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Experimental Evaluation of Medium Access Schemes in 802.11 Wireless Networks

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Abstract: Problem statement: Deployment of real time services over 802.11 wireless networks requires quality of service (QoS) differentiation mechanisms for different traffic types. This required investigations into the performance of the Medium access (MAC) schemes like Distributed Coordinated Function (DCF) and Enhanced DCF with respect to the stringent QoS requirements imposed by the real time services. Motivation for this research was to find the suitability of 802.11 MAC schemes for real time traffic. **Approach:** In this study, various available MAC schemes were experimentally evaluated for QoS provisioning in 802.11 wireless networks. Performance evaluation was done based on important QoS metrics like access delay, jitter, packet loss, Round Trip Time (RTT) and throughput of the traffic. Experimental Testbed based was established using off the shelf hardware and open source software. The traffic was captured in real time and analyzed thereafter for various QoS metrics. **Results:** The results indicated that there is considerable QoS improvement using 802.11e EDCF with reconfigured queues over the ordinary DCF mechanism. Results were obtained on experimental testbed using various types of UDP and TCP traffic. **Conclusion:** It can be concluded that proper differentiation and scheduling of traffic specific to application, helps in providing better QoS over the 802.11 wireless networks and improves their suitability for deployment of real time services.

Key words: QoS, 802.11, DCF, EDCF, UDP, TCP

INTRODUCTION

IEEE 802.11 based wireless Networks have become the favorite choice of the service providers for providing data and Internet services in university campuses, hotels, airports and other public places with high population density. IEEE 802.11 standards were originally developed to provide wireless alternative to the wired local area networks. Over the time, these standards have become very popular but certain problems like seamless mobility and wired equivalent quality of service are still major issues with such networks. Quality of service is a big hindrance for deployment of these networks for real time services like voice over IP.

The basic 802.11 MAC layer uses the Distributed Coordination Function (DCF)[1] to share the medium between multiple stations. DCF relies on CSMA/CA and optional 802.11 RTS/CTS to share the medium between the stations. RTS/CTS mechanism is used to avoid hidden terminal problem and reduce re-transmissions in the 802.11 based networks. IEEE has approved Enhanced DCF[2] based 802.11e as a standard defining set of Quality of Service enhancements for wireless LAN applications. The standard is considered of critical importance for delay-sensitive applications, such as Voice over Wireless IP and Streaming Multimedia. The protocol enhances the base IEEE 802.11 Media Access Control (MAC) layer.

The 802.11e enhances the DCF mechanism through a new coordination function called Hybrid Coordination Function (HCF). Within the HCF, there are two methods of channel access, similar to those defined in the legacy 802.11 MAC namely, HCF Controlled Channel Access (HCCA) and Enhanced Distributed Channel Access (EDCA). Both EDCA and HCCA define Traffic Classes (TC). In addition, each priority level is assigned a Transmit Opportunity (TXOP). The HCCA works a lot like the point coordinated function (PCF). However, in contrast to PCF, in which the

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interval between two beacon frames is divided into two periods of Contention Free Period (CFP) and Contention Period (CP), the HCCA allows for CFPs being initiated at almost anytime during a CP. This kind of CFP is called a Controlled Access Phase (CAP) in 802.11e.

