Fuzzy Based System For Assessing And Enhancing Qos For Wireless Networks

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Abstract: The problem of selecting an appropriate set of MAC protocol transmission parameters and QoS mechanism to provide predictable QoS using the IEEE 802.11 DCF scheme is an important issue in ad-hoc networks. Based on a simulated network using Network Simulator (NS) this paper aims to : (i) develop a Fuzzy Inference System (FIS) to intelligently assess the Quality of Service (QoS) for video and audio applications, (ii) develop a second FIS mechanism to adjust the minimum size of Contention Window (CWmin) in such a way to significantly improve QoS for the selected applications, (iii) Examine the implication of the developed approaches in real system. The results revealed that the developed FIS system has the capability of assessing the QoS wireless network for for multimedia transmission, and also has the ability for adjusting the wireless network parameters specially the minimum CWmin size. The results also indicated that a significant improvements in the network QoS for the whole network has been obtained. The implication of the proposed schemes in real networks has been examined. By using a systematic sampling method the results revealed that there was no significance statistical discrepancy between the actual data and the sampled version.

Index Terms: Quality of Service (QoS), Fuzzy logic, Wireless Networks, Contention Window.

1. INTRODUCTION

IEEE 802.11 is a relatively new standard for wireless networks [1, 2]. Its need started from the many differences between traditional wired and wireless networks and the increased need for interoperability among different manufacturers. Also, an inappropriate selection of the CWmin values led to a high number of collisions and large packet drop rates at the buffer. Based on these remarks, the standard IEEE 802.11 DCF protocol performed inappropriately for certain applications. Additionally, QoS support in wireless networks is more complicated than in the wired networks since bandwidth is more limited, unfairness, hidden terminal, delay and bit error rate are high and characteristics of the wireless channel vary over time and space, in addition to the rapid growth of multimedia applications. Those applications have strict requirements on network parameters, particularly, Quality of Service (QoS) parameters such as throughput, delay, delay variation (jitter), packet loss, and collision. Therefore, exceeding these requirements either decreases the communication quality or degrades it completely, since multimedia quality is governed by QoS offered by the network. Therefore, improving the performance of IEEE 802.11 MAC protocol and achieving QoS will be an aim for researchers. The use of Artificial Intelligence (AI) techniques such as fuzzy inference system for assessing QoS and optimizing the wireless ad-hoc network parameters played a major role in determining the performance of IEEE 802.11 DCF protocol. The simulations outlined in this paper are to study the capability of using AI techniques in assessing the QoS in wireless networks specifically in IEEE 802.11 protocol and in optimizing the CWmin size; since varying and optimizing the CWmin size have a significant positive impact on the network performance, in particular on the overall QoS.

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2 RELATED WORK

The effect of adjusting the value of the contention window and/or DIFS on the network performance has been analyzed in a number of studies. In [3] a simple self-adaptive contention window adjustment algorithm for IEEE 802.11 MAC protocol has been proposed. This demonstrated that the performance of the legacy IEEE 802.11 MAC protocol was sensitive to the initial parameter settings. DIFS parameter has been studied for providing service differentiation among different traffic priorities [4]. The value of DIFS in these studies was statically assigned for each class. However, less efforts has been made on tuning the DIFS for various traffic types. For instance, the proposed approach in [4] combined three MAC parameters to achieve service differentiation among the different priority classes. DIFS was one of these parameters which were statically assigned for each traffic class. A number of studies have used fuzzy logic in the area of computer networks. Fuzzy logic was used to assess the QoS for multimedia transmission [5, 6]. A dynamic contention window selection scheme to achieve a theoretical throughput limit in wireless networks based on fuzzy reasoning approach was proposed in [7, 8] proposed two distributed random access protocols for multi-channel WLANs. The proposed approaches were based on major modifications in the operation of the IEEE 802.11 standard protocol. Although the previous studies have reported an improvement in the network performance when the values of CW and/or DIFS were appropriately set, however, these methods did have limitations. For example, they did not assess the network QoS, used one or two QoS parameters, relied on estimation for the number of contending stations, caused major modifications to the structure of the standard, and only considered one application type. Therefore, the use of FIS enabled (i) transmission parameters (delay, jitter and packet loss) to be integrated to indicate the QoS for the applications, (ii) the CWmin value to be intelligently adjusted based on the assessed QoS, previous CWmin, and other QoS parameters such as collision.

