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Refine the Ideal Rate Adaptation Algorithm to optimize Wi-Fi Networks

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Abstract

Several Rate Adaptation Algorithms have been proposed and implemented over the years, ranging from simple fixed-threshold methods to more complex machine learning based approaches. These algorithms employ different strategies to determine the optimal data rate, such as monitoring the number of successful or failed transmission attempts and estimating the channel conditions based on SINR or RSSI. In this paper, we evaluated four different Rate Adaptation Algorithms. The primary focus of this analysis was to determine their performance in terms of throughput and packet loss across various network conditions. These algorithms, which represented a range of approaches to rate adaptation, were tested to help us understand their relative strengths and weaknesses and select the most effective one. We then discuss the lessons learned from the results of this evaluation.

Introduction

Wireless communication technologies have become an increasingly popular method for establishing connectivity between connected nodes without requiring extensive cable deployment. Such technologies are critical for many applications, especially ones that require mobility, including vehicular networks for Cooperative Intelligent Transport Systems (C-ITS) [1, 2], mobile-connected engines for precision farming [3, 4], and a wide range of applications used on mobile phones and that rely on cellular networks. Wi-Fi [5] is a popular way to provide wireless communication, offering high speed data transfer for various devices. Recent advancements in Wi-Fi standards, such as the introduction of Wi-Fi 6 and Wi-Fi 7 with data rates up to 30 Gbps, have led to improved network efficiency, increased throughput, and reduced latency, thereby supporting the growing demands of data-intensive applications. In this work, we decided to focus on Wi-Fi technology because it offers a good compromise between performance and availability. It is an autonomous system that can be deployed anywhere without the need for a telecommunication operator coverage. Furthermore, it offers high data rates that can support a wide range of modern applications.

Wi-Fi is a widely adopted wireless communication technology integral to a variety of devices. Wi-Fi networks are critical in wireless communication systems by offering internet connectivity and data transmission capabilities to various devices, including smart phones, laptops, tablets,

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and smart appliances. Typically, Wi-Fi networks adhere to the IEEE 802.11 standards, which have undergone numerous modifications to improve network efficiency and speed. Two primary types of Wi-Fi networks exist infrastructure mode and ad-hoc mode. In order to maintain high-performance Wi-Fi networks, optimization strategies are necessary to tackle these challenges effectively. Optimizing Wi-Fi networks involves various approaches on different network layers, including data rate adaptation, deployment optimization, QoS prioritization, and congestion control to ensure reliable connections even in dense network environments. In the first step of the thesis, we studied Rate Adaptation Algorithms that adjust the data rate on the lower layers of Wi-Fi. Various algorithms have been proposed over the years, each utilizing unique strategies to determine the optimal data rate. We categorized the algorithms according to the way they behave. Then, we picked and evaluated four algorithms from the previous related articles to determine their performance in terms of throughput and packet loss under different network conditions. We listed their strengths and weaknesses and the lessons learned from the study. Finally, we select the most effective algorithm based on our results.

Rate Adaptation Algorithms

Rate Adaptation Algorithm is an important feature of Wi-Fi that is not specified in the standard but is left for the manufacturer to decide. These algorithms are responsible for adjusting the data rate of a Wi-Fi transmission based on the channel conditions. In other words, Rate Adaptation Algorithm determines the maximum speed at which data can be transmitted over a wireless link. The objective of Rate Adaptation Algorithm is to achieve the highest possible throughput while maintaining a stable and reliable wireless connection. The algorithms are designed to take into account the capabilities of the devices involved in the communication, such as the MMCS values, channel widths, number of spatial streams, and guard interval lengths supported by the devices. The implementation of Rate Adaptation Algorithm can have a significant impact on the performance of Wi-Fi devices. A poorly designed algorithm can result in low throughput, frequent re-transmissions, and unstable connections, leading to a frustrating user experience. On the other hand, a well-designed algorithm can achieve high throughput, low latency, and stable connections, improving the user experience and enhancing the overall performance of the network. Rate Adaptation Algorithms can be classified into various categories according to the metrics that they use to evaluate the channel or link quality, such as frame loss and SINR in [6], or consecutive transmission count, frame loss ratio, transmission time, throughput, SINR, bit error rate, and combined metrics in [7]. We chose to classify Rate Adaptation Algorithms into three categories:

A. Explicit Feedback

Rate Adaptation Algorithms base their adaptation on the feedback of the receiver.

B. Implicit Feedback

Rate Adaptation Algorithms base their adaptation on the information available on the sender side.

C. Hybrid

which is a category that combines information from the feedback of the receiver and information available to the sender In what follows, we will describe each of these categories by selecting representative Rate Adaptation Algorithms of each category.

