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Published version

MARCHANG, Jims, GHITA, B. and LANCASTER, D. (2014). Hop-Based dynamic fair scheduler for wireless Ad-Hoc networks. In: 2013 IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS). IEEE, 1-6.

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Hop-Based Dynamic Fair Scheduler for Wireless Ad-Hoc Networks

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Abstract - **In a typical multihop Ad-Hoc network, interference and contention increase when flows transit each node towards destination, particularly in the presence of cross-traffic. This paper observes the relationship between throughput and path length, self-contention and interference and it investigates the effect of multiple data rates over multiple data flows in the network. Drawing from the limitations of the 802.11 specification, the paper proposes a scheduler named Hop Based Multi Queue (HBMQ), which is designed to prioritise traffic based on the hop count of packets in order to provide fairness across different data flows. The simulation results demonstrate that HBMQ performs better than a Single Drop Tail Queue (SDTQ) scheduler in terms of providing fairness. Finally, the paper concludes with a number of possible directions for further research, focusing on cross-layer implementation to ensure the fairness is also provided at the MAC layer.**

Keywords **– Ad-Hoc, fairness, hop-based routing, QoS.**

I. INTRODUCTION

A multihop ad-hoc network consists of independent mobile devices working collaboratively in a distributed fashion and operates by co-ordination and cooperation among the various wireless mobile devices without the need of any infrastructure. As each device is capable of sending, receiving and relaying data packets, any node can act as a source, destination or a router depending on its activity. These mobile devices work with slow processors, relatively small memory and low power storage [1]. Communication in ad-hoc networks is challenging particularly due to the shared channel, which introduces contention and interference, and the mobility of the nodes, which causes performance degradation and network inconsistency [2]. The provision of QoS in this environment is challenging and is the subject of considerable research [3-5]. The IEEE 802.11 DCF standard does not support QoS, while the IEEE 802.11e standard does supports QoS, but it is designed only for a single hop environment and is based only on prioritizing different types of data traffic. QoS provisioning for a data flow inherently requires an intelligent dynamic resource allocation decision, based on acquiring resource information along the transit route, which should help the contending nodes to achieve higher QoS [6]. Prior studies considered the impact of delay and jitter induced by scheduling techniques [7], nodes mobility and dynamic interference [8], cluster based scheduling [9-10], fairness and performance by enhancing random back-off values [11], as well as the overall capacity of the channel [12]. Among solutions proposed by prior studies [13-15], possible alternatives are to control the throughput of the already admitted flows versus new flows, based on saturated, unsaturated, and semi-saturated network conditions [16] or enhance the throughput of a flow by gathering capacity information such as bandwidth and delay at link layer [17].

The situation becomes even more complex, when there are multiple competing data flows. Requiring fairness leads to a trade-off between overall network utilization and distribution of traffic between competing flows. Fairness can generally be achieved by using different queues for each category (say) source or relay, or different queues for each flow with the same or different weights while scheduling [18].

This paper enhances the work proposed by past research on establishing fairness across multiple flows by considering the path length transited by each flow. On each forwarding node, the traffic priority is established based on the number of hops a packet has taken from its source; as a result, distant flows with high hop counts are favoured over new flows with low hop counts. In reference [19] packets are prioritised using IEEE802.11e together with time to live and hop count to ensure low end-to-end delay and decrease packet loss. However, reordering and selection of packets are required for each individual packet, making it unrealistic from a complexity and processing perspective.

To provide a clear foundation, the next section of the paper is an analysis of the impact that hop count and different data rates have on the network throughput. Section III gives details of the Hop Based Multi Queue (HBMQ) dynamic scheduler design based on the hop count of a data flow. Section IV describes the scenario and the network parameters considered in the simulation. Section V compares and analyses the simulation results of the HBMQ scheduler with those of the Single DropTail Queue (SDTQ) scheduler. Finally, section VI concludes the paper and proposes possible directions for future research.

II. PROBLEM STATEMENT

Contention is one of the core issues that impact the performance in wireless ad-hoc networks. As nodes route the traffic between source and destination, contention reduces the throughput of a flow as the length of the transited path increases. The aim of the section is to quantify through a series of simulations the relationship between the path length and the maximum performance achieved by a flow. In first instance, the analysis will focus on a single flow, in order to evaluate self-contention, then will expand to multiple flows to measure the contention impact.

