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Cross Layer Design to Improve QoS in Ad Hoc Networks

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Abstract: In mobile ad hoc wireless networks, multiple mobile stations communicate without the support of a centralized coordination station for the scheduling of transmissions. The dynamic nature of these mobile networks makes the support of quality of service challenging, because it is very difficult to maintain resource reservations. This study deals a combination of medium access control procedure employing distributed coordination function and suitable transport layer mechanism which improves QoS guarantee in Transport layer. IEEE 802.11e MAC employs a channel access function called the hybrid coordination function, which includes contention based channel access and a contention-free centrally controlled channel access mechanism. In the proposed method, IEEE802.11e and Additive Increase Multiplicative Decrease (AIMD) mechanism have been combined to analyze the quality of service in cross layer. The combined technique enhances the QoS parameters viz, throughput by 30-40% and decreases delay by 70-80% and packet loss by 30-40%.

Key words: Mobile ad hoc network, Quality of Service (QoS), Medium Access Scheme (MAC), hybrid coordination function (HCF), distributed coordination function (DCF) and Additive Increase Multiplicative Decrease (AIMD)

INTRODUCTION

Mobile ad hoc network consists of a collection of nodes which can communicate with each other without help from a network infrastructure. All or some nodes within an MANET are expected to be able to route data-packets for other nodes in the network who want to reach other nodes beyond their own transmission-range. This is called peer-level multi-hopping and is the base for ad hoc networks that constructs the interconnecting structure for the mobile nodes. It can communicate with each other within radio range through direct wireless links. Ad hoc supports for QoS provisioning and real-time applications, operative functioning, energy-efficient relaying, load balancing and multicast traffic.

Different applications have different requirements, the services required by them and the associated QoS parameters differ from application to application. In case of multimedia applications, throughput, bandwidth, delay and jitter are the key QoS parameters; whereas military applications have stringent security requirements. For applications such as emergency search-and-rescue operations, availability of the network is the key QoS parameter. Applications such as group communication in a conference require that the transmissions among nodes consume as little energy as possible, so battery life is the key QoS parameter. In traditional wired networks, where the QoS parameters are mainly characterized by the requirements of multimedia traffic, where in ad hoc wireless networks the QoS requirements are more influenced by the resource constraints of the nodes. Some of the resource constraints are battery charge, processing power and buffer space.

MEDIUM ACCESS SCHEME

The primary responsibility of a medium access control (MAC) protocol in MANET is the distributed arbitration of the shared channel for transmission of packets. The performance of any wireless network hinges on the MAC protocol, more so for ad hoc wireless networks. Medium Access Scheme is the major issue in ad hoc wireless networks. This study explains how to improve the MAC performance in ad hoc wireless networks.

Issues in medium access scheme

Hidden terminals: Hidden terminals are nodes that are hidden (or not reachable) from the sender of a data transmission session, but are reachable to the receiver of the session. In such cases, the hidden terminal can cause collisions at the receiver nods (Schiller, 2003). The presence of hidden terminals can significantly reduce the throughput of a MAC protocol used in ad hoc wireless networks. Hence, the MAC protocol should be able to alleviate the effects of hidden terminals.

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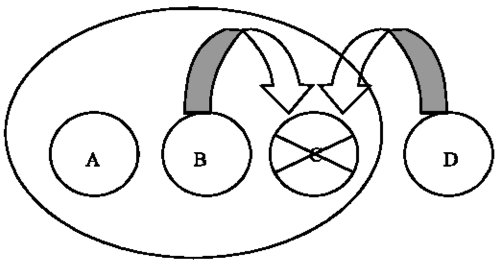

Fig. 1: Hidden terminal problem

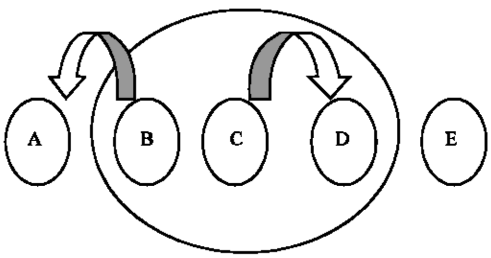

Fig. 2: Exposed Terminal problem

A major issue in Medium Access Scheme is hidden terminal problem shown in Fig. 1. Here, a transmission from B to C is heard by A but not by D. A hidden terminal problem results when D attempts to transmit to C without knowing the ongoing transmission.

