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Enhancing QoS Performance for Cell Edge Users Through Adaptive Modulation and Coding in IEEE 802.11ac WLANs

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Abstract—Wireless communication networks, such as IEEE 802.11ac Wireless Local Area Networks (WLANs), often encounter challenges in providing consistent Quality of Service (QoS) to users situated at the cell edge. The inherent variations in channel conditions, particularly lower signal-to-noise ratios (SNRs) in these regions, lead to compromised data rates and reliability, resulting in significant degradation of throughput. This study presents an innovative solution in the form of an Adaptive Modulation and Coding Scheme (AMCS) algorithm tailored to enhance QoS performance for cell edge users. The primary objective of the AMCS algorithm is to optimize QoS by dynamically adjusting the transmission data rate based on the observed channel conditions, quantified using SNR as a channel state indicator. Conventional approaches might unilaterally select the lowest data rate in challenging conditions, prioritizing reliability at the expense of throughput. However, the proposed AMCS algorithm takes a distinct approach by intelligently determining the Modulation and Coding Scheme (MCS) that offers an optimal balance between throughput and reliability for the given SNR level. To achieve this, the algorithm utilizes real-time SNR measurements to select an MCS that ensures a stable connection while also maintaining an acceptable data rate. By adapting the MCS based on the current SNR, the algorithm aims to mitigate the adverse effects of poor channel conditions experienced by cell edge users. The innovation of the AMCS algorithm lies in its ability to make dynamic adjustments, allowing users to experience improved data rates without compromising connection stability. Through extensive simulations and evaluations, the proposed AMCS algorithm showcases its efficacy in enhancing QoS performance at the cell edge. The algorithm's adaptive approach successfully achieves higher data rates and improved reliability by selecting appropriate MCS configurations tailored to the observed SNR levels. This innovative technique provides a promising solution to the challenge of striking the right balance between throughput and reliability in wireless communication networks, ultimately leading to an improved user experience for those at the network's periphery.

Keywords- Cell edge, QoS, throughput, signal to noise ratio, IEEE802.11ac

I. Introduction

The world is experiencing extreme urbanization as the global population is expected to double in the year 2050, thus in order to meet the needs of high-density urban application, further technological breakthrough is required. The requirement for high-speed data has resulted in the development of IEEE 802.11 ac where this standard enables the data to be transferred with a minimum speed of 1 Gbps and a maximum speed of up to 7 Gbps. IEEE 802.11ac is built on the strength of the previous IEEE 802.11 standard with the addition of new techniques that can ensure the achievement of high throughput [1]. IEEE 802.11ac can still deliver outstanding performance to every client served by an access point (AP) even at the peak load.

Wireless communication networks, including IEEE 802.11ac Wireless Local Area Networks (WLANs), frequently face the issue of maintaining satisfactory Quality of Service (QoS) for users located at the periphery of the network's

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coverage area. The irregularities in channel characteristics, notably the prevalence of lower signal-to-noise ratios (SNRs) in these outer regions, result in diminished data rates and reduced reliability. This investigation introduces a novel resolution: an Adaptive Modulation and Coding Scheme (AMCS) algorithm designed to address the QoS challenges experienced by users at the network's edge.

In this research, the focus is to improve the Quality of Service (QoS) performance of cell edge users by using Adaptive Modulation and Coding Scheme for the IEEE 802.11ac standard. The proposed algorithm adapts to the transmission data rate in order to enhance the cell-edge performance. Users at the cell edge region experienced poor QoS due to low data rate, high latency, and various fading effects. The cell edge is an area where the signal strength is becoming weak. Figure 1 shows the illustration of a cellular network consisting of cells. The cell area can be divided into two areas which are cell-center and cell-edge.

