

Impact of Ultra-Reliable Low Latency 5G on Internet of Everything

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ABSTRACT

Wireless technology has continuously evolved to cater to new applications and services. Till now, this evolution was mainly driven by the demand for high data rates. However, requirement for next generation wireless technology is much more than just high data rates. It is estimated that by 2025 there will be 25 billion wireless connections connecting people and things. This Internet of Everything (IoE) will continuously capture and exchange data. It will also be highly intelligent to aid quick decision making and to deliver high quality services. To achieve this, the underlying communication technology will have to be extremely reliable and should provide very low latency.

3GPP is working towards 5G technology, which is expected to be launched in 2020. Apart from supporting high data rates, it will also enable large scale IoE connectivity and extremely low latency applications. With 5G as the communication technology, AI enabled platforms can collect, exchange and store relevant data and can deliver more efficient products and services. This interworking of 5G and AI has the potential to bring a new era of intelligent connectivity that can drastically change our lives.

In this study, we have done systematic literature review of ultra-reliability and low latency (uRLLC) feature of 5G. We present an overview of uRLLC and also discuss some use cases of how 5G, AI and IoE can interwork to improve the lives of rural and urban population especially in important areas like Agriculture, Healthcare, Education and Transport.

Keywords: 5G, AI, IoE, uRLLC

1. INTRODUCTION

Mobile broadband traffic is increasing rapidly. This traffic growth is driven by new applications, services and device capabilities. Hence, providing high data throughput was the primary motivation for the evolution of wireless technology from 2G to 3G and later to 4G.

However, now there are additional requirements apart from high data rates. Today we require a technology that can provide massive connectivity along with high data rates. This technology should interconnect everything that we see around - people and things. This network is called Internet of Everything (IoE). It is estimated that by 2025 there will be 25 billion connections (GSMA, 2018b). This network will also be extremely intelligent, will aid in quick decision-making, and will deliver high quality services and applications. To achieve this, the underlying communication technology should be extremely reliable and should be capable of providing very low end-to-end latency.

3GPP is working towards 5G technology, which is expected to be launched in 2020. Apart from supporting bandwidth intensive content, 5G will also enable large-scale IoE connectivity and lower latency applications compared to existing wireless technologies.

In this paper, we present an overview of Ultra-Reliable Low Latency Communication (URLLC) feature of 5G. We also discuss the techniques used in 5G to achieve URLLC requirements. We then present some use cases of how URLLC, AI and IoE can interwork to improve the effectiveness and efficiency of some important areas like Agriculture, Healthcare, Education and Transport.

2. LITERATURE REVIEW

5G supports three broad categories of services namely eMBB, URLLC, and mMTC (Fig. 1). In this paper we focus on URLLC which is a very challenging feature because high reliability and low latency are conflicting requirements. For example, to achieve high reliability,

additional coding bits are added and robust retransmission schemes are deployed. However, these methods increase latency. Similarly, to reduce latency, coding should be minimal and retransmissions should be reduced.

However, this can increase packet error rates thereby reducing reliability. Hence, it is necessary to come up with a different approach to achieve both high reliability and low latency simultaneously.