Expose terminals: Exposed terminals, the nodes that are in the transmission range of the sender of an on-going session are prevented from making a transmission. In order to improve the efficiency of the MAC protocol, the exposed nodes should be allowed to transmit in a controlled fashion without causing collision to the on-going data transfer.

Another issue in Medium Access Scheme is exposed terminal problem shown in Fig. 2. Here, a transmission from C to D is heard by B but not by A. An exposed terminal problem occurs when B remains silent even if its transmission to A will not cause any collision.

Choi (2003) assigned priority for different types of data for transmission. Maarten *et al.* (2000) describes the enhancement of QoS parameters using IEEE802.11. Paolo (2006) the QoS parameters only for packet telephony over MANETS using 802.11 was discussed. Qixiang *et al.* (2005) addressed the reduction of packet loss by selecting a suitable MAC protocol. Schiller (2003) describes the basic concepts of various coordination functions and MAC protocols used in Ad hoc networks. Maarten *et al.* (2002) proposed multiple frame exchanges during enhanced distributed coordination function transmission priorities for EDCF. Xiao (2004-2006) made a performance analysis for IEEE 802.11 and IEEE 802.11e, reported that IEEE that IEEE 802.11e enhance QoS parameters viz the throughput, delay and packet loss. Peterson (2003) describes the various TCP mechanisms of AIMD, slow start and Fast transmit and Fast recovery.

IEEE 802.11 MAC MECHANISMS

IEEE 802.11e MAC mechanisms have point co ordination function and distributed co ordination function. Distributed co ordination function also called contention based channel access mechanism, which is very suitable in Ad hoc environment (Xiao, 2004). This paper describes IEEE802.11e MAC mechanism in MAC layer and AIMD mechanism in transport layer. Using this cross layer design technique, this enhances the QoS performance in Mobile Ad hoc Networks.

IEEE 802.11 DCF: The IEEE 802.11 legacy MAC is based on the logical functions, called the coordination functions, which determine when station operating within a Basic Service Set (BSS) is permitted to transmit and may be able to receive frames via the wireless medium. Two coordination functions are defined, namely, the mandatory DCF based on CSMA/CA and the optional point coordination function (PCF) based on polling response mechanism. Most of today's 802.11 devices operate in the DCF mode only.

This study explains how the DCF works because it is the basis for the Enhanced DCF (EDCF). The 802.11 MAC works with a single first-in-first-out (FIFO) transmission queue. The CSMA/CA constitutes a distributed MAC based on a local assessment of the channel status, i.e., whether the channel is busy (i.e., a station is transmitting a frame) or idle (i.e., no transmission). Basically, the CSMA/CA of DCF works as follows: When a frame arrives at the head of the transmission queue, if the channel is busy, the MAC waits until the medium becomes idle, then defers for an extra time interval, called the DCF Inter frame Space (DIFS). If the channel stays idle during the DIFS difference, the MAC then starts the backoff process by selecting a random backoff counter. For each slot time interval, during which the medium stays idle, the random BC is decremented. When the BC reaches zero, the frame is transmitted (Xiao, 2004).

On the other hand, when a frame arrives at the head of the queue, if the MAC is in either the DIFS difference or the random backoff process, the processes described above are applied again. That is, the frame is transmitted only when the random backoff has finished successfully. When a frame arrives at an empty queue with no ongoing backoff process and the medium has been idle longer than the DIFS time interval, the frame is transmitted immediately. Each station maintains a contention window (CW), which is used to select the random backoff counter. The BC is determined as a random integer drawn from a uniform distribution over the interval [0, CW]. How to determine the CW value is further detailed below. If the channel becomes busy during a backoff process, the backoff is suspended. When the channel becomes idle again and stays idle for an extra DIFS interval, the backoff process resumes with the suspended BC value.