Work done in[3] proposes Multirate Wireless Fair Scheduling (WMFS). In MWFS, each flow is granted temporal fair share of the channel, in contrast to the throughput fair share adopted by existing algorithms. Therefore, each flow receives services in proportion to its perceived transmission rate and high rate flows are able to opportunistically exploit their good channel conditions and receive more services. Authors in[4] have proposed the Impact of 802.11e EDCA on mixed TCP-based applications. They evaluated the impact of EDCA on TCP application traffic consisting of both long and short-lived TCP flows. In[5] authors have Proposed the effect of TCP synchronization on UDP traffic. They investigated the characteristics of UDP packet loss are investigated through simulations of WANs conveying UDP and TCP traffic simultaneously. Work in[6] identifies some challenges that need to be addressed in order to enable comprehensive QoS support using 802.11e. Authors have provided an overview of the challenges and their impact on QoS. Work in[7] Evaluates the performance of IEEE 802.11e contention-based channel access (EDCF). Author in[8] Proposes and discusses Contention Window Based Differentiation Mechanism for providing QoS in Wireless LANs. Authors in[9] have proposed adaptive EDCF: enhanced service differentiation for IEEE 802.11 wireless ad-hoc networks. This study describes an adaptive service differentiation scheme for QoS enhancement in IEEE 802.11 wireless ad-hoc networks. Work in[10] analyzes differentiated services in IEEE 802.11 and IEEE 802.11e wireless LANs. Work in[11] discusses the Performance analysis of priority schemes for IEEE 802.11 and IEEE 802.11e wireless LANs. This study studies backoff-based priority schemes for IEEE 802.11 and the emerging IEEE 802.11e standard by differentiating the minimum backoff window size, the backoff window-increasing factor and the retransmission limit. Authors in[12] propose certain techniques for making QoS a Reality over WLAN Connections. In[13], authors have performed Saturation throughput analysis of IEEE 802.11e enhanced distributed coordination function. This study[14] discusses the Quantifying Factors Affecting Quality of Service in Mobile Ad Hoc Networks. Work in[15] proposes an efficient technique for assignment of transmission opportunity in QoS guaranteed wireless LANs. Authors have also proposed a new scheduling scheme that associates each flow according to the hardness of the delay bound. Work in[16] investigates Quality of Service for Multimedia Transmission over Wireless Local Area Networks. Authors in[17] introduce an adaptive contention window mechanism and evaluate the performance via simulation. Article in[18] discusses Wireshark and its powerful features that make it the tool of choice for network troubleshooting, protocol development and education worldwide.

The current research investigates the suitability of various medium access schemes in IEEE 802.11 and 802.11e networks with regards to quality of service (QoS). Performance of various schemes in terms of Important QOS metrics like packet loss, access delay, Jitter, Throughput and Round trip time (RTT) have been evaluated. Various traffic types including UDP, TCP, VoIP and ICMP traffic have used in this study. In case of IEEE 802.11e networks, the five QoS parameters namely, Contention window size(CWmin, CW_{max}), Transmission Opportunity (TxOP), Arbitrary Inter-frame spacing (AIFSN) and packet queue limits have been configured to achieve the better results.

MATERIALS AND METHODS

Experimental testbed as shown in Fig. 1 has been setup to study the performance of various MAC schemes used in 802.11 and 802.11e based networks. The experimental testbed used in this research consist of the following hardware and software:

- Linksys WRT54GL access point
- Open source DD-WRT Firmware v.23 SP2
- Fedora based Wireless and Wired nodes
- Wireshark Network traffic capture tool
- D-ITG traffic generator for traffic generation
- Vsftpd FTP traffic generator
- Application to decode captured traffic

Testbed consists of two machines on the wired network and four machines on the wireless network. Wired and wireless networks have been bridged by Linksys WRT54GL access point. Various types of traffic have been generated by using Distributed Internet traffic generator (D-ITG) running on a machine in the wired network. Wireshark traffic capture tool has been used to capture this traffic on a laptop in the wireless network. D-ITG generator generates the VoIP RTP real time traffic. Wireshark captures the raw packets at the receiver side using capture filter which is further decoded using a custom C++ program with pcap library. One machine on the wireless network is running Vsftpd FTP server and remaining three machines on the wired domains are working as FTP clients. FTP clients are made to download heavy files available on the FTP server.

