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Quality of service adaptive modulation and coding scheme for IEEE 802.11ac

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ABSTRACT

Nowadays, the rising demand for digital communication technologies has contributed to the increase in the volume of traffic. This continuous trend of internet traffic has led to the deterioration of the quality of service (QoS) with reduced throughput and increased latency. This also is due to the proliferation of new broadband applications which require low latency and high throughput such as virtual reality and real-time gaming. Therefore, considering the aforementioned challenge in QoS of wireless networks, a link adaptation method is suggested in this study, in order to enhance the performance of the QoS in IEEE 802.11ac amendment wireless local-area network (WLAN). The proposed technique adaptively changes the transmission data rate by increasing or decreasing the modulation and coding scheme (MCS) level according to the traffic conditions. With the use of an OMNeT++ computer-aided design (CAD)-based simulation model, the effectiveness of the suggested approach is examined. Simulated findings were compared with the link adaptation approach of the default condition. The results of the simulation demonstrate that the proposed technique significantly increases throughput (36.48%) and decreases latency in comparison to the default situation. These findings demonstrate the technique's potential to improve WLAN QoS efficiency, notably in regard to throughput and latency.

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1. INTRODUCTION

Global internet usage accumulates to 63.1% by July 2022 [1] which results in a deterioration of the quality of service (QoS). Thus, there is a growing need for methods to enhance QoS performance. Researchers have developed a number of methods to address these issues, including link adaptation. Most of the recent studies of link adaptation technique focus on cellular networks and not much focus on wireless local-area network (WLAN). The achievement of IEEE 802.11 hinges heavily on its ability to offer QoS, as important applications are moving onto data networks [2] and the evolution of multimedia applications [3]. Due to an increase in applications for multimedia running on IEEE 802.11 networks, service providers have been motivated to enhance QoS [4]–[7]. Therefore, considering the aforementioned challenge in QoS, the link adaptation technique has been developed to solve the issues [8], [9].

The goal of numerous research is to provide IEEE 802.11 WLANs with QoS support capabilities [10]–[16]. The work in [17] suggested a dynamic learning approach called intelligent multi-user multiple input multiple output (MU-MIMO) user selection with link adaptation (IMMULA) which used software defined networking (SDN). The IMMULA approach achieved a throughput gain of 539.06%, 277.94% and 506.00% as compared to existing MU-MIMO user selection (MUSE) [18], electivity-aware MU-MIMO design (SAMU) [19], and SIEVE [20] systems. While the standard packet latency for IMMMULA was reduced by 17.65%, 86.69%, and 74.12%, respectively. Chandran *et al.* [21] conducted a study on the link adaptation technique and Karman filter. The authors proposed to use modulation and coding scheme (MCS) and repetition rate (MRR) as controllable factors. Karmakar *et al.* [22] proposed a closed-loop mechanism of high throughput mobility rate (HT-MobiRate) by using the link adaptation in a wireless channel under a mobile environment. In the mobile environment, the channel condition fluctuates, thus it is recommended to implement the Thompson sampling technique to evaluate the changes in received signal strength indicator (RSSI). In another study, Karmakar *et al.* [23] develop a smart link adaptation which transforms a wireless station into an intelligent device that can handle a variety of network situations. The proposed approach outperforms other techniques by a significant margin. Edalat *et al.* [24] suggested smart adaptive collision avoidance (SACA) method that combined air time and network contention to adaptively decide whether to enable or disable the request to send/clear to send (RTS/CTS) handshake. The SACA technique thus continually beats the state-of-the-art methods. The following paper suggested a synchronized mode full-duplex (SM-FD) media access control (MAC) protocol that utilized reserved fields in WLAN frames to adopt the advance of FD communication, with the aim to increase network performance [25]. The proposed protocol outperformed the slotted Aloha MAC protocol in terms of throughput by a factor of two. Nosheen and Khan [26] introduces a novel adaptive transmit opportunity (TXOP) packet transmission technique that adjusts the TXOP time in response to the degrees of congestion and speed detected by video terminals. In comparison to the conventional technique, the suggested flow rate adaptive-TXOP (FRA-TXOP) approach improves the QoS of video traffic while enhancing network throughput.