The simulations in this paper are based on NS2 [20] with the parameter listed in Table 1. In all cases the topology will be aligned with nodes spaced by 200m as shown in Figure 1. In consequence, packets hop between adjacent nodes but interference can occur up to next nearest neighbours.

Table 1

Name of the Parameter	Protocol used/Value of the parameter
Grid Size	2500mx2500m
Medium Access	IEEE 802.11DCF with RTS/CTS
Routing	AODV [21]
Queue	DropTail with size 200 packets
Bandwidth	2Mbps
Transmission Range	250m
Carrier Sensing Range	550m
Simulation Time	1000 Seconds
Traffic Type	CBR with Packet Size 500Bytes

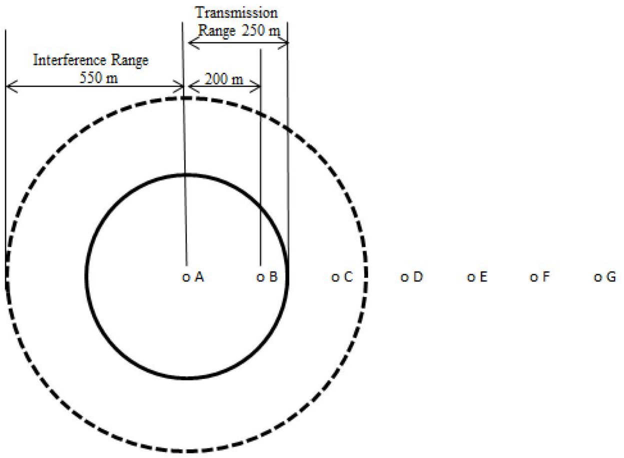

Figure 1. Topology settings of the Ad-Hoc Network

A. Single flow:

Simulations of a single flow using the standard DropTail queue were first performed. Simulations of 1000 sec. each were carried out for 32 different source data rates starting from 32Kbps up to 1024Kbps to determine the throughput for path lengths starting from one hop to six hops. Figure 2 summarises the results.

There are a number of conclusions from this data. Firstly, for a single hop, the throughput is directly proportional to the data rate of the source. Even though it is a single flow, there is a high self-contention and interference along the path; leading to a saturation of throughput. The saturation values are shown in Figure 3 indicating that the throughput is inversely proportional to hops. It also indicates that there is no point in sending data at a rate higher than the saturation throughput for that number of hops.