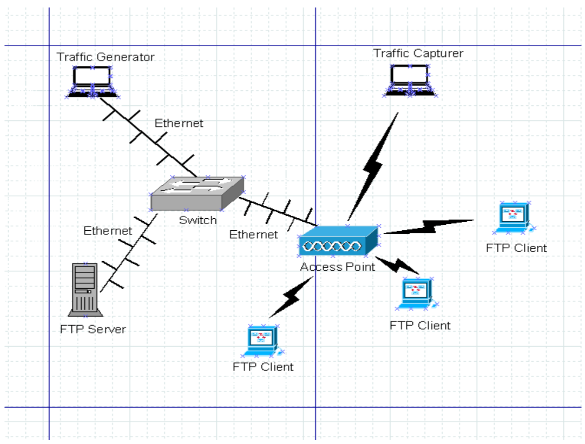

Fig: 1 Representation of Experimental testbed

The purpose of FTP download by the client is to heavily load the access point. In the presence of heavy FTP background traffic, D-ITG generator generates the VoIP RTP (real time traffic), via the same access point to the machine running Wireshark traffic capture tool. The basic idea behind the above scenario is to make the high priority real time traffic and low priority FTP traffic, share the same wireless medium. By doing so, the performance comparison of different types of MAC schemes running on the access point can be made. This is done by using different types of firmware on the Linksys WRT54GL access point. In This research, the 802.11 legacy firmware, DD-WRT 802.11e firmware with existing queues and DD-WRT 802.11e firmware using reconfigured queues have been used.

In this study, the priority queues of dd-wrt are customized using dynamic queuing strategies. Using Dynamic queuing strategy, data traffic of particular protocol is assigned to the appropriate queue and gets the corresponding quality of service. Queues have been customized based on protocol types. Default queues of dd-wrt firmware are Exempt, Premium, Express, Standard and Bulk. Queues can be reconfigured based on various parameter settings like Minimum Congestion window, Maximum congestion window, Transmission opportunity, Arbitrary Inter-frame spacing according to the user requirements. Using the above method on dd-wrt, performance comparison of the FIFO queues of 802.11 and Priority queues of 802.11e have been analyzed and results have been made available.

In the present researcher, various MAC scheme used in 802.11 and 802.11 e have been evaluated. This evaluation has been done based on important QoS metrics like access delay, jitter, packet loss, Round Trip Time (RTT) and throughput. IEEE 802.11 DCF use FIFO buffers and does not provide any QoS differentiation to various traffic types. To study the performance of real time traffic on DCF, heavy background traffic is generated by using FTP server. FTP downloads are initiated by four different stations from a single FTP server via 802.11 based Linksys WRT54GL access point, thereby generating the heavy background traffic causing tremendous load on the access point.

Simultaneously, the time traffic VoIP is generated by the machine on wired network and sent it to the destination machine on wireless network via same access point. The generated real time traffic is captured using Wireshark Network Analyzer at one of the machines in the wireless domain. In base 802.11 standards, FIFO queuing mechanism is used. Hence the parameters of real time traffic- access delay, Jitter, Packet loss, throughput, round trip time, usually get disturbed in case of heavy background FTP traffic, which otherwise should have the lowest priority. The results have been obtained for DCF and have been compared with 802.11e EDCF based networks with existing and reconfigured queues.

To study EDCF with existing queues, the Linksys WRT54GL access point is flashed with 802.11e Open source DD-WRT firmware. FTP downloads is initiated by four different stations from a single FTP server via 802.11e firmware based Linksys WRT54GL to generate heavy background traffic causing tremendous load on the access point. Since 802.11e support priority queues therefore lowest priority is assigned to the background FTP traffic. Simultaneously, the real time traffic VoIP is generated and sent it to the destination machine on the wireless domain via same access point. This real time traffic is assigned the highest priority based on the protocol type.

The real time traffic is captured using Wireshark Network Analyzer[18] on the machine in the wireless network. Higher priority traffic can starve lower priority queues of bandwidth. Due to Priority queuing, real time traffic gets better Quality of service even in the case of heavy background traffic.

Performance of 802.11e can be further improved by reconfiguring the existing queues. This has been done by changing the values of various MAC parameters like Congestion window (CW_{min}, CW_{max}), Transmission opportunity (TxOP), Arbitrary Inter-frame Spacing (AIFSN) etc. QoS in 802.11e using DD-WRT with existing queues cam be configured based on MAC parameters, type of protocol or maximum packet queue. Various QoS metric used in study are access delay, jitter and packet loss; round trip time (RTT) and bitrate of the traffic. For real time traffic, Access delay, jitter and packet loss depends upon MAC parameters namely TxOP and AIFSN.

RESULTS

VoIP is perfect example of real time traffic and can be imitated by the ICMP traffic. Variation in RTT of ICMP traffic depends upon Congestion windows size, AIFSN, TxOP and maximum packet limits of priority queue. However in case of TCP bulk traffic, bitrate is the most important parameter and it depends upon the size of CW_{max} and CW_{min}. In this research, two priority queues namely AC_BK/Bulk and AC_VO/Premium have been reconfigured by changing the default values of CW, TxOP, AIFSN and packet queue limits.