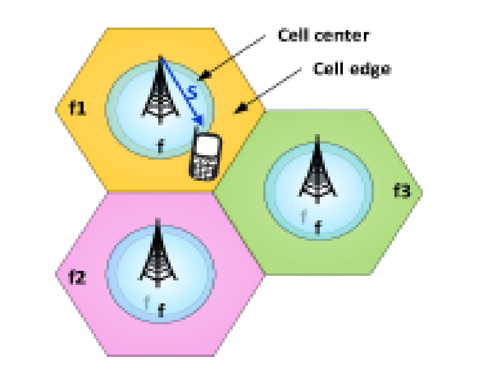

Figure 1. The center and cell-edge area of a cell

Adaptive Modulation and Coding (AMC) is a technique in digital wireless communication systems where it is used to indicate the matching of the modulation, coding and other signal and protocol parameters to the conditions of the radio link [2].

System capacity, peak data rates, and coverage reliability can be significantly enhanced through the implementation of adaptive modulation and coding techniques. This approach tailors the transmitted signal to individual users, effectively accounting for variations in signal quality. Furthermore, the dynamic nature of link adaptation involves continuous adjustments to both signal and protocol parameters in response to evolving link conditions. Radio links are susceptible to interference, path loss, scattering, diffraction, and absorption, making the adaptability of link parameters crucial. Consequently, the process of link adaptation remains dynamic, ensuring that signal and protocol parameters evolve in tandem with changing radio link conditions.

Figure 2 depicts the link adaptation process, showcasing how it adjusts modulation schemes and error correction coding rates in radio links. In favorable radio link conditions, minimal error correction is employed, coupled with high-efficiency modulation, resulting in increased data throughput in the radio channels. Conversely, in adverse radio link conditions, data throughput decreases due to the application of extensive error correction and the utilization of a lower-level, more resilient modulation scheme.

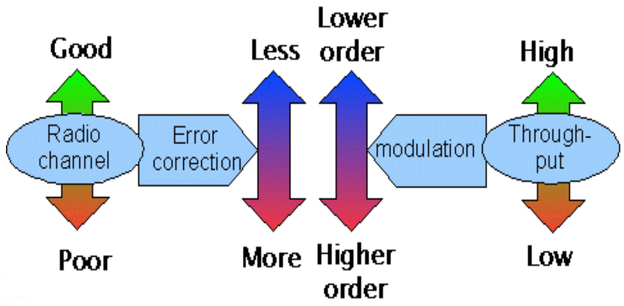

Figure 2. Method of Link Adaptation Technique

Adaptive modulation and coding scheme also known as rate adaptation is dynamic in nature, constantly varying the transmission rate to accommodate the ever-changing and location-specific channel quality. This variability is necessary to address factors such as signal fading due to distance, the delicate balance between data rate and coverage range, and interference from external sources. These adaptations in transmission data rate are guided by channel condition estimations, which are often derived from Channel State Information (CSI).

Channel State Information (CSI) serves as a vital descriptor of how a signal traverses the path from transmitter to receiver, encapsulating various factors like scattering, fading, and distance-related power attenuation. CSI plays a pivotal role in enabling adaptive transmissions that can cater to the prevailing channel conditions, a critical aspect for achieving dependable communication with high data rates.

Moreover, within communication links, channel properties are diverse and can be categorized into key parameters such as signal-to-noise ratio (SNR), bit error rate (BER), delay, and queue length. Link adaptation emerges as an efficient technique that harmonizes transmission parameters, including modulation format, code rate, and power, based on the CSI. Optimal CSI conditions facilitate higher data rates, while suboptimal CSI conditions necessitate lower data rates.

In the context of radio channels, good channel conditions conducive to higher throughput are characterized by employing advanced modulation schemes and minimal error correction. Conversely, employing lower modulation schemes with extensive error correction in poor channel conditions results in reduced data throughput. Hence, favorable channel conditions contribute to enhanced data throughput, whereas congested traffic and adverse channel conditions lead to diminished data throughput.

