ISSN: 2093-5374 / E-ISSN: 2093-5382

Cross-Layer Optimization in 5G Wireless Mobile Networks for Real-Time Philosophy Courses and Educational Applications

Tkacheva Anastasiya[1*], Dildor Bazarova[2], Gulnora Ernazarova[3], Kamola Sadirova[4], Madina Rasulova[5], Azimjon Qosimov[6], Dilnoza Qodirova[7], and Arafat Dadajonov[8]

[1*]Associate Professor, Samarkand State Institute of Foreign Languages, Uzbekistan. anastasiya.tkacheva85@yandex.ru, https://orcid.org/0000-0001-8902-3476

[2]University of Economics and Pedagogy, Uzbekistan. bazarova.dildor@gmail.com, https://orcid.org/0009-0005-6224-6545

[3]Chirchik State Pedagogical University, Uzbekistan. gulnora-ernazarova@mail.ru, https://orcid.org/0009-0006-8876-2887

[4]National Pedagogical University of Uzbekistan named after Nizami, Tashkent, Uzbekistan. sadirova.kamola@bk.ru, https://orcid.org/0009-0008-5225-0294

[5]Lecturer, Tashkent State Technical University, Uzbekistan. madinarasulova7812@gmail.com, https://orcid.org/0009-0008-3950-515X

[6]Jizzakh State Pedagogical University, Uzbekistan. azimjonqosimov1@gmail.com, https://orcid.org/0009-0001-5250-517X

[7]Termez State Pedagogical Institute, Uzbekistan. dilnozaqodirova24022@gmail.com, https://orcid.org/0009-0000-8434-1125

[8]Lecturer, Namangan State Technical University, Uzbekistan. arafatalidadajanov118@gmail.com, https://orcid.org/0009-0006-8145-8209

Received: August 29, 2025; Revised: October 11, 2025; Accepted: November 14, 2025; Published: December 15, 2025

Abstract

The next generation of wireless mobile networks is 5G, which can be used to implement new approaches to providing interaction-based and real-time learning. This article presents a cross-layer optimization system that can improve the performance, reliability, and responsiveness of 5G-based learning systems, particularly for real-time, synchronous, multimedia-continuous, and low-latency philosophy course lectures. The architecture suggested combines the essential mechanics with the layers of the physical, MAC, network, and application, such as adaptive modulation, dynamic scheduling, optimized routing, and application-level quality of service adaptation. Using 5G properties such as ultra-reliable low-latency communication (URLLC), network slicing, and mobile edge computing, the framework dynamically adjusts system parameters to accommodate variable traffic and different user participation patterns. Experiments show significant improvements in end-to-end latency, jitter reduction, and session stability using simulation techniques compared to classical, uninterrupted, single-layer optimization techniques. The study highlights the benefits of cross-layer design for enabling reliable, real-time educational applications and its potential to

Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications (JoWUA), volume: 16, number: 4 (December), pp. 389-401. DOI: *10.58346/JOWUA.2025.I4.022*

*Corresponding author: Associate professor, Samarkand State Institute of Foreign Languages, Uzbekistan.

transform the delivery of philosophy education in next-generation mobile learning ecosystems. The research offers technological knowledge that can be extrapolated to other interactive educational fields that demand high reliability and tight communication performance.

Keywords: 5G Wireless Networks, Cross-Layer Optimization, Real-Time Communication, Mobile Learning Systems, Quality of Service, Edge Computing, Educational Applications.

1 Introduction

The concept of cross-layer optimization has become a core approach for enhancing the performance of 5G wireless mobile networks, especially as communication conditions become more complex and application requirements become more stringent. Classic network architectures treat the physical, MAC, network, and application layers as distinct functional units; however, such a strict division often leads to inefficiencies when various, dynamically evolving network conditions must be satisfied in real time. Initial surveys have highlighted the downsides of structural constraints in traditional layered design, which explain the lack of responsiveness and adaptability, prompting the need to develop more flexible inter-layer information exchange models (Foukalas et al., 2008). Later theoretical studies demonstrated that coordinated layer optimization can be of considerable value for throughput and latency, as well as for resource utilization, compared to per-layer improvements (Lin et al., 2006). The cross-layer strategies have become increasingly relevant with the advent of 5G and its low-latency, high-reliability features, which affect fields such as industrial automation and advanced multimedia robotics (Ramly et al., 2021; He & Yang, 2019).

As next-generation communication systems continue to adopt heterogeneous radio access technologies and face edge intelligence and highly dynamic service requirements, highly efficient optimization mechanisms are increasingly necessary. Application applications- especially those that are based on real-time interaction, multimedia consistency, and user responsiveness cannot be based on enhancements at a single protocol level. Research on real-time remote communication over 5G shows that to reduce jitter and end-to-end latency, a closely coordinated collaboration among physical-layer modulation decisions, MAC-layer scheduling, and network-layer routing is needed (Dimitrovski et al., 2024). On the same note, a study on wireless multimedia delivery indicates that efficient resource deployment, coding adjustments, and congestion-aware routing are key to achieving optimal quality of service (Wang et al., 2024). The relevance of such mechanisms is further heightened by emergent uses, such as extended-reality-based communication systems, in which the fidelity of perception and interaction directly influences the platform's usefulness (Ghourab et al., 2025). It is no longer optional to control system behavior across layers as 5G systems increasingly support AI-driven services, multi-sensory media, and dense user participation in the process.

