Original scientific paper

https://doi.org/10.33180/InfMIDEM2025.103

Informacije MIDEM
Journal of Microelectronics,
Electronic Components and Materials
Vol. 55, No. 1(2025), XX – XX

Efficient Resource Allocation for Ultra Reliable Low Latency Communication Delay Minimization in Fifth Generation Networks

Parameswaran Ramesh[1,2], Bhuvaneswari Mohan[1,2], Hariharan Rajamanickam[1], Rishi Vharsun Jaikumar[1], Arun Lakshmanasam[1]

[1]Department of Electronics Engineering, Madras Institute of Technology, Anna University, Chennai, India
[2]Centre for Internet of Things, Madras Institute of Technology, Anna University, Chennai, India

Abstract: In Modern world, Fifth Generation (5G) technology is ubiquitous, so it is necessary to meet all of its service requirements. Hence, resource allocation for every service is very important. This research addresses the problem of resource allocation for both Enhanced Mobile Broadband (eMBB) and Ultra Reliable Low Latency Communication (URLLC) users. The work comprises both static and dynamic resource allocation for eMBB and URLLC users. This research aims to minimize latency for URLLC users by taking into account the time and energy constraints of both eMBB and URLLC in static resource allocation, formulating these constraints as a convex optimisation problem. The results show that the static resource allocation strategy performs better than the fixed bandwidth and Central Processing Unit (CPU) cycle schemes. However, the use of static resource allocation becomes inefficient as the number of users increases. We propose a dynamic resource allocation strategy to address this issue, which uses online conformal prediction to schedule URLLC traffic on top of eMBB. The dynamic resource allocation strategy outperforms all previous resource allocation methods, ensuring 67% eMBB efficiency and 1 millisecond latency for URLLC users.

Keywords: 5G; eMBB; URLLC; Conformal Prediction; Resource Allocation

Učinkovita dodelitev virov za izjemno zanesljivo komunikacijo z nizkimi zakasnitvami za zmanjšanje zakasnitev v omrežjih pete generacije

Izvleček: V sodobnem svetu je tehnologija pete generacije (5G) prisotna povsod, zato je treba izpolniti vse zahteve glede storitev. Zelo pomembno je dodeljevanje virov za vsako storitev. Raziskava obravnava problem dodeljevanja virov za uporabnike izboljšanega mobilnega širokopasovnega omrežja (eMBB) in ultra zanesljivega komuniciranja z nizko zakasnitvijo (URLLC). Delo vključuje statično in dinamično dodeljevanje virov za uporabnike eMBB in URLLC. Cilj te raziskave je čim bolj zmanjšati zakasnitve za uporabnike URLLC z upoštevanjem časovnih in energetskih omejitev eMBB in URLLC pri statičnem dodeljevanju virov, pri čemer se te omejitve oblikujejo kot konveksni optimizacijski problem. Rezultati kažejo, da je strategija statičnega dodeljevanja virov boljša kot sheme s fiksno pasovno širino in cikli centralne procesne enote (CPU). Vendar, ko se poveča število uporabnikov, postane uporaba statičnega dodeljevanja virov neučinkovita. Predlagamo dinamično strategijo dodeljevanja virov za reševanje tega vprašanja, ki uporablja spletno konformno napovedovanje za načrtovanje prometa URLLC na vrhu eMBB. Dinamična strategija dodeljevanja virov je boljša od vseh prejšnjih metod dodeljevanja virov in zagotavlja 67-odstotno učinkovitost eMBB ter milisekundno zakasnitev za uporabnike URLLC.

Ključnebesede: 5G; eMBB; URLLC; konformno napovedovanje; dodeljevanje virov

---

* Corresponding Author's e-mail: parameswaran0789@gmail.com.

1 Introduction

The need for high-speed internet in the modern world increases rapidly as automotive industries, augmented reality, and Internet of Things (IoT) based automation provide real-time data for processing, and the world is moving towards a greener future. Therefore, we need to reduce the energy consumption of cyber physical devices and base stations. The above requirements are satisfied by the Fifth Generation (5G) [1]. It offers a 20-G bit/s data rate, which is 20 times faster than Fourth Generation (4G). It can offer an ultra-low latency of 1 ms [2]. It has massive capacity so that it can connect billions of devices, enabling smart cities, connected homes, and the revolution in automobiles through vehicle-to-vehicle (V2V) communication [3]. It offers three services, namely massive machine-type communication (mMTC), enhanced mobile broadband (eMBB), and ultra-reliable low-latency communication (URLLC) [4]. URLLC devices require low latency (<1 ms), high reliability (99%), and moderate data rates. eMBB devices require ultra-high data rates, low energy, and high capacity. mMTC requires massive connectivity, extended battery life, and low data rates. The eMBB and URLLC are critical for day-to-day applications. Hence, this research focuses on the requirements of eMBB and URLLC.