There have been various techniques proposed in the literature to improve Quality of Service (QoS) performance at the cell edge in wireless networks. Zheng et al [3] presented a quasi-perfect resource allocation scheme (Q-PRAFFR). The proposed approach divides the cell-edge region, cell-edge bandwidth, and CEUs into six parts and distributes the resource to CEUs according to the predetermined resource allocation priority. When compared to the most cutting-edge FFR technology, the results of this technique show that the fifth-percentile consumers' outage probability is lowered by roughly 70% and the cell throughput increased by 10%.

Gatti et al [4] proposed a technique that assigns and allocates Carrier Components (CCs), Radio Blocks (RBs), and Modulation and Coding Scheme (MCS) indices in the best possible method. The suggested method separates the cell regions into cell centers and cell edges. The available RBs are distributed among these two regions' users in order to satisfy their on-demand needs. According to the simulation results, cell edge users' performance was ideally achieved with acceptable throughput and data rates for secure communication in the LTE-A system.

The downlink transmission in a clustered cellular network using orthogonal frequency division multiple access is proposed by Idress et al [5]. The suggested resource distribution plan focuses on enhancing individual performance, particularly at the cell edges, while increasing cluster throughput. The results show that clustering significantly decreases the scheduling complexity of the system while ensuring considerable increases in throughput per resource and spectral efficiency of edge users.

L. Qin [6] proposes a user-centric MEC (UCMEC) that can provide consumers with effective, dependable, affordable user-centric wireless transmission and edge computing services through the dense deployment of access points. Simulation results demonstrate that, compared to typical MEC, the suggested optimization technique offers customers lower energy usage, less latency, and a greater probability of successful offloading.

Other methods proposed in the literature to improve the QoS for cell edge users are based on scheduling techniques. B. Ezeribe [7] developed a proportional fair scheduling technique for downlink LTE cellular networks. The results obtained demonstrated that the proposed algorithm surpassed round-robin and proportional fair scheduling in terms of throughput performance. L. Himani et al [8] proposed Improved Extended Modified Largest Weighted Delay First (IE-MLWDF) which is the enhancement of the previous technique Modified Largest Weighted Delay First (MLWDF). The approach focuses on Improving the QoS of the cell edge user while improving network performance.

Advanced antenna techniques also contribute towards improving the cell edge QoS performances. The Massive multiple-input multiple-output (MIMO) technique utilizes a large number of antennas at the base station to serve multiple users simultaneously and can enhance capacity and signal quality, benefiting cell edge users as proposed by M. Zeng [9] and Z. Abdullah [10] and M. Koolivand [11]. G. Niu et al [12] proposed a cooperative multi-agent reinforcement learning in order to construct an effective and adaptive scheme that is adaptable to network dynamics. In addition to that, the beamforming approach also provides a distributed solution to improve the QoS of cell edge users. Directional transmission using beamforming can focus energy toward the desired user and reduce interference from other directions. The work in [13] proposed an optimization-based beamforming technique using MISO-NOMA to increase a cell-edge user's security and outage probability while preserving the near-user's quality of service and lowering the performance of the eavesdropper. The uplink-downlink (UL-DL) cellular system is achieved via a unique reconfigurable physical resource block (PRB) that interfaces mobile cell-edge terminals with long-term evolution (LTE) using a low-power tunable second-order GmC filter beamforming circuit as presented by W. P. Nwadiugwu [14].

Hybrid automatic repeat request (HARQ) is a technique that combines forward error correction (FEC) with automatic repeat request (ARQ) mechanisms to improve reliability and throughput at the cell edge. Both type-I and type-II HARQ techniques are investigated by Y. Zhu [15]. For NOMA-based transmission, a brand-new Hybrid Automatic Repeat and request (HARQ) scheme is recommended by R. Chandran [16]. The power level of users is constantly modified in retransmissions in the suggested technique in order to decrease the number of attempts for successful packet transmission.

