Puncturing Scheme for the Coexistence of URLLC and EMBB Networks

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Abstract

International telecommunication union (ITU) has defined new wireless services for the fifth -generation (5G) known as 5G-new radio (5G-NR). These 5G-NR services include enhanced mobile broadband (EMBB), ultra-reliable and low-latency communication (URLLC), and massive machine type communication (MMTC). Among these services, the coexistence of URLLC and EMBB services on the same spectrum is a challenge. This paper uses the puncturing scheme to schedule the URLLC packets on the pre-existing EMBB traffic. We formulate the optimization problem to optimize the efficient puncturing scheme to reduce the EMBB loss. Simulation results are drawn to show the impact of puncturing on the EMBB traffic.

I. INTRODUCTION

As a result of massive technological revolutions in the future mobile networks, the communication demands have been changing. This is due to the emergence of diverse applications for industrial development, vehicular communication and massive IoT deployments. To address these challenges, certain research dimensions have been introduced in 5G including LTE-U [1], NOMA [2], and 5G-NR [3]. To meet these variety of communication demands, ITU has introduced three main classification of future mobile services. These mobile services consist of ultra-reliable and low latency communication (URLLC), enhanced mobile broadband (EMBB) and massive machine type communication (MMTC) [4]. Among these 5G services, URLLC is applicable to event driven, mission critical, and industrial applications. Therefore, 5G is aiming to increase URLLC as one of the new service categories of 5G-NR. URLLC tries to meet the challenges of low latency and high reliability which are difficult to be accomplished simultaneously in current wireless network implementations. The standard URLLC requirements needed to be achieved are the latency requirement of 0.25-0.3 ms/packet and the reliability requirement of up to 99.999% successful packet delivery [4].

EMBB tries to enhance the overall network rate by improving the spectral efficiency while utilizing retransmissions to meet the stringent reliability demands at the cost of additional allocated resources. On the other hand, URLLC focuses on meeting the latency and reliability requirements. Therefore, the coexistence of EMBB and URLLC to meet URLLC requirements while maximizing the achievable EMBB rate is a challenge. As URLLC latency constraints restrain from using the retransmission options, meeting the opposing demands of high reliability under the strict latency constraints is a challenge in URLLC. To ensure the reliability, small packets with reliability overhead is to be carried which results in penalizing the spectrum efficiency as well as latency. In summary, the URLLC and EMBB coexistence is facing two opposing challenges which are needed to be balanced efficiently.

The main reason of reliability losses in current LTE system is erroneous channel estimation. Therefore, reliability for URLLC can be improved by improving channel estimation correction. This can be done by improving the control signaling mechanism for better channel estimation. One proposal to the problem of meeting such demands simultaneously is to reduce the packet size in URLLC which can result in meeting reliability constraints in given latency at the cost of less achievable rates. Moreover, spatial diversity can be used for better URLLC reliability by using multiple transmitters to send duplicate URLLC packets. As a result, the required reliability can be achieved at the cost of achievable rates [5].

For the coexistence scenarios of URLLC and EMBB, 3GPP has proposed a framework for the multiplexing/coexistence of both traffics. Such coexistence framework contains the puncturing scheme [4]. The puncturing scheme refers to the scheduling of URLLC traffic only in a mini slot and during that mini slot, EMBB communication is paused. In this paper,

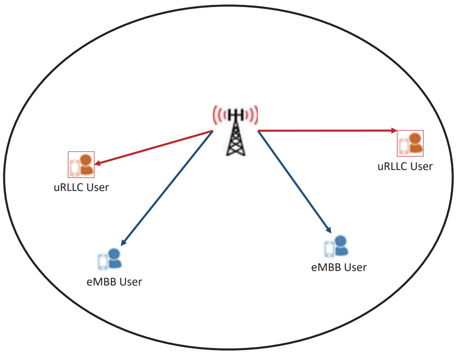

Fig. 1. System model of URLLC and EMBB coexistence network.

we implemented the puncturing scheme for the coexistence of URLLC and EMBB users on the same channel. We formulate the optimization problem to maximize the EMBB rate under URLLC reliability constraints.

