Optimizing Collision Mitigation in Wireless Networks by Integrating Opportunistic Access and MOAR Transmission

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Abstract

The rapid evolution of wireless communication necessitates innovative solutions to address the challenges posed by dynamic channel conditions and the proliferation of wireless devices. In this context, we propose a hybrid protocol based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) , integrating opportunistic access and Multi-Objective Opportunistic Auto Rate (MOAR) transmission. We aim to enhance spectral efficiency, reduce collision rate, and improve overall network performance. We identify and address the challenges associated with dynamic channel conditions, varying network loads, and the hidden node problem. Through extensive simulation and performance analysis, we demonstrate the efficacy of our hybrid protocol in reducing collision rates. Our findings highlight the potential of the proposed protocol to revolutionize wireless communication by providing a robust and adaptive solution for modern communication scenarios.

Introduction

Modern wireless communication landscapes undergo rapid evolution, fueled by escalating demands for efficient data transmission across diverse scenarios. Previous studies have explored opportunistic communication but face challenges in seamlessly integrating it with multi-objective MOAR transmission strategies [1]. The synergistic amalgamation of opportunistic access and MOAR transmission within CSMA/CA [2] presents a promising avenue for achieving enhanced spectral efficiency, reduced collision rate, and improved network performance [3].

However, challenges abound. Dynamic wireless environments demand efficient identification of idle resources, complicating the integration of opportunistic access and transmission [4]. Balancing throughput, latency, and adapting to variable channel conditions poses significant optimization challenges [5].

Existing CSMA/CA strategies such as Clear Channel Assessment (CCA) [6], Random Backoff [7], and RTS/CTS [8] encounter notable challenges. While CCA verifies channel availability, it grapples with the hidden node problem and potential interference issues [9]. Random Backoff mitigates collisions but struggles with trade-offs between collision avoidance and network performance. RTS/CTS alleviates collisions induced by hidden nodes but introduces its own set of challenges, including increased protocol overhead [10].

Hence, there's a pressing need for a comprehensive solution like the proposed hybrid protocol. Integrating opportunistic access and MOAR transmission within CSMA/CA is essential to overcome existing limitations and advance wireless communication networks' efficiency and adaptability [11]. This study aims to introduce such a hybrid protocol, addressing the challenges mentioned and providing a robust solution for modern wireless communication scenarios.

The remaining part of the paper is structured as follows, section 1 talks about the related work and literature survey. Section 2 gives us the design and Implementation of the proposed hybrid protocol, section 3 talks about the performance metrics and results, section 4 is the conclusion, and lastly section 5 talks about future works.

1 Literature Review

1.1 Research Paper 1

Title : MOAR: A Multi-channel Opportunistic Auto-rate Media Access Protocol for Ad Hoc Networks [1]
Authors: A. Sabharwal, E. Knightly and V. Kanodia

In their research, the authors propose (MOAR), a novel MAC protocol tailored for Wireless ad hoc networks operating on the IEEE 802.11 standard, supporting multiple channels and rates. MOAR seeks to leverage the natural diversity in frequencies across multiple channels by dynamically adapting channel configurations to enhance data transmission rates. Figure 1 briefly explains the MOAR protocol's working. Its core concept revolves around enabling mobile nodes to switch to channels with a different frequency dynamically when the current channel's signal-to-noise ratio is considered unfavorable. This flexibility allows for potential improvements in data transmission rates. To mitigate resource overhead associated with channel switches, the authors suggest an optimal skipping rule, enabling nodes to determine the ideal number of channel switches based on average channel conditions by correlating PHY layer channel conditions with a MAC rule. [1]

1.1.1 Advantages

• Improved Channel Utilization: MOAR leverages multiple channels and adapts the transmission rate based on channel conditions. This allows nodes to exploit better-quality channels and potentially transmit at higher rates, leading to increased overall network throughput and reduced congestion.
• Reduced Packet Collisions: By dynamically adjusting contention window sizes based on channel quality, MOAR helps to minimize the likelihood of collisions. This can lead to improved overall network efficiency and reduced packet loss.
• Through extensive ns-2 simulations the researchers deduced that MOAR consistently exhibits a throughput enhancement ranging from 20% to 25% when contrasted with the existing MAC protocols [1].

