Improving Fairness in IEEE 802.11 Wireless LANs

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Abstract—**In recent years, wireless computer networks have increasingly received critical attention in the networking research community. The IEEE 802.11 wireless local networks (LANs) employ the Binary Exponential Backoff (BEB) algorithm to resolve contention problems. In the contention resolution scheme of the IEEE 802.11 wireless LAN protocol, the contention window (CW) of a computer station doubles upon every contention loss and resets to the minimum CW size upon each successful completion of a packet handshake. Unfortunately, it has been shown that BEB is highly short-term unfair. In this paper, we propose a simple novel modification of BEB, known as Probabilistic Punishment and Release (PPR), to improve the fairness. Simulation results show that PPR improves the fairness as well as the total throughput of the network.**

I. INTRODUCTION

WIRELESS local area networks (LANs) have become increasingly popular in the computer communications industry since they do not require the expensive process of cable installation and extensive infrastructure setup that is necessary in traditional wired LANs. Instead, wireless networks can be set up quickly and relatively inexpensively. The IEEE 802.11 wireless LAN standard has gained growing acceptance, and these networks have been increasingly deployed in university campuses, coffee shops, and airports. Ad-hoc networks have been of particular interest to researchers since these networks are self-configurable and quick to set up.

An important resource in ad-hoc networks is the wireless medium (also known as the channel). Thus, a protocol for fair and efficient medium access control (MAC) is vital to facilitating communication amongst stations in the network. The IEEE MAC layer is specified in terms of one of the two coordination functions: the Distributed Coordination Function (DCF) and the Point Coordination Function (PCF) [1]. DCF is based on contention, whereas PCF uses a centralized contention-free polling mechanism. We direct our attention only to DCF in this paper, since commercially available wireless cards do not currently support PCF.

The IEEE 802.11 DCF MAC protocol uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) to prevent collisions in the radio environment. Fig. 1 depicts the 802.11 DCF MAC protocol operation.

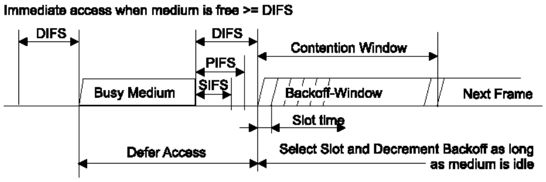

Fig. 1. 802.11 DCF MAC protocol operation

A station can transmit a pending data frame if the medium is idle for a time interval greater than or equal to the DIFS period. If the medium is found to be busy, the station continues to sense the channel for additional time after detecting the channel as being idle for the DIFS duration. The additional time period is randomly selected from the contention window (CW) and the size of CW, bounded by a maximum value CW_{max}, is doubled after each unsuccessful transmission to reduce the probability of collision. After each successful transmission, CW is reset to the minimum value CW_{min}. This process is defined by the Binary Exponential Backoff (BEB) algorithm, which can be expressed as the following equation [2]:

$$backoff\_time = randInt(0, min(CW_{min} \times 2^{retry}, CW_{max})) \times slot\_time$$

where *randInt*(*a*, *b*) generates a random integer in the range from *a* to *b* uniformly, *min*(*c*,*d*) gives the smaller value of *c* and *d*, *retry* is the number of retransmission attempts, and *slot_time* is a time duration specified by the physical layer parameters.

Resetting CW to CW_{min} after each successful transmission leads to short-term unfairness since a winning station will have a better chance than other stations of winning the contention on its next attempt at accessing the channel. If the load of the wireless network is heavy, the other stations will suffer severe throughput degradation resulting in unfair share of wireless channel bandwidth. The fairness problem is particularly important in wireless ad-hoc networks due to the lack of centralized control as well as the dynamic nature of the network topology [3].

