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Performance Evaluation of a Novel Fuzzy Based Priority Scheduler for Mobile Ad-hoc Networks and its Effect on MAC Protocols

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Abstract: As mobile computing gains popularity, the need for Ad-hoc routing will continue to grow. Mobile Ad-hoc network is an autonomous system of mobile wireless nodes connected dynamically without any preexisting infrastructure. Here, since the nodes are mobile, the network topology changes rapidly and unpredictably over time. The QoS routing has challenging problems due to the network's dynamic topology. The multi hop wireless forwarding of packets, broadcasting of control traffic and the fact that, all nodes may act as routers in addition to being sources and sinks of data in ad-hoc networks produce different Queuing behaviour. Hence, a scheduling algorithm to schedule the packets based on their respective priorities will improve the performance of the network. Here, we present a novel fuzzy based priority scheduler for mobile ad-hoc networks, to determine the priority of the packets. The performance of this scheduler is studied using GloMoSim and evaluated in terms of quantitative metrics such as packet delivery ratio, average end-to-end delay and throughput. It is found that the scheduler provides overall improvement in the performance of the system with three unicast routing protocols when run over different MAC protocols.

Key words: Mobile ad-hoc networks, priority scheduler, fuzzy logic, GloMoSim, MAC protocols

INTRODUCTION

Mobile ad-hoc network is cooperative engagement of mobile hosts or routers connected by wireless links. And multi hop ad-hoc networks are an ideal technology to extend the wired infrastructure to the mobile users to establish an instant communication infrastructure. These types of networks have many advantages such as self-reconfiguration and adaptability to highly variable mobile characteristics like the transmission conditions, propagation channel distribution characteristics and power level. Recently, interest in mobile ad-hoc networks has grown due to the increased availability of mobile wireless communication devices, improvements in CPU performance and reduction in cost.

In these networks, the mobility of nodes and the error prone nature of the wireless medium poses many challenges like frequent route changes and packet losses. Also the absence of a common base station or any centralized controller and forwarding of packets across multiple broadcast regions makes it difficult to satisfy a flow's end-to-end QOS target. And also the fact that all the nodes in MANET may act, as routers in addition to being sources and sinks of data will produce different queuing behaviour than in traditional wired networks. Hence, introducing a scheduling algorithm to determine which queued packet to process next will improve the overall end-to end performance.

Without scheduling, the packets will be processed in FIFO manner and hence there is more chance that either more packets may be dropped or may not meet the QOS target. A scheduler should schedule the packets to reach the destination quickly, which are at the verge of expiry.

There have been some discussions as to the correct Medium Access Control (MAC) protocol to use for channel access when performing these simulations. Many early protocol simulations utilized carrier sense Multiple Access (CSMA) protocol[1]. Since the advent of the IEEE 802.11 protocol[2], however, most protocol evaluation has elected to run over this channel access protocol, since it provides both prevention and detection of hidden terminal problem.

To analyze the effect of the scheduler with different MAC protocols, three Ad-hoc routing protocols are selected for study. The protocols are Wireless Routing Protocol (WRP), Dynamic source Routing (DSR) and Ad-hoc on Demand Distance vector routing (AODV)[3]. It is the intent of the study to compare the performance of the three routing protocols with the inclusion of scheduler and to determine whether the selection of MAC layer affects the relative performance of Ad-hoc routing protocols. It is likely that the performance of the protocols

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will be best when run over IEEE 802.11, due to its channel acquisition characteristics. To determine whether the selection of MAC protocol is a factor when comparing routing protocols with the scheduler, this study also explores the behaviour of different unicast routing protocols when run over varying MAC protocols.

In this study, we propose a Fuzzy based Priority Scheduler (FPS) for scheduling the packets based on its priority index. The priority index for each packet is determined generally based on number of hops the packet has suffered and the buffer size[4]. The fuzzy algorithm finds the priority of the packet based on some attributes of the packets. It is devised and coded in C language. The C code is linked with GloMoSim[5] and is tested. It is found that the proposed fuzzy scheduler provides improved packet delivery ratio, reduced average end-to-end delay and increased throughput, when tested with the three unicast protocols run over various MAC protocols.

Three ad-hoc unicast protocols are selected for study. The first is the Wireless Routing Protocol[6], which is a distance vector table driven protocol. Table driven protocols periodically exchange routing table information in an attempt to maintain an up-to-date route from each node to every other node in the network all the times. The second protocol is the ad-hoc on demand Distance Vector routing protocol[7] and it is included as an example of an on demand protocol. On demand protocols only establish routes when they are needed by a source node and only maintain these routes as long as the source node requires them. Finally, the Dynamic source routing protocol[6], is included which uses a technique where source of a data packet determines the complete sequence of the nodes through which packets are forwarded. It guarantees shortest path.