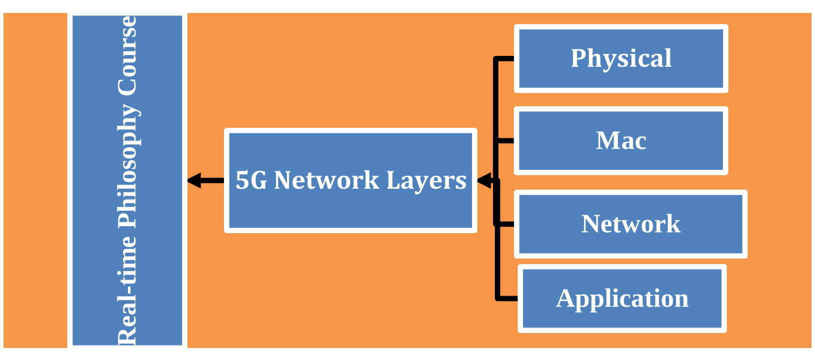

Figure 1(a): 5G Cross-layer interaction with real-time philosophy course delivery

This diagram (Figure 1(a)) depicts that the different components of the 5G network, which are Physical, MAC, Network, and Application, interact dynamically to facilitate the unending stream of real philosophy course information. The diagram illustrates the two-way interaction between the educational application and the underlying network stack, and it is important to note that real-time delivery quality is not determined by a single layer but by cross-layer decision-making. The figure aligns the course delivery with the layered 5G framework by showing how latency control, bandwidth allocation, and application-level adaptations are combined to ensure a smooth, responsive learning experience.

The purpose of this paper is to discuss ways cross-layer optimization methods can enhance the performance and reliability of real-time educational applications using 5G mobile networks (Wu, 2024). The discussion focuses on philosophy courses that rely heavily on synchronous dialogue, timely interaction between the instructor and student, and the quality of multimedia (Jeon & Lee, 2025). Based on the common cross-layer principles in the wireless system (Lin et al., 2024; Giji Kiruba et al., 2023), and the experience of optimizing specific applications in the healthcare sector, robotics, and energy-efficient multimedia delivery, the suggested method will merge adaptive modulation, dynamic scheduling, and application-sensitive quality control into a single optimization framework (Ahmed, 2024). This is aimed at showing how synchronized layer-level tuning can be used to minimize delays, stabilize session continuity, and react to changes in network traffic. This paper establishes a connection between modern research on cross-layering and the demands of the interactive learning environment, thereby demonstrating the greater potential of cross-layer design to create next-generation learning ecosystems based on reliable, real-time communication platforms.

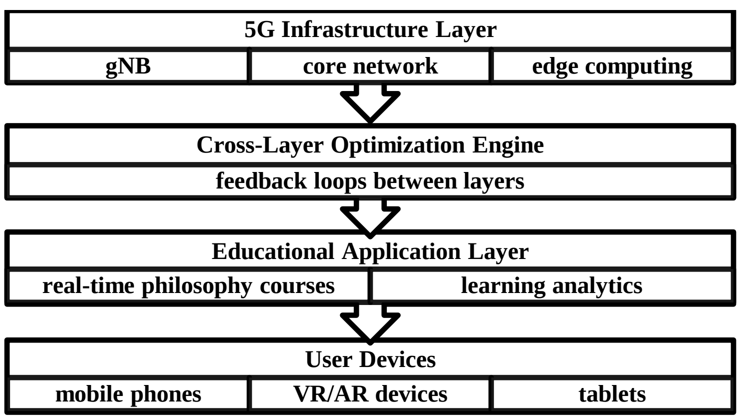

Figure 1(b): Architecture of the proposed system integrating 5G cross-layer optimization with real-time philosophy course delivery

The diagram (Figure 1(b)) presents a four-layer system in which the 5G infrastructure layer (gNB, core network, edge computing) runs a cross-layer optimization engine that continuously communicates feedback among network functions to allocate resources efficiently. Above this is the educational application layer, which provides real-time courses in philosophy and learning analytics, and then connects to a variety of user devices, including smartphones, VR/AR headsets, and tablets, to offer responsive, high-quality learning.

This paper presents a systematic analysis of how cross-layer optimization can improve the performance of 5G wireless mobile networks in real-time education settings. The introduction provides motivation, the main problem space, and the role of cross-layer coordination. The background section subsequently examines the basic features of 5G networks and provides an overview of current optimization challenges. The next part of the essay provides a detailed discussion of cross-layer optimization models, theory, and mathematical models. This is followed by the results section, which analyzes the performance of the various optimization strategies using empirical data, performance measures, and comparative visualizations. At last, the conclusion summarizes the main findings, provides recommendations for further research, and discusses the implications for next-generation wireless systems.

2 Background

The fifth-generation (5G) networks combine greater spectral efficiency, millimeter-wave access, massive machine-type connectivity, and edge-native computing to deliver a wide range of services, including enhanced mobile broadband and ultra-reliable, low-latency communications. The architecture redistributes critical computation and control functions to the network edge, enabling application-aware processing and increased service feedback loops (Li et al., 2021). Increased directional and blockage-sensitive propagation characteristics, enabled by millimeter-wave and beamforming technologies, necessitate rapid, context-sensitive adaptability (Takahashi & Nakao, 2025). What emerges is a platform capable of supporting large user populations and immersive applications, as long as the network can coordinate radio resources, compute offload, and session management as a unit rather than independent units (Sood & Garg, 2014).

