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On the evaluation of the IEEE 802.11ac WLAN performance with QoS deployment

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ABSTRACT

The increase in the number of users on wireless local area networks (WLAN) and the development of large size applications have increased the demand for high-speed data rate and low latency. The IEEE 802.11ac was developed to provide very high throughput WLANs. Many enhancements are added to the medium access control (MAC) and physical (PHY) layers to increase data rate and improve network performance, these features enable the IEEE 802.11ac standard to provide quality of service (QoS) for multimedia applications. This paper concentrates on the impact of QoS on the system performance in term of delay and throughput. Four scenarios are proposed to investigate the network performance with different (from 1 up to 8) spatial stream (SS). The objective modular network testbed in C++ (OMNet++ modeler v5.5.1) is used to simulate and model these scenarios. For 8×8 SS, the results of simulation show the best throughput (maximum) and delay (minimum) values of (622, 484, 399.3, 382.96 Mbps) and (0.0211, 0.0589, 0.1037, 0.1202 sec) for 5, 15, 30 and 45 node number scenarios respectively. Although the number of nodes increases, the system performance decreases, however when QoS is deployed the performance is enhanced and its best improvement is obtained at the highest (45) node number scenario with values of 94.4% and 56.1% for throughput and delay respectively.

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1. INTRODUCTION

Due to the enhancement and wide spread of wireless local area networks (WLAN) technology with increasing demand for high-speed applications, this technology is becoming increasingly popular and one of the most sought by consumers, around the world. It is known that the wireless technology must support high-quality multimedia services. Therefore, low latency and high throughput are required, so that reliable data transmission with quality of service (QoS) standards are satisfied. IEEE-802.11ac standard performs better in terms of reliability, range, throughput, and capacity. It operates in the 5 GHz frequency band, supports IEEE 802.11e QoS, and backwards compatibility with previous WLAN standards, it also provides distinctive services-for video, data, and voice [1], [2]. Due to congestion problem in the highly loaded WLAN, many new features and enhancements at the medium access control (MAC) and physical (PHY) layers of the wireless IEEE 802.11ac-standard are developed to allow for high data rates performance. The enhancement in the data rate is due to the improvements such as (256QAM) modulation level [3], channels bandwidth extended to include 20, 40, 80 and 160 MHz, and boosting the number of antenna to eight on the access point [2], [4]. To solve the contention and congestion problem among users of the WLAN the QoS feature can be applied through the enhance distributed channel access (EDCA) mechanism of this standard [5]. The IEEE 802.11ac uses an updated version of EDCA protocol, which is primarily introduced in IEEE 802.11e [6]. EDCA uses a contention based prioritized channel access. In the QoS application the services are scheduled into various access categories (ACs) (video, voice, background and best-effort) with different priorities (high to low) and contention windows. When station accesses the channel through EDCAs for particular AC, it can continuously transport data from that AC for a fixed period of time without causing further contention. Based on the volume of the transmitted traffic, dynamic bandwidth channel access (DBCA) in IEEE 8802.11ac can assist to determine the channel width, on top of which the Transmit opportunity (TXOP) will be reserved following the EDCA contention procedure [7]. The performance of congested network can be enhanced through the application of this feature. This paper contributes to the analysis of IEEE 802.11ac WLAN performance using the OMNET++ 5.5.1 modeler. When aggregation level and block acknowledgment are enabled, the effects of multiple parameters on network performance are verified using modeling process tool. These parameters involve the number of multiple-input multiple-output-spatial stream (MIMO-SS) and number of nodes, with EDCA mechanism enabled when QoS is applied. With and without QoS deployment, the WLAN performance evaluated in terms of delay and throughput.