MAC PROTOCOLS

The MAC protocols selected for this study represent a progression in protocol development. Each one builds upon the previous one through the addition of either control overhead or carrier sensing in order to mitigate the effects of the hidden terminal problem and achieve better network throughput. Table 1 summarizes the mechanism of each MAC protocol included in the study. Packet sensing (PSMA) implies that carrier sensing is not performed before packet transmissions. The following sections describe each of the MAC protocols utilized in this evaluation[8].

Table 1: Summary of MAC Protocols

Protocol	Mechanism
CSMA	CSMA
MACA	PSMA/RTS/CTS
IEEE 802.11 DCF	CSMA/CA/RTS/CTS/ACK

Carrier sense multiple access: The Carrier Sense Multiple Access (CSMA)[1] protocol is the most primitive of the MAC protocols utilized in this study. The CSMA version used is non-persistent CSMA. In this protocol, a node senses the channel for ongoing transmissions before sending a packet. If the channel is already in use, the node sets a random timer and then waits this period of time before re-attempting the transmission. On the other hand, if the channel is not currently in use, the node begins transmission.

Multiple access with collision avoidance: The Multiple Access with Collision Avoidance MACA) protocol improves upon CSMA by taking steps towards the avoidance of the hidden terminal problem. The protocol defines Request-To-Send (RTS) and Clear-To-Send (CTS) control packets to announce an upcoming transmission. A node wishing to send a data packet broadcasts a RTS message containing the length of the data frame that will follow. Upon receiving the RTS, the receiver responds by broadcasting a CTS packet, which also contains the length of the upcoming data frame. Any node hearing either of these two control packets must be silent long enough for the data packet to be transmitted. In this way, neighboring nodes will not transmit during the data transmission and the number of collisions is reduced. In the event that two nodes send simultaneous RTS frames to the same node, the RTS transmissions collide and are lost. If this occurs, the nodes, which sent the unsuccessful RTS packets, set a random timer utilizing the binary exponential back off RTS algorithm for the next transmission attempt.

IEEE 802.11 DCF: The IEEE 802.11 MAC protocol specifies a Distributed Coordination Function (DCF)[4], which is based, on the same RTS/CTS message exchange for unicast data transmissions as the previous MAC protocols. Where 802.11 differs, however, is in its use of collision avoidance before RTS transmission and its requirement of an acknowledgment (ACK) transmission by the receiver after the successful reception of the data packet[8]. The inclusion of the ACK allows immediate retransmission if necessary by verifying that the data packet was successfully received. In the case of node mobility, the ACK may also aid in the detection of hidden-terminal interference that was not detectable when the CTS message was sent.

SCHEDULING ALGORITHMS

For improving the performance of the mobile ad-hoc networks, a scheduler can be used. There are several scheduling policies for different network scenarios. Scheduling algorithms determine which packet is served next among the packets in queues. The scheduler is positioned between the routing agent and above the MAC layer, as shown in Fig. 1a. Figure 1b shows that in general control queues have higher priority than data queues. And among the data queues, the proposed scheduler is experimented.

The drop tail policy is used as queue management algorithm in all scheduling algorithm. It drops packets from the tail of the queue when queue is full. Except for the no priority-scheduling algorithm, all the other scheduling algorithms give higher priority to control packets than to data packets. The differences in the algorithms are in assigning priority between data packets. In priority scheduling, control and data packets are maintained in separate queues in FIFO order and it gives high priority to control packets. Currently, only this scheme is used in mobile ad-hoc networks[9]. Considering the suitability of the different types of scheduling methods for MANET, several scheduling schemes were studied in literature. Shortest path length first scheduling method, assign high priority to data packets, which have shorter path length from source to destination. Fewest remaining hops first scheduling method gives higher priority to data packets having fever hops to traverse. In round robin scheduling, each route queue is allowed to send one packet at a time in a round robin fashion. In the greedy scheduling scheme, each sends its own data packets before those of other nodes.

Due to the distributed nature of the ad-hoc networks, nodes may not be able to determine the next packet that would be transmitted in a centralized and ideal priority scheduler[4]. In wireless networks with base stations, the base stations acts as a centralization point for arbitration such QOS demands. If the goal is to support delay traffic using Earliest Deadline First (EDF) service discipline, each packet is given a priority index given by its arrival time plus the delay bound consequently, the base station simply selects the packets will the smallest priority index for transmission. However, in networks without base station, there is no centralized controller which can assess the relative priorities of packets contending for the medium consequently, the nodes actually possessing the highest priority packet is unaware that this is the case, nor are other nodes with lowest priority packets aware that they should defer access. In multihop Ad-hoc networks, in which packets are forwarded across multiple broadcast regions, it becomes increasingly challenging to satisfy a flow's end-to-end QoS target.