1.1.2 Disadvantages

• While MOAR improves throughput by utilizing better channels, it introduces overhead through constant channel measurement and switching. This can negate the benefits, especially in constantly changing environments where frequent switching outweighs the gains from short-lived opportunities.
•The MOAR protocol operates after the channel access contention, which continues to follow a conventional non-opportunistic method. MOAR leverages the temporal and spectral diversity of individual nodes, rather than the diversity of users within the network [12].

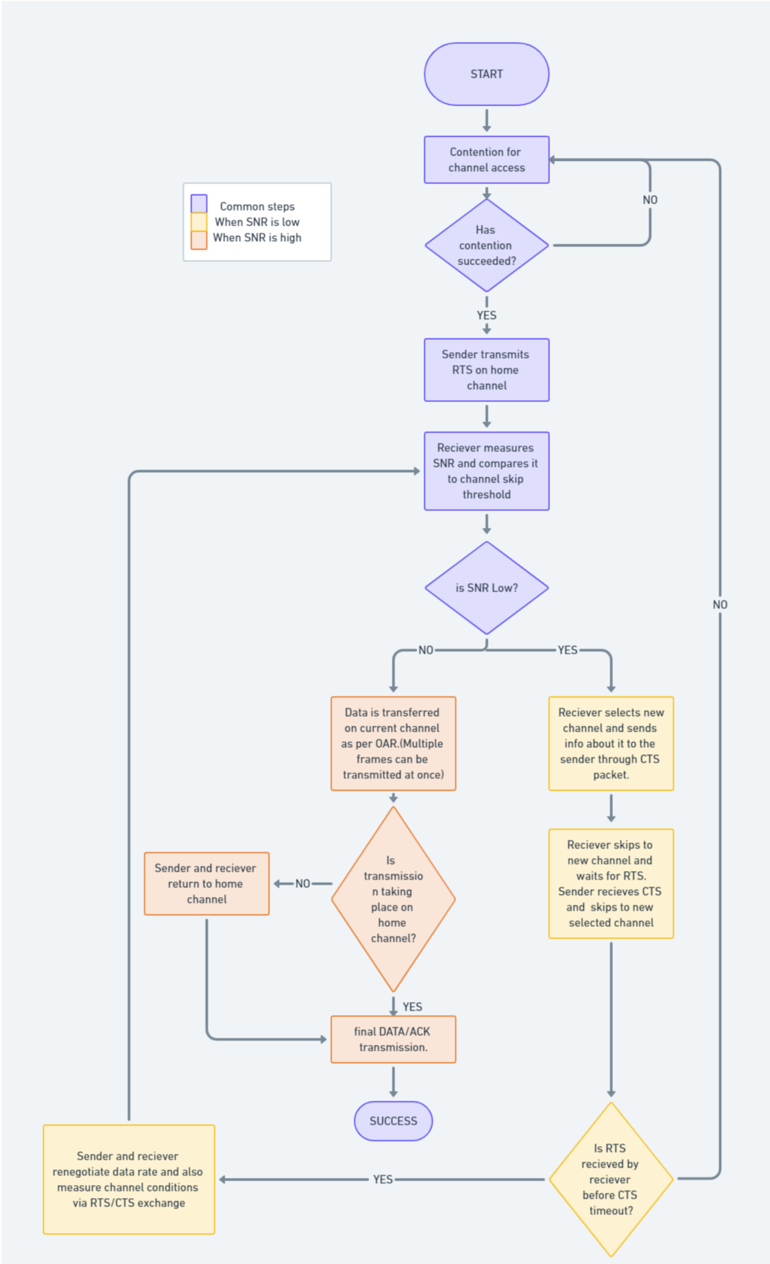

Figure 1: MOAR Protocol Mechanism Flowchart [1]