3 EXPERIMENTAL PROCEDURE

In order to simulate wireless networks with realistic topologies a simulation tool was required. In this research paper Network Simulator (NS) [9] is used. The simulated network model used in this paper consists of 40 fixed stations randomly deployed in an area of $100m \times 100m$ to represent a wireless ad-hoc network (IBSS). All stations in this model transmit audio, video and data applications and they could hear each other's transmission. The maximum distance between the furthest stations was less than 100 metres.The audio and video traffic of packet sizes 160 bytes and 512 bytes, respectively were modelled using Constant Bit Rate (CBR). The transmission rate for each audio source was 64 kbps and for the video sources were 1 Mbps and 384 kbps alternatively. Data stations generated data packet streams with fixed size of 1500 bytes, corresponding to File Transfer Protocol (FTP). User Data Protocol (UDP) was used as the main transmission protocol for most scenarios. The simulation period was 300 seconds. Simulations were repeated 10 times, each time used a different seed that introduced randomness in the network starting condition in order to avoid the bias of random number generation. The results of the 10 simulations were averaged to determine the general behavior of the network.

4. PROPOSED APPROACHES

4.1 QoS Assessment Fuzzy Inference System

A fuzzy logic approach for assessing the QoS for audio, video, and data traffic has been developed. The structure of the developed approach is shown in Figure 1. The FIS system consists of four main processes; fuzzy inputs, fuzzy rules, fuzzy inferencing, and fuzzy outputs. The inputs to the system were delay, jitter and packet loss for time-sensitive application such as audio and video. However, time-insensitive application, packet loss, collision, and MAC efficiency were considered as the fuzzy input parameters. According to the QoS requirements for each parameter, each fuzzy input was represented by three fuzzy sets to generate the required membership functions. The position and geometry of each membership function was calculated according to the degree of overlap between these membership functions as shown in Figure 1. A typical example of the Gaussian membership parameters and the position of these values (as indicated by the deviation from the mean value) are summarized in Table 1. These parameters were determined according to the application QoS requirements. The relationships between the inputs and the related QoS achieved by the applications were expressed by fuzzy rules. The number of fuzzy rules is related to the number of input variables and the number of sets associated with each input variable. The devised QoS assessment approach has nine rules formed from a combination of three input variables, each input represented by three fuzzy sets. Typical rule examples for audio and video application that include these three inputs are as shown in Figure 2. The rules were written after considering the ITU recommended ranges for QoS parameters for video and audio applications [10].

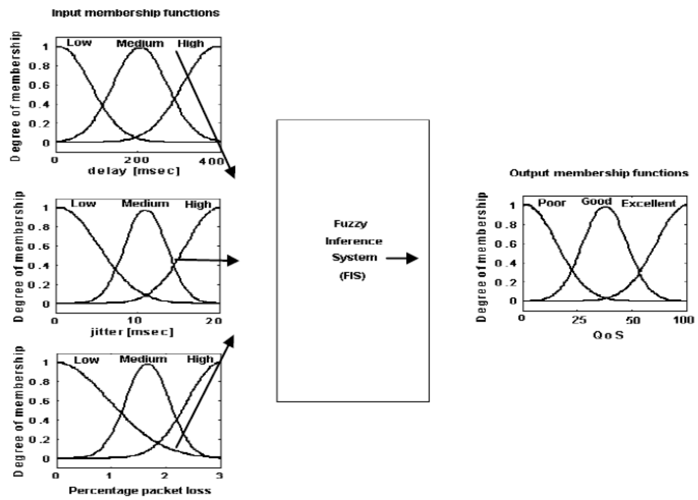

Figure 1: *FIS structure for QoS assessment.*

Table 1: *Input and output Gaussian membership functions settings that were used for QoS assessment FIS system (video application).*