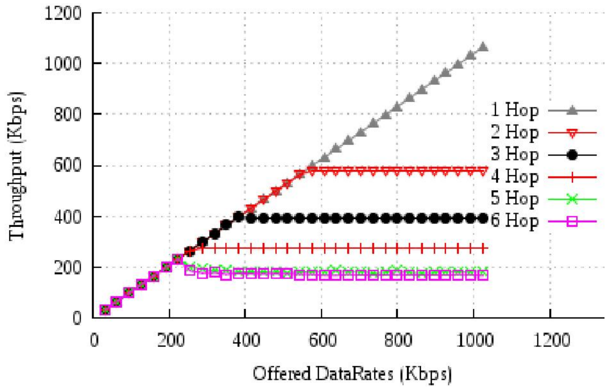

Figure 2. Throughput Vs Hops

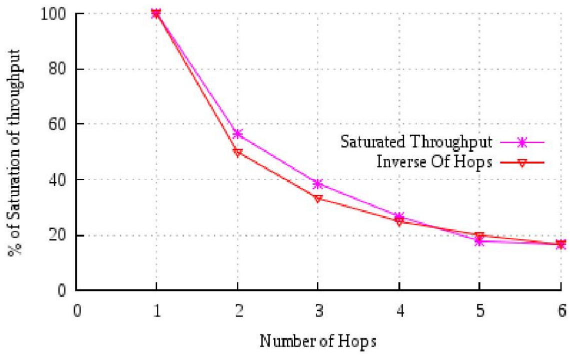

Figure 3. Saturation points of the throughput Vs number of hops

B. Multiple Flows.

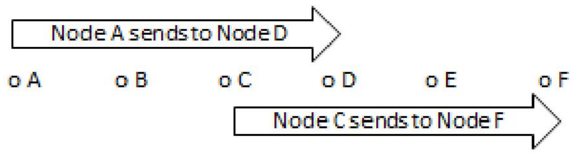

Figure 4. Multiple Hops with multiple flows Ad-Hoc network

In the case of multiple flows, a number of additional problems become evident. Consider the network topology of Figure 4, where Node A sends to Node D, at time t1 and Node C sends to Node F, at time t2; both the sources are sending at high data rates (>400Kbps) and t2 > t1. The single flow simulations indicated that, for a channel capacity of 2Mbps, the throughput becomes saturated at around 397Kbps for a 3 hop path length. Based on these simulation conditions, Node D will be receiving up-to 397Kbps, but when Node C becomes active (considering the shared channel) then the flow generated by Node C will induce more congestion on the already existing flow generated from Node A. If the nodes use a single queue, then the flow generated locally would definitely overload and overtake the distant flow and further reduce its data rate. When the source data rates are low the multiple flows share fairly due to resource overprovisioning; the challenge is to ensure fairness among the flows when the network becomes saturated.

To investigate in a more quantitative manner, consider two data flows as in Figure 5, where the two data flows (f1, f2) are generated from different sources, transit different path lengths, and transport different data rates. A set of network simulations was run to determine how the bandwidth is shared when the sum of the data rates of the two flows is fixed, while varying the ratio between the two flows. The total fixed load (sum of the data rates of f1 and f2 is fixed) for each simulation set is given in the first column of Table 2.

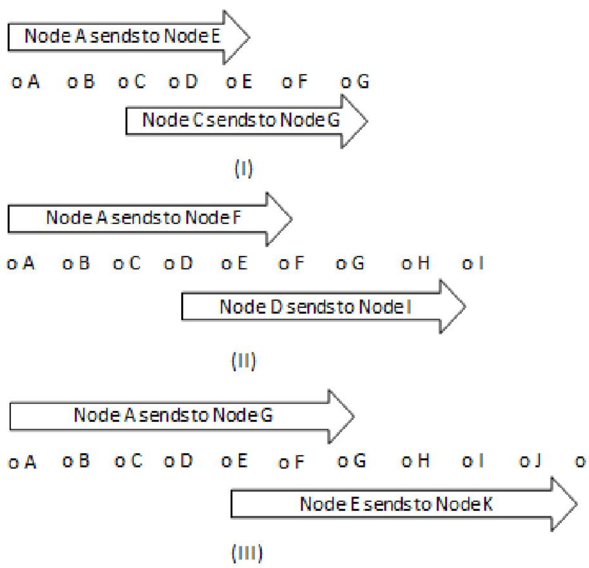

Figure 5. Simulation Scenario (I), (II) and (III).

For each simulation, Table 2 records the values of the data rates for the two competing flows that lead to equal throughput at their respective destinations. The results clearly show that when two data flows compete, the flow generated locally i.e. flow (f2) will take over and, in order for the two flows to have comparable throughput, the flow with higher hop count will require a significantly higher data rate.

Table 2

Total Loads (Kbps)	Scenario I. (f1,f2) Kbps	Scenario II. (f1,f2) Kbps	Scenario III. (f1,f2) Kbps
132	(68,64)	(68,64)	(68,64)
332	(212,120)	(248,84)	(248,84)
632	(509,123)	(554,78)	(563,69)
932	(815,117)	(851,81)	(851,81)
1056	(941,115)	(977,79)	(977,79)

III. PROPOSED SCHEDULER

The simulations presented in Section II demonstrated that the data rate of a single flow is reduced for each node transited by that particular flow by a factor that can be approximated with the inverse of hops. When two flows arrive at a node after having transited a different number of hops, the traffic of the more distant flow is further affected by the single queue, leading to an uneven distribution of resources across the network. This section proposes a scheduler to redistribute resources at the network layer based on the path length of individual flows reaching a node and competing for access.