1.2 Research Paper 2

Title: Opportunistic Random Access in CSMA/CA-Based Wireless Networks [12]
Author : J Balasubramani

The paper commences by providing an overview of CSMA/CA and associated mechanisms such as RTS/CTS, as well as opportunistic scheduling and transmission protocols like MOAR [12]. To harness user diversity, which pertains to variations in channel conditions among users, the author introduces and assesses three opportunistic access schemes within the CSMA/CA framework. A node in a CSMA/CA network, as depicted in the flowchart 2, first checks for channel availability through a channel sense operation [12]. If free, it transmits the data frame directly. When the channel is busy, the node enters a contention phase. The flowchart outlines two potential methods – overlapped and separated contention. In both methods, a contention window (CW) is calculated based on the node's bit rate. This window defines a range of backoff slots from which a random value is selected. The node then waits for the chosen number of slots to expire before attempting transmission again. This probabilistic approach reduces the likelihood of collisions by preventing multiple nodes from transmitting simultaneously. If a collision occurs, the flowchart indicates increasing the CW and re-entering the contention phase. This combination of channel sense, backoff selection, and potential retransmission ensures orderly data exchange in the CSMA/CA network [12].

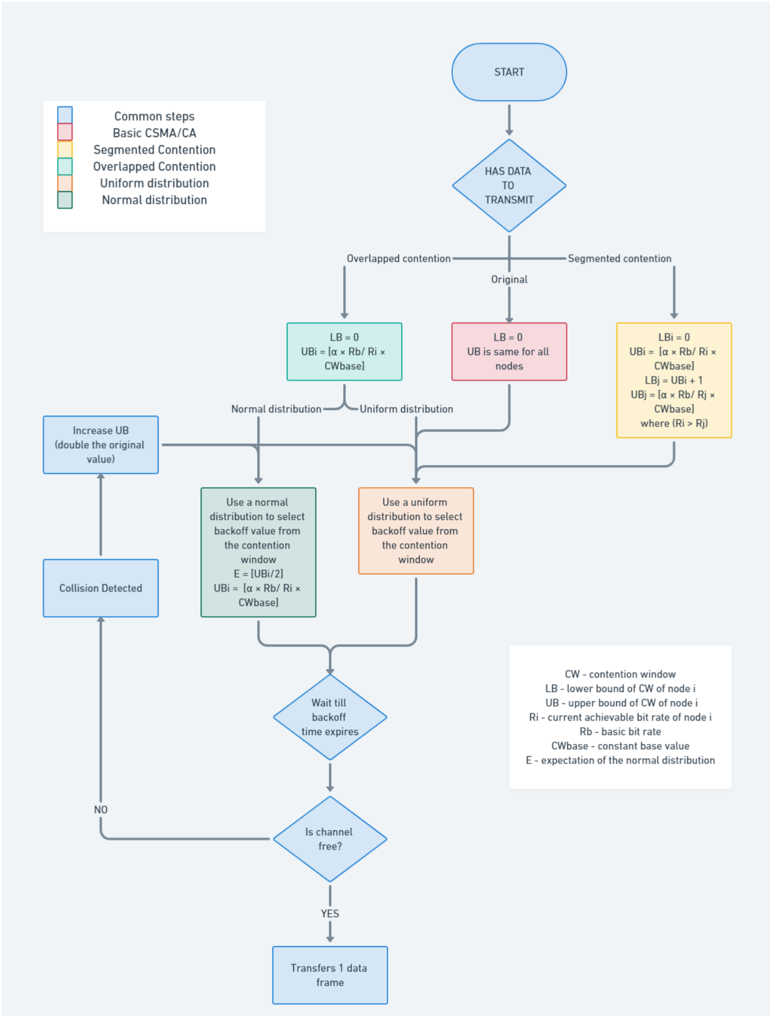

Figure 2: comparison between various opportunistic access methods in csma/ca [12]

