Resource Scheduling of URLLC/eMBB traffics in 5G New Radio: A Punctured Scheduling Approach

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Abstract

Ultra Reliable Low Latency Communications (URLLC) is a new service in 5G wireless networks to accommodate applications and services having strict reliability and latency requirements such as industrial IoT, autonomous vehicles, and virtual reality. Thus, the main objective of URLLC is to achieve low latency while ensuring high reliability. In this paper, the download resource scheduling of URLLC and enhanced Mobile Broad Band (eMBB) for non-orthogonal slicing is tackled. The objective is to assign the resources dynamically to eMBB and URLLC traffics such that the eMBB users data rate is maximized while satisfying the URLLC requirements. To this end, the problem of resource scheduling is formulated as a convex optimization problem of which objective is to maximize the sum data rates of all eMBB users under the URLLC constraints. The simulation results validate the proposed model.

1. Introduction

The upcoming Fifth Generation (5G) New Radio (NR) is designed to support three different types of traffic, *i.e.* enhanced Mobile Broad Band (eMBB), massive Machine Type Communications (mMTC) and Ultra Reliable Low Latency Communications (URLLC), allowing various devices with different characteristics and requirements to communicate through the cellular networks. eMBB is an extension of the LTE-Advanced service which objective is to maximize the peak data rate. mMTC is designed to support a large number of Internet of things (IoT) devices. The mMTC IoT devices send a small data sporadically during the active phase only. URLLC is designed to support services that require high level of reliability and low latency [1].

According to the Third Generation Partnership Project (3GPP), the main objective of URLLC is to minimize the latency (less than $0.5ms$) while ensuring high reliability (*i.e.* with a bit error rate less than 10^{-5}). These requirements are critical for some applications such as industrial IoT, autonomous vehicles, and virtual reality [2].

The first approach to support the three services in 5G wireless networks is the orthogonal slicing. In this approach, different slices (communication resources) are allocated to each service to satisfy the requirements of each service. The allocated slices (resources) are orthogonal in the frequency-time and there is no interference between these services [3, 4]. The main drawback of this approach is an inefficient use of the resources.

Th second approach is to share the resources between the different services (non-orthogonal slicing). Reusing the resources in non-orthogonal slicing increases the spectral efficiency but causes interference among the different traffics [5, 6, 7].

In this paper, the download resource scheduling of URLLC and eMBB for non-orthogonal slicing is tackled. Each time slot is divided into minislots with the length of $0.125ms$ [2, 8]. The arrived URLLC traffic scheduled immediately in the next minislot to satisfy the URLLC latency requirements. The frequency resources are allocated dynamically to eMBB and URLLC traffics such that the eMBB user's data rate is maximized while satisfying the URLLC reliability requirements. To this end, the problem of resource allocation is formulated as an optimization problem which objective is to maximize the sum data rates of all eMBB users under the URLLC reliability constraint which is a probabilistic constraint (chance constraint).

The remaining parts of this paper are organized as follows: section 2 presents the system model. In this section, the resource scheduling problem is formulated as an optimization problem with chance constraint and transformed into deterministic form. Section 3 introduces the simulation results. The sum data rate of eMBB users is illustrated with different reliability levels of URLLC. Finally, section 4 concludes the paper.

2. System Model and Problem Formulation

In this model, the time is divided into equally spaced slots with one millisecond time duration as that in the current cellular networks. The eMBB traffic shares the bandwidth over time-frequency in each slot and these shares are solved at the beginning of each slot and fixed during that slot. The stochastic downlink URLLC traffic may arrive during the time slot which already allocated to different eMBB users. We cannot delay the URLLC traffic into the next slot due to the latency constraint of URLLC traffic. Instead, each time slot is divided into minislots with duration of 0.125 ms and the arrived URLLC traffic scheduled immediately in the next minislot as shown in Fig. 1. Therefore, dividing each slot into minislots ensures the latency constraint of URLLC traffic. The Base Station (BS) allocates zero power

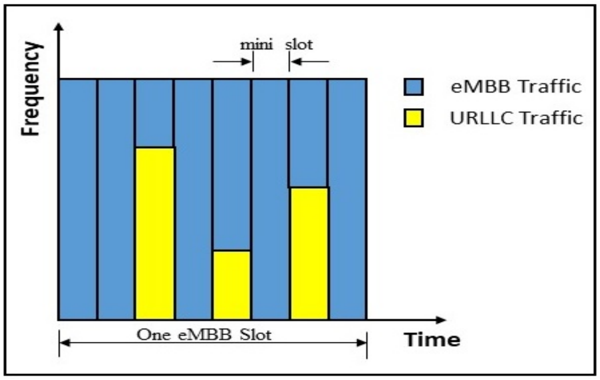

Figure 1: Puncturing approach for multiplexing of URLLC and eMBB

to the eMBB transmissions overlapped with URLLC traffic (puncturing) [9, 10].

We assume that the resource scheduling among the eMBB devices has been resolved prior to the time slot [11]. Allocating frequency resources to URLLC traffic in each slot impacts the data rate of eMBB users on that slot. Thus, our objective is to minimize the impacted eMBB data rate while satisfying the URLLC reliability constraint. We assume that the impacted rate of eMBB traffic is proportional to the punctured resources by the URLLC traffic. Therefore the data rate of the eMBB users is given by:

$$R_{eMBB} = \sum_{i=1}^{n} (b_i - f_{ui}) \log_2(1 + SNR_i) \quad (1)$$

where b_i is the resources allocated to eMBB user i in one slot, f_{ui} is the punctured resources from eMBB user i due to URLLC traffic, SNR is the signal to noise ratio of eMBB user and n is the number of eMBB users.

