Eliminating the Performance Anomaly of 802.11b

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Abstract. In this paper, we propose a mechanism to eliminate the performance anomaly of IEEE 802.11b. Performance anomaly happens when nodes that have different transmission rates are in the same wireless cell. All the nodes in the cell might experience the same throughput even though their transmission rates are different because DCF of WLAN provides equal probability of channel access, but it does not guarantee the equal utilization of the wireless channel among the nodes. To reduce such a performance anomaly, we adjust the frame size proportionally depending on the bit rate. Additionally, our scheme eliminates the performance anomaly in multi-hop case. Simulation study shows that our scheme achieves an improvement in the aggregate throughput and the fairness.

1 Introduction

The performance of IEEE 802.11b Medium Access Control (MAC) is a challenging issue. Especially, on the fairness of wireless channel utilization, many MAC layer's fair scheduling algorithms have been proposed [1, 2, 3, 4]. For the long term fairness, IEEE 802.11b defines Distributed Coordination Function (DCF), which gives every node a same probability to access the wireless channel.

In this paper, we address the problems in the Automatic Rate Fallback (ARF) of IEEE 802.11[5]. The basic CSMA/CA is at the root of the performance anomaly[1] of 802.11b MAC. If there are nodes which works at different bit rate in the same cell, the 802.11 cell shows the performance anomaly. The throughput of all hosts that have higher bit rate are degraded, and all the hosts in the wireless cell experience the same throughput regardless of the transmission rate. The main reason is that CSMA/CA mechanism does not provide the same probability to utilize the channel while it guarantees that all the nodes in the same wireless cell have the same probability to access the channel. In terms of the channel utilization, this is quiet unfair because the higher bit rate node defers transmission longer than that of the lower bit rate node.

To eliminate such a performance anomaly, we adopt the Maximum Transfer Unit (MTU) adaptation scheme. By adjusting the MTU size as to the transmission rate, all the nodes can fairly utilize the wireless channel. We show that our scheme achieves higher throughput than that of normal case. Moreover, it avoids the performance anomaly in multi-hop situation.

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This paper is organized as follows. We introduce the motivation of this study in Section 1. In Section 2, the ARF of WLAN and its performance anomaly are introduced. Section 3 presents our analysis which probes that our scheme achieves higher throughput than existing method. In Section 4, we differentiate our work from previous work. Simulation results by the NS-2 simulator are shown in Section 5. Finally, concluding remarks are given in Section 6.

2 Related Work

2.1 ARF of IEEE 802.11b and Its Variants

It is well known that IEEE 802.11 provides multi-rate capability at the physical layer. ARF defines several transmission rate of 802.11 for temporal degradation of wireless channel. When wireless channel is bad, the sender changes the sending rate to lower level.

ARF takes the advantages of positive ACK in explicit link layer. When a sender misses two consecutive ACKs, it drops the sending rate by changing the modulation or channel coding method. In contrast, when timer expires or consecutive 10 ACKs are received successfully, transmission rate is upgraded to the next higher data rate.

While the ARF mechanism provides good estimation of link condition between a fixed pair of nodes, it overlooks the fact that actually not the sender but the receiver need estimation of the channel condition. A direct disadvantage of ARF scheme can be clearly seen when there are multiple nodes communicating with each other in a wireless network. If a node moves to a location with a bad radio characteristics (communication blockage), other nodes communicating with this particular node may experience transmission failures and consequently the transmission rate would be dropped.

Holland [2] proposed the receiver based auto rate scheme (RBAR). In their scheme, the receiver estimates the wireless channel condition and gives the sender feedback information. The sender takes advantage of feedback information and selects the sending rate.

Sandeghi [6] proposed the opportunistic media access scheme (OAR) which extends RBAR. The main idea of OAR is to exploit good channel conditions to transmit as many as possible while retaining the long term fairness provided by 802.11b. OAR achieves fairness of channel utilization by sending a burst of packets for a single RTS-CTS handshake. The number of packets transmitted by OAR in any transmission burst should be limited so as to provide a fair channel access to all nodes. The fair temporal share is determined as the maximum time the channel can be occupied if OAR transmitted a single packet at the base rate. The base rate of a channel is the lowest possible rate with which data can be transmitted. For example, the base rate of 802.11b channel is 2 Mbps. Thus the number of packets sent in every burst is limited to at most 5 packets when the selected transmission rate is 11 Mbps. This guarantees that OAR inherits the same temporal fairness properties of the protocols based on original 802.11.