1.2.1 Advantages

Through extensive NS-3 simulations performed by the author, it is demonstrated that the suggested methods can notably enhance network performance in terms of jitter, latency, and throughput as compared to the existing CSMA/CA protocol in IEEE 802.11 networks. Specifically, the overlapping contention method can deliver enhancements of 37.5% and 73.3% in throughput for ad-hoc and infrastructure networks, respectively [12].

1.2.2 Disadvantages

• Nodes with high bit rates tend to possess smaller contention windows, escalating the probability of multiple nodes selecting identical back-off values and resulting in heightened collision rates. Although the binary exponential back-off mechanism can mitigate collisions, it incurs reduced network efficiency due to the wastage of channel resources.
• In scenarios with limited user diversity, opportunistic access shows minimal deviation from the original access method. Additionally, unlike MOAR, the opportunistic access method fails to exploit the time/frequency diversity of a node.

1.3 Conclusion

In conclusion, both methods(CSMA/CA with opportunistic transmission and CSMA/CA with opportunistic random access) aim to improve the performance of wireless networks by taking advantage of the varying conditions of wireless channels. However, their approaches and the specific mechanisms they use to achieve this are different. MOAR consistently exhibits a throughput enhancement ranging from 20% to 25% when contrasted with the existing MAC protocols, while the opportunistic access schemes show substantial improvements, with the overlapped contention method delivering enhancements of 37.5% and 73.3% in throughput for ad-hoc and infrastructure networks, respectively. This suggests that while MOAR provides a consistent increase in throughput, opportunistic access solutions can yield even greater improvements, particularly in scenarios where channel conditions vary significantly.

2 Design and Implementation

2.1 Opportunistic Access Module:

At the beginning of the process, the system initiates the procedure for accessing the communication channel. This marks the start of the opportunistic access protocol. The first action taken is to assess the current status of the communication channel. This step involves observing whether the channel is currently engaged in transmitting data or if it's available and not in use. If the channel is not idle, indicating that it's occupied with ongoing transmissions, the system responds accordingly, often by deferring transmission attempts until the channel becomes free. When the channel is confirmed to be idle, it signifies that there are no ongoing transmissions, and the channel is free for use. This condition prompts the system to move forward with attempting to access the channel. Before initiating opportunistic contention, the system selects the contention window size. This step determines the range of back-off slots from which a random value is chosen to decide the waiting time before reattempting transmission. Opportunistic channel contention involves nodes checking if the channel is idle. Upon detecting an idle channel, nodes opportunistically contend for access by initiating transmission attempts. If successful, the node starts transmission; otherwise, it retries after a random back-off period if contention fails. This approach optimizes channel utilization by dynamically seizing transmission opportunities, minimizing collisions, and enhancing network efficiency. If the contention for channel access is successful, it indicates that the transmission attempt was effective, and the node can proceed with sending its data or message over the channel. Once the transmission is successful, or if there are no further actions required, the process comes to an end, and the node resumes its regular operations. The flowchart 3 gives a brief idea about the processes involved in this module. The flowchart outlines a sequence of steps involved in opportunistic channel access within CSMA/CA, where nodes opportunistically contend for channel access when they detect that the channel is idle. This process ensures efficient utilization of the communication channel while minimizing the likelihood of collisions and interference, ultimately facilitating effective communication among network nodes.