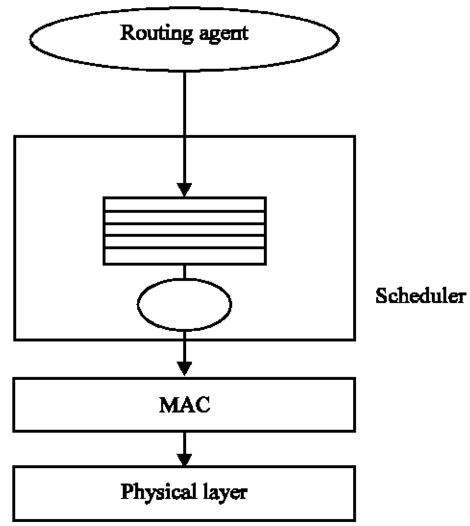

Fig. 1a: Position of the scheduler

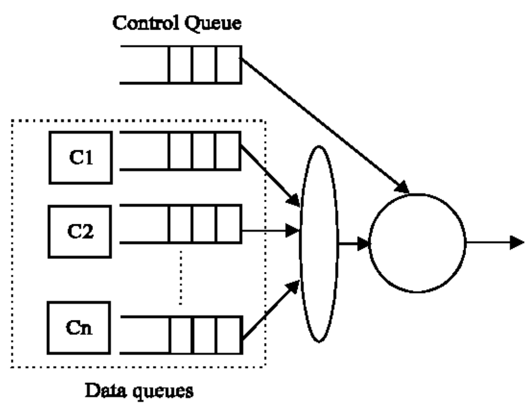

Fig. 1b: Packet Scheduler

The key insight is that the broadcast nature of the wireless medium together with the store and forward nature of the multihop networks provides opportunities to communicate and co-ordinate priority information among nodes[4]. Hence the goal is to exploit these system attributes and develop an integrated medium access and scheduling algorithms that satisfy a high fraction of QoS targets for Ad-hoc networks.

Hence, keeping all these things in mind, we have developed a scheduler based on fuzzy logic to find the priority of the packets, which has to be scheduled next. Since the three variables viz., expiry time of packet, queue length and data rate are considered as input variables, application of fuzzy logic to find the priority index of the packet is found to be suitable in improving the overall performance of MANET. This led to the design of a fuzzy based priority scheduler.

THE FUZZY SCHEDULER

Fuzzy logic implements human experiences and preferences via membership functions and fuzzy rules. It can be used as a general methodology to incorporate knowledge, heuristics or theory into controllers and decision makers. The general steps involved in designing a fuzzy model are fuzzification of inputs and output application of fuzzy operator, application of implication method, aggregation of all outputs and finally defuzzification.

The fuzzy scheduler proposed here, calculates the priority index of each packet as shown in Fig. 2. Here we consider all the inputs, which decide the priority, associated with the packet, unlike the previous scheduling schemes. The fuzzy scheduler uses three input variables and one output variable. The three input variables to be fuzzified are, the expiry time and data rate of the packet and Queue length of the nodes to which the packet is associated with. The inputs are fuzzified, implicated, aggregated and defuzzified to get the crisp value of the output i.e., the priority index.

The linguistic variables associated with the input variables are low (L), medium (M) and high (H). For the output variable, priority index, 5 linguistic variables are used, viz., very low (VL), low (L), medium (M), high (H) and very high (VH). The membership functions of the variables are shown in the Fig. 3.

Table 2 shows the fuzzy conditional Rules for the fuzzy scheduler. The three input variables have 27 combinations (3*3*3) and the corresponding output is shown in the tabulation. The rule base is split into three tables and the first table gives out the rule base for Expiry time low and nine combinations of the other two input variables. Table 2 gives out the rule base for Expiry time medium and the third for expiry time high. To illustrate one rule in the first table, the first rule can be interpreted as, if (Expiry time is low) and (Data rate is low) and (Queue length is low), then priority index is low. Since in this rule, Data rate and Queue length are low and

Table 2: Fuzzy rule base, D-Data rate, Q-Queue length

D\Q	L	M	H
Expiry time-low			
L	L	L	VL
M	VL	VL	VL
H	L	VL	VL
Expiry time-medium			
L	M	M	L
M	M	M	L
H	M	M	M
Expiry time-high			
L	VH	VH	H
M	H	M	M
H	H	H	M