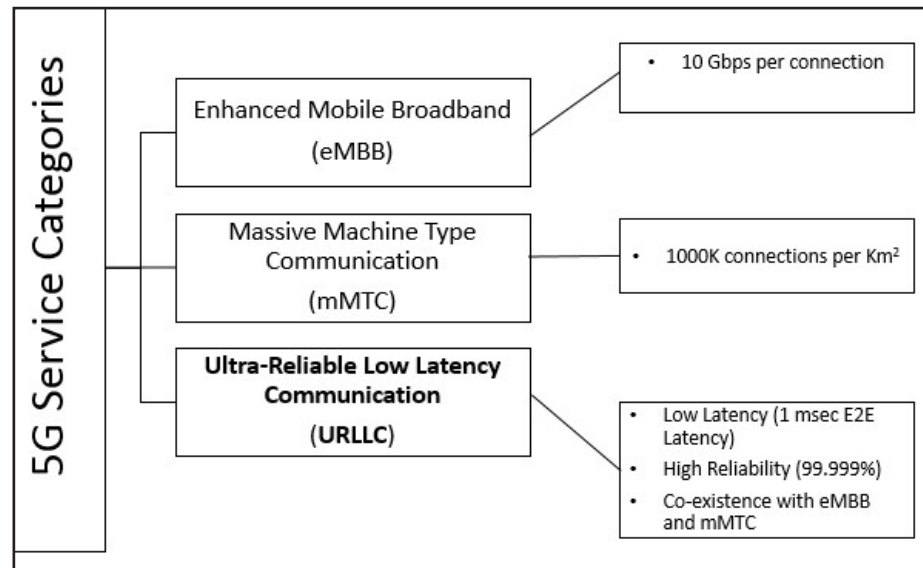


Fig. 1: 5G Service Categories

(Ji, et al., 2018) have explained URLLC Service requirements in detail. Physical layer enhancements required to achieve URLLC requirements are explained in (3GPP TR 38.824, 2018). In (Chen, et al., 2017) and (5G Americas, 2018), the authors discuss a few possible latency reduction measures. They also talk about emerging use cases, design challenges, and potential approaches in the design of URLLC communications.

Network operators and device manufacturers are accelerating the adoption of 5G URLLC for different use cases. Implementation of some interesting use cases in transportation and healthcare are detailed in (Qualcomm, 2019), (AUTO Connected Car News, 2019), (Enride, 2019) and (Donkin, 2019).

3. OBJECTIVE OF THE PAPER

We have done systematic study of URLLC and its technical requirements from existing literature. The purpose of this paper is to summarize the concept of URLLC and to highlight some methods that can help achieve URLLC requirements. We also discuss some implementation challenges of these methods. We then present a few use

cases of URLLC that have the potential to transform our lives.

4. ULTRA-RELIABLE LOW LATENCY COMMUNICATION

URLLC is a service category defined in 5G to support delay sensitive mission-critical services. These services require very high reliability or very low latency or both at the same time.

4.1 Latency Requirement

As per ITU recommendations (ITU, 2018), E2E latency for URLLC services should not exceed 1msec. To meet this requirement, 3GPP has set the average U-plane latency for URLLC services to be less than 0.5msec (3GPP TR 38.913, 2017). U-plane latency refers to the time from when application data enters Layer 2/Layer 3 in the transmitter to the time when the data reaches Layer 2/Layer 3 in the receiver successfully. The main contributors of U-plane latency are shown in Fig. 2.