Algorithm 1 Opportunistic Access with MOAR Transmission

Nodes, Time step t Collision count
Initialize $collisionCount = 0$
Simulate channel conditions:
$channelStatus = simulateChannelConditions()$
Iterate through each node:
node in nodes $channelStatus ==$ "idle" Node opportunistically accesses the channel for data transmission
Use MOAR for transmission
Simulate collision with a certain probability:
random() < 0.2 Collision occurred Increment $collisionCount$ Channel is busy, node waits

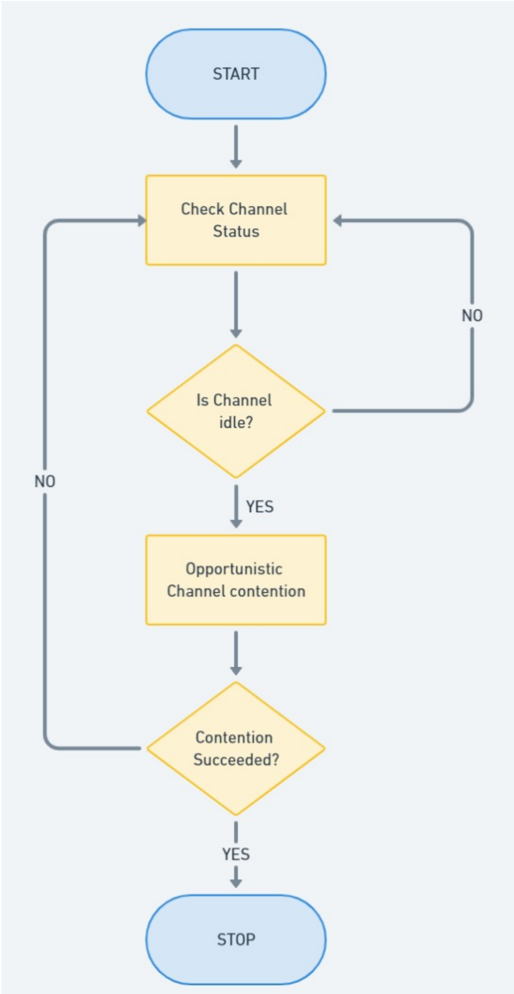

Figure 3: opportunistic access module

2.2 Multi-Objective Auto Rate Transmission Module:

The MOAR transmission module dynamically adjusts transmission rates based on the prevailing network conditions and objectives. This adaptation allows nodes to respond to changes in channel quality, traffic load, and other environmental factors in real time. By dynamically optimizing transmission rates, the module aims to achieve the best possible balance between competing objectives, such as maximizing data throughput while minimizing latency and energy consumption. To inform the rate adjustment process, the MOAR module utilizes feedback mechanisms to collect information about channel quality and network performance. This feedback may include metrics such as signal-to-noise ratio, packet loss rate, and round-trip time. By continuously monitoring network conditions and collecting feedback, the module gains insights into the current state of the network, enabling informed decisions regarding transmission rate adjustments. Algorithms inspired by [1] are employed to optimize transmission rates based on the observed network conditions. These algorithms consider various factors, including channel conditions, traffic patterns, and quality-of-service requirements, to dynamically adjust transmission rates. By leveraging sophisticated optimization algorithms, the MOAR module can adapt to changing network dynamics and achieve efficient utilization of available resources. The flowchart 4 gives an idea about the flow of processes in the MOAR module. Once the process starts, the most favorable channel for transmission is decided based on the sound-to-noise ratio (SNR), and then the channel conditions are measured. Lastly, there is the adjustment of the transmission rate based on channel conditions.

Algorithm 2 Multi-Objective Auto Rate Transmission

for each node in network:
adjust transmission rate based on network conditions and objectives
transmissionRate = node.TransmissionPower * networkConditions.channelQuality
Update node's transmission rate
node.TransmissionRate ← transmissionRate
Display transmission rate adjustment