Adaptive Modulation and Coding (AMC) is a technique used in wireless communication systems to optimize the transmission of data over a wireless link. Based on the current channel circumstances and link quality, AMC adapts the modulation scheme and error-correcting code rate in real-time. AMC's main objective is to increase data flow and network dependability while adjusting to shifting environmental conditions. X. Xu [17] presents a unique adaptive modulation strategy. A hybrid optimization technique of spectrum allocation and modulation scheme selection is developed to maximize learning efficiency in order to further enhance performance. Using a variety of datasets, researchers run extensive experiments. The suggested approach can improve the model training's convergence speed when compared to the more traditional adaptive modulation strategies. With the aim to provide QoS in wireless scalable video multicast, Q. Jiang [18] introduces an adaptive modulation and coding (AMC) technique that adjusts both spatial range and temporal fluctuation on users' channel circumstances. The efficiency of the proposed strategy has been shown by simulation results.

II. METHODOLOGY

The proposed algorithm of the adaptive modulation and coding scheme (AMCS) to improve the QoS performances at the cell edge region is executed by adapting the transmission data rate based on the channel conditions. In this study, the channel condition is represented by the signal-to-noise ratio (SNR) which acts as channel state information (CSI). The main goal of the AMCS algorithm is to enhance Quality of Service (QoS) performance in the cell edge region by dynamically adjusting the transmission data rate to optimize the QoS performances. The algorithm utilizes the signal-to-noise ratio (SNR) as a metric to gauge the quality of the wireless channel. Lower SNR values typically indicate poorer channel conditions, often experienced at the cell edge due to greater distance from the access point or increased interference. In the presence of poor channel conditions, such as at the cell edge, the default behavior (non-adaptation) might be to select the lowest data rate. While this decision increase’s reliability by allowing more robust communication, it significantly reduces throughput.

The innovative aspect of the proposed AMCS algorithm is that it does not blindly default to the lowest data rate in challenging conditions. Instead, it aims to maintain a certain level of throughput without compromising reliability. The AMCS algorithm selects the modulation and coding scheme (MCS) that offers

the best trade-off between throughput and reliability, given the current SNR. It strives to adapt to an MCS that is suitable for the observed SNR level, ensuring that the connection remains stable and the data rate remains reasonable.

By adapting to an appropriate MCS level, the algorithm manages to maintain a certain level of throughput even in poor channel conditions. This is achieved by dynamically adjusting the modulation and coding parameters to match the channel's capabilities. The algorithm's ability to adapt to varying channel conditions enables it to improve the QoS performance at the cell edge. Users in this region can experience a more stable connection with acceptable throughput, which contributes to a

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better user experience. The algorithm's effectiveness lies in its ability to strike the right balance between throughput and reliability. It selects the MCS that provides the best overall performance given the current channel conditions. In summary, the proposed AMCS algorithm is a sophisticated approach that aims to optimize QoS performance by dynamically adapting the transmission data rate through the selection of an appropriate MCS level based on the current SNR. This enables a more reliable and efficient wireless connection, particularly at the challenging cell edge region.

The proposed link adaptation algorithm's conceptual framework is shown in Figure 3. The transmission data rate adaptation exploits the MCS to improve the QoS performances in IEEE 802.11ac WLAN, hence the suggested link adaptation technique focuses on the PHY layer.