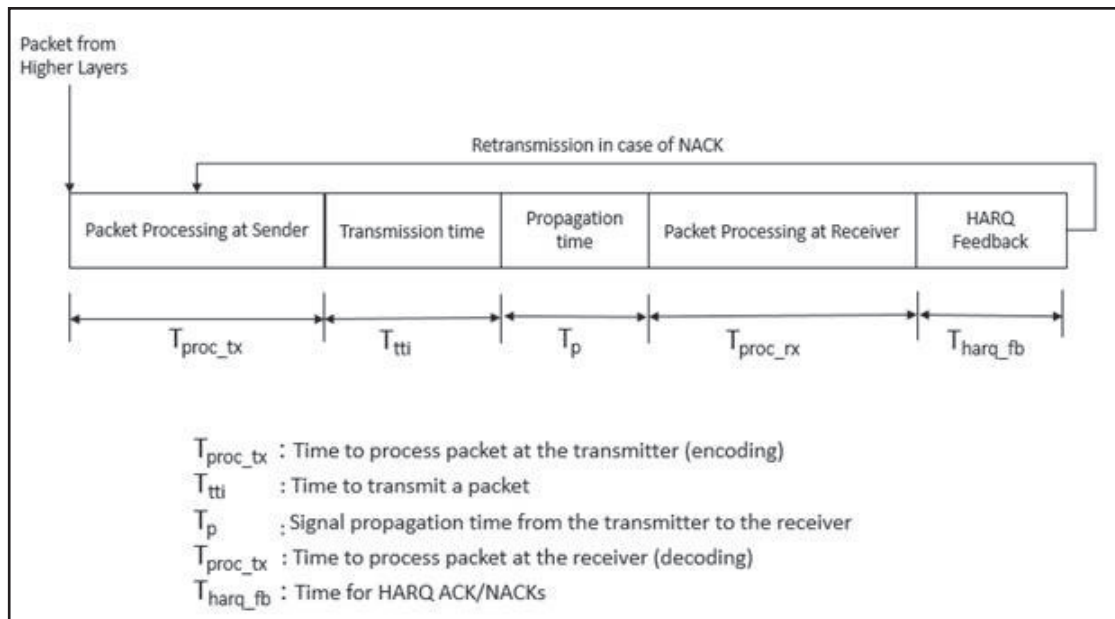


Fig. 2: U-Plane Latency

Apart from this, initial control message exchange (resource requests, grants) before data transmission also adds to delays. Some techniques used to reduce U-plane latency are explained in (3GPP TR 23.725, 2018) and (Bennis, Debbah, & Poor, 2018) and are listed below.

4.1.1 Advanced Channel Coding Schemes

5G uses LDPC coding for U-plane as against Turbo coding that is used in LTE (Khan & Roy, 2013). In both Turbo and LDPC, decoding is done iteratively. The accuracy of decoding improves with each iteration. However, the number of iterations in Turbo code is fixed which means the time spent in decoding is fixed irrespective of the probability of error. In LDPC, the decoder can stop the iterations when a legal code word is found. Hence, decoding time for LDPC is shorter when the channel conditions are good. When channel conditions are poor, number of iterations required will be higher and can be configured based on the latency requirement of the application. This provides a trade-off between the required bit error performance and latency. In addition, LDPC decoders are parallel in nature while Turbo decoders are serial in nature. This allows LDPC to support low latency applications in a better way than Turbo codes.

4.1.2 Shorter TTI

TTI is the periodicity at which a Transport Block is transferred by physical layer on the radio interface. In LTE each TTI is 1msec long corresponding to 14 OFDM symbols (normal cyclic prefix) with a subcarrier spacing of 15kHz.

In 5G, sub-carrier spacing can be 15kHz, 30kHz, 60kHz, 120kHz or 240kHz resulting in flexible symbol durations. Increasing sub-carrier spacing results in shorter symbol durations (Fig. 3). Short symbol durations work well with mmWave (> 6GHz) where cell sizes and delay spreads are small. However, in sub-6GHz frequencies, cell sizes will be large resulting in larger delay spreads. Using smaller symbol durations in large cells can result in excessive inter-symbol interference. Hence, short symbol durations corresponding to sub-carrier spacing of 120kHz and 240kHz are applicable only to mmWave and larger symbol durations corresponding to 15kHz, 30kHz are applicable only to sub-6GHz frequencies. 60kHz can be used in both cases. For sub-6GHz, solution for reduced TTI is to use mini-slot (2-3 symbols) and slot level (7 symbols) transmission. With this, TTI for each packet can be reduced to 142, 241, and 500 μ s, respectively.

