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Two-level frame aggregation with enhanced A-MPDU for signal-to-noise ratio efficiency in IEEE 802.11n WLANs

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ABSTRACT

One of the most important frame aggregation features for enhancing the speed of IEEE 802.11n wireless local area networks (WLANs) through sharing headers and timing overheads is an aggregate MAC protocol data unit (A-MPDU). However, because aggregation overhead affects A-MPDU frame size, the A-MPDU performance falls short of user expectations. The variable signal-to-noise ratio (SNR) is significantly decreased as a result of the influence of lost sub-frame on the volume of sub-frames that may be aggregated (the level of aggregation). In order to solve this issue, this study suggests an improved A-MPDU with reduced header overheads as well as a efficient two-level aggregation technique based on enhanced A-MPDU. To test the suggested plan, a simulation experiment was run on NS-3. The results show that the suggested two-level aggregation approach works better than the existing methods by achieving higher throughput, SNR, and a efficient medium access control (MAC) layer.

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1. INTRODUCTION

Frame aggregation is one of the features of IEEE 802.11n standard wireless area network and is particularly a method for reducing frame transmission overheads [1]-[3]. For example, frame aggregation at medium access control (MAC) layer enhances data rates performance [4], improves network goodput [5], as well as voice over internet protocol (VoIP) performance [6], and is regarded as a significant advancement in IEEE 802.11n [7]. Although, the two types of frame aggregation were referred to as the aggregated MAC service data unit (A-MSDU) and the aggregated protocol data unit (A-MPDU). The work by Qian *et al.* [8] highlighted that, two-level aggregation is created by combining A-MSDU and A-MPDU. However, the performance of frame aggregation methods suffered severely in an erroneous channel, which can lead to the emergence of unexpected problems such as corruption aggregation frames [9]-[12]. Certain improvements to the traditional frame aggregation method are suggested as a result of these challenges. For instance, Lin and Wong [13] introduced a frame size adaptation technique for A-MPDU aggregation that combines significant MSDU fragmentation with an analytical model that establishes the appropriate size of each aggregated fragment. Fragmentation usefulness can only be found at higher bit error rates (BERs) than those employed in actual applications. Despite the fact that aggregation types are adaptively chosen based on the buffer size [14].

Additionally, Li *et al.* [14] suggested an adaptive strategy based on a signal-to-noise ratio (SNR). Using this method, the transmitter can build a table using the optimal starting aggregation length, the associated SNR based on the aggregation frame length and its respective throughput at various SNRs [15]. After checking its capabilities, the transmitter sends data by selecting a suitable aggregate length based on the SNR that is currently being observed. Similar to this, it was suggested to use an adaptive A-MPDU aggregation that groups MSDUs according to the sub-frame size and the required minimum MPDU starting spacing. Even though this method lowers transmission overhead, throughput is still limited because A-MSDU effectiveness is underutilized [16]. Furthermore, Saif *et al.* [17] presents a frame aggregation method that allows for selective re-transmission at the MSDU level through the application of an implicit sequence control mechanism. The original MAC header is not altered in order to grant authorization. However, the method improves frame aggregation transmission efficiency and significantly changes the frame aggregation level. Furthermore, an adaptive two-level frame aggregation for fairness and efficiency [18], [19]. In addition, Das *et al.* [20] evaluate IEEE 802.11 WLAN frame aggregation under different network conditions, Hajlaoui *et al.* [21] applied two-dimensional Markov chain model, and Lee and Hwang [22] suggested A-MPDU aggregation with an optimal number of MPDUs for delay requirements. Moreover, Akpanobong *et al.* [23] extend the throughput performance of low SNR scenarios using the two-level frames aggregation with enhanced A-MSDU.