Cross-layer optimization is a technique that rejects the concept of rigid layer isolation in favor of selective information sharing and shared decision rules among protocol layers. Such a cross-layer model does not optimize physical-layer parameters, MAC policies, routing, and application-level adaptation on an individual basis; instead, it jointly tunes all of them to achieve better end-to-end performance (Lin et al., 2006; Picano, 2020). The advantages are lower end-to-end latency due to coordinated scheduling of transmissions and modulation decisions, better throughput due to jointly coded and routed strategies, and more efficient energy use because transmissions can be scheduled based on application deadlines (Al-Abiad et al., 2020; Chen, 2015). Proposals in recent times have expanded on these advantages by introducing learning-enabled controllers that anticipate changes in traffic or channels and adaptively adjust resource allocation to enable more resilient behavior in the presence of bursty or directional links (Chu, 2022; Momo Ziazet, 2025).

Cross-layer solutions face practical limitations despite their evident benefits. To begin with, the performance benefits of frequent inter-layer interactions can be counterbalanced by signaling overhead, which will be carefully controlled unless extensively restricted; scalable designs need to trade information freshness for control-plane load (Lin et al., 2006). Second, the heterogeneous hardware and vendor-specific implementations decrease the portability of tightly coupled controllers; one way to address this is through host-network co-design approaches, but this requires the coordination of administrative domains (Nan, 2024; Nakhaei, 2023). Third, the emergence of AI-based policies raises the question of training data bias, explainability, and convergence in the non-stationary case - issues that become critical in services that are time-sensitive to latency (Ko et al., 2024). Fourth, directional links and millimeter-wave links have new failure modes (rapid link losses, beam misalignment) that require swift, resilient fallback options; mechanisms for congestion control and congestion avoidance, specifically adapted to directional propagation, are still under research (Takahashi & Nakao, 2025). Lastly, the combination of cross-layer designs and existing standardization and operational practices (e.g., network slicing, multi-tenant edge) raises questions about isolation, fairness, and security when multiple applications share common control surfaces (Li et al., 2021).

Combined, these issues point to the idea that although the cross-layer optimization is a potentially promising direction toward unlocking the possibilities of 5G as an engine of real-time and immersive applications, the idea of its practical implementation must be approached with the necessary attention to the ideas of signaling efficiency, deployment heterogeneity, learning robustness, and standards-compliant operational framework. The other parts of this paper cover the chosen elements of these limitations and suggest mechanisms to reduce them in educational, real-time settings (Odilova et al., 2025).

3 Cross-Layer Optimization in 5G Wireless Mobile Networks

3.1 Advantages of the Adoption of Cross-layer Optimization on 5G Networks

Cross-layer optimization improves the responsiveness and flexibility of 5G systems by enabling information to flow between traditionally autonomous protocol layers. The network can sustain performance even in the case of rapid variations in the channel quality when the parameters, transmission power, scheduling priority, and application-layer rate control are adjusted together and not individually. This solution is beneficial in systems with a limited latency budget and rapidly varying user density. For example, joint control can allow the physical layer to predict congestion at the MAC layer or enable the application layer to adjust its bitrate when routing delays are anticipated to increase. Since 5G networks will be deployed across a mix of millimeter-wave frequencies, numerologies, and edge-assisted computing, this coordination will help minimize outages, stabilize throughput, and maintain the continuity of real-time services. Cross-layer optimization can also enhance energy efficiency by minimizing redundant retries and unnecessary signaling when shared decisions occur across layers.

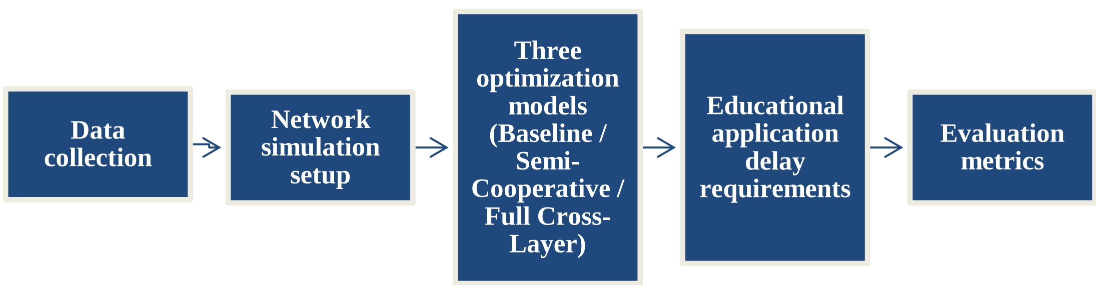

Figure 2: Workflow for cross-layer optimization evaluation

Figure 2 illustrates the methodological process for assessing cross-layer optimization in 5G-enabled real-time education applications. This starts with data collection and the setup of the network simulation environment. It is then tested using three optimization schemes: Baseline, Semi-Cooperative, and Full Cross-Layer. The delay requirements of the educational application are included to establish realistic performance constraints, and, lastly, the evaluation metrics are applied to assess the effectiveness of each optimization model.