Explicit Feedback Algorithms

Explicit Feedback is a receiver-driven rate adaptation scheme where the receiver makes a decision based on its estimation of the channel conditions and relays it back to the sender via different approaches using control frames, such as CTS and ACK. On-Demand Feedback Rate Adaptation (OFRA) [8] is a receiver-based Rate Adaptation Algorithm, where the channel quality is estimated at the receiver based on SINR values. The receiver selects the optimal bit rate from a lookup table created previously. It contains a set of thresholds at which data rates should be changed. This information is returned to the sender on demand while using ACK frames. In the case of ACKless traffic, OFRA uses a specially designed feedback frame. OFRA presents some limitations, such as modifying the ACK frame that violates the standard and introducing additional overhead with the special feedback frame sent at the lowest data rate. SNR-aware Intra-frame Rate Adaptation (SIRA) [9] selects two rates for a single Aggregate MAC Protocol Data Unit (Aggregated MAC Protocol Data Unit (AMPDU)) transmission. It finds the starting symbol “I” when the rate should be changed. When the condition $SINR_i < SINR_{th}$ is met, the symbol “I” is found. $SINR_{th}$ is the minimum SINR at which the theoretical Bit Error Rate (BER) of the primary rate is less than 10^{-4}. Subsequently, “I” is fed back to the sender via the BlockAck. The main drawback of SIRA is that it only determines two rates for an aggregated frame, which may not be enough for a fast-changing channel. An Ideal Rate Adaptation Algorithm is implemented in the famous network simulator NS-2. This Rate Adaptation Algorithm initially creates a table of SINR and MMCS pairs. The SINR thresholds in this table ensure selecting an MMCS that leads to a Bit Error Rate (BER) below a certain value. For example, the default value is 10^{-5}, and the SINR is fed back from the receiver to the transmitter via a perfect out-of-band mechanism. The main drawback of this mechanism is the use of an out-of-band channel for sending back the feedback, which is not available in the Industrial, Scientific, and Medical (ISM) bands used by IEEE 802.11. SNR-aware Intra-frame Rate Adaptation (SIRA) [9] selects two rates for a single Aggregate MAC Protocol Data Unit (Aggregated MAC Protocol Data Unit (AMPDU)) transmission. It finds the starting symbol “I” when the rate should be changed. When the condition SINRi <SINRth is met, the symbol “I” is found. SINRth is the minimum SINR at which the theoretical Bit Error Rate (BER) of the primary rate is less than 10−4. Subsequently, “I” is fed back to the sender via the BlockAck. The main drawback of SIRA is that it only determines two rates for an aggregated frame, which may not be enough for a fast-changing channel.

Implicit Feedback Algorithms

Implicit Feedback is a sender-driven rate adaptation scheme usually based on Packet Error Rate (PER). The main idea is for the sender to select an appropriate data rate based on the PER observed on his side. This mainly requires ACK to enable the sender to calculate PER.

MIMO Rate Adaptation (MRA) [10] is a rate adaptation used for MIMO channels. It overcomes MPDU loss by applying a zigzag rate adaptation between intramode and inter-mode. MRA first performs probing on the rate in MIMO intramode. If goodput is not increased in intra-mode, MRA zigzags to inter-mode MIMO. The probing mechanism only starts if significant changes occur in the measured moving average goodput of the current rate. The probing interval of MRA is also adapted, which limits the probing number when goodput is low. MRA also considers frame aggregation and Block Acknowledgement schemes when performing the best data rate probing. It also includes a collision-aware mechanism where the sender detects collision if it satisfies the condition that the aggregate frame has experienced at least one retry. The loss ratio of its sub-frames is less than 10%. If collision exists, it triggers the adaptive RTS/CTS mechanism. The main drawback of MRA is the introduction of overhead when using the RTS/CTS mechanism. Rate Adaptation for Multi-Antenna System (RAMAS) [11] is a credit based approach. The data rates are grouped into two groups: modulation and enhancement groups. The modulation group consists of different MMCS values. The enhancement group consists of spatial stream, guard interval, and channel width. RAMAS uses credit-based algorithms, which rely on the packets’ success and failure statistics, to adapt these groups independently of each other and combine the results together to decide the overall feature set. In each group, different rules are applied to increase or decrease the data rate sequentially. The main drawback of RAMAS is that it performs poorly because its credit-based scheme is conservative in adapting the number of streams and aggressive in adapting the MMCS. This mismatch causes RAMAS to often operate at sub-optimal settings with single stream and high MMCS values leading to higher losses and reduced performance, as shown in the evaluations in [12]. Damysus [13] addresses 802.11ax exploiting the Basic Service Set (BSS) Color Scheme. It increases transmission opportunities by using adaptive Overlapping Basic Service Set (OBSS)/Preamble-Detection (PD) thresholds, leading to a higher contention inside a BSS and jointly adjusting the transmit power level. A statistical study is done during an interval of 100ms and a cycle of 1 second, where packet transmissions’ success and failure are recorded and compared to the success and failure thresholds. Depending on the statistical results collected, it is then decided whether to increase or decrease either the rate, the OBSS/PD threshold, or the transmission power. The main drawback of Damysus is relying on packet loss ratio thresholds. In [14], several experiments were done to verify that no single best Packet Loss Ratio (PLR) threshold can help achieve the maximum throughput. MIMO Rate Adaptation (MRA) [10] is a rate adaptation used for MIMO channels. It overcomes MPDU loss by applying a zigzag rate adaptation between intramode and inter-mode. MRA first performs probing on the rate in MIMO intramode. If goodput is not increased in intra-mode, MRA zigzags to inter-mode MIMO. The probing mechanism only starts if significant changes occur in the measured moving average goodput of the current rate. The probing interval of MRA is also adapted, which limits the probing number when goodput is low. MRA also considers frame aggregation and Block Acknowledgement schemes when performing the best data rate probing. It also includes a collision-aware mechanism where the sender detects collision if it satisfies the condition that the aggregate frame has experienced at least one retry. The loss ratio of its sub-frames is less than 10%. If collision exists, it triggers the adaptive RTS/CTS mechanism. The main drawback of MRA is the introduction of overhead when using the RTS/CTS mechanism.