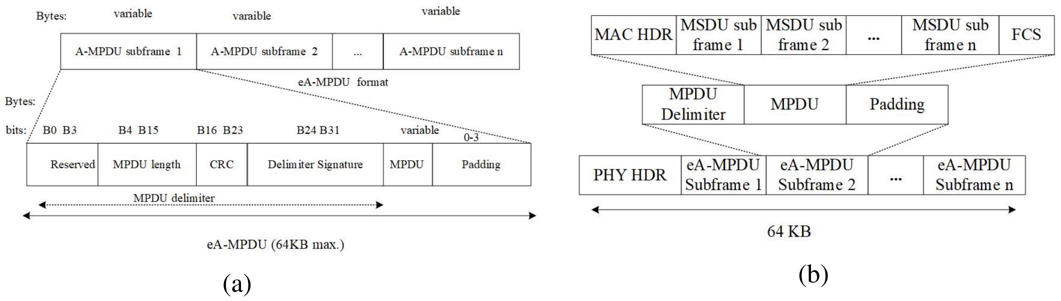
In view of the fact that frame aggregation techniques have improved network performance, they do so at the expense of more overhead. Therefore, a novel approach is needed to boost A-MPDU performance, by extending Akpanobong *et al.* [23]. As a result, this work develops an improved A-MPDU technique and efficient two-level aggregation to boost the throughput and efficiency of the classic A-MPDU. To increase the size of A-MPDU frames as they decrease, one of the prescribed frame aggregation sizes is adaptively modified based on overheads and existing aggregation levels. The rest of this paper is structured as follows: section 2 discussed the proposed procedure. Section 3 demonstrates the method of the study. Section 4 presents the result and discussion. Finally, section 5 concludes the paper and highlighted future work.

2. THE PROPOSED PROCEDURE

Figure 1 demonstrates the typical frame aggregation structures. Firstly, two-level aggregation can produce a longer frame length than the MPDU when aggregation sizes are identical. Thus, the two-level frame aggregation standard is used to increase the aggregated frame size, although this does not guarantee that more throughput is possible under all circumstances. In order to further increase the channel efficiency and throughput, this work proposes to integrate the new A-MPDU scheme into a two-level aggregation mechanism with eA-MSDU (shown in Figure 1(a)). The new A-MPDU aims to improve SNR and channel efficiency by reducing header overhead and integrating it with two-level aggregation.

Figure 1(b) demonstrates the integration of the legacy two-level architecture with the proposed eA-MPDU, as well as the efficacy of the header overhead. In the conventional two-level aggregation method, the A-MPDU is replaced by the eA-MPDU, which is created at the bottom layer. Moreover, in the typical two-level frame aggregation architecture that 802.11n permits, the maximum size of an upgraded A-MPDU is 64 KB. However, it may be further constrained by the static timing analysis (STA) abilities included in the high throughput (HT) capability element. The block ACK, utilized in the A-MPDU scheme, differentiates between lost and subsequent MPDU frames, enabling discretionary retransmission [8]. Consequently, the proposed two-level aggregation is acknowledged with compress block acknowledgment (CBA) and an 8 KB acknowledgment bitmap. In addition, the 64 bits in the bitmaps are adequate for recognizing the 64 sub-frames in the A-MPDU aggregation. Since the framework's primary objective is to further increase channel bandwidths, the request to send/clear to send (RTS/CTS) is optional and lessens the impact of collisions. As a result, employing large aggregated frames can be done to compensate for these overheads. Therefore, the procedures for aggregation and de-aggregation are designed to account for these characteristics.

In particular, the aggregation process commences with the MSDU received from the logical link control (LLC), where the eA-MPDU is produced. After analyzing the SNR for channel efficiency, if the SNR values are more than 21 dB, the A-MSDU is included in the aggregated A-MSDU. The completed A-MSDUs are utilized immediately to produce the A-MPDU. After completing this step, a delimiter and padding are added where appropriate. In addition, the channel is then contested, and any packet is sent to its destination. If $SNR \leq 21$ dB, the A-MPDU is utilized to create the eA-MPDU. Consequently, there is only one MSDU included within an eA- MPDU, and after the maximum length is reached or the delay constant is surpassed, the super-frame MPDU is utilized to generate the eA-MPDU, and the process is repeated. Hence, after the A-MPDUs have been received at the receiver end, the MPDUs will first check for mistakes or corruption. If an MPDU is lost or corrupted, it will be marked for retransmission and deleted; otherwise, it will be buffered. This repeats the process until all received MPDUs have been scanned. The Block acknowledgment is then created and retransmitted MPDU frames that have been corrupted are received. The buffered MPDUs is next searched for MSDUs, which are reconstructed from the information contained in their respective MAC super-frame headers, sorted, and transferred to the top layer. Figure 2 depicts the procedure.