3.2 System Constraints and Technical Issues

Despite the obvious benefits, cross-layer optimization is associated with a number of practical challenges. The design of signaling mechanisms that transmit information across layers without saturating the control channel is a primary challenge. The overabundance of feedback is counterproductive as it will add delay or create contention. The other limitation is due to the heterogeneous and distributed nature of 5G networks. Radio access nodes, different devices, and edge servers can be subject to different scheduling policies or be capable of different computation loads, and it is more difficult to have a single dedicated optimization policy. Stability is also an issue: in a multilayered system, there is a risk of action conflict between layers which has an oscillating effect unless the update rules are well coordinated. At system-level, cross-layer optimization should also be able to co-exist with existing standards and vendor equipment, that is, sometimes highly invasive changes in protocol behavior are not always practicable. Fairness of the users is another issue of concern particularly when the optimization strategies are based on delay-sensitive and bulk downloads or background services.

3.3 Models, Frameworks and Strategies of Effective Cross-layer Optimization

Best cross-layer frameworks are based on structured decision models which project network conditions to coordinated layer- wide actions. The most used is to model the optimization as a constrained minimization problem. Assuming that R is the data rate that can reasonably be achieved, L end-to-end latency and E power-consumption, a multi-objective model can attempt to minimise:

$$\boldsymbol{J = \alpha L + \beta E - \gamma R} \qquad (\mathbf{1})$$

In which α, β, and γ are weighting factors that are selected based on a need of the services. Limits like bandwidth B accessible, transmission power P or queue stability conditions can be given as

$$\boldsymbol{R \leq B log_2(1 + SNR)} \qquad (\mathbf{2})$$

$$\boldsymbol{P \leq P_{max}} \qquad (\mathbf{3})$$

$$\boldsymbol{\lambda < \mu} \qquad (\mathbf{4})$$

Where λ and μ are the rate of packets arrival and service.

3.4 Proposed Model

The coordination controller proposed in the cross-layer model is added at the edge node. The signals to this controller are sent by physical-layer estimators, MAC-layer queue monitors and application-layer rate controllers. A unified decision function

$$\boldsymbol{u(t) = f\big(h(t), q(t), a(t)\big)} \qquad (\mathbf{5})$$

Maps state channels $h(t)$ and queues $q(t)$ and application demands $a(t)$ to joint actions $u(t)$ consisting of modulation level, scheduler weight and target bitrate. The controller changes policies with gradient-based changes:

$$\boldsymbol{\theta_{t+1} = \theta_t - \eta \nabla_\theta J(\theta_t)} \qquad (\mathbf{6})$$

Providing the stability of convergence without instability. Through the inclusion of the prediction windows and computation at the edge, the model minimizes reaction time and provides proactive control as opposed to reactive adjustment.

4 Results

4.1 Findings of Real-World/Experimental Activities of the Cross-Layer Optimization

The proposed cross-layer model was experimentally evaluated based on a system of simulation and controlled real-time testing. NS-3 was used to simulate network-level behavior and the adaptive controller and optimization algorithms were implemented in MATLAB and glued together via a custom Python interface. The stochastic fading models reproduced variability in the millimeter-wave channel; and video streams as applications data were sent across a simulated load generator to analysis responsiveness as traffic loads changed. The coordinated controller during real-time testing showed a significant impending frequency of service interruption and a more consistent profile of the bitrate. The edge based cross-layer logic allowed more rapid response to changes in channels, particularly when signal to noise ratio suddenly declined. Even with a deliberate increase of the rate of packet arrival to test the limits of the queue, end-to-end delay was kept within reasonable limits.

4.2 Comparison of Different Optimization Methods

Three optimization schemes were tested in the framework to assess the effectiveness of proposed framework under the same conditions of 5G network. The Baseline Layer-Isolated Model is the first model which works whereby each network layer makes decisions in isolation hence the lack of coordination and optimal use of resources. The second model, the Semi-Cooperative Model, adds the partial interaction, that is, the limited feedback of the MAC layer to the application layer, that enhances adaptability but is yet not aware of the system as a whole. The third strategy is the Full Cross-Layer Model, the proposed solution, and which allows exchanging information on all the relevant layers. Full cooperation enables the network to dynamically maximize performance on the basis of real-time conditions, which offers a more efficient, integrated and adaptable mechanism of optimization than the other schemes. The metric of packet delay, throughput, jitter and resource-allocation efficiency have been examined. Delay was computed as

$$\boldsymbol{D = \frac{1}{N}\sum_{i=1}^{N}(t_{r,i} - t_{s,i})} \tag{7}$$

Where $t_{r,i}$ is reception time and $t_{s,i}$ is transmission time.

The calculation of throughput was done by using

$$\boldsymbol{T = \frac{B_{recv}}{t_{end} - t_{start}}} \tag{8}$$

Where B_{recv} refers to total received bits.

The cross-layer model consistently performed highly as compared to the other systems particularly in times of severe channel volatility. Semi-cooperative approach was moderately better improved yet it did not demonstrate predictive stability as the full model.