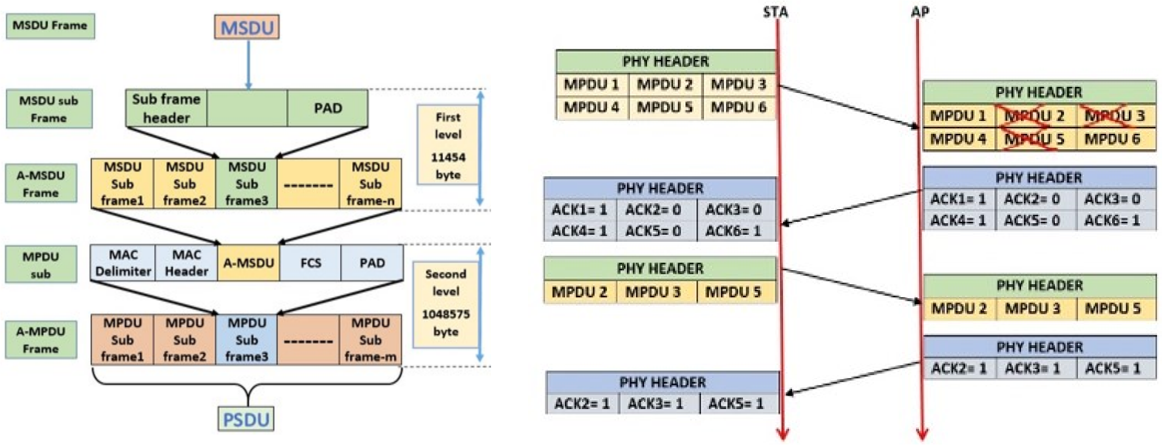
2. RELATED WORK

The performance of multiple input multiple output-orthogonal frequency division multiplexing (MIMO-OFDM) system is analyzed and investigated for IEEE 802.11ac for various digital modulations and coding rate by varying the number of transmit and receive antenna [8]. The results show better system performance and data rates enhancement in WLAN. The authors [9] compare the performance of MAC between 802.11n and 802.11ac over three various frame aggregation mechanisms. Their results indicate that 802.11ac with a configuration of 80 MHz and single SS out. performs 802.11n with a configuration of 40 MHz and two SS in terms of maximum throughput by 28%. By using the OMNet++ network simulator, a new Massive MIMO module is designed by [10] for verifying the operation of an IEEE 802.11ac wireless network according to the theoretical expectations. Sharma [11] has investigated the capabilities of the IEEE 802.11e protocol to improve QoS support in WLAN for time critical applications. A high throughput multi-level scheduler, which uses an adaptive learning algorithm to sense the channel, is developed by [7], to support dynamic bandwidth allocation and improve QoS performance whilst ensuring fairness among contending stations to access the channel. Kosek [12] has proposed a new DEMS queuing mechanism to support down link-multiuser-multiple input multiple output (DL-MU-MIMO) transmissions. The result shows throughput improvement and decrease in the queuing delay for high priority ACs. Andread is [6] proposed an algorithm to tune the value of the TXOP limit at the access point (AP), in order to dynamically change its channel resources according to the current traffic conditions. Simulation result shows significant enhancement in the QoS performance of multimedia traffics and also increase the global WLAN throughput. The authors in the the frame aggregation mechanisms of the IEEE 802.11ac standard is studied for very high throughput WLAN [13]. Their simulation results show enhancement in the MAC layer efficiency and achievable throughput.

3. RESEARCH METHOD AND MATERIAL

The IEEE 802.11ac WLAN interface has been improved to support very high throughput and satisfy the required QoS for dense multimedia (or congested) traffics networks. The standard's improvements are primarily achieved at the MAC and PHY layers. The four main enhancements at the PHY layer are the use of 256-QAM, down link multiuser MIMO, up to eight antennas and supports (20, 40, 80 and 160 MHz) channels bandwidth [4]. The IEEE 802.11ac supports MIMO with OFDM to increase channel capacity and allows maximum data rates of 693 (1×1 SS) and 6240 (8×8 SS) Mbps [14], [15].

At the IEEE 802.11ac PHY layer, three processing techniques are used in MIMO system to improve WLAN performance: i) First space or spatial division multiplexing (SDM), that is adopted in this paper; and ii) Second space diversity or space time block coding, and third low density parity check channel coding [8], [16]. At the MAC layer, frame aggregation is achieved by collecting multiple data packets from the upper layer into one large data frame for transmission. As a result, the over ead is decreased in multiple frame transmission since the header over head and inter-frame time are saved. The aggregation mechanism of the 802.11ac MAC layer, which is described by [17], [18], has two-level aggregation scheme as shown in Figure 1(a). With maximum physical service data unit (PSDU) size of 1,048,575 octets. The other MAC layer feature is the block acknowledgement (BA), the receiving station sends a BA to confirm receipt frames successively. As shown in Figure 1(b), frames can be sent without having to acknowledge each received unicast frame, making it ideal for unicast applications that are time sensitive or real-time applications (video conferencing or audio) when retransmission is critical [2], [19], [20].



(a) (b)

Figure 1. Shows the IEEE 802.11ac MAC layer features (a) frame aggregation levels and (b) block Ack with aggregation

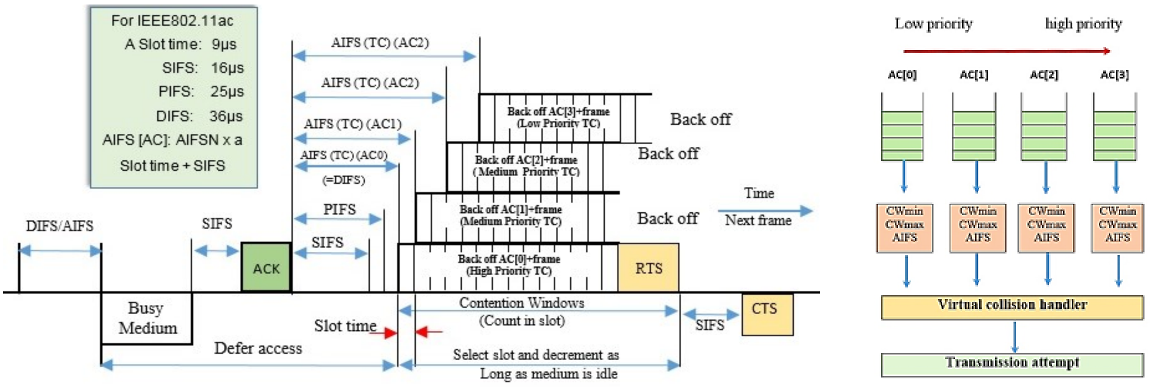
3.1. QoS deployment in IEEE 802.11ac standard