(a) (b)

Figure 1. Frame aggregation structures (a) eA-MPDU frame structure and (b) enhanced two-level aggregation frame structure

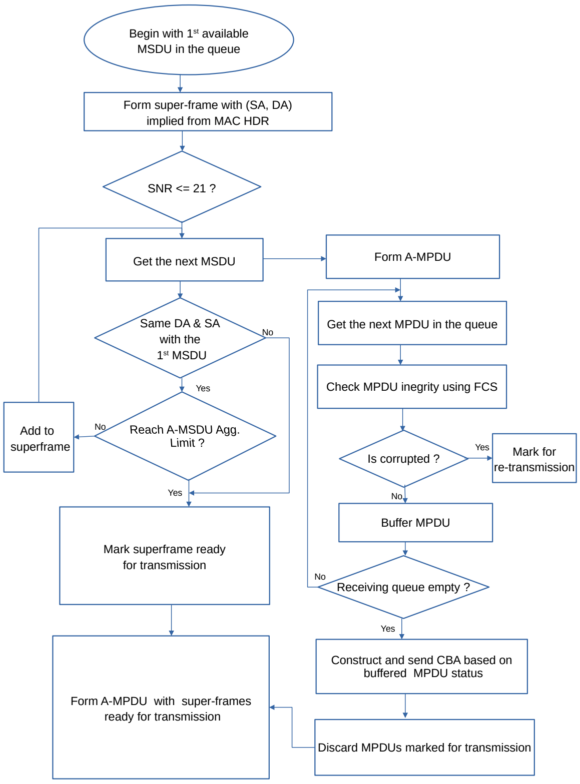


Figure 2. Proposed scheme process flowchart

3. METHOD

The throughput model was developed in order to access the performance throughput saturation based on the discrete-time Markov chain (DTMC) for a fixed number *(N)* of stations and A-MPDU [24], [25]. This study examines a single-HOP WLAN composed of HT-STAs and synchronized with an HT-AP in infrastructure mode, with the STAs exchanging traffic using the user datagram protocol (UDP). Analytical modeling required the use of mathematical formulations to assess the saturation throughput. Consequently, the analytical model was constructed and validated through simulation. Consequently, this paper presents an analytical model to examine overhead and throughput under saturation conditions (S). The overhead model is based on the work of Noma *et al.* [9], whereas the extension model of normalized distributed coordination functions (DCF) throughput in saturated channel situation to frame aggregation is based on the study of Bianchi [25].

Similarly, the study proposes a generic paradigm for studying aggregation techniques. In order to assess the models in this study, the following assumptions are made: the DCF saturation throughput based on the Bianchi model assumes that the probabilities of collision, denoted by p, for each of the N fixed number of STAs involved are constant and independent of the number of transmission attempts and retransmissions correspondingly. In addition, since padding to make either A-MSDU or A-MPDU a 4B-block is optional and the majority of packets come in the 4-block format, it is believed that the average packet size always fits multiples of 4 B. Next, the STAs operate under saturated conditions, with packets always available for full-frame aggregation. The signal strength was modified so that the STAs are within communication range. Therefore, the potential of hidden nodes is eliminated, and RTS/CTS methods are unnecessary.

3.1. Packet transmission probabilities

In accordance with the IEEE 802.11n specification, frame aggregation was regarded to be A-MPDU, A-MSDU, or both combining in two-level aggregation. A refers to an aggregation strategy that sends a specified physical layer convergence protocol service data unit (PSDU) to the PHY layer for transmission via the channel at the PHY bit rate, R, in Mbps. A then can be said to employ an A-MSDU aggregation scheme if there are $m > 1$ MSDUs in an MPDU and only if $n = 1$ MPDU in the PSDU. The PSDU contains only one (1) MPDU, and the MPDU encloses more than one MSDUs from LLC. For the A-MPDU scheme, if there is only $m = 1$ MSDU in every MPDU and there are $n > 1$ MPDUs in the PSDU, since, A-MPDU aggregation is the only aggregation that does not support A-MSDU at all. Therefore, the PSDU carries many MPDUs, each containing a single MSDU. For a two-level aggregation scheme, if there are $m > 1$ MSDUs in an MPDU and $n > 1$ MPDUs in the PSDU, the actual implementation of two-level aggregation may occasionally transmit PSDU containing just aggregated MSDUs or MPDUs; however, this is extremely uncommon. Nevertheless, this may occur if there are few MSDUs or MPDUs that satisfy the relevant aggregation condition, or if the MPDU length exceeds the 65 KB limitation. In light of the fact that each MPDU in the PSDU aggregates more than one MSDU and there are several MPDUs in the PSDU, this encapsulates the generality of the two-level aggregation. No aggregation is employed in A if in every case $m = n = 1$ (that is the PSDU encloses only one MPDU having one MSDU therein). Thus, the values of m and n denote the number of MPDU(s) and MSDU(s), respectively.

