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Review

Ultra-Reliable Low-Latency Communications: Unmanned Aerial Vehicles Assisted Systems

Mohamed Osama [1], Abdelhamied A. Ateya [1,*], Shaimaa Ahmed Elsaid [1] and Ammar Muthanna [2,*]

[1] Department of Electronics and Communications Engineering, Zagazig University, Zagazig 44519, Egypt
[2] Department of Telecommunication Networks and Data Transmission, The Bonch-Bruevich Saint-Petersburg State University of Telecommunications, 193232 Saint Petersburg, Russia
* Correspondence: a_ashraf@zu.edu.eg (A.A.A.); muthanna.asa@spbgut.ru (A.M.); Tel.: +20-1005-237-673 (A.A.A.)

Abstract: Ultra-reliable low-latency communication (uRLLC) is a group of fifth-generation and sixth-generation (5G/6G) cellular applications with special requirements regarding latency, reliability, and availability. Most of the announced 5G/6G applications are uRLLC that require an end-to-end latency of milliseconds and ultra-high reliability of communicated data. Such systems face many challenges since traditional networks cannot meet such requirements. Thus, novel network structures and technologies have been introduced to enable such systems. Since uRLLC is a promising paradigm that covers many applications, this work considers reviewing the current state of the art of the uRLLC. This includes the main applications, specifications, and main requirements of ultra-reliable low-latency (uRLL) applications. The design challenges of uRLLC systems are discussed, and promising solutions are introduced. The virtual and augmented realities (VR/AR) are considered the main use case of uRLLC, and the current proposals for VR and AR are discussed. Moreover, unmanned aerial vehicles (UAVs) are introduced as enablers of uRLLC. The current research directions and the existing proposals are discussed.

Keywords: ultra-reliable low-latency communications; 5G; 6G; unmanned aerial vehicles; virtual reality; augmented reality

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1. Introduction

With the release of the fifth-generation cellular system (5G), the demand for ultra-reliable low latency communications (uRLLC) has increased [1]. Traditional networks are working to provide communication between users from end to end with a latency of 20 milliseconds or more. This is not enough to meet users' requirements in modern communication systems, e.g., 5G and sixth-generation cellular (6G) systems [2,3].

Communication networks have evolved over the past years and have significantly impacted our lives, politics, world, and economy. The evolution in generations has led to a significant difference in coverage, security, cost, privacy and many more until the arrival of 5G to standardize its use into three categories: enhanced mobile broadband (eMBB), ultra-reliable low-latency communication (uRLLC), and massive machine type communications (mMTC), compared to previous generations [4,5].

The uRLLC is an important paradigm in accessing applications supported by the 5G network, managing the network, facilitating its work, and speeding response [6]. Many applications require an end-to-end latency within a millisecond or sub-millisecond, such as industrial applications, holographic applications, and the touch internet, i.e., Tactile Internet [7].

Traditional applications are expected to be handled with an end-to-end latency of 10 milliseconds, while ultra-reliable low latency (uRLL) applications require a round-trip time of 5-to-1 milliseconds [8,9]. Applications such as augmented and virtual reality (AR/VR) require a maximum of 5-millisecond end-to-end latency. Haptic-based communications require an end-to-end latency of one millisecond, including telesurgery operations [10].

The 6G communications are announced to be within the sub-millisecond latency. Such latency requirements for 5G and 6G systems put many constraints on the design of the communication networks that provide such applications [11]. Novel network structures, including technologies, methods, and communication interfaces, must be introduced to traditional network schemes. Introducing modern technologies to assist 5G/6G networks is a quantum leap in improving the network infrastructure by providing highly reliable data, extremely low latency from end to end, and improving network efficiency, life span, and energy savings [12–14].

Ultra-low latency and ultra-high reliability are key requirements for most 5G applications, including remote surgeries, self-driving vehicles, haptic-based applications and not only some cases that require very low latency and high reliability [15,16]. The next generations of mobile communications focus on providing seamless communications to end users by transferring a massive data rate at high reliability and ultra-low latency.

To enable such requirements and achieve the uRLLC, new technologies and network structures should be introduced to the traditional paradigms. Unmanned aerial vehicle has been announced as a key enabling technology of uRLL applications of 5G/6G [17]. Moreover, software-defined networking (SDN) and mobile edge computing (MEC) are two main promising solutions that provide milestones toward enabling uRLLC [18–20]. MEC and SDN can be integrated with UAVs to provide a reliable network structure that can support 5G/6G uRLLC [21].

This work considers introducing the main features, requirements, and challenges associated with the uRLLC of 5G/6G networks. Moreover, deploying UAVs to support uRLLC is introduced, including current proposals and future directions. The main contributions of this work can be summarized as follows.

1. Introducing the main requirements and challenges associated with the uRLLC of the 5G/6G network.
2. Providing AR/VR as a use case of the uRLL applications.
3. Using UAVs to assist uRLL 5G/6G applications.
4. Integrating SDN and MEC with UAVs to support uRLLC.
5. Providing the current state-of-the-art and future directions of UAV-based networks for uRLLC.