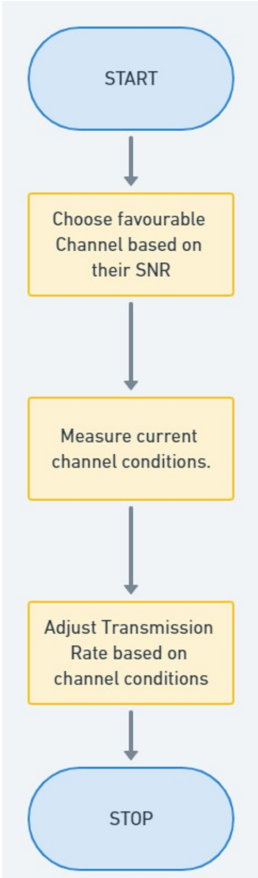

Figure 4: Multi-Objective Auto Rate Transmission Module:

2.3 Hidden Node Mitigation Module:

The protocol utilizes Request-to-Send / Clear-to-Send (RTS/CTS) mechanisms as a proactive measure to mitigate collisions caused by hidden nodes. When a node intends to transmit data, it first sends out an RTS frame to the intended receiver, indicating its intention to transmit and reserving the channel for communication. Upon receiving the RTS frame, the intended receiver responds with a CTS frame, confirming the availability of the channel and notifying other nodes to refrain from transmitting during the reserved time. By establishing this two-way handshake mechanism, RTS/CTS helps prevent collisions between hidden nodes, ensuring more reliable communication. Nodes exchange RTS and CTS frames to establish clear communication channels and avoid interference from hidden nodes. The RTS frame includes information about the sender's intention to transmit, the duration of the transmission, and the receiver's identity. Upon receiving the RTS frame, the intended receiver responds with a CTS frame, acknowledging the request and indicating its readiness to receive data. This exchange of frames allows nodes to coordinate their transmissions and avoid collisions, thereby enhancing the reliability of data transmission. Virtual carrier sensing techniques are employed to enhance the accuracy of channel assessment and mitigate interference caused by hidden nodes. Nodes use virtual carrier sensing to monitor the wireless medium for ongoing transmissions, even if they cannot directly detect signals from hidden nodes. By analyzing the activity on the channel and interpreting the RTS/CTS exchanges, nodes can infer the presence of hidden nodes and adjust their transmission behavior accordingly. This enhanced awareness of hidden nodes allows nodes to make more informed decisions about channel access, reducing the likelihood of collisions and improving overall network performance. This flowchart 5 describes the flow of processes in the hidden node mitigation module.

Algorithm 3 Hidden Node Mitigation Module

Hidden Node Mitigation Module
for each node in network:
simulate RTS/CTS exchange
if RTS sent but CTS not received:
Hidden node detected
Mitigate hidden node by interference using virtual carrier sensing
Node backs off for a random duration
Increment collision count