Let m = the quantity of MSDUs within a certain MPDU, n = average amount of MPDUs contained in a PSDU, and L= the length of the PSDU. From the A-MPDU level structure and aggregation procedure, as demonstrated in Figure 2; subframes are regarded as units regardless of whether they are constructed from MSDU or A-MSDU. Thus, the length of the PSDU, L, is expressed as:

$$L = \sum_{i=1}^{n} (L_{mpdu}(i) + L_{del}(i) + L_{pad}(i)) \tag{1}$$

where $n = 1$ if either only A-MSDU or no aggregation is employed at all.

3.2. Throughput model

There are four possible times for each multiple of a discrete slot in a WLAN technology in which several connected STAs compete over the same channel. These includes, an idle time (σ), transmission slot (T_s), collision slot (T_c), and time slot with error (T_e). Thus, the throughput can be represented from the perspective of one of the STAs in the system given the aforementioned assumptions. T = P (STA transmits in a randomly chosen time slot) as proposed in Bianchi [25], is expressed as:

$$T = \frac{2(1-2_p)}{(1-2_p)(W+1)+p^W(1-2_p)^m)} \tag{2}$$

where *p* = P (unsuccessful transmission attempt) and *W* is the window of choice. Note that a failed transmission can only be possible as a result of the collision. Hence, *p* is the probability of a collision occurring. After observing a collision, *T* is a function of double contention window *W*.

When p_{tr} = P (at least 1 STA attempt transition in a given slot) = $1-(1-T)^{N-1}$, and p_s = P (exactly 1 STA transmit and was successful) = $\frac{N_T(1-T)^{N-1}}{p_{tr}}$. Now let P_1 = P (selected slot is empty) = (1 - p_{tr}), P_2 = P (selected successful transmission) = $p_{tr}p_s$, P_3= P (collision occurs in the selected slot) = p_{tr}(1 - p_s), and σ = empty slot time.

In an idealized channel, a collision would be the ultimate cause of an unsuccessful transmission. Consequently, the normalized saturated throughput for aggregation S can be expressed as follows [24]:

$$S = \frac{p_{tr}p_sE(P)}{p_1\sigma + P_2T_s + p_3T_c} \tag{3}$$

where $T_s = T_{back} + T_{data} + T_{difs} + T_{sifs} + T_{ack}$, T_c = $T_{data} + T_{sifs}$, and $T_{back} + T_{data} + T_{difs} + T_{sifs} + T_{ack}$, are defined in Table 1.

The failure of the transmission on a channel error is possible to occur when there is a transmission attempt by the STA but fails as a result of the collision, or when the transmission succeeds but part or whole frame is corrupted owing to channel error. Thus, it is important to be aware that a single bit error corrupts a single MPDU carrying MSDU or A-MSDU. From the A-MPDU perspective, in (4) can be represented as follows:

$$S = \frac{p_{tr}p_sE(P)(1-p_b)^{\frac{L}{n}}}{p_1\sigma + p_2T_s + p_3T_c + p_eT_e} \tag{4}$$

whereas *p* represents the probability of an unsuccessful transmission attempt, is now written as:

$$p = 1-(1-p_e)(1-p_c)$$

with p_c is the collision probability expressed as $p_c = 1-(1-T)^{N-1}$, and p_e denotes the probability of a successful transmission as:

$$p_e = \prod_{i=1}^{n}(1-(1-p_b)^{\frac{L}{n}}).$$

An *n* being the number of MPDUs in a PSDU. Let p_2 is denoted as; p_2 = p_{tr} p_s (1 - p_e), while considering the error. Regarded BER as p_b and T_e = T_{data} + T_{eifs}. Therefore *S* is likewise an independent variable of the implementation either being an A-MSDU, A-MPDU, or a two-level aggregation variant.