2. uRLL 5G/6G Applications

Latency is critical in modern applications such as health care, self-driving, smart homes, and smart industries. Such applications require ultra-high reliability, high availability, and ultra-low response time [22]. The requirements of such applications differ from one to another; however, all of them share constraints in terms of latency, reliability, and availability [23]. Latency and reliability requirements put constraints on developing the communication network that provides such applications. Thus, such applications are announced in a certain category of 5G/6G services, which is the uRLLC services [24].

uRLLC services are the 5G/6G applications that require extreme latency and reliability. The applications of the uRLL share different requirements of latency that can be categorized into three main groups. The first group includes the uRLL applications that require an end-to-end latency of 5 ms or higher. This group includes applications such as AR, VR, and MR. The second group contains uRLL applications that require an end-to-end latency of one millisecond, such as the Tactile Internet. The third group contains the sub-millisecond applications, such as holographic communications.

We can list a part of such uRLL applications as follows.

1. **Smart Factories:** The use of devices and precision are controlled in real time for rapid production and facilitating the recycling process in factories. The presence of many production lines represents a great challenge in terms of latency and reliability. There-

fore, most services require very low latency, up to 5 milliseconds. Such application has great interest with the announcement of the industry 4.0 paradigm [25,26].

2. **Intelligent Transportation Systems:** Autonomous driving and traffic facilitation require a scalable infrastructure, highly reliable communication with very low latency, and special stations to achieve road safety. The maximum permissible latency for most of the vehicular applications is 5 milliseconds [27,28].
3. **Robots and remote control:** As an example of robots and remote control, the remote surgical operation in places affected by natural and industrial disasters protects the human element in the shortest possible time [29]. It is used to discover mines and dismantle explosive devices to reduce the loss of life. Many recently introduced teleoperations require a communication network with ultra-low latency communications.
4. **Virtual Reality (VR):** Many applications requiring very high data processing sensitivity and accuracy, such as remote surgery, need VR technology. VR simulates with a common tactile structure in a very low time. Supporting these services requires a very low response time [30].
5. **Augmented Reality (AR):** AR technology has made its way into several applications, including distance education, medical services, gaming, smart cities, and the training of firefighters to face fires without human losses [31]. Such applications require an end-to-end latency of 5 milliseconds at maximum [32]. This is to achieve the required quality of experience (QoE).
6. **Healthcare:** This includes remote surgery, remote diagnosis and performing dangerous operations using human-assisted robot systems. Such applications are based on real-time communications that should be achieved at a very low latency [33]. This is to transfer the human sense to haptic-based robots with maximum experience. Such applications require an end-to-end latency between 1 and 5 milliseconds [34].
7. **Smart grids:** Smart grids have important requirements in terms of reliability and latency, so it requires a very low latency to keep pace with these requirements and the applications in which smart grids are used [35].
8. **Tactile Internet:** It represents the fourth wave of the traditional internet that enables the transfer of human sense and actuation in real time. The main application that the Tactile Internet will support is haptic communications that require an end-to-end latency of one millisecond at maximum [36]. Such latency challenge is due to the physical parameters associated with the human senses as introduced in [37].

3. Augmented and Virtual Reality (AR/VR)

Augmented reality is the projection of information and virtual objects, three-dimensional or two-dimensional, into the real user environment to provide additional information that a person can deal with [38]. It supports the real world with virtual information through several devices, including the use of screens installed on the head, such as protective glasses and helmets, that integrate reality. Virtual objects and other portable devices, such as smartphones, use augmented spatial reality to allow users to interact with multiple virtual environments [39].

In addition, it is an interactive, participatory, synchronous technology that uses wired and wireless devices to add digital data to reality [40]. There are many fields in which augmented reality technologies can be used, such as propaganda, advertising, the military field, the field of art, the field of entertainment, games, the field of medicine, tourism, education, trade, industry and many other upcoming fields in which augmented reality technologies are strongly applied [41]. Augmented reality has the ability to transform the ways in which you learn and benefit from everything, unlike virtual reality, where everything is artificial, drowns the user in the virtual world, and misses the use of the senses because it is not real [42].

Virtual reality is the creation of virtual environments that completely simulate the real environments of the user using the computer. Such environments are three-dimensional to be realistic for the user, who performs the same movements in an imaginary way [43].

VR works to drop real objects into a virtual environment and implants the user in the virtual world through, for example, games and education. VR technology can be used in introducing students into three-dimensional environments, military exercises to reduce risks, flight simulations to save time and cost, training individuals to work in dangerous areas, or training on high-cost equipment. In addition, we can resuscitate the patient in dangerous surgeries.

Mixed reality (MR) is an important development of augmented reality and a competitor to virtual reality. It combines real and virtual reality to produce new environments and visuals where physical and digital things interact, meaning that virtual things hide behind real things [44].

