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The symbiotic influence of 5G and IoT on ultra-reliable low latency communications solutions

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Abstract. The rapid advancement of technology has brought about the era of Ultra Reliable Low Latency Communication (URLLC) which holds importance in today's world. This paper explores the significance of URLLC in relation, to the generation of mobile communications technology (5G) and the Internet of Things (IoT) by employing a methodical approach of literature analysis and synthesis. Through analysis, this paper discovered that both 5G and IoT individually play substantial roles in enhancing communication and connectivity, and their combined potential is truly transformative especially when it comes to achieving URLLC across industries. This convergence opens up possibilities for reality virtual reality warehouse automation and other groundbreaking applications. However, there are challenges that must be carefully examined and addressed on the path to achieving an integrated URLLC in the future. These challenges encompass problems related to scheduling and energy efficiency, alongside technical concerns such as economics and regulatory obstacles. By confronting these challenges and promoting a mindset it is possible to fully embrace the opportunity to enter an era where URLLC, 5G and IoT blend harmoniously enabling groundbreaking applications and fueling innovation, in industries.

Keywords: 5G, IoT, URLLC

1. Introduction

The concept of Ultra-Reliable Low-Latency Communication (URLLC) plays a crucial role in the modern technological landscape, introducing a new approach to data transmission. This characteristic gains even more significance when considering the advancements brought by fifth-generation mobile communications technology (5G) and the vast domain of the Internet of Things (IoT). While 5G and IoT individually contribute to improved communication and interconnectivity, their combined potential lies in realizing URLLC, which can bring transformative changes across various industries. This essay aims to thoroughly investigate URLLC's essence, and its criticality within the convergence of 5G and IoT, as well as explore the challenges and opportunities that arise from this integration. Through this exploration, the paper will provide an insightful academic perspective on how URLLC is central to our rapidly advancing digital era.

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2. Introduction to 5G and IoT

2.1. A brief overview of 5G

5G, which is also known as the fifth-generation mobile communications technology, represents the latest advancement in wireless communications technology. Compared to its predecessor, 5G offers higher data transmission speeds, lower latency and greater connectivity. This enables 5G to not only support a smoother network experience for smartphones and other consumer electronics, but also to advance cutting-edge technologies such as the Internet of Things (IoT), self-driving cars, and telemedicine.

The 1G was first developed in the 1980's. Its appearance drove people to stop using landlines and slowly increased the popularity of wireless communication. [1]

Over the next decade, 2G began the transition from analogue to digital. As well as enabling the miniaturisation of mobile phones and improving voice quality, 2G also introduced Short Message Service (SMS). This feature was particularly popular with younger users and led to a cultural trend of sharing jokes, stories and quick communications via SMS[1].

As the 21st century dawned, 3G was born. As the popularity of the World Wide Web skyrocketed, 3G supported this growth with increased data rates, enabling activities such as email, web browsing and messenger services. In addition, video calling became a reality, offering a more intimate form of long-distance communication [1].

With its primary concentration on data transfer via networks, 4G signaled a substantial shift. By enabling Voice over IP (VoIP), 4G altered the telecommunications industry. Smartphone use, online enterprises, e-commerce, online gaming, and innovative apps like real-time navigation and mobile cab services all experienced significant growth during this time [1].

Entering the 2020s, 5G pledged a significant shift. 5G is viewed as a technological catalyst that will completely transform various industries, not just an improvement in speed and latency:

eMBB (enhanced Mobile Broadband) guarantees unrivalled speeds, with the potential to reach up to 10GB/s[1].

URLLC (Ultra-Reliable Low-Latency Communication) assures robust, rapid, and dependable communication that is essential for applications like remote surgery[1].

mMTC (Massive Machine-Type Communication) has the potential to revolutionize co-communications among robots and inter-device communications, particularly in industries, thereby heralding a new era of automation and interconnectedness[1].

The scope of 5G, moreover, extends to reshaping transportation with improvements in vehicle communication, advancing industrial automation, and forming the basis for futuristic smart cities[1].

2.2. The future is connected: an introduction to IoT

Electrical or electronic devices that are connected to the Internet are referred to as "Internet of Things" (IoT). These gadgets come in a variety of shapes and sizes, from basic sensors to sophisticated smartphones and home appliances. IoT's fundamental idea is to make it possible for common devices to connect with one another across a network, which will increase automation and intelligence.

