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# Effect of service differentiation on QoS in IEEE 802.11e enhanced distributed channel access: a simulation approach

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## Abstract

The enhanced distributed channel access (EDCA) protocol is a supplement to IEEE 802.11 medium access control (MAC), ratified by IEEE 802.11e task group to support quality of service (QoS) requirements of both data and real-time applications. Previous research show that it supports priority scheme for multimedia traffic but strict QoS is not guaranteed. This can be attributed to inappropriate tuning of the medium access parameters. Thus, an in-depth analysis of the EDCA protocol and ways of tuning medium access parameters to improve QoS requirements for multimedia traffic is presented in this work. An EDCA model was developed and simulated using MATLAB to assess the effect of differentiating contention window (CW) and arbitration inter-frame space (AIFS) of different traffic on QoS parameters. The optimal performance, delay, and maximum sustainable throughput for each traffic type were computed under saturation load. Insight shows that traffic with higher priority values acquired most of the available channels and starved traffic with lower priority values. The AIFS has more influence on the QoS of EDCA protocol. It was also observed that small CW values generate higher packet drops and collision rate probability. Thus, EDCA protocol provides mechanism for service differentiation which strongly depends on channel access parameters: CW sizes and AIFS.

**Keywords:** EDCA protocol, Medium access control, AIFS, QoS, Contention window, MATLAB

## Background

Globally, IEEE 802.11 also known as wireless local area network is considered the most accepted and deployed wireless communication standards. It is flexible, mobile, easy to deploy, and capable of transmitting high data rate [1–5]. In wireless local area network (WLAN), users within an area of network coverage are connected to a common access point (AP) wirelessly. As connection requests to the AP are always undeterministic, a medium access control (MAC) protocol is required for access coordination to the offered medium. Some of the popular WLAN access control protocols are distributed coordination function (DCF), enhanced distributed channel access (EDCA), and hybrid



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coordination channel access (HCCA) [6–8]. The DCF protocol is a legacy channel access control protocol. Its distribution coordination mechanism is based on carrier sense multiple access with collision avoidance (CSMA/CA) [7, 9–11]. The DCF provides fair access to the contending terminal devices with no room for prioritization. Thus, the DCF does not guarantee QoS requirements for real-time services. This is because all the traffic is allowed to go through the same queueing and transmission processes. The EDCA is a state-of-the-art access control protocol that was designed to support differentiated services through prioritization. Nevertheless, the EDCA protocol cannot guarantee strict QoS to real-time applications. Whereas by using appropriate scheduler, the HCCA protocol can provide soft QoS guarantee to real-time applications [8].

The EDCA protocol of IEEE 802.11 supports priority of different classes of traffic which include background, data, video, and voice using differentiated parameters. The intention of prioritization of these traffic is geared toward meeting the QoS requirements of each traffic. In a quality enhanced network supporting EDCA protocol, traffic is categorized into four access categories (AC). Every AC has unique access parameters which include arbitration inter-frame space (AIFS), contention window minimum ( $CW_{min}$ ), and contention window maximum ( $CW_{max}$ ) [12]. The wireless stations use these parameters while contending for access to medium. The EDCA protocol allocates high priority to voice traffic while background is allotted the list priority. The effect is that in priority queueing, packets that occupied the highest prioritized queue are processed first, whereas the packets that occupied the lowest prioritized queue are last to be processed. With this protocol, higher priority traffic can reach the destination with less delay. Collision in this medium is resolved by granting the higher priority traffic an opportunity to transmit in all collision. In other words, as a result of differentiation which EDCA protocol supports, real-time traffic gets higher priority to win channel access during contention [12].

Amidst the enormous advantage of EDCA protocol, strict QoS support is not guaranteed. The best effort (BE) traffic is starved if the influx of real-time traffic is high [13]. Secondly, the number of collisions in the channel rises as the number of the stations contending to access the channel increase. At this point, access delay, traffic congestion and frame loss rate are high. Although the protocol implements binary exponential backoff algorithm to reduce collision, but ends up creating unnecessary idle state in most cases, leading to inefficient utilization of the available channel. As a consequence, throughput performance is highly degraded.

Several scholarly works have been proposed to support and enhance the performance of service differentiation in WLAN. In [6], OPNET simulator was used in analysis and evaluation of IEEE 802.11 that uses DCF access protocol. The simulation was carried out under different load condition, data rate, and fragmentation number of nodes parameter values. Results show that under heavily loaded network, DCF access mechanism performs below optimal. This could be attributed to the inability of DCF access mechanism to support service prioritization.

Fairness and QoS issues are analyzed in IEEE 802.11e WLAN. The IEEE 802.11e was compared with the legacy IEEE 802.11 on the basis of QoS and fairness [14]. The results of the simulation show that IEEE 802.11e outperforms IEEE 802.11 with regards to QoS. The reason is that IEEE 803.11e supports service differentiation and has improved architecture for queue management.

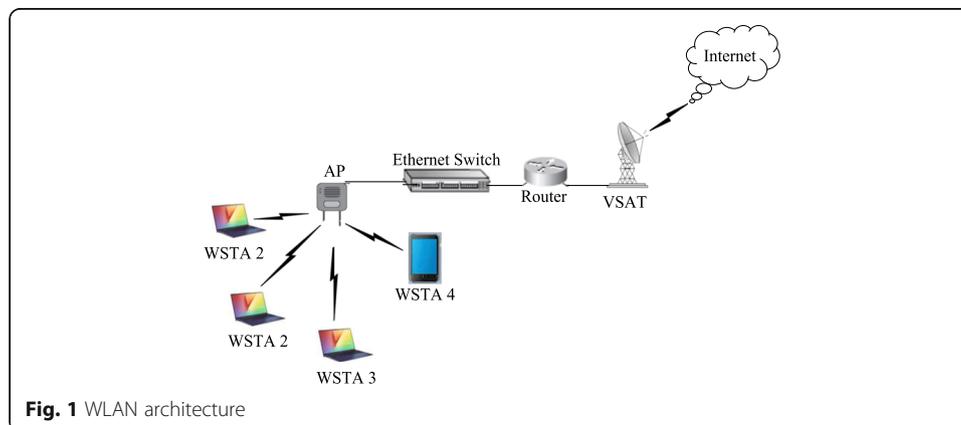
In IEEE 802.11e WLAN standard, two tier protection and guarantee mechanism are proposed for video and voice traffic [15]. This method performs better in channel utilization and in guaranteeing QoS for video and voice traffic. However, under high network load, the technique leads to the starvation of best effort traffic.

A differentiated service EDCA model that provides strict priority and fair service with weight was proposed for IEEE 802.11e [16]. The high priority traffic was strictly prioritized over the lower priority by adjusting the backoff interval of the lower priority traffic. This adjustment is in accordance with distributed scheduling discipline. Also, the same work proposed a tiered allocation method for IEEE 802.11e wireless LAN. Both the access point and mobile terminals are assigned different amount of channel. Simulation result with NS-2 shows that the proposed differentiated service EDCA model outperformed the IEEE 802.11e with EDCA. However, the work only adjusted the back-off interval of the lower priority traffic without considering the impact of other EDCA parameters such as AIFS and CW on the QoS requirements of the entire differentiated services.

