Evaluation of Channel Fairness Models for Ad-Hoc networks

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Abstract—**In this paper, we will first demonstrate the effects of unfairness performance of the IEEE 802.11 standard under a pre-computed routing scheme for two network configurations and a fixed traffic patterns. Firstly, we will examine the send rate, a quantity similar to the local throughput, for very simple chain and lattice networks with regular traffic patterns, and then we will investigate the performance of both types of fairness improvement schemes on this rate. The recently developed *JEmu* network simulator will be used for all simulations [1]. It is intended that the results will illustrate both the impacts of the traffic patterns on the performance of the link-level fairness models and will also highlight the better approach to guaranteeing fairness among subscribers..**

Index Terms—**Channel Fairness, ad-hoc networks, MAC protocol.**

I. Introduction

In recent years, mobile computing has enjoyed a tremendous rise in popularity. This has been encouraged by the miniaturization of the portable computing devices to provide cheap and powerful processing power for the user, along with efforts to develop mobile-orientated Internet applications that will attract a bigger class of customers. Another aspect that is receiving much attention recently is the creation of technologies that will allow a group of users to establish their own network structure without the need for the centralised backbone used in other wireless schemes, thus providing an infrastructure-free communications scheme. This new network structure is termed an Ad-Hoc network and is essentially a privately shared transmission medium formed by a group of mobile stations located within a certain fixed range. The advantages of these Ad hoc networks appear most distinctly in cases where there is a need for the rapid deployment of a number of independent mobile users but where reliance upon centralized and organized connectivity is impossible. Good examples of these users would be Military and Medical crises response units. Additionally, applications of AD-Hoc networking [2] have also been suggested for commercial products, for instance, business conferencing and home networking.

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II. Channel Allocation for AD-Hoc Networks

The design of network protocols for these networks is a complex issue. One key concern is the **M**edium **A**ccess **C**ontrol (MAC) protocol, which aims to ensure a *fair* and *maximum allocated* channel bandwidth to each subscriber, and thus provide a guaranteed **Q**uality **O**f **S**ervice (QoS). Because of the lack of the centralized control, each user with data to send has to contend with the others for access to the channel. Most of the MAC protocols use an exponential back-off scheme for the random access channel allocation strategy. However, random access channel allocation schemes cannot guarantee that all users will have the same opportunity to acquire the channel.

A. IEEE 802.11 Standard

The most popular commercial MAC protocol is the IEEE 802.11 standard [3]. The basic scheme is **C**arrier **S**ensing **M**edium **A**ccess with **C**ollision **A**voidance (CSMA/CA). When a packet is transmitted from a user, its 802.11 protocol layer first senses the channel to avoid potential collisions with the on-going transmission. If the channel is sensed idle, the data packet will be sent out. If the channel is sensed busy, the back-off window will be adjusted. After the back-of window timeout, the channel will be sensed again. In the event of long data packets, this protocol is extended where each node will introduce a threshold vector based on the packet length into the protocol. A four-way handshaking RTS/CTS/DATA/ACK is introduced for the data packets, which is longer than the threshold length, so that collisions caused by the hidden terminal problem are reduced.

The back-off window will be doubled each time the timeout occurs and the channel remains busy. The packet will eventually be dropped after the maximum back-off window limit is reached. This is reset to the minimum value each time the data has been sent or the packet dropped.

B. Metrics

The performance of 802.11 MAC protocol is generally evaluated in terms of two parameters: *collision probability* and *fairness* across competing stations [4]. To calculate these parameters an essential quantity is the local throughput P of a node that is defined by

$$P = \frac{S}{C} \qquad (2.1)$$

Where S is the successful number of retransmissions and C is the channel capacity. This is also called the transmission or send rate, and in this paper, the term 'send rate' is preferred For channel fairness, each note in the network should have the same 'send rate', thus fairness can be evaluated by a comparison of the 'send rate' value for the different nodes.

C. *Why Channel fairness?*

Usually the commercial ad-hoc networks, users are in a pay-for-use model. It is important then that the network provide fair allocation of the limited channel to the users. Since the link-layer protocol is taking an important role for achieving network-layer QoS in ad-hoc networks, the MAC protocols should include some notion of fairness so that channel resources are distributed as evenly as possible among the users, and prevent domination by aggressive users. One of the most popular solutions is the "weighted fairness" approach [5]. This can be subdivided into methods the create fairness by weight per-node and by weight per-flow [6]. Before discussing the principles of these techniques in detail, two assumptions [7] must first be introduced:

I. There can be an infinite number of nodes in the network.
II. All contending stations in the network always have packets to send.

1) *Per-node fairness weighting*

The back-off window length is related to a back-off level parameter W within $(0, S_{\max})$. Within the network, a node i with weight r_i receives a lower bound on channel allocation of

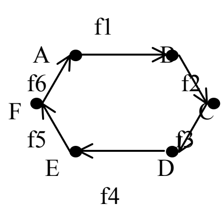


Figure 1 Contention graph

$$\frac{r_i}{\sum_{j \in N(t_1)} r_i} C(t_1, t_2) \qquad (2.2)$$

over the time period (t_1, t_2) [8]. Where C is the channel capacity, $N(t)$ is the set of node with packets to send at time t.