In this paper, we propose a simple novel modification of BEB, known as Probabilistic Punishment and Release (PPR), to improve fairness. As a method of evaluating fairness, we define the fairness index as follows [4]:

$$FI = max\left\{ \forall i, j : max\left(\frac{W_i}{\phi_i}, \frac{W_j}{\phi_j}\right) / min\left(\frac{W_i}{\phi_i}, \frac{W_j}{\phi_j}\right) \right\}$$

where ϕ_i is the pre-defined fair share for station *i* and W_i is the actual throughput achieved by station *i*. If we assume each station has the same priority (i.e. $\forall i, j : \phi_i = \phi_j$), a perfectly fair system will have *FI*=1. Hence, we aim for *FI* of our algorithm to be smaller and closer to 1 than that of BEB.

II. PROBABILISTIC PUNISHMENT AND RELEASE (PPR)

To improve the fairness of BEB, we seek to reduce the probability of a winning station continuing to win the next contention. In our proposed PPR algorithm, we assign a probability to "punish" a station possessing a small CW and winning the contention by doubling its CW. If a station has suffered consecutive unsuccessful transmissions, we assign a probability with which it has a chance to reduce its CW to CW_{min}. Reducing the CW to CW_{min} will "release" the station from having a high probability of losing the rest of the contention races.

