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Improved VoIP QoS over Wireless Networks

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Abstract: Voice over Internet Protocol (VoIP) is a famous time-sensitive voice communication application over the Internet. This technology has observed multiplicative growth in both wired as well as wireless networks. Every day thousands of devices are made which are compatible with the 802.11 and experience good throughput at PHY layer due to introduction of 802.11b, 802.11g, 802.11n and 802.11a standards. The Data link layer uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol which allows equal license-free channel sharing between nodes communicating in half duplex mode. CSMA/CA lacks in Quality of Service (QoS) support and priority provision to handle real-time multimedia applications. Challenges of the wireless networks make VoIP implementation a tough task. An amendment of WLANs 802.11e ensures the desired order of preference for channel access to the time-bound applications but the implementation still needs certain points to be considered and worked upon. A novel channel access scheme is developed which ensures QoS of VoIP over any size of wireless network.

Keywords: VoIP; QoS; wireless networks; channel access; data link; 802.11e

I. INTRODUCTION

Internet Telephony (IT) another name of VoIP is a mechanism of transmitting voice over the packet switched Internet, sharing the same data channel to carry analog voice signals in form of packets. Wireless and mobile devices have fueled explosive development in the field of wireless networks due to the urge of people for high speed audio, video and other web services even when they are moving around. They are very different from the traditional wired networks in their design, working and technological implementation. These networks have opened new research avenues for the platform of voice with their unique style and usage. Wireless networks face may issues in their implementation like varying number of nodes, signals, collisions, uplink and downlink variations and congestion.

The Media Access Control (MAC) layer makes it possible for several terminals (nodes) to communicate within a multiple access network by accessing the shared medium in a controlled manner even after lack of admission control [1]. Institute of Electrical and Electronics Engineers (IEEE) 802.11 is a standard for implementing WLAN and comprises of a set of physical layer (PHY) and MAC. The standard does not support delay-sensitive voice applications but only best-effort service [7]. After several refinements and with the increasing call for real-time multimedia applications a new amendment named "IEEE 802.11e" was designed [4]. This helped in improving the QoS of time-sensitive traffic with other types of data traffic even when the nodes operate during Contention Period (CP).

II. 802.11 VERSUS 802.11E

The mandatory channel access function of MAC known as Distributed Coordination Function (DCF) uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) mechanism to coordinate among the nodes and the optional one known as Point Coordination Function (PCF) works on poll and response mechanism. These functions are used in CP and Contention Free Period (CFP) respectively. In DCF frame transmissions are done on the basis of Backoff Counter (BC) which is a random integer value chosen from the uniform distribution value of Contention Window (CW) maintained by every station [8, 11]. This contention scheme along with acknowledgement mechanism is used to deal with collisions, which greatly reduces system efficiency as the network size increase [17]. DCF does not come with any QoS support which is the most important requirement for the acceptance and implementation of real-time applications.

802.11e improves the QoS of time sensitive applications when operating in contention with other traffic types [3,5]. This is guaranteed by dividing data traffic into four different Access Categories (ACs) namely voice (VO), video (VI), Best Effort (BE) and background queues (BK) [14]. Out of all these categories voice gets maximum priority. 802.11e MAC has Hybrid Coordination Function (HCF) which combines the traits of both DCF and PCF. It is composed of Enhanced Distributed Channel Access (EDCA) contention mode data transmission mechanism and HCF Controlled Channel Access (HCCA) which is a contention free mechanism [2,6,10,19]. Every AC has unique set of parameters which are changeable, unlike DCF, and gives an opportunity to individual stations to apply some kind of prioritization to different traffic types.

III. EDCA PARAMETERS

A. *QoS handling of Enhanced Distributed Channel Access*

EDCA parameters that contribute in QoS delivery and network performance enhancement are 'minimum' and 'maximum' set of permissible values for CW commonly called as "CWmin/CWmax", Arbitration Inter Frame Space (AIFS) and TXOP called as "Transmission Opportunity". Adjustments of these parameters can be done statically or adaptively by considering the network conditions. This flexibility helps in improving the performance of VoIP over wireless networks. Varying the size of CW and keeping it lowest for voice AC, having small value for AIFS and enabling TXOP helps in timely delivery of voice packets, cut down a lot on jitter and deteriorating packet loss rate, which further contributes to good voice quality [9,13].

