URLLC Service for LTE Radio Access Networks

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Abstract

Recently, ultra-reliable and low-latency communications (URLLC) service has been proposed for 5G networks. URLLC service requires hard guarantees for reliability and latency, the two main key performance indicators (KPIs) for networks. For radio access networks (RANs), the major challenge for the service provider, i.e., the base station, is to meet those stringent QoS requirements for the user with the worst wireless channel quality. In this paper, we explore if the current existing LTE network, i.e., hardware and PHY layer protocols, can support the QoS requirements of URLLC services.

1. Introduction

Ultra-reliable and low-latency communications (URLLC) service has been proposed for 5G networks [1] [2] [3] [4] [5] [6]. At first look, URLLC service emphasizes on reliability and latency which might seems similar to the existing QoS classes. However, if we explore the details, URLLC requires hard guarantees for reliability and latency. Hence, the major challenge for the service provider in the Radio Access Network (RAN), i.e., the base station, is to meet those stringent QoS requirements for the user with the worst wireless channel quality. In this paper, we explore if the current existing LTE networks can support the QoS requirements of URLLC services.

Previously, the hardware and PHY layer modulation and coding schemes for RANs was the bottleneck for reliability, latency and throughput, which are the major key performance indicators (KPIs) for network performance [7]. In the past decade, many advances have been made in signal processing and modulation and coding schemes which enables technologies such as Multiple Input Multiple Output (MIMO), Error Correction Codes (ECC). Hence, the bottleneck becomes the resource allocation and scheduling in the MAC layer [1] [4].

2. QoS Requirements for URLLC

Latency requirement: the service latency at PHY layer consists of the following five components:

$$T = T_{Tx} + T_P + T_C + T_R + T_S \ , \qquad (1)$$

where T_{Tx} is the time required to transmit a packet, T_P is the signal propagation time from the transmitter to the receiver, T_C is the time to perform the encoding and decoding, and also the channel estimation, T_R is the time caused by the retransmission, and T_S is the pre-processing time for the signaling exchange and control such as connection request, scheduling, channel training and feedback, and queuing delay.

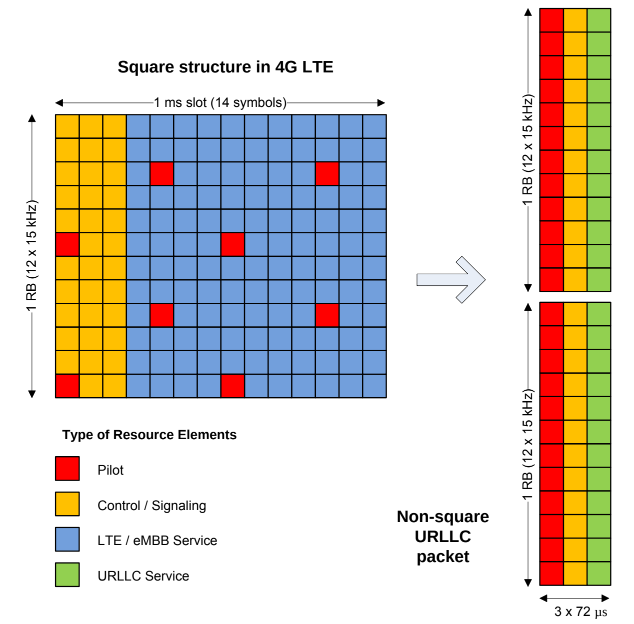

Fig. 1: LTE frame structure versus URLLC packet [1].

In 3GPP release 14, it is stated that the average latency of URLLC (from L2/L3 ingress to egress) should be less than 0.5 milliseconds [6], i.e.,

$$T \leq 0.5 \text{ ms} \ , \qquad (2)$$

Hence, existing LTE frames cannot support the URLLC service due to the structure of LTE resource blocks (RBs) [1] as shown in Fig. 1. To meet this stringent latency constraint, the packet transmission time should be in the order of hundreds of microseconds.

Reliability requirement: In 4G LTE systems, typical reliability for a packet transmission is 0.99 (packet error rate, $P^e_{\mathrm{pkt}} \le 10^{-2}$). In contrast, URLLC services require ultra-reliability, i.e., the target reliability within 1 ms period should be at least 0.99999 [5], i.e.,

$$P^e_{\mathrm{pkt}} \le 10^{-5} \quad (3)$$

Packet error rate is a function of bit error rate given as:

$$P^e_{\mathrm{pkt}} = 1 - (1 - P^e_{\mathrm{bit}})^N, \text{ and } P^e_{\mathrm{bit}} = 1 - (1 - P^e_{\mathrm{pkt}})^{1/N}, \quad (4)$$

where N is the number of bits in the packet. From (4), we can clearly see that bigger packet will lead to higher packet error rate. In order to meet the QoS requirements of URLLC service, it is necessary to redesign the resource allocation at MAC layer [1] [4].