Hybrid Adaptation

EasiRA [15] measures the link quality by two means. First, it calculates the FLR and combines it with mobility and other sensor information. Secondly, it obtains the Environmental Signal Strength (ESS) information to help differentiate the causes of packet loss. When a packet cannot be successfully received due to bit errors, the receiver sends a special control frame, named ”Non-Acknowledgements (NACK)”, to the transmitter to inform it that it may suffer a collision. If the transmitter does not receive an ACK or a NACK, it reduces the rate. Finally, it combines the random and deterministic rate adaptation mechanisms together. The main drawback of EasiRA is that it tries to identify collisions while using external information, such as sensor-hints and ESS, which may not be available on all devices. Rate Adaptation Algorithms play a crucial role in adjusting the data rate between access points and users based on channel conditions. Many of these algorithms use metrics such as SINR information to make decisions on MMCS. Maintaining a high SINR is essential to achieve high data rates. Thus, effective WiFi deployments could consider metrics like SINR as a significant design parameter. In the following section, we will explore channel modeling, which is considered a step before deployment that takes into account SINR based on the MMCS requirement of the application EasiRA [15] measures the link quality by two means. First, it calculates the FLR and combines it with mobility and other sensor information. Secondly, it obtains the Environmental Signal Strength (ESS) information to help differentiate the causes of packet loss. When a packet cannot be successfully received due to bit errors, the receiver sends a special control frame, named ”Non-Acknowledgements (NACK)”, to the transmitter to inform it that it may suffer a collision. If the transmitter does not receive an ACK or a NACK, it reduces the rate. Finally, it combines the random and deterministic rate adaptation mechanisms together. The main drawback of EasiRA is that it tries to identify collisions while using external information, such as sensor-hints and ESS, which may not be available on all devices.

Simulation and results

In this subsection, we assess the performance of representative algorithms from each Rate Adaptation Algorithm category (implicit, explicit, and hybrid) under mobility scenarios. The algorithms include Ideal, SIRA[9], MRA[10], and EasiRA[15]. Each algorithm represents a different category. MRA and SIRA are implicit feedback algorithms, with MRA being a commonly used algorithm implemented in the Linux kernel. It aimed to select a sampling rate resulting in the highest through- put and probability of successfully delivering frames. On the other hand, SIRA could serve as an extension algorithm to MRA, enhancing its performance by adapting the number of MPDUs in aggregated frames without reducing the transmission rate. To our knowledge, SIRA had not been tested in a dense environment. Among the few hybrid Rate Adaptation Algorithms in the articles, EasiRA was the most generic algorithm compared to the other hybrid algorithms proposed for specific scenarios. The idea behind EasiRA was promising since it could distinguish the reason for packet loss and relied on SINR. These algorithms offer a comprehensive understanding of Rate Adaptation Algorithms as they rely on various metrics and approaches commonly used in the previous related articles. We used the NS-2 network simulator to compare and evaluate the performance of the algorithms. Ideal and MRA algorithms were already implemented in the simulator. We modified the original implementation of the Ideal algorithm in the simulator to ensure a fair comparison among the selected algorithms. We included feedback in the reserved bits of the BlockAck[100], which was sent back to the transmitter on the same communication channel. We assumed all nodes had only one communication channel for data and control traffic exchange. We implemented SIRA and EasiRA algorithms and selected specific metrics to evaluate their performance, including throughput, selected MMCS values, FLR based on MPDUs, and FLR based on A-MPDUs.

- Throughput: provides a global view of the achieved performance and is calculated at the physical layer.
- Selected MMCS index: gives insight into the different choices made by Rate Adaptation Algorithms and their impact on performance.
- FLR (MPDU): provides an overview of overall lost MPDUs using the Block Ack information.
- FLR (A-MPDU): relies on the number of times the transmitter needed to retransmit the whole A-MPDU frame.

Table 1 presents the different modulation and coding schemes of IEEE 802.11ac. We evaluated all of these performance metrics based on the number of nodes in the network. To achieve this, we increased the number of nodes while keeping the deployment surface constant. This node increase resulted in higher traffic load and interference levels, allowing us to assess how the algorithms behaved under increased interference conditions.

We evaluated the algorithms in three different scenarios:

- Interference-free network: highlights the impact of link degradation on RATE ADAPTATION ALGORITHMs due to mobility. In this scenario, a mobile node is moving away from a static access point. This allowed us to evaluate the efficiency of Rate Adaptation Algorithms in adapting the rate according to RSSI values without interference.
- Infrastructure network: represents the most commonly used deployment mode. In this scenario, we evaluate the behavior of Rate Adaptation Algorithms in a standard deployment with one access point through which all network traffic needs to pass to be relayed to a wired network. There is only one receiver, and the SINR values for each link with the other mobile nodes in the network vary based on their mobility patterns.