The timing of DCF channel access is illustrated in Fig. 3. For each successful reception of a frame, the receiving station immediately acknowledges by sending an acknowledgement (ACK) frame. The ACK frame is transmitted after a short IFS (SIFS), which is shorter than the DIFS. Other stations resume the backoff process after the DIFS idle time. The SIFS interval between the data and ACK frames, the ACK frame transmission is protected from other stations contention. If an ACK frame is not received after the data transmission, the frame is retransmitted after another random backoff (Xiao, 2005).

The CW size is initially assigned CWmin and increases when a transmission fails, i.e., the transmitted data frame has not been acknowledged. After any unsuccessful transmission attempt, another backoff is performed using a new CW value updated by 2 • {CW + 1) - 1, with an upper bound of CWmax. This reduces the collision probability in case there are multiple stations attempting to access the channel. After each successful transmission, the CW value is reset to CWmin and the station that completed the transmission performs DIFS deference and a random backoff even if there is no other pending frame in the queue. This is often referred to as "post" backoff, as this backoff is done after, not before, a transmission.

Basic DFWMAC-DCF Using CSMA/CA: The mandatory access mechanism of IEEE 802.11 is based on carrier sense multiple access with collision avoidance (CSMA/CA), which is a random access scheme with carrier sense and collision avoidance through random backoff.

Contention window and waiting time process is shown in Fig. 4. If the medium is sensed idle for at least the duration of DIFS, a node can access the medium at once. This allows for short access delay under light load. But as soon as more and more nodes try to access the medium, additional mechanisms are needed. If the medium is busy, nodes have to wait for the duration of DIFS, entering a contention phase afterwards. Each node now chooses a random back off time within a contention window and additionally delays medium access for this random amount of time. As soon as a node senses the

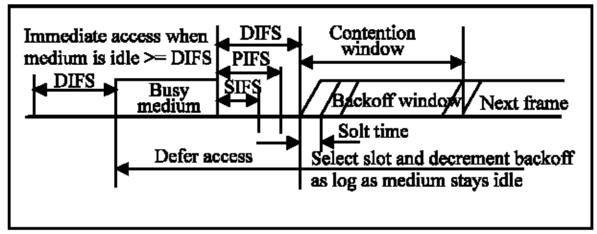

Fig. 3: DCF channel access

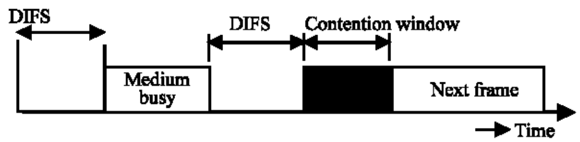

Fig. 4: Contention window and waiting time

channel is busy, it has lost this cycle and has to wait for the next chance, i.e., until the medium is idle again for at least DIFS. But if the randomized additional waiting time for a node is over and the medium is still idle, the node can access the medium immediately.

Obviously, the basic CSMA/CA mechanism is not fair. Independent of the overall waiting time for transmission, each node has the same chances for transmitting data in the next cycle (Schiller, 2003). To provide fairness, IEEE 802.11 adds a backoff timer. Again, each node selects a random waiting time within the range of the contention window. If a certain station does not get access to the medium, in the first cycle, it stops its backoff timer, waits for the channel to be idle again for DIFS and starts the counter again. As-soon as the counter expires, the node accesses the medium: this means that deferred stations do not choose a randomized backoff time again but continue to count down. Thus, longer waiting stations have the advantage over newly entering stations, in that they only have to wait for the remainder of their backoff timer from the previous cycles.