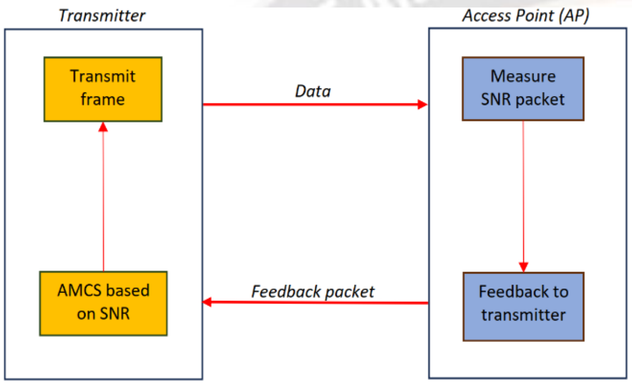

Figure 3. Conceptual framework of the proposed AMCS

Table 1 shows the IEEE 802.11ac WLAN modulation and coding scheme (MCS) with a single spatial stream. The highest modulation scheme is 256-Quadrature Amplitude Modulation which produces the highest data rate and is used in a good radio link condition. Higher MCS values typically correspond to higher data rates but may require more favorable signal conditions to maintain a reliable connection. In good radio link conditions with strong signal strength and minimal interference, higher MCS values can be used to achieve higher data rates. However, as signal quality degrades due to distance from the access point or environmental interference, the wireless system may need to lower the MCS to maintain a stable connection.

TABLE I. IEEE 802.11AC WLAN MODULATION AND CODING SCHEME FOR SINGLE SPATIAL STREAM

			Data Rate in Mbps			
MCS	***Modulation***	***Coding Rate***	***20MHZ***	***40MHz***	***80MHz***	***160MHz***
0	BPSK	1/2	6.5	13.5	29.3	58.5
1	QPSK	1/2	13	27	58.5	117
2	QPSK	3/4	19.5	40.5	87.8	175.5
3	16-QAM	1/2	26	54	117	234
4	16-QAM	3/4	39	81	175.5	351
5	64-QAM	2/3	52	108	234	468
6	64-QAM	3/4	58.5	121.5	263.3	526.5
7	64-QAM	5/6	65	135	292.5	585
8	256-QAM	3/4	78	162	351	702
9	256-QAM	5/6	N/A	180	390	780

MATLAB was chosen in designing the link adaptation algorithm as well as validating the effectiveness of the algorithm with the default condition of IEEE 802.11ac. Parameters for the simulation study are tabulated in Table II.

TABLE II. SIMULATION PARAMETERS

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	100 meters
Inter Arrival Time	0.1s
Simulation Time	100s

Figure 4 illustrates the flowchart of the proposed adaptive modulation and coding (AMCS) algorithm. The following section describes the process flow of how the proposed Adaptive Modulation and Coding Scheme (AMCS) is executed.

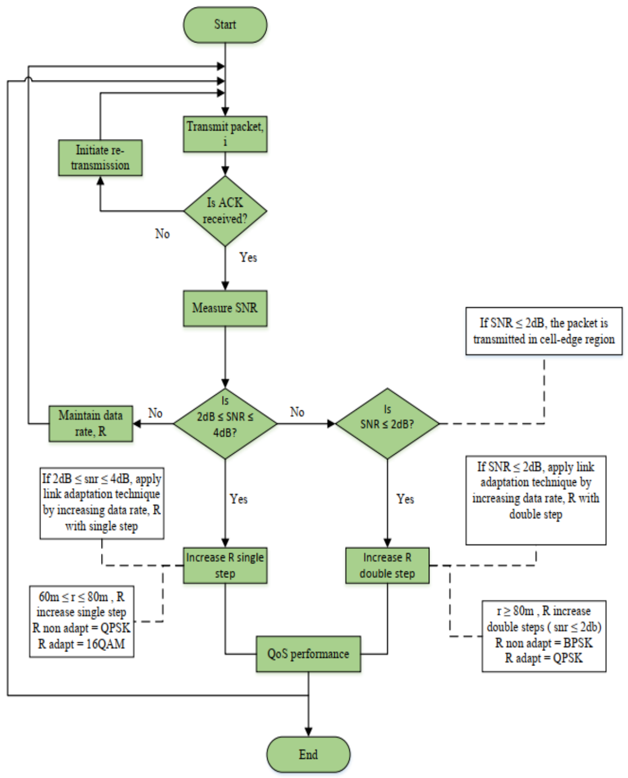

Figure 4. Flowchart of the proposed transmission rate adaptation algorithm.