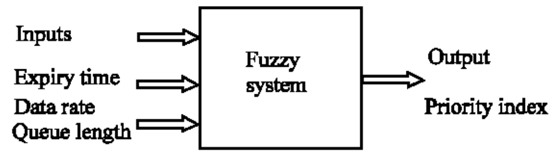

Fig. 2: Fuzzy scheduler

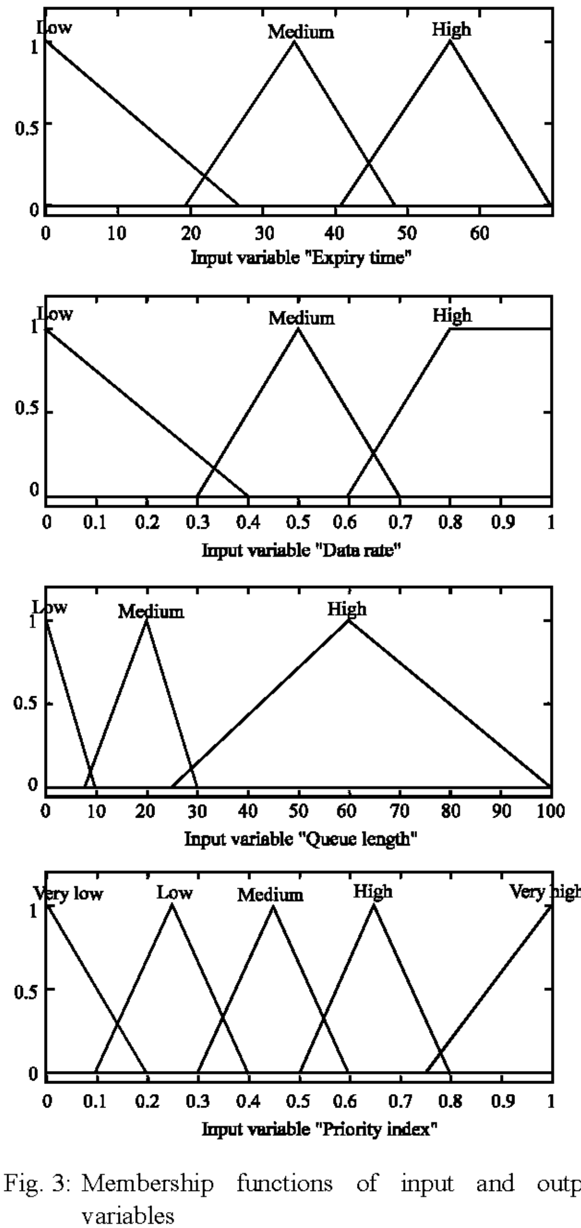

Fig. 3: Membership functions of input and output variables

packets are associated with low delay, the priority index is set to be low. In the Table 2, for medium expiry time when data rate and queue length both are high, the priority index is set to be medium as seen from the last column of the table. Similarly the other rules are framed. It is quite true that when many other factors are taken into consideration, the system is not scalable. Though manual tuning of rule base is done here, optimized tuning using GA is also possible.

The output priority index, if very low, indicates that packets are attached with a very high priority and should be immediately scheduled. Similarly, if the priority index is very high, it indicates that packets are attached with least priority and will be scheduled only after all high priority packets are scheduled.

PERFORMANCE EVALUATION

The proposed fuzzy scheduler is tested using the public domain simulator, GloMoSim. The algorithm is evaluated in terms of the metrics such as packet delivery ratio, average end-to-end delay and throughput.

Simulation environment and methodology: The simulation for evaluating the fuzzy scheduler was implemented within the GloMoSim library. The simulation package GloMoSim[4] is used to analyze and evaluate the performance of the proposed fuzzy scheduler. The GloMoSim (GLObal MObile information system SIMulator) provides a scalable simulation environment for wireless network systems. It is designed using the parallel discrete event simulation capability provided by PARSEC (PARallel Simulation Environment for Complex Systems)[5]. It is a C based simulation language developed by parallel computing laboratory at UCLA, for sequential and parallel execution of discrete event simulation model.

Our simulation modeled a network of mobile nodes placed randomly within 1000 x 1000 m area. Radio propagation range for each node was 250 m and channel capacity of 2 Mb/sec is chosen. There were no network partitions throughout the simulation. Each simulation is executed for 600 sec of simulation time. Multiple runs with different seed values were conducted for each scenario and collected data was averaged over those runs.