The IEEE 802.11ac defined hybrid coordination function (HCF) as a boosted medium access function using two access mechanisms: HCF controlled channel access (HCCA) and enhanced distributed channel access (EDCA) [6], [21]. The main feature in HCF is the introduction of transmission opportunity concept (TXOP) which is a time period where a QoS aware station (Q-STA) can send a frame burst. TXOP-limit is the maximum value of TXOP, this value is assigned by QoS enhanced access point to make delay control [22]. In IEEE 802.11ac (and depended on the size of transmitted data) the DBCA is utilized to specify the required channel width and as a result the needed TXOP will be reserved. EDCA implements four different buffers (i.e. data queues) with different access category (AC) in every QoS aware terminal. The basic function of EDCA is to support traffic differentiation. Traffic categories (TCs) are the prioritized service flows. Every TC is specified a minimum and maximum contention window (CW_{min} and CW_{max}) based on its priority. Every AC considered independent DCF terminal with dedicated access parameters (CW_{max} [AC], CW_{min} [AC], TXOP-limit [AC], arbitration inter-frame space (AIFS) [AC]) that are periodically broadcasted by AP during the beacon interval. EDCA introduce two techniques to support traffic differentiation: i) Use new inter-frame space (IFS) called arbitration IFS (AIFS) for each AC instead of DIFS. The timing diagram of EDCA mechanism is shown in Figure 2(a); and ii) Technique allocates different sizes of collision window for each AC. High AC priority has small window size which make frame belonging to this AC being transmitted before other frames related to different AC which has larger window size. The backoff time is randomly chosen between (1, CW[AC]), when the backoff process is invoked [23], [24], each AC in a QoS-aware terminal can send a QoS request to the AP, this request contains the application's traffic specification (T_{SPEC}), such as peak/average datarate and maximum/average frame size. When the demand is received by the AP, it makes admission control to determine if the request accepted or not. If the request accepted, it determines the duration for the admitted data to use the channel [25]. As shown in Figure 2(b), video, voice, back ground and best effort are scheduled service queues in four first in first out (FIFO) that defined by EDCA with associated priority (knows AC_S) [26].

The hybrid coordination function for the IEEE 802.11ac standard is considered in this paper, with (video, voice, best effort, and background) TC_S (AC_S). The QoS characteristics for these categories are provided in Table 1 together with their AIFS values measured in slots and transmission opportunities (TXOP in ms). The Table 1 illustrates that the data frame with high priority traffic is assigned minimum waiting time slots (defined by the AIFS). The upper and initial limits of the random back off waiting time (per data frame) are specified by the CW_{max} and CW_{min} parameters, respectively, through the contention interval of access point resources. The lowest or minimum time slot number for high priority TC is also included in these parameters.

Table 1. Illustrate TCs with parameters of QoS

Traffic	AC	AIFSN (back-off)	CW_{min}	CW_{max}	TXOP in (ms)
Voice	0	2	7	15	6.016
Video	1	2	15	31	6.016
Best effort	2	3	31	1023	3.264
Background	3	7	31	1023	3.264



(a) (b)

Figure 2. The enhance data channel access mechanisum with its: (a) timing daigram and (b) access categories

3.2. Theoretical performance of delay and throughput for the IEEE 802.11ac

The theoretical performance is presented to confirm the simulation results. According to the [1] analyses, the MAC layer delay and maximum data rate can be calculated as (1) and (2).

$$\text{Throughput}_{(bits/sec)} = \frac{N_{DS} * N_{SS} * N_{\text{Bits Per Symbol}} * \text{CR}}{OFDM_{SD}} \tag{1}$$

$$\text{Delay}_{\text{(second)}} = \frac{Max\ A\text{–}MPDU\ \text{Length}}{\text{Max DR}} \tag{2}$$

Where:

N_{DS} = Number of data subcarriers (for 20 MHz equal to 52 Subcarriers),

N_{SS} = Number of SS is variable from 1 to 8,

$N_{bit\ per\ symbol}$= Number of bit per symbol for 256QAM is 8,

CR= code rate (value 3/4),

$OFDM_{SD}$ = OFDM Symbol Duration (which is given by $\frac{1}{\Delta \text{F}}$ where ΔF equals subcarrier spacing) and its value=3.6 µs involve GI of 400ns,

Max A-MPDU: is the second level A-MPDU length = 1048575 Bytes,

Max DR = maximum data rate.

Table 2 illustrates the theoretical delay and throughput for various SS.

Table 2. Illustrate theoretical over all delay and throughput value of the 802.11ac standard

SS	1×1	2×2	3×3	4×4	5×5	6×6	7×7	8×8
Throughput (Mbps)	86.7	173.3	260	346.7	433.3	520	606.7	693.3
Delay (sec.)	0.0967	0.0484	0.03226	0.02419	0.01935	0.01613	0.01382	0.01209