DFWMAC-DCF with several competing senders: This is the basic access mechanism of IEEE 802.11 for five stations trying to send a packet at the marked points is shown in Fig. 5. Station 3 has the first request from a higher layer to send a packet, waits for DIFS and accesses the medium, i.e., sends the packet. Station 1, station 2 and station 5 have to wait at least until the medium is idle for DIFS again after station, has stopped sending. Now all three stations choose a backoff time within the contention window and start counting down their backoff timers.

The random backoff time of $station_1$ as sum of boe (the elapsed backoff time) and bor, (the residual backoff time). The same is shown for station 5. Station 2 has total

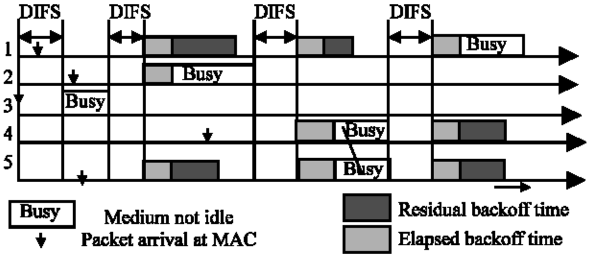

Fig. 5: DFWMAC-DCF with several competing senders

backoff time of only boe and thus gets access to the medium first. Therefore, no residual backoff time for station 2 is shown. The backoff timers of station 1 and station 5 stop and the stations store their residual backoff times. While a new station has to choose its backoff time from the whole contention window, the two old stations have statistically smaller backoff, values using their old values. Now station 4 wants to send a packet as well and thus after DIFS waiting time, 3 stations try to get access. It can now happen, as shown in the figure, that two stations accidentally have the same backoff time, no matter whether remaining or newly chosen. This results in a collision on the medium as shown, i.e., the transmitted frames are destroyed. Station 1 stores its residual backoff time again. In the last cycle shown station finally gets access, to the medium, while station and station 5 have to wait. A collision triggers a retransmission with a new random selection of the backoff time.

Still, the access scheme has problems under heavy or light load. Depending on the size of the contention window (CW), the random values can either be too close together, causing too many collisions, or the values are too high, causing unnecessary delay. Therefore, the system tries to adapt to the current number of stations trying to send. The contention window starts with a size of, e.g., CW min = 7. Each time a collision occurs, indicating a higher load on the medium, the contention window doubles up to a maximum of, e.g., CW max = 255 (the window can take on the values 7, 15, 31, 63, 127 and 255). The larger the contention window is, the greater is the reservation power of the randomized scheme. It is less likely to choose the same random backoff time using a large CW. However, under a light load, a, small CW ensures shorter access delays. This algorithm is also called exponential backoff and is already familiar from IEEE 802.3 CSMA/CD in a similar version.

802.11e MAC Enhanced DCF (EDCF): The DCF is supposed to provide a channel access with equal probabilities to all stations contending for the channel

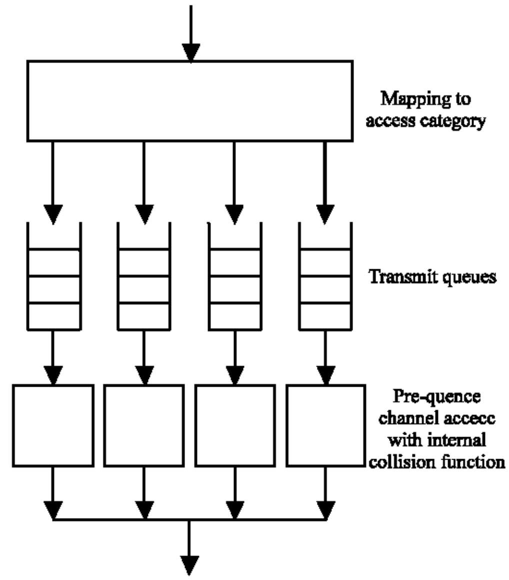

Fig. 6: Reference implementation model of ieee 802.11e

Table 1: EDCF user priority table

User priority	Access category	Designation
0	0	Best effort
1	0	Best effort
2	0	Best effort
3	1	Video probe
4	2	Voice
5	2	Voice
6	3	Video
7	3	Video

access in a distributed manner. However, equal access probabilities are not desirable among stations with different priority frames (Choi, 2003).