Though these works have made significant progress in supporting service differentiation, but strict QoS could not be addressed due to lack of in-depth analysis of EDCA protocol and inappropriate tuning of the medium access parameters. Thus, EDCA physical model was converted to a simulation model in MATLAB to assess the impact of differentiating channel access parameters (AIFSN and CW size) on different traffic QoS of IEEE 802.11e WLAN. This work has demonstrated how QoS performance of a specific traffic in the network can be enhanced by varying the aforementioned access parameters. The study will assist WLAN vendors to meet up with the QoS requirements of multimedia traffic. It will also remedy channel access starvation of lower priority traffic resulting from poor management of channel access parameters.

## Methods

The WLAN architecture presented in Fig. 1 was adopted for this work and the simulation model was based on the topology. The WLAN implemented four work stations (WSTA) transmitting video (VI), voice (VO), background (BK), and best effort (BE) traffic. These stations wirelessly connected to a central server interface, WLAN AP [14, 17]. The central server system connects the WSTA to the ethernet switch interfaced to the VSAT via router. The AP uses the EDCA protocol to control access to the channel.



**Fig. 1** WLAN architecture

It allows WSTA to transmit packets when it senses idle channel [18]. Once any WSTA starts transmitting, other stations having packets to transmit wait for the medium to return to the idle state before contention [19]. The packet generation is based on different distribution while arrival pattern is distributed following exponential law. The inter-arrival time and service time patterns follow the exponential service distribution. Each WSTA intending to transmit, decrements its binary exponential counter to zero before sending packets, after sensing the WLAN AP to be idle. This work is based on the activities that take place at the WLAN WSTA and AP; therefore, the model is based on WLAN AP which operates on CSMA/CA principles.

**WLAN architecture**

Fig.1.

**Enhanced distributed channel access (EDCA)**

The EDCA supports service differentiation by traffic prioritization. The access categories, EDCA parameters, which include AIFS,  $CW_{min}$ ,  $CW_{max}$ , and TXOP, are discussed next.

**Access categories (ACs)**

The EDCA extends the DCF protocol by differentiating traffic into 4 access categories to support 8 user priorities as specified in Table 1. Packets from distinguishable traffic types are mapped onto distinct ACs based on the traffic QoS requirement. The 4 ACs of the traffic are AC\_BK, AC\_BE, AC\_VI, and AC\_VO, for BK, BE, VI, and VO, respectively. The AC\_BK possesses the lowest priority while AC\_VO possesses the highest priority to access channel. A station accesses the medium on the basis of the AC of the packet that is to be transmitted.

**EDCA parameters**

The prioritization is a function of the channel access parameters which includes AIFS,  $CW_{min}$ ,  $CW_{max}$ , and TXOP. An EDCA function contends for medium based on AIFS,  $CW_{min}$ ,  $CW_{max}$ , and TXOP associated to an AC [12]. The default EDCA values for all the ACs are presented in Table 2.

**Table 1** The user priority to AC mapping [20, 21]

Priority	User Priority	AC	Traffic Types
Lowest  Highest	1	0 - (AC_BK)	BK
	2	0 - (AC_BK)	BK
	0	1 - (AC_BE)	BE
	3	1 - (AC_BE)	BE
	4	2 - (AC_VI)	VI
	5	2 - (AC_VI)	VI
	6	3 - (AC_VO)	VO
	7	3 - (AC_VO)	VO

**Table 2** EDCA default parameters [20, 22]

$CW_{min} = 31, CW_{max} = 1023, AIFS = SIFS + AIFSN \times SlotTime$					
AC	$CW_{min}$	$CW_{max}$	AIFS	TXOP limit (802.11b)	TXOP limit (802.11a/g)
0	$CW_{min}$	$CW_{max}$	7	0	0
1	$CW_{min}$	$CW_{max}$	3	0	0
2	$(CW_{min} - 1)/2$	$CW_{min}$	2	6.0 ms	3.0 ms
3	$(CW_{min} - 3)/4$	$(CW_{min} - 1)/2$	2	3.0 ms	1.5 ms

**Arbitration inter-frame space**

The arbitration inter-frame space (AIFS) is the period the medium is sensed to be idle before the backoff or transmission is initiated. AIFS is obtained from the expression presented in Equation (1);

$$AIFS = AIFSN \times SlotTime + SIFS \tag{1}$$

where AIFSN depends on the access category and the SlotTime value relies on the physical layer of the 802.11e employed [23]. The value of SIFS is specified as one of the simulation parameters in Table 3.

**Contention window minimum and maximum ( $CW_{max}$  and  $CW_{min}$ )**

The  $CW_{max}$  and  $CW_{min}$  limit of EDCA can be varied. The variability depends on the ACs. Thus, ACs with higher priority value have lesser  $CW_{max}$  and  $CW_{min}$  values to the ACs with lower priority. The  $CW_{max}$  and  $CW_{min}$  default values for each of the four considered ACs are presented in Table 2 and among simulation parameters in Table 3.

**Table 3** Simulation parameters [24]

S/N	Parameters	Values
1	Basic channel rate	1 Mbps
2	Maximum channel rate	11 Mbps
3	Packet size (bytes) [VO, VI, BE, BK]	160, 1280, 1500, 660
4	Packet interval (ms) [VO, VI, BE, BK]	20, 10, 12.5, 12.5
5	Data rate (kbps) [VO, VI, BE, BK]	64, 1024, 960, 1000
6	Retry limit	5
7	Slot time	20 $\mu$ s
8	SIFS	$1 \times 20 \mu$ s = 20 $\mu$ s
9	PIFS	$20 \mu$ s + $1 \times 20 \mu$ s = 40 $\mu$ s
10	AIFS [3] (AC_VO)	$20 \mu$ s + $2 \times 20 \mu$ s = 60 $\mu$ s
11	AIFS [2] (AC_VI)	$20 \mu$ s + $2 \times 20 \mu$ s = 60 $\mu$ s
12	AIFS [1] (AC_BE)	$20 \mu$ s + $3 \times 20 \mu$ s = 80 $\mu$ s
13	AIFS [0] (AC_BK)	$20 \mu$ s + $7 \times 20 \mu$ s = 160 $\mu$ s
14	$CW_{min}$ [3], $CW_{max}$ [3] (AC_VO)	7, 15
15	$CW_{min}$ [2], $CW_{max}$ [2] (AC_VI)	15, 31
16	$CW_{min}$ [1], $CW_{max}$ [1] (AC_BE)	31, 1023
17	$CW_{min}$ [0], $CW_{max}$ [0] (AC_BK)	31, 1023
18	TXOP limit	3000 $\mu$ s
19	Simulation run time	3600 s