B. *Channel Access in EDCA*

The most commonly used channel access algorithm that works on the idea of making a station wait for a random amount of time also called "random back-off time" during contention period of the network so as to maintain a collision free environment for all participating nodes. The random time value is selected from the static value of CW and is decreased to zero in a systematic counting down manner every time the medium is sensed free [9,13]. A load over the network increases collision probability, thus doubling the CW size minimizes the chances of selecting same random back-off time values and helps avoiding collision. Doubling the CW size (linear graph) names it BEB algorithm. Size of contention window is fixed according to the network standards for example CW limits of 802.11g ranges between CWmin=15 and CWmax=1023.

Introduction of eight classes to handle Traffic Stream (TS) and four queues for each AC at the MAC layer is a unique offering of HCF. Depending on the QoS requirement of the frame arriving at media access layer that fame is labelled according to the traffic class priority with Traffic priority Identifier (TID) for its identification [14,16]. The TID value can be taken from the range of 0 to 15 which is divided between EDCA and HCCA. Frames having TID from 0 to 7 can be plotted onto four queues of ACs with the help of EDCA scheme and those with 8 to 15 into eight TS queues following HCCA. This division helps in strict implementation of prioritized QoS at AC queues and parameterized QoS at TS queues [15].

The priority QoS contention oriented EDCA method provides QoS-enabled stations known as (QSTA) to map eight user priorities (UPs) with four queues (ACs). Taking less number of ACs than UPs is justifiable since eight types of application frames cannot be transmitted altogether and MAC overheads are also reduced. Every AC queue works as a sovereign DCF station employing its own back-off parameters [8, 10, 16].

IV. CONTENTION WINDOW MECHANISM

The EDCA working scheme of 802.11e protocol segregates data traffic and depending on the priority of frame plot it to the respective individually related AC. Each access category AC[x] is allotted its own set of channel access parameters represented as CWmin[x], CWmax[x] and AIFS[x]. The parametric values of all for Access Categories are shown in below figure. It can be clearly deduced that high priority ACs have least values for CWs and AIFSN and vice-versa [16]. The idea contributes high priority data in spending shortest waiting time for accessing the media and fastest arrival at the destination. This improves the quality of time-sensitive applications like VoIP by reducing delays. The table below gives value of each of the above discussed parameters.

Table 1. EDCA standard parameters [15]

AC	AIFSN	TXOP (ms)	CWmin	CWmax
AC[0] - BK	7	0	*CWmin*	*CWmax*
AC[1] - BE	3	0	*CWmin*	*CWmax*
AC[2] - VI	2	6.016	*CWmin/2*	*CWmin*
AC[3] - VO	2	3.264	*CWmin/4*	*CWmin/2*

The DCF of 802.11MAC layer and the EDCA of 802.11e are similar in using Binary Exponential Back-off (BEB) [6] that sets the CW of an access category (AC[x]) equal to twice the value of its size during a transmission failure and keep incrementing with the same approach till the maximum value CWmax[x] is reached.

$$CW[x] = max(CW[x]*2, CWmax[x]) \quad (1)$$

The contention window CW[x] is reset to the minimum value CWmin[x] after very successful transmission. This procedure is based on the assumption that factors causing failure will no longer exist after the occurrence of a successful transmission.

$$CW[x] = CWmin[x]; \quad (2)$$

The four ACs act as independent stations with in a station. This gives rise to two levels of packets conflict, one among different ACs of same station (internal) and second among different stations (external).

The contention window size of high priority ACs is small. This is the reason why their performance is affected by high collisions especially in large networks [16]. When the back-off timers of two or more ACs of the same node count to zero and try data transmission simultaneously internal or virtual collision arise. Highest priority AC among the colliding ones is given the access to the channel while the other back-off and double their Contention Window same as an external collision. A similar process of backing off, as internal collision, and doubling CW size takes place for colliding ACs of different stations. The rest non-colliding ones preserve their paused back-off timers.

The binary exponential increment of CW and back-off procedure is absolutely not a good choice for time-sensitive applications under low traffic scenarios, as large CW size degrades systems performance [18]. This approach may result performance degradation due to high collision rate. Moreover, the BEB scheme undergoes fairness concern and low throughput issues under high load and large network size. The fairness issue originates due to wrong application of CW resizing scheme.

A. Earlier work done

VoIP applications are most sensitive towards packet drops and delays [11]. The quality and interactivity of voice is majorly affected by packet drops and delays or jitter. Implementing QoS for efficient functioning of VoIP requires better MAC algorithms that can provide fair channel access on the basis of service differentiation. This section unveils several algorithms striving to achieve better throughput, quality, reduce jitter or delays or losses.

The effect of CW modifications was best shown in a research work of [13] where they had proved the influence of selecting appropriate back-off parameter on the performance of network. Random back-off value was taken from the CW range that helped in avoiding collision to some extent. Through experiments it was shown how incorrect CW parameters selection can degrade the overall throughput. The mean delay of packets also grew multiple times by taking inappropriate CW values.