Resource to the huge network traffic and computational resource requirements, resource allocation is crucial for all 5G services. The resource allocation ensures that bandwidth, power, energy, and Central Processing Unit (CPU) cycles are used optimally based on the user needs. The resource allocation strategy ensures spectral efficiency, as well as a reduction in latency and energy consumption.

In current technology, 5G uses dynamic spectrum sharing to allow for flexible allocation of frequency spectrum based on real-time needs. We use spectrum management algorithms for dynamic resource allocation to prevent interference. However, this strategy lacks the URLLC reliability constraint and eMBB efficiency, which gives scope for research.

The goal of this research is to address the reliability and efficiency of URLLC and eMBB, propose a static resource allocation strategy for a limited number of users and a dynamic resource allocation strategy to efficiently use the available bandwidth, computational capacity, and power, and develop an efficient scheduler based on conformal prediction to dynamically allocate resources to both eMBB and URLLC services, satisfying their Quality of Service (QoS) requirements.

The structure of the paper is outlined below: Section II describes the purpose of the literature survey of various research perspectives in relation to the research. Section III describes the proposed methodology and scenario for the research. Section IV presents the results and offers insights gleaned from them. Finally, Section V concludes with future work on the research.

2 Literature Survey

In [5], the authors proposed a downlink scheduler to regulate URLLC traffic and eMBB traffic using superposition techniques that share resources related to frequency and power. They made an optimization problem to make sure that the rate loss for eMBB users and the segmentation loss of URLLC packets were kept to a minimum while still meeting their QoS requirements. The considered problem is solved by decomposing into two sub-problems: one for finding the optimal resource and power allocation for each eMBB-URLLC pair, and another for finding an optimal pairing policy that uses a greedy algorithm.

In [6], the authors developed a mechanism to maximize the efficiency of eMBB User Equipment (UE) and address the latency specifications of URLLC users. They have developed a dynamic, programmable approach to satisfy the above requirements. When a URLLC packet arrives, the algorithm uses puncturing mechanisms to stop the ongoing eMBB traffic.

The author in [7] addressed the issues related to URLLC and eMBB. The authors have developed mechanisms to address energy consumption and resource allocation between eMBB and URLLC. The authors divide a major problem into several minor problems, then transform them into convex functions that run in a loop until they converge. To implement it, the authors have adapted the Block Coordinate Descent (BCD) algorithm.

In [8], the authors used particle swap optimization and graph allocation-based algorithms to minimize interference. These mechanisms did not compromise data rates or throughput. They also used the TOPSIS technique to order the user preferences.

In [9], authors used the concept of network slicing to allocate resources to eMBB and URLLC within a 5G Cloud Random Access Networks (CRAN). The authors solved the allocation problem using mixed-integer nonlinear programming. They defined the separation between eMBB and URLLC services. They also introduced randomness to their traffic load. The authors have considered transmitting data packets of small size to ensure the characteristics of URLLC, which are low response time and high reliability. Further, they have used successive convex approximation algorithms to provide solutions to the framed problem statements.

In [10], the authors focused on higher-order layers and provided solutions to avoid Packet Duplication (PD). The authors also presented techniques to enhance the performance of URLLC. The authors provided an optimization problem based on URLLC constraints and solved it as a heuristic function so that the asset configuration can be in terms of Modulation Coding Scheme (MCS) and Physical Resource Block (PRB) reservation over many links. The final outputs indicate that the implementation of PD in the different network scenarios provides efficient usage of radio resources.

The above literature reveals that the authors scheduled the time slots for the URLLC data based on previous URLLC traffic data, resulting in a system reliability of less than 90%. The authors have also overlooked the crucial factor of high eMBB efficiency. The traffic to URLLC varies with time. This is due to the dynamic nature of URLLC devices. URLLC devices have a minimal delay tolerance, and timeouts result in the loss of some generated packets. Hence, it is necessary to design a scheduler that takes care of the delay tolerance capability of URLLC devices. In this work, we design the scheduler to guarantee a reliability of more than 90% for URLLC devices, while also ensuring eMBB efficiency through both static and dynamic scheduling. Using a conformal prediction-based scheduler, URLLC's reliability is increasing.

3 Proposed Methodology

This section describes the suggested model flow for the static resource allocation system model. It is followed by the formulation of constraints and the dynamic resource allocation network scenario, as well as the naive scheduler and the Conformal Prediction (CP)-based scheduler [11].