Table 3 lists the simulation parameters, which are used as default values unless otherwise specified. A free space propagation model was used in our experiments. A traffic generator was developed to simulate CBR sources. The size of the data payload is 512 bytes. Data sessions with randomly selected sources and destinations were simulated. Each source transmits data packets at a minimum rate of 4 packets/sec and maximum rate of 10 packets/sec. The traffic load is varied by changing the number of data sessions and the effect is examined on scheduler with different routing protocols.

Performance metrics: The following metrics are used to evaluate the effect of fuzzy scheduler. The metrics were derived from one suggested by the MANET working group for routing protocol evaluation.

Table 3: Simulation parameters

Number of nodes	30
Terrain range	1000 x 1000 square
Transmission range	250 m
Simulation time	600 sec
Node placement	Random, uniform
Mobility model	random way point
Speed	0-10 m s^{-1}
Propagation model	Free space
Channel bandwidth	2 Mbps
Traffic type	CBR
Data payload	512 bytes/Packet
Examined routing protocols	AODV, DSR and WRP
MAC protocol	IEEE 802.11

Packet delivery ratio: Packet delivery ratio is the ratio of the number of data packets actually delivered to the destinations to the number of data packets supposed to be received. This number presents the effectiveness of the protocol.

Average end to end delay: This indicates the end-to-end delay experienced by packets from source to destination. This includes the route discovery time, the queuing delay at node, the retransmission delay at the MAC layer and the propagation and transfer time in the wireless channel.

Throughput: This is measured in bytes per sec, which also serve as the performance measure for the fuzzy scheduler.

Performance evaluation using GloMoSim: The simulation for evaluating the proposed fuzzy scheduler is implemented using GloMoSim Library First the task of identification of input variables used in fuzzy logic C code is performed. Then the calculated priority index is used for scheduling the packet. By this way of scheduling, the packets, which are about to expire, or the packets in highly congested queues are given first priority for sending. As a result of this, the number of packets delivered to the client node, the average end to end delay of the packet transmission and the throughput improves.

The inputs to the fuzzy system are identified by a complete search of the GloMoSim environment. The input expiry time is the variable TTL, which is present in the network layer of the simulator. TTL stands for time to live and is set a default value of 64 sec. For each hop it reduces by 1 sec. If the packet suffers excessive delays and undergoes multihop, its TTL falls to zero. As a result of this, the packet is dropped. If this variable is used as an input to the scheduler for finding the priority index, a packet with a very low TTL value is given the highest priority. Hence due to this, the dropping of packets experiencing multihops gets reduced. The next input to the scheduler is the data rate of transmission and it is normalized. The third input to the scheduler is the queue length of the node in which the packet is present. If the

Table 4: Packets delivered-for different routing protocols, with and without scheduler

	Packets Delivered	
Routing protocol	With scheduler	Without scheduler
AODV	33155	21818
DSR	30503	21676
WRP	32183	28373
Throughput-for different routing protocols with and without scheduler		
	Throughput	
Routing protocol	With scheduler	Without scheduler
AODV	263347	233513
DSR	249890	164680
WRP	263841	225320
End to end delay-for different routing protocols, with and without scheduler		
	Average end to end delay	
Routing protocol	With scheduler	Without scheduler
AODV	0.97	1.127
DSR	0.09	1.490
WRP	0.30	0.571

packet is present in a highly crowded node, it suffers excessive delays and gets lost. So, such a packet is given a higher priority and hence it gets saved.

The priority index is calculated with the inputs obtained from the network layer. This is then added to the header associated with the packet. Hence whenever the packet reaches a node, its priority index is calculated and it is attached with it. Each node has three queues. Each queue in the node is sorted based on the priority index and the packet with the lowest priority index (is packet with the highest priority), is scheduled next, when the node gets the opportunity to send. By this method of scheduling, the overall performance increases.

The performance of the network with the fuzzy code and without the code is studied under various conditions such as variation in network size, mobility of the nodes