An analytical model was presented by [4] well suited for all types of channel access schemes. The model calculated saturated throughput performance for 802.11 DCF. This work too proved that the basic channel access methods are sturdily dependent on system parameters. Idle channel conditions with limited number of nodes were taken for the working of the model.

A concept of using doubled size CW at the time of collision and reducing it to the half of its size after every successful transmission was presented by [2]. This CW resetting scheme proposed for the DCF resulted in improved system throughput. The implementation analysis of new back-off mechanism was done through Markov chain model. This model can be used to check the performance of basic as well as RTS-CTS access schemes. It confirmed the effectiveness of the suggested back-off method.

The author [17] discussed that reducing the CW very fast in case of BEB makes them unsuitable for heavy load networks. They proposed their own Exponential Increase Exponential Decrease (EIED) backoff algorithm which is based on the idea of increasing and decreasing the size of CW exponentially. The algorithm surpassed the results of BEB and MILD for throughput and delay.

The authors [4] extended the logic of MILD algorithm [7] and created their own algorithm based on linear estimation of CW size called the Linear Increase Linear Decrease (LILD) algorithm. The investigators set the increasing size of CW equivalent to CW+CWmin rather than using multiplicative value as that in MILD thus avoiding the slow linear changes for every unsuccessful transmission. LILD is a better choice of algorithm for delivering better quality performance over heavy networks. The authors also introduced one more backoff algorithm, named as Linear MILD (LMILD), in which nodes facing collision increase their CW size in multiplicative manner, while the remaining ones increase it linearly. The decrement of CW is always in a linear fashion for all the nodes. The feasibility of this algorithm lies in taking help from the physical layer for some additional physical carrier sensing signals. The nodes do not report any packet header reception during collisions. This algorithm outperforms PLEB scheme in small size networks and BEB mechanism in large networks. The scheme compromises a bit with fairness mechanism by not allocating sufficient back-off time before the retransmission of data packets.

A new efficient variant of DCF for collision resolution was investigated [14] which was called as GDCF (Gentle DCF). This scheme worked with fixed set of nodes where the size of the CW was halved after every successive successful transmission. This more conventional approach of gentle decrease of CW reduces collision probabilities predominantly when the number of opposing stations is large. The algorithm is simple and achieves better fairness as compared to DCF. It efficiently supports priority QoS. The performance of GDCF was not analyzed with varying number of nodes. To remove the fading effect of random number distribution [9] introduced a new back-off algorithm which is actually an improvised version of logarithmic back-off algorithm. This algorithm instead of exponential extension uses logarithmic increments for CW size. This algorithm achieved higher throughput in large sized networks.

Research of [3] was focused on traffic loads of the channels and proposed the Exponential Linear Back-off Algorithm (ELBA) that is a perfect combination of linear and exponential algorithms. They provide enhanced throughput compared to BEB, LILD and EIED algorithms. In [8] the authors used pause count back-off for monitoring traffic loads over the channel. CW size here is set on the basis of results estimations. The Pessimistic Linear Exponential Backoff (PLEB) algorithm was proposed [16] that coalesced two separate CW increment behaviours linear and exponential for the back-off value. It is based on the assumption that network congestion will not settle down shortly. In case of transmission failure the size of the contention window rises exponentially. After few increments of back-off value the size of CW is linearly increased. In large network sizes PLEB works better than others.

The back-off algorithm of 802.11 holds very important place in having a controlled access to the channel which maximizes the fairness and throughput [15]. Several methods for extending the existing or proposing altogether a new back-off algorithm have been proposed. Most of them are based on transforming the back-off parameters such as CW size and back-off stage. A fitting CW size results in improving system throughput by reducing the possibility of collisions. However, some of the methods do not account for dynamic traffic loads which influence the time-bound delay-sensitive VoIP applications the most.

B. VoIP QoS enhancement scheme

EDCA's performance and different schemes for enhancing its functionality by manipulation AIFS, CW or TXOP values have been investigated but petite attention has been paid to the collision management using traffic loads which is the major concern in WLANs and sturdily effect the QoS of real-time delay bound applications [15, 18]. The CW resizing by considering the network size or load on it delivers better performance to time bound applications like VoIP. We propose an enhanced traffic aware version of the existing EDCA called Enhanced VoIP-EDCA (E-EDCA). Simulation work further prove the advancement of E-EDCA scheme in reducing loss rates, jitter and thereby improving voice quality and system throughput under different network loads.