The proposed approach in this work is unique which focuses on improving the QoS in IEEE802.11ac WLANs, a standard that already provides high throughput. This is in contrast to most existing studies, which typically aim to improve QoS performance in other IEEE802.11 standards. By focusing on enhancing QoS in IEEE802.11ac, this work addresses an important and previously overlooked aspect of WLAN performance.

2. METHOD

Figure 1 shows the conceptual framework of the suggested link adaptation algorithm. Based on the framework, the adaptation algorithm executes at the physical layer (PHY layer) which exploits the MCS. The proposed link adaptation algorithm aims to optimize the system performance by dynamically adjusting the transmission data rate to suit the changing channel conditions.

For the adaptation case, at the beginning of the transmission process, a transmitter chooses the maximum transmission data rate to transmit the packet and the receiver measures the end-to-end delay in order to adjust the transmission data rate for the following packet transmission. Then, the receiver sends the information back to the transmitter via feedback packet. For the suggested algorithm, the delay is the variable which represents the current traffic conditions because the end-to-end delay consists of several components as in (1).

$$T_{ee} = T_{DIFS} + T_{backoff} + T_{queuing} + T_{data} + T_{SIFS} + T_{ACK} \quad (1)$$

The transmission data rate adaptation is a link layer method that represents the performance of a communication link. The MCS has an impact on the transmission data rate's effectiveness. Parameters for the simulation study are tabulated in Table 1.

Figure 2 shows the flowchart of the suggested transmission data rate adaptation algorithm. It starts with transmitting packet data, i. After transmitting a packet, the transmitter waits for the acknowledgement (ACK) packet. In the situation of no ACK packet received, the transmitter initiates re-transmission of the packet. When a packet is successfully received, the delay, t_i, is measured and the average value, $Avg\ t_i$, is recorded. In the proposed work, N samples of packet data will be taken for each channel conditions. There are three categories of traffic conditions that will be observed in this work which are low, medium and high traffic load. The number of samples, N that will be evaluated are 10, 20, and 30 packets. The average value must be measured as it indicates the level of property better than a single measurement. For the proposed algorithm, queue length and delay are chosen to be the adaptation parameters. This is because queue length and delay are the ideal indicators for traffic conditions. The threshold delay, which was set at 2 ms, determines whether to increase or reduce the transmission data rate for the suggested technique. The transmission data rate will be reduced to a lower range in the event that the average delay is less than the threshold value. In the other case where the delay is more than the threshold value, the QoS needs to be maintained which is delayed. By adapting to higher data rate, the delay can be controlled based on (2), where t is denoted as the delay in second, L is the packet length in bytes, and R is the transmission data rate in bit per second (bps).

$$t = \frac{L}{R} \quad (2)$$

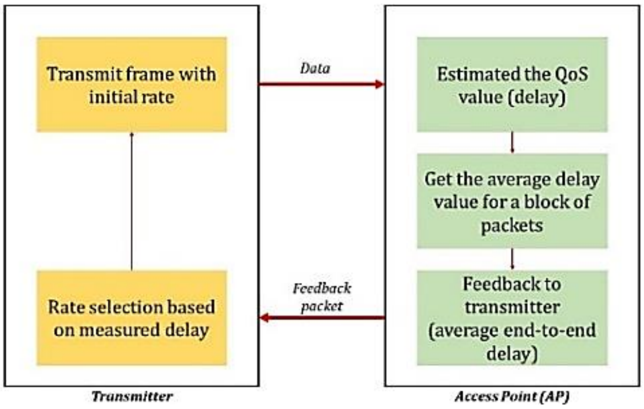

Figure 1. Conceptual framework of the data rate adaptation

Table 1. The simulation parameter

Parameters	Values
WLAN standard	IEEE 802.11ac
Operating frequency	5 GHz
Bandwidth	20 MHz
Spatial stream	8
Propagation model	Free space path loss
Transmission range	60 meters
Inter arrival time	0.1 s
Simulation time	100 s