3.1. Main Use Cases of AR Technology

AR is a promising technology that has applications in many fields. In this section, we introduce the main applications of AR systems.

- **Educational applications:** Some countries and organizations have been forced to use modern technologies, such as AR and VR, to teach and motivate students through educational content to combine facts with the virtual. Such organizations address traditional methods accompanied by boredom in accepting ancient and modern cultural information [45,46]. AR technology greatly contributes to the educational aspect in a way that helps both the student and the teacher. The students have become greatly involved in interactive learning and improved perception and understanding [46]. With the recent progress in smartphone and smart device manufacturing, new technologies support the augmented reality feature, such as the barometer and accelerometer, facilitating the use of new tools and technologies in education [47].
  Cultural and civilizational heritage is one of the most common educational branches that use AR as a main technology [48]. Using human senses, such as hearing, touch, and others, improves facts and provides users with information about cultural and historical heritage [49]. AR is used to improve the education process in studies of the ancient cultural and civilizational heritage of a particular country by transferring generations to simulate the ancient world; the knowledge of the ancient historical customs, traditions, and ancient civilizational buildings now become more developed, less expensive and increase the student's concentration more than virtual reality technology. The use of some devices, such as screens installed on the head, smartphones, also special lenses and glasses that support the augmented reality feature, in showing the ancient civilizations by displaying ancient warriors to the real world as well as adding buildings, historical museums, architectural artifacts and verifying their structure is an example [50].
- **Industrial applications:** AR can be used to automate industrial processes and develop modern technologies to increase the production and the sales process. Using AR, buyers can make the purchase decision more wisely and helps the company to modify or add the product before buying. It helps companies to customize the products and the needs required by the customers and reduces the time to deliver products to the customer [51]. AR can also reduce operating hours, increase product lines' flexibility, and improve product development and quality [52].
  AR is used in maintenance, quality and production lines enhancement for users. It reduces cost and time, as it does not require the presence of experts on the site by means of augmented reality technology assistance [51]. It is also used to improve the safety of the user in the use of robots while they are in dangerous places and places of accidents that are difficult for humans to reach and deal with, providing a three-dimensional image of the situation through robots in real time for the occurrence of risks [53].
  AR technology has helped many industries, including architecture, utilities, construction, energy, logistics and many other industries, and played an important role in their production and the installation of modern technology in their production lines [54].

Augmented reality technology helps some devices, including head-mounted screens, e.g., helmets and smartphones.

- **Tracking applications:** AR technology assisted the tracking process, increased the use of natural feature tracking (NFT) techniques in real-time virtual image detection, and facilitated the process of optimizing methods and locations [55]. It can assist with simultaneous localization and mapping (SLAM) guides, robots moving for the first time, and reducing delays in responding and executing things in real time [56].
- **Military applications:** AR has been used extensively in many areas that integrate real, virtual environments and real-time implementation, such as army exercises, where field equipment is trained and repaired, and soldiers are warned of the risks that may occur during battle. It enables virtual maps to help confront the enemy and simulate real reality, reducing the cost and time used in training [57,58].
- **Entertainment and gaming applications:** AR has many applications in 3D weather prediction. It is also used in concerts and cinemas at large scales [59]. Recently, AR was used to assist in broadcasting football matches and other sporting events [60]. Another common application of AR technology is online gaming, which represents a promising application. It gained much interest with the advances in the haptic devices used in online gaming [61].
- **Healthcare applications:** AR enables doctors to provide medical assistance during dangerous surgeries. Using AR, doctors can be trained to visualize critical emergencies during surgeries and treat them before they occur without causing loss of life when an unexpected problem occurs [62]. Moreover, AR can be used to provide medications remotely and provides the necessary data for medications [63].

3.2. Main Use Cases of VR

VR is a leading technology that represents a main 5G use case. Many applications and services have been introduced based on VR technology. In this section, we summarize the main categories of VR applications.

- **Educational applications:** The emergence of VR technology played a very important role in the education process, which became complex with the emergence of many modern curricula. Most countries turned to use modern technologies that depend on technological development in education to keep pace with the modern education process. However, this is no longer sufficient to facilitate understanding, except for the role of virtual reality in developing the education process in engineering, medicine and many other fields. Teaching methods became interesting and attractive to the learner and increased their acquisition of knowledge, skills and values that help to understand life and work [64].
  VR provides an interactive virtual environment using the computer that transfers the learner to a virtual environment that simulates reality to help them understand most fields such as medicine, psychology and cultural history [65]. Using VR to provide knowledge in certain areas, such as science and history, and to support students in acquiring knowledge of practical facts and theories that are difficult to assimilate in the old ways has gained great attention in recent years. Moreover, VR can be used in the education of history by simulating historical events, places, and their behavior in training to visualize the occurrence of people in emergencies, such as fighting fires, floods, volcanoes, road accidents, and many others [66].
  VR technology has many applications in simulation processes for learning applied sciences, engineering disciplines, and medical studies. The emergence of VR helped engineers choose the best design methods early, allowing them to decide before creating them [67] in order to reduce cost and change customer requirements before implementation, which helps reduce time, and also develop training processes for engineering disciplines, such as mechatronics and others [68].
  Medical virtual reality has become very important in our world. It helps doctors and students to practice the medical field on a daily basis, which increases the quality of

medical skills. Doctors have developed early predictions of dangerous diseases by simulating virtual things with real-life scenarios. It enabled them to understand the complexity of the heart system. Moreover, doctors have trained on how to recover and save the lives of accident patients in a very fast way. VR has been used in training to perform critical surgeries that require intense concentration, such as the eye, heart, and others that seriously affect the patient's life [69,70].