By reconfiguring the queues, the default values of the parameters have been changed for getting better QoS performance. Different parameters affect different QoS metrics and this effect has been studied. For example access delay of real time traffic with heavy background FTP traffic is heavily affected Maximum congestion window sizes, Transmission Opportunity and AIFSN. Similarly other QoS metrics are influenced by other parameters. The detail effect of the changing the QoS parameters on different traffic metrics has been presented.

Priority queues can be reconfigured for getting better access delay for real time traffic. MAC parameters are changed to reconfigure the AC_BK/Bulk and AC_VO/Premium priority queues of 802.11e for getting minimal access delays. Table 1 shows the changed parameters.

In this case only AIFSN and TxOP values have been changed as contention window size do not affect the UDP traffic.

In Table 2 (AC_BK CW_{min}/Bulk queue), AIFSN has been changed from 7 to 20, hence increasing the wait period for the bulk data over the real time traffic.

Table 1: Reconfigured priority queues for best access delay results

Parameters/Queue	CW_{min}	CW_{max}	AIFSN	TxOP
Bulk	15	31	20	0
Premium	3	7	1	2000

Table 2: AC_BK / Bulk queue

Parameters	Default value	Changed value
AIFSN	7	20
TxOP	0	0
CW_{min}	15	15
CW_{max}	1023	31

Table 3: AC_VO / Premium

Parameters	Default value	Changed value
AIFSN	1	1
TxOP	1504	2000

Table 4: Reconfigured priority queues for best Jitter results

Parameters/Queue	CW_{min}	CW_{max}	AIFSN	TxOP
Bulk	15	31	20	0
Premium	3	7	1	2200

CW_{max} has also been changed in low priority queue to reduce the back off wait time for retransmission of packets. This reduces the number of attempts made to retransmit the bulk data packet before being dropped. The real time traffic takes advantage of this situation.

In Table 3 (AC_VO/Premium queue), TxOP value has been changed from 1504-2000, thereby increasing the period of transmission for the real time traffic. Further increasing the value of TxOP might give better results but could cause starvation for the low priority bulk data.

Another important QoS parameter is Jitter which is defined as variation in packet inter-arrival times. In real time traffic packets are expected to arrive after fixed interval of time. Jitter should be kept to a minimum within a multimedia system. 802.11e with some reconfigured queues gives better delay results as compared to the 802.11e with preexisting queues. The reason behind the lower jitter as compared to other standards is the specification of the TxOP assigned to the high priority queues (for how long packets can be transmitted, once the queue is occupied).Hence by giving the large TxOP to the high priority queue, traffic belongs to that queue will be transmitted continuously, even in presence of large amount of low priority bulk traffic, hence resulting in low jitter.

As shown in Table 4-6, the value of TxOP of AC_Premium queue has been increased and at the same time the AIFSN of less priority queue (classified as bulk queue) has also been increased to increase the wait time for the frame before transmission.

Table 5: AC_BK / Bulk queue

Parameters	Default value	Changed value
AIFSN	7	20
TxOP	0	0
CW_{min}	15	15
CW_{max}	1023	31

Table 6: AC_VO/Premium

Parameters	Default value	Changed value
AIFSN	1	1
TxOP	1504	2200
CW_{min}	3	3
CW_{max}	7	7

Table 7: Reconfigured priority queues for decreased packet loss

Parameter/Queue	CW_{min}	CW_{max}	AIFSN	TxOP
Bulk	15	1023	20	0
Premium	3	7	1	2000

Table 8: AC_BK / Bulk queue

Parameters	Default value	Changed value
AIFSN	7	20
TxOP	0	0

Subsequently, the value of CW_{max} has been decreased from 1023 to 31 ms, thereby decreasing the retransmission attempts for the TCP packets, so that the real time traffic could make use of network efficiently. Therefore, better QoS in terms of jitter can be guaranteed to the real time traffic.

