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Radio Control Optimization for Enhanced QoS-based Spectrum Selection in Heterogeneous 5G Environments with eMBB and uRLLC

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Abstract: 5G mobile networks provide two main uses: enhanced mobile broadband (eMBB) and ultra-reliable low-latency communications (uRLLC) are two critical services. While eMBB focuses on maximum data rate, uRLLC prioritizes latency and reliability. However, sharing radio resources between these two use cases creates a complex planning problem due to the trade-off between these different factors. Our proposal introduces an efficient control strategy that optimizes the use of licensed and unlicensed radio resources across various services i.e., eMBB with guaranteed bit rate (eMBB-GBR) and uRLLC ensuring that the traffic requirements of each service are met. The main objective of the proposed control strategy is to maximize the utilization of resources by ensuring the availability of resources, reducing delays, and achieving high throughput. The simulation results clearly show the superiority of the proposed algorithm compared to the reference scheme. This significantly improves the performance of the network by improving the utilization of resources, reducing latency service, increasing the rate of successful packets, and reducing the probability of blocking. The algorithm shows significant improvements, particularly with an 8%, 22%, and 28 % increase in effective capacity for the eMBB-GBR service compared to the reference approaches when the session arrival rate is 1.2. In addition, it significantly reduces the probability of session drops for eMBB-GBR service by about 0.05, 0.12, and 0.17 compared to the reference approaches. Moreover, the proposed control strategy has a significant relative latency for uRLLC service of 13%, 21 %, and 26% compared to reference approaches when URLLC density is around 1000 UEs.

Keywords: Resource scheduling, 5G cellular networks, eMBB, uRLLC, Unlicensed spectrum.

1. Introduction

The rapid developments in mobile networks have driven extensive research to meet to the diverse requirements of upcoming mobile technologies [1]. New 5G system generations have arisen, supporting various use cases with various communication requirements [2-4], as depicted in Fig. 1. The design of 5G networks requires flexible approaches to meet the evolving service requirements of diverse vertical applications. A critical aspect of mobile networks is the licensed spectrum, which is regulated and allocated to specific mobile operators. With the continuous growth of connected devices and mobile data traffic, the demand for licensed spectrum has increased, which may lead to radio resource shortages in the future. The limitations on licensed radio resources present significant challenges to mobile phone operators and network designers. In densely populated urban areas and during periods of peak usage, licensed radio resources can become congested, reducing network performance and data transfer rates.

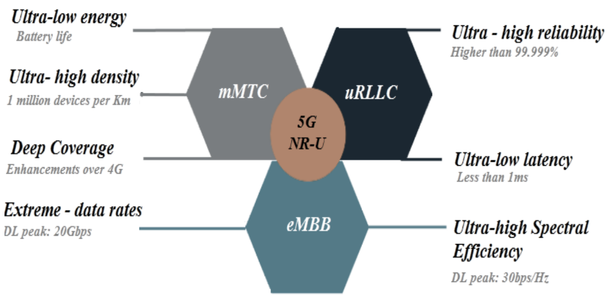

Figure. 1 5G NR heterogeneous usage scenarios

Additionally, in certain scenarios, the allocated licensed frequency may not be sufficient to meet the growing demand for high-speed data services, especially in applications that require low latency and high data rates. A highly promising solution in addressing QoS challenges and spectrum shortages for diverse 5G services, including reliability, latency, and capacity, is the adoption of new radio unlicensed access to 5G radio spectrum, known as NR-U [5]. NR-U uses a carrier aggregation of secondary unlicensed spectrum and licensed NR operators, enabling seamless offloading of traffic in scenarios where high data rates, low latency, and superior reliability are required.

The allocation of unlicensed radio resources among diverse services becomes a crucial concern as heterogeneous networks with 5G NR cellular and Wi-Fi coexistence gain attention [6]. By dividing radio resources at various levels, radio resource management (RRM) services can be essential in resolving this problem. In this context, the analysis of LAA/Wi-Fi coexistence systems make use of unlicensed spectrum in [7-11] takes into account parameters such as the sum rate, energy efficiency, and power. This consideration holds significance since typically guarantee fairness by dynamically pre-coordinating fairness between different operators supporting different services. Through centralized control, the coexistence of NR_U and WiFi systems including access points that are densely deployed with unlicensed bands and frequently cause co-channel interference, [12-14] proposed a channel allocation mechanism to improve average user throughput and fairness. Nevertheless, despite these initiatives, there are still issues in effectively allocating radio resources to satisfy the unique needs of various services.

