

# Utilization of Unlicensed Spectrum in Effective Coexistence of eMBB and uRLLC

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## Abstract

In the emerging 5G mobile network, ultra-reliable low-latency communication (uRLLC) and enhanced mobile broadband (eMBB) are two influential service classes. The coexistence of uRLLC and eMBB services on the same radio resource leads to a challenging scheduling problem because of the trade-off among latency, reliability and spectral efficiency. In this paper, a puncturing scheme based coexistence approach between uRLLC and eMBB traffic is proposed for the upcoming 5G mobile networks, while eMBB users are supported by additional unlicensed spectrum resources. We present two heuristic algorithms to resolve the resource allocation problems of eMBB and uRLLC users. Simulation results show the benefits of the proposed approach over other baseline methods in terms of the minimum achieved rate and fairness among eMBB users.

## 1. Introduction

Due to the evolution of different applications and services like virtual reality (VR), augmented reality (AR), autonomous cars, smart cities and factories, smart grids, remote medical diagnosis, unmanned aerial vehicles (UAV), artificial intelligence (AI) based personal assistants, sensing, metering, monitoring etc., wireless industries are already enduring lots of stress ahead of 5G era. The obligations of these applications and services are diverse in terms of data rate, energy efficiency, latency, reliability etc. International Telecommunication Union (ITU) has already listed 5G services into enhanced mobile broadband (eMBB), ultra-reliable and low latency communication (uRLLC), massive machine-type communication (mMTC) for managing their diversified requirements [1]. The first two are the major service class where eMBB requires gigabit level data rate in second and uRLLC needs very high reliability (99.999%) with extremely low delay (0.25 ~ 0.30 ms/packet)[2]. Generally, the major portion of wireless mobile traffic are contributed by eMBB users and uRLLC traffics need to be served promptly. Moreover, uRLLC traffic is sporadic in nature. To serve these two traffics, the simplest way is to use separate resource or heterogeneous orthogonal multiple access (H-OMA)[3]. But this may cause under-utilization of valuable radio resources, and thus, requires a dynamic multiplexing of different traffics.

Recently, resource sharing has drawn a lot of consideration for granting quality-of-service (QoS) or quality-of-experience (QoE) for the emerging services and it is also an important pillar in 5G new radio (NR). The authors of papers [4], [5], [6], [7] use game theory for sharing unlicensed spectrum between LTE-U and Wi-Fi systems, whereas the authors of [8] use ruin theory for sharing the same resources. The authors of [9], [10], [11] use puncturing technique for eMBB and uRLLC coexistence in the same physical resources. However, these puncturing based coexistence schemes cause performance loss for the eMBB users. For providing constant data rate to the eMBB users, we propose a coexistence mechanism between eMBB and uRLLC users with the help

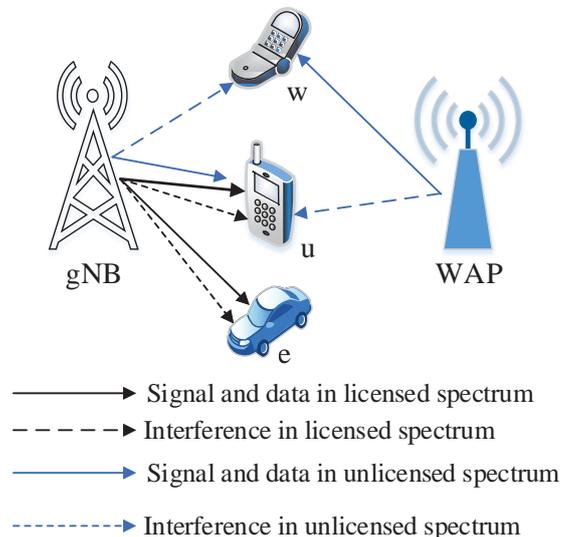


Figure 1: Illustration of the system model

of unlicensed spectrum. Specifically, loss rate of eMBB users will be recovered by utilizing unlicensed resource while considering the coexistence issue with Wi-Fi system.

## 2. System Model and Problem Formulation

Our deployment scenario consists of one next generation base station (gNB), a set of Wi-Fi access point (WAP) working in downlink mode for its users. gNB has a set of active eMBB users  $\mathcal{E}$  and a set of uRLLC users  $\mathcal{U}$ , whereas each WAP is serving a set of its users  $\mathcal{W}_i$ . For supporting eMBB and uRLLC users, gNB has a set of licensed resource blocks (RBs)  $\mathcal{L}$  of uniform bandwidth  $B$ . We assume both gNB and WAPs are working under same unlicensed band whenever necessary. gNB utilize traditional LTE time slot for eMBB users, whereas it uses mini-slot for supporting uRLLC users. Each time slot  $\Delta$  is divided into  $M$  mini-slots of length  $\delta$ . We assume that uRLLC traffics arrive at

the gNB in any mini-slot  $m$  of time slot  $t$  for uRLCC users follows Gaussian distribution,  $U \sim \mathcal{N}(\mu, \sigma^2)$ , where  $\mu$  and  $\sigma^2$  are the mean and variance of the distribution, referred to as uRLLC arrival rate with fixed payload size of 32 Bytes each.