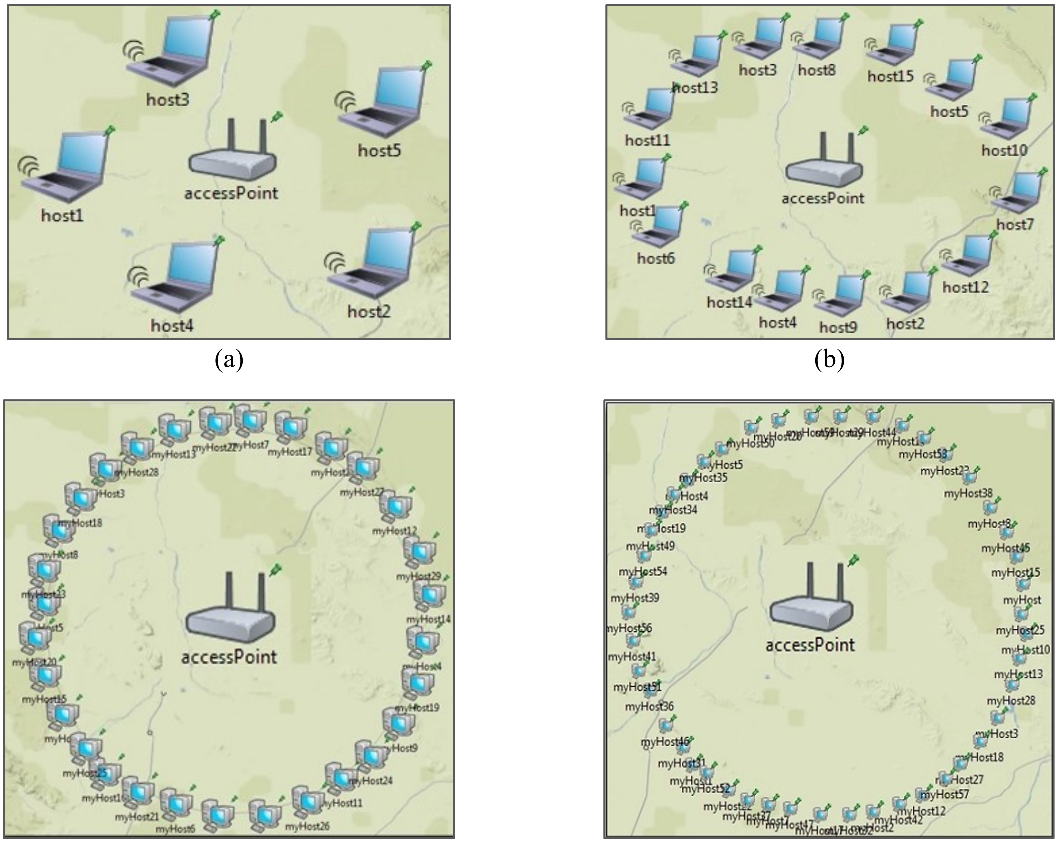
3.3. Proposed scenarios of the modeled network with assumption

Figure 3 shows four uniform topology (single hop) scenarios with varied number of nodes (5, 15, 30, and 45) to examine the performance of a WLAN based on the IEEE 802.11ac standard. The proposed WLAN scenarios are modeled and simulated using the discrete event objective modular network testbed in C++ (OMNet++) version 5.5.1. The modeling processes are accomplished under the following assumptions:

- The access point in the center of model and the nodes are distributed uniformly over 500×500 m^2 area.
- System nodes are fixed.
- The block acknowledgement feature is enabled.
- Base on the applied QoS the frame aggregation is enabled with optional TXOP size is selection (from 3.264 to 6.016 ms).
- When QoS is enabled, the selected backoff contention windows for various services are shown in Table 1.
- Short slot time is 9 µs, SIFS is 16 µs, DIFS is 34 µs, and GI is 400 ns.
- The range of transmission and reception is the same for all stations.
- Hidden terminal issues are not considered in the network.
- The receiving power of packets is -100 dBm.

– Support spatial streams (up to eight antennas).

The processes of simulation for the OMNet++ scenarios, are performed under simulation parameters as shown in Table 3.



(a) (b)

(c) (d)

Figure 3. Show four modeled scenarios (a) 5–nodei, (b)15–nodei, (c) 30–nodei, and (d) 45 node

Table 3. Parameters for simulation

Parameters	Values
Buffer length (bits)	2048000
Data rate size (Mbps)	693.3
Packet length (Kbytes)	2,048
The information contains in file (bytes)	high load
Transmitted power (Watt)	0.1
Power threshold of packets reception (dBm)	-100
First level frame aggregation A-MSDU (kbytes)	11,454
Second level frame aggregation A-MPDU (Mbytes)	1,048575
Physical characteristics	IEEE802.11ac, 5 GHz
Block ACK capability	Supported
Time of simulation (sec)	10
MIMO (SS)	1 to 8 streams
Modulation and coding scheme (MCS)	256-QAM
Coding rate	3/4
Channel bandwidth	20 MHz
Guard interval (ns)	400

4. SIMULATION RESULES AND ANALYSIS OF THE OMNet++ MODELED SCENARIOS

For the proposed scenarios, two performance metrics (Delay and Throughput) are considered to investigate the efficiency of the IEEE 802.11ac WLAN using OMNet++ simulations. Figures 4 and 5 illustrate the OMNet++ simulation results for the considered performance metrics. In the process of investigating the modeled WLAN performance for varied number of nodes, different MIMO or SS (1, 2, 3, 4, 5, 6, 7, and 8) antennae configurations (with and without QoS application) are considered as follows:

4.1. Throughput

Figure 4(a)-(h) illustrates the variance in throughput for various SS 1×1, 2×2, 3×3, 4×4, 5×5, 6×6, 7×7 and 8×8 MIMO respectively. It is clear when increases the number of the spatial stream the channel capacity and as a result the throughput increases. However, the throughput decreases when the nodes number increases and the cause for that is as the nodes number increases additional packets are inserted to the bottle neck or coordinator (AP) and that leads to packet drop and collision. Without QoS deployment the results for 1×1 SS show that the average throughput has maximum steady state values of 70, 49, 34.4 and 26.66 Mbps while that for 8x8 spatial stream are 540, 371, 258 and 197 for 5, 15, 30 and 45 nodes number scenarios respectively. When QoS is deployed and scheduled the data, the throughput is improved and (for 8x8 SS) its maximum steady state value are 622, 484, 399.3 and 382.96 Mbps for 5, 15, 30 and 45 nodes number scenarios respectively. In comparison with the no QoS case the best improvement in the throughput value is acquired at the highest (45) node number scenario. For (1×1 SS) and (8×8 SS) the improvement values are (11%, 24%, 45.2% and 83%) and (15.3%, 30.5%, 54.8% and 94.4%) for nodes number of 5, 15, 30 and 45 values respectively. The throughput and its improvement values for different spatial stream and nodes number scenarios are summarized in Table 4. From the Table, it can be noted (and for certain node number topology) when the number of SS increases, there is a small proportion increase in the improvement values and that is due to SS interaction and more likely the limitation of the protocol at the MAC layer.