Our paper is motivated by the need to overcome these challenges and proposes a new radio access control mechanism that optimizes the allocation of licensed and unlicensed spectrum, ensuring performance fairness, better spectrum efficiency, and resource usage optimization for different services. The focus is on the unique requirements of uRLLC service, which require reliable and low-latency connections and high-bandwidth with eMBB-GBR services such as HD video, effectively integrating both licensed and unlicensed spectrum. Through intelligently using available resources, our proposed strategy aims to maximize network performance and meet the diverse needs of uRLLC and eMBB-GBR services in a heterogeneous radio operating system.

The remaining sections of this paper are organized as follows: Section 2 provides a comprehensive survey of the existing literature and related works conducted in the relevant field. Section 3 presents a system model based on different assumptions and considerations. Section 4 presents a proposed solution for licensed spectrum and unlicensed spectrum allocation. Section 5 then presents a performance evaluation of our approach. Finally, Section 6 draws conclusions based on research insights and contributions.

2. Related works

The distribution of unlicensed available radio resources between different services in a heterogeneous network where a 5G NR cellular network coexists with Wi-Fi has been receiving interest in the literature during the current years. Focusing on packet scheduling (PS), various studies on scheduling are conducted to implement the dynamic allocation of radio resources licensed to different service users, i.e. eMBB and uRLLC. An improved licensed resources allocation is presented in [15-19] to enable improved sufficient capacity for users. The authors of [20] propose multi-user preemptive scheduling (MUPS) to enhance eMBB traffic spectral efficiency, response time, and reliability of uRLLC in conventional multiple-input-multiple-output (MU-MIMO) transmission when they identify the trade-off between the performance of uRLLC and overall capacity of the network system. In order to jointly service uRLLC and eMBB traffic in a high-density 5G system, the authors of [21] proposed null space-based preemptive scheduling (NSBPS). The proposed approach ensures that sporadic uRLLC traffic is promptly scheduled while improving the overall performance of the system. In [22], a joint scheduling problem of eMBB and uRLLC traffic is addressed for the purpose of achieving service improvement for eMBB users while satisfying random demand on URLC UEs. For uRLLC and eMBB services, a non-orthogonal coexistence scheme was proposed in [23, 24] by having the processing of uRLLC traffic performed independently by users, while the control of eMBB traffic is implemented centrally in the network considering the uplink and downlink. However, the aforementioned studies were only limited to using one licensed spectrum as a single resource.

The problems associated with using licensed spectrum include limited availability, high cost, and regulatory constraints. The scarcity of licensed spectrum can lead to congestion and hinder the deployment of new services. The cost of acquiring and maintaining a licensed spectrum can be prohibitive, especially for smaller operators.

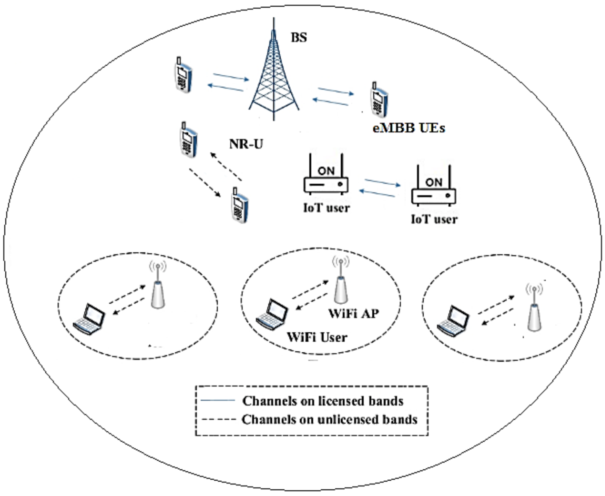

Figure. 2 System model

Additionally, strict regulations and licensing procedures may delay or complicate the deployment of wireless networks, affecting overall network efficiency and flexibility. To address these challenges, radio channels from licensed and unlicensed spectrum were jointly allocated to improve capacity and spectral efficiency [25–26].