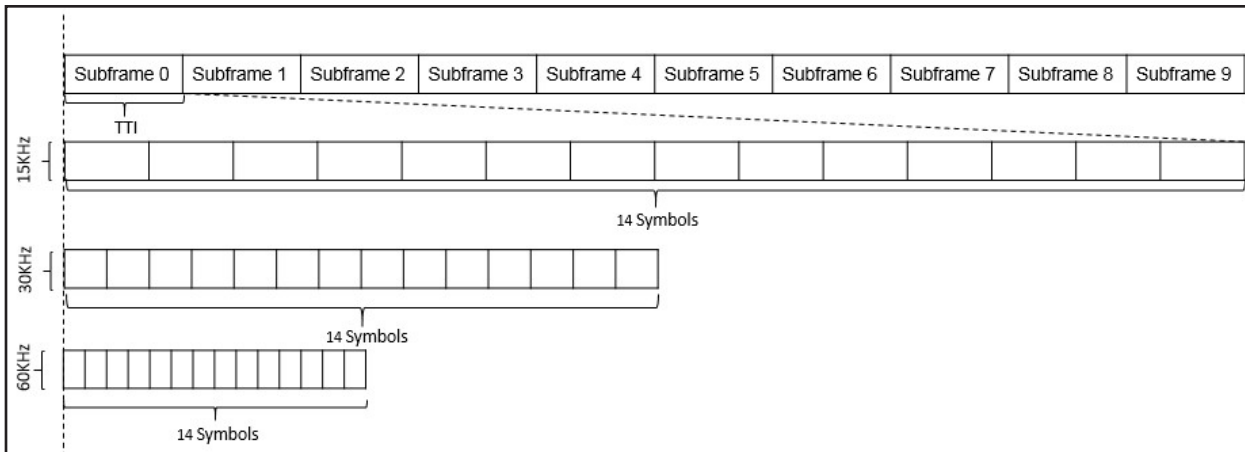


Fig. 3: Flexible Numerology

4.1.3 Faster HARQ Turn-Around Time

5G frame structure allows self-contained subframe for TDD where the DL transmission as well as the ACK/

NACK for that transmission are contained in the same subframe. In FDD also the turn-around time of HARQ ACK/NACKS and data retransmissions is made shorter (Fig. 4).

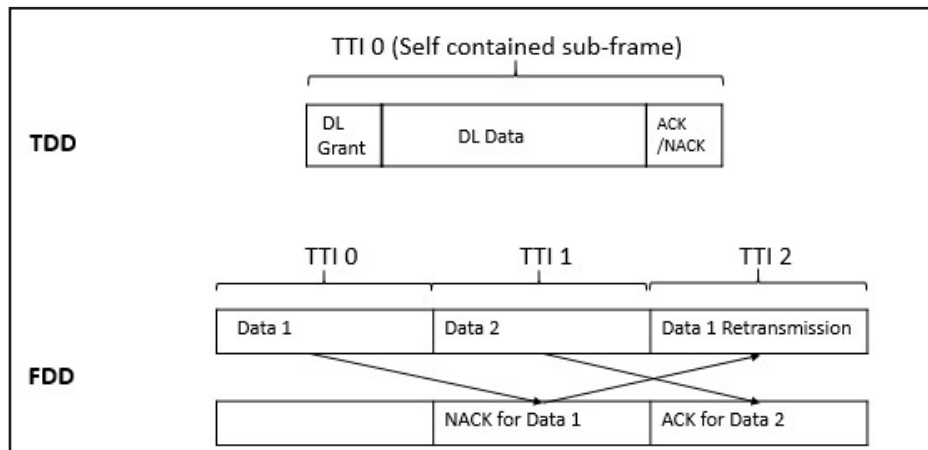


Fig. 4: Faster HARQ

4.1.4 Grant-Free Uplink Transmission

In Grant-free uplink transmissions, gNB configures periodic uplink resources for a UE. When UE has data, it can transmit on the configured resources without requesting for frequent uplink grants resulting in shorter uplink latency.

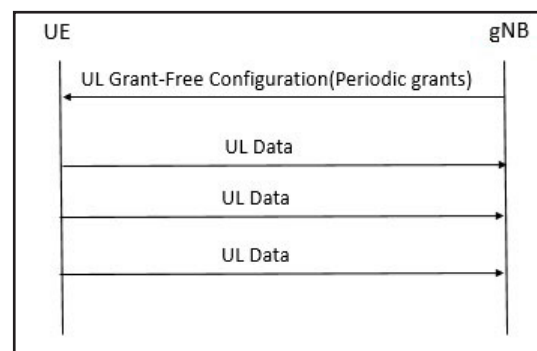


Fig. 5: Grant-Free Transmission

4.1.5 Pre-Emption

URLLC data is given higher priority over other services. When gNB receives URLLC data, it immediately transmits it by preempting ongoing eMBB transmission thus reducing latency for time critical services.



Fig. 6: Pre-Emption

4.2 Reliability Requirement

Reliability is defined as the probability of successfully transmitting and receiving a fixed size packet within a given time. The target reliability for URLLC is 99.999% in 1msec for a 32-byte packet. Some of the techniques used to achieve high reliability without affecting latency are listed below (Bennis, Debbah, & Poor, 2018).

4.2.1 Multi-Connectivity

5G supports data duplication through multiple links. Data between network and UE can be sent via multiple base stations. This increases robustness against adverse channel conditions like fading, shadowing and cell failures.