For example, as shown in Figure.1 [8], there are six nodes in the network. For fairness on a per-node level, each node should receive one sixth of the channel capacity. Therefore the send rate of each node should be approximately 17%. The protocol supervises the local send rate. If the send rate is higher than 17%, the level of the back-off window will be increased to slow down the contention time; otherwise the node will decrease the level of the back-off window to try to acquire more channel bandwidth. Figure 2 shows the flow chart of the algorithm.

2) *Per-flow fairness weighting*

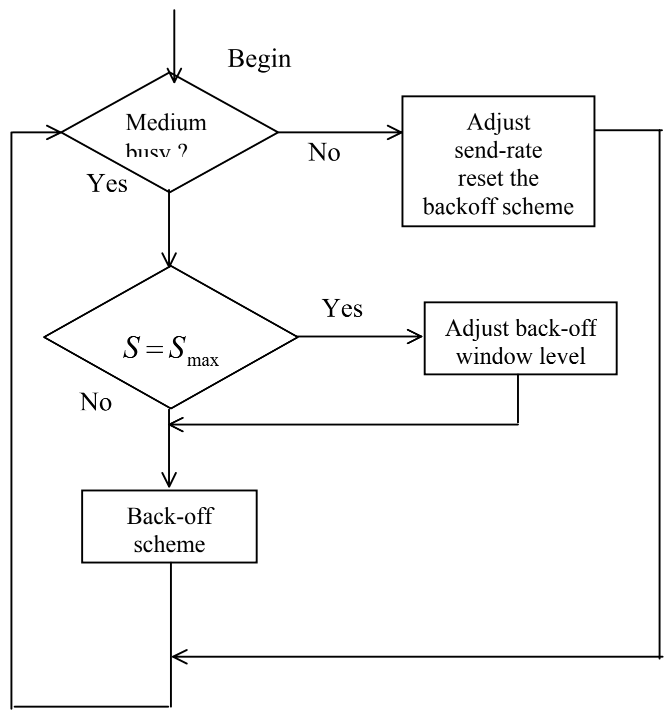


Figure2 Flow chart of per-node fairness

Where W is the send-rate, $W_{\max}$ is the allocated channel bandwidth

The Per-flow weighting method assigns weights to each traffic flow as shown in Figure 3. Each flow i with weight r_i receives the lower bound on channel allocation of

$$\frac{r_i}{\sum_{j \in F(t_1)} r_i} C(t_1, t_2) \qquad (2.3)$$

over the time period (t_1, t_2). $F(t)$ is the set of the contending flows at time t. Each flow f_i has its own queue

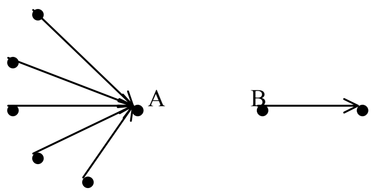


Figure 3 Unbalanced traffic

q_i for the transmission and. each q_i has a different back-off window and level. In Figure 3 [8] five nodes are communicating with node A, and only one node is communicating with B. With per-flow weight scheme, node A will get 83% of the channel bandwidth, node B and the rest of the nodes in the network will be allocated with 17% of the channel bandwidth.

D. Simulation Model and Results

To test the fairness methods the JEmu network simulator was used for the simulation [9]. There are three layers assumed within each node as shown in Figure 4. The performance of the MAC protocols is assessed using a pre-computed routing scheme contained in the tester layer. The IEEE 802.11 is used as the basic MAC scheme.

Two different traffic patterns were examined. Firstly, the chain networks, as shown in Figure 5 [10], was investigated. In the Figure the dotted circle depicts the interference range, and the solid-line circle depicts the correct receive range. The same experiment is then applied to the lattice network with only horizontal traffic as shown in Figure. 6.

Figure 7 shows the fairness of the 802.11 protocol in terms of the 'send rate' for the chain network of Figure 5. From this figure, the packets are sent from node 1 to node 7: Node 1 generates packets with the rate of 5000bps and each node receives the packets and passes it on to the next node on the right hand side. Node 7 receives the packets and puts them into a buffer. Figure 7 shows that with 802.11, the 'send rate' of the first node is very high, but at the end of the chain there are nearly no packets passing through. However, in contrast,

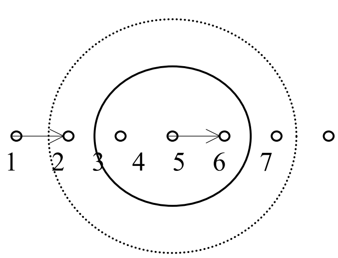


Figure.5 Chain network

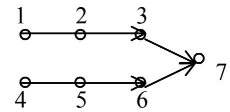


Figure 6 Lattice network

both with per-node and per-flow fairness the 'send rate' becomes more balanced across the nodes. The performance of the per-node method is better for the first few nodes and weaker towards the end of the chain. This pattern is the same for the per-flow method but it shows a better performance than the per-node method for a higher number of nodes.