A. Throughput

Provides a global view of the achieved performance and is calculated at the physical layer.

B. Selected MMCS index

Gives insight into the different choices made by Rate Adaptation Algorithms and their impact on performance.

C. FLR (MPDU)

Provides an overview of overall lost MPDUs using the Block Ack information.

D. FLR (A-MPDU)

Relies on the number of times the transmitter needed to retransmit the whole A-MPDU frame.

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B. Infrastructure network

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Table1: Modulation and coding schemes

MMCS Index	Modulation Type	Coding Rate
0	BPSK	1/2
1	QPSK	1/2
2	QPSK	3/4
3	16-QAM	1/2
4	16-QAM	3/4
5	64-QAM	2/3
6	64-QAM	3/4
7	64-QAM	5/6
8	256-QAM	3/4
9	256-QAM	5/6

C. Ad Hoc network

the most complex deployment in terms of interference where the receivers are randomly spread throughout the network and interference levels are highly unstable due to mobility. All nodes need to adapt their rates depending on the channel conditions and network dynamics, such as node density and mobility.
In the infrastructure and ad hoc scenarios, direct connectivity was ensured for the duration of the simulation to avoid routing protocol impact. This allowed us to concentrate on interference and mobility impacts on Rate Adaptation Algorithms. Each simulation result presented is the mean value of 70 simulations, with the bars in the graphs representing the standard deviation. Table 2 summarizes the network parameters of the simulation. Simulation duration of 50 seconds was sufficient to ensure randomness in the movement in the nodes within the square boundaries and for the selected algorithms to converge. We used Log Normal Shadowing and Weibull loss models to make the simulations more realistic regarding link quality and stability. We preferred UDP to TCP for traffic generation to avoid TCP overhead and its rate adaptation. As for packet size and mobility speed, we did not study their impacts, and the chosen values were representative of average to big-sized frames and relatively fast-moving nodes.

Scenario 1 - Interference Free Network

In this scenario, we consider a simple network configuration with only one communication link. One stationary AP and one mobile station moved away from the AP at a speed of 6 m/s, as stated in Table 2. The primary purpose of this scenario was to evaluate the efficiency of Rate Adaptation Algorithms under the influence of mobility in an interference-free network. We measured the throughput of the four algorithms as the station moved progressively away from the AP. As shown in Figure 1, although the results of all tested algorithms were similar, the Ideal and EasiRA Rate Adaptation Algorithms performed slightly better than the MRA and SIRA algorithms. The Ideal algorithm detected channel changes faster than other algorithms and adapted the rate accordingly due to its fast feedback and decision-making capabilities. EasiRA had a slightly lower throughput than Ideal due to the algorithm taking decisions every ten frames.

Table 2: Simulation parameters

Parameter	Value
Simulation Time	50 s
Runs	70
WLAN Standard	IEEE.802.11ac
Path loss model	Log Normal Shadowing
Fast fading loss model	Weibull
Traffic	UDP
Packet size	2000 Bytes
Data Rate	80 Mbps
Mobility model	Random Walk
Mobility speed	8 m/s
Topology size	200m*200m

As a result, when channel conditions deteriorated, the decision was not made immediately, resulting in frame losses. MRA and SIRA achieved lower throughput as these algorithms take some time to lower the rate when needed, as their decision-making process relies on random probing, FLR in the case of MRA, and A-MPDU size adaptation in the case of SIRA.

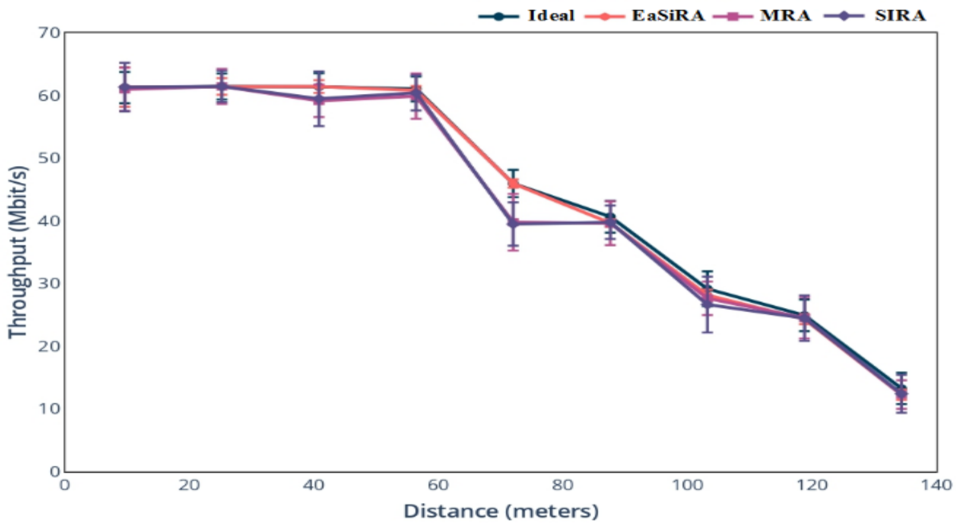

Fig. 1: Throughput of a station moving away from an access point at a speed of 6 m/s.

