ISSN: 2182-2069 / E-ISSN: 2182-2077

Evaluation of MAC Protocols for Real-time Multimedia Internet Applications

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Received: July 17, 2025; Revised: September 02, 2025; Accepted: October 07, 2025; Published: November 28, 2025

Abstract

These services have become popular amid the flood of real-time Internet applications (such as video streaming, online gaming, and voice-over IP (VoIP)). An increase in demand for low-latency, high-throughput, and reliable communication has accompanied this. The central part of this problem is the MAC (Medium Access Control) layer, which controls channel access and provides Quality of Service (QoS). This paper is a comprehensive survey of the most popular MAC protocols that factor in real-time multimedia traffic. Protocols that work with IEEE 802.11 DCF, EDCA, and TDMA have been studied. The evaluation was performed through simulations in the conditions of different network load levels and variations in traffic patterns based on critical quality of service measures of end-to-end delay, jitter, throughput, and loss rate. The simulation results showed an increase in multimedia traffic compared to basic DCF, but performance decreased under congestion. Deterministic TDMA algorithms are more efficient. The inflexibility of dynamically changing environments, however, is a challenge. In this work, the overlapping of divergent adaptive or hybrid MAC-based solutions is a promising direction for future research. The diversity of proposed

Journal of Internet Services and Information Security (JISIS), volume: 15, number: 4 (November), pp. 183-198.
DOI: *10.58346/JISIS.2025.I4.014*

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solutions can help engineers develop MAC protocols to address the challenges posed by real-time multimedia applications over the Internet.

Keywords: MAC Protocols, Realtime, Multimedia, Internet Applications, Evaluation, Quality of Service (Quality of Service), Wireless Communication.

1 Introduction

MAC Protocols for Real-time Multimedia Applications Over the Internet

The MAC layer plays a vital role in a system's network communication, as it regulates how devices share the medium. These protocols are essential in Real-time multimedia Internet applications like live video streaming, online gaming, and VoIP since they are effective in achieving hard quality of service requirements such as latency, packet drop rates, data throughput, and loss measures (Bianchi, 2002; Khanvilkar et al., 2004; Seidgar et al., 2024). Simple MAC schemes based on collisions, such as IEEE 802.11 DCF (Distributed Coordination Function), are collision-prone and can cause network congestion (Xiao, 2005). To overcome these constraints, e.g., protocols such as IEEE 802.11e with EDCA have been proposed, which assign different delay levels to different data categories (Klein et al., 2023). Tertiary Command and Control (TDMA) systems can support predetermined command-and-control queues, which are more likely to guarantee quality of service and deterministic access times. However, in practice, they may be less adaptive to mobile and dynamic environments. Moreover, hybrid MAC protocols merge contention-based and contention-free strategies, providing flexibility and determinism (Ulkilan et al., 2022). These protocols will be increasingly significant as the interactivity and bandwidth requirements of new multimedia applications grow.

Significance of Assessment of MAC Protocols in Real-Time Multimedia Application

There is an imperative to evaluate MAC protocols due to their sensitivity to delays, jitter, and packet loss, which are timeless conditions given workload demands (Yigitel et al., 2011; Mohammadi, 2019). Any delay, even a slight one, can degrade video or voice quality and worsen users' suffering. As MAC protocols control the use of the communication channel, their implementation determines the quality and efficiency of the services users receive (Nakamura & Lindholm, 2025; Vasquez & Sorensen, 2025). The problems mentioned above are compounded in wireless networks by mobility, interference, and dynamic channel conditions. This implies that, under the applied MAC scheme, there can be significant performance swings. For example, (Yang & Vaidya, 2002) reported that priority-based scheduling at the MAC level offers significant improvements in multimedia transfer in ad hoc networks.

Moreover, as wireless networks are becoming heterogeneous systems that combine Wi-Fi, LTE, and 5G, the need for adaptive MAC solutions is increasing. In order to enhance the quality of service in multimedia networks in multi-user mode, (Wang, 2004) suggested a dynamic bandwidth allocation MAC protocol to address the changing traffic requirements (Ben-Othman et al., 2010). Similarly, (Kim & Hou, 2003) introduced model-based frame scheduling to the IEEE 802.11 model to enhance protocol performance across a wide range of load conditions. Moreover, as wireless networks are becoming heterogeneous systems that combine Wi-Fi, LTE, and 5G, the need for adaptive MAC solutions is increasing. In order to enhance the quality of service in multimedia networks in multi-user mode, (Wang, 2004) suggested a dynamic bandwidth allocation MAC protocol to address the changing traffic requirements. Similarly, (Kim & Hou, 2003) introduced model-based frame scheduling into the IEEE 802.11 model to enhance protocol performance across a wide range of load conditions. By evaluating existing MAC protocols for real-time multimedia traffic, researchers can fill performance gaps and identify opportunities for improvement (Ziwei & Han, 2023; Sapna & Singh, 2022). Many researchers rely on simulation tools such as NS-3 and OPNET to model and analyze the behavior of complex networks, including evaluating MAC-layer performance under varied network conditions.

