid Collision**:- Capability to sense and avoid collision from nearby UAVs and territory.

Payload communication and CNPC require different set of spectrum. Table 2 and table 3 represents the network key points for UAV's communication. These communication parameters are specified in Release 17 by the 3GPP standards.

UAV Control and Non-payload Communication :- Table 2 represents the required QoS parameters for the CNPC communication. Here, uplink (UL) data transmission represents UAV to network side messages and downlink (DL) data transmission represents network to UAV side messages. Control and command communication is duplex communication and it may be integrated with video for controlling the operation of UAVs. Therefore, when a C2 message is sent with video, the required end-to-end latency is 1 second. A positive acknowledgment message for downlink transmission is necessary in this mode. On the other hand, when a C2 message is sent without video, end-to-end latency would be less than 40 milliseconds. This mode also requires a positive acknowledgment in downlink transmission. To communicate with the ATC relay, end-to-end latency should not be more than 5 seconds. To sense and avoid the collision with other UAVs and territories, the delay for the uplink transmission should be less than 140 milliseconds and in downlink transmission required delay is 10 milliseconds. In this mode, the reliability of the network should be 99.99% for the uplink transmission and 99% for the downlink transmission. However, network reliability should be 99.9% for the rest of the communication mode[18].

Table 2. UAV Control and Non-Payload Communication Requirements [18]

Control and Non-Payload Communication	Message Interval (UP/DL)	Message Size (UP/DL)(byte)	Max UAV Speed (km/h)	End-To-End Latency (UP/DL)	Reliability (UP/DL)	ACK (UP/DL)
Control & Command Message (Without Video)	1s/ >=1s	84-140/100	300	1s/1s	99.9%	Not Required/Required
Control & Command Message (With Video)	40ms/40ms	84-120/24	60	40ms/40ms	99.9%	Not Required/Required
Communication with UTM or ATC	1s/1s	1500/10K	300	5s/5s	99.9%	Required/Required
Detect & Avoid Collision With Other UAV	500ms/500ms	4K/4K	50	140ms/10ms	99.99%/99%	Required/Required

UAV Payload Communication :- The 5G cellular technology shall be capable to transmit data collected by the entity which are installed on UAVs, such as a camera to transmit images, videos, and data files. Depending upon the applications, UAVs require different uplink and downlink quality of service (QoS). Table 3 represents the UAV payload communication requirements. To transmit real-time video using a UAV up to 100 meters above ground level requires a 100 Mbps data rate for uplink transmission and 600 Kbps for downlink transmission. The allowed latency is 200 and 20 milliseconds for uplink and downlink transmission respectively. Using a UAV for surveillance needs 20 milliseconds of end-to-end latency in both uplink and downlink transmission. The essential data rate for this kind of application is 120 Mbps for uplink and 50 Mbps for downlink transmission. For controlling an UAV through HD video where the speed of the UAV is less than 160 km/h, the required uplink data rate is 25 Mbps and the downlink data rate is 20 Mbps. For this kind of application, end-to-end latency is 100 and 20 milliseconds for uplink and downlink transmission[18] respectively.

Table 4 represents the communication requirements for the different drone based use cases. These requirements are published by the China Mobile in a "4G+, 5G UAV white paper" [20].

3.3 3GPP Vision

In this section, we will discuss the UAV requirements described in the 3GPP Release 17[18]. The following section provides an overview of communication services for UAVs and problems in unmanned aviation.

Table 3. UAV Payload Communication Requirements [18]

UAV Applications	Above Ground Level (m)	Max UAV Speed (km/h)	End-To-End Latency (UP/DL)(ms)	Data Rate (UP/DL)
8K Video Real-Time Broadcasting	<100	60	200/20	100 Mbps/600 kbps
4X4K AI Surveillance	<200	60	20/20	120 Mbps/50 Mbps
Remote UAV Controller Through HD Video	<300	160	100/20	25 Mbps/300 kbps

Table 4. Communication Requirements for Drone Based Applications [20]

Drone Based Application Sector	Coverage Height (m)	End-To-End Latency (ms)	Throughput Requirements (UL/DL)
Delivery of Goods	100	500	200 kbps/300 kbps
Videography and Image Capturing	100	500	30 Mbps/300 kbps
Security and Inspection	100	3000	10 Mbps/300 kbps
Drone Fleet Show	200	100	200 kbps/200 kbps
Agriculture	300	500	200 kbps/300 kbps
Rescue Mission	100	500	6 Mbps/300 kbps