Table 4. The throughput performance summary for the four scenarios

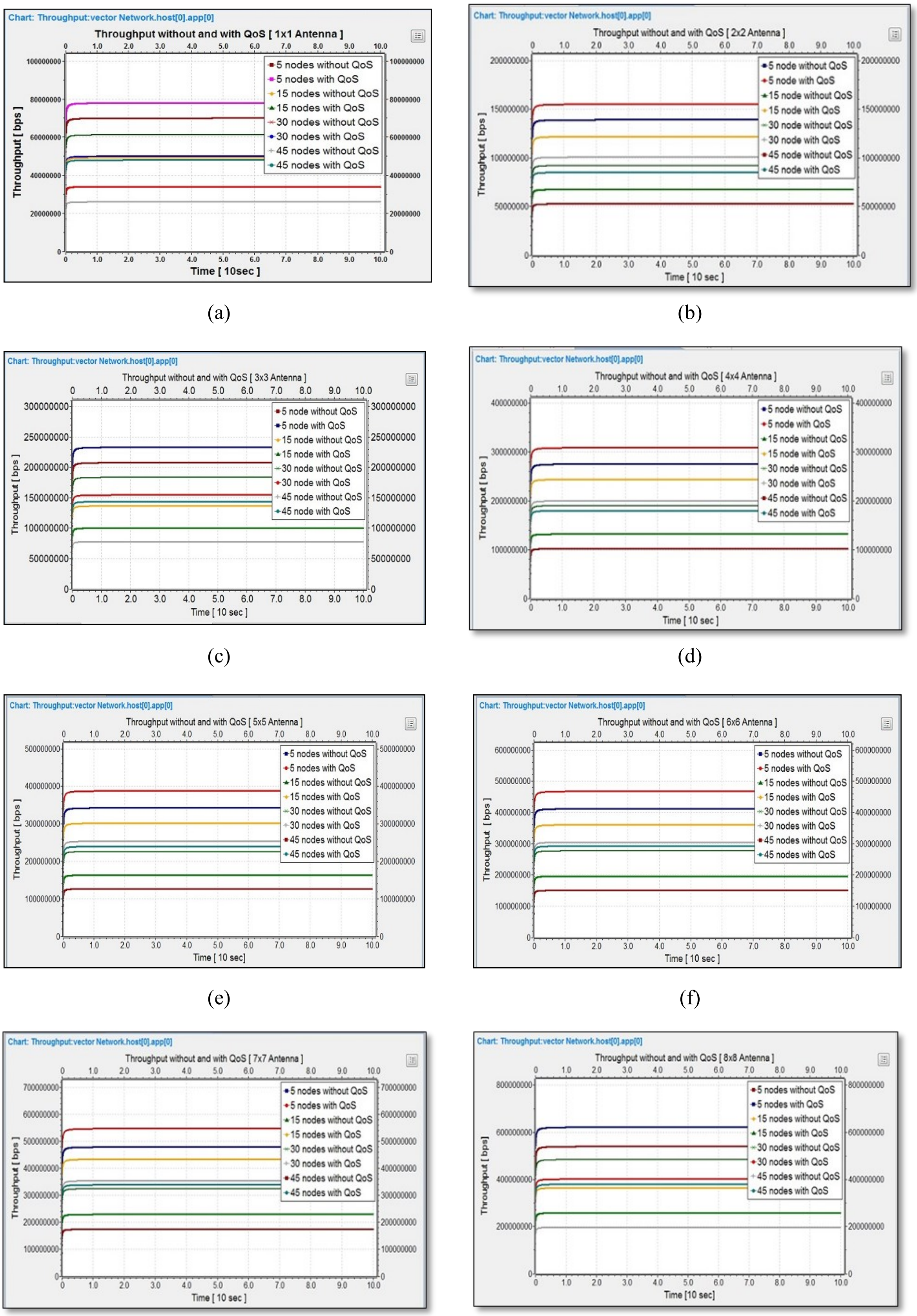
	5 Nodes			15 Nodes			30 Nodes			45 Nodes		
Spatial Streams	Without QoS	With QoS	% Improve	Without QoS	With QoS	% Improve	Without QoS	With QoS	% Improve	Without QoS	With QoS	% Improve
1x1	70	78	%11	49	61.2	24%	34.4	50	45.2%	26.66	48.78	83%
2x2	139	155	11.5%	97	122	25.6%	67.5	98.82	46.4%	52.6	96.78	84%
3x3	208	233	12%	145	183.4	26.3%	100.4	147.6	47.1%	77.8	144.1	85.3%
4x4	275	309	12.4%	192	244	27.2%	131.8	195.4	48.3%	101.6	190.8	87.8%
5x5	343	388	13%	236	302	28%	163.8	244.8	49.5%	127	240.3	90%
6x6	412	468	13.6%	280	361	28.9%	196.2	298.2	52%	151	290.97	92.7%
7x7	480	548	14.2%	335	435	29.7%	230	352.3	53.2%	175.6	339.9	93.6%
8x8	540	622	15.3%	371	484	30.5%	258	399.3	54.8%	197	382.96	94.4%