3.1 System Model

A network setup of 10 users is considered, as well as a mobile edge computing offloading scenario is shown in the Figure 1. Two types of 5G services are considered here, namely eMBB and URLLC, and each user will fall under one of the two categories. There are two sets of users here: one is URLLC users with a total number of 5 users, and another is eMBB users with a total number of 5 users again. The primary goal of URLLC users is to achieve the lowest possible delays. The delay includes the time required for transmitting data to the edge cloud, analysing, evaluating, and downloading the solutions to each of the URLLC UEs; this should be executed with an acceptable level of power consumption constraint, and in the case of eMBB users, the throughput and capacity are of the utmost importance. We built a single antenna within the network setup to serve as a gateway to the edge cloud, allowing users to offload. In addition to power and latency constraints [12], computation capacity and bandwidth constraints are also considered.

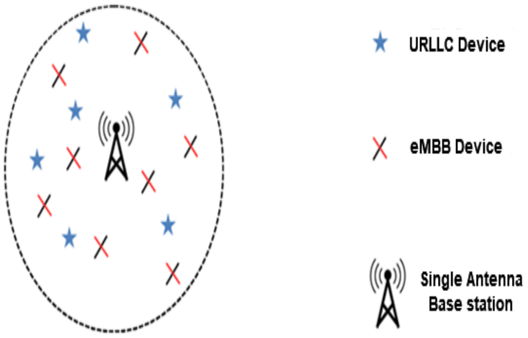

Figure 1: System model for Static Resource Allocation

Constraint of computation capacity, with C_i being the computation capacity allotted to ith user [13]

$$\sum_{i=1}^{10} C_i \leq C \tag{1}$$

and for bandwidth, consider a total of i sub-channels, where BW_i is the bandwidth allotted to the ith sub-channel.

$$\sum_{i=1}^{I} BW_i \leq BW \tag{2}$$

And for Transmission Power

$$0 < PW_i < PW_{max_i} \; \forall \; i \in I \tag{3}$$

3.1.1 URLLC Data Packets Estimation

In this research, we have run simulations for a total of 2000 frames, and for each frame f within that range, a total of $P_f \leq A$. URLLC data packets will be generated. The nth generated packet can be denoted as $P_f[n] \in A$ slot within the frame. Basically, we implement the process based on two assumptions

Along with the computation capacity, bandwidth, and transmission power constraints, a total of seven constraints are formulated [14]:

$$t_x \leq T_x = \frac{N_x}{BW_x \log2\left(1+\frac{pw_x g_x}{BW_x N_0}\right)} + \frac{CP_x N_x}{C_x} \leq T_x, t_x \geq 0 \; \forall \; x \in X \tag{4}$$

$$t_e \leq T_e = \frac{N_e}{BW_e \log2\left(1+\frac{pw_e g_e}{BW_e N_0}\right)} + \frac{CP_e N_e}{C_e} \leq T_x, t_x \geq 0 \; \forall \; e \in E \tag{5}$$

$$E_{off.x} \leq E_x = \frac{pw_x N_x}{BW_x \log2\left(1+\frac{pw_x g_x}{BW_x N_0}\right)} \leq E_x, E_{off.x} \geq 0 \; \forall \; x \in X \tag{6}$$

$$E_{off.e} \leq E_e = \frac{pw_e N_e}{BW_e \log2\left(1+\frac{pw_e g_e}{BW_e N_0}\right)} \leq E_e, E_{off.e} \geq 0 \; \forall \; x \in E \tag{7}$$

Equations (4) and (5) represent delay constraints for both URLLC and eMBB users, while equations (6) and (7) represent energy constraints.

For URLLC [15] users, the delay constraint is crucial, and for eMBB users, the energy constraint ensures a limit in energy consumption, and vice versa. We solve these constraints as convex optimization problems to determine the optimal delay and energy consumption for each user.

3.2 Dynamic Resource Allocation Network Scenario

Frame-based communication is discussed here, and each frame contains both eMBB and URLLC data packets as shown in the Figure 2. Moreover, we divide each frame into 12 slots, each lasting 0.5 ms. The scheduler at the base station generates either an eMBB or URLLC data packet for a specific slot, stores and displays this information as set A. Every time a new frame begins, the base station's scheduler defines each slot by assigning it to one of the users, and records this information in a set $D_f \subset$ A.

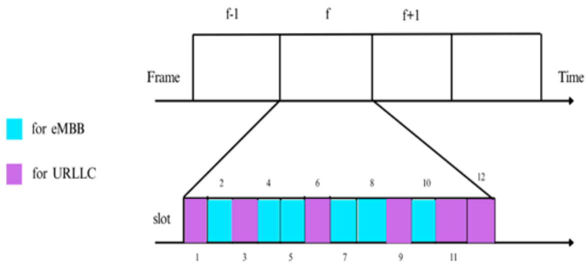

Figure 2: Proposed SDN Architecture Based Network Slicing in 5G network

3.2.1 *URLLC Data Packets Estimation*

In this research, we have run simulations for a total of 2000 frames, and for each frame f within that range, a total of $P_f \leq A$. URLLC data packets will be generated. The nth generated packet can be denoted as $P_f[n] \in A$ slot within the frame. Basically, we implement the process based on two assumptions: first, that the number of URLLC data packets generated within a single slot will not exceed one. Another thing is that the total number of data packets generated will not exceed the number of slots.