The remaining of the paper is organized as follows. Section II discusses the system model followed by URLLC and EMBB communication models. In Section III, we formulate the optimization problem and demonstrate the solution. Section IV presents the numerical results and Section V concludes the paper.

II. System Model

The system model consists of a cellular network containing a single macro base-station (MBS) and two set of associated URLLC and EMBB users. The set of URLLC users is denoted by $\mathcal{L} = \{1, 2, 3, \ldots, L\}$. The set of EMBB users is denoted by $\mathcal{B} = \{1, 2, 3, \ldots, B\}$. Both of the networks are using the same unlicensed spectrum consisting of a set of channels denoted by $\mathcal{C} = \{1, 2, 3, \ldots, C\}$ where each channel $c \in \mathcal{C}$ has a bandwidth of f kHz.

It can be seen from the Fig. 1 that both URLLC and EMBB users are scheduled on the same channel for the downlink communication in a cellular network. It is obvious that the arrival of URLLC traffic will affect the communication of EMBB users.

A. URLLC Model

We have considered a single MBS cellular network, therefore, the cellular users are not facing any interference from the neighboring communication networks. The finite block length rate for the URLLC users is given as follows [5]:

$$R_l(\epsilon_l, p_l, m_l) = \log(1 + p_l g_l) - \sqrt{\frac{1}{m_l}\left(1 - \frac{1}{(\sigma + p_l g_l + 1)^2}\right)}\frac{Q^{-1}(\epsilon_l)}{\ln 2}, \quad (1)$$

where P_l is denoting the downlink power from the MBS to the URLLC, user $l \in \mathcal{L}$, g_l is denoting the channel gain, and σ is denoting the noise level. ϵ_l and m_l is denoting the error probability and packet size of URLLC user l, respectively. Q^{-1} is denoting the inverse Q function.

B. EMBB Model

We consider that EMBB users are already allocated the bandwidth f and power P_b resources using a standard LTE resource allocation scheme. The power and channel allocation to the EMBB users is performed to maintain certain signal to interference and noise ration (SINR) level for every user. This is done according to the distance of EMBB users from the central BS. If an EMBB user b is closer to the BS, less power P_b is allocated to that user and vice versa. The Shannon capacity for the corresponding EMBB user rate on the RB of bandwidth f is given as follows:

$$R_b = f \log(1 + \frac{P_b g_b}{\sigma^2}), \quad (2)$$

where, f is denoting the bandwidth of channel. P_b, and g_b denote the power and channel gain for the EMBB user b.

III. Problem Formulation

In order to provide the communication services to both of the EMBB and URLLC networks, we consider the scheduling of EMBB users already performed by the network operator. On the other hand, URLLC users are punctured on the pre-allocated EMBB users based on the arrival of URLLC transmission requests. Therefore, we formulate the optimization problem to maximize the EMBB data transmission subject to the URLLC reliability constraint.

$$\max_{\boldsymbol{p}} \sum_{b \in \mathcal{B}} (f - \sum_{l \in \mathcal{L}} I(.)) \log(1 + \frac{P_b g_b}{N_0}), \quad (3)$$

$$\text{s.t.} \quad R_l(\epsilon_l, p_l, m_l) \geq \epsilon_u, \quad \forall u \in \mathcal{U}, k \in \mathcal{K}, \quad (3a)$$

$$p_l \geq 0, \quad \forall u \in \mathcal{U}, j \in \mathcal{J}. \quad (3b)$$

where $I(.)$ is denoting the indicator function which represents the count of URLLC packet requests. The factor $f - \sum_{l \in \mathcal{L}} I(.)$ is representing the bandwidth available to the EMBB users after URLLC allocation through puncturing. It can be seen that the problem is concave and easy to solve for the power allocation P_l to the URLLC users. As the problem (3) is a constrained maximization problem, therefore the solution lies on the boundary of the constraint (3a). Therefore, optimal power allocation can be performed by solving the following equation.