gNB allocates RBs to the eMBB users at the beginning of each time slot  $t$ . If gNB allocates a RB  $l \in \mathcal{L}$  to the eMBB user  $e \in \mathcal{E}$  at this current time slot  $t$  then the achievable rate of that user is as follows:

$$r_{e,l}^t = \Delta B \log_2(1 + \gamma_{e,l}^t) \quad (1)$$

where  $\gamma_{e,l}^t$  is the signal-to-noise ratio (SNR). Usually, gNB allocates many RBs to eMBB users for meeting high data demand and hence, the achieved rate:

$$r_{e,ls}^t = \sum_{l \in \mathcal{L}} \alpha_{e,l}^t r_{e,l}^t \quad (2)$$

where  $\alpha$  is the licensed resource allocation vector of the gNB for the eMBB users, and  $\alpha_{e,l}^t = 1$  if gNB allocates RB  $l$  for the eMBB user  $e$  at time slot  $t$ ,  $\alpha_{e,l}^t = 0$  otherwise.

Due to the latency requirements of the uRLLC traffic, it needs to be served immediately and puncturing technique can be a feasible way to do that. Thus, the achieved rate of uRLLC user  $u \in \mathcal{U}$  at mini-slot  $m$  of time slot  $t$  is as follows:

$$r_{u,ls}^{m,t} = \sum_{l \in \mathcal{L}} \theta_{u,l}^{m,t} r_{u,l}^{m,t} \quad (3)$$

where  $\theta$  is the resource allocation vector for uRLLC users and  $r_{u,l}^{m,t} = \delta B \log_2(1 + \gamma_{u,l}^{m,t})$ . However, one RB is enough for serving small payload size of uRLLC users.

But this effort will surely cause performance loss to the eMBB user  $e$  if uRLLC traffics are punctured within its RB(s). To provide the guaranteed data rate to the eMBB users, gNB can utilize unlicensed spectrum with the licensed one whenever necessary. But this will cause severe problem to the Wi-Fi users in that locality who are already using the same unlicensed band. For ensuring a fair coexistence between LTE-U and Wi-Fi systems, we have a optimal time sharing solution in one of our work [5] as follows:

$$t^* = \frac{1}{2} + \frac{R_W^{min}}{2R_W^{max}} \quad (4)$$

where  $R_W^{min}$  is the deliverable rate for a WAP when both WAPs and gNB use the same unlicensed band and  $R_W^{max}$  represents the same rate when only WAPs use the band. Thus, gNB can use  $1 - t^*$  time in any time slot  $t$  of the unlicensed band for maintaining similar rate of the eMBB users. For managing the unlicensed resource efficiently, gNB divides the band into a set  $\mathcal{K}$  of similar bandwidth of  $B$ . Thus, the effective achieved rate of eMBB user  $e \in \mathcal{E}$  at time slot  $t$  is as follows:

$$r_e^t = r_{e,ls}^t - r_{e,loss}^t + r_{e,us}^t \quad (5)$$

where  $r_{e,loss}^t = \frac{r_{e,ls}^t}{M} \sum_{l \in \mathcal{L}} \sum_{m=1}^M \sum_{u \in \mathcal{U}} \mathbb{I}(\alpha_{e,k}^t == \theta_{u,l}^{m,t})$  and  $r_{e,us}^t = (1 - t^*) \sum_{k \in \mathcal{K}} \beta_{e,k}^t r_{e,k}^t$  with  $\beta$  represents the unlicensed RBs allocation for the eMBB users.

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**Algorithm 1:** Resource Allocation for eMBBUsers in time slot  $t$

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**Input:**  $\mathcal{E}, U, t^*, \mathcal{L}, \mathcal{K}$

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1 if  $t == 1$  then
2   Compute  $r_{e,1}^t$  for each  $e \in \mathcal{E}$  by using (1);
3   for each  $e \in \mathcal{E}$  do
4     Compute  $N_{RB}^{ls} = \frac{Maxvalue - r_{e,1}^t}{\sum_{e \in \mathcal{E}} Maxvalue - r_{e,1}^t} \cdot |\mathcal{L}|$ ;
5     Update  $\alpha$  based on  $N_{RB}^{ls}$ ;
6   end
7 end
8 else
9   Compute  $r_{e,loss}$  for every  $e \in \mathcal{E}$ ;
10  for each  $e \in \mathcal{E}$  do
11    Compute  $N_{RB}^{us} = \frac{r_{e,loss}}{\sum_{e \in \mathcal{E}} r_{e,loss}} \cdot |\mathcal{K}|$ ;
12    Update  $\beta$  based on  $N_{RB}^{us}$ ;
13  end
14 end
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Now our intention is to maximize the delivered rate of every eMBB user over the time period while serving almost every uRLLC traffic within their stringent latency constraint. Hence, we formulate an optimization problem as follows:

$$\max_{\alpha, \theta, \beta} (\min_{e \in \mathcal{E}} (\mathbb{E} (\sum_{t=1}^{T_{max}} r_e^t))) \quad (6)$$

$$\text{s.t. uRLLC constraints} \quad (6a)$$

$$\text{Resource allocation constraints} \quad (6b)$$

The optimization in (6) is a combinatorial programming (CP) problem with randomness and time, which is NP-hard and cannot be solved in real time.