- **Space applications:** The emergence of virtual reality technology helped astronomers explain natural phenomena, simulate reality and understand the solar system by creating a three-dimensional model. It helped astronomers with the ability at any time and under any conditions to travel to outer space in a virtual world without cost and create an experience to train learners and their knowledge of the universe [71].
- **Medical applications:** The presence of virtual reality technology has helped the field of medical diagnosis to the highest levels, as the doctors were relieved of pressure during critical surgeries. The patient was visualized in virtual reality and diagnosed at the highest level; sudden changes were simulated during the patient's aid, as well as good planning for surgery and reducing pain during surgery and diagnosis. It is great in the treatment of dangerous and widespread modern diseases, such as breast cancer, colon cancer, Alzheimer's disease and many other different diseases, using video imaging through modern technologies and artificial intelligence devices, such as devices attached to the head and other sensors, such as lenses and others.

  For breast cancer, virtual reality has been introduced to reduce or limit the use of traditional methods, such as chemotherapy and radiation, to treat breast cancer or surgery that causes severe pain to the patient and increase anxiety as a result of harmful radiation to which they are exposed. Virtual reality solved the problem by providing a virtual headset to the patient that displays videos that help the patient to acclimate to situations that cause them anxiety, tension and pain, and providing information about their condition that they can easily understand. Finally, the physicists helped improve the drug dramatically by testing the drug with malignant cells before using it [72,73].

  Colon cancer is considered one of the most dangerous diseases currently in the world for women and men. The traditional treatment methods become more difficult and cause pain and anxiety for the patient. It has become difficult to assess the situation efficiently during the live broadcast. Therefore, they forced researchers and doctors to use virtual reality via virtual simulators. They have the ability to report information about the patient's condition, such as the visible mucous membrane, the detection rate of polyps, and others. Virtual colonoscopy has become an ideal solution instead to optical colonoscopy, which uses computed tomography, which is considered a blurring image for diagnosis [74,75].

  Alzheimer's disease is a disease of the age that causes disturbances in the brain, causing damage to the memory system. Virtual reality trains the patient to target things by default and improves the patient's driving skills significantly. In addition, it helps them to perceive things at home, in their daily life and in the early detection of Alzheimer's disease using the virtual reality maze test by testing specific cells of the brain to detect the disease early and test the strength of memory [76].

  The benefit of virtual reality in medical diagnosis and cognitive rehabilitation is to avoid sudden illnesses, such as stroke. It is used in physical therapy by visualizing the patient's movements in a virtual game instead of treating them in difficult gyms. It also gives doctors the freedom to perform surgeries in a virtual environment to simulate errors that could immediately be resolved by a computer [77]. It simulates real errors during the patient's diagnosis and works to increase the patient's physical and psychological comfort, reducing costs and providing health care. The use of virtual reality provides the interaction between reality (existence), virtual environments and the user's senses.

4. Specifications and Main Requirements of AR/VR Systems

AR and VR applications have many requirements to achieve the required user experience. Figure 1 summarizes the main requirements of AR/VR systems. AR/VR systems require a maximum end-to-end latency of five milliseconds in both directions of the communication medium [78]. This delay includes the required delay for the feedback signal. The end-to-end delay includes communication time over the communication medium, processing delay, and transmission delay. Ultra-high availability is another main requirement of AR/VR systems. Such availability requirement differs from one application to another; however, most AR/VR applications require nearly complete system availability. This requires introducing new technologies and novel network structures to achieve such an availability level [79].

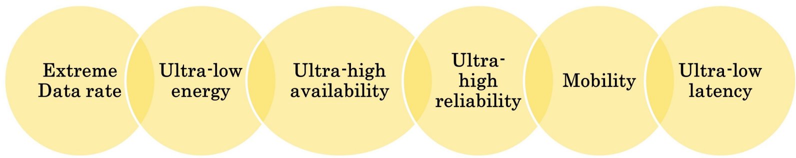

Figure 1. Main requirements of AR/VR systems.

As well as other 5G applications, AR/VR systems require ultra-high reliability of 99.999% [80]. Ultra-high system availability and full coverage are the other two main requirements of uRLLC. The communication network that provides uRLLC should provide full coverage with no dead zones, with an availability of around 100%. Latency is another requirement that should be achieved to enable uRLLC. Security is another requirement of AR/VR applications that requires introducing new schemes that achieve high data security with the required latency level [81].