Figure 8 shows the fairness feature with the lattice network as in Figure 3. There are two traffic flows. Flow1 is from node 1 to 3, and flow2 from node 4 to 6. Both flows end up to at node 7. Both nodes 1 and 4 generate the packets with a rate of 5000bps. Note that the transmission of flow 1 commences before the flow 2, so that the 'send rate' of the flow 1 will be higher than that of flow 2.

The Figures 8-a to 8-c shows the 'send rate' of the nodes in each stage of the flow. The labels Series 2 indicates the 'send rate' of the nodes in flow 1 and Series 1 indicates the 'send rate' of the nodes in flow 2. According to the Figure 8-a, the 802.11 shows that the first flow sends most of its packets but that the other one barely sends any packets through. Thus, the fairness feature of the 802.11 is very poor. From Figure 8-b, with the per-node fairness, more packets from the second flow get through, but the send rate of the second flow is still much lower than that of the first flow. With per-flow fairness, as seen in Figure 8-c, the send rates of the two flows are closer in terms of magnitude and similar in shape, with many more packets from the second flow getting through on this occasion.

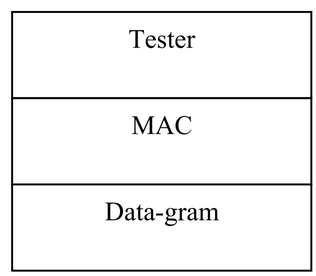


Figure4 The node structure

E. Future works

Overall, it appears the some form of fairness scheme is desirable for the 808.11 protocol when applied in Ad-Hoc networks. Specifically, the method that achieves fairness by a per-flow weighting appears to offer the best trade-off in terms of the 'send rate' for each user.

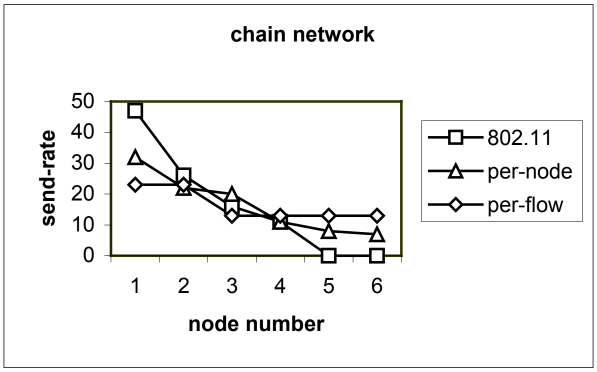
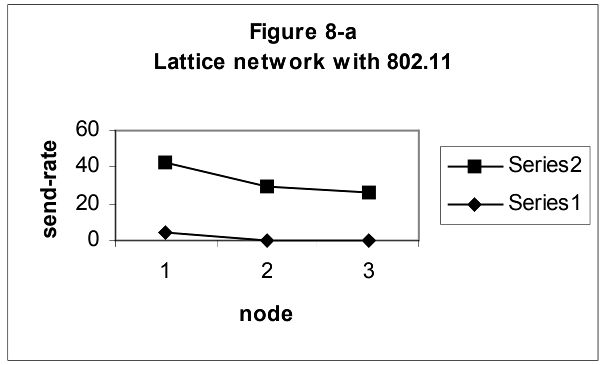
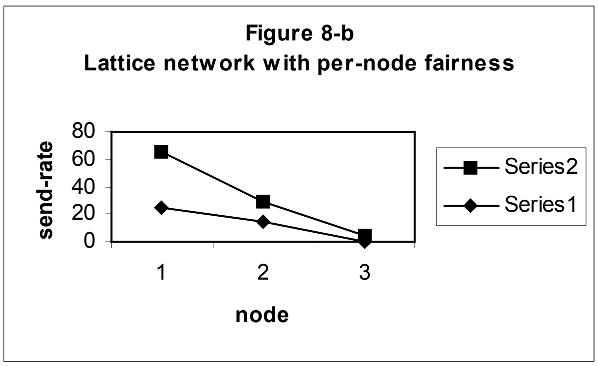


Figure 7 send rate of the chain network





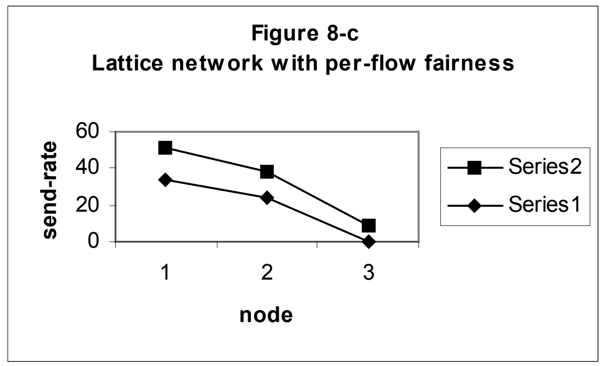


Figure.8 The send rate of each protocol

Future work will consider the performance of the fairness methods for the more realistic case of random traffic patterns and will then aim to include the effects of user mobility. Finally, it is hoped that at some stage in the future it will be possible to validate the results presented with a real hardware radio system.

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