A. Proposed Scheduler:

The new proposed scheduler, as shown in Figure 6, consists of several queues. They are as follows:

- QR – routing information queue - is a queue reserved for the routing information packets. This queue is given the highest priority in order to guarantee route establishment. If highest priority is not given, then the time-out will occur more frequently when the network gets congested, due to the maximum route request timeout Max_RREQ_Timeout= 10s and route reply waiting time RREP_Wait_time=1s timers within Ad-Hoc On Demand Distance Vector (AODV) routing protocol.

- Q_i , *i*-hops queue - individual queues for data packets that have transited *i* hops (i=0 for packets generated in the local node). This allows individual control for packets with different hop counts, potentially leading to a better chance of getting scheduled for the next hop and finally proceeding towards their respective destinations. In any practical application queues might be combined to conserve resources. Indeed, in the simulation presented here queue Q6+ is used for data packets that have transited six or more nodes in the network.

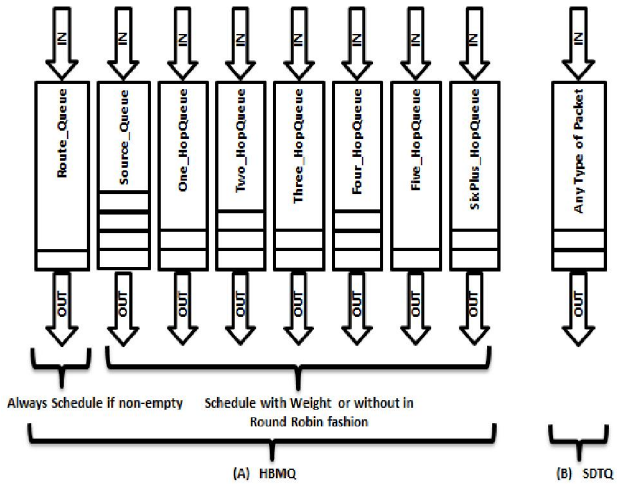

Figure 6. (A) Hop Based Multi Queue (HBMQ) Scheduler. (B) Single Drop Tail Queue (SDTQ) Scheduler

B. Scheduling scheme:

Medium Access Control (MAC) protocol sets the rules on how and when the channel is to be accessed. Since the wireless nodes of Ad-Hoc network are distributed in nature and use a shared channel, carrier sensing and contending for channel access is one of the most effective approaches and hence used by IEEE 802.11. In IEEE 802.11 series, in order to send a data packet, initially RTS (Request To Send) is sent, then upon receiving CTS (Clear To Send) from its next hop neighbour, the actual data packet is sent and finally it is acknowledged by an ACK packet. Before sending a control or a data packet, the system always waits for DIFS/SIFS + random back-off amount of time in order to prioritize the packets as well as reduce the chances of collision. The control packets RTS and CTS are used to solve the problem of hidden and exposed terminals of the error prone wireless shared channel of Ad-Hoc networks.

Whenever a packet is requested by the MAC protocol to send to the next hop, the scheduler first queries the QR queue and transmits any packets in it in order to provide highest preference to the routing related information. The scheduler then proceeds to query queues in a round robin fashion. The queue pointer or turn is preserved between calls and when a queue is empty, the next queue with lower hop number is queried and the queue pointer is decremented. If all the seven data queues are empty, the scheduler returns a NULL pointer to the calling MAC protocol. Considering that all the data flowing in the network are equally important, scheduling is done at the ratio of 1:1:1:1:1:1:1 , except for QR, which always takes precedence.

C. Pseudo code of the Scheduler:

Table 3 and Table 4 describe the pseudo code of the scheduler of HBMQ in terms of De-queuing and En-queuing respectively.