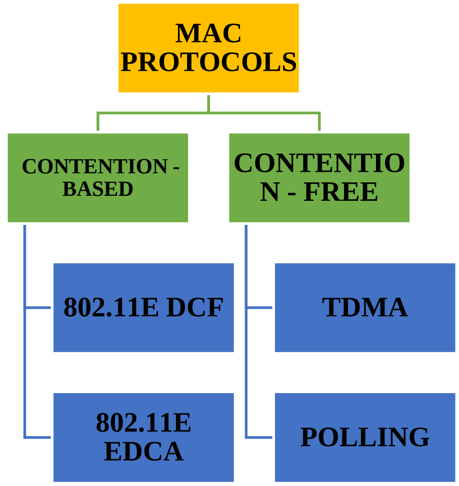

Figure 1(a): Classification of MAC protocols adapted for real-time multimedia internet applications

Figure 1(a) illustrates a MAC protocol hierarchy used in conjunction with the Internet's multimedia realtime applications. The protocols are divided into two large groups: Contention-Based and Contention-Free. Some Contention-Based protocols include IEEE 802.11 DCF and 802.11e EDCA schemes. These protocols are used on shared-access media, where devices compete for access, leading to greater latency uncertainty, but they have advantages in fluid environments. TDMA and Polling, on the other hand, are some examples of Contention-Free protocols. Such protocols prevent collisions by providing access time in advance or through centralized use. This would ensure performance and predictable oscillation, which are crucial for real-time multimedia delivery. This classification shows the limits of both versatility and determinism, with each protocol potentially performing poorly in situations that require a high level of delay.

Purpose of the Research Paper

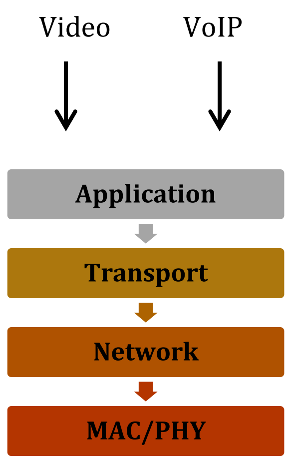

Figure 1(b): Architecture of a real-time multimedia communication stack, highlighting the MAC layer

This figure (Figure 1(b)) shows a detailed view of the stratified architecture of a multimedia communication system, indicating the direction of real-time information, including video and VoIP, to the MAC/PHY layer. All these layers are presented as a block: Application, Transport, Network, and MAC/PHY. Video data is moving downward, as depicted by the arrows. The application layer and MAC/PHY are highlighted with a dashed border, which defines media access and the timely delivery of data, and emphasizes their real-time nature. Besides the stack, the term "Realtime" further emphasizes that the system is highly responsive and sensitive to performance at the MAC level, which is a significant source of delays and hassles.

The purpose of this research paper is to evaluate and compare DCF, EDCA, TDMA, and other hybrid solutions for real-time multimedia Internet applications, and to determine the most efficient use of the MAC protocol. Using metrics (unutilized QoS-defined throughput, delay, jitter, and packet delivery ratio) to represent the results of a simulation-based evaluation, this research paper will illustrate the shortcomings these protocols experience in agile network environments. This will be done to produce an evaluative summary that considers both the benefits and shortcomings of the work and the protocols' design. The study will support the development of the next generation of scalable QoS-aware MAC protocols for relaying real-time multimedia in perspective communication networks.

The rest of this paper will be organized as follows. Section II provides a MAC Protocol Literature Review and examines the current MAC protocols for real-time multimedia internet applications, outlining their strengths and weaknesses. The protocols are studied in Section III, where we provide the evaluation criteria, simulation configuration, and metrics used to measure the results. Section IV presents the simulation results. This includes a discussion and analysis of the results, pointing out the overall performance evaluation and comparison. Section V includes a discussion of the effects of the results in the context of prior work, the limitations of the study, and suggestions for future research, which should be more focused. Lastly, Section VI concludes the study by summarizing the main contributions and the gaps in the search for MAC protocols for real-time multimedia applications.

2 Literature Review

Review of Existing MAC Protocols for Real-time Multimedia Applications

The research history of developing MAC protocols to meet the needs of real-time multimedia Internet applications is extensive (Eiriemiokhale & James, 2023). Contention-based approaches to access, such as the Distributed Coordination Function (DCF) in IEEE 802.11 MAC protocols, have proven problematic due to excess delay and packet collisions. To overcome these problems, the IEEE introduced the 802.11e standard, which incorporates Enhanced Distributed Channel Access (EDCA) and the Hybrid Coordination Function (HCF) to improve traffic mapping and prioritization. Other methods include TDMA-based protocols that assign time slots to individual nodes, making transmission times more predictable. As with many other delay-sensitive multimedia application solutions, these protocols exhibit poor scalability and excessive synchronization overhead. Other solutions include QoS-aware MAC (Q-MAC) and Multi-Priority MAC (MP-MAC), which aim to cater to different service levels based on traffic type (Parthipan et al., 2022). More recently, cross-layer designs have received attention because they enable MAC protocols to adapt their transmission strategies to the needs of the application layer. For instance, Adaptive MAC (A-MAC) adapts its backoff and retransmission strategies based on the video stream's qualitative metrics (Goljanin et al., 2024).