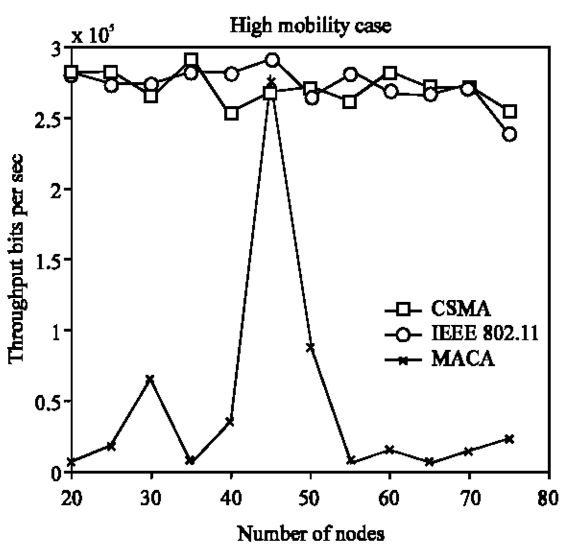

Fig. 4: Throughput vs number of nodes

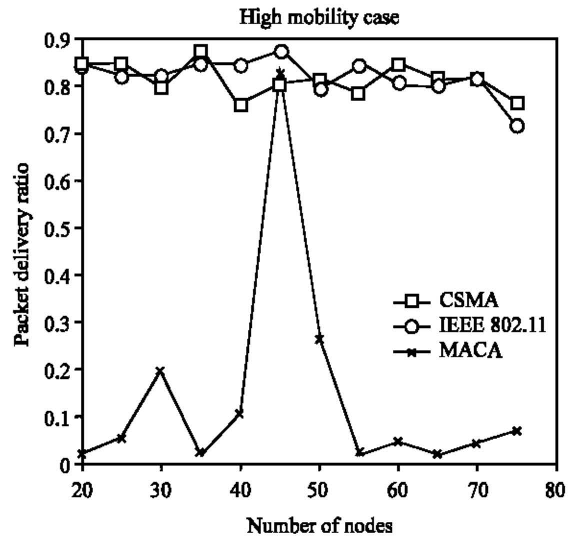

Fig. 5: Packet delivery ratio vs number of nodes

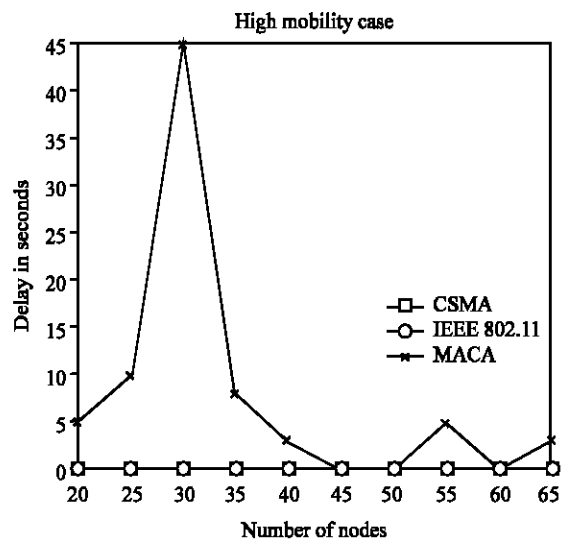

Fig. 6: Average end to end delay as a function of number of nodes

and the routing protocols used in the simulator. The results are verified[10,11] and it is found that the proposed scheduler works well with three routing protocols with IEEE 802.11 as MAC protocol and are shown in Table 4.

Scheduler performance with different MAC layer protocols-IEEE 802.11, CSMA, MACA: Experiments were performed to check the performance of the scheduler with different MAC layer protocols such as IEEE 802.11, CSMA and MACA. In IEEE 802.11 protocol, each node maintains the scheduling table by overhearing all the RTS and CTS transmitted by other nodes within its broadcast range. Here an acknowledgment (ACK) of transmission is required after successful reception of data packet. In CSMA, if the transmission medium is in use, the node