Table 3

PseudoCode for De-queuing

```
Scheduler preserves the queue pointer x between subsequent calls
IF QR_length > 0
        return(Dequeue_packet)
ELSE IF (Qi==0, i∈[0,6])
        return(NULL);
ELSE
    FOR(j=0;j<=6;j++)
        IF Qx_length > 0
            x=|(x-1) mod 7|   // Sets the turn of the next queue
            return( Dequeue_packet)
        ELSE
            x=|(x-1) mod 7|   // Sets the turn of the next queue
```

Table 4

PseudoCode for En-queuing

```
READ hop_travelled, ptype
x=hop_travelled
IF (ptype=R_info)
        Enqueue_packet in QR
ELSE
        Enqueue_packet in QX
```

IV. SIMULATION SCENARIO

In order to test the effectiveness of the new scheduler HBMQ, consider the scenario III of Figure 5 with two flows. A comparison is made with the standard DropTail scheduler and the data rates are set according to the following two cases.

CASE 1: The data flows (f1) and (f2) are generated from source A and source E respectively each with the same data rate which ranges from 32Kbps to 1022Kbps. Each simulation lasts for 1000 Seconds.

CASE 2: The data flows (f1) and (f2) are generated from source A and source E respectively with different data rates. In this case the sum of the data rates of f1+f2 is fixed at 1056Kbps; f1 increases from 32Kbps to 1022Kbps while f2 decreases from 1024Kbps to 34Kbps. Each simulation lasts for 1000 Seconds.

V. RESULT AND ANALYSIS

CASE 1:

Figure 7, shows that the average throughput of both flows initially increases as the supply data rates increases. When the supply data rate increases beyond 150Kbps the average throughput of f1 drops in both the scheduling schemes of SDTQ and HBMQ. The average throughput of the f1 flow, in this region is 9Kbps for SDTQ and 23Kbps for HBMQ. In a similar manner, beyond an offered data rate of about 250Kbps the throughput of flow f2 converges to an average of 172Kbps and 157Kbps in case of SDTQ scheme and HBMQ scheme respectively.

It can be concluded that as long as there is enough bandwidth and no congestion in the network, not only throughput increases, but the flows are perfectly fair. However once the network becomes saturated, HBMQ provides a better distribution of throughput in comparison with SDTQ scheduler. Thus, during high load in the network, the degree of fairness among the flows is higher in case of HBMQ to that of SDTQ and, in addition, the flow that has transited a longer path slows down much faster in SDTQ in comparison with HBMQ. From a statistical perspective, there is an increase of 14Kbps corresponding to 155% throughput on average in HBMQ for long transit path flow f1 in comparison to that of SDTQ, improvement that requires a trade-off of only 15Kbps corresponding to -8.7% throughput of flow f2.

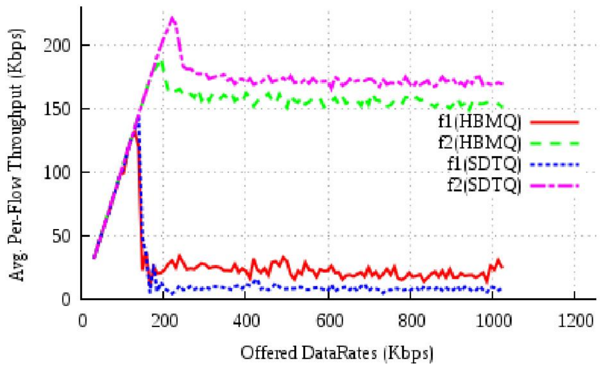

Figure 7. Throughput of flow1 and flow2 of HBMQ Vs SDTQ in CASE I

Figure 8, describes the fairness between flows f1 and f2 of case I using Jain's Fairness Index (1) where, n is the number of flows and $x_0, x_1, x_2, \ldots, x_n$ are the values for which the fairness index is to be found. In our case, we tested with n=2.

$$f(x_0, x_1, x_2, \cdots, x_n) = \frac{\left(\sum_{i=0}^{n} x_i\right)^2}{n \sum_{i=0}^{n} x_i^2} \quad \text{------} \quad (1)$$

At the lower data rates, the fairness index of both schedulers (SDTQ and HBMQ) is perfect, but as the network becomes saturated, the fairness index for the two flows when using HBMQ converges to a value of 65% compared to the 55% for the SDTQ scheduler.