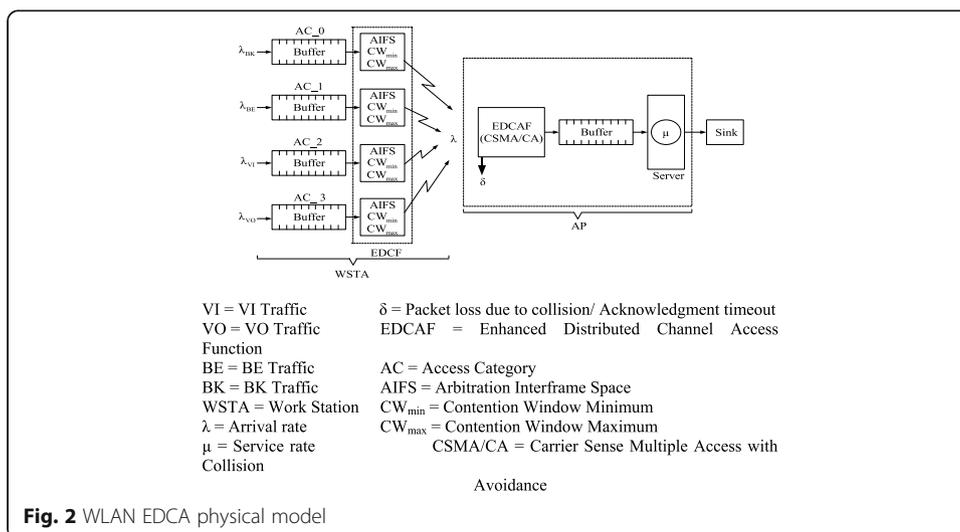
**Transmission opportunity limit (TXOP)**

The TXOP is the maximum duration which WSTA is granted an opportunity to transmit packets after winning access to the available medium. The allowable duration for transmission covers all the frame exchange sequence which include intermediate SIFS periods, request to send (RTS), ACKs, and clear to send (CTS). Different ACs with their default TXOP limits are presented in Table 2. A non-zero value of TXOP limit specify that multiple frames can be transmitted by EDCA function in a TXOP, as long as the transmission period is lower or equal to the TXOP limit and the frames belong to one AC [25].

**EDCA physical model**

Figure 2 is the IEEE 802.11e contention-based physical model. The model consists of four AC that represent a virtual station, EDCA MAC access controller that uses CSMA/CA protocol, and destination sink. The protocol differentiates traffic into 4 ACs to support 8 user priorities as specified in Table 1. Each of the traffic types uses the parameters of the AC which is periodically advertised by AP to access the medium.

Every AP maintains four transmission queues, one per AC as shown in Fig. 2. The EDCA protocol implements an independent back-off entity for each AC. Each queue work independently and uses its own parameter set (AIFS,  $CW_{min}$ ,  $CW_{max}$ , and TXOP limit). An AC with packet to transmit waits for a period of AIFS before accessing the medium [14, 26]. If at the end of AIFS and the medium is still busy, the station initiates back-off algorithm. It computes its exponential value of the back-off counter and keeps decreasing the value of its back-off counter after the medium is sensed to be idle but freezes once the medium is sensed busy again. The AC starts transmission once the back-off timer is zero. If the sink receives a correct packet, after a short inter-frame space (SIFS), it sends a positive acknowledgment (ACK). The CW size is initially set to its minimum value before an attempt to transmit the first packet is done. Each time the packets collide, the size of the CW is doubled before the next transmission attempt. However, the adjustment of the CW size cannot exceed the  $CW_{max}$  size. The number



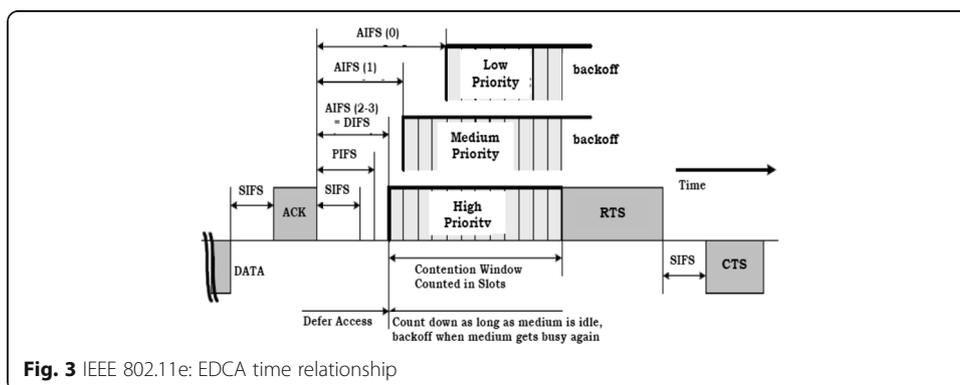
**Fig. 2** WLAN EDCA physical model

of packets transmitted from its queue is a function of TXOP limit. The time relationship for EDCA function is presented in Fig. 3.

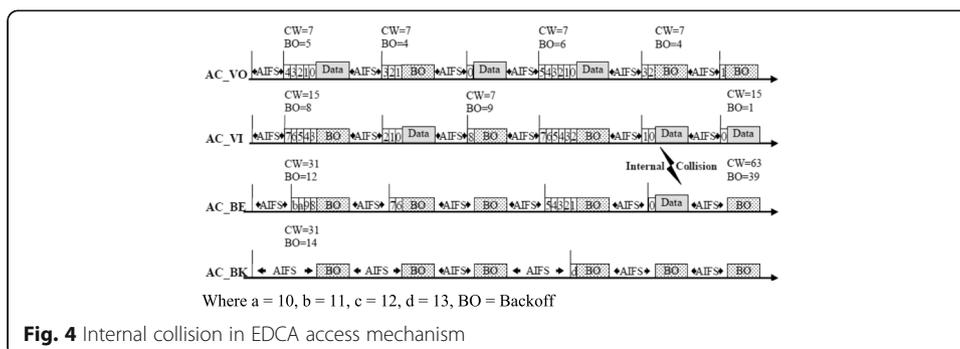
The probability of gaining access to the channel is determined by CW size and AIFS while the TXOP determines the duration of channel occupancy [25]. If two or more ACs competes for an access to a medium, a virtual collision occurs. This collision is resolved by allowing the higher priority packet to win the contention while lower priority packets make additional attempt after a waiting period elapse, using the exponential back-off algorithm [18]. In EDCA function, the backoff parameters of the 4 ACs provides a prioritized and differentiated channel access to each type of traffic in transit. The AIFS duration of ACs with higher prioritization value is shorter, which thus have a higher probability of accessing the channel than the lower ACs. This is to say that AC with higher priority is assigned a shorter CW in order to ensure that in most cases, higher-priority AC will be able to transmit before the lower-priority AC. In addition, there exist two types of contention: internal contention among the various EDCAFs/ACs inside indistinguishable station and external contention among the various stations. The model developed in this research experiences only the internal collision as the analysis focused on what happens in a virtual station. The internal collision in EDCA access mechanism is presented in Fig. 4.

**MATLAB Simevent EDCA simulation model**

This work favored simulation model due to the fact that there is no single analytical model that can be traceable and still handle all the QoS parameters as seen from all the models touched. As a result of the advantages offered by computer simulation techniques, an EDCA network model was therefore designed and implemented in MATLAB Simevent environment. The network model in Fig. 2 was converted to a simulation model in MATLAB environment as shown in Fig. 5. It is divided into three blocks: the sources, access point, and sink. The sources are made up of packet generator’s arrival rate, packet length, set attribute, and first in first out (FIFO) queue blocks. The AP consists of input switch, get attribute, FIFO queue, server, and output switch blocks. It also contains signaling loop that informs the sources about the busy and idle state of the input switch. These blocks are replicated into four places with each representing a different AC. For clarity, Fig. 5 is further presented in subunits as shown in Figs. 6, 7, 8, and 9.