2.2 Performance Anomaly of 802.11b

Heusse [7] showed the performance anomaly of 802.11b. They analyzed the anomaly theoretically by deriving simple expressions for the useful throughput, validated them by means of simulation, and compared with several performance measurements. In their results, the throughput experienced at each node is same although the data rate is different. The expression for a throughput is as follows:

$$X_s = X_f = \frac{S_d}{(N-1) \cdot T_f + T_s + P_c(N) \times t_{jam} \times N}, \tag{1}$$

Where X_f is throughput at the MAC layer of each of the N-1 fast hosts, X_s is throughput at the MAC layer of slow host. N is number of nodes, and T_f and T_s is transmission time for fast nodes and slow node for a packet, respectively. $P_c(N)$ is probability of collision, S_d is frame size and t_{jam} is the delayed time experienced by collision.

In the above expression, the throughput is not related with the sending rate of a node because all the nodes have the same transmission time and the same frame sizes.

3 Eliminating Performance Anomaly of 802.11b

If we adjust packet size depending on the bit rate of the node, the time to utilize a channel will be fair. MTU size for a node can be expressed as follows:

$$\frac{SMTU}{r} = \frac{LMTU}{R} \tag{2}$$

$$\frac{LMTU}{SMTU} = \frac{R}{r} = K, \ (K > 1) \tag{3}$$

Where LMTU is MTU size of a fast bit rate node, R is the transmission rate of the fast bit rate node at MAC layer, SMTU is MTU size of a slow node, r is the transmission rate of the slow node. The ratio between the high bit rate and the low bit rate is k.

The expression (1) could be modified as follows.

$$\begin{aligned} X_f &= \frac{LMTU}{(N-1) \cdot T_f + T_s + P_c(N) \times t_{jam} \times N} \\ &= k \cdot \frac{SMTU}{(N-1) \cdot T_f + T_s + P_c(N) \times t_{jam} \times N}, \end{aligned} \tag{4}$$

$$X_s = \frac{SMTU}{(N-1) \cdot T_f + T_s + P_c(N) \times t_{jam} \times N}. \tag{5}$$

Therefore, we can say that X_f, X_s is proportional to the bit rate of the node. Furthermore, we show that aggregated throughput in a cell increases. There are N nodes in the same wireless cell, N-1 of them have high bit rate, R, and there is only one node has low bit rate, r. To compare the aggregated throughput of a system, we define two different systems. At first, all the nodes are using the same LMTU frame size (system A). Secondly, lower bit rate node uses small MTU (SMTU), which is proportional to the bit rate (system B). We compare the aggregate throughput of two systems. We have the same assumptions with [7].

$$T_a = \sum_{i=1}^{N-1} X_f(i) + X_s(N) = N \cdot \frac{LMTU}{Time_A}, \tag{6}$$

$$T_b = \sum_{i=1}^{N-1} X_f(i) + X_s(N) = \frac{(N-1) \cdot LMTU + SMTU}{Time_B}, \tag{7}$$

$$T_b \geq T_a, \tag{8}$$

Where $X_f(i)$ is the throughput experienced at high transmission rate host i, $X_s(N)$ is the throughput experienced at low transmission rate host N. $Time_A$, $Time_B$ is the expectation of the time consumed for transmitting a packet. T_a and T_b mean the expectation of aggregated throughput of system A and B respectively.

We have to show that T_b is greater than or equal to T_a. We introduce more symbol conventions with [7].

$$t_{jam} = \frac{2}{N}T_s + (1 - \frac{2}{N})T_f$$

$$t_{jam}' = \frac{2}{N}T_s' + (1 - \frac{2}{N})T_f$$

$$Time_A = (N-1) \cdot T_f + T_s + P_c(N) \cdot N \cdot t_{jam}$$

$$Time_B = (N-1) \cdot T_f + T_s' + P_c(N) \cdot N \cdot t_{jam}'.$$

Applying the above equations to the equation (8), we get following inequality.

$$T_s - T_s' \geq \frac{(N-2) \cdot P_c(N) \cdot (LMTU - SMTU) - N \cdot SMTU}{(1 + P_c(N)) \cdot ((N-1) \cdot LMTU + SMTU)} \cdot T_f. \tag{9}$$

Using equation (2) and (3), we get absolute inequality (10) as follows:

$$(K-1) \cdot \{(K-1)(n-1) + n\} + (K-1) \cdot P_c(n) \cdot \{(K-1)(n-1) + 2\} + n \geq 0, \tag{10}$$

Where K is greater than 1, N is natural number greater than 1 and Pc(N) always resides between 0 and 1. So, it proves the inequality expression (8).

