

MaxMin Share Based Medium Access for Attaining Fairness and Channel Utilization in Mobile Adhoc Networks

P. Priakanth and P. Thangaraj

Abstract—Due to the complex network architecture, the mobile adhoc network's multihop feature gives additional problems to the users. When the traffic load at each node gets increased, the additional contention due its traffic pattern might cause the nodes which are close to destination to starve the nodes more away from the destination and also the capacity of network is unable to satisfy the total user's demand which results in an unfairness problem. In this paper, we propose to create an algorithm to compute the optimal MAC-layer bandwidth assigned to each flow in the network. The bottleneck links contention area determines the fair time share which is necessary to calculate the maximum allowed transmission rate used by each flow. To completely utilize the network resources, we compute two optimal rates namely, the maximum fair share and minimum fair share. We use the maximum fair share achieved in order to limit the input rate of those flows which crosses the bottleneck links contention area when the flows that are not allocated to the optimal transmission rate and calculate the following highest fair share. Through simulation results, we show that the proposed protocol achieves improved fair share and throughput with reduced delay.

Keywords—MAC-layer, MANETs, Multihop, optimal rate, Transmission.

I. INTRODUCTION

A multi-hop wireless ad hoc network is a set of nodes which are able to communicate with each other without any recognized infrastructure or centralized control. Each of these nodes is a wireless transceiver which is able to transmit and receive at a single frequency band which is common to all nodes. Though they are restricted by their transmitting and receiving capabilities [1], these nodes can communicate with each other. Most of the nodes are outside of the direct range so they are unable to reach all the nodes in the network directly. The network functions as a multihop fashion in order to overcome this problem. Nodes route traffic for each other. So a packet can travel from any source to its destination either directly or through some set of intermediate packet forwarding nodes in a connected ad hoc network. When we need a temporary network or when cabling is complex, Multi-hop wireless networks provide a quick and easy way for networking.

P.Priakanth, Assistant Professor, Department of Computer Science & Engineering, Kongu Engineering College, Perundurai, Erode, Tamilnadu, India. Pin : 638052. Email: mypiree@yahoo.com

Dr.P.Thangaraj, Professor, Department of Computer Science & Engineering, Kongu Engineering College, Perundurai, Erode, Tamilnadu, India. Pin: 638052. Email : ctptr@yahoo.co.in

The most popular MAC protocol for wireless communication [2] are 802.11 Distributed Coordination Function, Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) based.

Due to the complex network architecture the mobile adhoc networks multihop feature gives additional unfairness problems among the users. Every node along the path to a destination has to transmit other nodes' traffic in addition to transmitting its own traffic, according to its traffic pattern. In addition to the originally existing contention with other nodes for the same chosen destination, this results in an extra contention among a node's own traffic and its communicated traffic. When the traffic load at each node gets raised, the additional contention due its traffic pattern might cause the nodes which are close to destination to starve the nodes more away from the destination and also the capacity of network is unable to satisfy the total user's demand which results in an unfairness problem.

The main aim of the paper is to assure fair bandwidth utilization among all users by applying maximal allowed transmission rate to each flow. Also it ensures that the network resources are utilized to the maximum extent effectively.

In this paper, we propose to develop an algorithm to calculate the optimal MAC-layer bandwidth assigned to each flow in the network. The bottleneck links contention area determines the fair time share which is necessary to calculate the maximum allowed transmission rate used by each flow. To completely utilize the network resources, we compute two optimal rates namely, the maximum fair share and minimum fair share. The minimum fair share thus achieved limits the input rate of those flows which crosses the bottleneck links contention area in the network. We use the maximum fair share achieved to limit the input rate of those flows which crosses the bottleneck links contention area when the flows that are not allocated to the best transmission rate and calculate the following highest fair share. These steps should be repeated until all the flows are allocated to an optimal transmission rate.

II. RELATED WORK

Liansheng Tan et al. [1] have proposed the interaction between links in wireless multihop networks which introduces extra constraints on the combinations of achievable flow rates. This paper provides a simple price-based max-min fair rate allocation algorithm, building a utility maximization scheme

for such networks. With the time constraint of the MAC layer, max-min fairness can be achieved among multi-hop flows using this algorithm. This algorithm realizes fair rate allocation efficiently in dynamically varying wireless networks.