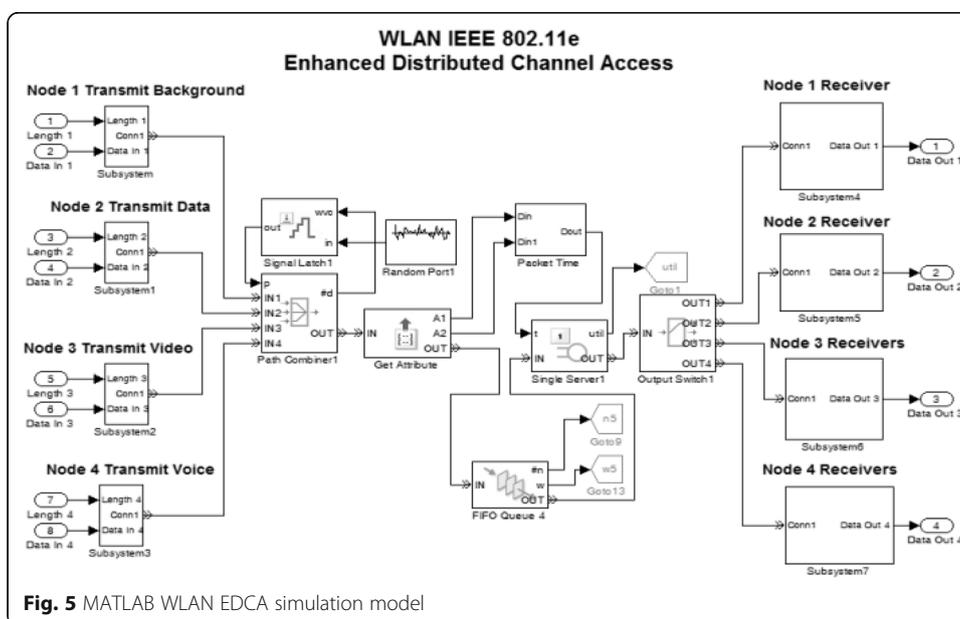
**Fig. 3** IEEE 802.11e: EDCA time relationship



The packet generation and arrival pattern depict bursty ON-OFF. Sometimes traffic arrivals are recorded. In some other times, the arrivals are sparingly while some others witnessed intense arrivals. These show the random nature of packet arrival patterns which depict Poisson process. The simulation was run for 3600 s in order to achieve normalization. During the simulation, source rate was varied in steps of 100 kbps from 0 to 1000 kbps. Simulation model is applied in this research to verify access parameters as it affects some QoS parameters in IEEE 802.11 wireless LAN EDCA protocol. The IEEE 802.11e simulation parameters used are shown in Table 3. The model performance was evaluated using throughput and delay. Probes were strategically placed to collect data for calculations. The data collected was analyzed by relating the point of the responses to the objectives of the study.

**Results and discussion**

In the first simulation scenario, four ACs were modeled using default EDCA access parameter. The result was used to test the service differentiation ability of the developed model. Because important factors in research methodology includes validity of research data, ethics, and the reliability of design, this result was validated using Bahi



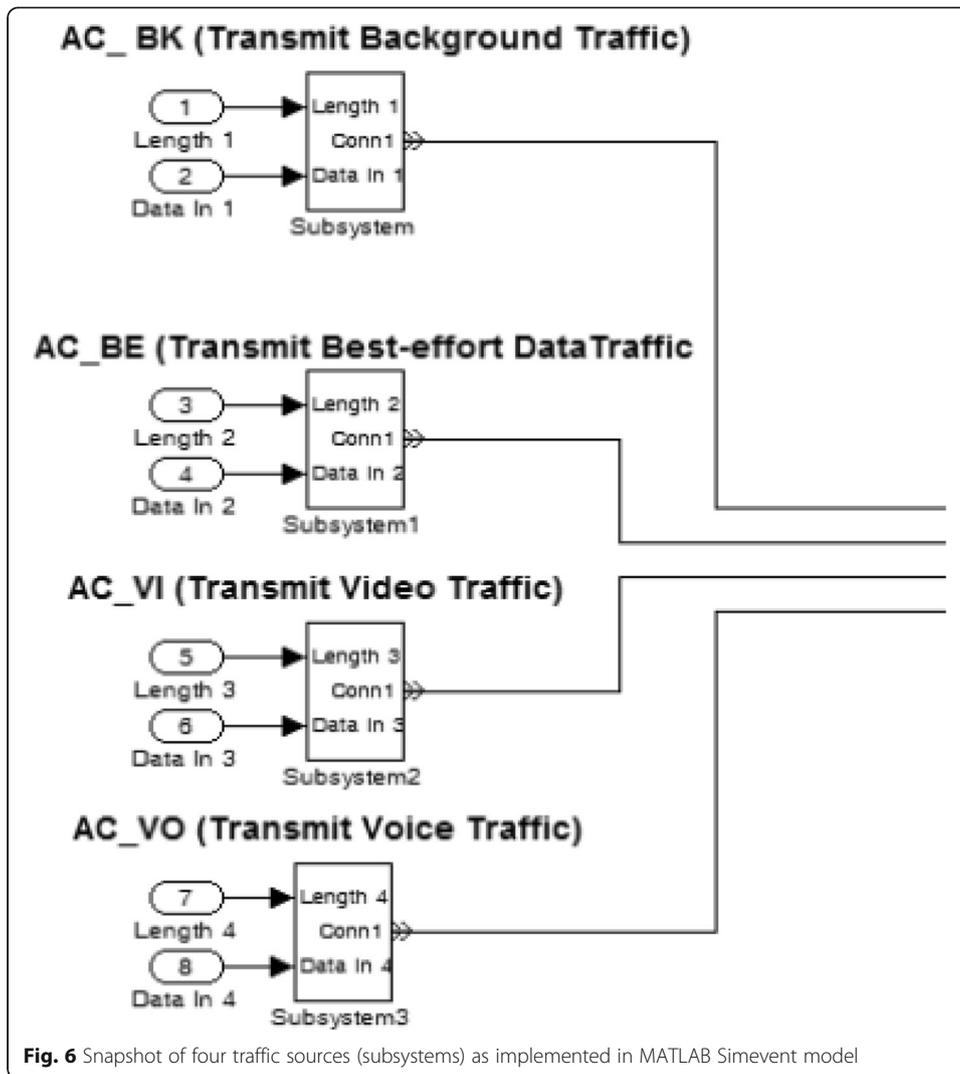


Fig. 6 Snapshot of four traffic sources (subsystems) as implemented in MATLAB Simevent model

