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Research Article

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Low-Latency and Ultra-Reliable Communication for Industrial 5G

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Abstract

The Internet of Things(IoT) is a planned Internet extension in which everyday objects are outfitted with circuitry, software, sensors, and internet connectivity is required so that data can be received and sent over the Internet. Emerging applications like factory automation and au- tonomous driving necessitate affordable, dependable, and low- latency communication making wireless architecture It's more convoluted than before.

The study's goal is to understand existing study issues and solutions in connection with 5G-enabled Industrial IoT based on both sectors' original goals and commitments. The fifty generation mobile technologies naturally provide these (These are naturally provided by 5G mobile technologies.), making it a strong choice for enabling scenarios for Industrial IoT(IIoT). This article discusses Low Latency and Ultra-Reliable, one of the pillar elements of 5G wireless systems introduced by 3GPP in release 15 and beyond.

It focuses on how to allow Low-Latency and Ultra-Reliable by combining metadata and data encoding approaches. Aside from evaluating, current issues and solutions, the study intends to get to a decision about the current research gaps by providing comparisons that are applicable to any of these subjects (in- relation to fifty-generation enabled-IIoT). Finally, it analyzes URLLC difficulties by assessing packet transmission reliability based on the packet time frame and the reliability impairment impacting communication dependability.

Keywords: 5G, IoT, Industrial IoT (IIoT) Sce- Narios, Ultra-Reliable Low Latency Communications, 5G Mobile Technology

1. Introduction

The growing trend in cellular wireless networks is ex- pected to continue. It began with 2G and progressed to 4G, and will continue with today's developing 5G. How- ever, 5G not only promises a bandwidth speed improvement over 4G, but will also include new operating modes such as eMBB (Enhanced-Mobile-Broadband), mMTC (Massive- Machine-Type-Communications), and most crucially, Low- Latency and Ultra-Reliable.

The Low-Latency and Ultra-Reliable is a 5G NR (New Ra- dio) (as defined by 3GPP) enablement feature for some unique and mission-critical use cases that demand data transmission with extremely low-latency (=1ms). Low-Latency and Ultra- Reliable is made up of two generally antagonistic components: reliability and latency. Reliability is the likelihood of success- fully transferring X bytes across a defined delay, while latency is the time it takes for data packet delivery from transmitter to receiver. For a 32-bit data packet transmission with a 1ms time delay, the Low Latency and Ultra-Reliable requirement is 1 - 10-9. Manufacturing automation and autonomous driving are examples of emerging applications that require cost-effective, trustworthy, and low-latency communication. Wireless design is becoming more complex than previously. This article ex- plains Low Latency and Ultra-Reliable), a key component of 5G wireless networks introduced by 3GPP in release 15 and beyond. It focuses on how to enableLow Latency and Ultra-Reliable through the use of metadata and data encoding techniques [8].

IIoT applications and their needs, mobile edge cloud, back- end performance optimization, network function virtualization, cybersecurity, IIoT blockchains, 5G AI enablement, and secure campus network are just a few of the subjects highlighted. By offering significant comparisons for each of these categories, the study hopes to make inferences on current research gaps (in relation to fifty generation-enabled IIoT)

Finally, it assesses Low-Latency and Ultra-Reliable concerns by measuring packet transmission reliability based on packet time frame as well as the reliability impairment affecting communication dependability. The study analyzes fifty generation(5G) deployment approaches [6].

2. URLLC Definition

In fifty generation(5G), Low-Latency and Ultra-Reliable consists of two separate technology groups: Ultra-reliability for reliable communication improvement and the other one which dramatically decreases latency for extremely low la- tency communication [1].

Latency for Extremely Low Latency Communication

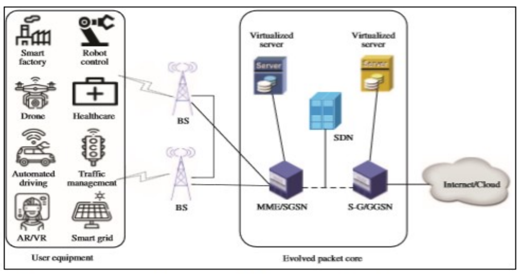

Fig. 1. Appliactions and network architecture of URLLC

Figure 1: Latency for Extremely Low Latency Communication.