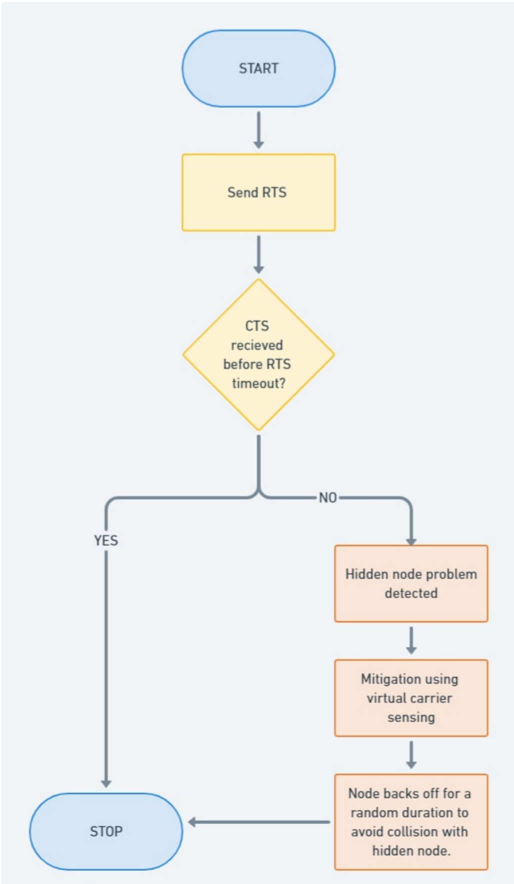

Figure 5: hidden node mitigation module

2.4 Summary:

In summary, the simulation progresses through each time step, simulating channel conditions, node behavior, and network interactions. Nodes operate based on the simulated channel conditions. When the channel is idle, nodes opportunistically attempt to transmit data. If the channel is busy, nodes wait for the next opportunity to transmit. The Multi-Objective Auto Rate (MOAR) transmission module dynamically adjusts the transmission rates of nodes based on network conditions. Request-to-Send (RTS) and Clear-to-Send (CTS) mechanisms are employed as proactive measures to mitigate collisions. This two-way handshake mechanism helps prevent collisions between hidden nodes and ensures more reliable communication. The basic flow of processes can be seen in 7

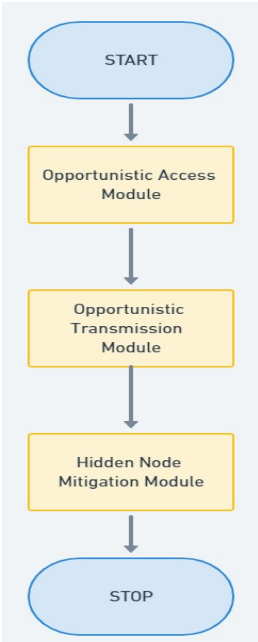

Figure 6: Summary

3 Result and Analysis

Our approach achieved a substantial reduction in average collision rates compared to traditional CSMA/CA protocols. After effectively implementing our protocol in MATLAB we subjected our protocol to extensive testing with large-scale scenarios, and we achieved a remarkable 84% reduction in the average collision count compared to the conventional CSMA/CA protocol. The average collision count using our protocol came to be around 0.76, for 10 nodes and a very large time step, on the contrary, csma/ca resulted in an average collision count of 5.06 in similar network and channel conditions. This can also be seen in Figure 7. The collision rate vs. time analysis depicted in Figure 8 underscores the steady and significant reduction in collisions facilitated by our protocol, reaffirming its practical utility and reliability in real-world scenarios.

