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Wireless Mesh Networks: Unfairness Issue and Way Out

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Abstract—**Wireless Mesh Network offer advantages in terms of scalability, self deployment and ease in implementation. As network resources are finite, fair allocation of these amongst nodes is major issue. This paper tries to address this issue by using dual queue approach.**

Keywords-ad-hoc networks; unfairness; dual-queue; wireless mesh nodes; throughput

I. INTRODUCTION

In contrast to the type of networks that rely on pre-deployed communication infrastructure, ad hoc networks attempt to meet the networking demand where it is very difficult or inefficient, if not impossible, to establish a network infrastructure. Ad-hoc networks are formed by a group of mobile nodes with wireless transceivers that can dynamically organize themselves into a temporary network with an arbitrary topology. The network resources (buffer space, bandwidth) are always finite in the any network to provide broadband access, so resources may have to be allocated and scheduling decisions have to be made [1] and there is possibility of delay in any system that involves waiting, so traffic flows that pass through many hops to their destination will experience more delay, and the end-to-end delay varies with the number of hops to the destination [2].

The throughput capacity of wireless mesh networks and the network performance will be increased if the issue of unfairness behavior of the flows in the network is addressed. The fair sharing of network resources can be achieved by giving the flows from distance source nodes crossing many network hops to the destination priority at each node queue over the flows from hops close to the destination (gateway). This reduces the end-to-end delay of the traffic flow and makes all the source nodes in the networks to have equal share of the network resources irrespective of their distance from the destination.

The aim of this paper is to investigate and provide a workable solution (using NS2) to address the end-to-end throughput unfairness behavior of traffic flows in multi-hop wireless mesh networks. The approach is based on the position (the number of hops passed to the gateway) of the traffic source in the network relative to the gateway; the investigation is performed at the network layer which is responsible for end-to-end packets transmission (from source to destination across multiple hops).

II. BASICS

A. Hidden and Exposed Nodes

The most well known single-channel MAC layer protocol is CSMA/CA, which is also widely used to form mesh of wireless ad-hoc nodes. Each wireless node has two sensing ranges namely transmission range (TX) and carrier sense range (CS). Normally CS range is adjusted in such a way that node can sense nearly two hops away from self. Within the TX range which is smaller than CS range node can decode packets correctly. CS range is used to sense whether the carrier is busy or not.

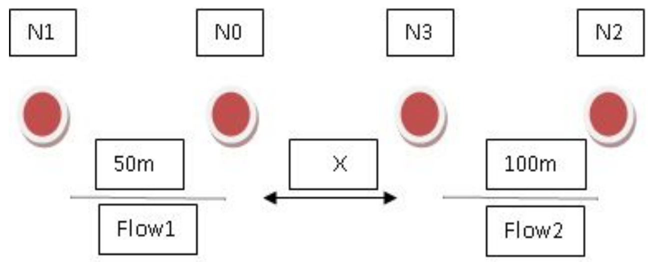

Figure1: Setup to study hidden and exposed node concept [3]

Node N0 and node N2 transmit CBR traffic to Node N1 and N3 respectively. As per the default NS2 settings transmit (TX) range is 250m and Carrier Sense (CS) range is 550m. The simulation carried out in NS2 with following parameters:

MAC: IEEE 802.11; Protocol: Ad-hoc on-demand distance vector (AODV); Traffic: Constant Bit Rate (CBR); Drop-tail Queue; Data Rate:2 Mbps; Packet Size: 512 bytes; Interface Queue Length: 50.

Simulation carried out for 10 seconds and obtained results are shown in Figure2. Analysis of obtained results is discussed to understand the effect of hidden and exposed nodes.

If a node correctly decoded the last packet detected, it must sense the channel to be idle for Distributed Inter Frame Space period (DIFS) prior to resuming back-off. If it detected a packet but couldn't correctly decode it, it must back-off for Extended Inter Frame Space period (EIFS). i.e. EIFS > DIFS. If a node sends Request to Send (RTS) and does not receive Clear to Send (CTS), it doubles its contention window and then retries. This simply means that nodes within TX Range can detect as well as decode the packet correctly but nodes outside TX Range but within CS range are only able to detect the packet. This further implies that such nodes (outside TX Range) would back off for EIFS and not DIFS.