Examining Strengths and Weaknesses of Existing MAC Protocols

EDCA's most prominent strength lies in its traffic classification, which allows multimedia data to be routed ahead of other best-effort traffic. Consequently, the performance improvement for latency and jitter in real-time applications is much higher. Nonetheless, with high load, EDCA suffers from priority inversion and throughput starvation of lower-priority flows (Sundaresan et al., 2004; Farhan, 2022). Protocols from the TDMA family, such as those used in wireless sensor networks, guarantee time slots that are ideal for fixed-rate media streams. Their deterministic feature guarantees the lowest jitter and packet loss (Feizollahi & Haeri, 2016).

On the other hand, TDMA protocols are inflexible and inefficient in environments with variable traffic, mobile conditions, or ever-changing conditions. To enhance flexibility while maintaining quality of service, hybrid MAC protocols combine contention-based and contention-free strategies. Reservations-based transmission with adaptive backoff in the PRMAC protocol improves energy consumption and delay. However, the struggles of complexity and implementation overhead remain. MAC protocols with cross-layer design have been successful in adapting to changing network conditions and optimizing end-to-end quality of service. However, the need for amalgamation with the network and application layers increases the barrier to deployment and standardization (Chen & Heinzelman, 2005).

Evaluation of Various MAC Protocols based on Their Efficiency and Applicability for Real-time Multimedia Tasks

In protocol comparisons, metrics such as latency, jitter, throughput, and packet delivery ratio (PDR) are key indicators of performance. Research indicates that with moderate traffic, EDCA latency, and jitter for VoIP and video conferencing are remarkably better than DCF; unfortunately, none of the 'best current practices' sustained performance at congested network conditions. TDMA protocols perform well in static topologies, but degrade in dynamic ones when the scheduling overhead outweighs the coexistence benefits. On the other hand, hybrid MAC protocols are more adaptive and flexible for most multimedia applications, especially in heterogeneous wireless networks (Yadav et al., 2009; Renner et al., 2011). In simulation tests on high-definition video streaming, cross-layer MAC protocols have shown the best results due to their responsiveness to application-level quality of service requirements. However, due to their added complexity, these protocols are best suited for custom solutions rather than for generic applications (Benny, 2017). To conclude, no single MAC protocol can provide universally applicable solutions. The choice depends on the specific characteristics of the multimedia application, the network topology, and the balance between performance, complexity, and scalability.

3 Methodology

Description of the Assessment Criteria for Evaluation of MAC Protocols

The assessment of MAC protocols for contemporary Internet applications with real-time multimedia involves defining criteria that measure the needs and challenges of streams that demand high bandwidth and low latency. The most important ones for this research are:

Latency: The round-trip time (RTT) or round-trip latency is very critical for real-time applications. Video conferencing and VoIP require a high level of interaction that must be maintained throughout the conversation.

Jitter: Highly variable delays can lead to uneven playback, posing a bigger problem than jitter itself for audio, especially video streams.

Throughput: The number of bits transmitted during a given interval of time; thus, it is a direct indicator of service quality. Multimedia applications are varied, and almost all of them require high throughput to support adequate transmission.

Packet Loss Ratio (PLR): The Number of packets lost in a specified time is termed the packet loss ratio. Real-time services have a minimal tolerance for PLR due to the risk of packet loss. Retransmission of lost packets can result in delays that are obtrusive to normal operations.

Fairness: Tend to focus on the capability of a MAC protocol to distribute resources fairly among all the data flows in such a way that none of the traffic is sent in a starved condition and all users get an acceptable service level.

Overall, the criteria enable evaluation of the protocol from different angles related to its performance and from the experience a user will get.

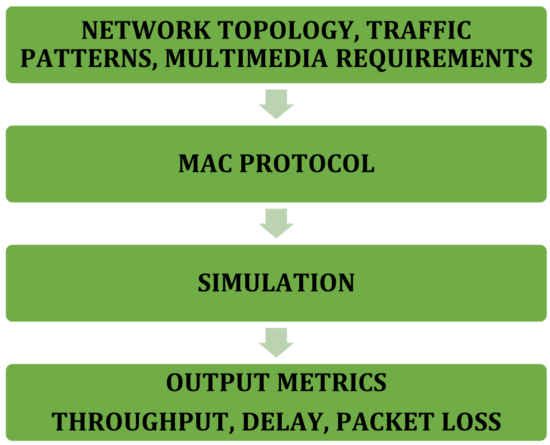

Figure 2: Simulation workflow for evaluating MAC protocols under real-time multimedia constraints

The diagram (Figure 2) is a simulation flowchart designed to evaluate MAC (Medium Access Control) protocols for real-time multimedia applications. The workflow starts by specifying input parameters, including the network's topology, traffic model, and multimedia parameters. These parameters are provided to the MAC Protocol Module, which defines the communication protocol under evaluation. The protocol is subsequently run in simulation, where its protocol-defined behavior is emulated in the given conditions. Ultimately, the resulting output metrics, such as throughput, and other vital constraints, such as delay and packet loss, are assessed to determine the adequacy of the protocol for real-time multimedia transmission.