Label	Input variables						Label	Output variable	
	Delay (msec)		Jitter (msec)		Packet loss (%)			QoS (%)	
	Mean	SD	Mean	SD	Mean	SD		Mean	SD
Low	150	15	15	1.44	0	0.57	Poor	0	11.5
Medium	355	70	33	10	1.4	0.4	Good	48	11.5
High	600	104	50	8.6	3	0.87	Excellent	100	11.5

"IF Delay is Low AND Jitter is Low AND Loss is Low THEN QoS is Excellent"
"IF Delay is Medium AND Jitter is Medium AND Loss is Medium THEN QoS is Good"
"IF Delay is High OR Jitter is High OR Loss is High THEN QoS is Poor"

Figure 2: *Typical set of rules for the QoS assessment FIS mechanism*

As indicated in Table 1, the three inputs, delay, jitter and packet loss were represented by high, medium, or low while only one single fuzzy output that represented the QoS by poor, good, or excellent. In this approach, the output variable was split into three singleton fuzzy sets, these are labelled as linguistic variables (Poor, Good, and Excellent QoS levels). The input and output variables employed several membership functions such Triangular, Trapezoidal, and Gaussian. Gaussian membership functions were used for the devised fuzzy system, because the tests showed that they provided best results, and had the capability of smooth transition from one membership function to another membership function, their short notation, and Gaussian membership functions proved effective in other studies in the area of networking such the work presented in [11,12]. In the FIS technique, the fuzzy input (crisp input) values were mapped into membership functions (fuzzification process) and assessed according to the rules considered. The output of each fired rule was aggregated and the output was used as an input to the defuzzifier that converts the inferred fuzzy control action into a nonfuzzy control action (i.e. QoS) under a defuzzification strategy. In this study the centroid defuzzification method was used since it provided the best results. The output range (i.e. QoS) was 0 – 100, which classified symmetrically into three classes. These classes were defined as the QoS levels which were Poor, Good, and Excellent. The values less than 33% were classified as a poor QoS level, the values between 34% - 66% were categorized as a Good QoS level, whereas, the values greater than 66% were considered as an Excellent

QoS level. After setting up the network topology, selecting the appropriate MAC parameters, and configuring the network traffic, QoS metrics were quantitatively assessed. This was carried out by following the steps depicted in Figure 3. After simulating the selected network, a data file was generated by the simulator. The QoS metrics such as throughput, delay, jitter, packet loss, and collision were extracted for each traffic type. So, for the assessing process of the QoS, the measurements of the QoS parameters were taken either with respect to the simulation time (i.e. averaging the value of throughput, delay, jitter and packet loss after every one second of the simulation) or with respect to the blocking process in which the generated packets were divided into groups of packets called blocks. The number of packets in each block was equal to the number of packets during one second of the simulation unless the number of blocks was specified.

4.2 Contention Window Adjustment Using a Fuzzy Inference System

A second FIS based on Mamdani fuzzy inference systems was implemented to adjust the CWmin size [13]. The QoS metrics throughput, delay, jitter, packet loss, MAC efficiency, and collisions were averaged and used by the QoS assessment FIS to assess the QoS for the transmitted application as discussed above. The assessed QoS was fed into the second FIS similar to the system shown in Figure 1 together with the previous CWmin size, MAC efficiency, average collision rate, and QoS difference (this was the difference between the current assessed QoS and the previous assessed QoS for the same type of traffic, and it was only used to determine whether the current QoS was improved or not when adjusting the CWmin). These parameters were considered as the input variables for the CWmin adjustment FIS. Concerning the CWmin input variable, each application had a different CWmin size range. For instance, the CWmin range for audio was from 7 to 31, for video the range was from 15 to 64, while for data the range was from 127 to 255. The selection of these ranges was based on the application type and its QoS requirements. Each input variable had a different number of membership functions. E.g., the previous value of CWmin had seven Gaussian membership functions which were labelled as extremely low (Elow), very low (Vlow), Low, Medium, High, very high (Vhigh), and extremely high (Ehigh). The other input variables had a smaller number of membership functions. The locations and the degree of overlap between these membership functions were chosen as indicated in Table 2 since these values provided best results. The second FIS processed these inputs by following the processes of assessing the QoS to provide a new CWmin size for each application. The new CWmin size was used for the next simulation run. Examples of the rules used are presented in Figure 4.