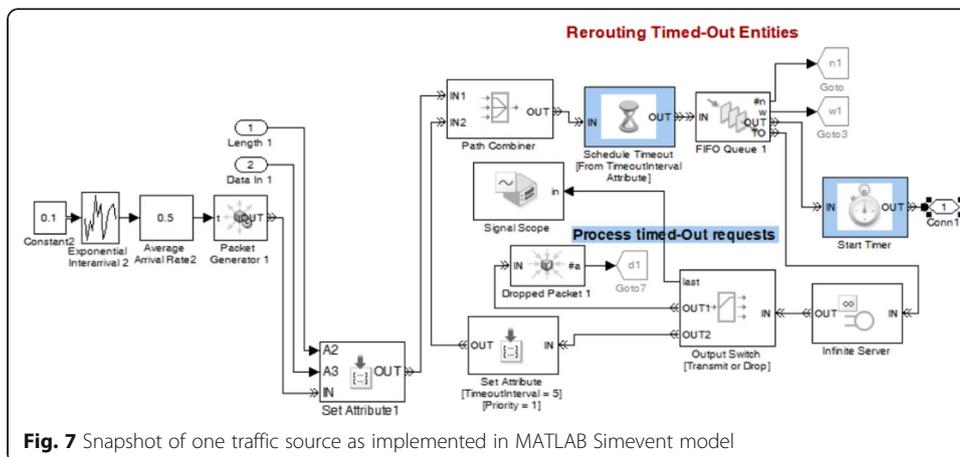
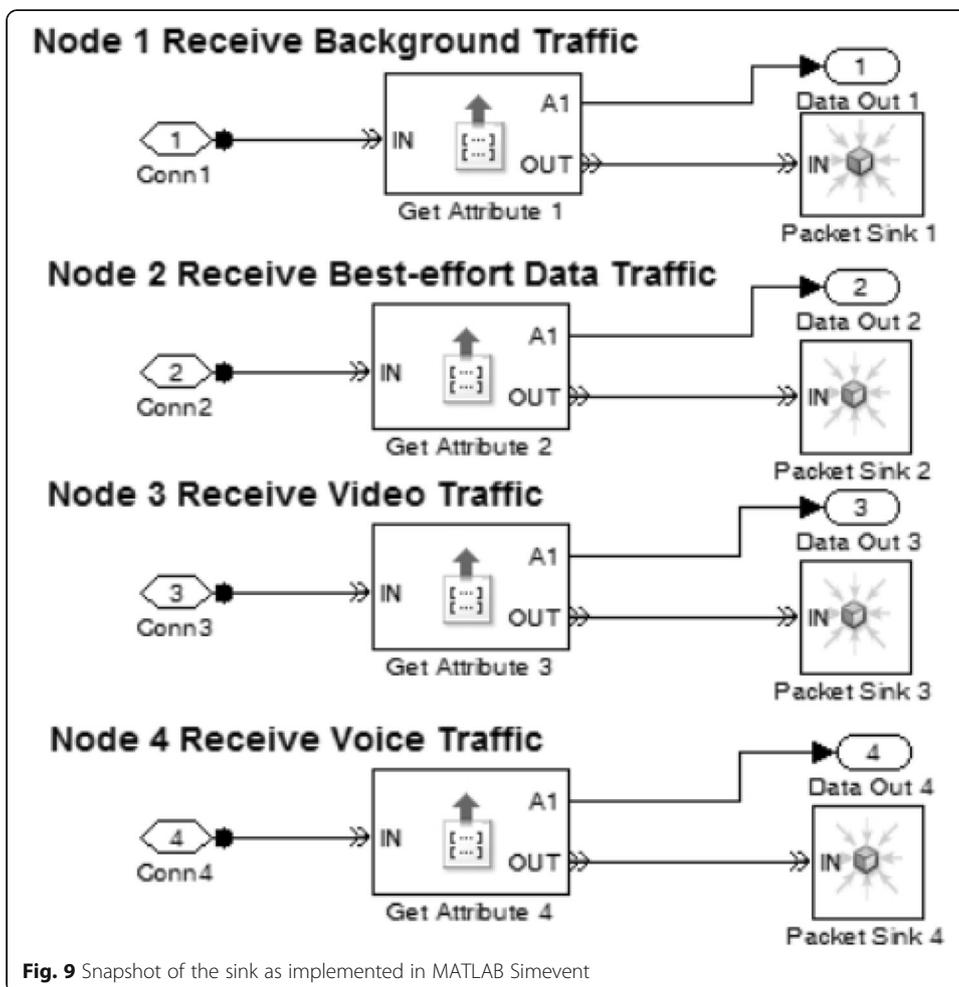
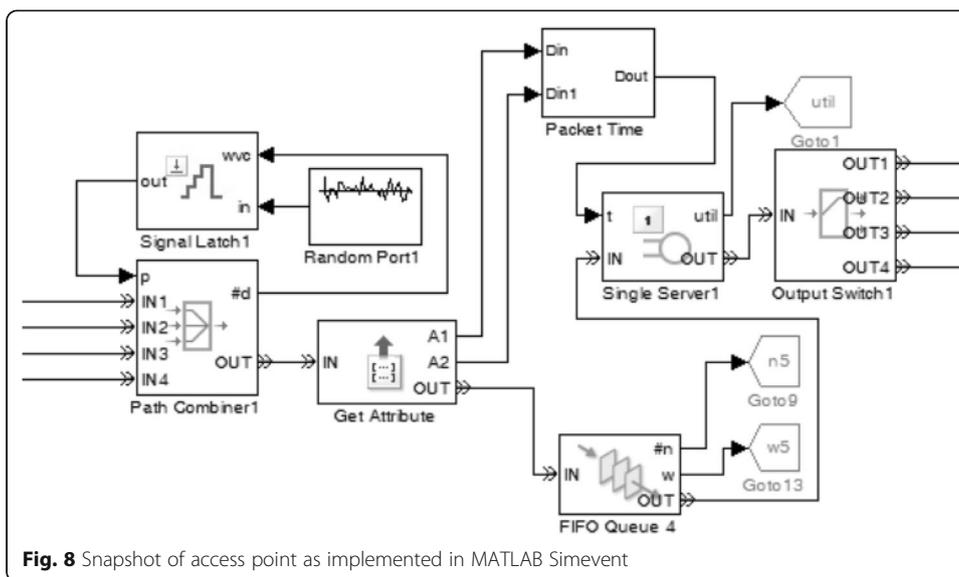


Fig. 7 Snapshot of one traffic source as implemented in MATLAB Simevent model



Hour et al.'s simulation parameters [27]. In the second scenario, AC1 (BE) and AC3 (VO) only were modeled using default EDCA access parameters. They were configured with the same AIFS value but different CW size and vice versa to analyze the impact of AIFS number and CW size on QoS parameters. At the end of each scenario, results were obtained and presented in graphical form. The graphs present the relationship between QoS parameters (throughput and delay) and source rate for different traffic classes.

**First simulation scenario**

Figure 10 is the throughput graphs of the simulation model and validation. It illustrates the effect of network load on the throughput of the four ACs. As observed, VO and VI traffic recorded 38% and 29% while BE and BK traffics recorded 19% and 14% of the mean throughput. The EDCA parameters provided optimal performance at 600 kbps source rate. The validation result shows that VO and VI traffics recorded 36% and 28% while BE and BK traffic recorded 20% and 15% of the mean throughput. The validation parameters provided optimal performance at 500 kbps source rate. In comparison, validation parameters provide almost the same throughput as the simulation model. It recorded 0.01 Mbps throughput higher than the simulation model. Figure 11 presents the delay results of the simulation model and validation. The VO and VI traffic recorded 4.2% and 16.3% mean delay while BE and BK traffic recorded 33.6% and 45.9% of mean delay. The validation result shows that VO and VI traffic experienced 8% and 20% of mean delay while BE and BK traffic recorded 30% and 42% of mean delay.