Channel load is separated into two modes of light and heavy traffic. If the value of CW of a station "x" denoted by CW[x] is less than or equal to the threshold value i.e., CWt, the channel is under light mode of traffic else it's a heavy load mode. High priority AC data needs small increments of CW for quick delivery and vice-versa. During light traffic loads smaller increments should be made to the CW and in large traffic conditions CW needs multiplicative expansion followed by linear add ups. This gives sufficient adjustment time to CW to adapt to the traffic situations with making complex overheads. Switching between multiplicative and linear scheme of CW adjustment is decided with the help of one more threshold value CWth.

C. Working of the E-EDCA scheme

The E-EDCA scheme checks the current size of CW[x] against a specific threshold value CWt to find the load status of the network. Under low load of traffic the first step is to check the AC of the frame. A voice or video holds highest position in AC and cannot wait for long in the queue. This calls for smaller increments in their minCW[x] size thus a linear increment algorithm is chosen in this case. A linear addition to CW size in low load is justifiable with the fact that the probability of multiple successive collisions is very less. Every unsuccessful effort will continue increasing the CW value by one till the maximum size CWmax[x] is reached. Background and best effort AC packets have a proliferating increase in their CW size which is attained by multiplying them with 1.5. This helps in keeping their CW size more than that of the CW size of voice or video AC and maintaining higher values of back-off to avoid quick clashes.

From light to medium traffic mode the scheme works in following way

```
// For voice and video traffic
If (CW[x]<=CWt)

CW[x] = min(CW[x]+1, CWmax[x]);

//For background and best effort

If (CW[x]<=CWt)

CW[x] = min(CW[x]*1.5, CWmax[x]);
```

High traffic loads require implementation of different scheme since the probable rate of collision is more here. [19] proved through simulation that a linear increment adaptation does not provide enough time and result in frequent back-offs in large networks. Small increments must be followed after large increments. Packet of voice or a video AC is checked against double the size of minimum contention window which is represented by another threshold CWth. If the threshold is more than the current contention window size CW[x] increment is set by multiplying its value with 1.5 till the CW reaches its threshold CWth or the channel becomes free. In another case where the CW[x] is more than the CWth, linear incremental approach is implemented. For heavy traffic mode the scheme works in following way

```
// For voice and video
If (CW[x]>CWt)
        If (CW[x]<=CWth)
                CW[x] = min(CW[x]*1.5, CWth);
        else
                CW[x] = min(CW[x]+1, CWmax[x]);
        Endif
Endif
//For background and best effort
If (CW[x]>CWt)
CW[x] = min(CW[x]*1.5, CWmax[x]);
Endif
```

The dual approach helps in trimming down the delay variation of the packets transmitted from dissimilar rounds of back-off times, thus cutting off on the likelihood of collision in successive rounds.

D. Implementation and analysis

The design and implementation model consists of a Wireless Local Area Network (WLAN) of an office. Scenarios of different size with varying number of nodes are designed to test the behaviour of VoIP data in response to various types of contention based media access mechanisms over diverse network sizes. OPNET simulator has been used for WLAN design and VoIP technology is deployed on it.

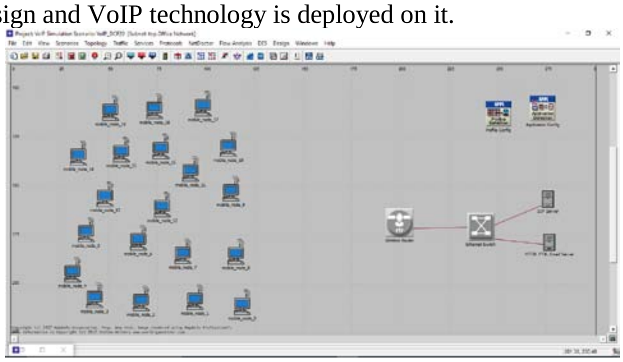

Figure 1. Network structure

A wireless router node is also added in the network which is the AP for all the nodes. This node is further connected with the server node via a switch node. The router node is customized to have all the functionalities of a centralized AP to receive traffic from the wireless nodes.

Experiments are done to check the QoS behaviour of VoIP for E-EDCA at different number of nodes by measuring jitter and MOS score. The results are compared with the basic EDCA scheme with QoS support.