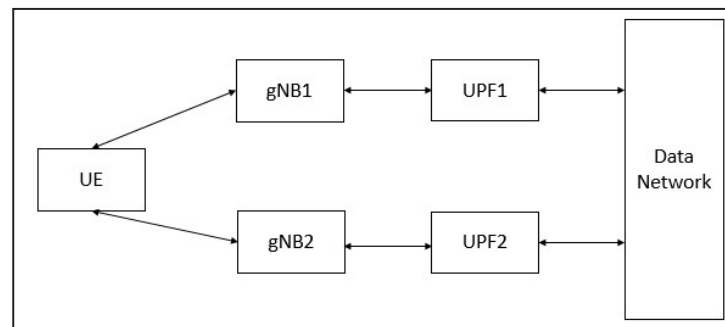
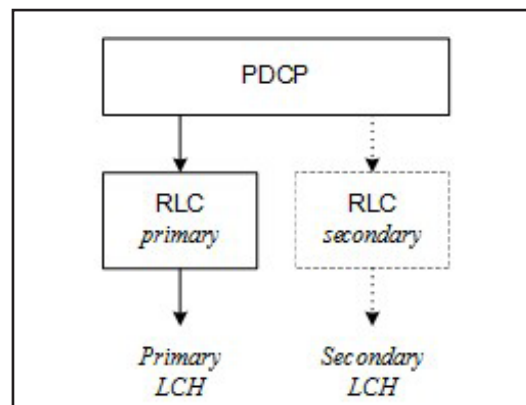


Fig. 7: Multi-Connectivity

4.2.2 Data Duplication

Data duplication at PDCP level is also supported in 5G. When duplication is configured for a radio bearer, an

additional RLC entity and an additional logical channel are added to the radio bearer to handle duplicated PDCP PDUs.

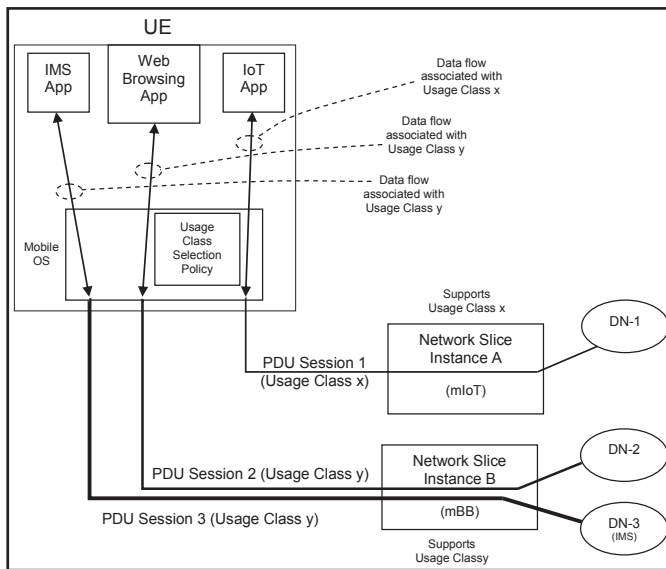


Source: 3GPP TS 38.300

Fig. 8: PDCP Duplication

4.2.3 Network Slicing

Network Slicing is the process of slicing a physical network into logical sub-networks for specific types of services. The idea is to allocate dedicated resources for each of these services. For example, one slice with stringent reliability guarantees can be allocated to mission-critical applications like V2V applications.



Source: 3GPP TR 23.799

Fig. 9: Network Slices

4.2.4 Blind Repetition

In Blind repetition or K-repetition, same data packet is sent K times without waiting for HARQ feedback. Higher layers configure redundancy version for each repetition. Frequency hopping can also be configured for these repetitions, which will further increase reliability by providing both time diversity and frequency diversity. Since the transmitting side does not wait for HARQ feedback before K-repetition, this technique improves probability of successful reception without additional latency.

4.2.5 Interference Mitigation

With massive MIMO it is possible to focus transmitted signal into very narrow beams thus reducing intra-cell interference. Network-based inter-cell coordinated scheduling will also be implemented to reduce inter-cell interference. 5G devices will also implement advanced interference cancellation receivers (MMSE-IRC or

NAICS) which will further improve signal reception and thereby improve reliability.