Major reason behind loss of packets in real time traffic under heavy load is the delay. To avoid dropped packets, delay needs to be controlled for the real time traffic to some extent. Hence, there is need to reconfigure the MAC parameters to better the delay metric as compared to the 802.11e with existing queues. This reconfiguration will result in reduced packet loss. Table 7 shows the reconfigured queue parameter settings for reduced packet loss metric.

Table 7 shows the parameters settings for the reconfigured queues to achieve the lower packets loss rate. Table 8 and 9 shows the old and new values of the individual MAC parameters for bulk and premium queues. The primary parameter affecting the packet loss is AIFSN.

Round trip time is another important QoS parameter and ICMP ping can be used to imitate the two way voice communication. With the heavy background traffic, ICMP traffic (real time traffic) gets disturbed if no prioritization of the queues is being done. The major factors affecting the RTT are the amount of traffic on the WLAN to which the end user is connected and the number of additional requests being handled by intermediate nodes and access point as shown in Table 10. 802.11e with the reconfigured queues can be used to control these two factors.

Table 9: AC_VO / Premium

Parameters	Default value	Changed value
AIFSN	1	1
TxOP	1504	2000

Table 10: Reconfigured priority queues for Round Trip Time

Parameters/Queue	CW_{min}	CW_{max}	AIFSN	TxOP
Bulk	31	1023	20	0
Premium	3	7	1	2000

Table 11: AC_BK / Bulk queue

Parameters value	Default value	Changed
CW_{min}	15	31
AIFSN	7	20
TxOP	0	0

Table 12: AC_VO / Premium

Parameters value	Default value	Changed
AIFSN	1	1
TxOP	1504	2000

Amount of background traffic can be decreased in comparison to ICMP traffic by increasing the Contention window size, increasing the AIFSN and decreasing the TxOP. Second factor could be minimized by limiting the number of packets at each priority queue, so that ICMP traffic packets could be processed first and background traffic could not even get the turn for queue. Parameters settings for the reconfigured queues in case of RTT are shown in Table 10-12.

Throughput is defined as amount of work done per unit time we analyze the bitrate of TCP traffic with respect to the time. TCP traffic possesses the Variable Bit Rate (VBR). Hence bit rate of TCP traffic varies frequently under heavy load in wireless networks. The factors affecting the throughput are shown in Table 12. In the case of TCP traffic, either there is chance of loss of TCP segment or TCP ACK. This requires the congestion control algorithm which results in retransmissions and consequently lesser throughput. Congestion window sizes play important role in increasing throughput. Congestion window defines the maximum number of TCP packets that can be carried out by network at one time. If there is no congestion, congestion windows will be increased after every transmission. The minimum and maximum sizes of congestion windows define the lower and upper bounds on the window sizes. Small size of the windows results in more Retransmission Time out (RTO) and hence results in low throughput. To avoid the RTOs, it is required to increase the size of the congestion windows. If the CW_{min} value is reduced,

Table 13: Reconfigured priority queue for bitrate

Parameters/Queues	CW_{min}	CW_{max}	AIFSN	TxOP	PQL
Bulk	3	1023	7	0	50
Premium	3	7	1	2000	10

Table 14: Bulk queue

Parameters	Default value	Changed value
AIFSN	7	7
TxOP	0	0
PQL	40	50
CW_{min}	15	3

Table 15: Premium queue

Parameters	Default value	Changed value
AIFSN	1	1
TxOP	1504	2000
PQL	10	10

initial random wait period is reduced when no congestion occurs, hence more packets can be transmitted in the given time which would otherwise wasted in the retransmission. The other factor affecting the throughput is the packet limit on the priority queues. Therefore to increase the bitrate of TCP traffic, high packet limit is assigned to the low priority queue.

In Table 13 and 14, the values of AIFSN and TxOP remain unchanged and value of CW_{min} is changed from 15-3. Minimum Contention window size determines the random initial wait period between 0 and CW_{min}. The value of CW_{min} has been changed to 3 based on the assumptions that if sufficient bandwidth will be available, some packets could be sent and acknowledged all in all within less time determined as compared to the time earlier determined using value of 15, hence comparatively more packets could be transmitted resulted in high throughput. Second parameter is packet queue limit of priority queue. Hence to improve the throughput, the packet queue limit of the low priority queue has been increased so that the available capacity could be efficiently utilized. To prevent the premium queue from being starved the value of Transmission opportunity has been increased as shown in Table 15.