A. Reliability

The network reliability is the capacity of the network to continue offering same services throughout during failure, whereby the higher reliability is the characteristic of the network to guarantee nearly 100 percentage up time and ultra- consistent service delivery.

B. Latency

Latency is defined as time delay it takes to data from transmitter to reach the destination. Hence, for shorter time delay (i.e., low-latency), the better user-experience and longer time delay (i.e., high-latency), the poor user-experience. The latency defines how fast data packets can travel from sender to receiver across network.

The URLLC is a communication service that enables the successful delivery of packets with severe constraints, partic- ularly in terms of availability, latency, and reliability Zexian Li et al. [2018]. It's a 5G NR feature enabler for mission- critical developing applications and services that demand low latency and reliable connectivity. In version 15 and release 16, 3GPP's URLLC technology enables for higher dependability of more than 99.999 percent and ultra-low latency of less than 1 millisecond.

This allows the realization to take place of vertical applica- tions such as industry automation, Internet tactile, Healthcare industry, smart energy, intelligent transportation, etc [2].

3. URLLC Use Cases and Requirements

In 3GPP Release 15 and 16, 5G URLLC has been intro- duced as a deterministic component of cellular networks to enable the support for emerging mission-critical applications and services where URLLC will provide capabilities which; with existing wireless network; could not be achieved such as ultra-reliability and latency levels of 1ms for real-time communications as per requirements as per in Fig.2.

URLLC USE CASES

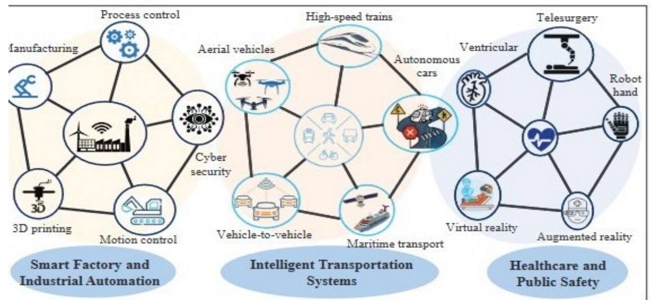

Figure 2: URLLC Use Cases.

The applications across industries such as industrial and process control in industrial automation; remote surgery and emergency response in the healthcare industry; traffic manage- ment and autonomous driving in intelligent transport; motion and remote control in the manufacturing industry; and smart energy and smart grid in the energy sector will all require [1]. The table below illustrates the required Key Performance Indicators KPIs but only considering end-to-end reliabURLLC as drivers and enabling communication services [2]. These applications require ultra-low latency of ¡1ms levels and BLER (Block Error Rate) less than 10-9 of reliability [ility and latency even though other key parameters like availability, jitter, and user experienced data rates will be equally important keys [3].

USE CASES WITH MINIMAL LATENCY AND HIGH DEPENDABILITY, TOGETHER WITH THEIR PREREQUISITES.

Scenario	End-to-end latency	Reliability
Discrete automation – motion control	1 ms	99,9999%
Electricity distribution – high voltage)	5 ms	99,9999%
Remote control	5 ms	99,999%
Discrete automation	10 ms	99,99%
Intelligent transport systems – infrastructure backhaul	10 ms	99,9999%
Process automation – remote control	50 ms	99,9999%
Process automation – monitoring	50 ms	99,9%
Electricity distribution – medium voltage	25 ms	99,9%

Figure 3: Example of Low Latency and High- Reliability Use Cases and Their Requirements.

• Ultra Reliable Low Latency Communication (URLLC): The eMMB and mMTC were intended specifically for humans and machines, respectively, whilst the URLLC was created when it comes to personal communication. This connection is designed to have near-zero latency and packet losses, enabling mission-critical applications such as driverless vehicles, augmented virtual reality, remote patient surgery using robots, and so on.

• Enhanced Mobile Broadband (eMBB): eMBB enables higher data capacity and moderate latency improvements on both 5G NR and 4G LTE networks. This will aid with the development of today's mobile broadband use cases, such as developing AR/VR media and applications, UltraHD or 360-degree streaming video, and a variety of others.