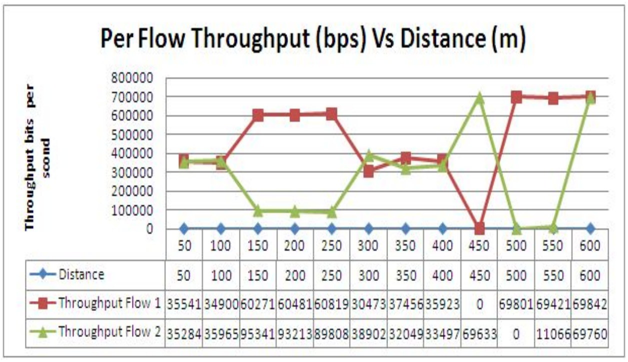

Figure2: Graph of obtained results,-hidden / exposed nodes

B. Forwarding Unfairness Amongst WMN nodes

A user node in a multi-hop network has to transmit both relayed and its own traffic. Therefore, besides the contention with other nodes for the same destination node, there is an inevitable contention between its own and relayed traffic [4]. This contention does not occur in fixed wireless local loops or wireless LANs in infrastructure mode where user nodes are always at one-hop distance from the base station or the access point.

As shown in Figure 3, experimental simulation set-up shows Node A, Node B and Gateway Node C. Node A and Node B are single hop and two hops distance to Gateway Node C. Node A and Node B send CBR traffic on wireless channel of 2MBPS to Gateway Node C.

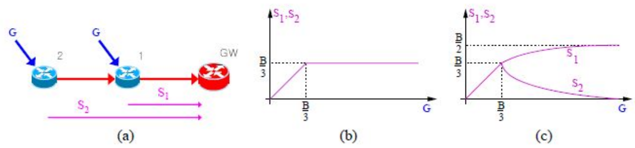

Figure3: Forwarding Unfairness Amongst WMN nodes

As can be seen in Fig. 3(c), as the load at both nodes is increased, node 2 is gradually, but eventually completely starved by node 1. The overall system throughput (measured at the gateway) when the offered load is very high is $B/2$, where B is the throughput of the system when only node 1 forwards data to gateway. So, the system operates at 75% efficiency because it gets B/2 while 2B/3 is ideal and is unfair. This is further illustrated in figure-4.

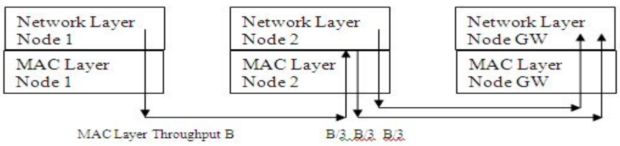

Figure4: Bandwidth allocation at MAC layer

The unfair behavior observed in Fig.3(c) is rooted in the fact that both the traffic originating at node 1, as well as the relayed traffic from node 2, are queued together at node 1. When the traffic load increases, the network cannot forward all data en-queued at node 1, and the queue starts to overflow. With a probability that increases with the offered load, the queue will be full when a new packet arrives from node 1, and it will be dropped immediately after it is received. The exact, expected throughput was determined theoretically, and it was verified using ns-2.

As shown in figure3 (a), in NS2 environment 3 nodes simulated, node 0 and node 1 attached with UDP agent and CBR traffic source. Node 2 is behaving as Null node for this traffic. Traffic load from node 0 to node 2 is named as Flow 1, and traffic load from node 1 to node 2 as Flow2. Various results obtained from varied traffic load processed using "gawk" and "grep" utility of Linux environment. Results stored in excel file and put into graph. Figure-5 shows the graph from the obtained results. PDR stands for Packet Delivery Ratio.