4.2. Delay

Figures 5(a)-(h) illustrates the variance in delay for various spatial streams 1×1, 2×2, 3×3, 4×4, 5×5, 6×6, 7×7 and 8×8 MIMO respectively. For all the proposed scenarios, it is obvious when increases the number of SS the overall delay decreases. However, the overall delay increases when the nodes number increases and the cause for that is as the number of nodes increases more packets are inserted to the AP and that leads to more congestion and as a result more collisions and packet drop. Respectively in comparison with the no QoS case the best improvement in the delay value is obtained at the highest (45) node number scenario. For (1×1 SS) and (8×8 SS) the improvement in steady state delay values are (9.1%, 15.4%, 26.2% and 43.2%) and (18.7%, 28.2%, 38.6% and 56.1%) for node number 5, 15, 30 and 45 scenarios respectively. The delay and its improvement values for different spatial stream and nodes number scenarios are summarized in Table 5. From the summarized delay performance and for any node number scenario, it can be seen when the number of SS increases the delay enhances in a small propotion. The reason for that again may be the interaction among SS (especially at high number of antenna) and the constraint in MAC layer protocol.

Table 5. The delay performancei summary for the four scenariosi

		5 Nodes			15 Nodes			30 Nodes			45 Nodes	
Spatial Streams	Without QoS	With QoS	% Improve	Without QoS	With QoS	% Improve	Without QoS	With QoS	% Improve	Without QoS	With QoS	% Improve
1x1	0.175	0.159	9.1%	0.538	0.455	15.4%	1.082	0.798	26.2%	1.633	0.9275	43.3%
2x2	0.092	0.082	10.8%	0.281	0.232	17.2%	0.569	0.409	28.1%	0.862	0.469	45.5%
3x3	0.062	0.054	12.2%	0.191	0.155	18.7%	0.387	0.271	29.8%	0.587	0.3064	47.8%
4x4	0.049	0.0422	13.4%	0.149	0.1188	20.3%	0.304	0.2076	31.7%	0.461	.02341	49.2%
5x5	0.041	0.0348	14.9%	0.125	0.0973	22.1%	0.258	0.1723	33.2%	0.401	0.1944	51.5%
6x6	0.036	0.0301	16.3%	0.112	0.0847	24.3%	0.229	0.148	35.3%	0.380	0.1763	53.6%
7x7	0.030	0.0247	17.5%	0.098	0.0726	25.9%	0.198	0.125	37%	0.323	0.1459	54.8%
8x8	0.026	0.0211	18.7%	0.0821	0.0589	28.4%	0.169	0.1037	39.4%	0.274	0.1202	56.1%



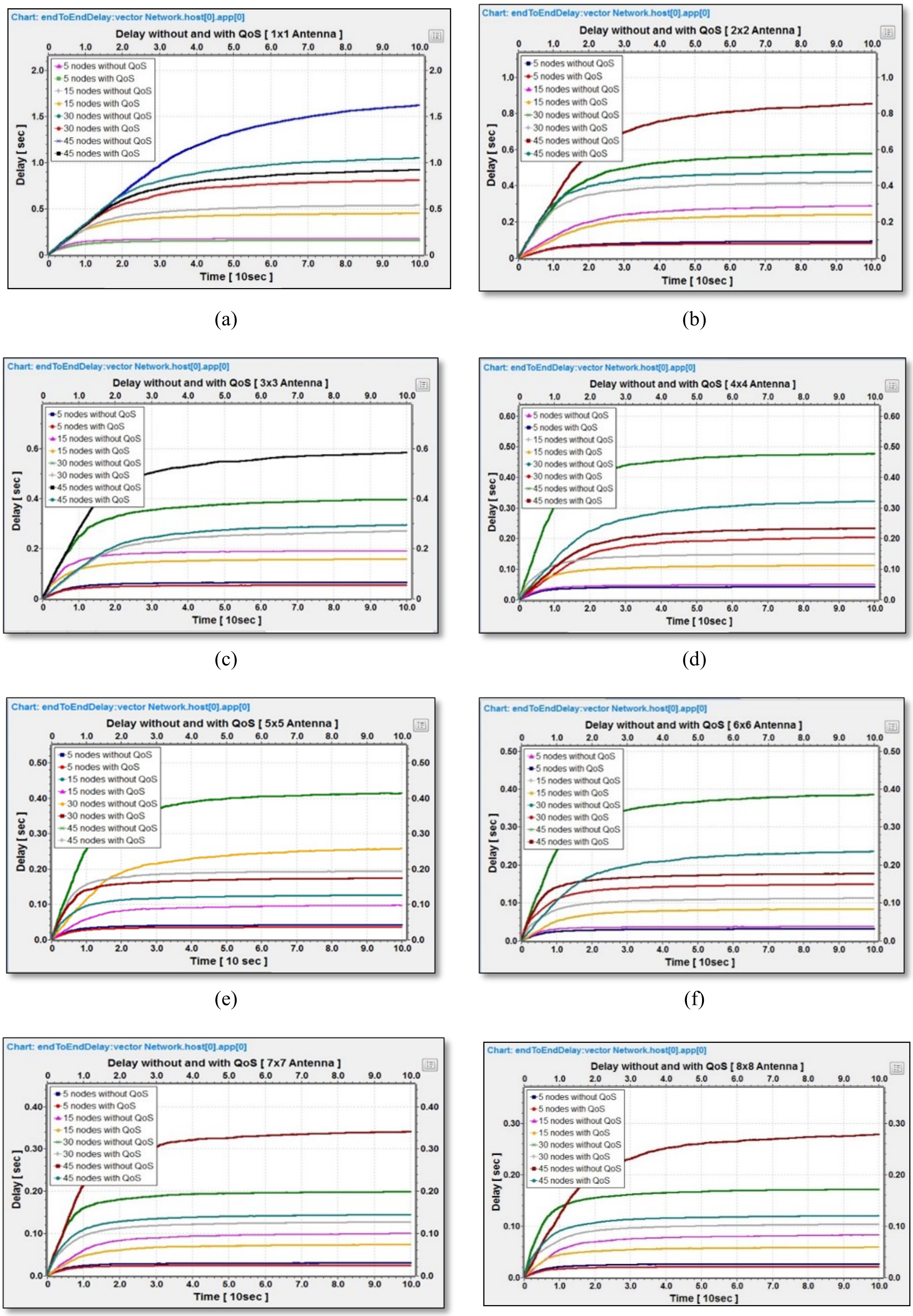
(a) (b)