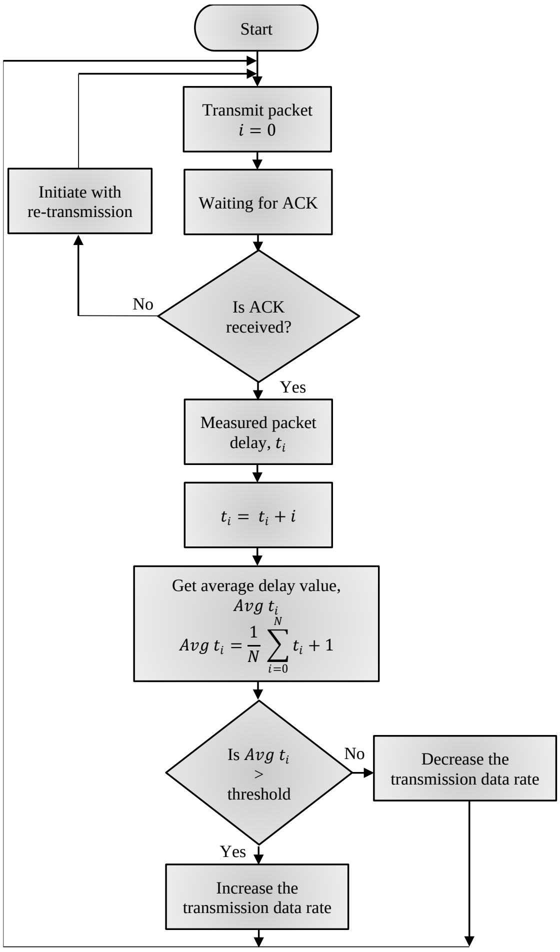

Figure 2. Flowchart of the proposed transmission data rate adaptation algorithm

Distributed coordination function (DCF) is a basic MAC protocol to maximize the throughput whilst preventing packet loss due to collision in WLAN IEEE 802.11. The total time will increase if the channel is busy since the back-off period would lengthen. The accumulated time to transmit a packet is increased if the condition of the channel is congested due to an increase in $T_{backoff}$ and $T_{queuing}$. The $T_{backoff}$ is analysed based on the average contention window time, $\overline{CW}$.

3. RESULTS AND DISCUSSION

This section analyses the performances of the proposed adaptive transmission data rate in IEEE 802.11ac WLAN in terms of QoS performances which are throughput and delay. The simulations were performed using the simulation parameters as listed in Table 1 and executed by using OMNeT++ computer-aided design (CAD). Because the proposed algorithm needs to gain both energy efficiency and QoS performances, the algorithm adaptively adjusts the transmission data rate according to the current contention level.

3.1. End to end delay

The performances analyses were carried out to examine the QoS performances as a function of the traffic load. This approach is different from other methods in the literature that may use fixed data rates or pre-determined scheduling schemes. By adaptively adjusting the data rate according to traffic conditions, the proposed algorithm can optimize the network performance by efficiently utilizing the available bandwidth while avoiding congestion and delays. The three different traffic conditions mentioned in the proposed algorithm - high traffic, medium traffic, and low traffic load is used to categorize the network traffic based on the amount of data being transmitted at a given time. This allows the algorithm to dynamically adjust the data rate to meet the varying demands of the network. Simulation results illustrate how the transmission data rate adapts to the different traffic conditions with the main goal to improve the throughput. Table 1 shows that the inter-arrival time has been set to 0.1 s which indicates that 10 number of packets are sent from transmitter for every 0.1 s. In order to indicate the network's traffic load for each condition, the number of packets was divided into three parts; 1 to 320 packets are low traffic loads, 330 to 650 packets are medium traffic loads, and 660 to 1,000 packets are high traffic loads. The first part of this section analyses the end-to-end delay for the default condition and the link adaptation approach in ideal channel condition. An ideal channel is defined as the communication channel without any obstacle or fading occurred. In an ideal channel, it is assumed that packet loss happens due to collisions. In the case where the channel condition is congested, the total time which is the end-to-end delay will increase due to the back-off period is increased. Theoretically, the relationship between the throughput and the end-to-end delay are inversely proportional which works for the default condition and it is known as trade-off in order to serve a good QoS in WLAN. The higher the end-to-end delay, the lower the throughput and vice versa. However, the link adaptation approach may exhibit a different relationship between throughput and end-to-end delay compared to the default condition. Specifically, as the data rate is increased in response to higher traffic loads, the throughput may increase while the end-to-end delay also increases. This is because the increased data rate allows for more data to be transmitted, but the time it takes for packets to travel from the source to the destination may also increase due to the increased congestion. Figure 3 shows the recorded average end-to-end delay for both the default condition and the link adaptation approach over a number of packets, illustrating the trade-off between throughput and end-to-end delay in both scenarios.