IoT now encompasses more than just M2M (machine-to-machine) connectivity. As technology develops, a growing number of items and equipment may be linked to the internet to allow for remote management, data gathering, and analysis. For instance, a smart refrigerator can check the food's storage state and notify the user, while a smart thermostat in the home may automatically change the temperature based on the user's behavior.

With the proliferation of IoT technologies, the impact of the Internet is becoming more pervasive, personal and intimate in everyday life. According to CISCO Internet Business Solutions Group (IBSG), "IoT will make the impact of the Internet even more pervasive, personal and intimate in daily life" [2].

The Imperative of ultra-reliable low latency communication: As highlighted by Park et al., In the current rapidly-evolving technological landscape, the requirement for low-latency solutions is gaining importance across numerous industries. The necessity for instantaneous data transfer and processing,

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from autonomous automobiles to real-time financial transactions, is altering industries and establishing novel benchmarks for communication systems.

Autonomous driving: The transportation sector is currently experiencing a significant shift with the emergence of autonomous cars. These vehicles heavily depend on instantaneous data processing to make quick decisions while travelling on roads. According to Park et al., vehicle-to-vehicle (V2V) communication necessitates highly dependable updates to guarantee the safety and efficacy of self-driving[3].

Industrial Automation: Modern factories and production lines are becoming more and more automated using wireless technology. Communication solutions that provide high reliability and low latency are essential for high-precision robot control and real-time monitoring[3].

Augmented and Virtual Reality: The effective immersive experience offered by augmented and virtual reality (AR/VR) technologies is reliant on low-latency communication. Any hindrance in data transmission could potentially ruin the user experience. This underlines the significance of predictive URLLC as examined by Park and colleagues[3].

Healthcare: Telemedicine and telesurgery are growing in popularity, particularly in xlight of the worldwide health crisis. To guarantee patient safety and effective medical interventions, these programs necessitate real-time data transmission.

3. The symbiotic influence of 5G and IoT on low-latency solutions

3.1. 5G – the enabler of ultra-low latency

5G technology plays a vital role in the advancement of URLLC, which is essential for many critical applications. According to the Third Generation Partnership Project (3GPP), the primary goal of URLLC is to reduce latency to 1ms while maintaining packet error rates below 10-5[4]. The application of 5G not only lowers the latency, but also enhances the overall performance and reliability of the network. Furthermore, by supporting edge computing, it brings cloud capabilities closer to the end users, addressing challenges like high latency and security concerns inherent in traditional cloud systems. By situating computational resources at the edge of the network, closer to user equipment (UEs), edge computing can efficiently handle the demands of applications that are interactive in nature, such as augmented reality, virtual reality, and those requiring URLLC [5].

3.2. IoT's pivotal role in real-time solutions

The emergence of IoT has facilitated economical interconnectivity between IoT devices and the network, all while upholding strict latency and dependability standards. Consistency in URLLC trustworthiness often necessitates diversity; however, there is also a need to weigh the augmented latency linked with auxiliary operations, specifically in scenarios involving low-budget IoT devices. In this context, the Select Combination (SC) and Switch-and-Sustain Combination (SSC) diversity schemes have been examined as feasible methods for enabling high-quality, low-latency downlink communication for low-cost IoT devices [6].

3.3. The confluence of 5G and IoT and their applications

As mentioned above, the advanced development of 5G and IoT gives the opportunity to realize the possibility of URLLC. Nowadays, there are already some applications of URLLC in our daily life.

Warehouse Automation: In an automated grid-based warehouse scenario, URLLC is required for both the kinematic energy consumption of the robots and the communication between the central controller and the robot swarm to be jointly optimized in real-time. Deep reinforcement learning (DRL) based approaches that employ the deep deterministic policy gradient (DDPG) method and convolutional neural network (CNN) can be used to achieve a stationary optimal control policy that consists of a number of continuous and discrete actions [7].

Industrial Verticals: Customized 5G and beyond private networks (C5GBPN) can be used to provide URLLC, enhanced mobile broadband, massive machine-type communications, and positioning for

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various application scenarios of industrial verticals. The flexibility of C5GBPN is of paramount importance for various application scenarios of industrial verticals [8].