The authors [27] propose a traffic offloading strategy, for improving the throughput of cellular systems as well as Wi-Fi. The LAA scheme and equity-based radio resource scheduling are introduced in [28] to enhance spectral efficiency and system throughput. An effective user association control mechanism is proposed in [29] to optimize the system data rate in the downlink of cellular networks, focusing on keeping the dynamic load balance between access points and base station (BS) when using available licensed/unlicensed resources. However, none of these studies considers radio control mechanism to jointly address radio channel access in heterogeneous radio access technologies including Wi-Fi and NR-U, considering different services such as 5G NR network with a commercial operator providing 5G uRLLC service (i.e., NR-IoT service support industrial IoT devices with reliable and low latency requirements) differentiation with high bandwidth requirements to eMBB-GBR services (i.e., Video HD). Both services have access to licensed and non-licensed spectrum. From the above, the main contributions of this paper can be summarised as follows:

1- We propose a novel radio access control strategy (RACS) solution that solves the problems associated with the efficient allocation of radio spectrum in heterogeneous network environments with the co-existence of URLLC service i.e., 5G NR-IoT service and eMBB-GBR service. The proposed RAC solution enables eMBB-GBR users to access unlicensed spectrum when the conditions are met.
2- The mechanism is optimized to maximize resource efficiency and achieve high throughput and minimize delays while meeting the unique needs of URLLC service with IoT devices and eMBB with Guaranteed Bit Rate (eMBB-GBR) services.
3- We comprehensively evaluate the effectiveness of the proposed mechanism through extensive simulations. The evaluation focuses on latency, packet success rate, and resource usage, demonstrating the effectiveness of the approach across various system parameters.

3. System model

We consider a heterogeneous network that includes the 5G NR cellular network within a network infrastructure that includes coexistence with WiFi, as shown in Fig. 2. Assuming a 5G NR network with a commercial operator, the scenario involves the provision of uRLLC service i.e., NR-IoT service support industrial IoT devices with low latency and high-reliability requirements, which are numbered as $i = \{1, ..., N\}$. In addition, the operator allocates a portion of the NG-RAN network's capacity to eMBB-GBR services such as HD video services, randomly distributed around gNB and numbered as $m = \{1, ..., M\}$.

The proposed model considers potential Wi-Fi users and access points that are randomly distributed within network coverage and have the potential to operate at an unlicensed 5 GHz band. Similar to [30], IoT users in the 5G NR network can transmit in two ways: direct transmission in D2D mode or indirect transmission by transmitting through the gNB in cellular mode. Specifically, different licensed resources are allocated for IoT users in direct D2D mode while eMBB-GBR users working in D2D mode have the ability to use licensed channels as well as share and access unlicensed channels for WiFi APs. The model assumes an OFDMA access is configured when using the licensed channel where there are a number of radio resources allocated in the time/frequency domains. More precisely, the cellular bandwidth in the frequency dimension is partitioned into resource blocks, RBs each of which includes of 12 sub-carriers with a sub-carrier separation Δf corresponding to one of the numbers specified in [31]. To achieve low latency requirements as well as high reliability for the IoT service, the RB can be assigned in mini-slots (i.e., 0.25ms) without having to wait longer. Correspondingly, there are W unlicensed channels that are assumed to be available for use by eMBB-GBR UE transmissions i.e., one unlicensed channel can be allocated to eMBB-GBR UE, to avoid interference on unlicensed channels among D2D pairs. The notations used this paper are indexed in Table 1.

In the context of IoT services, our scenario considers NR-IoT users who generate packets of length ϕ_p. The average number of required RBs by the IoT service per transmission time interval (TTI), denoted as Ψ_{IoT}, can be estimated as follow,

$$\psi_i^{IoT} = \frac{\sum_l^L \beta_{i,f}.P_{i,l}.\Phi_p}{\Delta_d.B.S_{eff}} \qquad (1)$$

$P_{i,l}$ "refers to the number of packets that must be transmitted by an IoT user equipment (UE). S_{eff} represents the spectral efficiency that is dependent on the modulation and coding scheme used for communication between UEs in the licensed spectrum. "B" is the bandwidth of the subchannels, and " Δ_d " is the duration of the transmission time interval (TTI). " $\beta_{i,f}$ " is the resource allocation vector, and each of its elements follows a specific format as follows,

$$\beta_{i,f} = \left\{\begin{matrix} 1 & if\ RB\ f\ allocated\ to\ user\ i \\ 0 & otherwise \end{matrix}\right\} \qquad (2)$$

Each GBR UE user randomly generates sessions based on the poisson process at a rate of λ_s (sessions/s) and these sessions require a certain guaranteed bit rate. Thus, the average number of RBs required for GBR users in order to support a given guaranteed bit rate R_m, can be calculated statistically as follows:

$$\psi_{GBR} = \frac{\sum_{t=1}^{T}\sum_{m=1}^{M}\psi_m^{GBR}(t)}{T} \qquad (3)$$