The flow starts with the transmission of a packet i from the transmitter to the receiver. The transmitter waits for an acknowledgment (ACK) packet after sending a packet. If an ACK packet is not received, the transmitter initiates re-transmission of the packet via the carrier sensing multiple access/collision avoidance (CSMA/CA) procedure. The SNR value is recorded once a packet is successfully received. In the context of the cell-edge, an area is typically considered to be in the cell-edge region when the SNR falls below a certain threshold. The exact threshold SNR value can vary based on the

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technology and network design, but it is generally in the range of 0 to 10 dB [19].

The Adaptive Modulation and Coding Scheme (AMCS) is implemented as follows: Within the central and edge regions, the system employs the signal-to-noise ratio (SNR) as a channel indicator. Unlike conventional approaches that default to lower data rates, such as Binary Phase Shift Keying (BPSK) (as can be seen from the flowchart), the proposed AMCS takes a more adaptive approach by increasing the transmission data rate with a single step as compared to the default MCS. It dynamically adjusts the data rate to achieve significantly higher levels, all while maintaining an acceptable performance level based on the SNR value. In cases where the SNR indicates favorable conditions, the AMCS adapts the transmission data rate to more advanced modulation schemes, like Quadrature Phase Shift Keying (QPSK) or 16 Quadrature Amplitude Modulation (16QAM). This adjustment allows for improved throughput while still operating within a reasonable range determined by the SNR value.

Instead of remaining confined to lower data rates like BPSK, which can limit throughput, the AMCS capitalizes on better channel conditions by increasing the data rate. This dynamic adaptation strategy strikes a balance between achieving higher throughput and maintaining reliable communication. By optimizing the modulation and coding parameters according to the real-time SNR, the AMCS effectively leverages the available resources to enhance data rates and consequently, user experiences within the wireless communication system.

III. RESULTS AND DISCUSSIONS

This section analyses the performances of the proposed adaptive transmission data rate in IEEE 802.11ac WLAN in terms of QoS performances which are the throughput and spectral efficiency The simulations were performed using the simulation parameters as listed in Table II in and executed by using Matlab.

There are two QoS performance metrics that are evaluated in this simulation which are the throughput and the spectral efficiency. Throughput is a measure of the data transfer rate or the amount of data successfully transmitted over a communication link, network, or system in a given time period. It indicates how much data is effectively being delivered from source to destination. Throughput takes into account factors like protocol overhead, retransmissions, and any delays in the network. Spectral efficiency is a crucial concept in wireless communication that measures how efficiently a given bandwidth of the radio spectrum is utilized to transmit data. It quantifies the amount of information that can be transmitted over a specific bandwidth while maintaining a certain level of performance. In essence, it's a measure of how efficiently a communication system uses the available spectrum to achieve a desired data rate.

Figure 5 shows a plot for transmission data rate against radius for non-adaptation and adaptation cases. It can be seen from the figure that the transmission data rate is much higher at the center region and gradually decreases towards the cell edge. In a wireless communication system without adaptive modulation and coding, the data rate (or achievable data rate) is influenced by factors like signal strength, interference, and path loss, which are related to the distance from the cell's base station. At the center region, the signal strength tends to be stronger due to reduced path loss and lower interference. This means higher signal-to-noise ratios (SNR), which allows the system to use higher-order modulation schemes and coding rates. As a result,
the data rate will be higher near the center. At the cell edge region, which is farther away from the base station (cell edge region), the signal strength decreases due to increased path loss and potential interference. The lower SNR limits the modulation and coding options, causing the data rate to drop. In this region, the data rate may be significantly lower compared to the center.

With adaptive modulation and coding, the system can dynamically adjust the modulation scheme and coding rate based on the real-time signal-to-noise ratio (SNR) at different locations. At the center region, where the signal strength is strong, adaptive modulation and coding can offer benefits. The system might use higher-order modulation and coding to achieve very high data rates when SNR is favorable. This can result in a higher data rate compared to a fixed scheme, enhancing spectral efficiency.