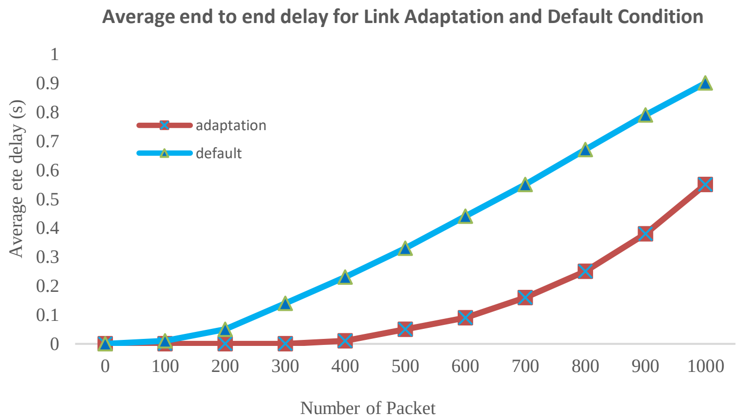

Figure 3. Average end-to-end delay against number of traffic

From Figure 3, it is apparent that the average end-to-end delay increases as the number of packets increases for both conditions. This indicates that the traffic channel conditions have a significant impact on the end-to-end packet delay. In order to transmit packets, the transmitter must wait until all packets are collected before the MAC frame can be transmitted. Additionally, queued packets must also wait until previous packets have been successfully transmitted, which can contribute to high queuing delay. As the traffic load increases, more packets are being transmitted, which can lead to congestion and longer waiting times for transmission. This can result in higher backoff and queuing delays, leading to an overall increase in end-to-end delay. The average end-to-end delay for default condition is higher than the average end-to-end delay for link adaptation because there is no adaptation implemented. It can be concluded that the total end-to-end delay is inversely proportional to the transmission data rate. As the transmission data rate increases, the end-to-end delay would be much lower. For the link adaptation approach, as the network becomes congested, the transmission data rate is adapted to a higher level with the main goal to improve the throughput while controlling the delay. Meanwhile, for the default condition, the transmission data rate remained at the same level for all traffic conditions. In high traffic conditions, the average end-to-end delay is increased due to the excessive of packets in the network that need to be transmitted simultaneously which had led to packets collision and retransmission process. Therefore, the probability of packets collision is higher as compared to other traffic conditions. The average end-to-end delay for default condition is 2.56% higher than the link adaptation approach.

3.2. Default condition

Figures 4 and 5 show the transmission data rate and corresponding throughput for default conditions over a number of packets. In the default condition where no adaptation was applied and the transmission data rate remained fixed, the produced throughput would decrease as the number of packets increased. As more packets are transmitted, the network becomes congested, leading to increased packet loss, delays, and retransmissions. These factors can lower the overall throughput.