Description of the Simulation Environment and Tools Used for Assessment

To perform a coherent, repeatable assessment, simulations are conducted with NS-3 (Network Simulator 3). NS-3 supports the simulation of a range of wireless MAC protocols, including IEEE 802.11 DCF, EDCA, and TDMA-like architectures. It supports network parameter configuration, node mobility, and multimedia traffic profiling, making it suitable for multimedia testing. The simulation topology includes several wireless nodes that can be arranged in a mesh or infrastructure configuration. Bandwidth-intensive multimedia traffic is emulated using VoIP and video models in accordance with realistic codec standards such as G.711 for voice and MPEG-4 for video. Additional realistic operating conditions are simulated by adding background traffic, and scenarios differ in node count (10, 25, or 50 nodes) and load intensity (light, moderate, or heavy). As with all simulations, a 300-second simulation period is used for each scenario, with performance data accumulated continuously for the duration. Surrounding factors are controlled to remove variance, thereby mitigating the influence of external factors and allowing only the protocol performance to be measured.

Assessment of the Various Aspects Measured to Evaluate the Efficiency of MAC Protocols

About measuring protocol performance, several sequentially dependent metrics are derived with the use of simulation trace files:

Average End-to-End Delay (D):

$$D = \frac{1}{N}\sum_{i=1}^{N}\left(t_i^{recv} - t_i^{send}\right) \qquad (1)$$

Where t_i_send and t_i^{recv} represent the send and receive times of packet i, respectively, and N is the total number of received packets.

Jitter(J):

$$J = \frac{1}{N-1}\sum_{i=2}^{N}|(D_i - D_{i-1})| \qquad (2)$$

Where D_i is the delay of the $\boldsymbol{i}$-th packet.

Throughput (T):

$$T = \frac{Total\ Data\ Received}{Simulation\ Time} \qquad (3)$$

Packet Loss Ratio (PLR):

$$\text{PLR} = \frac{P_{sent} - P_{recv}}{P_{sent}} \times 100\% \qquad (4)$$

Fairness Index (F) (using Jain's fairness index):

$$\text{F} = \frac{(\sum_{i=1}^{n} x_i)^2}{n \cdot \sum_{i=1}^{n} x_i^2} \qquad (5)$$

Where x_i is the throughput of the i-th flow and n is the number of flows.

In order to achieve a normalized performance score for each protocol under different scenarios, we propose a Composite Performance Index (CPI) calculated as follows:

$$\text{CPI} = \text{w}_1 \cdot \left(\frac{1}{D}\right) + \text{w}_2 \cdot \left(\frac{1}{J}\right) + \text{w}_3 \cdot \text{T} + \text{w}_4 \cdot \left(\frac{1}{PLR}\right) + \text{w}_5 \,.\, F \qquad (6)$$

Where:

$w1, w2, w3, w4, and\ w5$ are the weights assigned to each metric according to their importance in real-time applications (for instance, $w1 = 0.25, w2 = 0.20, w3 = 0.25, w4 = 0.15, w5 = 0.15$).

The proposed system has an advantage over other systems that measure performance using a single calculation, as it provides protocol assessment across multiple metrics, thereby improving the accuracy and fairness of comparisons.

Expected Outcomes and Interpretation of Results

Assessing MAC protocols against the given criteria (latency, jitter, throughput, packet loss ratio, and fairness) will indicate the extent to which they meet the needs of real-time multimedia applications. The expected values of the metrics are as follows.

- **Latency:** In real-time applications, the communication should not have latency. Therefore, the protocols should have lower latency, especially in applications like video conferencing and VoIP.
- **Jitter:** Delays cause instability, which can be catastrophic in real-time multimedia applications, particularly video and audio streams. Protocols with lower jitter will provide more stable playback, minimizing disruptions to the user.
- **Throughput:** In bandwidth-intensive multimedia applications, higher throughput is much more effective. Protocols that enable higher throughput will be effective for streaming video and voice.
- **Packet Loss Ratio (PLR):** Real-time multimedia applications are more sensitive to packet loss. Because of this, protocols with lower PLR will be more reliable and avoid service loss during multimedia applications.
- **Fairness:** Within a protocol, fairness guarantees that all users have equal access to the facilities and that no user is bandwidth-starved. A higher fairness index means that all users had access to the system.