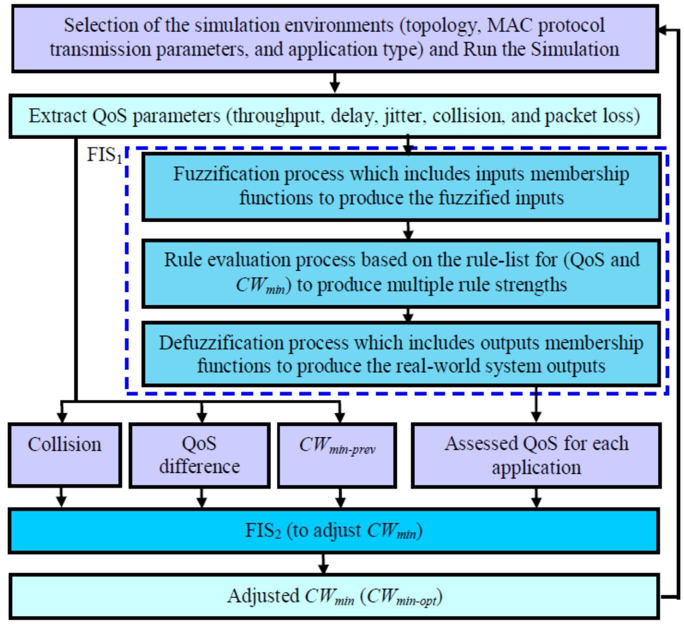

Figure 3: *Fuzzy logic model for assessing QoS and optimising the CWmin value.*

When the system outlined in Figure 3 was used to control the value of CWmin, the measurements of the QoS parameters were averaged for the whole period of the simulation time and then fed to the first FIS to assess the QoS. Thereafter, the assessed QoS, the previous CWmin, collision rate, and QoS difference were fed to the second FIS to obtain the controlled CWmin. The adjusted CWmin was fed to the network for the next simulation run. This implied that the adjusted CWmin was only fed to the network once at the beginning of the simulation and remained constant until the end of simulation.

Table 2: *Input and output Gaussian membership functions settings used for CWmin adjustment of FIS system (video application).*

Input variable	Label	Mean	Standard deviation
CWmin previous	Extremely Low	15	3
	Very Low	21	2
	Low	26	2.05
	Medium	31	2.14
	High	36	2.25
	Very High	41	1.75
	Extremely High	64	11.5
Current QoS	Poor	0	11.5
	Good	48	11.5
	Excellent	100	11.5
QoS difference	Positive	-100 → 0	-
	Negative	→ 0 +100	-
Collision	Extremely Low	2.29	0
	Very Low	5.7	1.49
	Low	10	1.76
	Medium	15	1.91
	High	21	2.29
	Very High	27	2.95
	Extremely High	40	4.6
Output variable	**Label**	**Mean**	**Standard deviation**
CWmin suggested	Extremely Low	15	3
	Very Low	21	2
	Low	26	2.05
	Medium	31	2.14
	High	36	2.25
	Very High	41	1.75
	Extremely High	64	11.5

"IF QoSprev is Excellent AND CWmin_prev is Low AND collision is High AND QoSdifference is positive THEN CWmin_new is Medium"

"IF QoSprev is Good AND CWmin_prev is VLow AND collision is High AND QoSdifference is Negative THEN CWmin_new is Low"

"IF QoSprev is Poor AND CWmin_prev is High AND collision is Low AND QoSdifference is Positive THEN CWmin_new is Medium"