Algorithm – Probabilistic Punishment and Release

```
If (we won our last contention)
  If ($CW_{old} > CW_{threshold}$)
      // similar to BEB algorithm
      $CW_{new} = CW_{min}$
  Else    // Probabilistic Punishment
      Random = Rand(0, 99)
      Switch ($CW_{old}$)
          Case $CW_1$
              // 80% chance of punishment
              If (Random < 80)
                  $CW_{new} = CW_{old} \times 2$
              Else
                  $CW_{new} = CW_{min}$
          Case $CW_2$
              // 40% chance of punishment
              If (Random < 40)
                  $CW_{new} = CW_{old} \times 2$
              Else
                  $CW_{new} = CW_{min}$
          Case $CW_3$
              // 20% chance of punishment
              If (Random < 20)
                  $CW_{new} = CW_{old} \times 2$
              Else
                  $CW_{new} = CW_{min}$
Else    // we experienced a collision
  If ($CW_{old} < CW_{threshold}$)
      // similar to BEB algorithm
      $CW_{new} = CW_{old} \times 2$
  Else    // Probabilistic Release
      Random = Rand(0, 99)
      Switch ($CW_{old}$)
          Case $CW_4$
              // 20% chance of release
              If (Random < 20)
                  $CW_{new} = CW_{min}$
              Else
                  $CW_{new} = CW_{old} \times 2$
          Case $CW_5$
              // 40% chance of release
              If (Random < 40)
                  $CW_{new} = CW_{min}$
              Else
                  $CW_{new} = CW_{old} \times 2$
          Case $CW_6$
              // 80% chance of release
              If (Random < 80)
                  $CW_{new} = CW_{min}$
              Else
                  $CW_{new} = CW_{old} \times 2$
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The terms CW_{new} and CW_{old} are the sizes of the new CW and the old CW respectively and CW_{min} is the minimum size of the CW. The function *Rand*(a,b) returns a pseudo random integer drawn from a uniform distribution over the interval [a,b]. Our presented algorithm depends on a number of parameters, namely $CW_{threshold}$, CW_1, CW_2, CW_3, CW_4, CW_5 and CW_6, where $CW_1 < CW_2 < CW_3 < CW_{threshold} < CW_4 < CW_5 < CW_6$.

III. SIMULATION MODEL

To study the performance of BEB against PPR in 802.11 wireless LANs, we simulate it using OPNET Modeler 9.1 [5]. We evaluate the performance of BEB and PPR using two scenarios in which wireless networking is likely to be used: voice over IP (small packets) and FTP data transfer (large packets).

A. *Simulation parameters*

We test the PPR and BEB algorithms in an ad-hoc 802.11b wireless network with voice stations only in the voice over IP scenario and FTP clients and servers only in the FTP data transfer scenario. For performance estimation under heavy load condition, we assume that the MAC-layer buffer size is infinite and therefore no packets are dropped due to buffer overflow. The parameters used in the simulations are listed in Table I.

TABLE I
PARAMETERS FOR SIMULATIONS

Parameter	Value
Physical layer specification	Direct Sequence
Channel rate	11 Mbps
Slot time	20 μs
SIFS	10 μs
DIFS	50 μs
CW_{min}	32
CW_{max}	1024
$CW_{threshold}$	192
CW_1	32
CW_2	64
CW_3	128
CW_4	256
CW_5	512
CW_6	1024
Short retry limit	255