(c) (d)

(e) (f)

(g) (h)

Figure 4. Illustrates the performance of throughput without and with QoS application for (a) 1×1, (b) 2×2, (c) 3×3, (d) 4×4, (e) 5×5, (f) 6×6, (g) 7×7, and (h) 8×8 antenna systems



(a) (b)

(c) (d)

(e) (f)

(g) (h)

Figure 5. Illustrate delay performance without and with QoS application for (a) 1×1, (b) 2×2, (c) 3×3, (d) 4×4, (e) 5×5, (f) 6×6, (g) 7×7, and (h) 8×8 antenna systems

5. CONCLUSION

In this paper, four scenarios (5, 15, 30 and 45 node number) are proposed to model and simulate WLANs IEEE-802.11ac standard. The simulation program (OMNet++ v5.5.1) is utilized to investigate and assess the performance of the WLANs based on IEEE 802.11ac standard, Extensive simulation processes for these scenarios are achieved in order to make network performance optimization. Without QoS and for a 8×8 MIMO the results of simulation illustrate that the maximum throughput values are (540, 371, 258 and 197 Mbps), while when QoS is applied the maximum throughput values are (622, 484, 399.3 and 382.96 Mbps) for 5, 15, 30 and 45 node number scenarios respectively. The highest effect of QoS deployment on the throughput and delay performance is at the highest (45) node number scenario. At 8x8 SS the highest improvement value are (94.4% and 56.1%) for throughput and delay respectively. These improvement values reflect the standard efficicey for scheduling services at the MAC layer and also clarify the standard feasability to work in more congested enviroment with high dense multimedia traffic networks.

REFERENCES

[1] Z. K. Farej and M. M. Jasim, "Investigation on the performance of the iee802. 11n based wireless networks for multimedia services," in *2018 2nd International Conference for Engineering, Technology and Sciences of Al-Kitab (ICETS)*, 2018, pp. 48-53.

[2] N. Khalil and A. Najid, "Performance analysis of 802.11ac with frame aggregation using NS3," *Int. J. Electr. Comput. Eng.*, vol. 10, no. 5, pp. 5368-5376, 2020, doi: 10.11591/IJECE.V10I5.PP5368-5376.

[3] A. Z. Yonis, "Performance analysis of IEEE 802.11ac based WLAN in wireless communication systems," *Int. J. Electr. Comput. Eng.*, vol. 9, no. 2, p. 1131, 2019, doi: 10.11591/ijece.v9i2.pp1131-1136.

[4] E. Charfi, L. Chaari, and L. Kamoun, "PHY/MAC enhancements and QoS mechanisms for very high throughput WLANs: A survey," *IEEE Commun. Surv. Tutorials*, vol. 15, no. 4, pp. 1714-1735, 2013.

[5] Z. K. Farej and M. M. Jasim, "Performance evaluation of the IEEE 802.11n random topology WLAN with QoS application," *Int. J. Electr. Comput. Eng.*, vol. 10, no. 2, pp. 1924-1934, 2020, doi: 10.11591/ijece.v10i2.pp1924-1934.

[6] A. Andreadis and R. Zambon, "QoS enhancement for multimedia traffics with dynamic TXOPlimit in IEEE 802.11 e," in *Proceedings of the 3rd ACM workshop on QoS and security for wireless and mobile networks*, 2007, pp. 16-22.

[7] R. Karmakar, S. Chattopadhyay, and S. Chakraborty, "Learning Based Adaptive Fair QoS in IEEE 802.11ac Access Networks," *2019 11th Int. Conf. Commun. Syst. Networks, COMSNETS 2019*, pp. 22-29, 2019, doi: 10.1109/COMSNETS.2019.8711461.