Where $\psi_m^{GBR}(t)$ is number of required RBs by UE m and,

$$\sum_{m=1}^{M}\psi_m^{GBR} = \sum_{m=1}^{M}\frac{R_m}{B.S_{eff}} \qquad (4)$$

This paper addresses the issue of allocating radio resources and monitoring the availability of radio resources for transmission. Specifically, it focuses on IoT devices and eMBB-GBR UEs that require reliable and low-latency connections, which are expected to utilize licensed radio resources. However, when there is a scarcity of licensed resources due to heightened demand or overload, new requests from eMBB-GBR UEs will be redirected to unused unlicensed radio resources instead of utilizing the licensed ones. This approach avoids interfering with Wi-Fi users who are already utilizing the licensed resources. To maintain a reliable connection and low latency for NR-IoT services, we can allocate licensed radio resources to them while redirecting eMBB-GBR users to unlicensed channels. This allows us to reserve licensed resources for critical services, while still ensuring that users receive high-quality service by avoiding collisions and evenly distributing the load across the network. By doing so, we can prevent service drops and relieve network congestion.

Table 1. List of notations

Definition	Notation
Δf	Sub-carrier separation
ϕ_p	The length of packets
Ψ_{IoT}	The average number of required RBs by the IoT service
$P_{i,l}$	The number of packets that must be transmitted by an IoT User
B	The bandwidth of the subchannels
Δ_d	The duration of the Transmission Time Interval
$\beta_{i,f}$	The resource allocation vector
λ_s	eMBB- GBR sessions arrival rate (sessions/s)
ψ_m^{GBR}	Number of required RBs by UE m
$\gamma_{t,f}^{i}$	SINR of UE *i* over RB *f*
R(*i*)	A set of RBs assigned to user *i*
S(*i*)	A set of candidate RBs for user *i*
α_m	Indicator to reflect the radio access mode
$\Delta\rho_{GBR}$	The estimated number of RBs required by the new GBR sessions
$\Delta\rho_{IoT}$	The estimated number of RBs required by IoT traffics
$\sigma_{i,t}$	Indicator for serving the IoT UE *i* ∈ N at t
$P_{RX}(\bar{m}$, w)	Power received by receiver $\bar{m}$ of link *l*
P_{RX}(m, w)	Power received by transmitter m of link *l*
P_{TH}	Power threshold
λa	IoT Packet arrival rate

4. The proposed radio access control strategy (RACS)

The proposed radio resource allocation strategy enables eMBB-GBR services to access licensed spectrum (refer to as LSP) as well as unlicensed spectrum (refer to as USP), depending on the

Algorithm1: Radio access control strategy (RACS)

```
1. Inputs:
   F_RB: Set of licensed radio resource.
   W_RB: Set of unlicensed radio resource channels
   N: number of IoT UEs.
   M: number of eMBB UEs.
2.  while $t < T$
3.     for each $i \in$ N
4.        for each $f \in F_{RB}$   do
5.           Determine the received SNRs.
6.           Specify the highest SNR received by UE . $i$ on RB.
             $f = arg \max_{i \in N} \gamma^{i}_{t,f}$
7.           Compute $\psi_i^{IoT}$ based on (1).
8.        $|R(i')| = R(i) \cup S(i)$ until $R(i') = \psi_i^{IoT}$
9.           $S(i^{-}) = S / R(i)$
10.       End
11.    End
12. for each $m \in$ M   do
13.       Compute $\psi_m^{eMBB}$ based on (3).
14.    If eq. (5) satisfied   do
15.       for each $f \in F_{RB}$   do
16.          $|R(m')| = R(m) \cup S(m)$ until $R(m') = \psi_i^{eMBB}$
17.          $S(m^{-}) = S / R(m)$
18.       End
19.    Else
20.       eMBB UE $m$ uses unlicensed spectrum . following Category 4 LBT.
21.    End
22. End
23. End
```