Long retry limit	255

B. *Traffic sources*

For the voice over IP scenario, we use the G.729 coder (bit rate of 8 kbps and frame size of 8 ms) to generate voice packets. Since we want to evaluate fairness, we turn off the silent suppression of the coder to ensure that a constant stream of voice packets is coming from the application layer. We disable the RTS/CTS mechanism since the frame size is very small and RTS/CTS is mainly used to obtain a better transmission behavior for large frame sizes [6]. Each station runs only one bi-directional voice session over UDP/IP.

For the FTP data transfer scenario, we assume that the upload and the download stream are identical with 200 kbps of data traffic in each stream. We assume that the size of each file is 576 bytes, the typical size for web browsing [7]. We also assume that the inter-request times of file transfers follow an exponential distribution. RTS/CTS is used prior to the transmission of a data frame and TCP is used for transporting the FTP traffic.

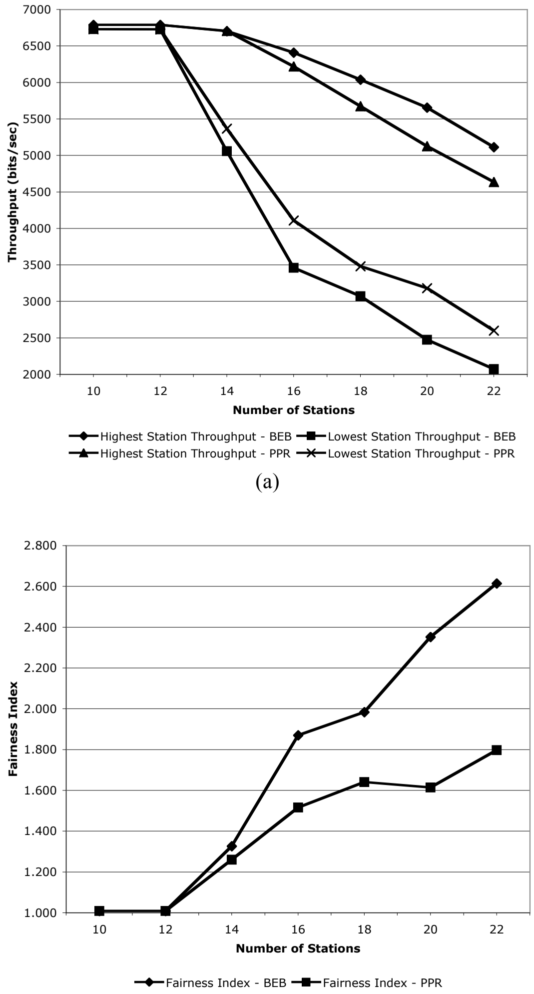
IV. SIMULATION RESULTS

In our simulations, each scenario is an independent basic service set with *n* stations having the same pre-defined fair share, and we assume that no hidden stations are present. The simulation time is 3 seconds (short-term) and the results are the average of ten seed numbers.

A. *Voice over IP scenario*

In the voice over IP scenario, we compare the highest throughput station with the lowest throughput station to determine the difference in fairness when PPR is used instead of BEB. As shown in Fig. 2(a), using PPR decreases the difference in throughput between the highest and the lowest throughput stations. Fig. 2(b) illustrates PPR's increased improvement in fairness over BEB as the number of stations increases.

For voice traffic, performance is often measured in terms of delay and delay variance, which are shown in Fig. 3 and 4. Since PPR adjusts the CW better than BEB, resulting in an efficient channel access, delay and delay variance are slightly lower and total throughput of the network is increased, as shown in Fig. 5. The results are obtained from a long simulation time, which demonstrates that PPR improves fairness without sacrificing other important areas of network performance.



(a)

(b)

Fig. 2. (a) Highest/lowest throughput for voice, (b) Fairness index for voice

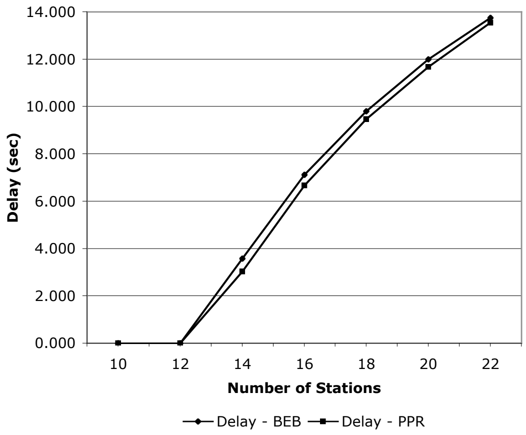


Fig. 3. Delay for voice

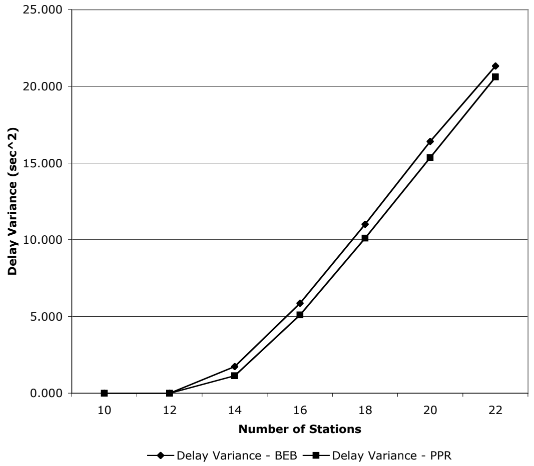


Fig. 4. Delay variance for voice

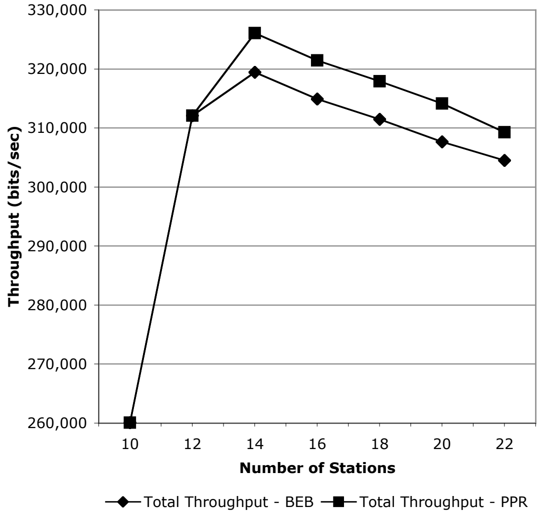


Fig. 5. Total network throughput for voice

B. FTP data transfer scenario

In the FTP data transfer scenario, we observe improvement in fairness and total throughput when PPR is used instead of BEB as illustrated in Fig. 6 and 7. Greedy TCP connections are able to achieve higher throughput with better transmission and retransmission schemes presented by PPR at the MAC layer.

V. DISCUSSION

The results from the two scenarios demonstrate that PPR is a fairer and more efficient algorithm than BEB. BEB gives the winning stations a good

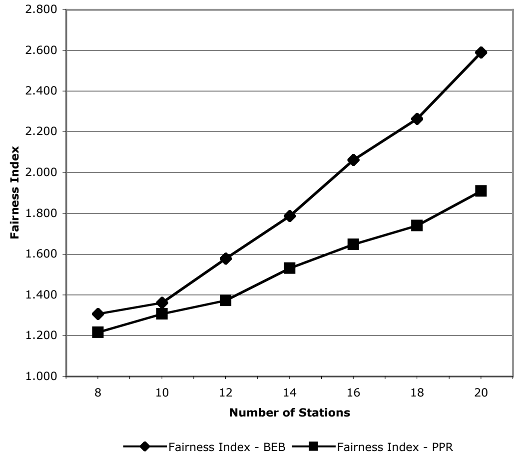


Fig. 6. Fairness index for FTP

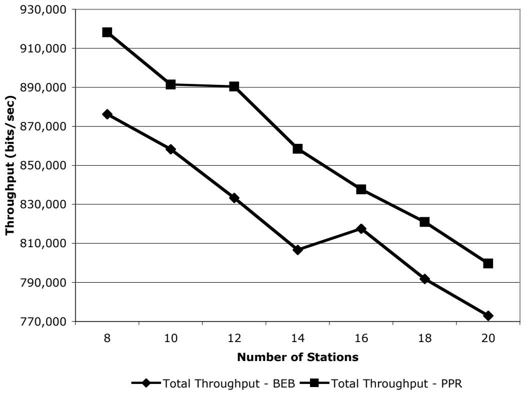