Scenario 2 - Infrastructure Network

In this scenario, we consider an infrastructure mode network, with a stationary access point positioned at the center of a square field, and all stations moving randomly while sending constant traffic of 80 Mb/s to the access point. The number of stations is gradually increased from 5 to 50.

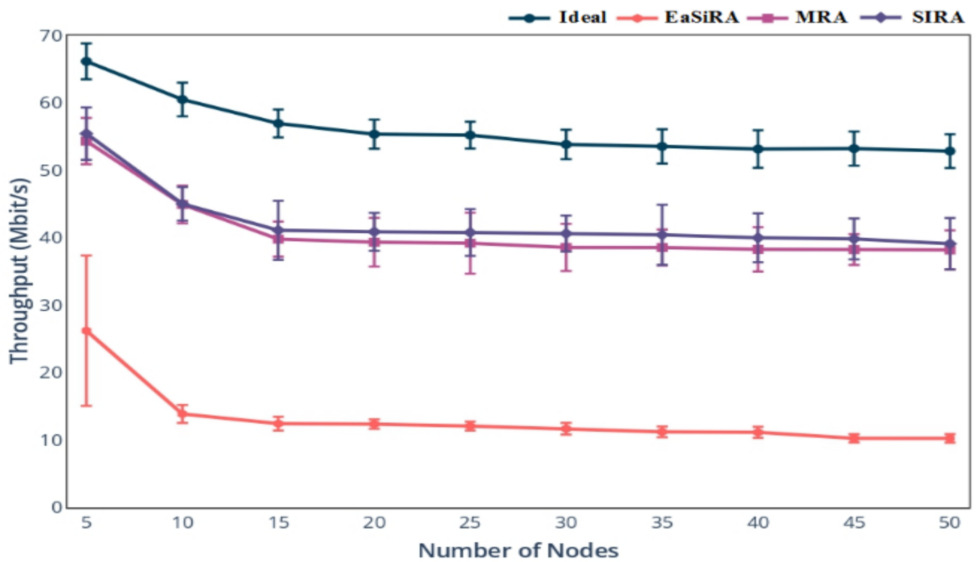

Fig. 2:overall throughput received at the access point

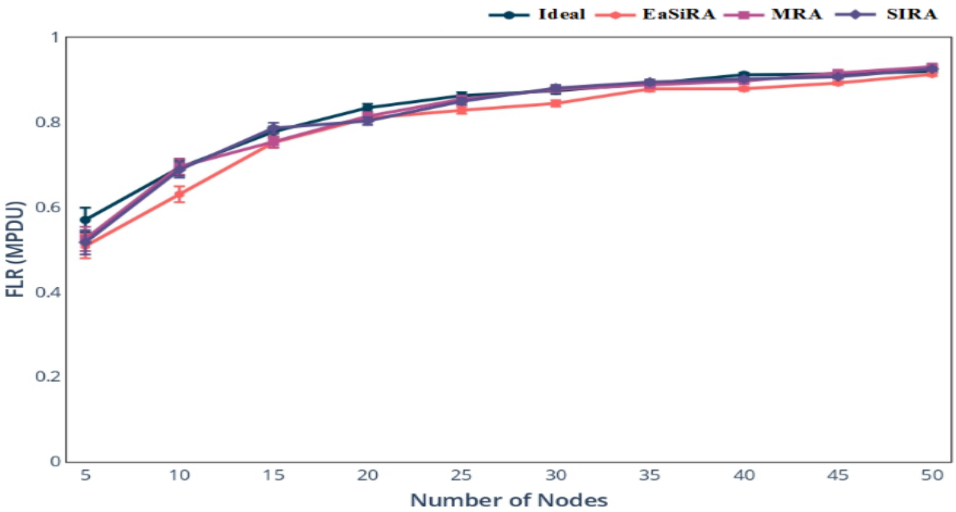

Fig. 3: MAC Protocol Data Unit (MPDU) Frame Loss Ratio

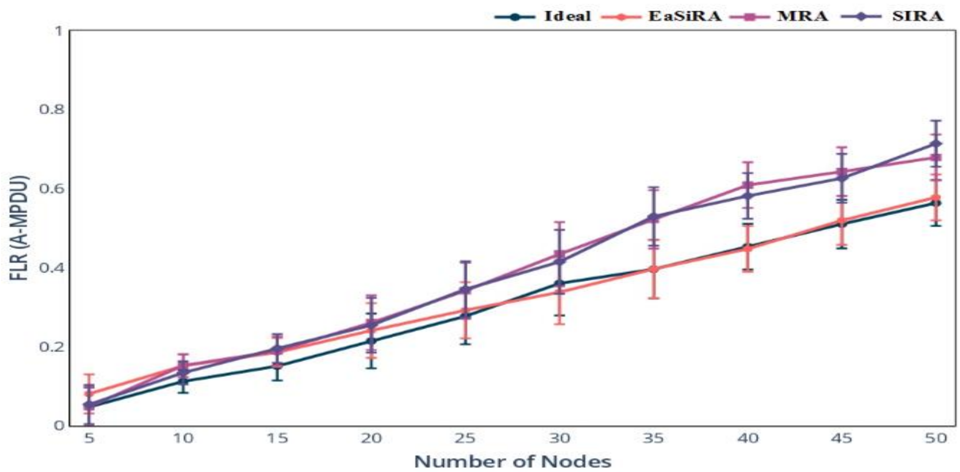

Fig. 4: A-MPDU Frame Loss Ratio

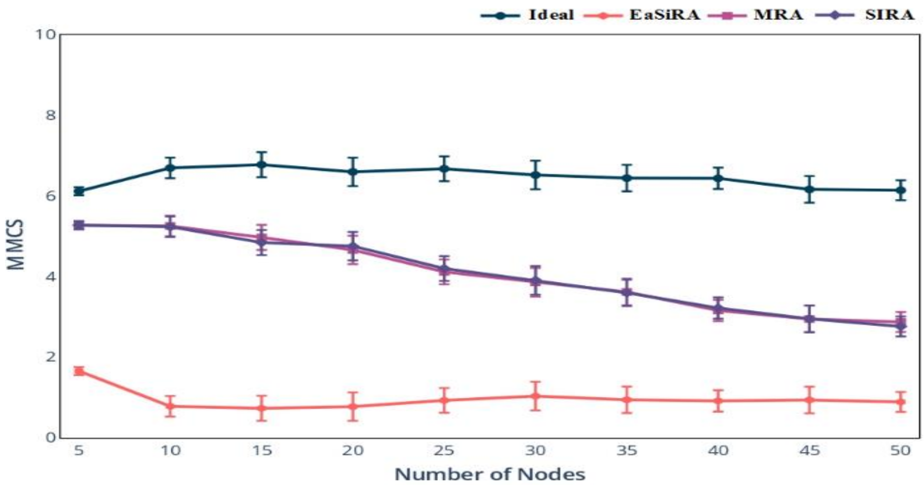

Fig. 5: Mean value of the modulation and coding schemes (MMCS) used by the nodes.

The physical throughput received at the access point is shown in Figure 2. The Ideal Rate Adaptation Algorithm performed better than the other algorithms due to its quick reaction to changes in channel conditions. The two implicit feedback algorithms (SIRA and MRA) take longer to recover after channel conditions change. The SIRA algorithm performed slightly better than MRA because it seeks an optimal A-MPDU size instead of reducing the rate. FLR based on MPDU losses and A-MPDU losses are shown in Figures 3 and 4, respectively. High MPDU FLR values are observed because all stations are within the transmission range of each other, increasing interference as node density increases. A-MPDU FLR is a false-positive rate increase in a fast-changing channel, which can occur when the transmitter increases the rate. However, the channel conditions deteriorate before sending the frame. Figure 5 shows the average MMCS index values selected by the stations. Ideal Rate Adaptation Algorithm selected higher MMCS index values with almost the same MPDU FLR and lower A-MPDU FLR, leading to higher achieved throughput. EasiRA had the worst performance among the tested algorithms due to the frequent rate reduction caused by frame losses. Figure 4 indicates that as node density increases (>20, for instance), causing the interference level to rise, the A-MPDU FLR gap between SINR-reliant and other Rate Adaptation Algorithms also widens. This is because SINR values better reflect the channel condition.