Figure 4: *Typical set of rules for the FIS adjustment mechanism.*

5. Results and Discussions

5.1 QoS Assessment of the Basic IEEE 802.11 DCF Scheme

The IEEE 802.11 DCF scheme is only able to support best-effort service without any QoS guarantees or differentiation. In this section the accuracy of the FIS assessment system is discussed. Further, the QoS for audio, video, and data applications is assessed with the current settings supported by the IEEE 802.11 standard. It also outlines how the IEEE 802.11 DCF scheme with these settings is incapable of effectively utilizing the channel capacity. A typical set of results obtained using the QoS assessment FIS system is provided in Table 3. It can be observed that the mechanism has successfully processed the QoS requirements of the video and audio applications. For instance, high values of delay, jitter, or packet loss resulted in a poor QoS. However, medium and low values of these parameters resulted in good and excellent QoS levels, respectively.

Table 3: *Typical set of results for the QoS assessment FIS mechanism.*

Application type	Inputs (QoS Parameters)			Output (Assessed QoS)	
	Delay (msec)	Jitter (msec)	Loss (%)	QoS (%)	Linguistic Term
Video	112	40	3.9	15.8	Poor
	600	22	4	10.2	Poor
	300	20	0.9	44.8	Good
	330	21	1.8	40.1	Good
	10	2.3	0	89.6	Excellent
	130	13.3	1.7	79.2	Excellent
Audio	600	8	1.3	9.5	Poor
	300	1.7	5.1	26.4	Poor
	261	2.1	1.0	55.1	Good
	263	0.8	2.9	53.1	Good
	15.6	1.3	2	89.7	Excellent
	70	2.4	0.9	78.6	Excellent

Each traffic type has different delay requirements. Video traffic for example requires the following: low delay (less than 400 msec) [10], a packet loss rate less than 3%, and jitter has to be less than 50 msec. Therefore, these parameters should be kept small. Average delay for the three video connections using the standard IEEE 802.11 DCF scheme exceeded the minimum QoS requirements for video transmission. The values of average delay were 421.2, 441.5, and 620.7 msec for the first, second, and third video connections, respectively. The causes of this increase in the delay for video connections were: all stations started with the same CWmin size. This implied that they had the same chance to access the channel; thus, the probability of simultaneous transmission was very high which in turn increased the probability of collisions. The collided packets in this case required retransmission by the MAC protocol which in turn led to late arrivals of these packets at the destination as well as a higher drop of the waiting packets at the buffer. Further, the default size of CWmin was not optimal. When the CWmin size was too high, a number of empty time slots were wasted and resulted in an unjustified waiting time of packets at the buffer. This led to high values of delays and smaller throughput. When the CWmin size was too small, this increased the probability of collisions which in turn increased the delay for the transmitted packets (i.e., increased the number of retransmissions of the collided packets). The reduction in average throughput and the increase of packet loss ratio for video connections were due to the high competition among the active stations in the same IBSS. These stations had the same chance to access the channel (same CWmin size), which led to high collisions between them. Moreover, the high number of collisions reduced the MAC protocol efficiency which in turn increased the number of retransmissions of the collided packets resulting in high delay and high drops of the packets that were waiting in the buffer. The average values of throughput and jitter were outside the desired range of QoS. The mean values of these parameters are summarized in Table 4. The QoS parameters for each connection were averaged and fed into the QoS assessment FIS to assess their QoS. The assessed QoS for video and audio traffic according to the basic IEEE 802.11 DCF scheme resulted in poor QoS levels for some connections (i.e., they achieved QoS less than 33%). The third video connection had a poor QoS with mean value equal to 18.3%. The second and third audio connections also experienced a poor QoS with mean values equal to 17.7% and 15.8%, respectively. The degradation of the QoS for video and audio connections was due to the high values of delay and jitter which also resulted in high fluctuations in the assessed QoS. Therefore, the standard IEEE 802.11 protocol was incapable of achieving the minimum QoS for multimedia transmission especially at heavy load traffic as illustrated in Figure 5.