We note the slots allocated for the URLLC data packets and add them to a new set defined as in the equation 8,

$$p_f = \{p_f[1], \dots . p_f[p_f]\} \subseteq A \quad (8)$$

3.2.2 *Latency and Reliability constraints Associated with URLLC User*

Here, we express the latency as two slots, imposing a latency threshold of 1 ms. We set the threshold for reliability to be 90 percent by defining the unreliability rate alpha at 0.1. Frame f's reliability measure can be defined as in the equation 9 [16].

$$r\left(d_f|p_f\right) = \begin{cases} 1, & if\ d_f\ L - Covers\ p_f \\ 0, & otherwise \end{cases} \quad (9)$$

This is for a single frame and for the total of F frames,

$$R\,U\,(d1{:}\,F|p1{:}\,F) = \frac{1}{F}\sum_{f=1}^{F} r\,\left(d_f|p_f\right) \quad (10)$$

3.2.3 *eMBB Efficiency*

We can mathematically express the eMBB efficiency [17] in equation 11 as the ratio of the number of slots allocated for the eMBB users to the total number of slots within a given frame window:

$$\eta_{eMBB}(d_{1:E}) = \frac{1}{F}\sum_{f=1}^{F}\frac{A-|d_f|}{A} = 1 - \frac{1}{FA}\sum_{f=1}^{F}|d_f| (11)$$

3.3 *Naive Prediction Based Scheduler*

The conventional scheduler [15] is shown in the Figure 3, and its output entirely depends on the predictor that the base station has adapted.

Figure 3: Naive prediction-based scheduler

We use the Naive Scheduler to minimize the U_f of assigned slots, ensuring that the sum of possibilities $q_f(h)$ across all intervals h that are L-covered by d_f is no smaller than $1 - \varphi$. To address this issue, we use a two-step heuristic approach in equation 13.

Initially, we identify the smallest set φ of slot birth patterns hf to which the predictor $q_f(.)$ assigns a probability of at least $1 - \varphi$.

$$\Gamma\left(\frac{\alpha}{\mathrm{qf}}\right) = argmin_{\ \Gamma \in 2^s} |\Gamma| \sum_{P \in \Gamma} q_f(\mathrm{h}) \geq 1 - \varphi \ (13)$$

The scheduler first finds the subset $\varphi(\alpha/q_f)$, then identifies an assignment df that guarantees maximum reliability and eMBB efficiency.

3.4 *CP Based Scheduler*

A conformal-based scheduler will output prediction intervals is shown in the Figure 4. Based on the confidence value and interval obtained from the conformal prediction, it is useful for the users to understand the nature of the input given and analyse the data efficiently. The online conformal prediction works initially with a smaller number of datasets, but as time progresses, the test data, i.e., the generated URLLC packets on successful transfer, will also become the trained dataset, and the model will get stronger as the dataset increases. We use the cumulative distribution function to calculate reliability constraints. The slot allocation will be made based on reliability. We will allocate the URLLC packet with high resource requirements and high reliability first, and then schedule the subsequent packets. Gamma indicates whether the URLLC packet reached its destination. We transform the beta using the stretching function to update our online conformal prediction model using the stretching function µ.

Figure 4: CP based scheduler

The equation 14 gives the CP-based traffic predictor's stretching function. The predictor uses stretching functions and learning rates to optimize the online CP algorithm and predict URLLC traffic.

$$\mu(\beta) = \frac{1}{2}\ (1 + \cos(\pi\ (max\{0, \min(1, \beta)\} - 0.5)))(14)$$

4 Results and Discussion

4.1 Simulation Parameters

This section delves into the simulation outcomes and provides a comprehensive discussion on the implications of these results. We conducted the simulations under various sets of parameters, each tailored to explore specific aspects of the system under study. Following this, we detail the performance metrics derived from these simulations, offering a comprehensive assessment of the system's behavior and efficacy under various conditions. Table 1 depicts the parameters for the static resource allocation.