### 3. Solution Approach of (6)

For solving the problem (6) in each time slot  $t$ , we propose a heuristic solution as shown in the Algorithm 1. We use Algorithm 2 for allocating resource to the uRLLC users in any mini-slot  $m$ .

### 4. Performance Evaluation

We assume that gNB is located in the center of an area of radius 200 m and users are distributed randomly in the coverage area of the gNB. gNB operates on 10 MHz licensed band and sharing 20 MHz traditional unlicensed band with WAPs. We also assume that each uRLLC user requires single licensed RB for its operation. Moreover, gNB uses free space propagation path-loss model with Rayleigh fading for eMBB users. We verify the performance of the system based on the minimum achieved rate and fairness among eMBB users. The major simulation parameters for the gNB are shown in Table 1. We compare the performance of the proposed scheme with Random (uRLLC users are served by picking RBs randomly from eMBB users) and Equal (uRLLC users are served by

**Algorithm 2:** Resource Allocation for uRLLC Users in mini-slot  $m$  of time slot  $t$

**Input:**  $\alpha, U, \mathcal{E}$

- 1 Compute  $N_{e, RB}^{ls}$  for each  $e \in \mathcal{E}$  from the allocation vector  $\alpha$  and sort it in descending order;
- 2 Compute  $N_u^e = U \div |\mathcal{E}|$ ;
- 3 Allocate  $N_u^e$  RBs from each of eMBB users and update  $\theta$ ;
- 4 Set  $u=1, i=1$ ;
- 5 **while**  $u \leq (U \bmod |\mathcal{E}|)$  **do**
- 6     Select  $e$  as  $i$  eMBB user from  $N_{e, RB}^{ls}$ ;
- 7     Update  $\beta$  based on  $e$  for  $u$ ;
- 8     Update  $u = u + 1$  and  $i = i + 1$ ;
- 9 **end**

Table I: Value of the principal simulation parameters

Symbol	Value	Symbol	Value
$ \mathcal{E} $	10	$ \mathcal{L} $	50
$T_{max}$	1000	$M$	8
$\Delta$	1ms	$\delta$	0.125 ms
$P_e, \forall e$	21 dBm	$N_0$	-114 dBm
$B$	180KHz	$ \mathcal{K} $	100
$\sigma$	2	W	5

equally picking RBs from the eMBB users) mechanism after taking 1000 runs for all the methods.

Figure 2a represents the minimum achieved rate of eMBB users using empirical cumulative distribution function (ECDF) among different methods considering  $\sigma = 5$ . The proposed method provides better minimum achieved rate for the eMBB users as shown from the ECDF of Figure 2a. Moreover, the proposed and Equal approaches provide minimum rate of 15 Mbps in 95.4% and 85.8% cases, respectively, while Random approach offers minimum of below 5 Mbps all the time. Moreover, the proposed method offers 9% and 89.95% more minimum rate to the eMBB users on average than Equal and Random methods, respectively.

Figure 2b shows a comparison of fairness scores among eMBB users for different approaches. The fairness scores of the proposed approach are better than that of the Equal and Random approaches. The median of the fairness scores are 0.9895, 0.9394, and 0.6971 for the proposed, Equal and Random approaches as shown in Figure 2b. Moreover, the proposed approach is 5.06% and 27.22% more fairer than the Equal and Random approaches, respectively.

## 5. Conclusion

In this paper, we have proposed a novel approach that enables uRLLC and eMBB users to coexist in the same radio resource for 5G wireless networks. We formulated the problem as maximizing the minimum expected achieved rate

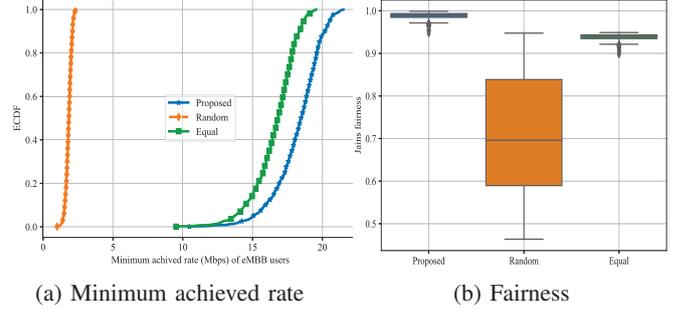


Figure 2: Comparison of a) minimum achieved rate of eMBB users, and b) fairness among eMBB users

of the eMBB users while meeting the uRLLC requirements and solved with the heuristic algorithm considering the presence of unlicensed spectrum. Simulation results show that the proposed approach gives a better minimum expected achieved rate and fairness for eMBB users compared with the other methods.

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