4. RESULTS AND DISCUSSION

4.1. Experiment

A simulation experiment was conducted on NS-3, to evaluate the proposed A-MPDU throughput with two-level aggregation and the ratio of MAC throughput to PHY bit rate. Considering the SNR sensitivity of WLANs, the technique was compared to A-MPDU, A-MSDU, and two-level aggregation implementations. With frame widths of 64, 128, 256, 512, and 1,024 bytes, Table 1 displays the configurations for a few of the simulation's major parameters. In addition, multiple aggregate sizes in the range of 2, 4, 16, 32, and 64 bytes were specified. Consequently, among the nodes and AP, the distance between the aggregation response to SNR was minimized so that the influence of noise was negligible until SNR values obtained were less than 15 dB of the noise.

Table 1. Simulation parameters used

Parameter	Description	Value
CBA	CBA frame size	30 B
R'	Basic rate	54 Mbps
R	Data rate	144 Mbps
CWmin	Minimum contention window	15
CWmax	Maximum contention window	1,023
Tdifs	DIFS period	0.000034 s
Tslot	Slot time	0.000009 s
Tpreamble	Preamble transmission time	0.000016 s
Tplcphdr	PLCP header transmission time	0.000004 s
Tsifs	SIFS period	0.000016 s
SNR	Default signal to noise ratio	27 dB

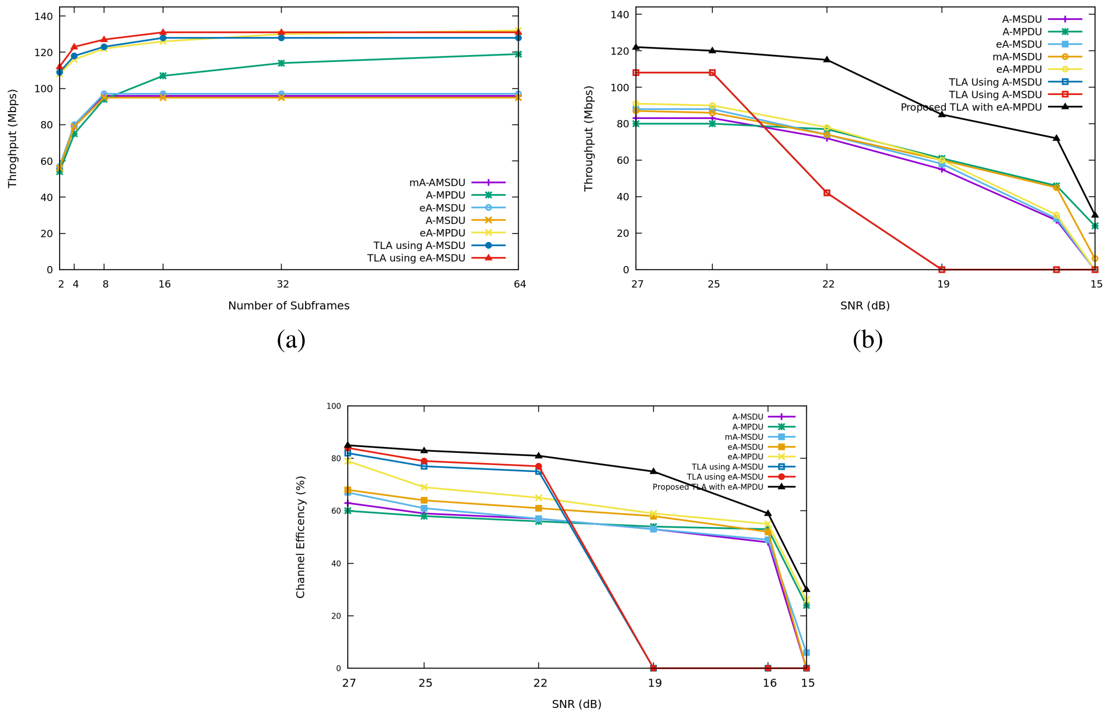
The experiment was conducted on a single-hop WLAN (HT-STAs and an HT-AP) in infrastructure mode. The STAs exchange traffic using the UDP protocol. Two unique STAs are utilized, separated by approximately 20 meters, with adequate signal strength to ensure that no packets are lost due to channel error and no concealed terminal. Also, CBR traffic of 128 B frames is formed under saturated conditions within the source STAs. To determine the impact of aggregation size, the number of packets in an A-MPDU aggregation was modified, and the aggregation size was limited to 65 KB. The research guaranteed that the inter-arrival frame rate was tweaked each time the simulation changed, up until the point of saturation, which is then preserved.