availability of physical resources in the licensed spectrum. To allocate radio resources to both IoT and eMBB-GBR services from the LSP, the strategy is implemented dynamically, with orthogonal radio resources allocated to each service in every time slot. The proposed approach works sequentially, prioritizing the highest-priority users with the best channel conditions, as determined by SINR over RB $f, \gamma^{i}_{t,f}$ and allocating RBs to users with urgent packets following Algorithm 1 (lines 5-7). The computation of SINR follows the same method as described in [28]. Once the IoT users are allocated resources, the strategy moves on to allocate resources to GBR users, but only after checking that there are no pending requests from IoT users with urgent packets and that enough radio resources are available to accommodate eMBB-GBR traffic requests. To ensure that more resources are available for the eMBB-GBR service, Algorithm 1 enforces a condition to be met (lines 13 and 14). Once the RBs are allocated to IoT users, the set of RBs assigned to user *i*, R(*i*) is updated following the union with a set of candidate RBs for user *i* , S(*i*), and this process is repeated until the desired number of RBs Ψ_{IoT} is reached, i.e., |R(i')| = R(*i*) ∪ S(*i*). Subsequently, the RBs assigned to user *i* from the candidate list S are removed from the updated set i.e., the new set S(i^{-})= S/ R(*i*) (lines 8 and 9). The process is also applied to assign RBs to eMBB-GBR users (lines 16 and 17). In the radio access control strategy (RACS), two different aspects are considered: First, it must ensure that the required radio resources by the IoT UEs and GBR UEs to transmit their traffic is less than the number of available radio resources in LSP. Therefore, the radio resource check must be passed with the following condition

$$\sum_i \psi_i^{IoT} + \alpha_m \sum_m \psi_m^{GBR} + (\Delta\rho_{GBR} + \Delta\rho_{IoT}) < \Gamma_{RB} \quad (5)$$

Where $\Delta\rho_{GBR}$ and $\Delta\rho_{IoT}$ is the estimated number of RBs required by the new GBR sessions and IoT traffics. The indicator α_m is introduced to reflect the radio access mode, so that,

$$\alpha_m = \begin{Bmatrix} 1 & if\ UE\ m\ operates\ in\ LSP \\ 0 & if\ UE\ m\ operates\ in\ USP \end{Bmatrix} \quad (6)$$

Secondly, the algorithm guarantees that both reliability and latency will be maintained simultaneously, as long as the total number of requests from all IoT UEs, N_{IoT} does not exceed the number of IoT UE requests that are served on time, as follows:

$$P\left(\sum_i \sigma_{i,t} < N_{IoT}\right) < \varepsilon_o \quad (7)$$

where $\sigma_{i,t}$ is an indicator for serving the IoT UE $i \in$ N at t, and thus,

$$\sigma_{i,t} = \begin{Bmatrix} 1 & if\ UE\ i\ served\ in\ LSP\ at\ t \\ 0 & otherwise \end{Bmatrix} \quad (8)$$

The channel access in the algorithm follows the aforementioned conditions. In order to serve both IoT UEs and GBR transmissions, the algorithm ensures that there are sufficient radio resources in the LSP and that the latency and reliability conditions are met for IoT UEs (line 14). If either of these conditions is not met, new requests from GBR users are not allowed to operate in LSP. However, they can switch to operate in USP, which is available for sharing with Wi-Fi systems after performing channel sensing (line 20). Particularly, using a Category 4 LBT procedure of this sensing is done as defined in [32] by which,

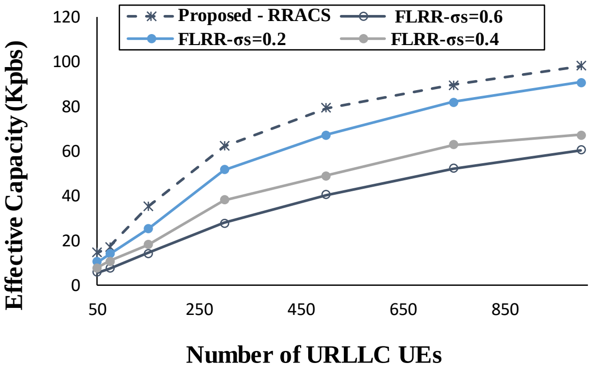

Figure. 3 The effective capacity Vs the number of uRLLC-IoT devices

Table 2. Simulation parameters

Parameter	Value
Cell radius	1000m
Channel bandwidth	400MHz
RBs per cell	80 RBs
Noise power	-174 dBm/Hz
PRB Bandwidth (*B*)	180kHz
Spectral Efficiency (*Seff*)	5.6 b/s/Hz.
Path loss model for licensed Network	$128.1+37.6\log_{10}(d[km])$
Path loss model for Unlicensed Network	$148.1+\alpha x\ 10\log_{10}(R)$ $\alpha = 4$
URLLC Service	
Transmit power of CU	46 dBm
Number of IoT UEs	900
λa , Packet arrival rate	1 packets/s
IoT Packet size	192 byte
TTI length	0.25 ms
GBR Service	
λ_s , GBR session arrival rate	{0.2-1.2}
Number of GBR UEs	50
Transmit power of CU	23 dBm
Guaranteed Bit Rate (GBR)	10 Mb/s
Average session duration	120s
Wi-Fi Traffic	
Number of WiFi UEs	5-15
Channel bandwidth	400MHz
CWminw	16
CWmaxw	1024
WiFi bit rate	300 Mbps