3. Packet Structure of URLLC

To reduce the transmission time T_{Tx} of the current 4G LTE systems from 1 ms, a new frame structure for URLLC is proposed as shown in Fig. 1 [1]. Governed by the strict latency constraint, the packet structure resembles a long rectangle whose long side resides in frequency domain. Furthermore, the latency from channel estimation and feedback can cause a bottleneck, and hence, URLLC may require a transmission scheme that does not rely on channel information.

Next, we analyze the reliability of the packet structure. The target reliability for URLLC is given in (3). Given that, there is no changes in PHY hardware (i.e. base numerology of 5G new radio), there can be $\lfloor 1\ \mathrm{ms}/216\ \mu\mathrm{s} \rfloor = 4$ transmissions in 1 ms [1] [6]. From (4), we get $P^e_{\mathrm{bit}} \le 6.944 \times 10^{-8}$. Then, we plot Fig. 2 which shows the feasible reliability region with respect to different modulation schemes.

4. ECC and MIMO for URLLC

In traditional IP networks such as LTE, high reliability is achieved in a layered approach where each layer has its only reliability mechanism. For instance, PHY layer has ECC, (such as Turbo and convolution code), every MAC layer packet carries a cyclic redundancy check (CRC) field for error detection and Transport layer uses Hybrid Automatic Repeat Request (HARQ). However, due to the stringent latency requirement in URLLC service, the reliability mechanism on the upper layer cannot be used anymore.

Hence, the PHY layer must carry out the required ultra-reliability. Hence, the advanced channel coding scheme and error correction codes are essential for URLLC service. Existing 4G LTE systems use two types of approaches. The first type is the channel coding scheme (Turbo and convolution code) with cyclic redundancy check (CRC) attachment for the large-sized packet [1]. The second type is to use a simple code (the repetition and Reed-Muller code) without CRC attachment for the small-sized packet [1].

In contrast, 5G New Radio system has adopted Polar code and low density parity check (LDPC) code (a type of orthogonal space time block code (OSTBC)) for the enhancement of control and data channel, respectively [1][5][6].

Fig. 3 shows the bit error rate versus the signal to interference plus noise ratio (SINR) of 4-QAM modulation with OSTBC codes. From Fig. 3, we can see that ultra-reliability can be achieved around 19 dB without MIMO [7]. With 2x2 MIMO, which is currently the SINR requirement decreases to approximately 13 dB [7]. 4x4 MIMO has been proposed in 5G New Radio and is expected to further decrease the SINR requirement.

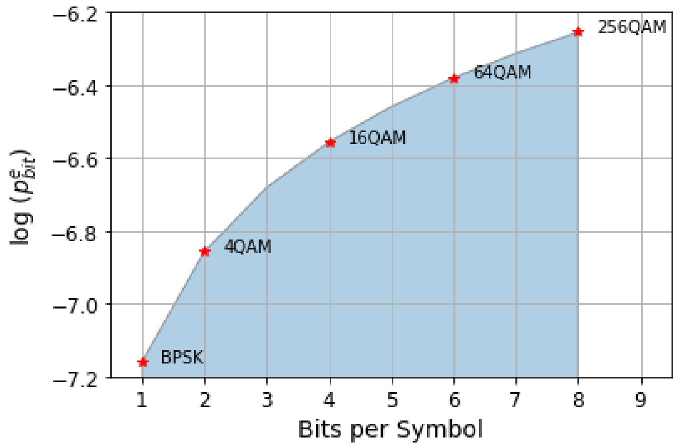

Fig. 2: Bit error rate versus bits per symbol

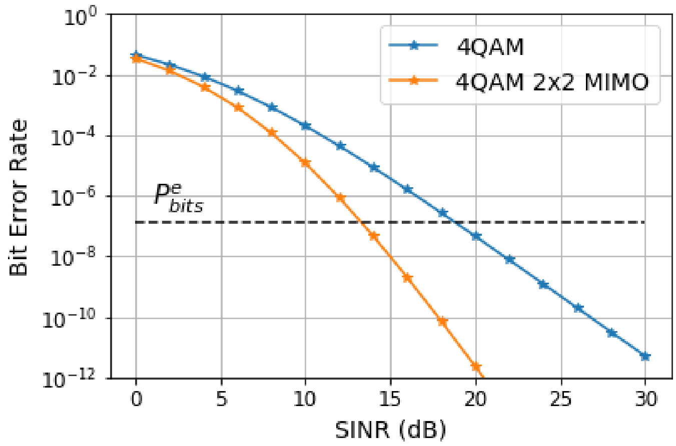

Fig. 3: BER of 4-QAM modulation with orthogonal STBC over exponentially correlated Rayleigh fading MIMO channels as a function of SINR

5. Conclusion

In this paper, we considered URLLC service for LTE radio access networks and its implications. Due to the stringent requirements for low latency, a new packet structure was proposed at MAC layer. The packet payload size is also limited to meet the ultra-reliability requirement which must be met at the PHY layer due to the low-latency constraint. We perform some numerical analysis to explore the feasibility of the URLLC service in existing LTE networks. Our analysis results show that URLLC service is indeed possible. In our future work, we will explore the optimal scheduling for URLLC traffic coexisting with enhanced Mobile Broadband (eMBB) traffic.

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