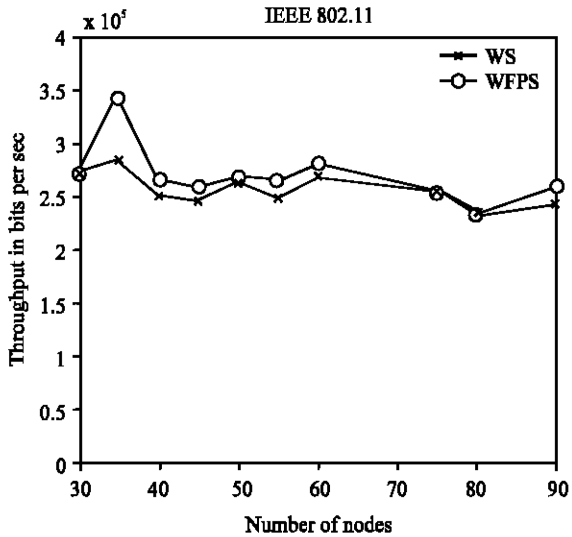

Fig. 7: Throughput as a function of number of nodes-high mobility case

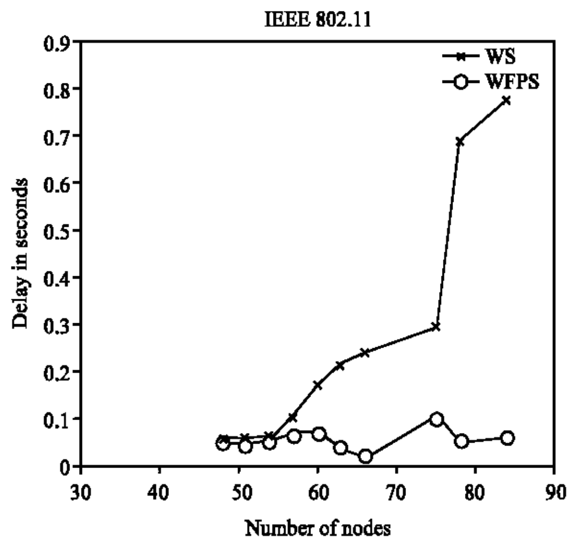

Fig. 9: Average end to end delay as a function of number of nodes-high mobility case

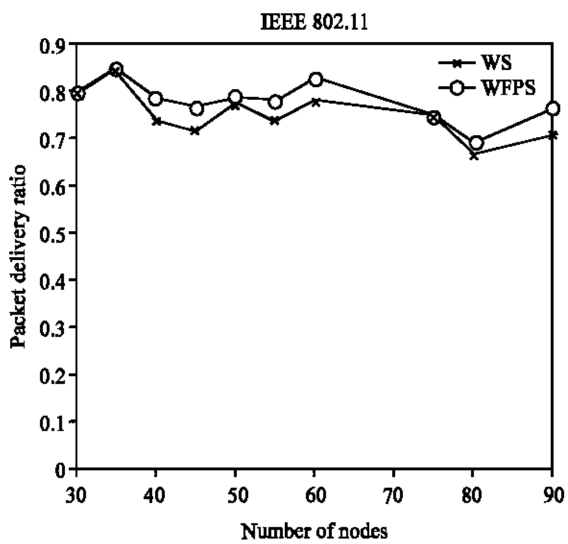

Fig. 8: Packet delivery ratio as a function of number of nodes-high mobility case

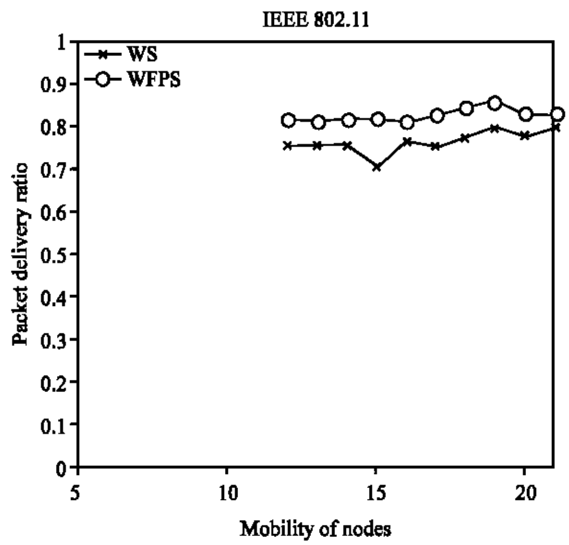

Fig. 10: Packet delivery ratio as a function of mobility

waits. It is limited by the hidden and exposed terminal problem. This can be solved by the use of RTS/CTS dialogue for collision avoidance. Hence IEEE 802.11 always shows a better performance compared to CSMA and MACA protocols as seen from Fig. 4-6. The collision avoidance mechanism in IEEE 802.11 aids in reducing the number of collisions and hence more data packets reach the destination. And also in an exposed terminal scenario, both CSMA and MACA present poor performance behaviour.

The results are verified for varieties of combinations of nodes and results are averaged out. The performance of the scheduler is also tested under high mobility conditions, with IEEE 802.11 as the protocol. In this simulation, moving directions of each node are selected randomly. When nodes reach the simulation boundary, they are bounced back and then continue to move. The mobility speed of the node generally varies from 0 to 72 km h^{-1}. Here in this simulation, to test the scheduler under high mobility conditions, the mobility is kept at the higher level. It is seen from the Fig. 7-9 that since the fuzzy scheduler calculates the priority of the packets based on the three input parameters, it gives an overall improvement in the performance parameters even under the high mobility conditions. In the graph, WS indicates