3.3. Scenario 3 - Ad hoc Network

In this scenario, we consider an Ad hoc network with randomly placed nodes in a square field. The nodes move randomly at 8 m/s and change their direction every 3 seconds. Half of the nodes are traffic generators, and the other half are sink nodes, with a constant UDP traffic rate of 80 Mb/s flowing toward the sink nodes. We gradually increase the number of nodes from 5 to 50 to evaluate the performance of the Rate Adaptation Algorithms under increasing node density and interference. Figure 6 presents the overall average physical throughput achieved by all the sink nodes, while Figures 7 and 8 show the FLR based on MPDU losses and A-MPDU losses, respectively. Figure 9 shows the selected MMCS values by the stations. The stations using the Ideal Rate Adaptation Algorithm achieve the highest throughput among the studied algorithms, thanks to its fast adaptation to the changing channel conditions. However, in scenarios where frame losses occur, the lack of feedback from the receiver prevents the transmitter from adapting the rate, leading to more frame losses until the channel conditions improve. False-positive MMCS rate decisions can also result in more A-MPDU frame losses in some cases, as seen in scenario 2. We also observe that the average MMCS values in Ad hoc mode are slightly lower than in infrastructure mode, which explains the lower throughput achieved in Adhoc mode. Additionally, the FLR results suggest a high interference level in this scenario, leading to higher MPDU FLR values. The A-MPDU FLR results also show that using SINR values for rate adaptation improves performance in high interference-level scenarios.