The degree of freedom (DoF) of the hardware used by the end users is the main factor that affects the required user experience. With the recent advances in haptic devices, there are market-available AR/VR devices with a DoF of seven [82].

5. Challenges with AR/VR Systems

The announced requirements of AR/VR systems that were previously discussed introduce many design challenges to the communication networks required for such systems. These challenges can be divided into three main categories; challenges with the communication network design, challenges with the resources, and challenges with the end-device manufacturing.

Designing communication networks for AR/VR systems faces many challenges, including end-to-end latency, reliability, availability, security, and spectrum management [83]. The second group of challenges is the challenges associated with the energy, processing, and storage resources. The management of such resources in a way that meets the required quality of experience (QoE) is a challenge that should be solved [84]. Depending on centralized processing and storage schemes cannot support the required QoE and the required battery life for 5G applications. The third group of challenges is the challenges associated with the manufacturing of end devices, including the device's size, weight, and DoF [85]. With the recent advances in sensory development, such challenges are eliminated.

Traditional networks cannot be used for such systems since these networks cannot meet the required specifications and user experience of AR/VR services. Thus, novel network structures and recent technologies should be introduced. Unmanned aerial vehicles (UAVs), distributed edge computing, softwarized networking, artificial intelligence (AI), virtualization, device-to-device communications (D2D), and terahertz communications (THz) are recent technologies that can be used to assist AR/VR applications [86,87]. UAVs can be used to provide coverage and resources to end devices in AR/VR system and, thus, achieves the required level of availability and reliability [88].

Distributed edge computing is a recent paradigm that can be introduced to AR/VR systems to achieve the required latency. Two main forms of distributed computing can be deployed for AR/VR systems; mobile edge computing (MEC) and fog computing. Both technologies provide the computing resources near to the end user and, thus, eliminate the communication path in a way that reduces the end-to-end delay [89].

Software-defined networking (SDN) is another technology that can be deployed for AR/VR systems to achieve the main announced requirements [90]. It splits the network into two planes; the data plane and the control plane. Using a control scheme implemented over single or multiple controllers located at the core network, SDN can manage the whole network to reduce latency and congestion. Deploying SDN for AR/VR can achieve the required end-to-end latency, ultra-high availability and reliability, system flexibility, and a high level of security [91].

AI can also be deployed to assist the release of AR/VR applications in many ways. AI algorithms can be deployed to assist communication networks for AR/VR systems and reduce communication latencies via intelligent edge computing units [92]. Model-mediated schemes can be built using AI to predict the remote side of the AR/VR system, thus reducing the communication distance, as the communication is held between the transmitter and the model at the edge server.

D2D and THz communications are technologies that can be deployed for AR/VR systems to achieve a high data rate, increase the spectrum, and increase system availability. Deploying such technologies for AR/VR systems is the way of achieving the required QoE and developing more applications in many fields.

6. Unmanned Aerial Vehicles for uRLLC

Unmanned aerial vehicles (UAVs) have many uses in civilian and military applications due to their low cost, high proliferation capacity, high mobility, and ability to overcome the challenges faced by information and communication technology development. Unmanned aerial vehicle technology captured the interest of the whole world once it was authorized. It has many uses in many fields, including smart cities, real-time monitoring, military applications, 5G networks, and remote sensing [93]. It provides many solutions due to its ease of movement in three-dimensional environments. UAV has been announced as a 5G/6G use case. It is considered one of the key enabling technologies of 5G/6G systems due to its flexibility and ease of deployment, especially in harsh environments.

Unmanned aerial vehicles can be used as relays, air stations to provide coverage, or moving edge computing servers to provide computing resources for 5G/6G networks. This is the way that UAVs can be used to assist heterogeneous uRLL applications. It can be used to achieve the required full coverage by acting as a 5G/6G base station in uncovered or crowded areas. Moreover, UAVs can be used to support dense networks by providing computing resources near end users. Recently, UAVs have been used to provide wireless charging to distributed devices, which meets the requirements of uRLLC [94].

6.1. UAVs for uRLLC Applications

In this sub-section, we consider deploying UAVs for uRLL applications.

- **Industrial Internet of things (IIoT):** UAVs can be used to increase production, monitor industrial areas, and control production processes in dangerous places. IoT-based industrial systems, e.g., industry 4.0, can use UAVs to support the communication network by providing the required coverage and latency [95].
- **Augmented reality and virtual reality (AR/VR):** Deploying UAVs for AR/VR systems, users can see real video from high altitudes with very good quality. The use of unmanned aerial vehicles in the market helped virtual reality technology in the purchase decision process by offering the best product to the buyer [96].
- **Real-Time Monitoring:** UAVs are used to monitor road traffic, regulate traffic, and reduce road density by sending directions to control towers and traffic lights by collecting road traffic information and sending it to act. UAVs are used in monitoring

railways and highways to facilitate road management and achieve a high level of safety [97].