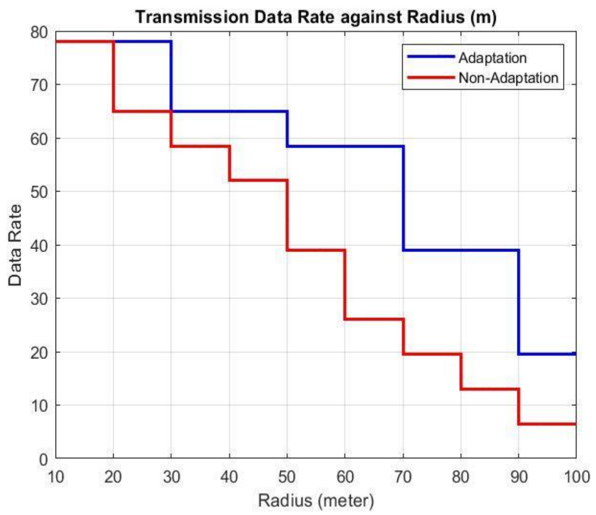

Figure 5. Data rate against radius plot (m) for non-adaptation and adaptation cases

The most significant advantage of adaptive schemes is seen at the cell edge region. As users move towards the cell edge, where the SNR drops, the adaptive system can automatically switch to more robust modulation schemes and coding rates. This helps maintain reliable communication even in challenging conditions, at the cost of reduced data rates. However, the reduction in data rate might not be as severe as in the non-adaptive scenario. As a result, the adaptive data rate against the radius plot shows a more consistent and smoother curve. Data rates will remain relatively higher compared to non-adaptive schemes at the cell edge due to the ability to adjust to lower SNR conditions.

Figure 6 illustrates the throughput against the radius plot for both cases. It can be seen from the figure that for both cases, at the center region, with stronger signals and higher data rates, the system can often achieve higher throughputs. Since the SNR is favorable, the likelihood of errors and the need for retransmissions are relatively low. Whereas at the cell edge region, where the SNR is lower, there is a higher probability of bit errors and packet loss. This leads to retransmissions, reducing the effective throughput. The system might need to operate at

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lower data rates to maintain reliability, further impacting throughput.

Throughput is a measure of the actual data transferred successfully over the communication channel, accounting for various factors including retransmissions, errors, and overhead. Without adaptive modulation and coding, the throughput trends can be more complex due to the impact of packet loss and retransmissions. Adaptive modulation and coding can help mitigate these effects by dynamically adjusting modulation and coding parameters to achieve a better balance between data rate and throughput across different regions of the cell's coverage area.

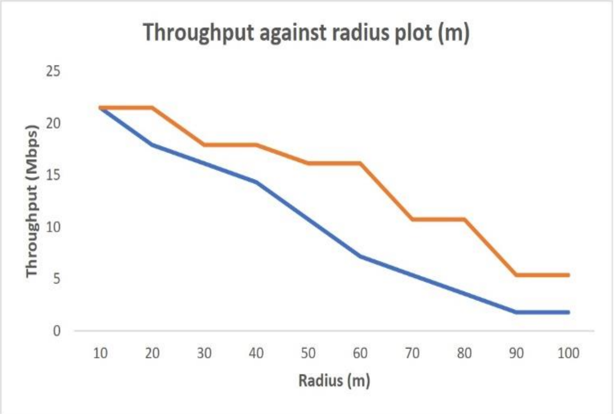

Figure 6. Throughput against radius plot for non-adaptation and adaptation cases.

Adaptive modulation and coding also have a positive impact on throughput, particularly in the presence of varying channel conditions and SNR. The center region has higher throughputs due to the generally stronger signals and higher data rates achievable with adaptive modulation and coding. With an adaptive approach, significant improvement can be seen at the cell edge region where the AMCS can substantially enhance throughput at the cell edge compared to non-adaptive schemes. By adapting to lower SNR conditions, the system can minimize packet loss and reduce the need for retransmissions. This leads to higher effective throughput even at lower data rates.