Diego Ferrero and Guillaume UrvoyKeller [2] have proposed to replace the FIFO policy by LAS (Least Attained Service). In ad-hoc chain and a hotspot scenario, LAS manages to enforce fairness, almost irrespectively of the advertised window size and also the fairness is not obtained at the expense of a decrease of the utilization of the network is shown. The performance of TCP under FIFO/drop tail is very dependent on this parameter.

Sachin Ganu et al. [3] have experimentally verified the physical layer capture effect in 802.11 network cards. The related throughput fairness issue is addressed by evaluating several PHY and MAC layer options and their effectiveness in restoring fairness. Then they have added a heuristic correction method (combined AIFS and TxOp) that yields an improvement of 25% in throughput fairness when compared to default settings.

Yongkang XIAO et al. [4] have proposed a novel protocol, neighbor-medium-aware MAC (NEMA-MAC), is proposed to improve the TCP fairness. By adding a medium (channel) state field in the head of the traditional IEEE 802.11 MAC frame, the NEMA-MAC protocol provides a communication mechanism to resolve the hidden station problem. In addition, when a collision occurs, the new backoff algorithm makes the sender to cooperatively adjust the contention window according to their local and neighbors' channel usage indexes. The simulation results show that TCP sessions can acquire satisfying fairness and increase the throughput in the NEMA-MAC-based multihop ad hoc networks.

Yongkang XIAO et al. [5] have reviewed some of the results on the fairness of decentralized medium access control protocols based on CSMA/CA, such as IEEE 802.11, in large multi-hop wireless networks. They focus on the trade-off between high spatial reuse and fairness and show that the widely observed unfairness of the protocol in small network topologies does not always persist in large topologies.

Ping Wang et al. [6] have showed that it is challenging to evaluate service fairness in multi-hop wireless networks due to intra-flow contention and unequal channel capacity. Thus the channel time in the maximal clique is proposed to provide the conventional fairness criterion in the wireless environment. The channel time in a clique reflects the resources consumed either in wireless networks or wireline networks, to evaluate max-min fairness in multi-hop wireless networks. This research provides insight into the problem of resource management for multi-hop wireless, wireline, or hybrid networks with fairness consideration.

In [7] which is our previous paper, in that we deal with the energy management problem. We present a channel adaptive energy efficient MAC protocol, for efficient packets scheduling and queuing in an adhoc network, with time varying characteristic of wireless channel taken into consideration. Every node estimates the channel and link

quality for each contending flow based on which a weight value is calculated and propagated using the routing protocol. Since a wireless link with worse channel quality can result in more energy expenditure, the transmission is allowed only for those flows whose weight is greater than channel quality threshold (CQT). For flows with weight less than CQT, the packets are buffered until the channel and link quality recovers or the weight becomes greater than CQT.

In another previous work [8], we propose energy efficient and channel aware (EACA) MAC protocol to advance the fairness among wireless nodes that may practice location-dependent channel errors. By scrutinizing the traffic, a collective score is designed and the feasible bandwidth and the channel state of each wireless link is estimated. A routing protocol is used to send the score. The nodes with high scores are transmitted. Nodes attempting to access the wireless medium with a low score will be allowed to transmit again when their score becomes high. Thus this protocol attains fairness with minimum energy in multi-hop adhoc networks.

Nagesh S. P. Nandiraju et al. [9] have proposed a simple enhancement to the IEEE 802.11 DCF, which provides priority to the AP and thus enables it to acquire a larger share of the channel when required. The unfairness problem through systematic measurements in an experimental test bed of WLAN using the legacy 802.11 DCF is demonstrated. Analytical models to calculate the throughput of AP and the STAs is developed. BDCF protocol enables the AP to access the channel more frequently by granting a preferential treatment. In addition to this, our protocol also reduces the time wasted in channel contention and backoff mechanism at the MAC layer.

Hung-Yun Hsieh and Raghupathy Sivakumar [10] have proposed the impact of the medium access control (MAC) layer and the routing layer on the performance of a multi-hop wireless network. At the medium access control layer, they argue that the notion of per-node fairness employed by the IEEE 802.11 standard is not suitable for a multi-hop wireless network where flows traverse multiple hops. A new MAC protocol is proposed which supports prioritized per-node fairness and significantly improves performance in terms of both throughput and fairness. At the routing layer, load balanced routing improves performance regardless of the nature of the underlying MAC protocol.