$$R_l(\epsilon_l, p_l, m_l) = \epsilon_u. \quad (4)$$

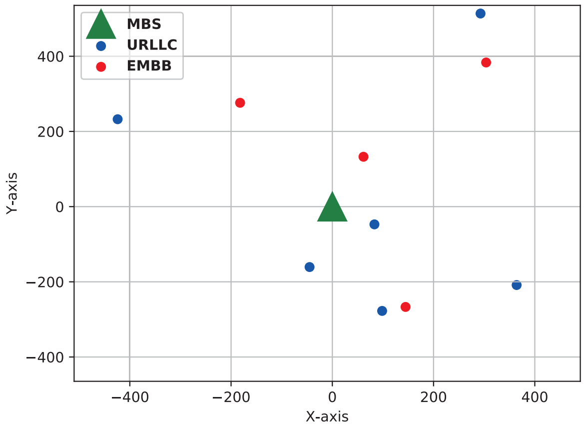

Fig. 2. Network topology

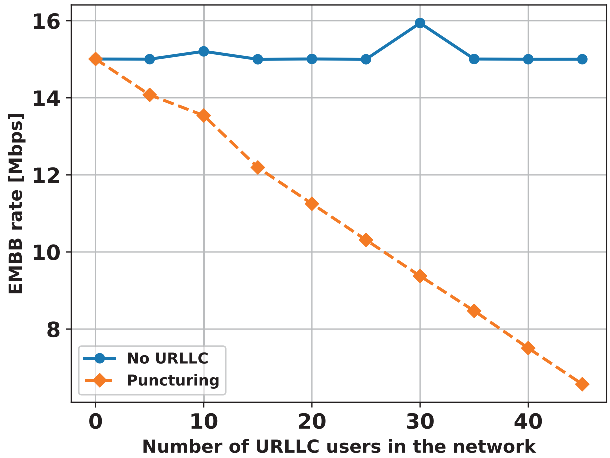

Fig. 3. Plot of WiFi throughput vs. the Wi-Fi duty-cycle

The same distance-based mechanism for power allocation to the URLLC users is adopted as explained before for the EMBB users. In this mechanism, the users closer to the BS are allocated less transmission power and vice versa.

IV. Numerical Results

In this section, we present the simulation results for the proposed puncturing scheme. Using the Python programming language, we built the network topology consisting of up to 50 URLLC users. We made the simulations for a number of runs and took average to show the results. The number of EMBB users are fixed in the network. Fig. 2 shows the snapshot of the network topology consisting of a central BS and multiple URLLC and EMBB users uniformly deployed in the geographical area of the cell.

Fig. 3 shows the plot of EMBB rate against the increasing number of URLLC users in the network. We compared the puncturing scheme with the No URLLC case. In the No URLLC case, no URLLC allocation is performed and all the network resources are given to the EMBB users. It can be seen that No URLLC users case has almost constant EMBB rate. On the other hand, in the puncturing scheme there is significant decrease in the EMBB rate as the number of URLLC users are increased in the network. This is due to the fact that the channel resources are allocated to the URLLC users to meet the reliability constraints. As a result, EMBB rate is significantly reduced.

V. Conclusion

In this paper we adapted the puncturing scheme to deploy the URLLC transmission on the underlay EMBB traffic. To do this, we have formulated the optimization problem where EMBB rate is maximized under the reliability constraints of the URLLC users. Simulation results showed that the rate of EMBB users is significantly reduced by using the puncturing scheme. In the future work, we will use the superposition scheme where both URLLC and EMBB users will be communicated simultaneously on the same channel by utilizing the non-orthogonal multiple access scheme.

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