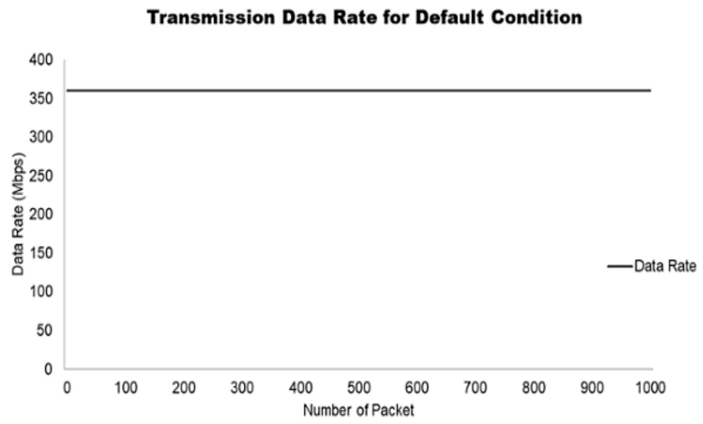

Figure 4. Transmission data rate for default condition against number of packets

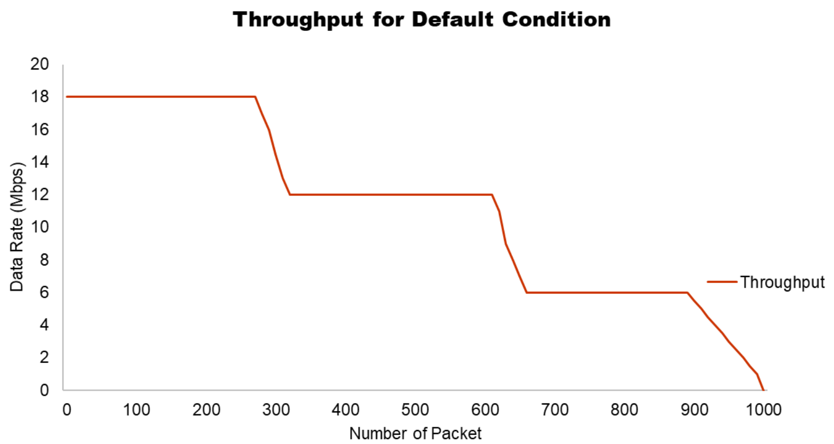

Figure 5. Corresponding throughput for default condition against number of packets

In the default condition, no adaptation was applied, since there is no adaptation executed, the transmission data rate remained at 360 Mbps. However, the trend of the produced throughput from the transmission data rate decreased as the number of packets increased as shown in Figure 5. In low traffic conditions, the throughput was consistently transmitted at 18 Mbps. However, at 281 packets, the throughput slowly decreased as the traffic in the network channel began to enter the medium channel state. In the medium channel condition, the throughput constantly remained at 12 Mbps before dropping to 620 packets while moving to the congested state. In the congested load, which is high traffic, the throughput remained at 6 Mbps. However, at 900 packets, the network was very congested which resulted in the throughput drop and at 1,000 packets the throughput was at 0 Mbps where the collision occurred in the network channel which caused no packet to be received at the receiver side. In sum, the trend of the throughput decreased due to the traffic condition in the network channel getting busy which has led to the increment of the packet’s retransmission as well as the packets loss, thus indirectly affected the decrement of the throughput.

3.3. Link adaptation approach

In Figure 6, the link adaptation approach is depicted, illustrating the adaptive changes in the transmission data rate based on traffic conditions. As a consequence of this adaptive behavior, the throughput, which refers to the amount of data transferred per unit of time, also varies accordingly with the corresponding transmission data rate. Corresponding throughput for link adaptation approach against of packets as shown in Figure 7.

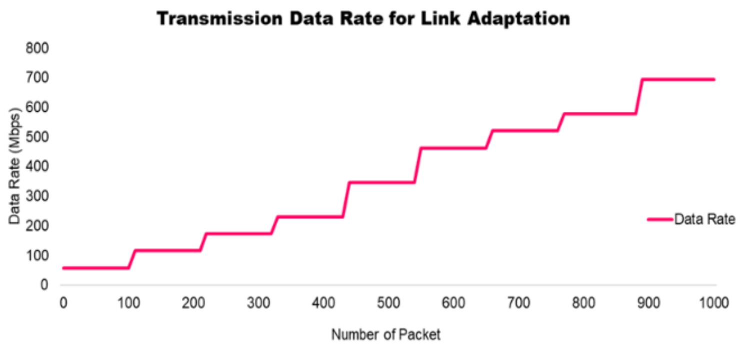

Figure 6. Transmission data rate approach against number of packets

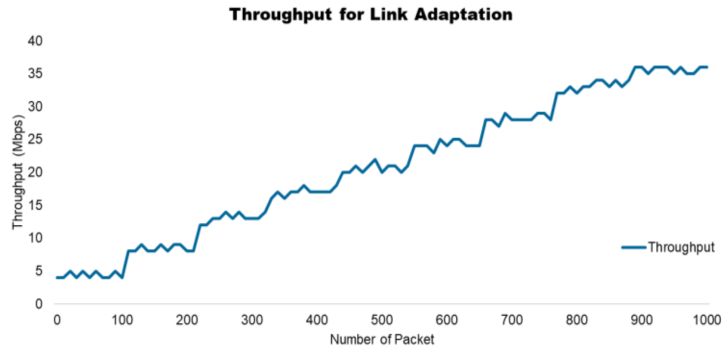

Figure 7. Corresponding throughput for link adaptation approach against of packets