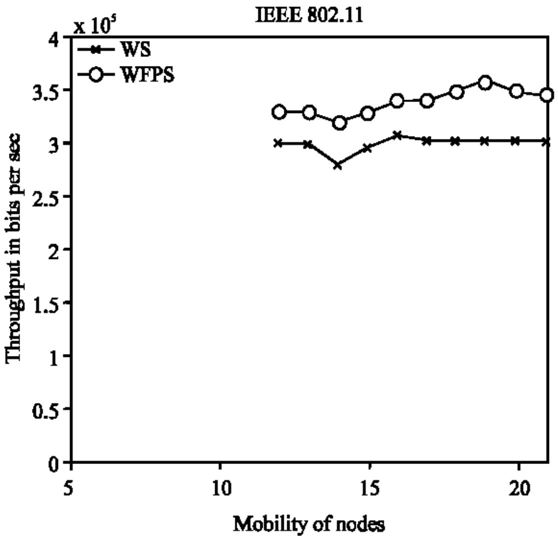

Fig. 11: Throughput as a function of mobility

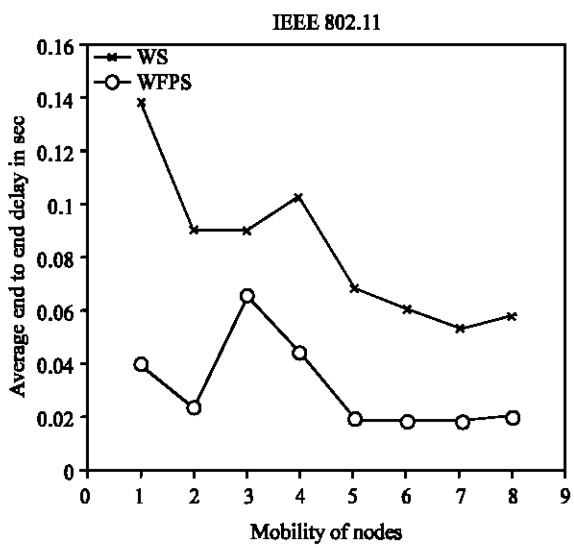

Fig. 12: Average end-to-end delay as a function of mobility

the performance of the network without simulator and WFPS indicates the performance of the network with fuzzy Priority scheduler. From Fig. 7, it is clear that Packet delivery ratio of network with fuzzy scheduler improves by 5% as compared to the one without scheduler, as the number of nodes is increased to as high as 80 nodes.

Scheduler performance with mobility changes-Two nodes transmitting at same time to same node: When two different nodes transmit at the same time to same node, with CSMA, only lesser than half the number of total packets is received by the receiving node due to collision. This scenario is presented for both MACA and IEEE 802.11 protocols. It is seen that a better behaviour is obtained with IEEE 802.11. When used along with the scheduler the performance with respect to throughput, packet delivery ratio and Delay improves further. The results are proved by experimenting with mobility changes under random way point condition in GloMoSim and are plotted in graphs. It is clear from the Fig. 10-12 that fuzzy scheduler performs well with two nodes transmitting to the same node.

From Fig. 10, it is evident that, Packet delivery ratio of the network with scheduler improves by 2-5% as the mobility of the nodes varies from low to high range. The results are again verified for varieties of combinations of nodes and results are averaged out. Similarly, there is an increase in Throughput also as verified from the Fig. 11. There is a marked reduction in delay, which measures as low as 0.02 sec under high mobility of nodes as seen from the Fig. 12.

CONCLUSIONS

This study addresses a fuzzy based priority-scheduling scheme, which improves the Quality of service parameters in Mobile Ad-hoc networks. The fuzzy scheduler algorithm attaches a priority index to each packet in the queue of the node. It combines the input parameters such as queue length, data rate and expiry time to find the priority index. Unlike the normal sorting procedure for scheduling packet, the crisp priority index is calculated by the fuzzy scheduler based on the above inputs, which are derived from the network. The membership functions and rule bases of the fuzzy scheduler are carefully designed. The coding is done in C language and output is verified using MATLAB fuzzy logic toolbox with FIS editor. Then the inputs are identified in the library of GloMoSim and the fuzzy scheduler is attached.

In this study, the performance of the fuzzy scheduler is studied for Mobile Ad-hoc networks using GloMoSim simulator and results are presented. It is found from the results that, priority scheduling helps in effective routing of packets without much loss and with less delay. In real network environment, where timely reception of each packet plays a crucial role, priority scheduling helps in effective transmission of packets.

Based on the studies, we conclude that the proposed fuzzy based scheduling algorithm performs better compared with the network performance without scheduler. The results are also verified for different routing protocols under different mobility conditions, run over different MAC protocols and they are found to be encouraging.

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