The Composite Performance Index (CPI) should indicate the expected overall score per protocol from the weighted aggregation of the metrics. Protocols with elevated CPI indices are expected to deliver superior performance in dynamic multimedia settings.

Comparison of Protocols

After finishing the simulations, the responses will be assessed against various MAC protocols using specific KPIs. This will identify the merits and demerits of each protocol to the real-time multimedia stream. The analysis will be done in the following areas:

- **Latency and Jitter:** The protocols will be examined in terms of their capability to reduce delays and stabilize. Real-time applications, including video and VoIP, must be delivered with no latency or jitter and function without delays or interruptions.
- **Throughput:** The protocols will be examined for their ability to optimize real-time performance in multimedia applications. For multimedia applications, especially services that require high-definition on-demand video streaming, higher throughput is needed.
- **Packet Loss:** The protocols will be assessed in terms of their ability to manage packet loss (for real-time communication). For multimedia services, such protocols will be deemed more reliable for communication.
- **Fairness and Load Balancing:** This section of the assessment will look at the degree of fairness in distributing resources across multiple users/data streams.

While all participants in the network receive an equitable level of service, no user or flow will be starved of bandwidth in a fair protocol. Now, comparing these factors will help determine optimal protocols for real-time multimedia services such as video streaming and VoIP.

4 Evaluation Results

Exposition of Simulation Outcomes on MAC Protocol Evaluation

The simulation results help evaluate changes in MAC protocols across different conditions and workloads. Data was collected for the three described traffic scenarios: Low (10 nodes), Moderate (25 nodes), and High (50 nodes). Each MAC protocol was measured for delay, jitter, throughput, packet loss ratio, and fairness metrics, compared with IEEE 802.11 DCF, IEEE 802.11e EDCA, and a TDMA-based MAC. All protocols under low-traffic scenarios achieved reasonable values for the delay and jitter metrics, yielding suboptimal results. There were deviations when the measurement pressure and the traffic load were increased. DCF showed significant performance deterioration under high load, with collisions. EDCA has been designed to enable more efficient management of multimedia traffic and to improve throughput, delay, and jitter for high-priority traffic. However, it is prone to sustaining rapid changes. The TDMA-based protocol performed consistently, without a reduction in quality, even under high loads, thanks to its rigid time-slot assignment methodology.

$$EER = \frac{T}{E} \tag{7}$$

T: Throughput

E: Energy consumed during the transmission

This could estimate the energy efficiency with which a protocol expends energy per bit of data conveyed.

The average transmission delay as a function of network size is shown in Figure 3 for the three MAC protocols. As expected, all protocols show an increase in delay as the number of nodes increases due to higher network contention. The worst performing protocol among the three is the IEEE 802.11 DCF protocol, whose delay jumps from 20ms to 80ms when the network is scaled from ten nodes to fifty nodes. This increase is associated with the protocol's fundamental problem of increased congestion and its simple contention-based approach. EDCA achieves lower delay peaking at 55ms than DCF due to its QoS aware traffic prioritization toward multimedia streams, but still suffers mild congestion. Unlike EDCA, the TDMA-based protocol does not spike under high congestion conditions, yielding the lowest result. It increases only from 10 to 20ms of delay under the same circumstances proving TDMA's superiority over EDMA under deterministic, contention free access.