Table 1: Simulation Parameters for Static and Dynamic Resource Allocation

	Parameters	Value
	Bandwidth	1 MHz
Static Resource Allocation Parameters	Capacity	10 bit/s
	Power Spectral Density	-174 dB/Hz
	Input Data	50 K bits
	Total CPU Cycles	100
	Maximum Power of each user	0.5 Watts
	Radius	500 meters
	Number of users	10
Dynamic Resource Allocation Parameters	b_mismatch	0,1
	h_case	0,1
	b_adaptive	0,1
	p_plus pop	0.16
	p_plus hat	0.16
	G_num_min_pop	0

4.2 Performance Analysis

The suggested optimization beats the constant CPU frequency strategy by 10% and the fixed bandwidth method by 72%, as shown in Figure 5. In order to achieve the lowest feasible latency without sacrificing time limitations for the eMBB customers, it increases CPU computation capacity and bandwidth for the URLLC users.

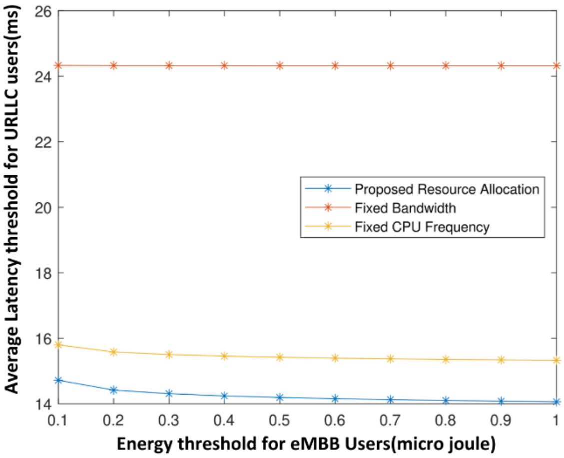

Figure 5: Average Latency Threshold for URLLC user vs Energy threshold

According to Figure 6, the proposed optimization performs significantly better than the fixed bandwidth scheme (by 71%) and the fixed CPU frequency scheme (16%). By increasing CPU capacity and bandwidth, it ensures optimal latency for URLLC users while also addressing the needs of eMBB users.

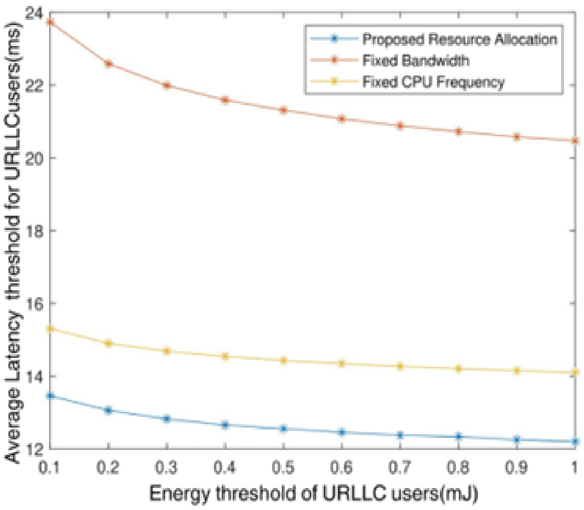

Figure 6: Average Latency Threshold for URLLC user vs Energy threshold for URLLC users

As shown in Figure 7, the proposed optimization significantly outperforms the fixed bandwidth and fixed CPU frequency approaches. The proposed optimization has a 17% decrease in delay when compared to a fixed CPU frequency and an 87% decrease in delay in comparison with the fixed bandwidth scheme.

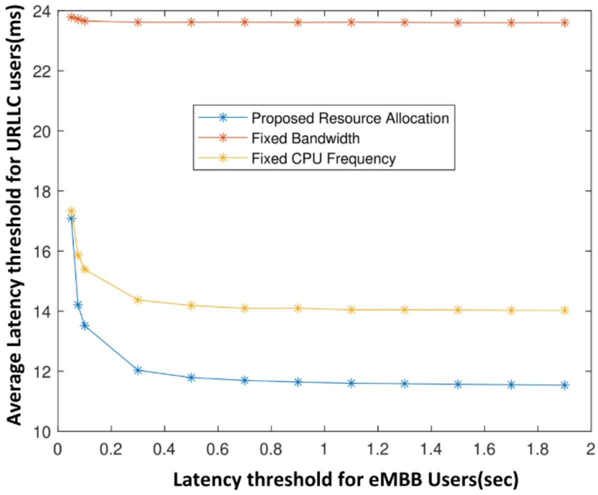

Figure 7: Average Latency Threshold for URLLC user vs Latency threshold for eMBB users

As expected, as the number of devices increases, the delay also increases due to the increased complexity, as illustrated in Figure 8. The proposed optimization has reduced the latency by 4% compared to a fixed CPU capacity and by 45% compared to a fixed bandwidth.