5. CHALLENGES

Though the methods discussed in the previous section can help achieve URLLC requirements, there are certain implementation challenges. For example, LDPC code's high error correcting capability and its potential to approach Shannon capacity limit is a key enabler for URLLC. However, computational complexity of LDPC is a critical issue especially in devices with limited battery power. A lot of research has been aimed at optimizing and reducing the complexity of LDPC decoding algorithms. Some of these techniques like early termination and forced convergence are detailed in (Sarajlic, Liu, & Edfors, 2014). Usage of short TTI also has a drawback in terms of higher overhead (CP and resource grants). This may not have any significant impact on services that require infrequent bursts of data. However, if the service requires continuous data for a long duration, the additional overhead can adversely affect the overall performance. Hence, it is important to choose the appropriate TTI duration depending on the service requirement. Similarly, the techniques used for improving reliability like K-repetition, data duplication etc. will result in inefficient use of radio resources. Pre-emption of eMBB data for URLLC services can also have adverse impact on the performance of high data rate applications. Hence, for fair co-existence of different services, network should implement intelligent and efficient scheduling algorithms that can balance the requirements of URLLC and other service categories.

6. USE CASES OF URLLC

URLLC can be an enabler for a wide range of mission-critical delay-sensitive applications. When combined with AI, it has the potential to bring about a phenomenal change in the way we work and live. A few use cases that can transform some important areas that affect rural and urban life (namely, agriculture, education, healthcare and transport) are described below.

6.1 Agriculture

Precision Farming: Agricultural productivity depends on extremely granular environmental variations that farmers cannot monitor manually. For autonomous surveillance

of fields, sensors embedded in farms can collect data on factors such as weather, sunlight, soil nutrients, water content in soil and plant health in different areas of the field. This data can be sent to Agricultural Bots. Team of robots guided by AI enabled systems will traverse the fields autonomously and perform weeding, watering, apply fertilizers and pesticides in the necessary areas (Brown, 2018). This will optimize the use of agricultural inputs (water, fertilizer, pesticides etc.) by applying just the right amount of inputs only in the areas of the field that require it.

Such autonomous operations in the field require precise and quick data exchange between all the entities (sensors, AI systems, robots). URLLC will enable this precision and speed in the field and will help create higher crop production.

6.2 Education

Primary Education: There is a severe shortage of schools in rural areas and hence many children are deprived of basic education. In addition, poor quality of teachers, low teacher-student ratio and non-availability of good learning material contribute to early school dropouts.

One solution for this is to use internet to connect teachers in urban areas to students in every village. However, this has not been very effective mainly due to high latency of existing internet connections. With 5G, connectivity to villages will be highly reliable and responsive. This can pave the way for new methods of teaching like sharing digital images, videos or even simulating real world in virtual reality. It will also be possible for teachers and students to perform science experiments interactively. These methods can make education very interactive and immersive and will encourage more and more students to go to school.

Enhanced Training: 5G based AR and VR simulations can be used for vocational training where artisans, trainee engineers and mechanics could be taught the necessary skills for their jobs. Highly reliable and responsive 5G connectivity will enable trainees to see, hear and feel the exact hand movements of the instructor. Instructors can also feel the trainee's movements and correct them when necessary (GSMA, 2018a).

6.3 Healthcare

Telemedicine: Availability of timely professional healthcare is also a challenge in rural areas. There aren't enough primary healthcare centers in many villages. 5G enabled wellness monitors or kiosks can improve primary healthcare drastically. People in villages can approach their nearest kiosk, which will collect their vital signs and connect them to qualified doctors in cities. Doctor can perform remote physical examination with full audio-visual feedback and can provide remote consultation (Stefano & Kream, 2018).

Tele-Surgeries: Tele-surgery requires extremely low latency and high reliability, which existing technologies cannot guarantee. With URLLC, it will be possible for surgeons to carry out remote procedures using specialized robots with great precision. At MWC2019, the first tele-mentored surgery over a 5G connection was demonstrated with a renowned medical expert advising an in-theatre surgeon in near real time (Donkin, 2019).