4 Discussion

4.1 Comparison with Other Fairness Methods

Many studies proposed the fair scheduling mechanisms in MAC layer. They usually modify the mechanism that controls the contention window. MACAW

[1], Estimation based backoff[3], and Distributed Fair Scheduling[4] consider the fairness problem in 802.11. However, they do not address the problems that occur with multi-rate PHY.

TXOP which is adopted in 802.11e is a good approach to be compared with. TXOP regulates Network Allocation Vector (NAV) to utilize the network fairly for all the nodes in the same wireless cell. By allocating more time to the higher bit rate nodes, QoS for each nodes is discriminated. Thus, TXOP achieves fairness without fragmentation. However, in multi-hop environments, TXOP has problems in cases. When adjacent cells presents different lowest bit rates as in figure 2, several problems occur. At first, the forwarding node is located in the intersection of two cells, the forwarding node's TXOP operation oscillates. The reason of oscillation is that the nodes in the intersection of two cells may communicate to either a cell presents lower bit rate or that presents higher bit rate. In addition, the cell which has lower bit rate nodes have more time utilization. The forwarding node's oscillation makes serious impact on network traffic pattern. Because the nodes in the lower bit rate side may send more packets per channel acquisition than the other side, the forwarding node could not send all the packets that it has received even though the forwarder catches the channel. That is, performance anomaly is diffused from a node to a cell and the forwarder may congested by this inter-cell performance anomaly.

For the same case, on the other hands, our scheme succeeds in keeping fairness of channel utilization among the nodes in both cells. Because all the nodes in the both cells have same time utilization, the forwarder does not congested by the inter-cell performance anomaly.

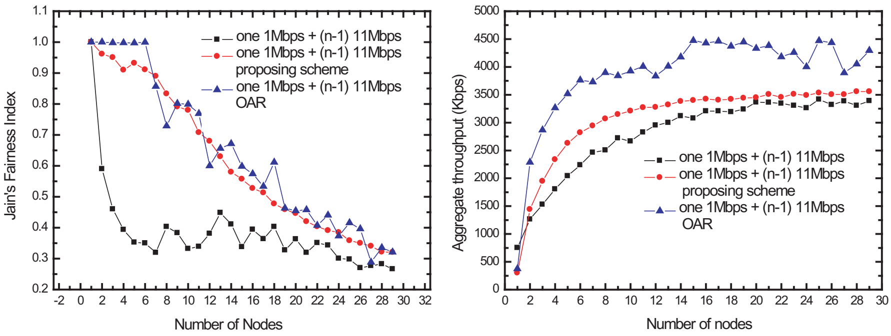
4.2 Implementation Issue

Our scheme works well with other receiver based feedback mechanisms. We just modified the packet size, so other rate control scheme can be applied transparently. Our scheme can be simply applied by adjusting the MTU size or MSS (Maximum Segment Size) of TCP. That is, by simply modifying a variable, we can achieve fairness of the WLANs while the previous schemes need modification at MAC layer.

5 Simulation Results

We did simulation study through NS-2 simulator[9]. We show that our scheme can easily eliminate the performance anomaly. In the point of view of both the throughput and the fairness sides, our results show higher values. Specifically, the throughput has been increased up to 20% in best case. Moreover, fairness improves up to 70% than normal cases.

All the nodes are in the communication range and only one of them works at 1Mbps and the rest of the nodes work at 11Mbps rate. We use uniform random error model and ricean propagation model. Nodes are placed at randomly-chosen location within 250m ranged area. Simulation time is 150s and all the nodes use the same TCP traffic. We measure the throughput of each TCP sessions, and



Jain' s Fairness Index through the number of nodes

Aggregate throughput through the number of nodes

Fig. 1. Fairness Index and Aggregate throughput through the number of nodes

compare the aggregate throughput and throughput fairness. The fairness follows the Jain's fairness index[8].

Figure 1 shows the improvements in throughput and fairness index in one hop case. In one hop case, OAR have the highest throughput, but fairness value oscillates. In the proposed methods, throughput is lower than OAR because our scheme have more overhead from channel contention. On the other hands, fairness keeps almost same value with OAR and it shows more stable behavior than OAR.

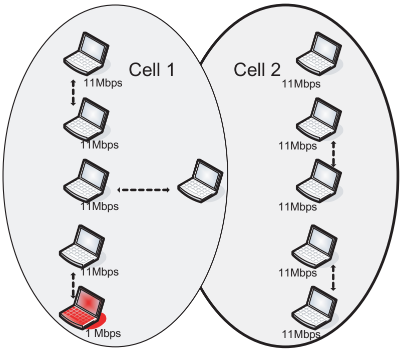


Fig. 2. Topology for Multi-hop case

OAR achieves higher throughput than normal case in one hop case. However, it presents serious fairness degradation in multi-hop case. To investigate the anomaly in multi-hop case, we modified the topology of the network as in figure 2.