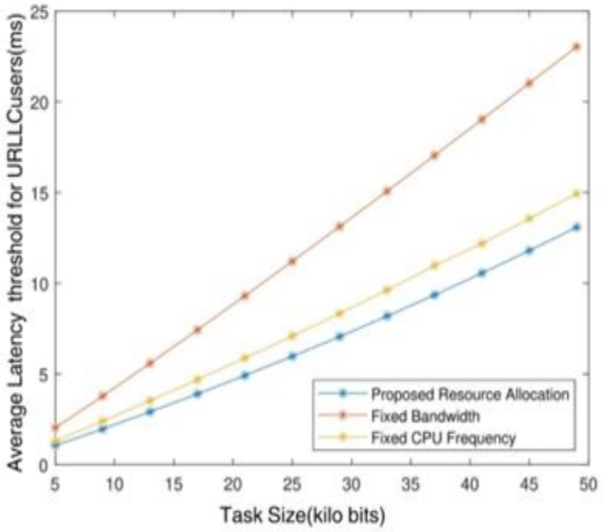

Figure 8: Average Latency Threshold for URLLC users vs. Task size

The suggested optimization outperforms the fixed bandwidth and fixed CPU frequency methods, as seen in Figure 9. It exhibits superior performance compared to the fixed allocated Multi Access Edge Computing (MEC) capacity and fixed bandwidth schemes, leading to a reduction in latency of 16% and 90%, respectively.

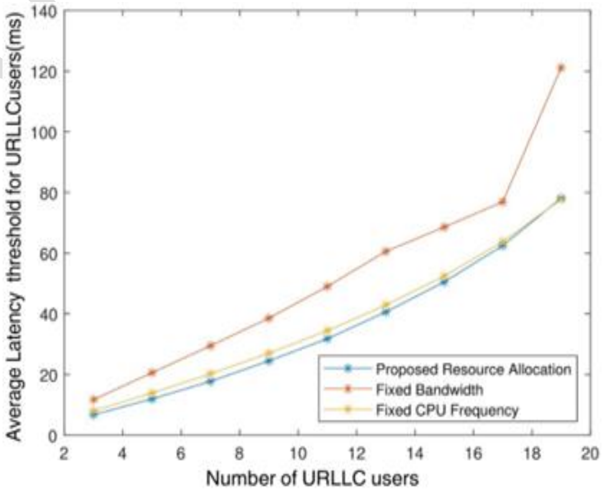

Figure 9: Average Latency Threshold for URLLC user vs Number of URLLC Users

The contour plot illustrates the comparison of resource allocation between the conventional scheduler and the CP-based scheduler [18] as shown in the Figure 10. The contour plot illustrates the comparison of resource allocation between the conventional scheduler and the CP-based scheduler. The first column in the contour represents URLLC traffic generated, which has pink-coloured slots, and eMBB traffic, which has blue-coloured slots. When the predictor underestimates URLLC traffic, the second and third columns represent comparisons between conventional schedulers and CP-based schedulers. According to equation 10, the average frame success ratio for predicting URLLC traffic in the conventional scheduler in figure 2 is 83 percent, whereas it is 93 percent in the CP-based scheduler. The fourth and fifth columns are the comparisons between conventional schedulers and CP-based schedulers. When the predictor overestimates URLLC traffic, the average frame success ratio for conventional schedulers is 90 percent, and CP-based schedulers is 92 percent based on equation 10. In both cases, the CP-based scheduler achieves URLLC reliability of more than 90 percent. This makes it perfect for forecasting URLLC traffic.

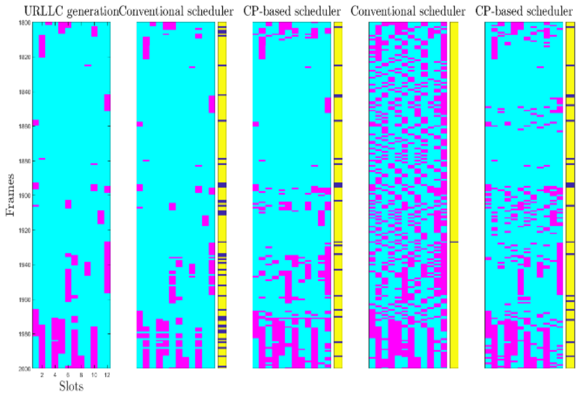

Figure 10: CP-Based Scheduler Output

4.3 Performance Metrics

4.3.1 Efficiency

When the mismatch factor is zero, Figure 11 illustrates the relationship between the number of delayed slots and efficiency. It demonstrates that as the number of slots rises, the efficiency steadily rises until it reaches 0.70, at which point it stabilizes.

When the mismatch factor is one, Figure 12 illustrates the relationship between the number of delayed slots and efficiency. It demonstrates that as the number of slots rises, the efficiency consistently rises until it reaches 0.75, at which point it stabilizes.