DISCUSSION

In case of real time traffic like VoIP, if the access to the media is delayed for an excessively long time, the buffered packets become useless. In this case the average access delay metric has been investigated for high priority traffic using priority queues and results compared to the 802.11 under the same load conditions. The case of 802.11e with some reconfigured queues have also been investigated and has been found to give better results as compared to preexisting queues and FIFO queues. Larger buffer size can be assigned to the priority queues by specifying the maximum size of the priority queues. But, larger the size of the queue, more data will be buffered. But in real time traffic, packets cannot be buffered for long. Smaller the size of the queue, lesser is the delay incurred by the packet. But small sized queues result in packets being lost. 802.11e scheme gives lower average access delay to high priority traffic, but still many packets are delayed and hence rendered useless for time critical applications. In Fig 2, the cumulative distribution of the packet Inter arrival delay has been represented. It shows that in case of the legacy 802.11 firmware only 25 percent of the packets arrive at the expected inter arrival time and rest of them arrive either earlier or later. In case of 802.11 e with existing queues, around 80 percent of the packets arrive on time and this is further increased to around 85 percent with reconfigured queues.

Jitter should be minimal in the case of real time voice and multimedia traffic. In the current experiment, the packet inter arrival time has been fixed at 10 ms. The real time UDP traffic has been generated by D-ITG traffic generator. Results in Fig. 3 show 802.11e has lower jitter as compared to the 802.11 legacy firmware. Further, 802.11e with reconfigured queues gives lesser jitter as compared to the 802.11e with preexisting queues. The reason behind the lowest jitter with reconfigured queues as compared to other schemes is due to different TxOP assigned to the high priority queues (for how long packets can be transmitted, once the queue is occupied). Thus by assigning large value of TxOP to the high priority queue, traffic can be transmitted continuously, even in presence of large amount of low priority traffic. This results in low jitter for high priority traffic. The required parameters settings for the Reconfigured queues have been done as explained in the previous section.

In case of packet loss, packets with the Inter departure time of 10ms have been generated using D-ITG traffic generator. Packets received every 100ms at the receiver end via access point have been calculated. Analysis is based on three different network configurations-legacy networks, 802.11e with existing queues and 802.11e with reconfigured queues for low packet loss. Figure 4 shows that in legacy 802.11 firmware, packets are frequently lost under heavy load signified by the sharp dips in the graphs.