**Second simulation scenario**

*Impact of AIFS number on throughput*

Figure 12 shows the throughput graph of three different cases obtained by differentiating the AIFS number of VO and BE traffic at a fixed CW size. In comparison, the combined effect of the result of these three different cases enables us to examine closely the contribution of each of the arbitration values to service differentiation. As identified,

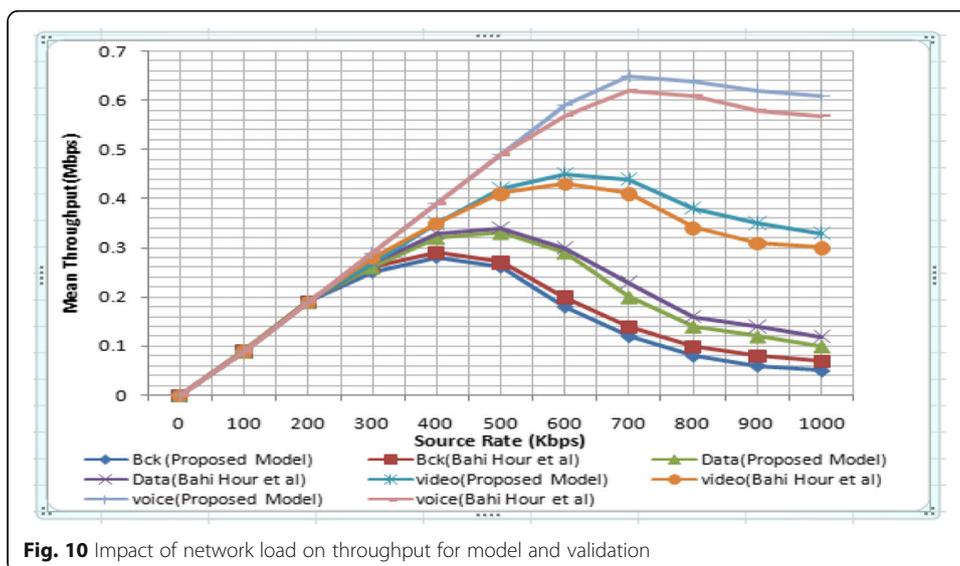
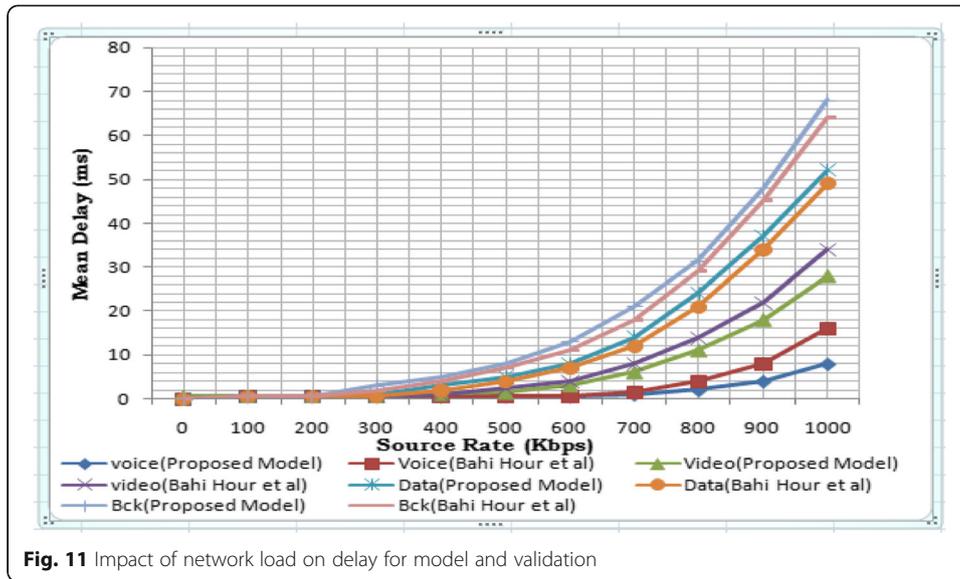
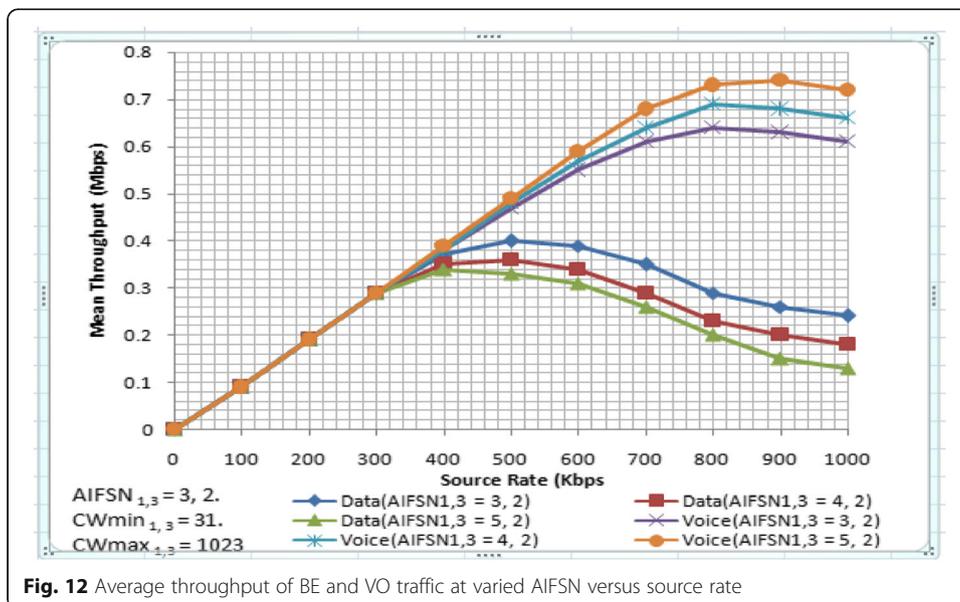


Fig. 10 Impact of network load on throughput for model and validation



VO achieved 61% while BE recorded 39% of the mean throughput. However, the effect of an increase in BE traffic AIFSN from 3 in the first case to 4 in the second case decreased the throughput result of BE traffic by 4% and increased VO throughput by the same percentage. In the third case, VO throughput further increased by 3% while BE throughput decreased by the same percentage. This result shows that high AIFSN for BE traffic improves the throughput of VO traffic and vice versa. It also shows that these changes have a negligible effect on the optimum performance of the communication system as it remained stable at 700 kbps source rate. Table 4 presents the AIFS tuning numbers used to show the impact of AIFS numbers on throughput of both VO and BE traffic at fixed CW size.