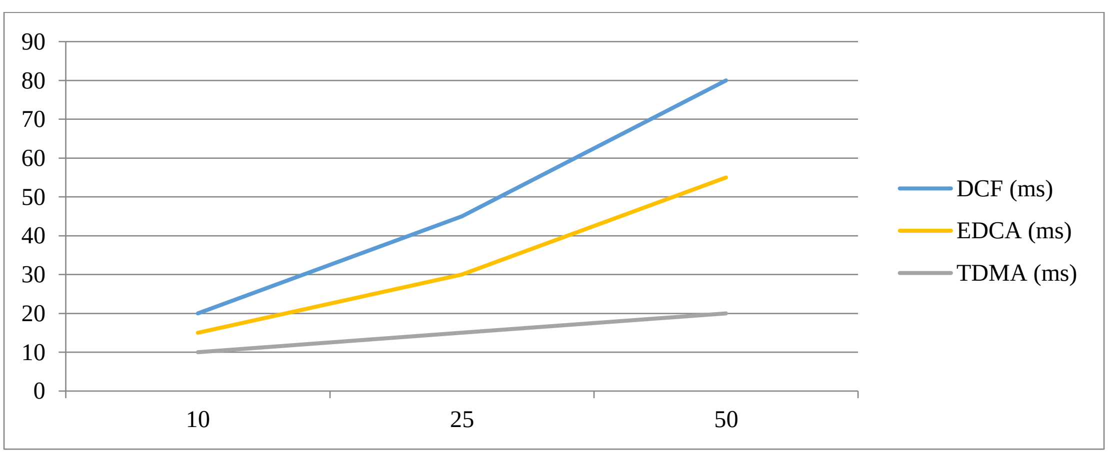

Figure 3: Average delay vs. number of nodes

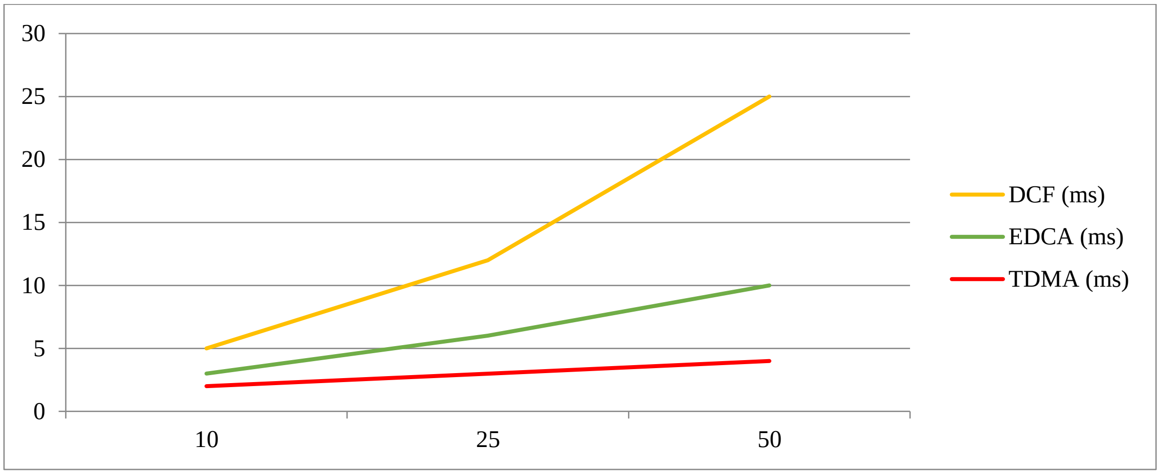

Figure 4: Jitter vs. number of nodes

The graph (Figure 4) illustrates the changes in packet arrival times, which is very important for the sustaining levels of quality in realtime multimedia applications. IEEE 802.11 DCF protocol again performs the worst; jittered delay increases from 5 ms to 25 ms as network size increases, demonstrating volatile delivery time. EDCA address this shortcoming by reducing jitter through prioritizing traffic at moderate loads, particularly underneath moderate loads. Due to fixed slot scheduling, TDMA maintains the lowest and most stable jitter profile, increasing from 2 ms to 4 ms across all traffic conditions. All these results tend to indicate that TDMA has a lot more capabilities than other protocols in supporting applications like video streaming and VoIP, which require precise timing of packet delivery.

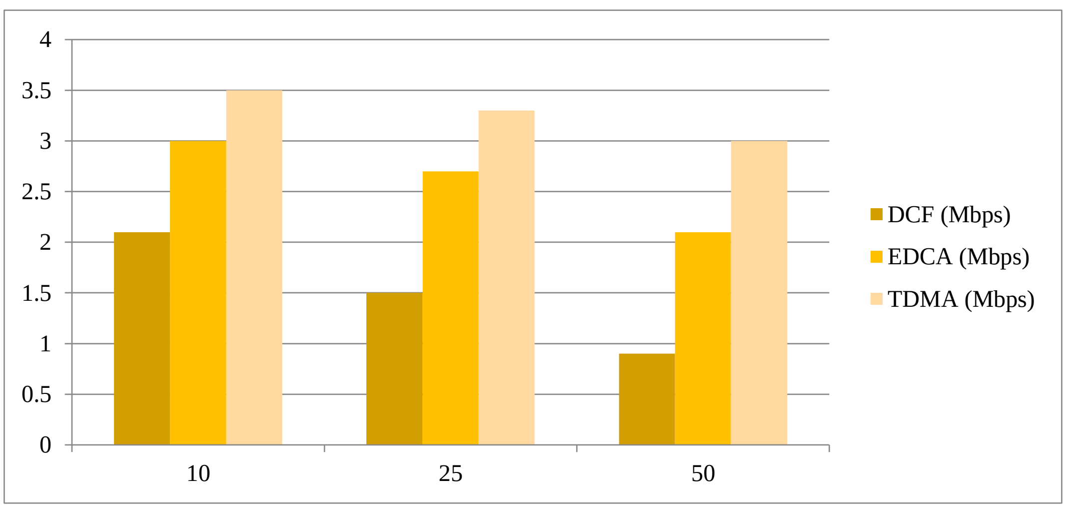

Figure 5: Throughput vs. number of nodes

This graph (Figure 5) depicts the effective data transmission rate for each MAC protocol. At lower traffic levels (10 nodes), all protocols operate at a reasonably good level, with TDMA, marginally outperforming others as well. However, with increasing node counts, DCF's throughput declines steeply due to heavy collision and retransmission, plummeting to a meager 0.9 Mbps at 50 nodes. EDCA demonstrates greater scalability, however, by retaining over 2 Mbps even in high-load conditions. Once more, TDMA outperforms others, maintaining throughput greater than 3 Mbps irrespective of network size. These results suggest that TDMA's controlled access yields optimal performance in bandwidth consumption, making it exceptionally suitable for realtime applications that are sensitive to bandwidth.