In the adaptive throughput versus radius plot, it can be observed that while still generally decreasing towards the cell edge due to the decreasing SNR, the proposed technique maintains higher throughput values in comparison to the non-adaptive scenario.

Figure 7 shows the spectral efficiency for the proposed AMCS as compared to the non-adaptation case. The spectral efficiency is a critical metric that quantifies how efficiently the available spectrum is being utilized to transmit data. Generally, spectral efficiency is calculated as the ratio of the achievable data rate to the available bandwidth, higher spectral efficiency indicates more efficient utilization of the spectrum. At the center region of the coverage area, where signal strength is typically stronger and interference is lower, users in this region generally experience better channel conditions. Due to favorable channel conditions, users at the center region achieve higher data rates and, consequently, higher spectral efficiency as can be seen from the figure for both cases. However, spectral efficiency gradually decreases as users move away from the center due to worsening channel conditions. Users at the edge experience challenging channel conditions. Thus, users at the cell edge are more likely to experience lower data rates and, thus, lower spectral efficiency due to the unfavorable channel conditions. Adaptive modulation and coding can play a crucial role in maintaining spectral efficiency at the edge by adjusting transmission parameters to match the channel conditions.

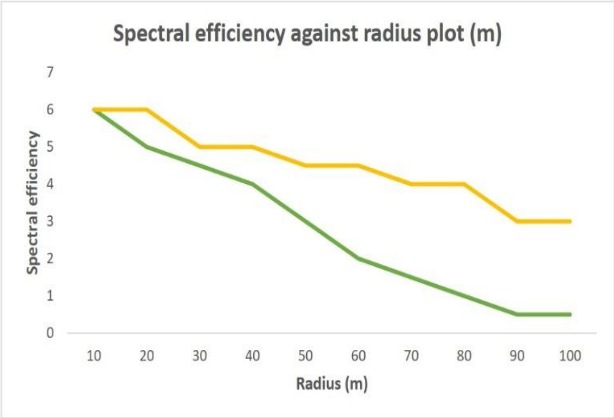

Figure 7. Spectral efficiency against radius plot for non-adaptation and adaptation cases.

Even for both conditions, the spectral efficiency at the center region deteriorates, but the proposed AMCS performs better compared to the non-adaptation case in terms of spectral efficiency. This can be explained due to optimal resource utilization by the proposed AMCS algorithm. The AMCS optimizes the use of available resources by adapting the transmission parameters to match the current channel conditions. This ensures that the spectrum is used efficiently. Due to the adaptive approach, the AMCS case achieves higher spectral efficiency at the cell edge. This increase is a result of better-suited MCS selection for the given SNR levels.

CONCLUSION

In this study, we introduced and investigated the efficacy of an adaptive modulation and coding scheme as a potent solution to enhance the Quality of Service for cell edge users in wireless communication systems. The outcome of the proposed approach demonstrates the substantial impact of this technique on addressing the unique challenges faced by users located at the cell periphery, where signal quality tends to degrade. The findings reveal a significant enhancement in achievable data rates, throughput, spectral efficiency, and overall user experience for cell edge users. This enhancement is crucial for promoting a more equitable distribution of network resources and bridging the gap between users at different distances from the base station. By leveraging the adaptive nature of this technique, operators can optimize resource allocation, reduce unnecessary retransmissions, and ultimately elevate the QoS delivered to these users. As the demand for high-quality wireless connectivity continues to grow, the proposed adaptive modulation and coding scheme offers a viable and scalable approach to address the QoS challenges faced by cell edge users. While this study sheds light on the potential benefits of this technique, there remains room for further exploration, such as investigating its compatibility with other advanced technologies like Massive MIMO and beamforming. In conclusion, the results obtained from this study underscore the effectiveness of the adaptive modulation and coding scheme in improving the QoS performance of cell edge users. This technique has the potential to revolutionize the way wireless networks cater to users across varying distances from the base station, ultimately contributing to a more robust and equitable communication ecosystem.

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