each transmitter and receiver of link *l* measures the received power denoted by $P_{RX}(\bar{m}$, w) and $P_{RX}(m,$ w) respectively and compare it to a specific P_{TH} threshold.

When the power received by both transmitter and receiver of link $l < P_{TH}$, the channel is considered an unoccupied channel and can be used for transmission. Then, the algorithm determines the fractions of time during which eMBB-GBR users can occupy USP. If one of the conditions is not met, the channel is marked as a busy channel and there is no possibility to use it for transmission.

5. Results and discussion

We consider a simulated network, involving the deployment of a heterogeneous network including a 5G NR cellular network with a Wi-Fi network. The 5G-NR cellular system uses gNB in the center of the coverage area and includes different traffic generated by eMBB-GBR providing premium HD video service and URLLC service support industrial IoT devices. The IoT users supported by URLLC service and eMBB-GBR UEs are randomly distributed within the coverage area and generate traffic that satisfies the Poisson distribution with coefficient λ_a and λ_s, respectively.

In the gNB, there are f RBs, each of which is made up of 12 subcarriers, and each subcarrier has a spacing of 15 kHz. Thus, the bandwidth will be 180 kHz per RB. In this study, the main simulation parameters including Wi-Fi, unlicensed spectrum parameters based on [28], and licensed spectrum parameters based on [33] are comprehensively shown in Table 2. In line with our study's objectives, we intentionally consider a comparable reference approach for comparison, wherein the licensed spectrum is utilized denoted as “FLRR-σ_s”, allocating PRBs based on σs (i.e., $\Delta_s = \sigma_s.N_{RB}$ of PRBs for GBR service and $\Delta_s = (1- \sigma_s.). N_{RB}$ for uRLLc service). This reference approach draws inspiration from the methodologies investigated in the research survey which focuses on exploring only licensed spectrum. The FLRR-σ_s reference approach explores varying σs values, specifically σs = 0.2, 0.4, and 0.6, to investigate its impact on resource allocation.

Fig. 3 shows the effective capacity of uRLLC-IoT users relative to the number of uRLLC-IoT devices, for the reference and the proposed approach. The effective capacity of both approaches increases progressively with the observed increase in the number of uRLLC - IoT devices.

The reason is that more requests from devices lead to more traffic sent. On the other hand, the proposed approach performed better than the standard, as our proposed strategy achieved

Table 3. URLLC effective capacity of the proposed RRACS and reference approaches

URLLC UEs Density	Proposed - RRACS	FLRR-σs=0.2	FLRR-σs=0.4	FLRR-σs=0.6
URLLC Effective Capacity (Kpbs)				
50	14.4	10.3	7.7	5.7
75	17.19	13.8	10.8	7.4
150	35.2	25.2	18	14.2
300	62.2	51.8	38	27.8
500	79.3	67.2	49	40.4
750	89.6	82	62.9	52.2
1000	98.2	91	67.2	60.6

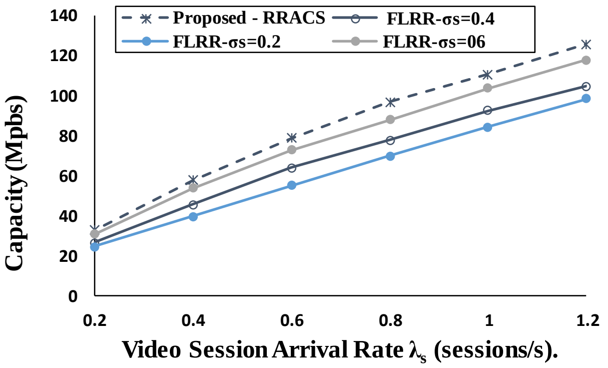

Figure. 4 The eMBB-GBR capacity Vs the number of session arrival rate λs (sessions/s)