The emerging EDCF is designed to provide differentiated, distributed channel accesses for frames with 8 different priorities (from 0-7) by enhancing the DCF as shown in Table 1. As distinct from the legacy DCF, the EDCF is not a separate coordination function. Rather, it is a part of a single coordination function, called the Hybrid Coordination Function (HCF), of the 802.11 MAC. The HCF combines the aspects of both DCF and PCF.

The EDCF adopts eight different priorities that are further mapped into four access categories (ACs) as shown in Fig. 6. ACs are achieved by differentiating the arbitration inter frame space (AIFS), the initial window size and the maximum window size. For the AC i (i = 0, 1, 2,3), the initial backoff window size is CWmin[i](= Wi,0), the maximum backoff window size is CWmax[i] and the AIFS is AIFS[i].

For 0 = i <j = 3,

CWmin[i] = CWmin[j],

CWmax[i] = CWmax[j],

AIFS[i] = AIFS[j],

and at least one of the above inequalities must be strict. If one class has a smaller AIFS or CWmin or CWmax, the class's traffic has a better chance to access the wireless medium earlier. Four transmission queues are implemented in a station and each queue supports one AC class, behaving roughly as a single DCF entity in the original IEEE 802.11 MAC.

It is assumed that a payload from a higher layer is labeled with a priority value and it is pushed into the corresponding queue with the same priority value (Xiao, 2005). Each queue acts as an independent MAC entity and performs the same DCF function with a different inter frame space (AIFS[i]), a different initial window size (CWmin[i]) and a different maximum window size (CWmax[i]). Each queue has its own backoff counter (BO[i]) that acts independently the same way as the original DCF backoff counter introduced in the previous study. If there is more than one queue finishing the backoff at the same time, the highest priority frame is chosen to transmit by the virtual collision handler. Other lower priority frames whose backoff counters also reach zeros will increase their backoff counters with CWmin[i] (i = 0, 1... 3), accordingly. Use EDCF (enhanced distributed co ordination function) and AIMD mechanism of Transport layer enhance the MAC performance and also transport layer performance.

PROBLEM DESCRIPTION

From the literature, many authors worked for QoS improvements in MANETS. They mainly concentrate either 802.11 or 802.11e.Cross layer based on 802.11 with different TCP mechanisms is available only for infrastructure networks. Cross layer design for 802.11e with different TCP mechanisms for MANETS is the challenging work for QoS parameters.

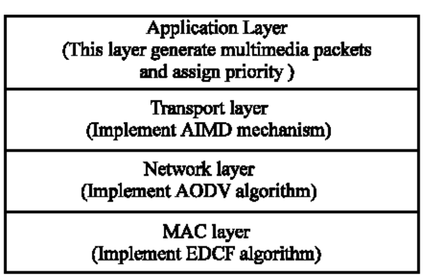

Fig. 7: Layered diagram for the proposed method

Proposed method: In this paper the IEEE 802.11e and AIMD techniques have combined to enhance the QoS in MANETS. As shown in Fig. 7. The analysis based on throughput, delay and packet loss.

RESULTS AND DISCUSSION

MAC layer: To simulate the MAC layer performance and transport layer performance NS-2 is used. Using the cross layer design technique, it improves the QoS performance in Mobile Ad hoc Networks. To create a MANET with a collection of 30 nodes over a common wireless medium and exchanging different bytes of multimedia data (160, 810 and 1310 b) with different priorities of FIFO queuing, AODV algorithm for routing. The packet which contains 1310 b of data is video, 810 b of data is audio and 160 b of data is text. Each node is equipped with a transmitter, a receiver and a buffer used for storing data and assume that a node cannot transmit and receive at the same time (i.e., communication is half duplex).