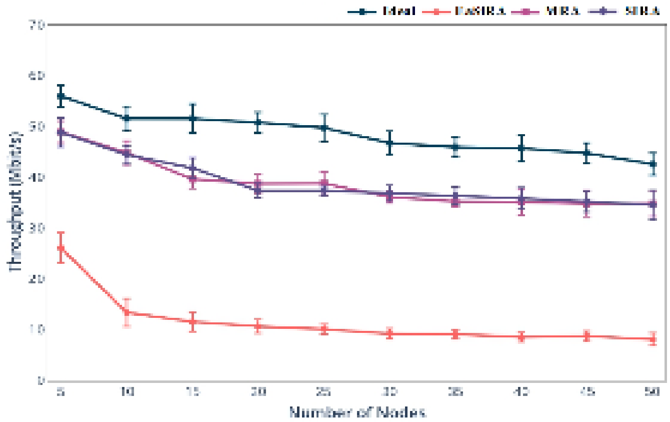

Fig. 6: Average throughput of sink nodes in an Ad hoc network

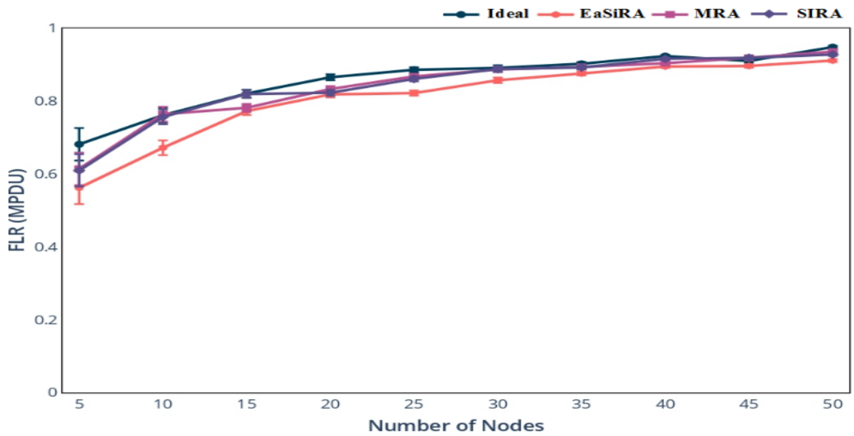

Fig. 7. MPDU Frame Loss Ratio

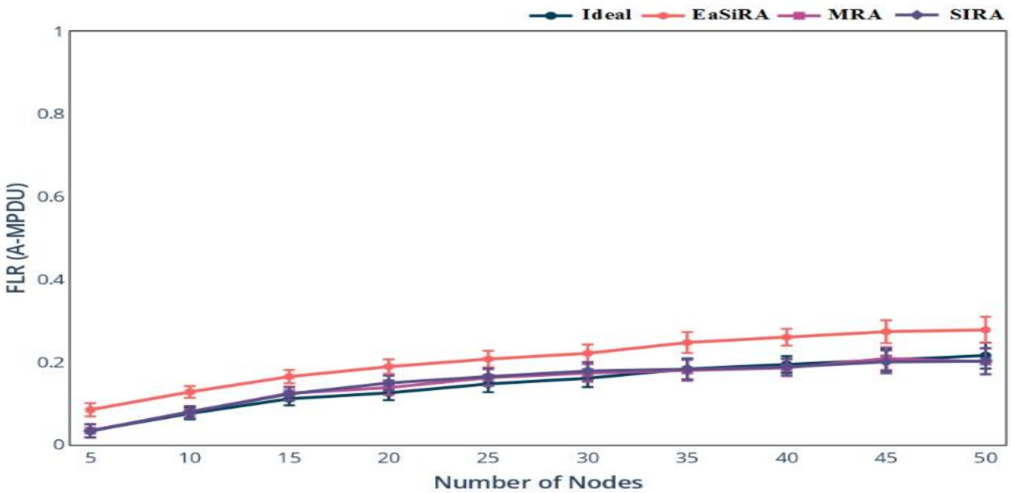

Fig. 8: A-MPDU Frame Loss Ratio

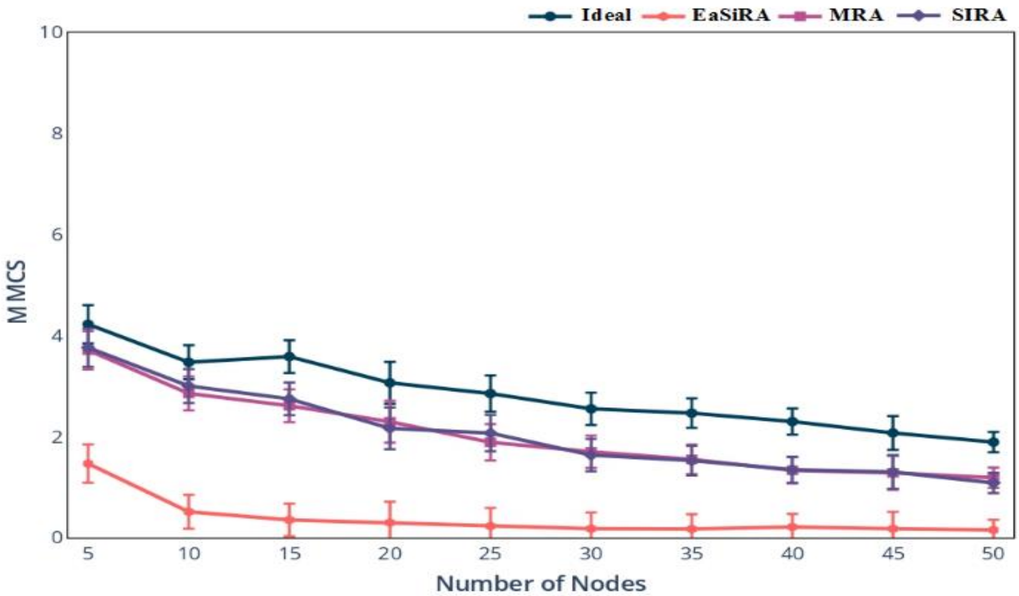

Fig. 9. Mean value of the MMCS selected by sender nodes

It is important to note that in scenarios 2 and 3, all nodes are in the communication range of each other, causing the interference level to increase with each new sender node added to the network. As a result, we observe high FLR values in both scenarios. Specifically, the FLR based on MPDUs counted in Block Ack reaches over 80% in both scenarios when the number of nodes exceeds 20. The FLR based on A-MPDUs also increases gradually with the number of nodes in the network.

3.4. Lessons Learned

In this subsection, we share the lessons learned from our study of the existing Rate Adaptation Algorithms and the simulation results.

3.4.1. Explicit Feedback

Most explicit feedback approaches rely on physical layer metrics, mainly SINR. However, for such an approach to be used on real devices, several conditions must be met, such as having hardware that provides SINR values and a method for relaying the feedback to the transmitter that does not violate the standard. Furthermore, the simulation results indicate that more than relying solely on SINR values for decision-making may be required. In some cases, the lack of feedback may result in multiple frame losses until the channel quality is suitable for the current rate. One possible solution to this issue may be implemented on the transmitter side. Although explicit feedback algorithms, such as Ideal Rate Adaptation Algorithms, outperformed other algorithms in a dense environment in both ad hoc and infrastructure modes, much work remains to minimize FLR and achieve better overall performance. Combining the current explicit approach with implicit approaches, such as changing A-MPDU size, which results in lower channel occupancy, and collecting statistical information at the transmitter that aids in the decision-making of future transmissions, may be considered to reduce FLR.

3.4.2. Implicit Feedback

The implicit feedback algorithms commonly use frame loss ratio and probing rates different from the selected rate. However, caution must be exercised when using random probing rates due to the risk of excessive frame losses. This may result in slow convergence of the algorithm towards the optimal rate. Although implicit feedback algorithms have shown promising results in a mobile, collision-free environment, their performance has not been found to be superior to other categories. To improve their performance, it may be useful to detect the degree of mobility and investigate its direct effects on frame transmission results. In dense environments, it is essential for Rate Adaptation Algorithms to accurately estimate the cause of frame loss and rely on different metrics to make more precise rate decisions. Additionally, a rate-changing method should be implemented to increase the rate when channel conditions improve and decrease it when they deteriorate. However, achieving this is a challenging task, as the algorithm needs to have real-time estimates of conditions such as SINR.