- **Lifeline applications:** Unmanned aerial vehicles can be used as an air station to receive data in hard-to-reach places and places of volcanoes and earthquakes. It is able to provide real-time communications in such hard situations. It monitors and forecasts areas affected by natural disasters. It works to preserve protected areas and forests. It monitors borders and arrests terrorists and outlaws. It also works in search-and-rescue operations against destructive activities affecting the state [98].

6.2. UAVs for AR/VR Systems

AR/VR applications are the main use cases of uRLLC, and thus we consider how UAVs assist them in this section. Drones are widely used to serve modern technologies that use augmented reality, virtual reality and mixed reality to save lives, time and cost in several applications, including helping fire crews fight forest fires, monitoring hard-to-reach places with fixed cameras to help the state in early prediction of the occurrence of the incident, and collecting real-time data on the fire to provide the means to confront it.

Forest fires are one of the most severe cases that affect all creatures, such as the emission of harmful rays, global warming and other serious damage to our world. Firefighting crews are trained using augmented and virtual reality techniques to visualize the expected events during the disaster without causing harm to the individuals. This development has helped use robots that also help them by using augmented and virtual technologies to guide them and fight fires and other natural and industrial disasters [99].

Drones can take three-dimensional images to plan the most harmful places and draw roads and maps for firefighting personnel in rugged and far from satellite coverage and under different weather conditions at a lower cost and without major losses. The vision devices on board the UAVs enjoy their flexibility and speed of discovery, taking pictures and analyzing them through the existing sensors and ground stations to control them.

Finally, virtual reality technology was applied to visualize fires by default, enabling them to collect the required data without causing losses, allowing the user to navigate the fires and identify the places of danger and the most affected. In addition, augmented reality technology provides virtual information about fires in their real environment, which works to confront unexpected developments or perceptions [100].

The application of virtual reality has helped several systems, including the geographic information system in which UAVs are used, which helped humans to know the changes that affect humanity in the present and compare them with the past. UAVs collect images that are not clear and of poor quality [101]. Virtual reality technology helps visualize space in a virtual world that can predict cosmic events without the need for expensive efforts and early planning for them to face cosmic changes. To improve these technologies, the digital terrain model was created with the data we obtained from UAVs to improve roads and geographical surveys, avoiding natural, industrial disasters and others.

Unmanned aerial vehicles are used in military life and the army to monitor, secure state borders, collect information about the enemy, and clear minefields [102]. Unmanned aerial vehicles collect information about the ground and the enemy's fortifications. VR simulates real things in a virtual world to confront these fortifications and train them to avoid losses in troops and equipment. In addition, the AR worked on visualizing emergency variables by creating a virtual environment in our world, greatly reducing losses and costs in carrying out these works. It is used to monitor open coal mines and volcanoes and to follow up on emerging variables. The goal of using modern technologies is to convert aerial images captured by UAVs into a model that is easy to use in virtual reality theory.

Augmented and virtual reality has helped in agricultural operations, monitoring production and diseases that cause damage to crops and avoiding them [103]. Accurate follow-up, education, construction, and the discovery of natural and industrial disasters are difficult to reach. The crews of workers have actual training in how to deal with disasters using modern technologies.

The use of unmanned aerial vehicles in various means of entertainment supports modern technologies, such as virtual reality and augmented reality, and in various fields such as science, civilization history, trade and in the fields of military sciences [104]. They are also used in the fields of entertainment and art in more than one application, including music. They are used as a human player in front of the masses in more than one scene, the circus, in art, in acting, in interactions with humans, and in drone dancing.

The use of UAVs has greatly supported the fields of augmented and virtual reality, allowing video games to become real and enabling the user to control them with mobile devices, such as smartphones, cellular networks and Wi-Fi [105]. It is used in filming their various sports activities and could be a way to practice sports in all its forms. Developed from the uses of virtual and augmented reality in racing and games in general, these allow the user to live the truth in a virtual world by using modern tools, such as wireless video glasses.

We use UAVs as means of collecting data and information, mapping, architectural construction, building engineering, aerial photography, route planning, freight services, air transport, military, in rapid air surveys and smart tourist environments because they produce 3D models of historical and urban buildings with high accuracy [106]. It requires operators of UAVs to stand or sit in a position that achieves the line of visual sight with UAVs, so it causes fatigue and exhaustion and is difficult to control in dangerous places and stand next to them. In addition, all international organizations have prohibited their use in places of equipment and construction, and above people, to maintain the safety of citizens.