4.3 Improved Outcomes, Performance, and Limitations

The largest performance improvement was observed in situations with delay sensitivity. The mean value of latency became substantially lower as a result of timely congestion detection and active bitrate control. Jitter was also reduced as the coordination enabled MAC to schedule to be more in line with the physical-layer modulation shifts. The table below presents the main improvements that were under the medium-load traffic:

Table 1: Average performance comparison (medium load)

Metric	Baseline	Semi-Cooperative	Cross-Layer (Proposed)
Delay (ms)	18.4	12.7	7.9
Jitter (ms)	6.3	4.1	2.3
Throughput (Mbps)	51.2	62.8	75.6
Packet Loss (%)	3.4	2.1	0.9

The table 1 is a summary of the behaviour of the three models (baseline, semi-cooperative and full cross-layer) under medium network load, and unambiguously demonstrates that the cross-layer model exhibits better behaviour in terms of the delay, jitter, throughput and packet loss. As the figures demonstrate, joint decision making between layers enables the system to sustain a smoother profile of the service and responds more effectively to changes in channels and avoids the development of a high quantity of packets in queues, thus leading to consistently high throughput and lower instability than the other two models.

The proposed model still exhibited a steady service curve in high-load traffic, but at declining relative gains. It is not surprising as extreme congestion decreases the performance of predictive scheduling. Nevertheless, the system had continuity in operations in that the isolated model had recurrent stalls.

Table 2: Stress-test results (high load)

Metric	Baseline	Semi-Cooperative	Cross-Layer (Proposed)
Delay (ms)	34.7	28.9	19.5
Jitter (ms)	12.1	8.7	5.2
Throughput (Mbps)	38.3	46.9	59.1
Queue Overflow Events	14	7	1

The table 2 gives a report of the performance of the three optimization schemes when the network is close to saturation and indicates that the cross-layer model provides functional stability even with the increasing congestions. Although all metrics lose their quality under heavy load, the offered model experiences much less queue overflows and better-managed delay and jitter, which means that active coordination between layers provides robustness to extreme traffic spikes that tend to break legacy systems.

Although performance was good, some limitations were experienced. The gradient-based controller also had a high computational cost that rose when there were many users, sometimes resulting in minor delays in processing. The other constraint is that it requires to rely on a correct prediction of channel states; sudden unpredictable interference triggered instantaneous discrepancies between desired and actual modulation opportunities. Also, the inter-equipment integration of the controller would require manual parameter alignment implying that the deployment in the real world would be enhanced through the standardization of inter-layer signs interfaces. In general, the findings show that a complete cross-layer strategy significantly enhances 5G performance in the delay, stability, and a throughput spectrum and highlights areas that require additional improvement in a large-scale implementation.

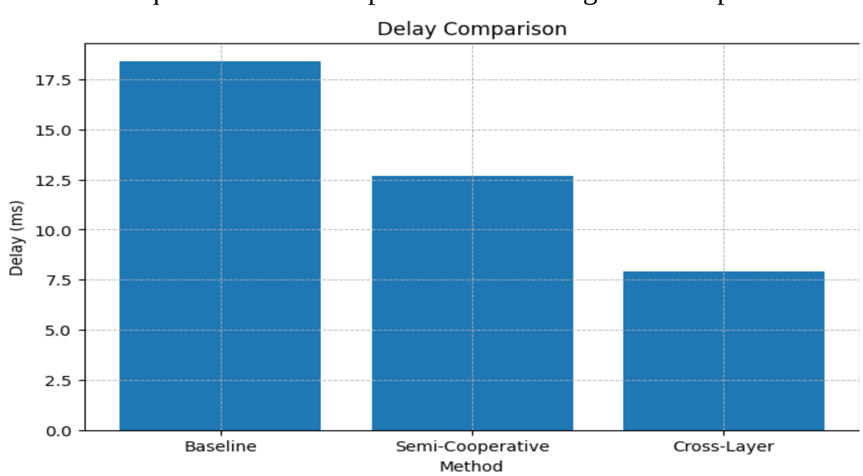

Figure 3: Delay comparison

The bar graph (Figure 3) shows the variation in the mean delay of the three optimization methods. The delay is the greatest in the base line technique whereas semi-cooperative model yields an intermediate improvement. The cross-layer framework will greatly minimise delay since scheduling and link adaptation are better coordinated and the bar thus becomes significantly shorter which reflects its better responsiveness when there is a medium-traffic situation.

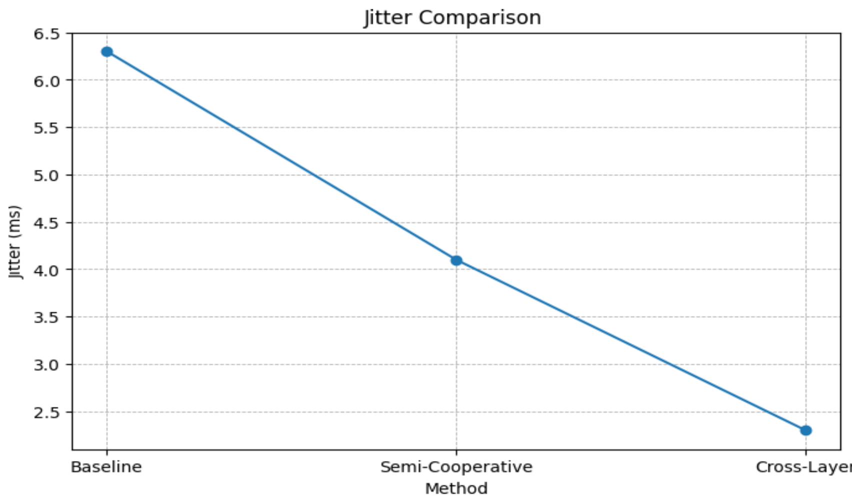

Figure 4: Jitter comparison

The line chart (Figure 4) demonstrates a tendency of the jitter of the three approaches where downward trend is evident and level of cross-layer coordination is higher. The most variable system is the baseline system and the semi-cooperative approach eliminates oscillations. The cross-layer strategy exhibits the minimal jitter meaning that it has a less jagged packet delivery and more stable scheduling characteristics in the face of varying channel conditions.