Comparison of Varying MAC Protocols Performance Metrics

The aggregate method of metric analysis focuses on establishing factors and ratios that would simplify calculation affording a greater scope of range simplify and expand their quality on the combined use of different performance evaluation metrics at once. Such a model was developed as Composite Performance Index (CPI) in the Methodology. The CPI results for the high-traffic (50-node) scenarios are listed below.

802.11 DCF: 0.45

802.11e EDCA: 0.62

TDMA-based protocol: 0.78

As the values indicate, linear TDMA-based protocols indeed showed the best results among the other protocols, in particular, for delay and jitter management. Though EDCA did improve on DCF due to the presence of some differentiation and priority queuing, performance limitations under oversaturated conditions were still bound due to contention. DCF in any case underperformed in terms of congested network performance due to excessive packet collisions and retransmission delays. Another noticeable fact is that low TDMA responsiveness to dynamic or irregular traffic patterns could be addressed with responsive rigid scheduling is actually the reason for the high TDMA CPI. Integrative slot allocation methods could enhance responsiveness within certain bounds.

$$S_i = \frac{X_i - X_{min}}{X_{max} - X_{min}} \quad (8)$$

S_i: Score that has been normalized for metric i

X_i: Unprocessed figure of metric i for a specific protocol

X_{max}, X_{min}: Minimum and maximum values for the metric of interest across protocols

It is evident that every metric was adjusted to a common scale (0-1) prior to ensuring its relevance and total aggregation in the CPI.

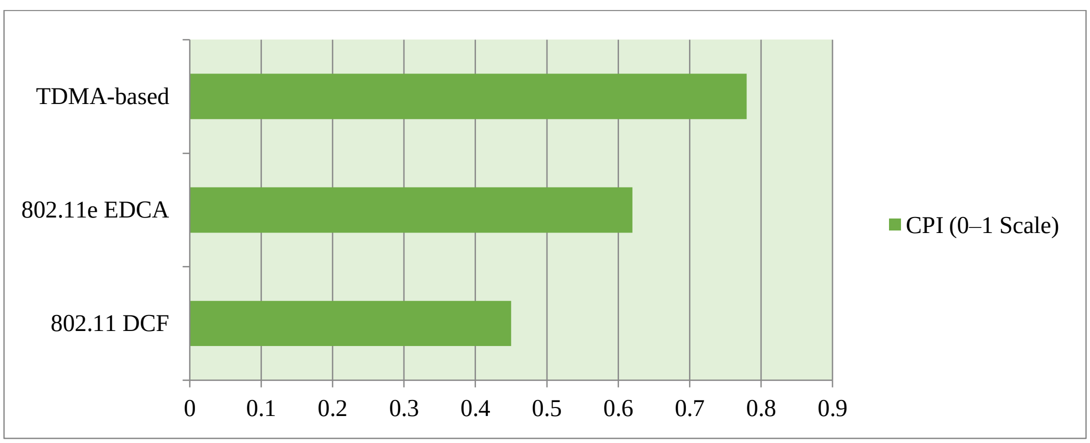

Figure 6: Composite performance index (CPI) vs. protocol

The CPI bar chart (Figure 6) captures the protocol performance scores alongside delay, jitter, throughput, packet loss, and fairness. In contrast, the TDMA-based protocol scores highest with the CPI score of 0.78, validating his dominancy in efficiently managing the requirements of real time multimedia. EDCA follows with a 0.62 score, still contention limited and under heavy load, but demonstrating improvement over DCF due to QoS support. DCF remaining weakest at 0.45 illustrates its unsuitability for demanding realtime applications. This comparison of a singular metric achieves the goal of illustrating the impact of dynamic choices for multi-focal design problems.

Analyze Conclusions and Consequences for Multifunction Realtime Applications

The prior results point towards an important balance that must be struck between access techniques when creating a MAC protocol. Sensitivity to Delay and Jitter: Coverage, whether for support or removal of coverage, calls for high responsiveness. With a view mark on smoothing jitter and optimizing valor, real time pulling out fulfills this requirement at low latency and smoothing. Versus random access methods, TDMA more successfully guarantees these conditions.

Adaptability and Scalability: While TDMA still tops in performance underload, high mobility environments or dynamically still has its cons. Beyond the occassional spike in smoothing jitter, EDCA pays for better adaptability enabling higher responsiveness.

Efficiency vs. Fairness: Fairness under all the protocols will generally be consistent, but occasionally DCF bias was seen towards aggressive senders. Although EDCA was biased towards multimedia traffic at the disadvantage of background traffic, TDMA was fair in design.