Fig. 7. Total network throughput for FTP

chance of continuing to win the contention, whereas PPR offers stations possessing relatively large CWs a chance to go back to CW_{min} and punishes stations having relatively small CWs. PPR introduces an enhanced alternation of CWs leading to a fair and efficient use of the channel. As the number of stations in the network increases, the improvement in fairness becomes more noticeable and pronounced.

We make the assumption that the network is under heavy traffic load since fairness is not a problem when the channel is mostly idle. Using PPR instead of BEB results in higher overall throughput, indicating that PPR manages the contention for the medium well under high traffic load. Although improving the total throughput is not the intent of this paper, we welcome the result. Because PPR makes more efficient use of the channel, which leads to fewer collisions in the wireless medium, the enhancement in fairness does not reduce but rather increases the total throughput of the network.

In the voice over IP scenario, we find that PPR demonstrates a slight advantage in delay and delay variance compared to BEB. As with throughput, these are not the areas we are targeting to enhance, but the improvement in fairness does not adversely affect these areas of network performance.

VI. CONCLUSION

In this paper, we used the idea of a fairness index to test the proposed PPR algorithm against the existing BEB algorithm in an ad-hoc 802.11b wireless network. PPR is based on the novel idea of assigning a probability that a station is "punished" for possessing small CWs as well as assigning a probability that a station should be "released" from large CWs. Simulation results show that PPR outperforms BEB in all areas of network performance that we tested: fairness, total network throughput, delay and delay variance (for voice). As PPR offers significant improvement to BEB without having a major modification of the physical hardware, it is an effective low-cost alternative to BEB.

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REFERENCES

[1] IEEE Computer Society LAN MAN Standards Committee, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," *ANSI/IEEE 802.11 Std, 1999 Edition*, The Institute of Electrical and Electronics Engineers, New York, 1999.

[2] W. Chen, B. Jian, and S. Lo, "An Adaptive Retransmission Scheme with QoS Support for the IEEE 802.11 MAC Enhancement," in *Proc. IEEE VTC Spring 2002*, Birmingham, USA, pp. 70-74, May 2002.

[3] K. Tang and M. Gerla, "Fair Sharing of MAC under TCP in Wireless Ad Hoc Networks," in *Proc. IEEE MMT'99*, Venice, Italy, Oct. 1999.

[4] B. Bensaou, Y. Wang, and C.C. Ko, "Fair Medium Access in 802.11 based Wireless Ad-Hoc Networks," in *Proc. IEEE/ACM MobiHoc 2000*, Boston, USA, pp. 99-106, Aug. 2000.

[5] OPNET Modeler. URL: http://www.mil3.com/

[6] R. Bruno, M. Conti, E. Gregori, "IEEE 802.11 Optimal Performances: RTS/CTS Mechanism vs. Basic Access," in *Proc. IEEE PIMRC 2002*, Lisbon, Portugal, pp. 1747-1751, Sept. 2002.

[7] K. K. Leung, B. McNair, L. J. Cimini, Jr., J. H. Winters, "Outdoor IEEE 802.11 Cellular Networks: MAC Protocol Design and Performance," in *Proc. IEEE ICC 2002*, New York City, USA, pp. 595-599, Apr. 2002.