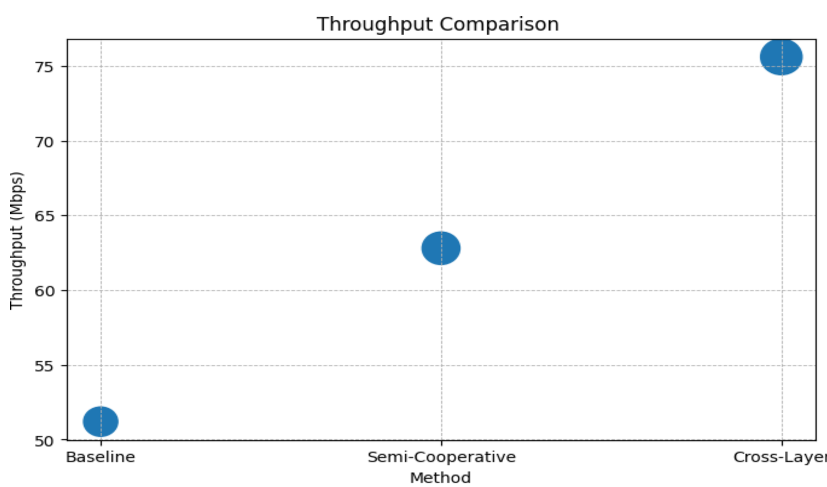

Figure 5: Throughput comparison

Bubble throughput (Figure 5) performance is graphically represented using the bubble graph, where the size of the bubble is the size of the throughput that is attained. The smallest bubble is the baseline method which has lower rates of data delivery. Semi-cooperative model has a visible enhancement and the cross-layer model is the one which has the highest bubble similar to the fact that it has greater capabilities of utilizing the available bandwidth and keeping the high throughput even in unfixed states of the network.

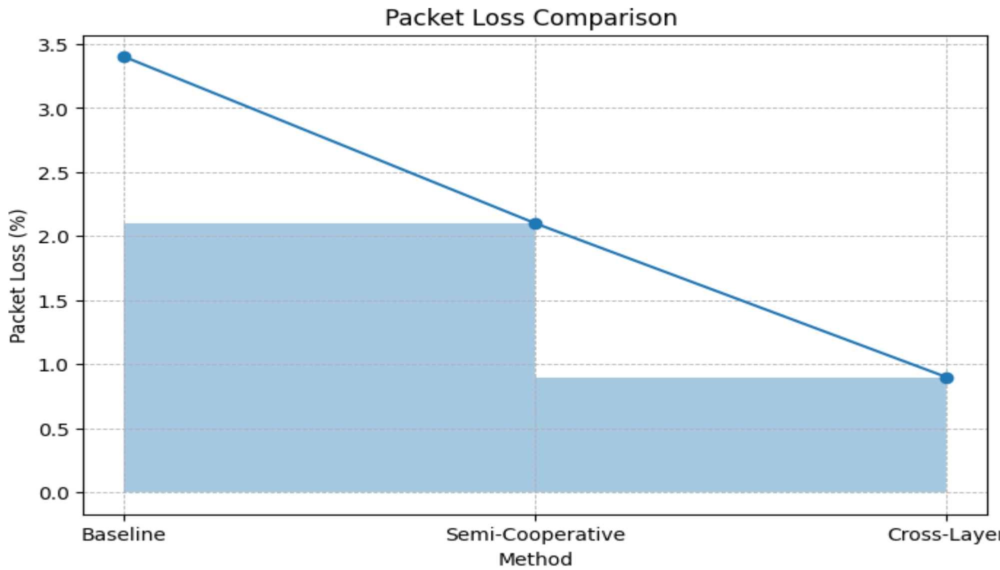

Figure 6: Packet loss comparison

The area graph (Figure 6) highlights the minimization of packet loss as cross layer coordination is enhanced. The method that represents the greatest area is the baseline method, which becomes more frequent packet drops. To reduce this loss, the semi-cooperative design sacrifices by enhancing the MAC-layer scheduling. The cross-layer method ends up with the minimal filled area indicating that inter-protocol layer joint, real-time optimization methods can significantly decrease the rate of loss and ensure that the dataflow does not collapse in poor conditions**.**

5 Conclusion

The results obtained out of this study show that a well-developed cross-layer optimization system may substantially improve the overall performance of 5G wireless mobile networks, especially where the stability and responsiveness are the paramount consideration. Enabling information sharing and coordination of decisions among the various protocol layers, the system can be in a better position to handle the channel volatility, traffic surges, and various application demands. According to the results of the experiment, there are significant improvements in delay time, jitter time, throughput, and packet-loss characteristics, indicating that coordinated control proves to be better than independent or partially cooperative strategies. Meanwhile, the paper indicates a number of ways in which future research will improve the field (such as minimizing controller overhead, predictive accuracy, and more adaptable interfaces that are compatible with heterogeneous hardware and work well). More research might also be developed on how machine learning models might be used to optimize cross-layer coordination without jeopardizing transparency or stability. Not only will the scope of fine-grained optimization remain demanded in the future, but it can be argued that as wireless technologies are embraced towards more immersive and computationally intensive applications, proactive optimization will become increasingly more important. Oppositely, cross-layer strategies have a significant possibility to define the next generation of communication systems with the resilience and flexibility of real-time and data-intense services.