Table 4: *Assessed QoS for audio and video traffic using the standard IEEE 802.11 DCF scheme.*

Connection	Delay (msec)	Jitter (msec)	Throughput (Kbps)	Packet loss (%)	QoS (%)	QoS level
	Mean	Mean	Mean	Mean	Mean	
Video connection 1	421.2	5.6	337.7	4.9	49.7	Good
Video connection 2	441.5	6.4	336.8	5.1	42.2	Good
Video connection 3	620.7	9.9	284.7	26.4	18.3	Poor
Audio connection 1	32.9	3.9	63.5	0	59.7	Good
Audio connection 2	79.78	12.5	59.6	0	17.7	Poor
Audio connection 3	121.8	13.6	55.6	1.1	15.8	Poor

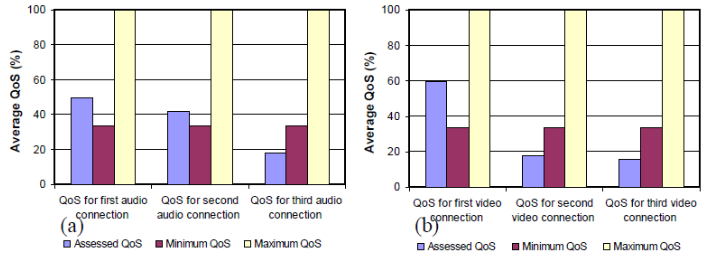

Figure 5: *Assessed QoS for video and audio vs. the minimum and maximum QoS, (a) assessed QoS for video connections, and (b) assessed QoS for audio connections.*

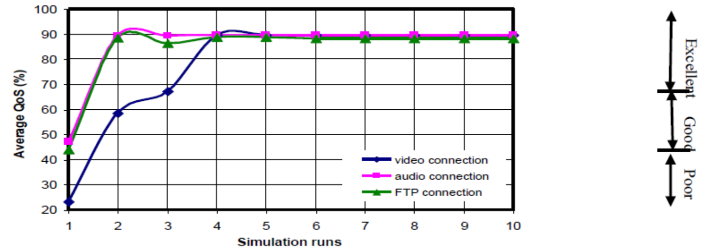

Figure 6: *QoS for video, audio and FTP traffic according to the adjusted CWmin using FIS system.*

Fuzzy Logic Adjustment of the Minimum CW size

According to the results discussed above, the audio and video traffic were more sensitive to a variation in the CWmin size than FTP traffic. Therefore, the audio traffic was given a higher priority over the video and FTP traffic by assigning smaller CWmin sizes in the range of (7 - 31 slots). Video traffic was given a medium priority through specifying higher CWmin sizes in the range of (15 - 64 slots); whereas the FTP traffic was specified lower priority by assigning a higher range of the CWmin sizes (127 - 255 slots). As shown in Figure 6, during the first run of the simulation, one video application was in the poor (i.e. 0 to 33%) QoS range while one audio and FTP connections were in the good range (i.e. 34% to 66%). Following the application of the developed method, all three connections had an excellent QoS (i.e. 67% to 100%). Consequently, using different CWmin ranges for audio, video, and FTP traffic resulted in a reduction in number of packet collisions and allowed for creating priorities for their transmission. During the first simulation run, the CWmin size was set to the default value (i.e., 31) for all traffic. For the rest of simulations, the CWmin values were adjusted by the FIS system according to the current QoS, previous CWmin size (CWmin-prev), QoS difference, and collision parameters. The selection of these four input parameters was due to their close relationship with the adjusted CWmin (CWmin-opt) size. For example, the current QoS input parameter for each type of traffic was chosen to determine the current network performance. However, the previous value of CWmin (CWmin-prev) was selected in order to help in a decision making process i.e., what the next CWmin size (i.e., CWmin-opt) should be, lower or higher than the previous one. The third input variable was collision; this was added to provide the FIS system with a global knowledge about the network condition by determining the amount of competition among these active stations. The last parameter was the QoS difference and was used to track the QoS variation by providing a positive or a negative sign to the controller. Consequently, combining these parameters together resulted in an accurate adjustment of the CWmin. This implied that the FIS system was a better control mechanism. The results obtained for this investigation are shown in Table 6.