• Massive Machine-Type Communication(mMTC): mMTC is a use case in which the network must enable the mass deployment of billions of low-cost, low-power devices that connect over mobile networks rather than Wi-Fi or Bluetooth. Hence, this is a critical requirement for 5G to support use cases including low-data-rate sensors, actuators, and machine-monitoring systems. [4].

4. Challenges for URLLC

Cellular systems preceding 5G were designed with the main objective to achieve high data transmission rates. With 5G URLLC, the aim is to design a system that will significantly reduce latency time (e.g., ¡ 1ms) while ensuring connectivity with low error probability (e.g., 10-9 of reliability) and also keeping the throughput of the system. Hence the design chal- lenge jointly considers the latency, reliability, and throughput. However, ensuring reliability requires resources such as longer block lengths and retransmissions which normally increase latency. The latency duration mainly depends on the transmission of resource grant (RG), transmission time interval (TTI), and positive/negative. [5].

A. The use cases of 5G can be broadly divided into three major categories:

SIGNALING PROCEDURE FOR DOWNLINK DATA TRANSMISSION IN LTE.

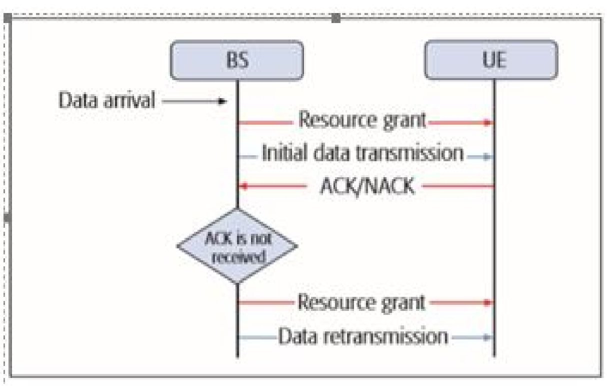

Figure 4: Signaling Procedure for Downlink Data Transmis - Sion in LTE

Acknowledgment (ACK/NACK) between transmitter and receiver as can be seen from Fig.2 in a simple communication performing data transmission from Base Station (BS) and a User Equipment (UE).

The URLLC application also faces the challenge of co- existence with other services of 5G NR and integration of new architectures. In the 3GPP service definition for 5G is provision of capabilities to handle eMBB, mMTC and URLLC itself and all these services require different metrics and different transmission policies and techniques.

The necessity to give priority to URLLC should be handled in a way to avoid severe degradation of other services, for example using a proper scheduling between services where the dynamic multiplexing, which itself poses a challenge to set a joint scheduling of multiple services over different time- scales. The incorporation of; for example, edge caching in edge computing scenarios which reduces delays; is another challenge to overcome while designing the URLLC systems.

5. URLLC Enabling Techniques and Solutions

Reliability and latency requirements for various URLLC use cases could be achieved by key enabling techniques as 3GPP Release 15 adopted it, while Release 16 improved on it.

Those techniques; which include (but not limited to) flexible frame structure, scheduling schemes and reliability improve- ment techniques; are applied on PHY and MAC layers to support extra low-latency and ultra-high reliability levels . Flexible frame structure offers possibilities to shorten the Transmission-Time-Interval (TTI) duration [1] which consists of controlling subcarrier spacing which reduces symbol period, TTI duration and hence the overall latency. Flexible frame structure technique also creates opportunities of more retrans- missions which increases reliability too. From Fig. 3, it is illustrated how length of subframe/slot can be subdivided into mini-slot to make TTI duration even shorter with the use of OFDM (Orthogonal Frequency Division Multiplexing) [7].