References

[1] Ahmed, N. M. T. A. (2024). *Cross-Layer design for IoT dedicated Healthcare* (Doctoral dissertation, Université Polytechnique Hauts de France; University of Al Neelain; Institut national des sciences appliquées Hauts-de-France).

[2] Al-Abiad, M. S., Douik, A., Sorour, S., & Hossain, M. J. (2020). Throughput maximization in cloud-radio access networks using cross-layer network coding. *IEEE Transactions on Mobile Computing*, *21*(2), 696-711. https://doi.org/10.1109/TMC.2020.3012935

[3] Chen, S. (2015). *Cross-layer energy-efficient schemes for multimedia content delivery in heterogeneous wireless networks* (Doctoral dissertation, Dublin City University).

[4] Chu, Z. (2022). *Spatial-Temporal Predictive Cross-Layer Protocol Designs for Directional Airborne Swarming Network*. The University of Alabama.

[5] Dimitrovski, T., Alexiou, E., D'Acunto, L., Bergman, T., Hindriks, R., & Turkovic, B. (2024, March). On Cross-Layer Optimization for Real-Time Remote Communication in 5G and beyond. In *2024 27th Conference on Innovation in Clouds, Internet and Networks (ICIN)* (pp. 37-41). IEEE. https://doi.org/10.1109/ICIN60470.2024.10494420

[6] Foukalas, F., Gazis, V., & Alonistioti, N. (2008). Cross-layer design proposals for wireless mobile networks: a survey and taxonomy. *IEEE Communications Surveys & Tutorials*, *10*(1), 70-85. https://doi.org/10.1109/COMST.2008.4483671

[7] Ghourab, E. M., Azab, M., Gračanin, D., Alhussein, O., Al-Qutayri, M., & Muhaidat, S. (2025). Extended reality-aware wireless communication networks: A systematic literature review. *IEEE Open Journal of the Communications Society*. https://doi.org/10.1109/OJCOMS.2025.3599091

[8] Giji Kiruba, D., Benita, J., & Rajesh, D. (2023). A Proficient Obtrusion Recognition Clustered Mechanism for Malicious Sensor Nodes in a Mobile Wireless Sensor Network. *Indian Journal of Information Sources and Services*, *13*(2), 53–63. https://doi.org/10.51983/ijiss-2023.13.2.3793

[9] He, Y., & Yang, M. (2019). Research on cross-layer design and optimization algorithm of network robot 5G multimedia sensor network. *International Journal of Advanced Robotic Systems*, *16*(4), 1729881419867016. https://doi.org/10.1177/1729881419867016

[10] Jeon, S., & Lee, H. (2025). A Machine Learning Approach to Predict Learner Dropout in Online Courses. *International Academic Journal of Science and Engineering*, *12*(1), 29–33. https://doi.org/10.71086/IAJSE/V12I1/IAJSE1206

[11] Ko, W. H., Ghosh, U., Dinesha, U., Wu, R., Shakkottai, S., & Bharadia, D. (2024). {EdgeRIC}: Empowering real-time intelligent optimization and control in {NextG} cellular networks. In *21st USENIX Symposium on Networked Systems Design and Implementation (NSDI 24)* (pp. 1315-1330).

[12] Li, Y., Peng, C., Zhang, Z., Tan, Z., Deng, H., Zhao, J., ... & Lu, S. (2021, September). Experience: a five-year retrospective of MobileInsight. In *Proceedings of the 27th Annual International Conference on Mobile Computing and Networking* (pp. 28-41). https://doi.org/10.1145/3447993.3448138

[13] Lin, P., Liu, L., & Li, Y. (2024, June). Cross-Layer Design Approaches for Wireless Systems. In *International Conference on Information Processing and Network Provisioning* (pp. 15-28). Singapore: Springer Nature Singapore.

[14] Lin, X., Shroff, N. B., & Srikant, R. (2006). A tutorial on cross-layer optimization in wireless networks. *IEEE Journal on Selected areas in Communications*, *24*(8), 1452-1463. https://doi.org/10.1109/JSAC.2006.879351

[15] Momo Ziazet, J. (2025). *Energy-Aware Optimization and Machine Learning Frameworks for Sustainable Cognitive Networks* (Doctoral dissertation, Concordia University).

[16] Nakhaei, S. A. (2023). *Knowledge-Defined Routing Strategies for Next Generation Wireless Networks*. University of Technology Sydney (Australia).