III. FAIRNESS IN 802.11 WIRELESS NETWORKS

A. Definition of Fairness

According to some pre-determined condition, the optimal allocation of the available resources is identified by the fairness definition. The following are the three popular types of the fairness definitions:

Let M be a vector of flow rates

$$M = (M_k); k \in K$$

where M_k is the flow rate of flow k for all active flows K in the network. We assume that unlimited demand is present for all the flows. If rates are non-negative and the

aggregate rate of all flows are smaller than the link capacity then a feasible set of flow rates are defined.

B. Absolute Fairness

The rates are equally dispersed between all the flows under the absolute fairness. Consider a system in which there are two flows, f_1 and f_2 for an example. If the system always provides the same data rate B to both flows, then it provides absolute fairness.

C. Proportional Fairness

An allocation M is defined as proportionally fair if for any other feasible allocation M' , the aggregate of the proportional change is 0 or negative.

$$\sum_{f \in S} (Mf' - Mf_s) / Mf \leq 0$$

TCP is an example of proportional fairness, as it provides throughput which is proportional to a flow's round-trip-time (RTT).

D. Max-Min Fairness

It is not a good solution by simply allocating rates to each flow equally. This is because without decreasing others shares some flows are capable to get more than others, which leads to the definition of max-min fairness.

If there is no rate in the allocation which can be increased and simultaneously without decreasing the rate of another allocation that is already smaller, then an allocation is said to be max-min fair.

Mathematically, a vector of rates

$$M = (Mf; f \in F)$$

is max-min fair if for each $f \in F$, Mf cannot be increased while maintaining feasibility without decreasing some Mf_0 , for some f' for which $Mf' < Mf$.

Consider a system in which there are two flows, f_1 and f_2 for example. Assume that flow f_1 gets a data rate of d_1 and flow f_2 gets a data rate of d_2 , where $d_1 < d_2$. If d_2 cannot be increased without decreasing the flow rate d_1 , then the system is called as max-min fair.

In addition to channel assignment among the network, channel utilization depends on link utilization of the active streams also.

IV. ESTIMATING FAIR SHARES

To make full use of network resources, we should calculate two optimal rates and call them the minimum fair share and maximum fair share respectively instead of calculating one optimal rate based on the most demanded route and rate limiting of all the streams to this optimal rate.

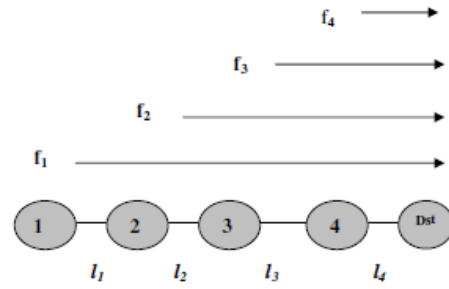


Fig. 1 A simple network with 4 streams

The network for discussion consists of N nodes and k flows. The following notations are used in our derivation.

R_k : the predetermined route each flow k traverses

H_k : the number of hops flow k traverses

TH_i^k : throughput of flow k crossing link i

T_i^k : the time needed for flow k traffic to be transmitted on link i

BW_l : Fixed capacity of link l .

The spatial reuse constraint can be stated as: for all flows f in the same contention area

$$\sum_{k=1}^K \sum_{l \in vk} T_l^k \leq 1 \quad (1)$$

then the throughput TH of link l is given by

$$TH_l = T_l^k, BW_l \quad (2)$$

and the time share for the flow k for any link l can be given as

$$T_l^k = \frac{TH_l}{BW_l} \quad (3)$$

The computation of fair share of each stream is only based on a certain link's contention area. In order to compute the fair time share and throughput of each flow regarding to the overall network, we adopt the concepts of link-usage matrix and medium-usage matrix.

We use the scenario depicted in Fig 1, to illustrate the computational process. The link-usage matrix is defined to be L , where

$$L[i, j] = \begin{cases} 1 & \text{when flow } f_i \text{ uses link } l_j \\ 0 & \text{otherwise} \end{cases}$$

which for the sample network in Figure 1 is:

$$= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 \end{bmatrix}$$

If we include the link capacity values, then define L' as

$$L'[i, j] = \frac{1}{BW_j} L[i, j]$$

$$= \begin{bmatrix} 1/BW_{11} & 0 & 0 & 0 \\ 1/BW_{12} & 1/BW_{12} & 0 & 0 \\ 1/BW_{13} & 1/BW_{13} & 1/BW_{13} & 0 \\ 1/BW_{14} & 1/BW_{14} & 1/BW_{14} & 1/BW_{14} \end{bmatrix}$$

The medium-usage matrix is defined to be M , where:

$$M[i, j] = \begin{cases} 1 & \text{when } l_j \in u_i \\ 0 & \text{otherwise} \end{cases}$$

$$= \begin{bmatrix} 1 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 \end{bmatrix}$$

The stream throughput vector $V[f]$ is the throughput for a certain flow f .

By using link-usage matrix and medium-usage matrix, Equation (1) can be written as

$$ML'V \leq 1 \quad (4)$$

where M is medium-usage matrix, L' is link-usage matrix with link-capacity, and V is a flow vector

For the sample Figure 1, Equation (4), with each row of M representing one constraint, should be applied as follows:

$$\begin{bmatrix} 1 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} 1/BW_{11} & 0 & 0 & 0 \\ 1/BW_{12} & 1/BW_{12} & 0 & 0 \\ 1/BW_{13} & 1/BW_{13} & 1/BW_{13} & 0 \\ 1/BW_{14} & 1/BW_{14} & 1/BW_{14} & 1/BW_{14} \end{bmatrix} \begin{bmatrix} V(f_1) \\ V(f_2) \\ V(f_3) \\ V(f_4) \end{bmatrix} \leq \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}$$

Hence, from (2) we get,

$$V(f_1) = T_{11}^{f_1} BW_{11} = T^{(1)} BW_{11}$$

$$V(f_2) = T_{12}^{f_2} BW_{12} = T^{(1)} BW_{12}$$

$$V(f_3) = T_{13}^{f_3} BW_{13} = T^{(1)} BW_{13}$$

$$V(f_4) = T_{14}^{f_4} BW_{14} = T^{(1)} BW_{14}$$

where $t^{(1)}$ denotes the fair time share for each stream based on link 1's contention area, solving the first constraint is same as:

$$T^{(1)} [BW_{11}(1/BW_{11} + 1/BW_{12} + 1/BW_{13} + 0) + BW_{12}(0 + 1/BW_{12} + 1/BW_{13} + 0) + BW_{13}(0 + 0 + 1/BW_{13} + 0) + 0] = 1$$

Hence,

$$T^{(1)} = [BW_{11}(1/BW_{11} + 1/BW_{12} + 1/BW_{13}) + BW_{12}(1/BW_{12} + 1/BW_{13}) + BW_{13}(1/BW_{13})]^{-1}$$

So, for all streams f that are in the same contention area,

$$T_1^i = \left(\sum_{f=1}^F BW_{11}^f / TH_i^k \right)^{-1}, 1 \leq i \leq F \quad (5)$$

$$TH_i^k = \left(\sum_{l \in V} 1/BW_l \right)^{-1} \quad (6)$$

We can prove that the above three equations are equivalent.

As we got $T^{(1)}$ from the first constraint, we can also get $T^{(2)}$, $T^{(3)}$, $T^{(4)}$ from the last three constraints, which are the fair time shares computed based on link 2, link 3, link 4's contention area. The fair time share for each stream based on the bottleneck link's contention area is:

$$T = \min(T^{(1)}, T^{(2)}, T^{(3)}, T^{(4)}) \quad (7)$$

The fair time share computed from the bottleneck link's contention area should be used to calculate the maximal allowed transmission rate used by each stream:

$$V(f_1) = T \cdot BW_{11}$$

$$V(f_2) = T \cdot BW_{12}$$

$$V(f_3) = T \cdot BW_{13}$$

$$V(f_4) = T \cdot BW_{14} \quad (8)$$

A. MaxMin Fair Share

Because of the traffic pattern, all the traffic is designated to the same destination. This makes the last hop to the destination, the bottleneck link.

To make full use of network resources, instead of calculating one optimal rate based on the most-demanded path, and rate limiting all the streams to this optimal rate, we calculate two optimal rates, and call them the minimum fair share and maximum fair share, respectively. Let P_0 , P_1 and P_2 be the paths to the destination and P_d be the most demanded path.

The computation of the minimum fair share V_{\min} , which is obtained from the most-demanded path P_d , is the same as the computation of fair throughput share in (8). Next, we use this minimum fair share to limit the input rate of those streams which take the most-demanded path to reach the destination, and compute the second optimal rate, the maximum fair share, the rest of the streams can achieve.