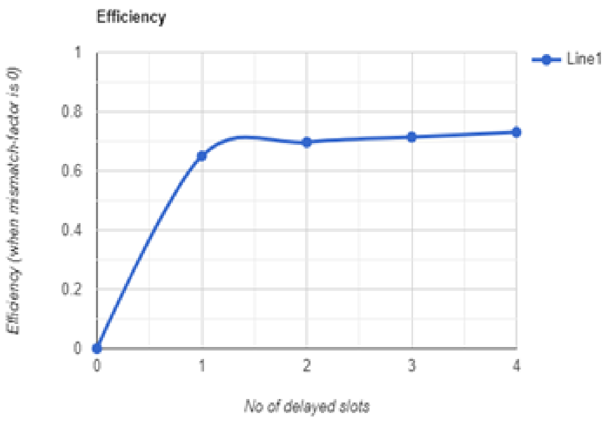

Figure 11: Efficiency (Mismatch factor is 0)

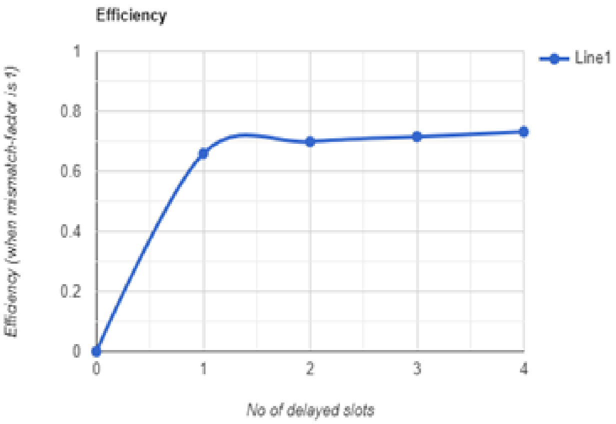

Figure 12: Efficiency (Mismatch factor is 1)

4.3.2 Coverage Reliability

When the mismatch factor is zero, Table 2 displays the coverage reliability of a normal scheduler and a CP-based scheduler. From the table, we infer that the coverage reliability is independent of the number of delayed slots because it is almost constant for all the delayed slots, and the coverage reliability of the CP-based scheduler is slightly greater than that of the normal scheduler.

Table 2: Coverage Reliability-When mismatch factor 0

Number of Delayed Slots	Coverage Reliability of Normal Scheduler	Coverage Reliability of CP-Based Scheduler
1	0.8185	0.8990
2	0.8186	0.8993
3	0.8188	0.8995
4	0.8189	0.8998
5	0.8191	0.8999

When there is a mismatch factor 1, Table 3 shows the coverage reliability of a normal scheduler and a CP-based scheduler. From the table, we infer that the coverage reliability is independent of the number of delayed slots because it is almost constant for all the delayed slots, and the coverage reliability of the CP-based scheduler is slightly greater than that of the normal scheduler.

Table 3: Coverage Reliability-When mismatch factor 1

Number of Delayed Slots	Coverage Reliability of Normal Scheduler	Coverage Reliability of CP-Based Scheduler
1	0.9855	0.9525
2	0.9856	0.9535

3	0.9856	0.9555
4	0.9858	0.9575
5	0.9859	0.9585

5 Conclusions

The proposed work creates a framework for static resource allocation for a limited number of users and a dynamic resource allocation for a larger number of users. The proposed static resource allocation strategy has outperformed the fixed bandwidth and fixed frequency resource allocation strategies. The parameters such as efficiency, Reliability of the users has been carried out to monitor the performance of it and with respect to mismatch values. The proposed dynamic resource allocation strategy achieves an eMBB efficiency of 70% and URLLC reliability of 90%.

6 Acknowledgments

The authors are grateful to the Centre for Internet of Things (CIoT), Madras Institute of Technology Campus, Anna University, for providing the resources needed to complete the research.

7 Conflict of Interest

The authors declare that there is no conflict of interest.

8 References

[1] P. Ramesh and P. T. V. Bhuvaneswari, "Non Orthogonal Multiple Access Requirements for 5G and Its Myths," 2022 IEEE Delhi Section Conference (DELCON), 2022, pp. 1-6, doi: 10.1109/DELCON54057.2022.9752790.

[2] M. Alsenwi, S. R. Pandey, Y. K. Tun, K. T. Kim, and C. S. Hong,``A chance constrained based formulation for dynamic multiplexing of eMBB-URLLC traffics in 5G new radio,'' in Proc. Int. Conf. Inf. Netw. (ICOIN), Kuala Lumpur, Malaysia, Jan. 2019, pp.

[3] M. Kokilavani, R. Siddharth, S. Mohamed Riyaz, P. Ramesh, S. Ezhilarasi and P. T. V. Bhuvaneswari, "Downlink Performance Analysis of 5G PD-NOMA System," 2022 IEEE Global Conference on Computing, Power and Communication Technologies (GlobConPT), 2022, pp. 1-6, doi: 10.1109/GlobConPT57482.2022.9938331.