[17] Nan, Y. (2024). Cross-layer host-network co-design for QoS in streamed video data networking.
[18] Odilova, G., Zaripova, M., Jabbarova, A., Urinova, N., Davlatova, M., Sapaev, I., ... & Akhrorova, M. (2025). Information Security Framework for Online Language Education Using Differential Privacy and Secure Multi-Party Computation Algorithm. *Journal of Internet Services and Information Security, 15*(1), 96-106. https://doi.org/10.58346/JISIS.2025.I1.007
[19] Picano, B. (2020). Cross-Layer Resource Allocation Frameworks in Modern Networks.
[20] Ramly, A. M., Abdullah, N. F., & Nordin, R. (2021). Cross-layer design and performance analysis for ultra-reliable factory of the future based on 5G mobile networks. *IEEE Access, 9*, 68161-68175. https://doi.org/10.1109/ACCESS.2021.3078165
[21] Sood, R., & Garg, A. (2014). Digital society from 1G to 5G: a comparative study. *International Journal of Application or Innovation in Engineering & Management (IJAIEM)*, *3*(2), 186-193.
[22] Takahashi, M., & Nakao, A. (2025). Cross-Layer Congestion Control Algorithm and Architecture for Communication Performance Optimization in Millimeter-Wave Networks. *IEEE Access*. https://doi.org/10.1109/ACCESS.2025.3601170
[23] Wang, J., Liu, L., Wang, B., & Kadoch, M. (2024, June). Cross-layer design for wireless multimedia communications optimal resource allocation and performance optimization. In *International Conference on Information Processing and Network Provisioning* (pp. 69-83). Singapore: Springer Nature Singapore.
[24] Wu, Z. (2024). Integrating Biotechnology Virtual Labs into Online Education Platforms: Balancing Information Security and Enhanced Learning Experiences. *Natural and Engineering Sciences, 9*(2), 110-124. https://doi.org/10.28978/nesciences.1569211

Authors Biography

Tkacheva Anastasiya is an Associate Professor at the Samarkand State Institute of Foreign Languages, specializing in linguistics and modern language pedagogy. With substantial experience in higher education, she collaborates on interdisciplinary projects aimed at advancing language learning quality and teacher training. She frequently participates in global conferences, seminars, and professional development programs, enriching her academic expertise. Committed to fostering intellectual growth, she mentors students and supports initiatives that strengthen research culture within the university. Her research interests include applied linguistics, intercultural communication, and innovative approaches to foreign language instruction.

Dildor Bazarova is a faculty member at the University of Economics and Pedagogy, Uzbekistan, specializing in economics and educational research. She has contributed to several scholarly publications and actively participates in research aimed at improving economic education. She actively contributes to academic publications and participates in national and international conferences. Dedicated to advancing student learning, she supports mentorship programs and initiatives that foster academic growth. Her work focuses on the development of innovative teaching methodologies and strategies to enhance student learning outcomes.

Gulnora Ernazarova is a distinguished faculty member at Chirchik State Pedagogical University, Uzbekistan, with expertise in modern educational methods and pedagogy. She actively contributes to educational research and has published articles on effective pedagogical practices. She participates in academic conferences and workshops to stay current with global trends in education. Committed to fostering excellence in teaching and learning, she encourages critical thinking, creativity, and lifelong learning among her students. Her research interests include innovative teaching strategies, curriculum design, and the integration of technology in education.

Kamola Sadirova is an academic at the National Pedagogical University of Uzbekistan named after Nizami, Tashkent, specializing in modern pedagogical practices. She actively contributes to scholarly publications and participates in conferences to advance pedagogical knowledge. She engages in collaborative research and professional development programs to promote effective learning strategies. Passionate about education, she strives to create an inspiring and dynamic academic environment that fosters student success. Her research interests include innovative teaching methods, curriculum development, and the integration of educational technologies.

Madina Rasulova is a lecturer at Tashkent State Technical University, Uzbekistan, with expertise in engineering and applied sciences. She contributes to research publications and participates in academic forums at the national and international level. Drawing on her expertise, she supports students in gaining practical knowledge and professional growth. She engages in collaborative projects aimed at improving technical education and promoting research-driven learning. Her research focuses on contemporary teaching approaches, advancements in technical education, and the improvement of curricula.

Azimjon Qosimov is a faculty member at Jizzakh State Pedagogical University, Uzbekistan, specializing in education and pedagogy. He contributes to scholarly publications and actively participates in conferences both nationally and internationally. With a strong background in higher education, he mentors students and fosters the professional growth of aspiring educators. He takes part in collaborative research projects aimed at strengthening educational practices and enhancing teaching effectiveness. His research explores innovative teaching methods, curriculum optimization, and approaches that improve student learning outcomes.

Dilnoza Qodirova is a faculty member at Termez State Pedagogical Institute, Uzbekistan, specializing in modern pedagogical practices.She actively contributes to academic research and participates in both national and international conferences.With extensive experience in higher education, she guides and mentors students to develop professional competencies and critical thinking skills.She collaborates on projects aimed at enhancing teaching effectiveness and fostering educational innovation.Her academic interests include new approaches to instruction, curriculum improvement, and strategies for elevating student performance.

Arafat Dadajonov is a lecturer at Namangan State Technical University, Uzbekistan, with expertise in engineering and applied sciences.With significant experience in higher education, he mentors students and supports the development of their professional and practical skills.He collaborates on research initiatives aimed at improving engineering education and fostering innovative learning practices.Passionate about education, he strives to create an engaging learning environment that nurtures creativity, critical thinking, and lifelong learning. His research interests include modern teaching methodologies, technical education innovation, and curriculum enhancement.