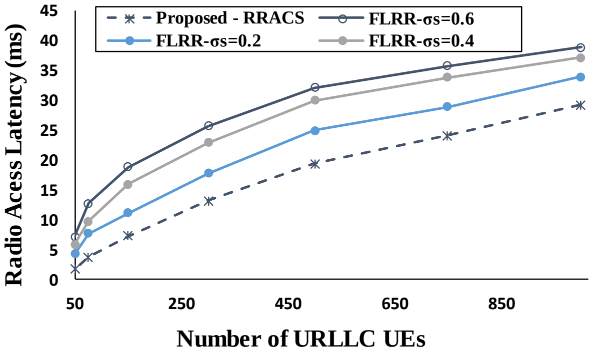

Figure. 5 The channel access latency Vs the number of uRLLC devices

maximum capacity gains of 9%, 39%, and 68% compared to the FLRR-σ_s = 0.2, compared to the FLRR-σ_s = 0.4, and FLRR-σ_s= 0.6 standard models respectively, when number of uRLLC devices is 750. Furthermore, as the number of IoT devices increases, the proposed strategy can achieve better performance ratios compared to the FLRR-σs = 0.2, compared to the FLRR-σ_s = 0.4, and FLRR-σ_s= 0.6 approaches even for highly populated networks.

According to Fig. 4, the proposed solution has demonstrated a remarkable enhancement in the capacity achieved for the eMBB-GBR service, which is attributable to the utilization of unlicensed radio resources that remain unutilized by Wi-Fi users. Additionally, it is worth mentioning that there is a correlation between the number of incoming sessions and the resulting capacity, which improves as more traffic is transmitted. The proposed algorithm's scalability compared to the standard FLRR-s = 0.2, FLRR-s = 0.4, and FLRR-s = 0.6 models in terms of capacity under different scenarios with varying session access rates is illustrated in Table 3. The results clearly indicate the superior scalability of the proposed algorithm, achieving significantly higher capacity compared to the standard models, especially across different eMBB loads.

The effectiveness of the proposed approach in enhancing the capacity of eMBB-GBR and URLLC services is clearly demonstrated by its consistent ability to achieve higher data rates when compared to the FLRR-s = 0.2, FLRR-s = 0.4, and FLRR-s = 0.6 approaches, as presented in Table 3 and Table 4, respectively. This outcome emphasizes the approach's ability to strategically allocate resources, resulting in optimized capacity and improved network performance within practical wireless communication scenarios.

Fig. 5 shows the average uRLLC latency due to access to licensed channels. From Fig. 5 we conclude that the latency increases for both the proposed model as well as the standard models when the number of uRLLC devices increases because there will be more access requests by network users and thus more consumption of radio resources that are allocated as resources available to users who intend to send traffic. From the obtained results, it can be deduced that latency when applying the proposed approach decreased compared to the reference schemes. For the proposed approach, the average latency is about 1.8 ms when the number of uRLLC devices is 50 device, while for the FLRR-σ_s = 0.2, FLRR-σ_s = 0.4, and FLRR-σ_s = 0.6 standard models, the latencies are 4.3ms, 5.9ms, and 7.2 ms, respectively. Table 5 provides a comprehensive comparison of system performance in terms of latency between the proposed algorithm and the FLRR-σs = 0.2, FLRR-σs = 0.4, and FLRR-σs = 0.6 standard models under

Table 4. eMBB-GBR capacity of the proposed RRACS and reference approaches

Session Arrival Rate λs (sessions/s)	Proposed- RRACS	FLRR-σs=0.2	FLRR-σs=0.4	FLRR-σs=0.6
eMBB-GBR Capacity (Mpbs)				
0.2	33	24	26	31
0.4	58	40	44	54
0.6	79	56	60	73
0.8	97	70	74	88
1	111	85	89	104
1.2	126	98	103	118

Table 5. URLLC latency of the proposed RRACS and reference approaches

URLLC UEs Density	Proposed - RRACS	FLRR-σs=0.2	FLRR-σs=0.4	FLRR-σs=0.6
Radio Access Latency (ms)				
50	1.8	4.3	5.9	7.22
75	3.8	7.8	9.8	12.76
150	7.3	11.2	16	18.9
300	13.216	17.8	23	25.8
500	19.4	25	30	32.16
750	24.2	29	33.9	35.8
1000	29.3	34	37.2	38.9

Table 6. The eMBB-GBR session drops of the proposed RRACS and reference approaches