Researchers have worked to apply modern technologies that help train operators of UAVs using virtual reality technology to create a virtual environment that is parallel to the real environment to reduce the mental and physical workload and pressures they face when operating drones [107]. The use of modern devices in facilitating the work and application of virtual reality with UAVs has increased many other opportunities, including devices to change the heart rate, the interval between pulses, respiratory rate and many other devices that have spread because of the development in the use of modern technologies. Augmented reality is the process of creating a three-dimensional virtual environment in our real world. It helps reconstruct old historical buildings and make them more interesting in using mobile devices, smart glasses, and other devices. Nevertheless, another dimension to using AR with the historical, cultural heritage is using UAVs, called remote AR [108]. The goal of its use is to increase 3D video images using modern tracking technologies and modern cameras. In addition, modern tracking methods integrate images captured by unmanned aerial vehicles with three-dimensional images generated by a computer, such as the global positioning system and monocular scene tracking method.

Augmented reality has increased people's awareness of their landmarks in a new way and the transfer of historical heritage to future generations, which increases historical knowledge and the community's awareness of their ancient landmarks and ancient historical structures subjected to earthquakes, wars and natural disasters [109].

6.3. UAVs-Based Framework to Assist uRLL Applications

This subsection introduces the recently developed systems that consider deploying UAVs for uRLL applications. In [110], unmanned aerial vehicles were used in firefighting, prevention, monitoring and control, solving problems facing firefighters, and guiding robots used to fight fires in hard-to-reach places. Therefore, the authors suggested using augmented and virtual reality technology in training and guiding UAVs and facilitating firefighters' work by making a simulation model for the development of rescue operations. In this work, we study the problems and challenges facing firefighters in modern technological solutions and the challenges facing robotic technologies and UAVs in this way.

In [111], the authors used unmanned aerial vehicles to analyze terrain and geographical visualization to relieve very high altitudes and monitor minefields. The developed work uses virtual reality technology in first-person view mode (FPV), allowing more realistic real-time exploration. VR also takes part in converting low-level aerial images captured by unmanned aerial vehicles to a digital terrain model (DTM), using head-mounted devices. In addition, in verifying the accuracy of the 3D model with the results of GNSS RTK (real-time kinematic) measurements, the location is determined in real time.

In [112], the authors provided a framework to use UAVs in various forms of entertainment such as music, art, games, augmented and virtual reality technology, and in the field of live shows. The developed framework uses augmented and virtual realities for video games. They are used to display historical images of the surrounding environment everywhere, which becomes a distinctive way to show tourist attractions by exploring virtual places and making them real in front of users before visiting them.

In [113], the authors deployed unmanned aerial vehicles to assist in the construction of modern projects. This causes danger to workers in the sites and violates the operating rules and safety regulations that exist in all laws. In addition, it causes fatigue, exhaustion and tension for users of unmanned aerial vehicles. Therefore, researchers in this work had to increase the reliability of the use of UAVs in all work, and the use of physiological measures to measure performance, and reduce stress and mental workload (MWL). In addition, modern technologies, such as virtual reality and machine learning (ML) models, solve these challenges and difficulties facing users of UAVs.

In [114], unmanned aerial vehicles were used to collect 3D data on urban buildings, smart cultural heritage, and dangerous places that are difficult to access. The 3D data were difficult to obtain and it was a complex matter, consuming a long time and very high cost. In this work, we focus on the role of modern technologies, such as augmented, virtual and mixed reality, in providing three-dimensional models of urban places. The development in the use of modern technologies has helped the role of UAVs in the possibility of low-cost photogrammetry in modern tourism, simulating historical buildings and three-dimensional cultural heritage.

In [115], unmanned aerial vehicles have taken the augmented reality technology used to reconstruct the ancient buildings of cultural heritage sites to the extreme after using smart glasses, mobile phones and other modern technologies that are used to show the ancient tourist attractions only. In this work, the researchers had to present a new dimension: the remote augmented reality using UAVs to increase the data captured with 3D technology. They also added modern technologies to the tracking process, namely the GPS-based tracking of UAVs and vision-based scene tracking, to increase the accuracy of the work of unmanned aerial vehicles.

7. Distributed Edge Computing for uRLLC

The main requirements of modern communication networks make it difficult to depend on the traditional centralized cloud in computing and control operations. Therefore, they require the use of modern technologies that keep pace with this huge progress and rapid development in the use of the internet, such as unmanned aerial vehicles, the internet of things, machine learning and other modern technologies that keep pace with change [116].

With the increase in the volume of internet use, traditional cloud still cannot create, store and process a large amount of data due to its limited capabilities, limited communication resources and limited storage capacity. Thus, it requires the creation of large mobile computing that helps keep pace with the progress in information technology and the massive use of the Internet by transferring computing to the edge of the network, e.g., radio access network (RAN), which reduces the network congestion and the communication latency and increases the network availability and reliability [117].

The novel paradigm is referred to as distributed edge computing, which is available in two main forms; fog computing and mobile edge computing (MEC) [118]. Fog computing was first introduced to move cloud computing from the kernel to the edge of the network to reduce bottlenecks in the network, but there were also some challenges. Fog nodes are small distributed servers that provide limited computing resources near end devices [119]. Figure 2 presents the main benefits of fog computing.

