Coexistence of eMBB and uRLLC in 5G Wireless Networks
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Abstract
Emerging 5G systems need to support diversified services with varied requirements, and ultra-reliable and low latency communication (uRLLC), massive machine-type communication (mMTC), and enhanced mobile broadband (eMBB) are some of the major user cases. Among these, uRLLC and eMBB will share the same physical resources, and hence, need a good coexistence mechanism. In this paper, we propose an effective coexistence mechanism for eMBB and uRLLC users for 5G wireless network. Effectiveness of the proposed method is represented through simulation results.

1. Introduction
With the explosive trends of mobile traffic [1], the wireless industries are also experiencing diverse set of emerging applications and services. The mobile application market is expected to grow in a cumulative average growth rate (CAGR) of 29.1% in the estimated period 2015-2020 [2]. The requirements of these applications and services are different in terms of energy efficiency, latency, reliability, data rate etc. For handling these diversified requirements, International Telecommunication Union (ITU) has already listed 5G services into three prime categories: ultra-reliable and low latency communication (uRLLC), massive machine-type communication (mMTC), and enhanced mobile broadband (eMBB) [3]. uRLLC traffic requires very high reliability (99.999%) with extremely low delay (0.25~0.30 ms/packet), whereas mMTC needs high connection density with better energy efficiency, and eMBB expects gigabit per second level data rates [4].

Generally, eMBB devices produce the major portion of wireless traffic. But the uRLLC traffic is sporadic in nature and hence, need to serve instantaneously. For resolving this issue, the simplest way is to reserve some time/frequency resources for uRLLC transmission. But this may cause under-utilization of radio resources. Therefore, it is necessary to coexist eMBB and uRLLC traffic in the same resource and 3GPP has already proposed superposition/puncturing framework for multiplexing these two traffic in 5G cellular system [4]. To meet the latency requirement of uRLLC traffic, two time units namely slot (1 ms) and mini-slot (0.125 ms) are identified in 5G new radio (NR) proposal. The scheduling for eMBB traffic is made at the beginning of a slot and remains fixed during the slot. Thus, the uRLLC traffics are overlapped onto scheduled eMBB transmission at each mini-slot boundary if they use the same physical resources. Therefore, superposition mechanism is almost impossible for uRLLC to provide high reliability, and hence, puncturing mechanism can be used for providing high priority and high reliability of uRLLC.

Recently, resource sharing has attracted a lots of attention for providing quality of experience (QoE) to the users in different areas. Authors of [5] and [6] talk about sharing of unlicensed spectrum between LTE and WiFi systems whereas the authors of [7] speak about sharing of resources between LTE-A and NB-IoT. The effective resource sharing between eMBB and uRLLC are discussed in the works [8] and [9]. In the work [8], the authors propose a dynamic puncturing of uRLLC traffic inside eMBB traffic for increasing the resource utilization. The authors formulate a joint scheduling between eMBB and uRLLC in the paper [9]. Specifically, they introduce linear, convex and threshold models for throughput loss of eMBB users.

In this paper, we propose an effective coexistence mechanism for eMBB and uRLLC users working under same
small-cell base station (SBS) while satisfying diversified requirements. The paper consists of Section 2, 3, and 4 where system model and problem formulation, solution approach and performance evaluation are discussed respectively. Finally, the paper is concluded in Section 5.

2. System Model and Problem Formulation

Our deployment scenario consists of one small-cell base station (SBS), a set of active eMBB users $E$ and a set of uRLLC users $U$ working in downlink mode. SBS has a set of licensed resource block $L$ of bandwidth $B$ for supporting eMBB and uRLLC services. One slot is divided into $M$ mini-slots for providing low latency services. We consider $T$ time slots $\delta = 0.001s$ for eMBB users.

At the beginning of each time slot $t$, BS allocates the physical resources to the eMBB users. If SBS allocates a RB $k$ to eMBB user $i \in E$ then the achievable rate of that user is as follows:

$$r_{i,k}^t = 6B \log_2(1 + \gamma_{i,t})$$  \hspace{1cm} (1)

where $\gamma_{i,t}^f$ is the signal-to-noise ratio (SNR) and $\gamma_{i,t}^f = \frac{P_i h_i^2}{N_0 B}$.

The symbols $P_i$ and $h_i$ are transmission power of SBS for user $i$, gain of user $i$ from SBS respectively, and $N_0$ is the noise spectral density. Generally, eMBB users need more RSBS for satisfying its’ gigabit requirements and hence, the user $i$ can obtain the following rate at time slot $t$:

$$r_{i}^t = \sum_{k=1}^{M} a_{i,k}^t r_{i,k}^t$$  \hspace{1cm} (2)

where $\alpha$ is the resource allocation vector of the SBS for it’s eMBB users at $t$ and $a_{i,k}^t = 1$ if SBS allocates RB $k$ for user $i \in E$ at time slot $t$, $a_{i,k}^t = 0$ otherwise.