Augmented Reality (AR): Augmented Reality (AR) is transforming various sectors, including architecture, construction, energy, and logistics. AR overlays virtual information onto the real world, enabling it to play a crucial role in improving production processes and integrating advanced technology into several production lines. Head-mounted screens, helmets, and even smartphones are now equipped with AR capabilities. Moreover, the competency of AR in tracking has resulted in the emergence of natural feature tracking techniques, refining the proficiency of instantaneous virtual image identification and locating methodologies [9].

Virtual reality (VR): VR provides a simulated experience that can be similar to or wholly different from the physical world. In military situations, VR is utilized to simulate genuine difficulties, allowing soldiers to practice against virtual enemy fortifications. This not only fine-tunes their skills but also decreases the risk of losses in real-world scenarios. Outside of the military, VR and AR have found usefulness in agriculture, helping with monitoring crop production and detecting diseases. They also have a pivotal impact on education, construction, and disaster management, providing valuable perspectives on fields that might otherwise be difficult to explore [9].

Robots and Remote Control: Robots and remote-controlled devices are becoming indispensable, especially in areas affected by natural and industrial disasters. For instance, remote surgical operations conducted in such places not only ensure the safety of medical personnel but also provide a real-time, three-dimensional view of the situation. This real-time feedback, facilitated by robots, is crucial for assessing risks and making informed decisions [9].

4. Potential challenges and considerations

While URLLC holds immense potential for future applications, it is crucial to objectively address and consider the associated challenges and considerations.

From the perspective of technology, although the progression of 5G and IoT presents a glimpse into the future of URLLC, there are still outstanding concerns that must be dealt with if it is to be seamlessly integrated into our daily lives. The scheduling of the URLLC comes first. “The scheduling of an unexpected packet generation by URLLC is one of the most significant issues” says Siddiqi, Yu and Jound [10]. Instant scheduling may cause service disruptions when it gives URLLC packets priority. On the other side, reservation-based scheduling reserves spaces that could go unused, resulting in inefficiencies [11]. The concern over energy efficiency for end-user devices is the second factor. Even though many wireless devices include sleep modes to save energy, the quick response time needed for packet receipt might reduce energy efficiency. Because URLLC-based services require frequent data checks, the existing energy-saving states created for user equipment are inadequate for them, which results in considerable battery depletion [10].

Moreover, when URLLC comes into play, non-technical issues should also be considered. a. Economic factors: A significant financial investment is required for the deployment and upkeep of a URLLC network. Operators need to be sure that anticipated profits will cover both the high initial investment and ongoing running costs. The return on investment is also unknown due to the technology’s fast advancement. b. Regulation and policy: The adoption and operation of URLLC may be hampered globally by regulatory barriers related to spectrum utilization, data protection, and network security. Operators must work closely with the relevant authorities and policymakers to fulfill all regulatory responsibilities. c. Security and Privacy: Security and privacy concerns are anticipated to be major challenges since application scenarios for URLLC, including self-driving cars or medical equipment, are frequently crucial to their purpose. d. Interoperability: Ensuring compatibility across different devices and solutions can be difficult as more suppliers enter the market. It is vital to create and sustain standards in order to guarantee reliable and high-quality service delivery.

5. Conclusion

This paper mainly focuses on exploring the Symbiotic Influence of 5G and IoT on URLLC and its

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potential challenges. In the world of technological advancement, the emergence of 5G and the Internet of Things (IoT) signifies a momentous era for its potential for ultra-reliable low-latency communication (URLLC). This convergence, albeit in its infancy, exposes revolutionary applications such as AR, VR, and warehouse automation, which signify an unparalleled future of automation and real-time responsiveness. However, this path presents numerous technical challenges, including scheduling and energy efficiency, alongside wider concerns such as economic viability and regulatory hurdles. In this promising era, it is imperative that stakeholders from across the spectrum collaborate to address these challenges, unlocking the full potential of 5G and IoT in shaping a connected, efficient and transformative future.

Future research could delve deeper into the economic implications of URLLC, exploring models that could potentially offset the high initial investments required for network deployment. Moreover, an extensive investigation into the security and privacy issues, and their efficient resolution to promote a more secure URLLC environment could be a potential avenue for further research.

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