To increase the performance there should be different types of priority level or traffic categories (TC) for data transmission in MAC layer and use user priority level of 0, 1 and 2. For simulation 1310 b of data as priority 0 (high priority), 810 b of data as priority 1 (medium priority) and 160 b of data as priority 2 (low priority). To send acknowledgements from transport layer in SIFS interval, a acknowledgement packet which contains 60 b of data is transmitted for all different types of traffic categories. The Fig. 8 shows the time slots for various inter frame spacing is set as SIFS = 16 μs, PIFS = 25 μs, DIFS = 34 μs, $AIFS_1$ (priority level = 0 or TC1) >= 34 μs and every contention slot is equal to 9 μs interval. If there is no high priority packet for the specified time interval immediately medium level packet are transmitted.

Transmission in transport layer: In transport layer using Additive Increase and Multiplicative Increase technique (AIMD) by starting from one packet transmission and by increasing one by one for all types of data (Peterson, 2003).

Performance analysis: Taking 3 parameters into account and compares the performance of DCF, EDCF with Transport layer. From the results inferred that the performance of EDCF and Transport layer are improved when comparing with DCF. The parameters which taken into account for comparison is Throughput, Delay and Packet Loss.

Throughput: The number of bits successfully transmitted per second. With 10 nodes 802.11 successfully

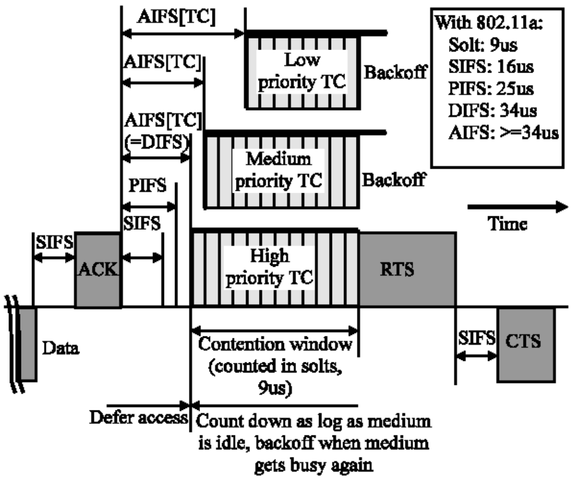

Fig. 8: IFS relationships in 802.11e

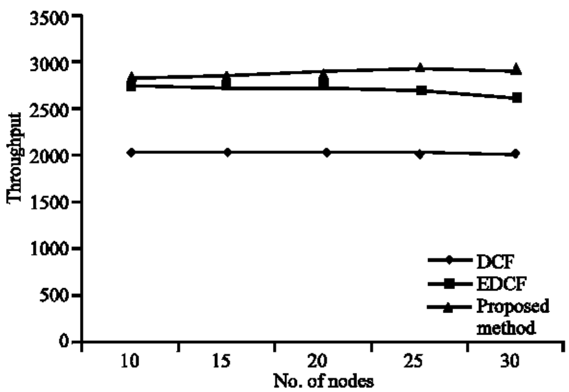

Fig. 9: Number of nodes Vs throughput

transmitted 2037 packets, 802.11e transmit 2734 packets where proposed method transmits 2817 packets successfully. With 30 nodes 802.11 successfully transmitted 2008 packets, 802.11e transmit 2610 packets where proposed method transmits 2907 packets successfully. The proposed technique improves 30-40% whereas EDCF improves 25-30% only.

Figure 9 shows comparison of throughput performance of DCF, EDCF and proposed method.

Delay: The time taken by the packets to reach the destination successfully. With 10nodes 802.11 have 41 μs delay, 802.11e have 13 μs delay where proposed method takes only 3 μs. With 30nodes 802.11 have 48 μs delay, 802.11e have 13 μs delay where proposed method takes only 6 μs. The proposed technique reduces 70-80% whereas EDCF reduces 25-30% only.