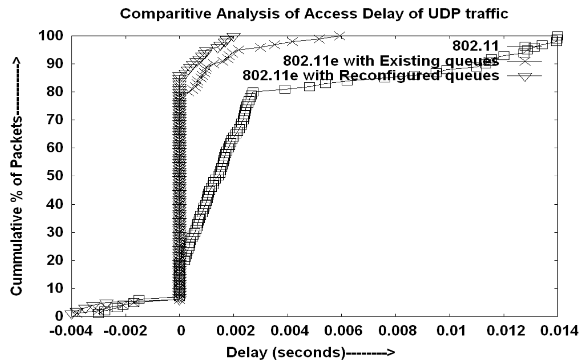

Fig. 2: Comparative study of access delay

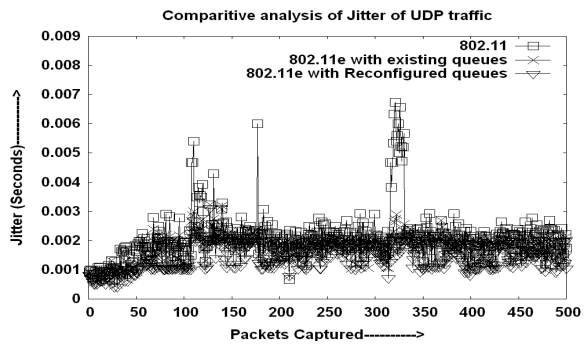

Fig. 3: Comparative study of jitter

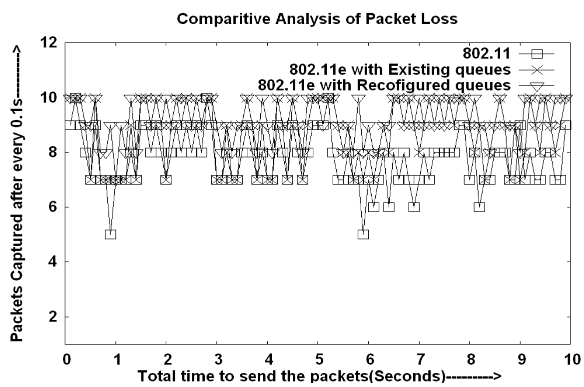

Fig. 4: Comparative study of packet loss

However some what better results have been achieved using the existing priority queues of 802.11e standard (DD-WRT firmware). The results have further improved by using reconfigured queue. For high priority queues, the parameters namely AIFSN and TxOP have been reconfigured. The reason behind the loss of packets in real time traffic under heavy load is heavy delay. Real time traffic packets can not

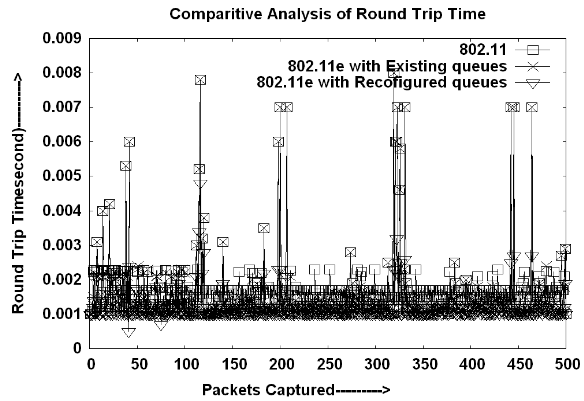

Fig. 5: Comparative study of round trip time

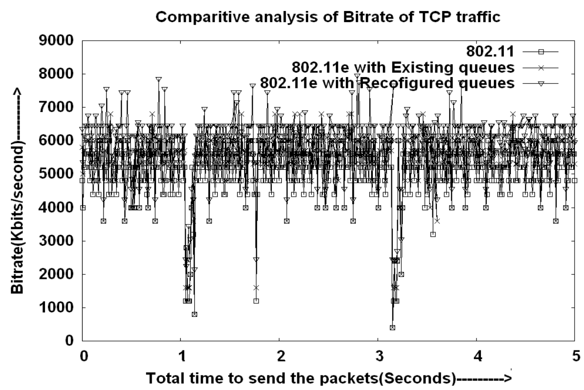

Fig. 6: Comparative study of bitrate of TCP traffic

tolerate the delays, so using large sized buffers will not be useful. However, small buffer size results in packet being lost. Therefore, to avoid packets being lost, packet delay has to be controlled. This has been achieved by reconfiguring the AIFSN and TxOP parameters of the 802.11 e priority queues for the high priority traffic.

Experimental measurements in Fig 5 shows that that there is huge variation in RTT in case of legacy 802.11 firmware as compared to the 802.11e with existing queues in presence of heavy low priority background traffic. Variation in ICMP RTT has been further decreased by using the 802.11e reconfigured queues. All the required parameters settings for the reconfigured queues have been adjusted.

Figure 6 show the bitrate comparison of FIFO queuing mechanism of 802.11, priority queuing mechanism of 802.11e and 802.11e with reconfigured queues. 802.11e queues have been reconfigured by changing the values of $CW_{min\ and}$ the packet queue limit of the low priority queue. This shows that 802.11e with reconfigured queues provide far better results in term of throughput as compared to both the 802.11 and 802.11e with existing queues.

CONCLUSION

This research compares the performance of various MAC schemes for QoS provisioning in 802.11 wireless networks in terms of metrics like access delay, jitter, packet loss, round trip time and throughput. It can be concluded that Access delays, Jitter and Packet Loss are highly influenced by the TxOP and AIFSN. RTT of ICMP traffic is influenced by the Packet queue limit, TxOP, AIFSN. Bitrate of TCP traffic can be improved significantly by decreasing the minimum contention window size and increasing the packet queue limits. In the future study, the parameters settings like Contention windows sizes, Transmission Opportunity, Arbitrary Inter Frame Spacing and Packet queue limits of the priority queues can be done dynamically depending on the basis of the desired traffic metric.

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