1. **Mobility Management:** 5G network should be able to relatively quickly adapt to the mobility pattern of UAV during an active session. This primarily includes maintaining IP addresses and reducing packet loss and interruption time while performing handover at relatively high speeds.
2. **Security:** 3GPP has paid special attention towards maintaining high-security standards for UAV communication. Some of the features include encrypting data exchanges between UAV and Unmanned Traffic Management (UTM) and blocking data from unreliable UAV. 5G should be able to provide confidentiality regarding personally identifiable information from UAV, and 5G should also be able to support various levels of integrity and privacy protection.
3. **Priority, QoS, and Policy Control:** 5G communication systems should be able to provide different priority levels to the services which may share the same QoS characteristics but varying levels of priority. It should also be able to provide mechanisms for measuring E2E QoS and the dependability of the network and different services offered.
4. **Positioning Services and Remote Identification:** Accurate identification of the location of a UAV in the cell is an extremely important feature of the 5G system. 3GPP systems should provide a way to validate the position reported by the UAV utilizing 3GPP and non-3GPP positioning systems. The network should also be able to provide UE identity by means of IMEI, IMSI, IP, etc. UE capabilities and other flight-related information at any given time.
5. **UAS Traffic Management:** 5G network should be able to traffic manage the communication between UAV and UTM with a maximum latency of 500ms. The network should be able to carry out short-range message transfer (up to 600m) such as position and collision avoidance data intra-network as

well as inter-networks with less than 100ms of latency at a relative speed of 320 km/h

6. **Service Performance Requirements:** The 3GPP system should be able to provide network-related Key Point Indicators (KPIs) (UL/DL data, packet drop, latency, etc.) for payload (e.g., images, real-time video, sensory information, etc.) as well as non-payload related services (e.g., C2, telemetry, etc.) offered by the system.

4 Related Work

In this section, some previous research works and findings are given. We have divided these findings based on cellular technical parameters, which play a significant role in communicating and navigating the drones.

- **Security:** Authentication and key agreement, data integrity, cryptographic algorithm, etc. are the key elements of the 5G security standards. 5G standard significantly improves consolidated authentication procedure than the one used in 4G. Apart from the network-provided security improvements, it is also crucial to provide different ways to encrypt the application data. One such approach is described in [25] by integrating blockchain into 5G communication by implying permission blockchain technology for decentralized data management system.
- **Latency:** The latency constraints imposed by the 5G standard for supporting critical applications is very high. For instance, a remote UAV controller through HD videos has a latency budget of 20ms, whereas an 8K video live broadcast at 100Mbps has a budget of 200ms. The requirements get even stricter when it comes to command and control UAV applications. UAV terminated control messages have a maximum latency budget of 10ms in an autonomous flight. Xiaopan Zhu and et.al [21] have managed to successfully implement a Clustering method for large-scale drone swarms to reduce the latency. The OPNET model can effectively form different sizes of clusters to improve the transmission efficiency and ability to execute the task. Xiangwang Hou and et.al [22] describes a distributed fog computing architecture for improving the latency and reliability of wireless communication. Another method described in the 3GPP standards is to use Network-slicing to improve the network's performance and reduce the latency of the communication.
- **Bitrate:** Most commonly described application of the use of drones is to stream high-quality video for surveillance, remote inspection, etc. In order to transfer HQ video from a drone to an application server, the communication system should be able to provide high bitrate in the Uplink direction. The use of millimeter-wave (mmWave) frequency band for communication will definitely help in achieving high bitrates; however, the performance is susceptible to obstacles and beam misalignment. Woongsoo NA and et.al [23] their work proposes a deep-learning-based TCP (DL-TCP) model that can quickly adapt to the TCP conjugation and window sizing by prediction

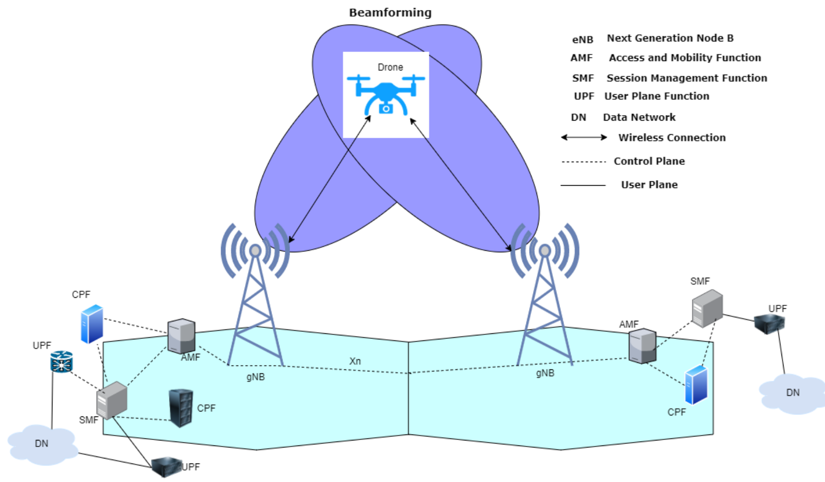

Fig. 2. Operation of UAV Over Cellular Coverage-5G

based on the network performance. DL-TCP shows much higher network throughput and stability than just using TCP for the data transfer.

– **Wireless Coverage:** Bin Li et al. have explored some potential challenges for drone communication in [24]. One of the crucial challenges in UAV based application is to provide reliable coverage to command, control, and navigate. To ensure reliable coverage in a particular direction beamforming technique is feasible. It uses multiple antenna array to transmit uniform signal to one direction. It helps to enhance signal strength, data transfer speed and avoid the interference [28]. H.C Nguyen et al. have surveyed that beamforming solution has capability to increase the Signal to Interference plus Noise Ratio (SINR) in both uplink and downlink transmission [29]. Drones have possibility to detect higher number of interfering signals from the cellular base stations deployed in the vicinity [26][27]. This is because of elevated height. Interference due to multiple neighbouring or line of sight base stations can be mitigated using the beamforming technique. Figure 2 shows the operation of a drone over cellular coverage using beam-forming mechanism.