[4] P. Ramesh et al., "Software Defined Network Architecture Based Network Slicing in Fifth Generation Networks", Inf. Midem-J. Microelectron. Electron. Compon. Mater., Vol. 54, No. 2(2024), pp. 123–130

[5] A. Anand, G. De Veciana and S. Shakkottai, "Joint Scheduling of URLLC and eMBB Traffic in 5G Wireless Networks," IEEE INFOCOM 2018 - IEEE Conference on Computer Communications, Honolulu, HI, USA, 2018, pp. 1970-1978, doi: 10.1109/INFOCOM.2018.8486430.

[6] R. Kassab, O. Simeone and P. Popovski, "Coexistence of URLLC and eMBB Services in the C-RAN Uplink: An Information-Theoretic Study," 2018 IEEE Global Communications Conference (GLOBECOM), Abu Dhabi, United Arab Emirates, 2018, pp. 1-6, doi: 10.1109/GLOCOM.2018.8647460.

[7] Y. L. Lee, J. Loo, T. C. Chuah and L. -C. Wang, "Dynamic Network Slicing for Multitenant Heterogeneous Cloud Radio Access Networks," in IEEE Transactions on Wireless Communications, vol. 17, no. 4, pp. 2146-2161, April 2018, doi: 10.1109/TWC.2017.2789294.

[8] S. Cavallero et al., "A New Scheduler for URLLC in 5G NR IIoT Networks with Spatio-Temporal Traffic Correlations," ICC 2023 - IEEE International Conference on Communications, Rome, Italy, 2023, pp. 1010-1015, doi: 10.1109/ICC45041.2023.10279558.

[9] Praveenkumar Korrai , Eva Lagunas , Shree Krishna Sharma , Ashok Bandi, Symeon Chatzinotas And Björn Ottersten , " A Ran Resource Slicing Mechanism For Multiplexing Of eMBB And URLLC Services In OFDMA Based 5g Wireless Networks . " IEEE Access – 2020 .

[10] S. Chauhan, A. Gupta, V. T, and N. S, "Efficient Resource Allocation algorithms for Multihop D2D approach in 5G network," International Journal of Communication Systems, 2023. doi:10.1002/dac.5520.

[11] P. Popovski, K. F. Trillingsgaard, O. Simeone, and G. Durisi, "5G wireless network slicing for eMBB, URLLC, and mMTC: A communication-theoretic view," IEEE Access, vol. 6, pp. 55 765–55 779, Sept. 2018.

[12] Yan Kyaw Tun , Do Hyeon Kim , Madyan Alsenwi ,Nguyen H. Tran , Zhu Han And Choong Seon Hong " Energy Efficient Communication and Computation Resource Slicing for eMBB and URLLC Coexistence in 5G and Beyond . " IEEE Access – 2020

[13] A. A. Esswie and K. I. Pedersen, ``Opportunistic spatial preemptive scheduling for URLLC and eMBB coexistence in multi-user 5G networks,'' IEEE Access, vol. 6, pp. 38451 38463, Jul. 2018.

[14] K. M. Cohen, S. Park, O. Simeone, P. Popovski and S. Shamai, "Guaranteed Dynamic Scheduling of Ultra-Reliable Low-Latency Traffic via Conformal Prediction," in IEEE Signal Processing Letters, vol. 30, pp. 473-477, 2023, doi: 10.1109/LSP.2023.3264939

[15] A. A. Esswie and K. I. Pedersen, "Opportunistic Spatial Preemptive Scheduling for URLLC and eMBB Coexistence in Multi-User 5G Networks," in *IEEE Access*, vol. 6, pp. 38451-38463, 2018, doi: 10.1109/ACCESS.2018.2854292.

[16] C. Padilla, R. Hashemi, N. H. Mahmood and M. Latva-Aho, "A Nonlinear Autoregressive Neural Network for Interference Prediction and Resource Allocation in URLLC Scenarios," *2021 International Conference on Information and Communication Technology Convergence (ICTC)*, Jeju Island, Korea, Republic of, 2021, pp. 184-189, doi: 10.1109/ICTC52510.2021.9620845.

[17] P. R and B. P. T. V, "Performance Analysis of NOMA under Power Control Mechanism," 2021

Innovations in Power and Advanced Computing Technologies (i-PACT), Kuala Lumpur, Malaysia, 2021, pp. 1-5, doi: 10.1109/i-PACT52855.2021.9696636.
[18] Xu & Xie "Conformal prediction for time series "- IEEE Transactions on Pattern Analysis and Machine Intelligence – 2023

Arrived: xx.xx.xxxx
Accepted: xx.xx.xxxx