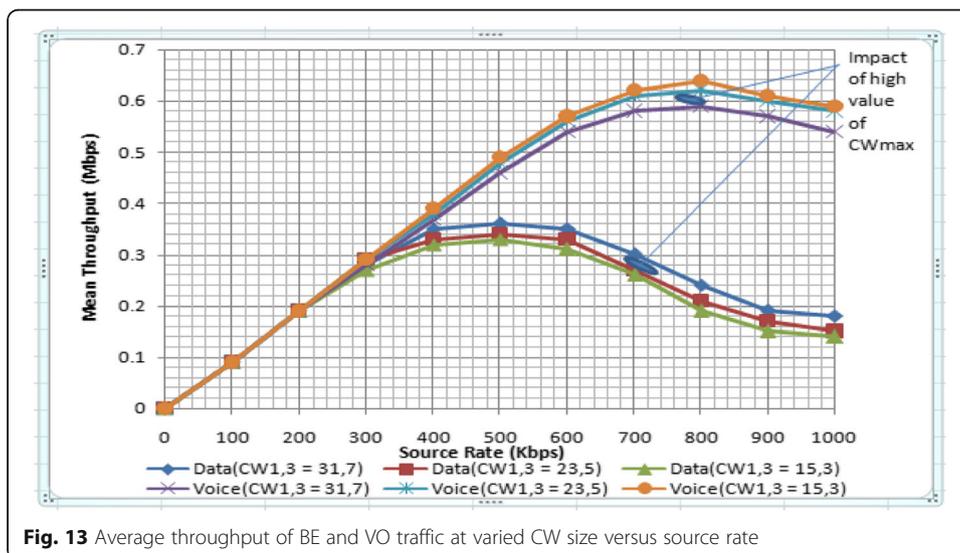


**Table 4** The AIFS tuning numbers at a fixed CW size

Case	EDCA parameters	Best effort (AC1)	Voice (AC3)
Case 1 CW = Constant AIFS <sub>n</sub> = Vary	CW <sub>min1,3</sub>	31	31
	CW <sub>max1,3</sub>	1023	1023
	AIFS <sub>n,3</sub>	3	2
Case 2 CW = Constant AIFS <sub>n</sub> = Vary	CW <sub>min1,3</sub>	31	31
	CW <sub>max1,3</sub>	1023	1023
	AIFS <sub>n,3</sub>	4	2
Case 2 CW = Constant AIFS <sub>n</sub> = Vary	CW <sub>min1,3</sub>	31	31
	CW <sub>max1,3</sub>	1023	1023
	AIFS <sub>n,3</sub>	5	2

**Impact of CW size on throughput**

Figure 13 shows the throughput graph of three different cases obtained by differentiating the CW size of VO and BE traffic at a fixed AIFS number. The mean throughputs for the three CW variations are compared. The results show that VO traffic at  $CW_{min1,3} = 15,3$  and  $CW_{max1,3} = 63,7$  recorded highest throughput, followed by  $CW_{min1,3} = 23,5$  and  $CW_{max1,3} = 363,11$ , and lowest at  $CW_{min1,3} = 31,7$  and  $CW_{max1,3} = 1023,15$ . On the other hand, BE throughput was lowest at the first case and highest at the last case. In other words, an increase in CW size decreases VO throughput and favors BE throughput as a result of reduced backoff and collision in the network. It was also observed that, as the CW size of the first case increased, the throughput showed just 2% reduction for VO traffic and the same percentage increase for BE traffic. When the CW size of the second case increased to  $CW_{min1,3} = 31,7$  and  $CW_{max1,3} = 1023,15$ , a significant increase in throughput values of BE traffic and decrease in VO traffic was observed, respectively. This result is the effect of significant change in  $CW_{max}$  of BE traffic from 363 to 1023. Table 5 presents the CW tuning numbers used to show the impact of varying CW on the throughput of both VO and BE traffic at a fixed AIFS number.



**Fig. 13** Average throughput of BE and VO traffic at varied CW size versus source rate

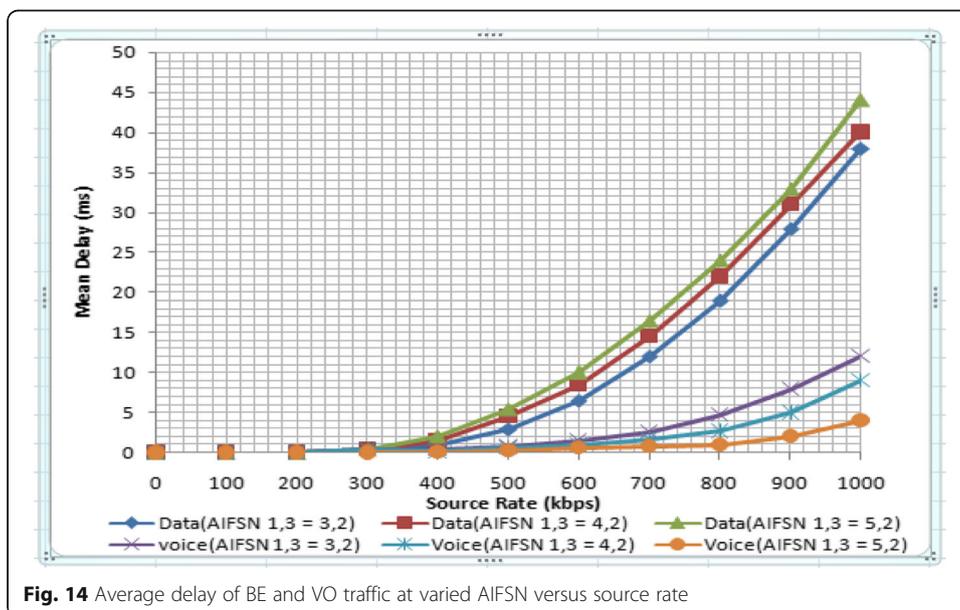
**Table 5** The CW tuning numbers at a fixed AIFSN

Cases	EDCA parameters	Service types tuning values	
		Best effort (AC1)	Voice (AC3)
Case 1 CW = Vary AIFSN = Constant	CWmin <sub>1,3</sub>	15	3
	CWmax <sub>1,3</sub>	63	7
	AIFSN <sub>1,3</sub>	3	2
Case 2 CW = Vary AIFSN = Constant	CWmin <sub>1,3</sub>	23	5
	CWmax <sub>1,3</sub>	363	11
	AIFSN <sub>1,3</sub>	4	2
Case 3 CW = Vary AIFSN = Constant	CWmin <sub>1,3</sub>	31	7
	CWmax <sub>1,3</sub>	1023	15
	AIFSN <sub>1,3</sub>	5	2

Figures 12 and 13, revealed the relationship between AIFSN and CW size, and by comparison, it shows that effect of AIFS of service differentiation is more severe. However, by increasing AIFSN of AC3 by one has more effect on optimal throughput performance than CW size in Fig. 13. This is because it was stable at 700 kbps source rate against 600 kbps source rate recorded in the later parameter.

**Impact of AIFS number on delay**

Figure 14 shows the delay graph of three different cases obtained by differentiating the AIFS number of VO and BE traffic at a fixed CW size. The graph X-rays the impact of AIFS number on delay. A compromise of the AIFSN variation shows that, first, increase in source rate results to increase in the delays of both class of traffic. This can be justified on the basis that, first, under unsaturated condition, the level of collision is sufficiently low resulting to collision probability that is below 0.1 and the queue does not gradually increase. Consequently, the queuing delay is small and the MAC layer service



**Fig. 14** Average delay of BE and VO traffic at varied AIFSN versus source rate

time dominates the delay. When the number of competing traffic increases, the collision increases and so does the MAC layer service time. Secondly, the delay experienced by VO traffic type is much smaller compared to the BE traffic. This is because VO traffic has been prioritized over the BE traffic and their access to channel is dependent of the priority value of the individual traffic. Thirdly, when the value of the AIFSN of AC1 changed from 3 to 4 and AC3 fixed at 2, the total delay of VO traffic decreased by 10 ms approximately 9% while that of BE increased by 14.5 ms which is 9% increment. At the same AC3 parameters, AC1 AIFSN was ones again changed from 4 to 5. The mean delay of the BE traffic increased by 13 ms (8%) while VO traffic delay reduced by 11.8 ms which also amount to 8% increase. It is worthy to note that when network is working under unsaturated condition, the delays experienced by BE and VO are sufficiently small to satisfy their specified QoS [5, 22, 23, 25]; the transmission delay for VoIP and VI must be less than 400 ms, and should be if possible less than 150 ms. The AIFS tuning numbers used to show the impact of AIFS numbers on the delay of both VO and BE traffic at a fixed CW size are presented in Table 4.