[8] S. R. Chaudhary, A. J. Patil, and A. V. Yadao, "WLAN-IEEE 802.11ac: Simulation and performance evaluation with MIMO-OFDM," *Conf. Adv. Signal Process. CASP 2016*, pp. 440-445, 2016, doi: 10.1109/CASP.2016.7746211.

[9] E. H. Ong and J. Kneckt, "IEEE 802. 11ac : Enhancements for Very High Throughput WLANs," pp. 854-858, 2015.

[10] V. Inzillo, F. De Rango, and A. Ariza-Quintana, "Supporting 5G Wireless Networks Through IEEE802. 11ac Standard With New Massive MIMO Antenna System Module Design in OMNet++ Simulator.," in *SIMULTECH*, 2018, pp. 62-72.

[11] V. Sharma, H. Singh, and J. Malhotra, "Performance Analysis of IEEE 802.11e (EDCF) and IEEE 802.11(DCF) WLAN Incorporating Different Physical Layer Standards," *J. Inst. Eng. Ser. B*, vol. 93, no. 4, pp. 247-253, 2012, doi: 10.1007/s40031-013-0034-3.

[12] K. Kosek-Szott, "Improving DL-MU-MIMO performance in IEEE 802.11ac networks through decoupled scheduling," *Wirel. Networks*, vol. 24, no. 8, pp. 3113-3127, 2018, doi: 10.1007/s11276-017-1520-3.

[13] M. Yazid, L. Bouallouche-Medjkoune, and D. Aïssani, "Performance Study of Frame Aggregation Mechanisms in the New Generation WiFi.," in *VECoS*, 2016, pp. 85-92.

[14] A. T. Al-Heety, M. T. Islam, A. H. Rashid, H. N. Abd Ali, A. M. Fadil, and F. Arabian, "Performance evaluation of wireless data traffic in mm wave massive MIMO communication," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 20, no. 3, pp. 1342-1350, 2020, doi: 10.11591/ijeecs.v20.i3.pp1342-1350.

[15] A. Stelter, P. Szulakiewicz, R. Kotrys, M. Krasicki, and P. Remlein, "Dynamic 20/40/60/80 MHz Channel Access for 80 MHz 802.11ac," *Wirel. Pers. Commun.*, vol. 79, no. 1, pp. 235-248, 2014, doi: 10.1007/s11277-014-1851-7.

[16] E. Ghayoula, M. H. Taieb, J.-Y. Chouinard, R. Ghayoula, and A. Bouallegue, "Improving MIMO systems performances by concatenating LDPC decoder to the STBC and MRC receivers," in *2015 world symposium on computer networks and information security (Wscnis)*, 2015, pp. 1-6.

[17] O. Sharon and Y. Alpert, "A New Aggregation Based Scheduling Method for Rapidly Changing IEEE 802.11ac Wireless Channels," *Wirel. Sens. Netw.*, vol. 08, no. 08, pp. 145-165, 2016, doi: 10.4236/wsn.2016.88013.

[18] A. U. Syed and L. Trajković, "Improving VHT MU-MIMO communications by concatenating long data streams in consecutive groups," in *2015 IEEE Wireless Communications and Networking Conference Workshops (WCNCW)*, 2015, pp. 107-112.

[19] J. Govindarajan and C. Mohanapriya, "Study on real-time media congestion avoidance technique for video streaming over wireless local area network," vol. 15, no. 3, pp. 1535-1543, 2019, doi: 10.11591/ijeecs.v15.i3.pp1535-1543.

[20] N. S. Ravindranath, I. Singh, A. Prasad, and V. S. Rao, "Performance Evaluation of IEEE 802.11ac and 802.11n using NS3," *Indian J. Sci. Technol.*, vol. 9, no. 26, 2016, doi: 10.17485/ijst/2016/v9i26/93565.

[21] G. Cecchetti and A. L. Ruscelli, “Real-time support for HCCA function in IEEE 802.11 e networks: a performance evaluation,” *Secur. Commun. Networks*, vol. 4, no. 3, pp. 299-315, 2011.

[22] A. A. Ghafar, M. Kassim, N. Ya’acob, R. Mohamad, and R. A. Rahman, “Qos of wi-fi performance based on signal strength and channel for indoor campus network,” *Bull. Electr. Eng. Informatics*, vol. 9, no. 5, pp. 2097-2108, 2020, doi: 10.11591/eei.v9i5.2251.

[23] A. Refaet, M. A. Amed, W. Abed, and Q. Aish, “WLAN performance evaluation in different wireless access techniques (DCF, PCF, HCF),” *Period. Eng. Nat. Sci.*, vol. 8, no. 3, pp. 1309-1320, 2020, doi: 10.21533/pen.v8i3.1433.g614.

[24] I. Paudel, “QoS provisioning in future wireless local area networks.” Institut National des Télécommunications, 2015.

[25] I. B. Arun, T. G. Venkatesh, and B. Dappuri, “QoS provisioning with adaptive backoff algorithm for IEEE 802.11ac under multipacket reception,” *2014 9th Int. Symp. Commun. Syst. Networks Digit. Signal Process. CSNDSP 2014*, pp. 826-830, 2014, doi: 10.1109/CSNDSP.2014.6923941.

[26] Z. K. Farej, “Investigation on the performance analysis of the IEEE 802.11a standard based WSN with QoS application,” *Int. Conf. Adv. Sustain. Eng. Appl. ICASEA 2018 - Proc.*, pp. 43-47, 2018, doi: 10.1109/ICASEA.2018.8370953.

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