ILLUSTRATION OF SLOT AND MINI-SLOT FOR DIFFERENT SUBCARRIERS

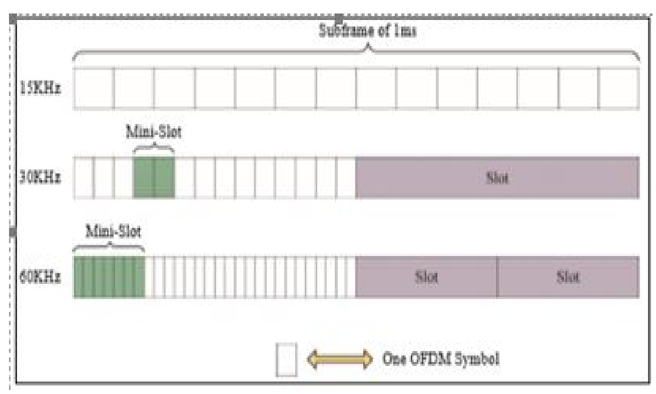

Figure 5: Illustration of Slot and Mini-Slot

Grant-Free (GF) random access transmission can be used to skip a normal 4-way handshake; usually used in a Grant- based transmission; procedure to avoid large latency and signaling overhead, and so to reduce access latency. In GF, BS detects transmitted preambles through active devices and issues scheduling grant in response and connected device starts transmitting data packets. The GF procedure is shown in Fig.4. with comparison to G-based random access.

Illustration of GF Random Access procedure in comparison

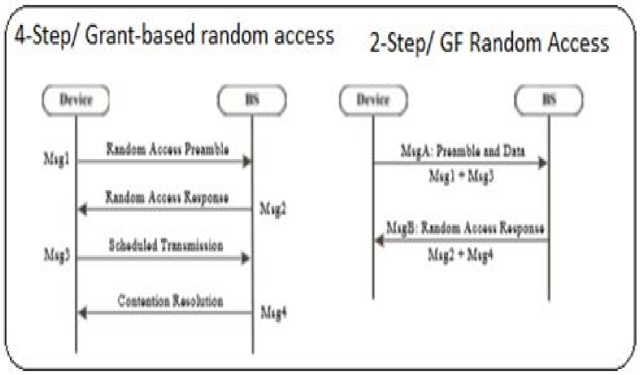

Figure 6: Illustration of GF Random Access Procedure in Comparison.

Different HARQ retransmission schemes are incorporated in GF random access in order to support the URLLC under a targeted latency. They include reactive HARQ retransmission scheme where a retransmission is solely done after reception of NACK, K-repetition HARQ retransmission scheme where a number of K repetitions is transmitted before reception of feedback from BS and BS combines these packets to enhance the reliability, and proactive HARQ retransmission scheme which is much similar to K-repetition HARQ retransmission scheme.

Deployment of a significant number of antennas in what is known as massive MIMO is another key enabling for URLLC based on the use many antennas to serve different end users in the same time-frequency resource at the same moment.

To deal with and overcome the challenge of coexistence for URLLC with other services (mMTC and eMBB), the URLLC is given precedence over other services via a reac- tive strategy consisting of preemption indicator transmission and re-transmission of selected code-blocks, and a proactive strategy that ensures the reliability of ongoing services while supporting URLLC transmission.

6. Performance Evolution of Macro-Diversity

It is often assumed that different multi-connectivity sys- tems can provide diversity gain in order to boost reliability. Macroscopic diversity, i.e., data duplication and redundant transmission/reception from multiple cells/TRPs, it is also necessary to provide mobility robustness during handovers and to avoid fading effects (such as shadowing and/or blocking) over time.

In addition, macro-diversity provides benefits in terms of resilience against failures of the cellular infrastructure. In this context, the 3GPP Rel-15 has agreed to data duplication, and one of the most common types of non-coherent is inter-cell joint transmission the packet data convergence protocol (PDCP) layer for NR. At the physical layer, one of the most common types of inter-cell non-coherent joint transmission is promising and successful transmission techniques. For URLLC, multi-TRP communication can be one of the potential enablers of high reliability. With multiple TRPs, Data packets, control packets, or both can be replicated and transmitted to the target through numerous TRPs. UEs by multiple TRPs. Various iterations of the same data packet can be received or the same control information at the same time. And it's possible that UE will be able to incorporate these into the PHY layer. Therefore, the spatial diversity gain can be achieved.

7. Conclusion

The 5G URLLC proves to be more important with respect to use cases for applications with critical-mission requirements in both industrial modernization and social life development. The emerging and stringent applications and services require connectivity with high reliability, availability and extremely low latency for their achievement. That is the connectivity anywhere, anytime. The main URLLC challenge is to achieve high reliable transmission at same time with extremely low time delay. Therefore, it is required to design novel technology concepts and approaches to increase reliability and reduce latency.

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