5 Role of 5G in Drone Applications

Critical use cases and applications of drone have stringent requirements on the reliability and efficiency of the communication technology used. The advancements and improvements offered by the 5G technology make it an excellent candidate to be used as a control and data communication technology for drones. 5G offers guaranteed service and data delivery. 5G being a WAN technology makes it also easy to scale up the deployment of the application. Unlike other RF-communication technologies, the use of a private spectrum helps in controlling

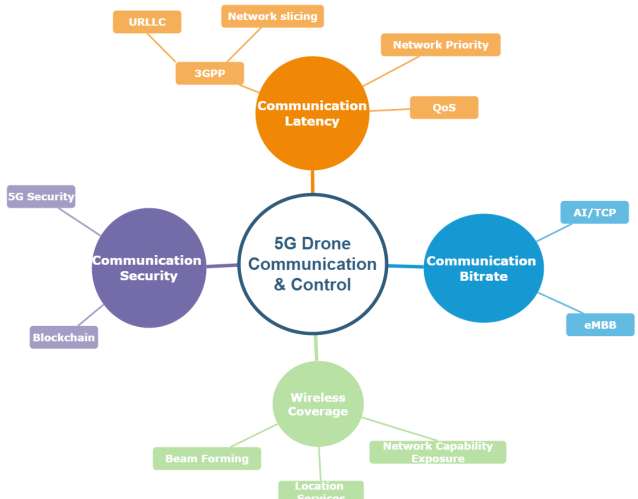

Fig. 3. Summary of Communication and Control of UAV Over 5G

the interference and noise in the communication channel. 5G also offers enhancement to communication security, which is important from a critical application perspective.

Table 5 shows the network KPIs of 5G cellular technology. It has data rate up to 10 Gbps and 20 Gbps for uplink and downlink transmission respectively. The promised latency of 5G network is less than 1 millisecond and reliability is 99.999%. It can connect 100x number of devices per unit area [31]. 5G standalone system also includes the functionality of Ultra-Reliable Low Latency Communications (URLLC) and enhanced Mobile Broadband (eMBB). In Release 16, 3GPP has enhanced URLLC and able to reduce the latency up to 0.5 milliseconds [32]. To design and develop a drone based application on cellular based command, control and navigation, the required communication QoS are summarised in the table 2 and 3. These standardized parameters are given by 3GPP. If we compare these QoS with 5G, we can say that the 5G communication system can support drone based applications. Figure 3 shows some substantial specifications of 5G, that can be utilized to strengthen drone communication and control.

Table 5. 5G Network Key Point Indicators[31][30]

Service Parameter	Network KPI	Section
Peak Data Rate	DL: 20 Gbps, UL: 10 Gbps	eMBB
Throughput	DL: 100 Mbps, UL: 50 Mbps	eMBB
Latency	4 ms for eMBB, 1 ms For URLLC	eMBB, URLLC
Reliability	99.9999%	URLLC

Based on 3GPP documentation reliability depends upon packet loss in uplink transmission. Mentioned in release 15, reliability is defined as successfully delivery of X bytes of data packet with-in acceptable delay. Where delay is the time taken to deliver the data packet from layer 2 of radio protocol transmitting ingress point to layer 3 of radio protocol receiving egress point at adequate signal strength. In general, URLLC vision defined by 3GPP is $1 - 10^{-5}$, which means in available coverage, for a single transmission, probability of successful delivery of packet data unit should be 99.999% in 1 ms of time interval [33]. Whereas, if we define the reliability in terms of drone community or drone based application, network connectivity should be available for 99.999% of time. Hence, it can be inferred that cellular network operator and application developer based on drones they have different terms for defining reliability.

It concludes, requirements specified by 3GPP are expressly overlaying user plan. Therefore, to develop an application using 5G as communication backbone with UAVs, end-to-end latency and reliability requirements of specific application should also be taken into consideration. The mentioned specification of reliability is inadequate to outline the variety of use cases such as enhanced Vehicle to Everything (eV2X) and drone communication and navigation based on 5G cellular communication [34]. In summary, defining reliability is critically important for communication and navigation of drones. There should be common parameters which will be used to define the reliability for cellular based drone communication.

6 Conclusion

In this paper, the authors have given an overview of drone communication requirements and challenges for the upcoming 5G standard and 3GPP vision for UAV communication. We have described improvements supported in the 3GPP Release 17, and related works and techniques to achieve them. The paper goes over the essential parameters for drone communication and navigation as well as provides an overview of rules and regulations imposed by governmental bodies in different regions at the time of writing this article. Although there are several improvements both in the 5G standards as well as by individual researchers to provide better UAV communication, there is still further field testing required before autonomous drones can be deployed for various industrial applications.

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