General Suitability: The evidence indicates that TDMA-based MAC protocols are best suited in the fixed, or predictable environment to a tiered, latency-sensitive application, like remote learning or telemedicine. EDCA suits better in agile and dynamically evolving environment needing a combination with QoS class differentiation in control.

$$DJIF = \alpha \cdot D + \beta \cdot J \qquad (9)$$

D: Delay

J: Jitter

α, β: Sensitivity weights (e.g. $\alpha = 0.6, \beta = 0.4$)

This allows to order the protocols regarding user experience, i.e., not by individual delay or jitter but by their sum resulting influence. In summary, simulation results validated the employing of access techniques such as TDMA in high-demand multimedia contexts. Adaptability would further increase their effectiveness.

5 Discussion

Analyzing Results within the Scope Context of Literature

Arguing with the results presented in this study is the claim that better performance with contention free MAC protocols particularly with TDMA systems are in favor of internet realtime multimedia applications. These findings substantiate the generalized idea that deterministic access techniques are more advantageous to the time-sensitive traffic due to their ability to provide predetermined limits on the latency, jitter and steady-throughput. In contrast, contention-based protocols such as the IEEE 802.11 DCF have a decreasing performance with network load as a result of collisions and consequent mandatory retransmissions. The EDCA and other improved versions do offer some degree of improvement over the legacy DCF in that it does deploy traffic prioritization mechanisms, however, they can still be termed as best-effort resource allocation with no guarantees. This performance analysis confirms the hypothesis that whereas contention-based systems are suitable in the low to moderate traffic conditions, they get unresponsive at high intensity multimedia flows. The findings of the study allow supporting the conclusion according to which TDMA-based MAC designs are ideal in QoS assurances in the usage of video-conferencing, VoIP, and live streaming since they necessitate uniformity and reduced latency.

Discussion on the Limitations of the Study and Suggestions for Further Research

The study has not failed to come up with critical conclusions in an attempt to illuminate the performance comparison of different MAC protocols. Nevertheless, there has been certain weaknesses that should be mentioned. Firstly, a simulator was used to carry out the evaluation that although this is also helpful, it might not reflect the practical realities and complexities of a real network environment. Such factors as interference, mobility of nodes, and heterogeneous nature of traffic do not leave an impact of protocol behaviour. The other weakness is the direction of the activity, which cantered on the few performance measures, including delay, jitter, throughput and a composite measure of performance that contains all the previous measures but is not as important as such areas as energy efficiency, implementation complexity and ability to scale to larger network infrastructures. In addition, the simulation scenarios had a restricted fixed node density and models of traffic that fail to reflect the spectrum of application requirements. Studies on adaptive MAC protocols alternating contention-based and contention-free and vice versa on demand of the condition of the network would be a genuine enhancement to the field. Further studies can also be used to show the practicality of machine learning algorithms to optimize MAC algorithms that do not only find the most appropriate traffic but also adjust access control dynamically to secure QoS.

Guidelines for Choosing and Implementing MAC Protocols

Based on the analysis, two-level recommendation model, as proposed, may be offered to network planners as well as multimedia application developers. TDMA-based MAC protocols are recommended in high traffic requirements with a strict realtime performance requirement, such as in telemedicine, online gaming, or remote industrial surveillance, where traffic conditions are always high and require unreliable performance. But in less demanding applications where the multimedia traffic is intermittent, superior contention protocols such as IEEE 802.11e EDCA offer an attractive and easy to implement solution. The case of heterogeneous networks whereby the nature of traffic is mixed should be investigated as well through hybrid strategies. A switchable MAC protocol that is capable of dynamically switching modes and allocating channels to realtime streams can be used to improve the efficiency and experience of such networks. Overall, the selection of a MAC protocol must be preceded by a detailed study of the requirements of particular application-level performance, the volume of traffic to expect, and network support in advanced forms of scheduling, coordination, or control subsystems.

6 Conclusion

In conclusion of the current work, the MAC protocols such as the IEEE 802.11 DCF, the IEEE 802.11e EDCA and a TDMA scheme were well evaluated relative to the realtime multimedia internet applications. The analysed data has revealed that contention-based protocols may be used successfully in the context of low network load, although their performance decreases dramatically when the load grows. An example of this is the EDCA, which has high throughput of certain types of traffic, but fails to comply with the requirements of a sensitive stream of data such as time-dependent data. Conversely, findings of all measurements delay, jitter, and throughput have shown good performances by the TDMA-based protocols, implying that they are more applicable in case of an application that has strict quality-of-service requirements. The outcomes indicate that it is necessary to select the appropriate MAC protocol based on the operating environment and peculiarities of multimedia traffic. This puts network developers and engineers that aim at optimising communication systems that are geared towards video conferencing and online gaming of services with high latency needs into a progressive perspective. The optimal method with regard to testing dynamic routers with adaptive protocols or hybrid MAC protocols as well as real world testing changes the scope of research and consequently the future research direction shifts to be offering solutions rather than imagining the solutions to the real-world problems. The additional areas of expansion of MAC prototype development are energy efficiency and mobility, as well as addressing machine learning.

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