3.4.3. Hybrid Approach

The simulation results indicated that decreasing the rate after failed transmissions in a dense environment can result in longer transmission times, reduced throughput, and increased channel occupation time, which affects all nodes in the network. One possible solution to this problem is to use a sliding window approach that can predict future channel conditions and adjust transmission accordingly. Designing an efficient hybrid approach has proven to be a challenging task, with few existing studies focused on it. The simulation results showed that the EasiRA hybrid algorithm performed worse than other algorithms, mainly due to its method of decreasing the bit rate, which leads to decreased throughput, increased interference, and frame loss. Ideally, a hybrid algorithm could be built on top of an explicit algorithm by incorporating additional metrics, such as collecting statistics on frame loss ratio, to adapt the number of MPDUs in an A-MPDU. Based on our performance evaluation results, we decided to use the modified ideal Rate Adaptation Algorithm as the Rate Adaptation Algorithm in the rest of our work since it outperformed the rest of the algorithms in the Previous related articles. An in-depth understanding of Rate Adaptation Algorithms offers valuable insights into the performance and adaptability of Wi-Fi networks in different network conditions. This knowledge can help optimize Wi-Fi networks for specific applications and use cases, and drive the deployment of Wi-Fi networks in accordance with application requirements by considering MMCS and SINR requirements. In the following section, we will focus on the deployment of Wi-Fi networks using MIMO and beamforming in the context of smart farming, taking into account the specific requirements of the application.

4. Conclusion

In Interference Free Network model, MRA and SIRA achieved lower throughput as these algorithms take some time to lower the rate when needed, as their decision-making process relies on random probing, FLR in the case of MRA, and A-MPDU size adaptation in the case of SIRA. In Infrastructure Network model, the Ideal Rate Adaptation Algorithm performed better than the other algorithms due to its quick reaction to changes in channel conditions. SIRA and MRA take longer to recover after channel conditions change. The SIRA algorithm performed slightly better than MRA because it seeks an optimal A-MPDU size instead of reducing the rate. EasiRA had the worst performance among the tested algorithms due to the frequent rate reduction caused by frame losses. In Ad hoc Network model the average MMCS values are slightly lower than in infrastructure mode, which explains the lower throughput achieved in Ad hoc mode. Additionally, the FLR results suggest a high interference level in this model, leading to higher MPDU FLR values.

5. References

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