Now due to the aperiodic nature of uRLLC traffic, it can reach at any time of within time slot $t$. If SBS use puncturing technique for serving uRLLC traffic then eMBB user $i \in E$ will surely lose some data at this slot. For calculating the losses occurred to user $i$, we use linear model as proposed in [9]. Thus, eMBB user $i$ loses an amount as follows:

$$r_{i}^{t,\text{loss}} = \sum_{k=1}^{M} a_{i,k}^t \sum_{u \in U} (a_{u,k}^t = \beta_{u,k}^m)$$  \hspace{1cm} (3)

where $\beta$ is the resource allocation vector for uRLLC users and $\beta_{u,k}^m = 1$ if SBS allocates RB $k$ for uRLLC user $u \in U$ at mini-slot $m \in M$, $\beta_{u,k}^m = 0$ otherwise.

Hence the actual rate achieved by eMBB user $i$ in time slot $t$ is as follows:

$$r_{i}^{t,\text{actual}} = r_{i}^t - r_{i}^{t,\text{loss}}$$  \hspace{1cm} (4)

Now our goal is to maximize the achieved rate of every eMBB user over the time period while satisfying almost every uRLLC request within their expected time period. For this purpose, we formulate an optimization problem as follows:

$$\begin{align*}
\max & \left( \min \left( \mathbb{E}(\sum_{t=1}^{T} r_{i}^{t,\text{actual}}) \right) \right), \text{for all } i \in E \\
n\text{s.t. } & c1: P(\sum_{u \in U} S_u > 1 - \varepsilon), \text{for all } m \text{ and } t \\
& c2: s(t) \leq \gamma_u \text{ for all } u \in U
\end{align*}$$  \hspace{1cm} (5)

Here, constraint $c1$ ensures that almost every uRLLC request is served irrespective of mini-slot and slot, whereas constraint $c2$ ensures the service time of every uRLLC request is within stipulated time period. This problem (5) is NP-hard due to the aperiodic nature of uRLLC traffic over the time slots.

3. Solution of the Problem

eMBB users are scheduled in the beginning of every time slot and uRLLC are allocated resources in every mini-slot. So for fulfilling the goal of problem (5), SBS can decide the allocation of resources to the uRLLC users in time slot $t$ depending upon the expected results till $t - 1$ slots. SBS can make a preference list (PL) for time slot $t$ of eMBB users based upon the ascending expected achieved rate till $t - 1$ as shown follows:

$$\text{PL}^t = \mathbb{E}(\sum_{i=1}^{E} r_{i}^{t,\text{actual}}), \text{for all } i \in E$$  \hspace{1cm} (6)

When uRLLC requests for services within the time slot $t$, SBS immediately follow $\text{PL}^t$ to take RBs from eMBB users to satisfy uRLLC users.
4. Performance Evaluation

We assess the performance of the proposed method by using MATLAB simulation. The SBS assumes to have 10 active eMBB users and maximum 30 uRLLC users. The SBS supports it’s users using 50 traditional LTE RBs for 50 time slots. Each time slot is divided into 8 mini-slot for supporting uRLLC users and a subset of uRLLC users are randomly active in every mini-slot. We use $15.3 + 37.5 \log_{10}(d_m)$ as path loss model for eMBB users where $d_m$ is the distance between SBS and the respective eMBB user. SBS employs 21 dBm power for each eMBB user. We compare empirical cumulative distribution function (ECDF) of minimum achieved rate and fairness among the eMBB users between the proposed and random (uRLLC users use RB from randomly chosen eMBB users) approaches after running the program 1000 times and show in Fig. 2 and Fig. 3 respectively. Fig. 2 shows that the proposed method give better minimum achieved rate than the random approach. Specifically, the proposed approach provides at least 250 Mbps in 80% of cases, whereas the random approach gives the same in less than 40% of cases. Fig. 3 shows that the fairness of the proposed method is better than the random approach. Precisely, the proposed approach gives fairness score better than 0.9 in more than 70% of cases, where the random approach give similar scores in less than 50% of cases.

5. Conclusion

In this paper, we propose a coexistence mechanism between eMBB and uRLLC users for upcoming 5G network. Simulation results show that the proposed approach is better than the random approach. We want to use machine learning for getting better allocation scheme in future.

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