Table 6: *QoS and the CWmin-opt obtained using the FIS system.*

Video		Audio		FTP	
CWmin-opt (slots)	QoS (%)	CWmin-opt (slots)	QoS (%)	CWmin-opt (slots)	QoS (%)
31	23.3	31	47	31	44
37	58.5	19	89.5	207	88.6
52	4.04	24	89.5	200	86.3
52	67.3	24	89.5	203	88.8
48	89.5	25	89.5	204	88.8

5.2 Implication of the Developed Approaches in Real System

The ability of implementing the proposed systems discussed above in a real system is discussed in this section as depicted in Figure 7. The measurements of QoS parameters and the adjusted CWmin can be measured in both, the sender and the receiver. This can be conducted by exchanging a small number of control messages between the communicating pair at specific time duration. The source sends a control message to the destination to start measuring the QoS parameters such as the time received for the sent packets. Hence, the receiver starts recording a sample of traffic that is sufficient to represent the whole population. After a predefined time interval, the source sends a control message to the receiver to send the recorded QoS information. During this period, the source has the time and the number of sent packets, and the time and the number of received packets. Based on this information, the source is capable of determining the QoS and is able to adjust the required MAC protocol transmission parameters. If the control message is lost between the communicating pair, the source waits for an expiry period and then sends another control message to the destination to send the recorded information again or to start new measurements. The transmission of measured or recorded data between stations or to the collection points can consume significant amounts of network resources which in turn degrades the performance. To overcome these shortcomings a form of sampling such as systematic sampling can be employed. The use of sampling can offer information about a specific characteristic of the parent population [14]. The difference between the actual data and the sampled one was statistically analyzed using the t-test [15]. The results indicated that the sampling method could represent the whole population since there was no statistical difference between the parent population and the sample version. The network parameters of each application were calculated for each connection. For instance the average delay was calculated based on the difference between the values of the timestamps of arrival times for two monitoring points of the sampled packet. In order to ensure the correlation between the two timestamps of the same packet, packet ID has to be the same at the monitoring points (sending point and receiving point). The count-based trigger frequency was set to 10 packets. Thus, the selection of 10 for this aim was sufficient. The same remarks were considered for the rest of network parameters, i.e., throughput, packet loss and jitter.