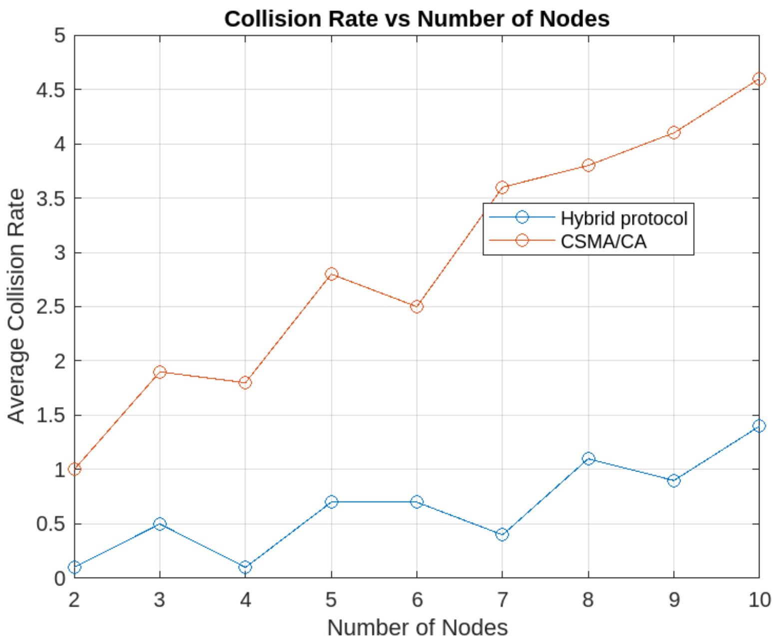

Figure 7: Comparison of collision rate between CSMA/CA and hybrid protocol

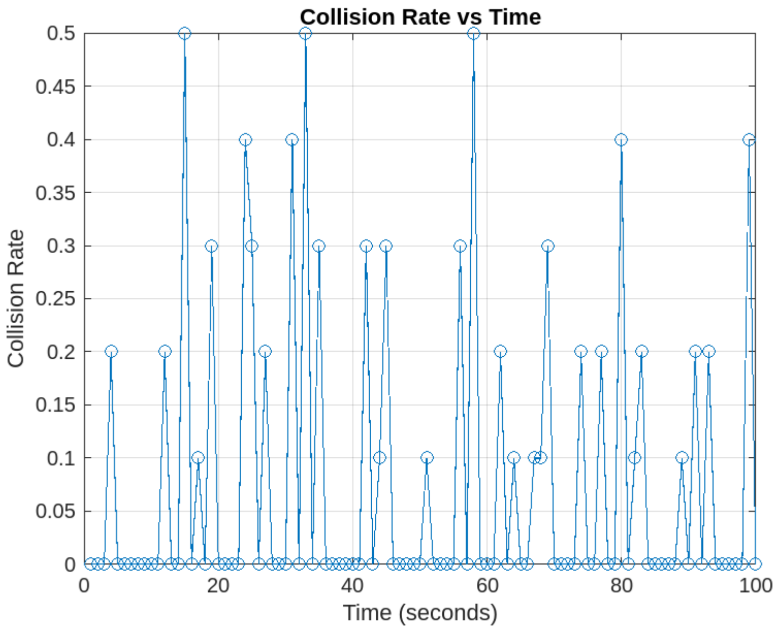

Figure 8: collision rate vs time for hybrid protocol

4 Conclusion

In conclusion, our research presents a substantial advancement in the domain of wireless communication protocols. Our extensive testing encompassed large-scale scenarios, ensuring the robustness and scalability of our proposed solution. Through these simulations, we observed a consistent improvement in collision mitigation, reinforcing the efficacy of our hybrid protocol across diverse network environments. By seamlessly integrating Opportunistic Access and MOAR Transmission into the CSMA/CA framework, we have devised a solution capable of significantly reducing collision rates and enhancing network performance. We believe that our findings pave the way for future innovations in protocol design, offering promising avenues for optimizing wireless communication systems to meet the demands of evolving networking paradigms.

5 Future Work

While our hybrid protocol has shown promising results in reducing collision rates, it is imperative to acknowledge the challenges encountered in improving latency and throughput metrics. Despite our efforts in optimization and refinement, the gains achieved in these areas did not meet our initial expectations. This highlights the intricate nature of balancing competing objectives in wireless network design and emphasizes the need for continued research and innovation.

One avenue for future exploration involves delving deeper into the optimization of latency and throughput metrics within the context of our hybrid protocol. This could entail further refinement of transmission scheduling algorithms, exploration of advanced coding and modulation schemes, or even integration of machine learning techniques to dynamically adapt protocol parameters based on network conditions.

Additionally, investigating the impact of varying network topologies and traffic patterns on protocol performance could provide valuable insights. Conducting experiments in real-world deployment scenarios or utilizing more advanced simulation techniques could help validate and refine our findings.

Addressing the challenges posed by latency-sensitive applications and high-throughput requirements remains a critical area for future research. By iteratively refining our hybrid protocol and exploring innovative approaches, we can strive towards achieving a more balanced optimization of latency, throughput, and collision rates, ultimately advancing the state-of-the-art in wireless communication protocols.

In conclusion, while our study has laid a solid foundation for collision mitigation within wireless networks, there exists ample room for further investigation and refinement. By embracing these challenges and continuing to push the boundaries of protocol design, we can unlock new possibilities for enhancing the performance and reliability of wireless communication systems in diverse application domains.

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