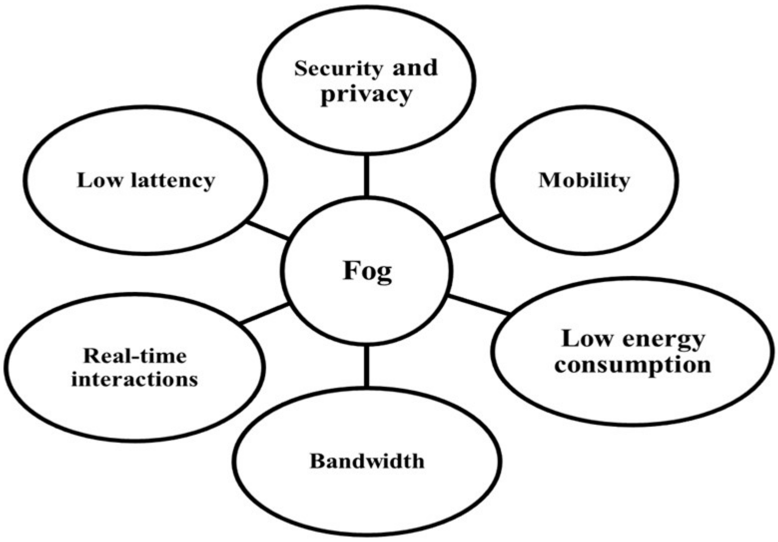

Figure 2. Main benefits of deploying fog computing for uRLLC applications.

Due to the limitations of fog nodes, MEC was developed mainly for cellular networks and has been modified to fit other networks. The main idea of MEC is to move cloud computing to the edge of the network near the users, which facilitates the rapid deployment of smart devices, speed in data volume, increased bandwidth, low latency, and increased requirements of the quality of the service [120]. Figure 3 summarizes the main benefits of MEC technology. Applications of the previous mobile generations, i.e., 3G and 4G, were not fast enough to be marketed; thus, it was required of the mobile phone operators (MNOS) to develop the mobile computing process to be near the users to provide the application latency and be at high speed [121].

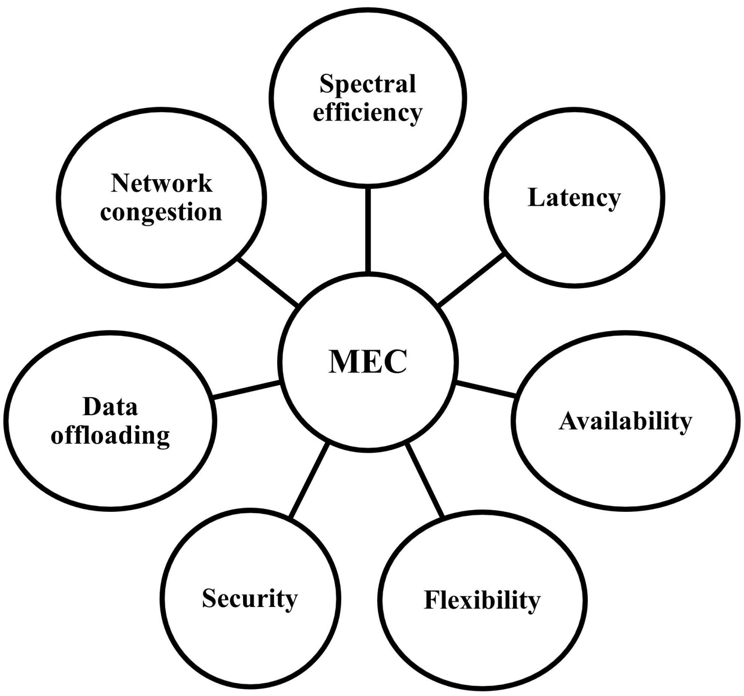

Figure 3. Main benefits of deploying MEC computing for uRLLC applications.

The emergence of MEC helped in the emergence of various groups of uRLL applications, including IIoT, vehicle-to-everything communication, vehicle-to-vehicle communication, VR, and AR [122].

MEC can be operated independently from the rest of the network. The MEC server is placed close to the users at the network's edge to reduce the time in collecting and analyzing data. It reduces the communication latency, making it widely used in 5G applications. MEC improves the network, relieves stress on the network, and reduces network bottlenecks due to moving computing to the edge of the network [123]. In addition, MEC improves delays, availability, flexibility, security, data offloading tolerance, network congestion, and spectral efficiency. Due to such benefits, it represents a promising solution to enable uRLLC.

8. Conclusions

uRLL communications are the main applications run over 5G/6G systems. Such applications introduce many constraints on the communication network design due to the required ultra-low latency and ultra-high data reliability. This makes traditional networks inappropriate for such applications and pushes toward introducing novel technologies to communication networks. The work reviewed the main features, specifications, and requirements of uRLLC. Moreover, the key enabling technologies used to achieve uRLLC applications are presented. This includes UAVs, distributed edge computing technologies, and the current proposals considering deploying them for different uRLLC applications. A use case of AR/VR is considered.

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