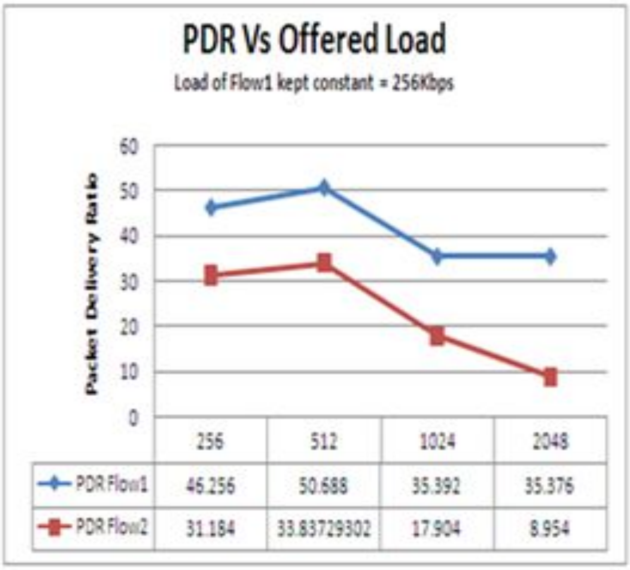

Figure5: Graph of obtained Results-Forwarding Unfairness

III. ANALYTICAL MODELING

Figure 6 shows our model where a node is simplified as a server with a queue. The server represents the wireless /conventional wired medium. If the network in Fig. 6 is assumed to be a conventional wired network, it can be modeled as Figure-7. In a typical wireless ad hoc network, nodes are expected to have a single transceiver and share a common channel. Thus, the server in node 1 is not independent of the server in node 2. The server in Fig. 7 can be corrected as Fig. 8 where two flows contend with each other to access the wireless medium. Figure 8 indicates that the traffic flow generated by node 2 has to go through two queues and get served twice by one server to reach the destination. In contrast, the traffic flow of node 1 goes through the queue and the server only once, which implies an unfair competition between the two flows unless otherwise controlled. In the same manner, the analysis can be extended to the networks with longer chain.

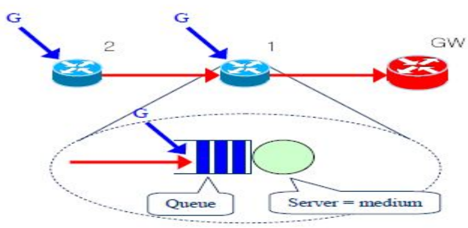

Figure-6: Two source chain network

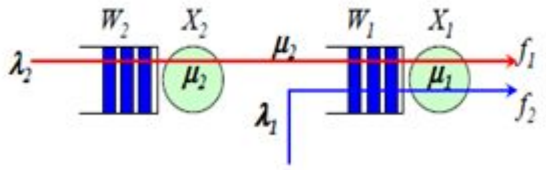

Figure 7: Conventional Wired Network: Two Source Chain

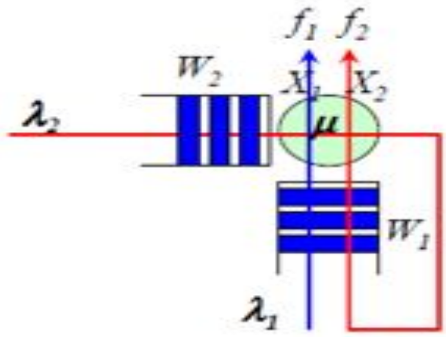

Figure 8: Wireless Network: Two Source Chain

Where each parameter is defined as follows:

λ_i = arrival rate of i^{th} node (i.e., rate of the generated traffic)

μ_i = service rate of i^{th} node

W_i = queuing delay of i^{th} node

X_i = service time of i^{th} node (= transmission delay + propagation delay + others (e.g., random back-offs))

f_i = flow throughput of i^{th} node

------------------------- (1)

IV. PROPOSED SOLUTION

In this section, we propose various solutions to address the problem described in section II and explain the advantages and disadvantages of each scheme. For clarity, a simple multi-hop wireless network with four nodes as shown in Fig.9 is used in the analysis. We assume that all the traffic flows are unidirectional toward the gateway. Each node in Fig. 9 can be modeled as a wireless router with network-layer queue(s) and MAC-layer queue(s) as shown in Fig. 8.

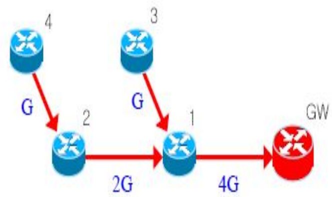

Figure 9: Multi-hop Wireless Network with four nodes and single gateway

A. *Isolate the Originating Traffic*

Assuming that Fig.10 shows the network and MAC queues of node 1 in Fig. 9, f_1 is the originating traffic flow and f_2, f_3 and f_4 are the relayed ones.