Through the simulation, we found that the throughput of the cell 2 is seriously degraded. This agrees with our expectation as stated in previous Section. Moreover, the fairness of cell 2 also degrades. The reason for this degradation is that the relay node catches the wireless channel longer than neighbor nodes.

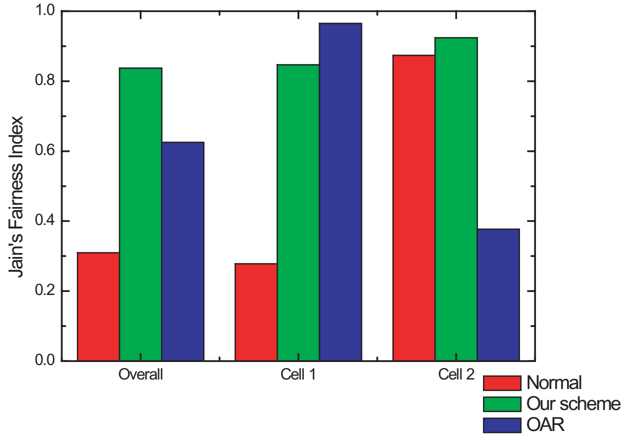


Fig. 3. Comparison of Jain's Fairness Index

While all the nodes in the same cell have the same probability to catch the wireless channel, the relay have higher probability in the same time. We present the throughput fairness index of the both schemes.

Figure 3 shows fairness index of cell 1, cell 2, and overall cases. In normal case, cell 1 has performance anomaly because different rate nodes are transmitting data simultaneously in the cell. On the other hands, OAR has performance anomaly in cell 2. The degradation of OAR is owing to the unfair channel utilization among the nodes. The relay node catches the wireless channel longer than its neighbors. As a result, cell 2 presents the performance anomaly. Our scheme avoids performance anomaly because our scheme keeps utilization same with its neighbor by adjusting the MTU size. Additionally, our scheme has more fine-grained channel access control, so the fairness is kept higher value.

6 Conclusion

In this paper, we present a scheme which eliminates the performance anomaly of 802.11b. By adjusting the packet size to the transmitting bit rate, we can successfully overcome the performance anomaly. Presented solution makes an improvement not only in throughput but also in fairness among the sessions by 20% and 70% in our best cases. Compared with TXOP operation in 802.11e, our solution does not present the fairness problem even in the multi-hop case.

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References

1. V. Bharghavan, A. Demers, S. Shenker, and L. Zhang , *MACAW: A Media Access Protocol for Packet Radio,* Proc. ACM SIGCOMM 1994, pp. 212-225
2. Gavin Holland, Nitin Vaidya, and Paramvir Bahl, *A Rate-Adaptive MAC Protocol for Multi-hop Wireless Networks,* Proc. ACM Mobicom 2001, pp. 236-251
3. Zuyuan Fang, Brahim Bensaou, and Yu Wang, *Performance Evlauation of a Fair Backoff Algorithm for IEEE 802.11 DFWMAC,* Proc. Mobicom 2002, pp 48-57
4. Nitin H. Vaidya, Paramir Bahl, and Seema Cupta, *Distributed Fair Scheduling in a Wireless LAN,* Proc. ACM Mobicom 2000, pp. 167-178
5. Ad Kameramam and Leo Monteban, *WaveLan-II: A High-Performance Wireless LAN for the Unlicensed Band,* Bell Labs Technical Journal, pp. 118-133, Summer 1997
6. B. Sandeghi, V. Kanodia, A. Sabharwal, and E. Knightly, *Opportunistic Media Access for Multirate Ad Hoc Networks,* Proc. ACM Mobicom 2002, pp. 24-35
7. M. Heusse, F. Rousseau, G. Berger-Sabbatel, and A. Duda, *Performance Anomaly of 802.11b,* Proc. IEEE INFOCOM 2003, pp. 836-843
8. R. Jain, D.M. Chiu, and W.R. Hawe, *A Quantitative Measure of Fairness and Discrimination for Resource Allocation Shared Computer Systems,* Digital Equipment Corporation technical report TR 301, 1984
9. K. Fall and K. Varadhan, *NS notes and documentation,* the VINT Project, UC Berkeley, LBL USC/ISI, and Xerox PARC, available from http://www-mash.cs.berkeley.edu/ns, November 1997.