6.4 Transport

Road Safety: URLLC based V2X communication can be used for road safety applications like collision warning, collision avoidance etc. Vehicles can exchange information with each other about their speed, location, trajectory, road conditions, traffic congestion etc. This data can help neighboring vehicles to take informed decisions. For these applications to be effective, communication between all traffic entities (vehicles, infrastructure, pedestrians) should be almost instantaneous. Even a millisecond delay can lead to fatality. Hence 5G URLLC based V2X will be better equipped than technologies like DSRC and LTE to enable road safety applications. At CES2019, a use case of how vehicles can co-operate autonomously in a non-signalized intersection was demonstrated (Qualcomm, 2019). Many network operators are also adopting URLLC for road safety applications (AUTO Connected Car News, 2019).

Intelligent Public Transport: Fleet of buses can exchange real-time information about traffic pattern, road conditions etc. so that the entire fleet can take autonomous decisions regarding optimized routes leading to better schedule management. Real-time information regarding number of

commuters in each location can also help the fleet operator take quick decisions about adding or reducing buses in different routes thereby improving commuter experience and optimizing operational costs. In MWC2019, an implementation of 5G-connected transportation solution was demonstrated that improves user-experience and work environment for operators remote-controlling fleets of autonomous vehicles (Enride, 2019).

7. URLLC PERFORMANCE

Field trials are currently being done to evaluate the performance of URLLC. In (Liu, Guangyi, 2018) U-plane latency was measured for 32-byte packets using short TTI and grant-free transmissions. It was observed that U-plane latency was around 0.5msec for a 32-byte packet and around 1msec for a 1500-byte packet. An interesting

observation in these measurements is that SINR had almost no impact on U-plane latency (Table 1).

Table 1: Latency vs. SINR

SINR	U-Plane Latency (msec)
Bad	0.5
Medium	0.5
Good	< 0.5
Perfect	0.5

(NTT DoCoMo, 2018) presents the results of tests carried out using 20MHz bandwidth in 4.5GHz band. Trials were carried out with both stationary and moving vehicles. Results showed that the URLLC requirements of latency and reliability were met both in stationary and mobility scenarios for different packet sizes.

Table 2: Latency and Reliability Measurements

Test Vehicle Speed	Packet Size (Bytes)	Distance from gNB	U-Plane Latency	Successful Transmission Rate
0Kmph (stationary)	200	0.33 Km	0.5 to 0.7 msec	99.999 to 100 %
	200	0.8 Km		
	100	1.0 Km		
25Kmph	100	0.3 to 0.6 Km		

8. CONCLUSION

5G URLLC is expected to be a game changer for mission-critical delay sensitive applications. As compared to existing technologies like LTE, 5G provides better performance in terms of scaling, latency and reliability. This will enable large scale IoE connectivity and extremely low latency applications. It can be used not only for sophisticated applications like autonomous cars, but also for some very basic human needs like education and healthcare. When combined with AI, 5G has the potential to bring a new era of intelligent connectivity that can drastically improve the quality of our lives.

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GLOSSARY

Term	Expansion
3GPP	Third Generation Partnership Project
AI	Artificial Intelligence
AR	Augmented Reality
DSRC	Dedicated short-range communication
eMBB	Enhanced Mobile Broadband
E2E	End-to-End
FDD	Frequency Division Duplex
gNB	Next Generation Node B
HARQ	Hybrid Automatic Repeat Request
IoE	Internet of Everything
ITU	International Telecommunication Union
LDPC	Low-density parity-check
MIMO	Multiple Input Multiple Output
mMTC	Massive Machine Type Communication
MMSE-IRC	Minimum Mean Square Error – Interference Rejection Combining

Term	Expansion
NAICS	Network Assisted Interference Cancellation and Suppression
PDCP	Packet Data Convergence Protocol
PDU	Protocol Data Unit
PUCCH	Packet Uplink Control Channel
RLC	Radio Link Control
SINR	Signal to Interference Plus Noise Ratio
TDD	Time Division Duplex
TTI	Transmission Time Interval
UE	User Equipment
UPF	User Plane Function
URLLC	Ultra-Reliable Low Latency Communication
VR	Virtual Reality
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything