

# Per Flow Packet Scheduling Scheme to Improve the End-to-End Fairness in Mobile Ad Hoc Wireless Network

K. Sasikala, R. S. D Wahidabanu

**Abstract**—Various fairness models and criteria proposed by academia and industries for wired networks can be applied for ad hoc wireless network. The end-to-end fairness in an ad hoc wireless network is a challenging task compared to wired networks, which has not been addressed effectively. Most of the traffic in an ad hoc network are transport layer flows and thus the fairness of transport layer flows has attracted the interest of the researchers. The factors such as MAC protocol, routing protocol, the length of a route, buffer size, active queue management algorithm and the congestion control algorithms affects the fairness of transport layer flows. In this paper, we have considered the rate of data transmission, the queue management and packet scheduling technique. The ad hoc network is dynamic in nature due to various parameters such as transmission of control packets, multihop nature of forwarding packets, changes in source and destination nodes, changes in the routing path influences determining throughput and fairness among the concurrent flows. In addition, the effect of interaction between the protocol in the data link and transport layers has also plays a role in determining the rate of the data transmission. We maintain queue for each flow and the delay information of each flow is maintained accordingly. The pre-processing of flow is done up to the network layer only. The source and destination address information is used for separating the flow and the transport layer information is not used. This minimizes the delay in the network. Each flow is attached to a timer and is updated dynamically. Finite State Machine (FSM) is proposed for queue and transmission control mechanism. The performance of the proposed approach is evaluated in ns-2 simulation environment. The throughput and fairness based on mobility for different flows used as performance metrics. We have compared the performance of the proposed approach with ATP and the transport layer information is used. This minimizes the delay in the network. Each flow is attached to a timer and is updated dynamically. Finite State Machine (FSM) is proposed for queue and transmission control mechanism. The performance of the proposed approach is evaluated in ns-2 simulation environment. The throughput and fairness based on not mobility for different flows used as performance metrics. We have compared the performance of the proposed approach with ATP and MC-MLAS and the performance of the proposed approach is encouraging.

**Keywords**—ATP, End-to-End fairness, FSM, MAC, QoS.

## I. INTRODUCTION

THE Transmission Control Protocol (TCP) over IEEE 802.11 and the media access control is designed for wired network and found to be not suitable for multihop ad hoc

wireless networks. The properties of these protocols have demonstrated serious concerns and thus a large number of research studies have highlighted several research issues of TCP in ad hoc networks [1]-[9]. It is observed that there is a great deal to design and develop a suitable rate based transport control protocol for mobile ad hoc network, which can effectively handle the fairness issue among multiple flows. The rate based transport protocol should be effectively and fairly allocate the bandwidth among the concurrent flows. Recently, few rate based transport protocols have been proposed specifically for ad hoc network. However, most of them fail to investigate thoroughly the fairness related issues with multiple flows and queuing dynamics at nodes in the context of ad hoc network [10]-[13]. The transport layer protocol uses IEEE 802.11 as the underlying data link layer protocol and as a result fairness cannot be achieved in a reasonable way. Alternatively, IEEE 802.11 can provide only per node fairness and that falls apart in the presence of asymmetric contention neighborhood. Further, the MAC layer of the IEEE 802.11 is used by the transport protocol and thus the bandwidth allocation between concurrent flows is not encouraging. In general, the data transmission process in the wireless network contends for the channel and obtains the same. In case, the channel is not available to the contending process or the contending node, the packet to be transmitted is buffered in the queue. Suitable scheduling algorithm is used for processing the queued packet and the design aspect of the scheduling algorithm plays an important role in determining end-to-end bandwidth of the flow of the respective packet.

The important research issue that is to be tackled in multihop ad hoc wireless network is the guarantee of fairness for concurrent flows in rate based transport protocol [14]. Various scheduling algorithms have been proposed in recent times and however, most of them are found to be not effective and consistent for ad hoc network. This is due to the fact that these scheduling algorithm only solve the per node based fairness in rate. The per node or window based transmission employs cross layer design and can also be called as per flow fairness with layered design. Also, most of the approaches, in the literature focus on First In First Out (FIFO) queuing and it is not suitable for providing a fair share of bandwidth to multiple flows. Thus, it is required to solve the per flow based unfairness caused by cross layer interaction of IEEE 802.11 MAC protocol and rate based transport protocol. The scheduling algorithm also should achieve per flow fairness in rate based transport protocol.

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A general cross-layer optimization problem, to maximize network efficiency (min-max power) of ad-hoc networks, is formulated including power adaptation, scheduling and routing functionalities. The non-convexity of the link capacity, high dimensionality of multi-hop routing and inter-layer interactions among the protocol layers, has resulted in more problems [15]. The concept of dividing a problem into a sub problems are used for demonstrating the functionalities of the protocol layers. Using a simple shortest path based algorithm to the high-dimensional routing, the sub problem is demonstrated. Recent technological advances have led to a growing interest in multi-antenna wireless ad hoc networks in which each node has more than one antenna. A crosslayer approach called QoS-aware smart antenna protocol (QSAP) is proposed for such networks that assures quality of service (QoS) needs of applications with reduced energy consumption [16]. The special multi-scenario of the topology in the wireless hybrid ad hoc networks is studied and a new performance evaluation Link Cognitive Cooperation Air Time Metric (LCCATM) and a novel cross layer multicarrier MIMO cognitive cooperation scheme are proposed [17]. In this scheme, the attributes both of the new performance evaluation of the cooperative diversity and the attributes of the topology space are integrated. It is observed that the cooperative ability of the networks is not only cognitive and also topology aware. The average achievable sum rates and the outage probability of the networks are all examined with the cross layer constraints.

The support of voice communication is fundamental in the deployment of an ad hoc network for the battlefield or emergency response. The QoS requirements of voice to identify the influencing factors in terms of communication and validate their significance through statistical analysis are used. An opportunistic protocol is proposed within a cross-layer framework that adapts these factors at different time scales [18]. PHY/MAC interaction is exploited in terms of Hop-by-hop adaptation to improve the use of the spectral resources through opportunistic rate-control and packet bursts. The end-to-end adaptation exploits the LLC/application interaction to control the demand per call through voice coding and packet size selection. The objective of this approach is to improve the number of calls admitted by minimizing loss of quality. A cross-layer quality of service (QoS) optimization policy is proposed for computational grid [19]. Generally, there are different QoS metrics at different layers of computational grids. To improve perceived QoS by end users over computational grid, QoS supports can be addressed in different layers. The cross-layer grid QoS optimization is tackled as optimization decomposition and each layer is considered as a decomposed sub-problem. This policy produces an optimal set of grid resources, service compositions and user's payments at all the layers.

A direct-Sequence Spread-Spectrum (DSSS) is proposed for scheduling transmissions in a mobile ad hoc network [20]. In this approach, multiple-access interference handled effectively for spatial reuse by reducing the transmission overhead to certain extent. This approach achieves greater en-to-end

throughput and terminal mobility. The network connectivity is preserved by adjusting the protocol overhead. It is known that radios in ad hoc networks support multi-rate transmissions and it is noticed that the traditional routing protocols in general do not use this feature well in multi-rate ad hoc networks. Thus, the performance of the network and resource utilization is not optimized. Various algorithms have been proposed to take advantage of the multi-rate transmission scheme and found that their performance is not optimized. A cross-layer optimization based approach can significantly improve the performance of multi-rate ad hoc networks over existing routing algorithms. As a result, link interference is considered and a joint routing and flow rate optimization is proposed for optimal performance in multi-rate ad hoc networks and named as a Cross-layer Optimization based Model for Multi-rate Ad hoc Networks (COMMAN) [21]. This approach is a distributed heuristic of this centralized model and considers the characteristics of multi-rate ad hoc networks. The fundamental scheduling, multiplexing and diversity trade-off in MIMO ad hoc networks has been analyzed. A unified framework for the scheduling-multiplexing and scheduling-diversity sub-problems is proposed that constitutes a major step towards solving the overall problem [22]. The fundamental trade-off between scheduling full and low multiplexing gain with interface nulling is the motivation of this approach. A scheme is proposed that employs TCP-aware network coding with opportunistic scheduling to enhance TCP throughput in wireless mobile ad hoc networks. The TCP parameter such as congestion window size and wireless channel conditions are considered simultaneously to improve TCP throughput performance. This approach also proposed a new adaptive-W (i.e., adaptive Waiting time) scheme whose objective is to adaptively control waiting time of overheard packets that are stored in a buffer to achieve tradeoff between throughput and overhead [23].

Based on the above discussion, it is noticed that all of these approaches use rate based transport protocol and ignores throughput unfairness of concurrent flows in the nodes of ad hoc network. In this paper, throughput unfairness of concurrent flow is analyzed. Based on the number of transmission hops, the end-to-end throughput of a packet flow degrades. In fact, for more number of transmission hops, the end-to-end throughput of a packet flow degrades significantly. In general, the fairness can be analyzed based on per node fairness and per flow fairness and in this paper, we analyze the per flow fairness of concurrent ATP flows. The rest of the paper is organized as follows. The next section presents the review of the literature. In Section III, the proposed approach is presented. The experimental result is presented in Section IV and we conclude the paper in the last section.

## II. LITERATURE REVIEW

The cross layer design and principle has been used for achieving fairness for concurrent flows [7], [24]-[26]. Similarly, the layered design has also been used for achieving fairness for a concurrent flow mechanism [27]-[29]. In cross layered design, the transport layer uses the information

available in the MAC and network layers for achieving fairness. In contrast, in layered approach, suitable modification is carried out to the protocol operated in the respective layer. In this approach, the information present in the other layers is not effectively used by the protocol running in one layer and thus there is no coordination among them to achieve fairness. The well-known rate based protocol ATP employs cross layer design approach by using information in the MAC layer with per node queue. The FIFO based packet scheduling mechanism has been used to determine the transmission rate. Based on the per node queue in the MAC layer of the intermediate nodes, the transmission rate is calculated by which the ATP calculates the delay based on per node basis and not on per flow basis. As a result, there exists unfairness in terms of throughput among the concurrent flows. In this paper, we address the above issue by adapting cross layer design approach in the intermediate node of state-of-the-art rate based transport protocol ATP by using the information present in the MAC layer. The per flow queue and round robin (RR) based scheduling mechanism has been applied to determine the transmission rate. A set of efficient resource allocation algorithms and channel access scheduling protocols based on Latin squares and social centrality metrics for wireless mesh networks (WMNs) has been proposed. This approach has multi-radio multichannel (MRMC) communication capabilities and coexists with IEEE 802.11 [30].

The authors [31] have proposed Wireless Congestion Control Protocol (WCCP) to support the transport service in multihop ad hoc networks. WCCP has used cross layer design approach and used the MAC layer information for improving the fairness in transport layer. In this approach, all the participating forward nodes in the path allocate the resources effectively and determine the MAC layer feedback accordingly. The end-to-end feedback determined by the end node along the data flow path is carried back to the source for controlling its sending rate. It is noticed that the performance of WCCP is encouraging compared to the traditional TCP in terms of channel utilization, delay, and fairness, and eliminates the starvation problem. Here the intermediate node uses channel business ratio for rate estimation unlike ATP which uses queuing delay and transmission delay. Reference [32] has proposed model for bandwidth sharing and fair allocation of bandwidth in wireless multihop networks as a general utility maximization problem with link bandwidth constraints. Lagrangean relaxation and duality are invoked to derive a gradient based iterative algorithm to solve the problem.

A per flow packet scheduling scheme has been proposed in which packets in a wireless node are classified as packets from the node and packets from the forwarding node [33]. The uplink and downlink packets are queued separately and the uplink packets are classified into packets originated within the node and forwarded packets from adjacent wireless nodes and queued. When the node transmits a packet, the fairness among the nodes is improved by scheduling based on the source identifiers in a round robin fashion of the queued packets. This

scheme is designed for achieving the same throughput among different flows irrespective of number of hops. However, the performance of this approach is encouraging while the transmission rate of the packets in all the nodes is same and also the link capacities are the same.

A scheduling method of wireless control networks for factory automation using IEEE 802.15.4 networks has been proposed. The superframe of IEEE 802.15.4 is used for the transmission of real-time mixed data for wireless control systems. The schedulability of real-time data is defined and scheduling algorithms are proposed for the efficient transmission of real-time mixed traffic [34].

Wireless data networks such as cdma2000 1x EV-DO and UMTS HSDPA use downlink scheduling that exploits channel fading to improve throughput. As future wireless networks will eventually support multimedia traffic, a proper criterion for scheduling is required that can count various service requirements [35]. Most of the opportunistic schedulers at the lower layer fail to handle explicit QoS defined in the upper layer. This approach proposed a hierarchical scheduling model for provisioning QoS and time varying channel feature separately. The upper level QoS scheduling is focused that supports various traffic classes in a unified manner.

The IEEE 802.11e Wireless Local Area Network (WLAN) provides controlled access features that can be used with scheduling algorithms for obtaining guaranteed per-session services. However, the multirate operation of the WLAN complicates the design of scheduling and Quality of Service (QoS) provisioning algorithms. A new solution based on Controlled Access Phase Scheduling (CAPS) framework has been introduced for fixed rate WLANs in our earlier works and employs a new fair central scheduler to achieve guaranteed fair services in a WLAN [36].

It is well-known that the data aggregation is an important and time consuming process in wireless sensor networks. For handling the interference in long latency of TDMA aggregation scheduling, the multi-channel design is considered a promising technique. Large numbers of parallel transmissions are available different frequency channels for minimizing time latency. A multi-channel minimum latency aggregation scheduling protocol, named MC-MLAS is designed using tree construction, channel assignment and transmission scheduling [37]. This work combines orthogonal channels and partially overlapping channels to consider the total latency involved in data aggregation.

In wireless networks, there is strong coupling among the traditional layers of the architecture, and these interactions are not ignored. The interaction between routing in the network layer and access control in the MAC layer is one of the classical examples. Similarly, the coupling between power control in the physical layer and scheduling in the MAC layer also considered as strong interaction. A TDMA-based wireless ad hoc network is proposed with a centralized algorithm of joint power control, scheduling, and routing [38]. The improvement of the network performance is achieved based on throughput, delay, and power consumption by using the joint algorithm.

IEEE 802.11 MAC protocol for medium access control in wireless local area networks is the de-facto standard for ad hoc wireless networks. However, the performance of the protocol such as fairness, delay and throughput is low in multihop wireless network. This is due to the fact that both the MAC and link layer tend to be contented. Various methods have been proposed based on the issue in both academia and industry. A suitable modification of IEEE 802.11 MAC protocol has been proposed to achieve per node fairness. However, the modification will influence the design and corresponding change is required in the hardware and is difficult to implement. In addition, this approach fails to solve the per flow unfairness problem. A Flow based Media Access Control (F-MAC) has been proposed for mobile ad hoc network, in which the 802.11 MAC is modified to resolve efficiency and fairness issue [39]. This approach uses the flow concept, incorporated with faster end-to-end forwarding by assigning higher priority to a node that has packet to relay compared to other nodes. After the transmission is completed, lower priority is assigned to the transmitted node to yield of ad hoc networks. At the same time, fair sharing of bandwidth is maintained among all the mobile nodes. A Probabilistic Control on Round Robin Queue (PCRQ) scheduling algorithm has been proposed and is aiming to achieve per flow fairness in multihop and ad hoc networks [40]. This algorithm works in the link layer without modifying IEEE 802.11 MAC protocol. Reference [41] has proposed a new media access control algorithm to achieve per flow fairness for maximizing throughput.

It is observed that all the above schemes concentrate on improving per node fairness in rate or window based transport protocol by employing cross layer design or per flow fairness in data link layer. Most of the above approaches employ layered design approach and however, the outcome of the analysis of the above mentioned approaches is not for achieving per flow fairness in rate based transport protocol with cross layer design. Thus, it is imperative that per flow fairness in rate based transport protocol should be achieved and per flow based queuing delay required to be computed for concurrent flows.

The focus of this paper is to present an efficient scheduling mechanism for the queue maintained by an intermediate node of ATP with per flow queue. It is found that the ATP flow experiences problems while queuing and transmission delay on per basis is maintained. In the proposed approach, the FIFO approach used in TP is replaced with the round robin scheduling, which overcomes the per flow unfairness problem caused by the single queue. The state on per flow is maintained instead of flow based on nodes. It is observed that considerable performance improvement is obtained in terms of fairness ratio and ns-2 simulator is used.

### III. PROPOSED WORK

Various fairness models and criteria proposed by academia and industries for wired networks can be applied for ad hoc wireless network. However, realizing end-to-end fairness in an ad hoc wireless network is a challenging task compared to

wired networks, which has not been addressed effectively. Most of the traffic in an ad hoc network are transport layer flows and thus the fairness of transport layer flows has attracted the interest of the researchers. The factors such as MAC protocol, routing protocol, the length of a route, buffer size, active queue management algorithm and the congestion control algorithms affect the fairness of transport layer flows. However, for achieving acceptable end-to-end fairness all the above mentioned factors are required to be investigated [42]. In this paper, we have considered the rate of data transmission, the queue management and packet scheduling technique. However, based on the understanding of the literatures, there is a gap in understanding the queue dynamics in nodes of ad hoc networks. Also, there is no thorough investigation on the effect of queue management and packet scheduling approaches in the intermediate nodes of the ad hoc network. The ad hoc network is dynamic in nature due to various parameters such as transmission of control packets, multihop nature of forwarding packets, changes in source and destination nodes, changes in the routing path influences determining throughput and fairness among the concurrent flows. In addition, the effect of interaction between the protocol in the data link and transport layers has also played a role in determining the rate of the data transmission.

#### *A. Maintaining Per Flow Queue in the Intermediate Node for Scheduling*

The IEEE 802.11 MAC protocol is the standard for wireless LANs and is also widely used in wireless ad hoc networks. However, as IEEE 802.11 has limitations when used in wireless ad hoc networks [4] has evaluated the performance of TCP in MANET using IEEE 802.11 as the underlying MAC protocol and determined that the fundamental reasons for TCP's instability is IEEE 802.11's unfairness problems. The unfairness problem in 802.11 MAC is caused by the behavior of the transport protocol, thus degrading the ability of the transport to achieve fairness [43]-[45]. Say for instance, while two TCP sessions are competing for the same channel and if one is scheduled back by a timeout. This situation is further complicated by the back off nature of both MAC and TCP timeouts and the session is lost. In IEEE 802.11, the nodes present closer to the network are able to access the channel frequently compared to the nodes present near the edge of the network and this kind of unfairness can lead to starvation of nodes [24]. As a result, there is a possibility to get the false route failures [46]. The well-known rate based transport protocol ATP also uses IEEE 802.11 as the underlying MAC protocol and the uneven distribution of bandwidth is considered as a challenging problem in MAC. Since ATP uses IEEE 802.11 MAC, ATP also suffers from unfairness problem. In addition, ATP uses only per node based delay to determine the current rate of data transmission and so achieving per flow fairness in ATP is not possible. It is required to achieve per flow fairness among the competing concurrent flow for effectively sharing the resources. We demonstrate the concept of per node and per flow based scheduling by depicting the scenarios below. In Fig. 1, per

node based scheduling is presented and per flow based scheduling is shown in Fig. 2.

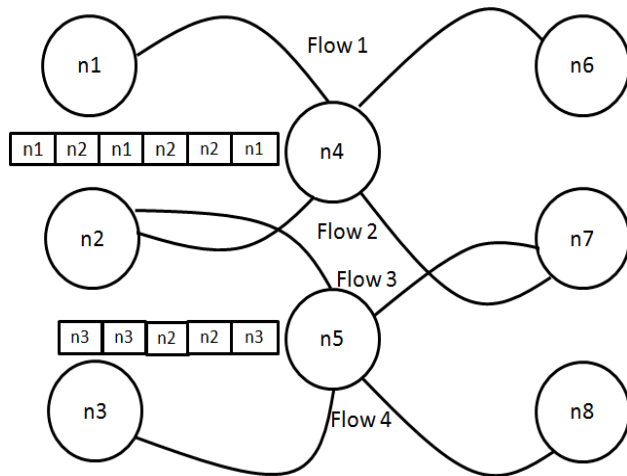


Fig. 1 Scheduling based on per node concept

In Fig. 1, n1 to n8 are nodes in a sample ad hoc network and arranged in such a way that the transmission range of n1 and n2 covers n4 and n7 and n6 covers n4. Similarly, n2, n3, n7 and n8 covers n5. In the conventional ATP based flow, the flow 1 between n2 and n6 is via n4 and flow 2 between n3 to n8 is via n5. As shown in flow1, the FIFO is used and due to back off procedure in MAC, other data in the queue may take large time. The similar procedure is visible in flow 4 also. In Fig. 2, we show the sample ad hoc network for demonstrating per flow scheduling and it is observed that the flow is segregated based on the flow from various nodes and thus is called as per flow scheduling. It is observed on both Figs. 1 and 2 the delay due to per node scheduling is greater than that of the delay due to per flow scheduling. This is due to the fact that the unfairness in MAC layer of the previous node of the flows path. The problem of unfairness is inversely proportional to the number of hops in the path. This issue needs to be solved by a suitable scheduling mechanism by considering the behavior of queues in the intermediate node. In the well-known that in ATP, the delay is calculated in the intermediate node and it is maintained on per node basis alone. In this paper, we have maintained the state of on per flow and found that the fairness ration is good. Compared to the features of the well-known ATP, the proposed protocol incorporating features such as per flow rate based scheduling and creating as well as maintaining the flow queue. As a result, the instantaneous throughput and fairness is improved. As shown in Fig. 2, the intermediate node, say n5, maintains for queue for each flow. Also, using these queue information, more accurate picture of the information needed for each flow is maintained, which helps us to predict the correct rate for the corresponding flows.

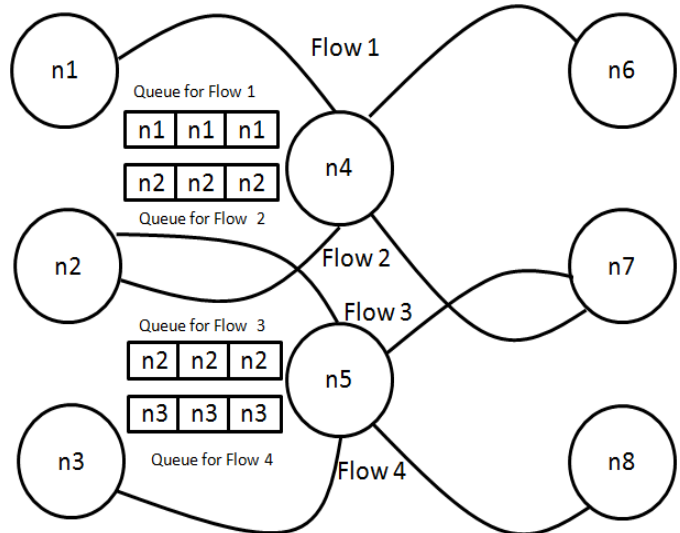


Fig. 2 Scheduling based on per flow concept

In general, the flow is classified using the combination of source address – destination port number. The source address, destination address of IP datagram header and source port number, destination port number of transport layer segment header do not change anywhere in between source and destination. Thus, various flows in each node match with its own flow in any other node. In the proposed protocol, the task and processing happens only up to physical, data link and network alone, which is in contrast to the ATP, where the information belongs to physical, data link, network and transport of intermediate node is processed.

This is due to the fact that the delay information is stored and processes in the data link layer header only and not in the transport layer header. Thus, the source and destination address combination is used for separating the flows and the transport layer information is not processed. As a result, the processing time, which is copying transport layer segment and delay from network to transport layer is minimized to great extent. The data packet of concurrent flows of same sender and destining at same receiver is considered as the data packets belonging to the same flow. The queue is created based on the source and destination combination and is uniquely maintained. Each flow is attached with a timer and is updated with a predetermined value. Each packet has to reach the flow within the timer expiry period and otherwise the flow is cancelled. Similarly, if there is no packet in the transmitted queue, the flow is cancelled. In this paper, we have fixed the timer value five second and this is due to the fact that in ATP the epoch period is set as one second. A robin round mechanism is used to enforce fairness and packet is removed from the flow, processed, sent to the MAC layer for transmission and removed from flow.

For each flow a delay parameter ( $D$ ) is maintained and is given below

$$\text{Delay } (D) = WT + TNH \quad (1)$$

In (1),  $WT$  is the waiting time of the packet in queue before processing and  $TNH$  denotes the time required by MAC layer to send the data packet to the next hop. The delay calculated as exponential average as follows

$$\text{Delay } (D) = (w1) D + (1-w1) D \quad (2)$$

The value of  $w1$  calculated based on the previous delay value so that the value reflects the current delay in the network. This is due to the fact that the ad hoc network is dynamic in nature. Thus, based on various experiments, 75 percent of previous delay is averaged with 75 percent of current delay. While new flow starts, a probe packet is sent by the sender and the delay value is calculated in the intermediate nodes. In addition, there will not be any delay value associate with the new flow with refer to (2) and the delay for the new flow is calculated as,

$$\text{Delay } (D) = \frac{1}{n} \sum_{i=1}^n D_i \quad (3)$$

Refer to (3),  $D_i$  is the  $i^{\text{th}}$  flow and its delay and  $n$  is the number of active flows in the queue.

#### B. Finite State Machine (FSM) for Queue and Transmission Control

In Fig. 3, the Finite State Machine (FSM) for the queue control mechanism is depicted. A set of per flow queue is maintained for each source and destination address combination for holding the packet during the process. The queue control process waits for an incoming signal and based on its characteristics, the output of the queue controller varies.

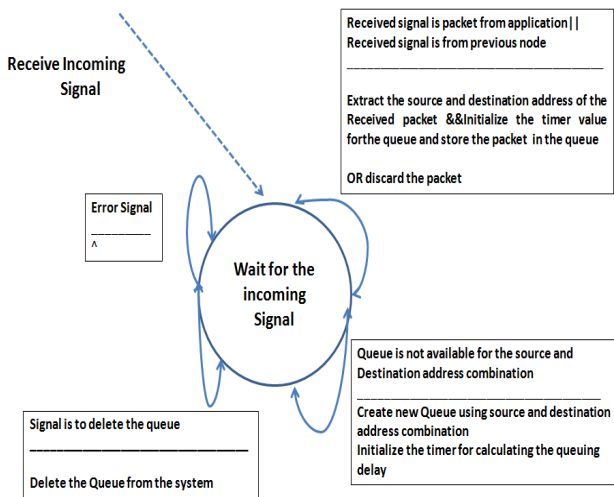


Fig. 3 FSM for Queue Control Mechanism

There are four states for the FSM of the queue control and first state is for the error signal. In the second state, the signal is received from an application or from the previous node. The state performs activities such as extracting the source and destination address of the received packet and initializes the timer value. If both of the above mentioned points are not true,

the packet is discarded. In line with the above, the scheduler of the proposed approach selects an element from a queue and de-queue the packet based on round robin fashion and the packet is transferred to the output queue. In addition, if the queue is empty, based on the timer value the corresponding queue is deleted.

Below, in Fig. 4, the FSM for transmission control is presented. There are four states in the FSM and the first state, event-action is for the signal from the scheduler and the output buffer has sufficient space. The timer is initialized and the transmission delay is calculated and the packet is successfully stored in the output buffer. The second event-action combination receives the signal and determines the successful transmission of a packet and return the state.

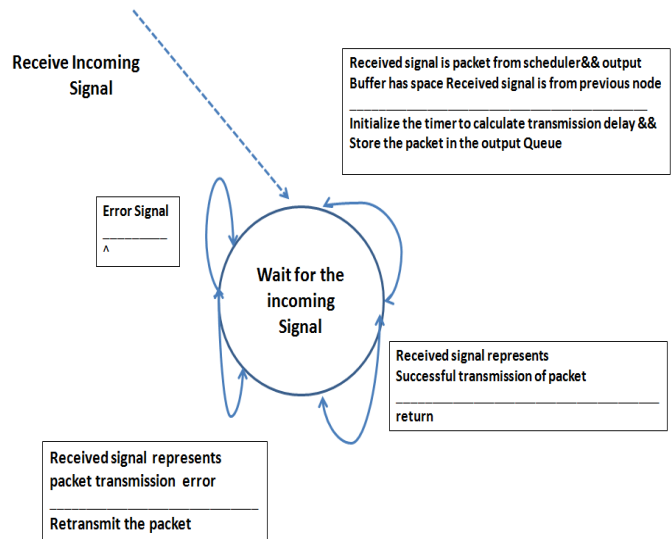


Fig. 4 FSM for Transmission Control Mechanism

The third event-action combination is invoked for a transmission error and the packet is re-transmitted and final event-action combination works for the error signal.

#### IV. EXPERIMENTAL RESULTS

We have used NS-2 network simulator for the experimental purpose. The effect of throughput and fairness on concurrent flows is studied. A stationary grid topology with twelve nodes and a mobile topology with 1000m X 1000m grid with fifty nodes by using random way point mobility model. The effect of mobility is constrained while measuring the effect of fairness of concurrent flows and stationary grid topology is used for simulation. Radio transmission range of each node is maintained with 200 meters and a node covers neighboring nodes in all the four directions. We have considered 2 Mb/s/sec. as the channel capacity and free space. Dynamic source routing and IEEE 802.11b is used as the routing and MAC protocol respectively and FTP is used as the application layer protocol. Packet size of 512 bytes is used and the simulation is conducted for 100 seconds. The average values are measured from ten simulation runs. We have used the Jain's fairness index for measuring the fairness ratio. The



available bandwidth should be equally shared among all the competing flows. The Jain's fairness index can be calculated as follows:

The fairness index of a set of throughput  $(x_1, x_2, x_3, \dots, x_n)$  is,

$$f(x_1, x_2, \dots, x_n) = \frac{\left(\sum_{i=1}^n x_i\right)^2}{n * \left(\sum_{i=1}^n x_i^2\right)} \quad (4)$$

The values of the fairness index is [0-1] and for the maximum value the measurement values,  $(x_1, x_2, x_3, \dots, x_n)$  is absolute equal or otherwise. In the experimental setup i.e. in the stationary grid topology, the effect of concurrent flows on the throughput and fairness index is investigated. Below in Fig. 5 the throughput is shown for ATP, MC-MLAS [37] and the proposed approach. The proposed approach has achieved 99% fairness index while the ATP has achieved only 97%.