Figure 8. Jain's fairness index of HBMQ Vs SDTQ in CASE I

CASE 2:

This case is constructed to observe how performance of data flows, as shown in Figure 9, is affected as the ratio of traffic between competing flows varies. Initially, the data rate of flow f1 starts with a very low value and the data rate of flow f2 with a very high value, then gradually the data rate of flow f1 increases and the data rate of flow f2 decreases. It is observed that flow f2, which is along the route of flow f1, takes over the channel most of the time even when its source data rate is only around 200Kbps, despite a high data rate (around 850Kbps) of flow f1. As the source data rate of flow f1 goes above 850Kbps and data rate of flow f2 drops below 200Kbps, the performance of flow f1 gradually increases. This indicates that, despite having a source with high data rate, if another flow starts sending data along its route, then its performance is highly degraded. In this case, the synchronizing point (highest degree of fairness in terms of throughput) between the two flows is when the source data rate of flow f1 and flow f2 is around 970Kbps and 80Kbps respectively in both the schemes. It means that for a data flow arriving from a far distance, it needs to inject the data with a very high rate to be able to compete with the flows generated locally.

On an average, the performance of flow f1 in case of HBMQ is much better to that of the SDTQ. And the degree of fairness among the flows f1 and f2 in HBMQ is higher to that of the SDTQ.

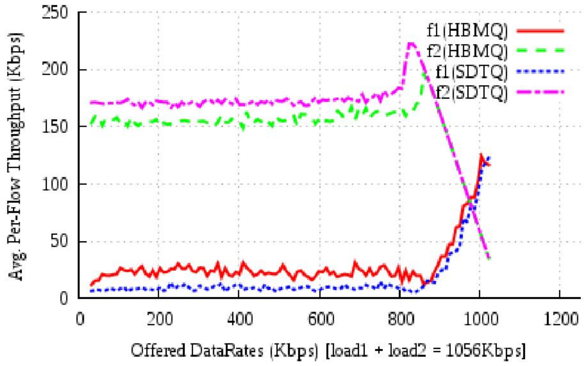

Figure 9. Throughput of flow1 and flow2 of HBMQ Vs SDTQ in CASE II

Figure 10, describes the fairness index of flows f1 and f2 of case 2 using SDTQ scheduler and HBMQ scheduler. The average fairness index of HBMQ outperforms the SDTQ scheduler when the network becomes saturated.

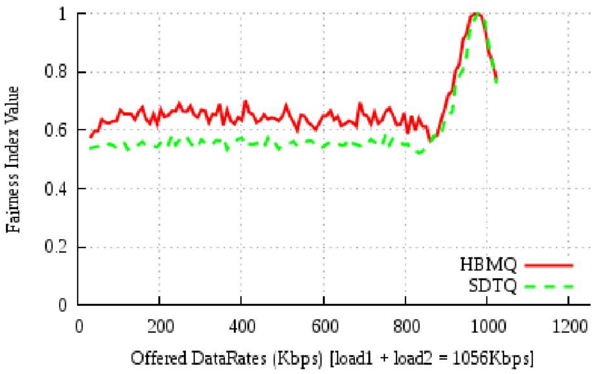

Figure 10. Jain's fairness index of HBMQ Vs SDTQ in CASE II

VI. CONCLUSION AND FUTURE DIRECTION

This paper investigated the impact of path length on network performance and the effects of competing flows and proposed a dynamic hop based scheduler, called HBMQ, that aims to alleviate the unfair scheduling inherent for Ad-Hoc wireless networks. Simulation results show that the proposed scheduler shares the channel more efficiently than a standard wireless scheduler when the sources data rates are of the same or of different values. Since we worked in the context of IEEE 802.11DCF random access mechanism, even though the proposed scheduler uses prioritized hop based multiple queues, the MAC layer mechanism does not provide any form of priority to the nodes which are arriving with higher hop count, so the performance gain is bounded by MAC behaviour. As a result, a clear direction for future work is to couple the priority provided at the scheduler level with the access mechanism of the IEEE 802.11e protocol. Finally, it is also observed that despite the high availability of bandwidth, the throughput in the network is comparatively low, so we are also looking forward to explore the effects of congestion, interference and idle time in the network apart from contention issues. We are also investigating the design of a MAC protocol based on the hop count of the data packets travelling in the network, so that it will be synchronized with the prioritized data packets of the scheduler level.

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