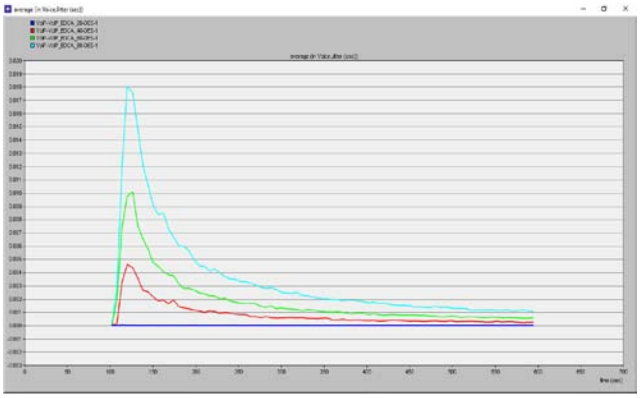

Figure 2. Jitter for EDCA Scheme

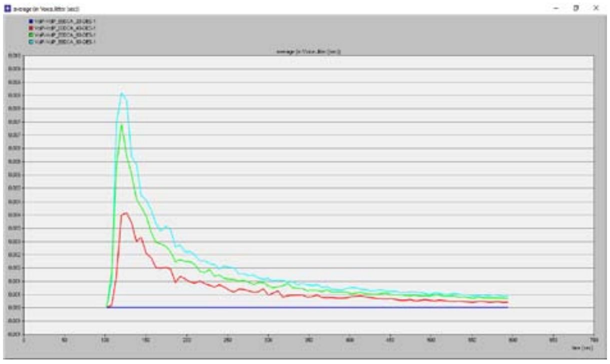

Figure 3. Jitter for E-EDCA scheme

Table 2. Comparative average jitter values

Nodes	EDCA	E-EDCA
20	1.0769E-07	-2.1819E-08
40	0.00479	0.00421
60	0.01026	0.00783
80	0.01805	0.00824

The jitter experienced by EDCA is more for all the nodes than the proposed scheme. Jitter should be less for good voice quality.

MOS score is also generated for both the schemes which further prove that our scheme provides better voice quality for all network size than the EDCA scheme.

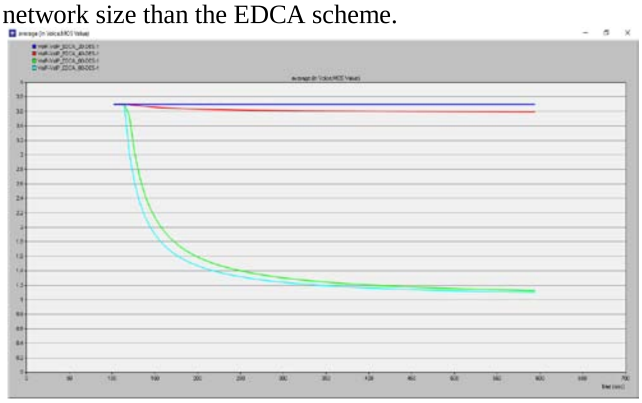

Figure 4. MOS for EDCA

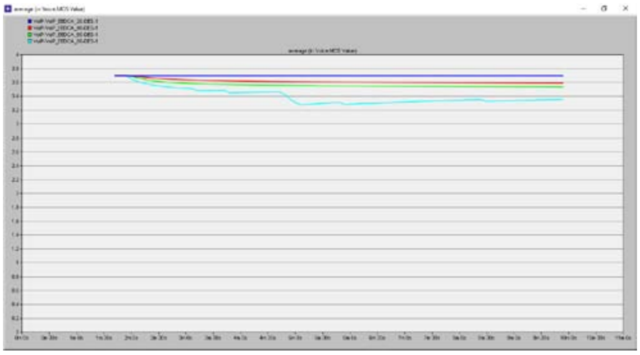

Figure 5. MOS score for E-EDCA

Table 3. MOS score values for both the schemes

Nodes	EDCA	E-EDCA
20	3.6936	3.7375
40	3.6133	3.6459
60	1.4859	3.5798
80	1.4058	3.3858

The scheme E-EDCA dynamically resizes the CW by considering network load. This is the reason that its performance is better than EDCA. Reduced jitter improved in quality enhancement of voice which is measured through MOS score. E-EDCA reduces collision, reducing jitter and improves the voice quality of VoIP applications.

V. CONCLUSIONS

QoS is a major issue of concern for real-time applications in wireless networks. The channel access methods of MAC layer control the access of different nodes of the network and avoid collision. 802.11 does not provide any integrated QoS support. 802.11e implements prioritized QoS through different parameters. Contention window is one of the parameters whose resizing affects VoIP QoS remarkably. A novel contention window resizing approach is designed and implemented that aims at providing better QoS support to VoIP applications than EDCA itself. The performance of Enhanced VoIP-EDCA (E-EDCA) is analyzed and compared with existing EDCA scheme performing different experiments. Results show that the E-EDCA scheme delivers better VoIP QoS and voice quality than EDCA for different loads over wireless networks.

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