Figure 10 shows the comparison of delay performance of DCF, EDCF and proposed method.

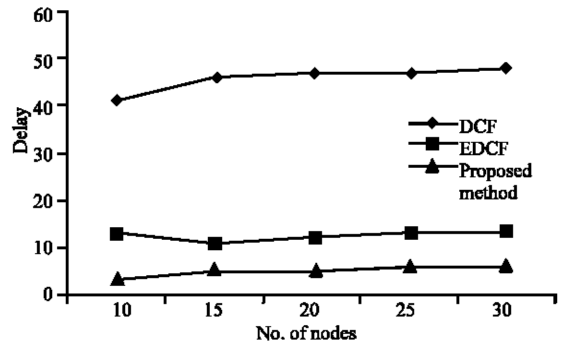

Fig. 10: Number of nodes Vs delay

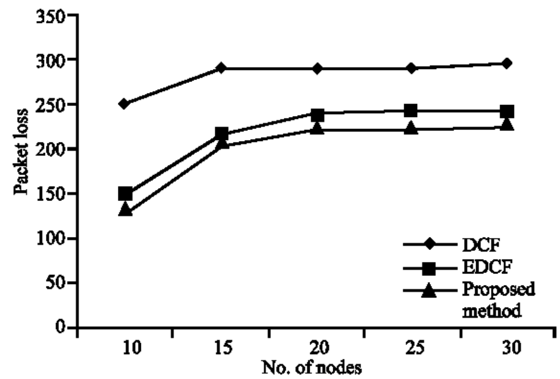

Fig. 11: Number of nodes Vs packet loss

Packet loss: The number of packets missed to reach the destination. With 10 nodes 802.11 lost 249 packets, 802.11e lost 147 packets where proposed method lost only 126 packets. With 30 nodes 802.11 lost 290 packets, 802.11e lost 243 packets where proposed method lost only 225 packets. The proposed technique reduces 30-40% packet loss whereas EDCF reduces 20-25% packet loss.

Figure 11 shows the comparison of packet loss performance of DCF, EDCF and proposed method.

In this study, evaluate the performance of QoS parameters in MAC layer and its interaction with the transportation layer protocol in a mobile ad hoc network is tabulated in Table 2. This system using IEEE 802.11e MAC mechanisms are contention based channel access function or distributed coordination function and a contention-free centrally controlled channel access function or point coordination function, it improves quality of service in MAC layer. To improve the performance of at the transport layer will require the design of distributed medium access control scheme and packet scheduler. A suitable MAC layer protocol and additive increase and multiplicative decrease algorithm improves quality of service in transport layer.

Table 2: Comparison of QoS parameters

QoS Para meters	No. of Nodes	Existing CSMA\CA Using DCF	In MAC layer using EDCF	Proposed method using cross layer based on EDCF and AIMD
Throughput In bps	10	2037	2734	2817
	15	2024	2718	2840
	20	2026	2711	2887
	25	2034	2683	2911
	30	2008	2610	2907
Delay in µs	10	41	13	3
	15	46	11	5
	20	47	12	5
	25	47	13	6
	30	48	13	6
Packet loss	10	249	147	126
	15	289	217	202
	20	290	240	220
	25	290	242	222
	30	296	243	225

This results show that the interaction between transportation and the MAC protocol has a significant impact on the achievable throughput in ad hoc networks and suggest that improving scalability will result in the greatest improvement in network throughput, packet loss and delay is very much reduced.

The future work is to consider remaining QoS attributes like reliability and pause time by combining with other TCP mechanisms like slow start and Exponential increase algorithms that can be exploited to design predictive path reliability metric that provides some type of probabilistic bound on throughput and perhaps end-to-end delay. Such a metric would be helpful in designing adaptive QoS mechanisms for ad hoc networks at both the transport and MAC layers.

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