If we assume each link has equal link capacity among the whole network, we have:

$$ML'V \leq BW_1 \quad (9)$$

In order to compute maximum fair share, Equation (9) should be applied to all the paths in the network, along with the following two different sets of V :

$V(f_k) = V_{\min}$, when f_k taking P_d to reach the destination node

$V(f_k) = V$, when f_k not taking P_d to reach the destination node.

The lowest value among V_{P0} , V_{P1} and V_{P2} should be taken as the higher fair share for each stream, and used as

optimal transmission rate for the streams not taking the most demanded path to reach the destination.

$$V_{\max} = \min(V_{P0}, V_{P1}, V_{P3}) \quad (10)$$

V. PERFORMANCE EVALUATION

A. Simulation Model and Parameters

We use NS2 to simulate our proposed algorithm. In our simulation, the channel capacity of mobile hosts is set to the same value: 2 Mbps. In our simulation, 50 mobile nodes move in a 1000 meter x 1000 meter rectangular region for 100 seconds simulation time. Initial locations and movements of the nodes are obtained using the random waypoint (RWP) model of NS2. We assume each node moves independently with the same average speed. All nodes have the same transmission range of 250 meters. In this mobility model, a node randomly selects a destination from the physical terrain. It moves in the direction of the destination in a speed uniformly chosen between the minimal speed and maximal speed. After it reaches its destination, the node stays there for a pause time and then moves again. In our simulation, the speed is 10 m/s. and pause time is 10 seconds. The simulated traffic is Constant Bit Rate (CBR). For each scenario, ten runs with different random seeds were conducted and the results were averaged.

B. Performance Metrics

We compare our proposed MaxMin MAC protocol with our previous CAEFS MAC protocol [7] and the standard IEEE 802.11 MAC protocol. We mainly evaluate the performance according to the following metrics:

Aggregated Throughput: We measure aggregated throughput of all flows

Average Delay: We measure the average end- to-end delay of the flows.

Fairness Index: For each flow, we measure the fairness index as the ratio of throughput of each flow and total no. of flows.

The performance results are presented in the next section

C. Results

A. Effect of Varying Flows

In the first experiment, we vary the number of flows as 1, 2, 3 and 4.

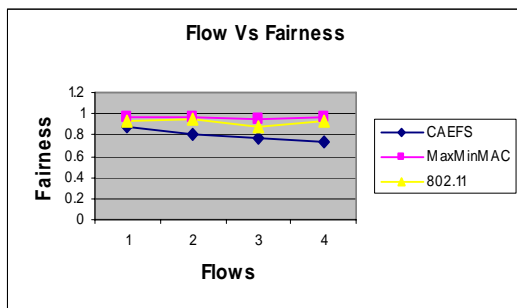


Fig. 2 Flow Vs Fairness

Initially we measure the Fairness. Fig 2 shows that MaxMinMac achieves more fairness than 802.11 and CAEFS, when the number of flows is increased.

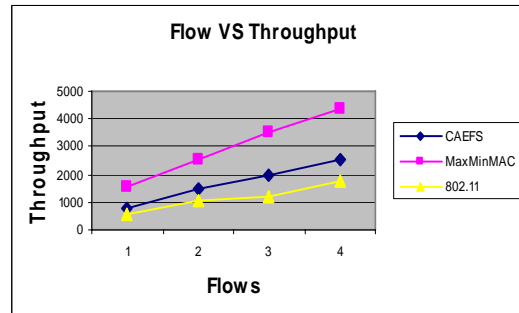


Fig. 3 Flow Vs Throughput

Next we measure the throughput. Fig 3 shows that MaxMinMac achieves high throughput than 802.11 and CAEFS, when the number of flows is increased

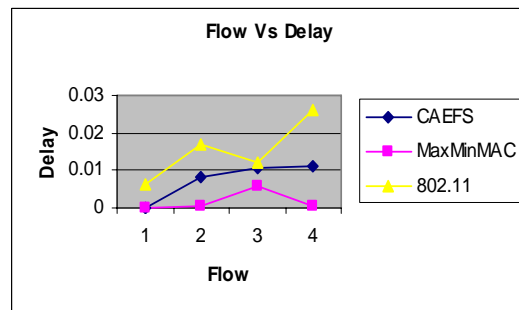


Fig. 4 Flow Vs Delay

From Fig.4, we can see that the fairness of 802.11 is less when compared to MaxMinMac and CAEFS. Also we can see that, the delay increases, when the number of flows is increased.

The delay against the number of flows is calculated for all the 3 protocols and the results are presented in figure4.