Initially, in the default condition, the maximum data rate is selected by the transmitter for packet transmission. In contrast, for the link adaptation approach, the initial transmission data rate is set lower at 57.8 Mbps binary phase shift keying (BPSK) and is then adjusted based on the traffic load to optimize the network's performance. As the number of packets increases, the average delay exceeds the threshold value of 2 ms, which may negatively impact the network's QoS performance. In response, the transmission data rate is increased to the next step of MCS to provide a better QoS performance to the user. This adaptive approach allows the network to maintain a good balance between delay and throughput while also ensuring that the QoS requirements are met. Figure 6 shows how the transmission data rate is increased step-by-step based on the IEEE 802.11ac WLAN MCS data rate as the traffic load increases. As a result, the throughput for the link adaptation approach also increases, as shown in the same figure. This indicates that the link adaptation approach can effectively optimize the network's performance by adjusting the data rate to match the changing traffic conditions.

At the beginning of the simulation, the transmission data rate was set to 57.8 Mbps while the throughput recorded was 4 Mbps. Even when the lowest transmission data rate is used for the link adaptation, packet data are successfully received at the receiver. In low traffic load, the transmission data rate increased from 57.8 Mbps BPSK to 173.3 Mbps quadrature-PSK (QPSK) with recorded throughput in between 4 to 14 Mbps. In medium traffic load, the transmission data rate increased to 231.1 Mbps 16-QAM to 462.2 Mbps 64-QAM, and the throughput is between 17 to 24 Mbps. In the high traffic load, the transmission increased from 520.0 Mbps 64-QAM to 577.8 Mbps 64-QAM. However, at 900 packets, the maximum transmission data rate increased to 693.3 Mbps 256-QAM with the maximum throughput recorded at 38 Mbps in order to ensure the user experiences excellent QoS performance. It can be seen from these figures that the transmission data rate increases to the next step of MCS based on the need to adapt the traffic loads as well as the throughput.

Simulation results presented in the figures indicate that as the transmission data rate increases, the throughput will be increased. Instead of staying at the same transmission data rate as the default condition, the link adaptation approach tries to adapt the transmission data rate according to the channel condition which is represented by the traffic load. The advantage of this approach is it is able to improve the throughput. For an ideal channel condition, there are no fading occurred thus lowering the transmission data rate to combat the varying channel condition is not an issue. Based on that reason, transmission at a higher data rate will give advantage in terms of throughput. The link adaptation approach achieved higher throughput rather than the default condition, which is 38 Mbps, while the default condition higher throughput is 18 Mbps. It can be concluded that the implementation of the link adaptation technique in IEEE 802.11ac WLAN has improved the throughput.

4. CONCLUSION

This paper presented a link adaptation technique to improve a QoS in IEEE 802.11ac WLAN in terms of throughput and delay. Rapid growth of internet traffic cause traffic congestion which contributes to low throughput and high delays. Throughput and delay are important performance metrics in ensuring the WLAN usage access by user. In this paper, the link adaptation technique is proposed to help in improving the QoS in WLAN. The proposed technique is able to adapt the transmission data rate in WLAN according to the traffic condition. For instance, in the case where traffic condition is congested, the proposed technique will play its role by increasing the transmission data rate to the next stage to boost the QoS performance, specifically the throughput. Simulation results show that the proposed link adaptation technique achieved 36.48% throughput improvement compared to the default condition. The effectiveness of the link adaptation approach in improving the QoS in WLAN has been compared with the default condition. As a result, it shows that the link adaptation is a technique that is able to improve the QoS performance in WLAN especially in terms of throughput and delay.

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