**Impact of CW size on delay**

The forgone simulation considered only the impact of AIFSN on the differentiation of VO and BE in terms of delay. The IEEE 802.11e standard also defines service differentiation by using different CW size. In Fig. 15, the delay graph of three different cases obtained by differentiating the CW size of VO and BE traffic at a fixed AIFSN is shown. This graph was used to analyze the impact of CW size of VO and BE traffic at a fixed number on delay. By comparison, it is observed that as CW size of the first case was decreased to  $CW_{min1,3} = 23,5$  and  $CW_{max1,3} = 364,11$ , the BE delay increased by 6% while VO traffic delay decreased by the same percentage. The BE delay further increased by 3% and VO traffic decreased by the same value, when decreased, the CW size of the third case  $CW_{min1,3} = 15,3$  and  $CW_{max1,3} = 63,7$ . This result shows that high

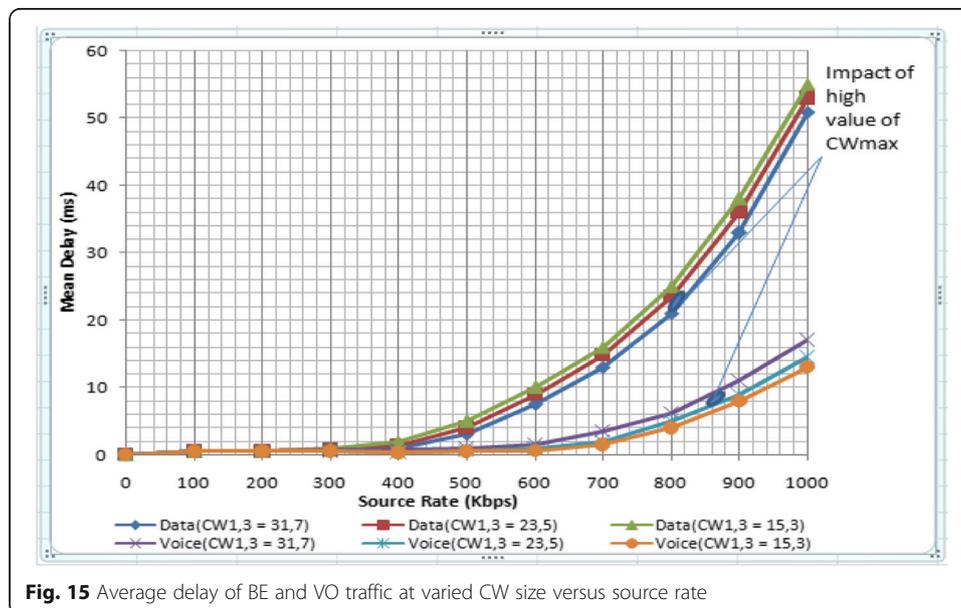


Fig. 15 Average delay of BE and VO traffic at varied CW size versus source rate

CW size especially under saturation condition improves the performance of lower priority traffics as it decreases the collision in the network. At low CW size, VO traffic experienced the least delay due to the collision effect. We also noted the 3% impact introduced by high reduction of  $CW_{max}$  of BE traffic from 1023 in the first case to 63 in the third case. This impact is advantageous to traffic with higher priority and against the traffic with lower priority. A comparison of the graphs shown in Figs. 12 and 13, however, reveals the relationship between the impacts of AIFS number and CW size on mean delay. Table 6 presents the CW tuning numbers used to show the impact of varying CW on the delay of both VO and BE traffic at a fixed AIFSN.

### Conclusions

This work, presented a MATLAB simulation model that can be used to evaluate the service differentiation effect on QoS parameters in IEEE 802.11 EDCA protocol. The model implemented four WSTAs accessing an isolated AP based on EDCA MAC protocol that employs CSMA/CA mechanism. Throughput and delay are used as metrics for performance evaluation of the EDCA protocol. The simulation model was validated and analyzed graphically. The result shows that EDCA protocol provides mechanism for service differentiation which strongly depends on channel access parameters (AIFS and CW sizes). The improvement comes at a cost of reducing the performance of traffic with lower priority up to the starvation point. The protocol is, therefore, not considered efficient for networks that records high volume of BE traffic.

The default setting of channel access parameters was varied and simulated at different intervals to X-ray the impact of CW size and AIFS number. The result of the study shows that AIFSN has more effect on the QoS performance of the protocol. Relatively, this is an indication to show that a patch has been successfully designed for the platform.

It is recommended that tuning AIFS (small value) has to be cautiously done, so as not to starve best-effort traffic. The CW size has to be tuned dynamically in response to varying load. For a network that involves high influx of real-time service or BE, smaller AIFSN is advised to be used for such traffic while larger CW size is advised to reduce the collision. At a very high network load, admission control or appropriate scheduling scheme is needed to guarantee channel access to real-time traffic while at

**Table 6** The CW tuning numbers at a fixed AIFSN

Cases	EDCA parameters	Service types tuning values	
		Best effort (AC1)	Voice (AC3)
Case 1 CW = Vary AIFSN = Constant	$CW_{min_{1,3}}$	31	7
	$CW_{max_{1,3}}$	1023	15
	$AIFSN_{1,3}$	5	2
Case 2 CW = Vary AIFSN = Constant	$CW_{min_{1,3}}$	23	5
	$CW_{max_{1,3}}$	363	11
	$AIFSN_{1,3}$	4	2
Case 3 CW = Vary AIFSN = Constant	$CW_{min_{1,3}}$	15	3
	$CW_{max_{1,3}}$	63	7
	$AIFSN_{1,3}$	3	2

the same maintain some level of fairness at which the data traffic access the same channel.

#### Abbreviations

EDCA: Enhanced distributed channel access; MAC: Medium access control; IEEE: Institute of Electrical and Electronic Engineers; QoS: Quality of service; MATLAB: Matrix laboratory; CW: Contention window; AIFS: Arbitration inter-frame space; WLAN: Wireless local area network; DCF: Distributed coordination function; CSMA/CA: Carrier sense multiple access with collision avoidance; AC: Access categories;  $CW_{max}$ : Contention window maximum;  $CW_{min}$ : Contention window minimum; BE: Best effort; AIFS: Arbitration inter frame space number; WSTA: Work station; VO: Voice; VI: Video; BE: Best effort; BK: Background; AP: Access point; EDCAF: Enhanced distributed channel access function; TXOP: Transmission opportunity; SIFS: Short inter-frame space; ACK: Acknowledgment; FIFO: First in first out; TXOP: Transmission opportunity limit; RTS: Request to send; CTS: Clear to send

#### Authors' contributions

GOU designed, performed the experiment, and wrote the paper. UNN analyzed the generated data and edited the paper. MAA significantly contributed in editing the paper. CIA supervised the entire work. All the authors read and unanimously approved the final manuscript.

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#### Declarations

#### Competing interests

The authors declare that they have no competing interests.

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