4.2. Discussion

Figure 3 depicts the simulation analysis comparing the new eA-MPDU scheme with A-MPDU, A-MSDU, mA-MSDU, and two-level aggregation using the eA-MSDU scheme enhancements. Figure 3(a) indicates that frame size influences throughput, which begins at 55 Mpbs and grows to approximately 122 Mpbs when 64 sub-frames are aggregated. The result demonstrates that two variables (MPDU subframe size and aggregation) affect total throughput efficiency. A-MPDU is among the most sensitive aggregations to frame size increases. Nonetheless, reduced frame sizes degrade performance, resulting in a limited throughput. Due to channel fault, SNR performance was so unpredictable that packets could not reach consumers beyond 19 dB. In addition, the result shows that as frame size grows, so does the throughput of all frame aggregation methods. When employing the two-level frame aggregation with the eA-MPDU method, the loss of throughput as a result of changing SNR is properly compensated. To improve the SNR value, the technique was incorporated into a conventional two-level aggregation. The throughput of the suggested eA-MPDU system consistently outperforms the other schemes.

Figure 3(b) shows the impact of decreasing SNR on response throughput. The SNR and throughput also decrease, and each aggregation algorithm responds differently to varying SNR. A-MPDU aggregation is less sensitive to SNR at 27 dB, leading to the A-MSDU scheme. As the SNR decreases, the A-MSDUs become increasingly sensitive. However, this does not apply to the mA-MSDU because the selective re-transmission advantage follows a similar pattern to the A-MPDU. At SNRs above 24 dB, eA-MPDU, eA-MSDU, and mA-MSDU perform wonderfully, but their throughput is inferior to that of two-level aggregation approaches employing A-MSDU and eA-MSDU. The suggested two-level aggregation employing eA-MSDU and eA-MPDU outperforms conventional techniques at higher SNR levels due to a header reduction. In contrast to A-MSDU and A-MPDU aggregation techniques, the proposed method performs poorly with lower SNR values.

Figure 3(c) demonstrates that at a higher SNR rate of 27 dB, the throughput performance is around 122 Mpbs, which corresponds to a channel efficiency of 85%. The performance of the channel efficiency was maintained up to an SNR value of 25 dB, after which its efficiency decreased to 84%. Moreover, at an SNR value of 22 dB, throughput decreased by approximately 23% to 95 Mpbs. In addition, the study found that at an SNR of 21 dB, the throughput dropped to 67 Mpbs and the channel efficiency was approximately 50%, which was somewhat greater than the efficiency attained with two-level aggregation using the eA-MSDU. Similarly, at 19 dB, the throughput performance decreases to 67 Mbps, or approximately 47% channel efficiency. Consequently, the proposed approach has demonstrated superior throughput performance compared to the historical two-level scheme employing eA-MSDU, which had a channel efficiency of roughly 4.3%, thus the proposed scheme can achieve a 43% improvement. Consequently, the proposed eA-MPDU was able to increase the throughput performance for the consumers by more than 15 dB.



(a) (b)

(c)

Figure 3. The comparison of the new eA-MPDU scheme with A-MPDU, A-MSDU, mA-MSDU, and two-level aggregation using the eA-MSDU scheme improvements (a) proposed eA-MPDU with increasing frame size, (b) aggregation responses to SNR, and (c) channel efficiency with increased SNR

5. CONCLUSION

This work developed an improved A-MPDU scheme by overcoming its aggregation overhead, throughput, and aggregation responsiveness to SNR performance. To improve the throughput and channel efficiency, the study proposed a two-level aggregation system with an upgraded A-MPDU at higher SNR values and adapted the classic A-MPDU method at lower SNR levels. The upgraded A-MPDU system surpasses the conventional A-MPDU scheme in terms of throughput MAC efficiency and got a lower SNR value. In addition, results indicate that the suggested aggregation strategy greatly enhances throughput performance. In the future, it will be necessary to add adequate scheduling and adaptive mechanisms to the current approach.

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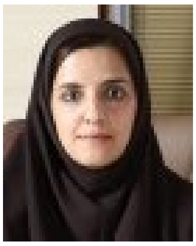

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