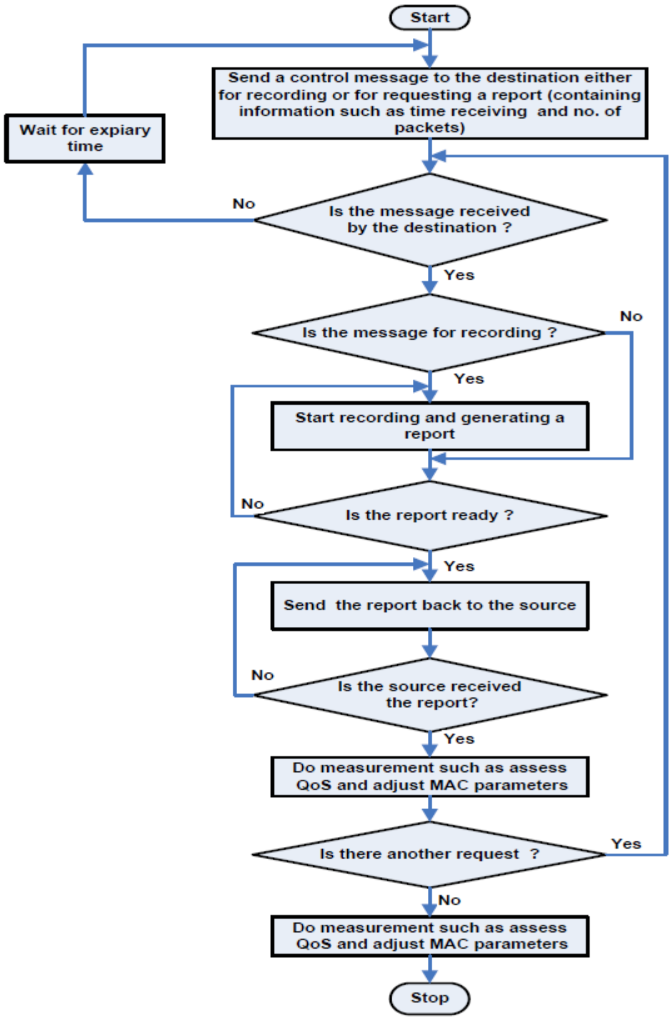

Figure 7: *Proposed method for measuring the QoS parameters and adjusting MAC protocol transmission parameters such as CWmin value in physical networks.*

After generating the sampled population of the network parameters using systematic sampling, the discrepancy between the actual data and the sampled one was statistically analyzed for the linear increase and fuzzy logic approaches. This included the mean value, the standard deviation, and Standard Error (SE) of difference. Some of these statistic values which were carried out using the t-test are summarized in Table 7 and Figures 8a and 8b [16].

Table 7: *The means and the standard deviations of the QoS obtained for the population and the sampled version for, (a) simple linear adjustment mechanism, and (b) fuzzy logic adjustment technique.*

Approach	Statistic measure	Basic access mechanism			RTS/CTS access mechanism		
		QoS for video (%)	QoS for audio (%)	QoS for data (%)	QoS for video (%)	QoS for audio (%)	QoS for data (%)
Linear increase	Mean / sampling	82	89	86.8	80.7	89.5	89.5
	STD / sampling	15	1.7	2.8	17.3	0.1	0.5
	Mean / population	82	89.5	85.2	80.7	89.5	89.7
	STD / population	14.8	0.2	8	17.3	0	0
Fuzzy logic	Mean / sampling	76.3	89.2	77	74.2	76.2	89.7
	STD / sampling	31.5	0.6	16.5	31.7	31.7	0
	Mean/ population	75.3	89.3	83.3	83.3	81	89.7
	STD / population	23.7	0.5	14.8	12.2	25.5	0

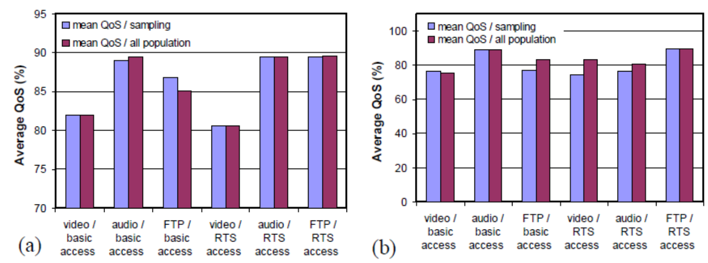

Figure 8: *The means of the QoS obtained for the population and the sampled version for, (a) simple linear adjustment mechanism, and (b) fuzzy logic adjustment technique.*

The degree of significance was performed to check if the discrepancy between the parent population and the sampled version was statistically significance. This was recognized depending on the P threshold value which was set to 0.05 (a value that has been widely adopted). If the P value was smaller than the threshold value, the difference was statistically significant. Otherwise, the difference was not statistically significant. T -test was carried out for the linear increase scheme and the fuzzy logic approach. The P values were 0.472 for linear increase and 0.192 for fuzzy logic approach. This implied that the systematic sampling method can be used to represent the whole population since there was no statistical difference between the parent population and the sample version in the selected scenarios.

6. CONCLUSIONS

In this paper a FIS mechanisms were proposed to assess the QoS for multimedia transmission over wireless networks and to adjust the CWmin. Moreover. The implication of the developed approaches in real system has been examined. The key issue of these approaches was to guarantee the different QoS requirements for different traffic classes, while simultaneously ensuring that the limited channel bandwidth is utilised efficiently. The study indicated that the developed FIS system was capable of assessing the network QoS for multimedia applications, and also capable for adjusting the minimum CWmin size which resulted in significant improvements in the network QoS. Using a systematic sampling method the results revealed that there was no significance statistical discrepancy between the actual data and the sampled version.

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