Session Arrival Rate λs	Proposed - RRACS	FLRR-σs=0.2	FLRR-σs=0.4	FLRR-σs=0.6
eMBB-GBR Session Drops				
0.2	0.008	0.04	0.035	0.01
0.4	0.025	0.07	0.061	0.03
0.6	0.066	0.12	0.106	0.08
0.8	0.108	0.18	0.157	0.13
1	0.166	0.28	0.245	0.2
1.2	0.191	0.36	0.315	0.23

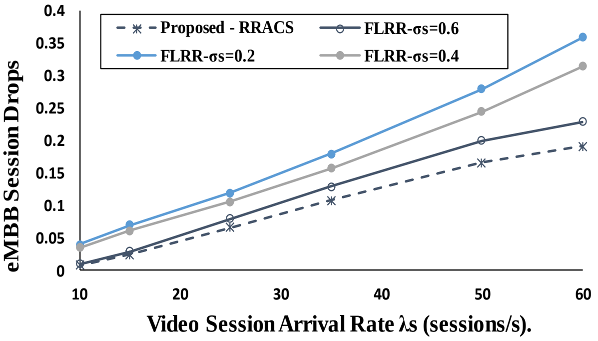

Figure. 6 The eMBB- GBR session drops Vs the number of session arrival rate λs (sessions/s)

various uRLLC traffic conditions. The lower latency values achieved by the proposed algorithm emphasize its capability to handle different traffic loads and enhance user experiences.

Fig. 6 presents a graphical representation of the session drop probability for eMBB-GBR users concerning the number of GBR sessions, comparing the standard and proposed strategies. The session drop probability is analyzed for different traffic variances. Additionally, Table 6 provides a detailed comparison between the proposed solution and the standard FLRR-s = 0.2, FLRR-s = 0.4, and FLRR-s = 0.6 models for the GBR drop probability under varying IoT traffic loads. The results demonstrate a consistent trend: as the number of eMBB sessions increases, there is a noticeable escalation in the likelihood of eMBB sessions being dropped.

The increased presence of eMBB UEs contributes to network congestion and resource contention, negatively impacting the performance and reliability of eMBB sessions in all cases. This can be attributed to the fact that a greater number of eMBB sessions are consuming more licensed resources, thereby reducing the number of licensed resources available for eMBB-GBR sessions. Nevertheless, the proposed model exhibits superior performance by enabling eMBB-GBR users to leverage unoccupied unlicensed resources that are not being used by Wi-Fi stations.

The effectiveness of the proposed approach in improving the quality of service for eMBB-GBR and uRLLc services is evident in its consistent achievement of reduced latency and the session drops when compared to the FLRR-s = 0.2, FLRR-s = 0.4, and FLRR-s = 0.6 approaches, as presented in Table 5 and Table 6, respectively. This accomplishment directly corresponds to the proposed approach's ability to efficiently use both licensed and unlicensed spectrum, and the proposed approach can accommodate changing traffic loads and adapt to changing network conditions. This flexibility in spectrum usage plays a vital role in alleviating congestion, bottlenecks, and resulting in fewer delays.

6. Conclusions

In our paper, we introduce a novel control mechanism for radio resource distribution that enables the dynamic multiplexing of eMBB-GBR and URLLC support industrial IoT devices on the same radio resources. The control algorithm determines the maximum percentage of PRBs required to ensure full radio resource availability for serving users. Additionally, the algorithm regulates the minimum percentage of PRBs guaranteed for eMBB-GBR service, based on the remaining radio percentage of the licensed spectrum. If this percentage is insufficient, eMBB-GBR service users are switched to unlicensed spectrum usage to ensure adequate resource availability. We compared our approach with reference methods that allocate resources in proportion to the traffic rate for each service. To demonstrate and verify the potential improvements of the proposed radio control strategy, we performed extensive simulations of different radio resource allocation configurations in a multi-service scenario with URLLC and eMBB-GBR services. Our simulation results showed that our proposed strategy can efficiently allocate licensed and unlicensed radio spectrum resources between different services and improve network performance in terms of capacity for eMBB-GBR and uRLLC services, the probability of session drops, and latency compared to the reference approaches.

Conflicts of interest

The author declares and confirm that there is no conflict of interest to declare.

Author contributions

The study was conceptualized and designed by Haider Albonda, including the proposed solution and simulation. In addition, Haider Albonda, made research efforts, conducted the research comprehensively, analyzed the data, contributed to writing the manuscript, and covered all sections including the introduction, related works of the system model, results, and discussions.

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