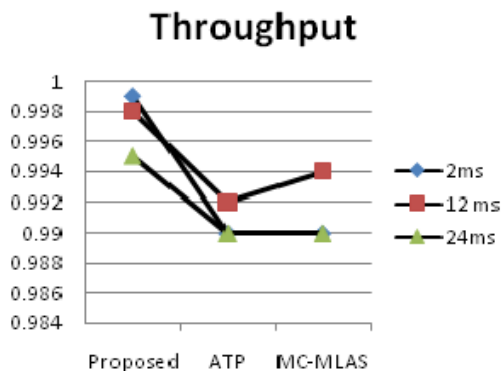


Fig. 5 The average throughput of the proposed approach

The fairness index for various mobility values are presented in Fig. 6 and it is observed that the fairness index of ATP is lower than the proposed approach.

#### Mobility Vs. Fairness Index (5 Flows)

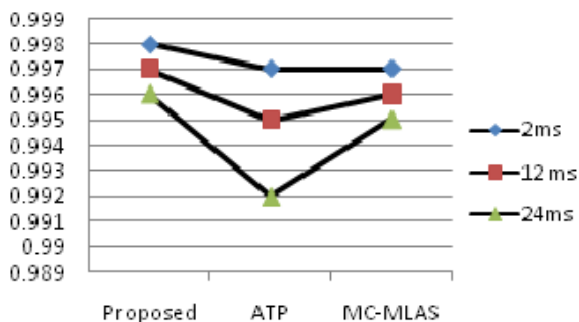


Fig. 6 The mobility and fairness index

#### Mobility Vs. Fairness Index (15 Flows)

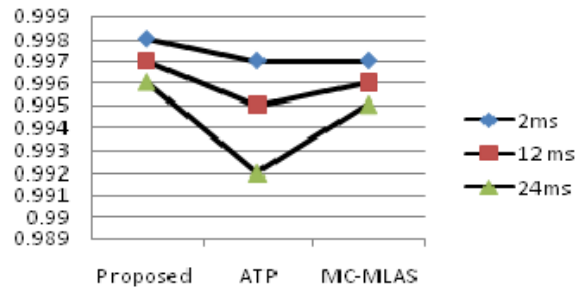


Fig. 7 The mobility and fairness index

This is due to the fact that the ATP maintains a delay on per node basis and the proposed approach maintains a delay on per flow basis. It is a well-known fact that the intermediate node processing the scheduling tasks with more than one flow fails in sharing the bandwidth. Also, packets from different flows are being scheduled on par and it is difficult to measure the optimal flow rate. This is due to the fact that the unfairness caused by MAC layer and it does not allocate equal shares of bandwidth to the computing nodes. However, the proposed approach achieves a higher fairness index and this is due to the fact that the rate is determined on per flow basis. In the mobile topology, the fairness ratio between ATP and the proposed approach is compared to 2 m/s, 12 m/s, 24 m/s mobility for 5 flows and 15 flows and the result is depicted in shown in Figs. 6 and 7. In the result, the source and destination nodes are chosen in random order. Also, it is observed that the fairness ratio decreases with an increase in the mobility and for the proposed approach has achieved a higher fairness index for 5 and 15 flows compared to the conventional ATP.

#### V. CONCLUSION

We have proposed a fairness model for a mobile ad hoc network. The fairness in the transport layer flow is analyzed and data transmission rate, queue management and packet scheduling issues are considered. In each node, queue is maintained for each flow and all are identified based on the source and destination address of the respective nodes. The flow header is not processed in all the layers of the intermediate nodes and thus the delay in the network is reduced, where each flow has a separate delay time stamp. The fairness index for mobility and throughput are considered using ns-2 simulator. While comparing the performance of the proposed approach with the some of the recently proposed approach, it is found that the proposed approach performs well.

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