With the basic queuing scheme as shown in Fig. 10, it is clear that the traffic flow f_1 will receive more bandwidth and eventually starve others due to the problem described in the previous section. Since this problem stems from the fact that both the relayed and the originating traffic share a common queue [4], [9], the first solution that comes to one's mind is to use different queues for the relayed and for the originating traffic and to serve them in a round-robin fashion. This scheme will isolate the originating traffic which dominates the relayed traffic and protect the relayed traffic from being starved by the originating one.

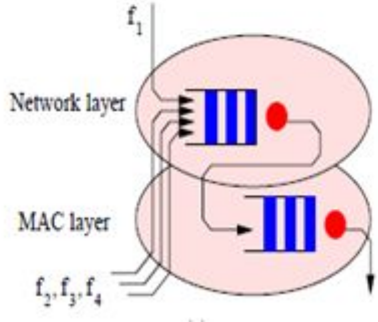

Figure 10: Basic Queuing Scheme

B. *Different Weight on Relyed Traffic*

To alleviate the unfairness shown in the previous section, one can assign different weights to each queue so that the queue for the relayed traffic will receive more scheduling time when needed. This scheme is modeled as shown in Fig. 11, where the larger disk indicates that a greater weight is given to the forwarding queue.

The weight of the forwarding queue can be fixed in all the nodes of the network, or different weights can be used, depending on the amount of relayed traffic at each node. The latter assumes that the amount of relayed traffic can somehow be determined in a distributed manner. For the network shown in Fig. 3, the desirable weight ratios of the originating versus relayed traffic are 1:3 and 1:1 for nodes 1 and 2, respectively.

Per flow queuing is more complex to design and may increase processing delay due to increased computation. And hence the study is focused on using two queues at network layer with different weights to alleviate unfairness problem experienced by wireless mesh nodes.

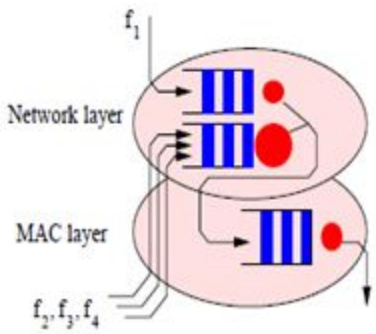

Figure 11: Different Weight for relayed traffic

C. *Methodology and Scheduling Algortihm*

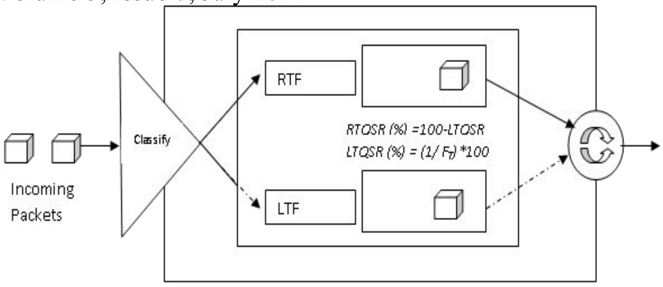

Figure 12: Methodology of Related Work

Where RTF = Relayed Traffic Flow, LTF = Local Traffic Flow, RTQSR=Relayed Traffic Flow Queue Scheduling Rate, and LTQSR=Local Traffic Flow Queue Scheduling Rate, FT= Total number of Traffic Flows.

The network clock cycle consists of two phases. In the first phase, traffic flow control information passes through the network from the last stage to the first one. In the second phase, packets flow from one stage to the next in accordance to the flow control information.

The arrival process of each packet is Poisson process, that is, the probability that a packet arrives within a clock cycle is constant and the arrivals are independent of each other. We will denote this probability as λ. This probability can be further broken down to λ_l and λ_r, which represent the arrival probability for local and remote traffic packets, respectively. It holds that $\lambda = \lambda_l + \lambda_r$ .Under the dual-priority mechanism, when applications or architectural modules enter a packet to the network, they specify its priority, designating it either as high or low. The criteria for priority selection may stem from the nature of packet data. A high-/low-priority packet arriving at the first stage is discarded if the High low-priority buffer of the corresponding network switch is full, respectively. Upon reception, packets are first classified according to their priority and are then assigned to the queue specifically dedicated to the particular priority Each packet priority queue is mathematically calculated *weight*, which specifies the time ratio that will be dedicated to schedule that particular queue. Naturally, the sum of all time scheduled must be equal to network clock cycle.