B. Effect of Varying Rates

In our second experiment, the packet sending rate is varied from 0.1Mb to 0.5 Mb.

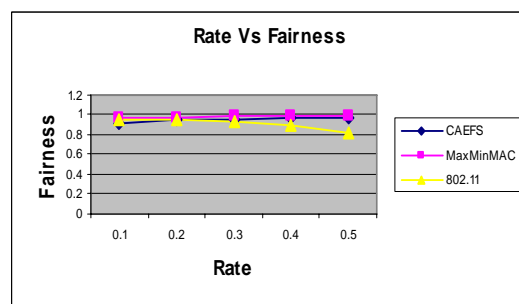


Fig. 5 Rate Vs Fairness

Fig 5 shows the Fairness of the nodes. From the figure, we can see that MaxMinMac consume more fairness than CAEFS and 802.11, when the rate is increased.

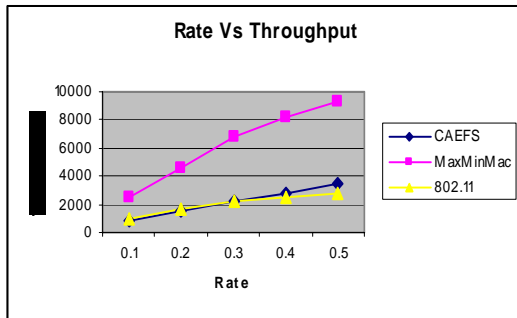


Fig. 6 Rate Vs Throughput

Fig 6 shows that. MaxMinMac achieve more throughput than CAEFS and 802.11, when the rate is increased.

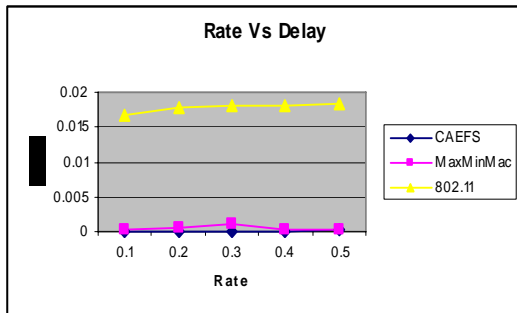


Fig. 7 Rate Vs Delay

Fig 7 shows that 802.11 achieve less delay than CAEFS and MaxMinMac, when the rate is increased.

VI. CONCLUSION

The more unfairness problems among the users due to its complicated network architecture occurs by the mobile adhoc networks multi hop feature. The traffic load at each node gets increased because of the additional conflict due to its traffic pattern which causes the nodes which are near the destination to starve the nodes further away from the destination. Also the network capacity is not able to satisfy the total users demand. These are the results for the unfairness problem. In order to calculate the optimal MAC layer bandwidth which is allocated for each flow in the network, we have proposed and created an algorithm in this paper. When there are flows that are not allocated to an optimal transmission rate we have used the maximum fair share achieved for limiting the input rate of those flows which are crossing the bottleneck link's contention area. It is also used to calculate the subsequent highest fair share. Our proposed protocol attains improved fair share and throughput with reduced delay which is proved through our simulation results.

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P. Priakanth received the Master of Computer Applications degree in 1998 from Bharathiar University. His Masters Thesis research was on "Throughput comparison of various Medium Access Techniques of wireless networks", and has completed Master of Engineering in Computer Science at Anna University in the year 2005. His M.E thesis research was on "Scalable Time slot Medium Access techniques for Multi Hop Adhoc Networks". Currently he is an Assistant Professor and research scholar at Kongu Engineering College, Anna University. His area of research is Medium access techniques in Ad-hoc Networks.



Dr.P.Thangaraj received the Bachelor of Science degree in Mathematics from Madras University in 1981 and his Master of Science degree in Mathematics from the Madras University in 1983. He completed his M.Phil degree in the year 1993 from Bharathiar University. He completed his research work on Fuzzy Metric Spaces and awarded Ph.D degree by Bharathiar University in the year 2004. He completed the post graduation in Computer Applications at IGNOU in 2005. His thesis was on "Efficient search tool for job portals". He completed his Master of Engineering degree in Computer Science in the year 2007 from Vinayaka Missions University. His thesis was on "Congestion control mechanism for wired networks". Currently he is a Professor and Head of Computer Technology Department at Kongu Engineering College, Anna University. His current area of research interests are in Fuzzy based routing techniques in Ad-hoc Networks.