Let D be a random variable denoting the URLLC load. Then, the outage probability of URLLC can be agiven as follows:

$$P(E) = P[\sum_{j=1}^{m} f_{uj} \log_2(1 + SNR_u) < D] \leq \epsilon \quad (2)$$

Where ϵ takes a small value and denotes the maximum allowed outage probability (*i.e.* reliability level on URLLC traffic), and m is the number of minislots.

The objective is to assign frequency resources in each minislot to the URLLC traffic, when arriving, such that the impacted eMBB users is minimized while satisfying the URLLC constraints. This can be formulated as the following optimization problem:

$$\begin{aligned} \underset{f_u}{\text{Maximize}} \quad & \sum_{i=1}^{n} (b_i - f_{ui}) \log_2(1 + SNR_i) \\ \text{subject to} \quad & P[\sum_{j=1}^{m} f_{uj} \log_2(1 + SNR_u) < D] \leq \epsilon, \\ & \sum_{j=1}^{m} f_{uj} \leq B. \end{aligned} \quad (3)$$

The first constraint represents the reliability constraint and the second constraint ensures that the total resources allocated to URLLC traffic is less than the total number of available resources B.

This optimization problem contains a probability constraint (chance constraint). Then, We can transofrm it into a deteminstic form usign the Cumulative Distribution Function (CDF) of the random variable D. Therefore, the reliablity constraint can be written as follows:

$$\begin{aligned} P(E) &= P[D > \sum_{j=1}^{m} f_{uj} \log_2(1 + SNR)] \leq \epsilon \\ &= 1 - F_D(\sum_{j=1}^{m} f_{uj} \log_2(1 + SNR)) \leq \epsilon \\ &= \sum_{j=1}^{m} f_{uj} \log_2(1 + SNR) \geq F_D^{-1}(1 - \epsilon) \end{aligned} \quad (4)$$

Where $F_D(x)$ is the Cumulative Distribution Function (CDF) of D.

Therefore, the optimization problem can be written as follows:

$$\begin{aligned} \underset{f_u}{\text{Maximize}} \quad & \sum_{i=1}^{n} (b_i - f_{ui}) \log_2(1 + SNR_i) \\ \text{subject to} \quad & \sum_{j=1}^{m} f_{uj} \log_2(1 + SNR) \geq F_D^{-1}(1 - \epsilon), \\ & \sum_{j=1}^{m} f_{uj} \leq B. \end{aligned} \quad (5)$$

We consider that the URLLC load D follows the Pareto Distribution. The CDF of Pareto distribution is given by:

$$F(x) = P(X \leq x) = 1 - (\frac{x_m}{x})^{\alpha}, \quad for x \geq x_m \quad (6)$$

Where x_m is the minimum value of X, and α is a positive number.

Accordingly, we achieve the following optimization problem:

$$\begin{aligned} \underset{f_u}{\text{Maximize}} \quad & \sum_{i=1}^{n} (b_i - f_{ui}) \log_2(1 + SNR_i) \\ \text{subject to} \quad & (\sum_{j=1}^{m} f_{uj} \log_2(1 + SNR))^{\alpha} \geq \frac{x_m^{\alpha}}{\epsilon}, \\ & \sum_{j=1}^{m} f_{uj} \leq B. \end{aligned} \quad (7)$$

Setting $\alpha = 1$ gives a convex optimization problem. Thus, we can easily solve it using any convex optimization algorithm.

3. Simulations

In this section, we present simulation results of the proposed model. A system with a total bandwidth of 100 MHz is considered. The URLLC traffic is generated from Pareto Distribution with $\alpha = 1$. The optimization problem, which is a convex optimization problem, is solved using cvxpy.

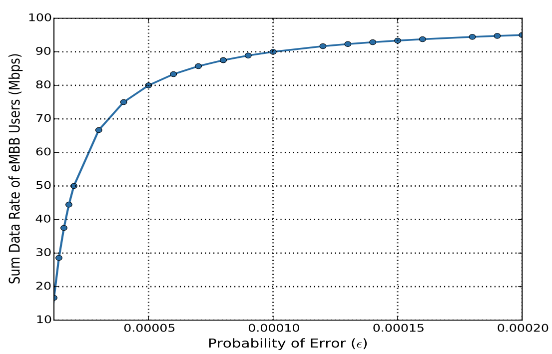

Figure 2: Sum data rates of eMBB users with different reliability levels of URLLC traffic (ϵ)

Fig. 2 shows the sum data rate of all eMBB users with probability of error (ϵ) of URLLC traffic (*i.e.* reliability level of URLLC traffic). The increase in the probability of error of URLLC traffic causes decrease the reliability of URLLC traffic and this increases the total data rate of eMBB users as shown in Fig. 2. As the objective of the proposed optimization problem is to maximize the total eMBB data rate under the reliability constraint of URLLC traffic then increasing the probability of error of URLLC traffic leads to decrease the reliability constraint of URLLC traffic and this means that the constraint of the optimization problem is relaxed.

4. Conclusion

In this paper, we have considered that the URLLC traffic is dynamically multiplexed through puncturing the eMBB resources. We have formulated the problem of resource scheduling of URLLC and eMBB traffic as an optimization problem with chance constraint. The Cumulative Distribution Function (CDF) of the URLLC load, which is a random variable, has been used in order to transform the problem into an optimization problem with deterministic constraints. The results show that the URLLC traffic with high-reliability level impacts the data rate of eMBB users.

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