V. RELATED WORK

There are two nos. of simulation, simulation of unfair scheduling; dual queue option is set to 0 in routing protocol code, while simulation of fair scheduling use dual queue option in routing protocol code. Table I lists files from ns2 directory which underwent changes to develop modified AODV protocol [5] named here as Fair Resource Wireless Mesh Network Protocol (FRAWMN)

TABLE I. CHANGES DONE IN AODV PROTOCOL

File Name	**Function**	**Additional functions**
aodv.cc	C++ code	ltf.enqueu(), rtf.enqueu()
aodv_rqueue.cc	Queuing C++ code	compute_weight()

The simulation is carried using NS2 scripts under Fedora operating system on VMware machine. Table II lists simulation parameters. Various results for both simulations compared together to depict behavior of modified AODV protocol herein named as FRAWMN. Nomenclature FS means Fair Scheduling and NFS means No Fair Scheduling. As shown in figure 13, obtained results are plotted to depict how the flow 1 is fairly treated using modified protocol FRAWMN. In absence of dual queue option, throughput of flow 2, 3 and 4 drops, and flow 1 acts as greedy flow. Figure 14 shows the flow id versus throughput for each flow id.

TABLE II. SIMULATION PARAMETERS

Parameter	**Value**
Flat-grid Topology Dimensions	1000m X 1000m
Number of Gateways	10
Number of Mesh Nodes	50
Packet Interval Time	0.05 Second
Traffic	CBR
Traffic Packet Size	2000 bytes / 512 bytes
Connection Agent	UDP

Jain Fairness Index is given as

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Where Xi is flow id and n = number of contending flows.

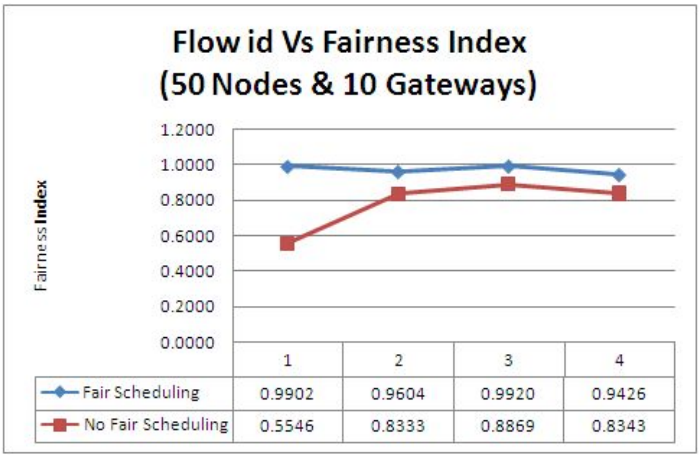

Figure 13: Flow id Vs Fairness Index- Fair & No Fair Scheduling

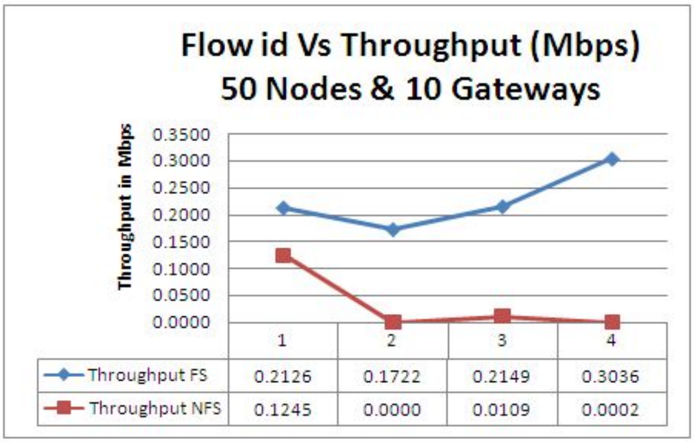

Figure 14: Flow id Vs Throughput – Fair & No Fair Scheduling

VI. CONCLUSION

Thus mechanism to isolate originating traffic and allocating a proportional part of network cycle for catering relayed traffic shown improvement in fairness index as well as throughput. Further planning is to test this for wider ranges, varied traffic, different protocol and more number of nodes with limited number of gateways

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