Probabilistic Contention Window Control in 802.11 WLANs

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***Abstract*—In IEEE 802.11 wireless local area networks (WLANs), the binary exponential backoff (BEB) algorithm is used in the medium access control (MAC) protocol to resolve contention problems. Unfortunately, BEB has been shown to be highly short-term unfair. In this paper, we propose a probabilistic contention window control mechanism to improve the fairness of the backoff procedure and we evaluate its performance on real-time applications such as voice over IP and video conferencing. Simulation results reveal improvements in fairness and throughput, without detriment to delay and jitter.**

I. Introduction

THE growth in the popularity of portable computing has led to an increased interest in wireless local area network (WLAN) technology. Although Ethernet has long been established in the networking research community, the merits of WLANs have been quickly recognized: WLANs provide greater workstation mobility in addition to being easier and less expensive to install. In recent years, the IEEE 802.11 standard for WLANs has become widely accepted.

The wireless medium is a valuable resource in wireless networks, and hence, a fair and efficient medium access control (MAC) protocol is essential for effective communication amongst networking stations to take place. The distributed coordination function in the 802.11 MAC protocol utilizes binary exponential backoff (BEB) to solve contention problems. Unfortunately, BEB has been shown to be highly short-term unfair.

In this paper, we propose a simple novel modification of BEB. Using a probabilistic contention window control mechanism, which we shall call Probabilistic Punishment and Release (PPR), we seek to improve fairness of 802.11 at low cost and without having to make major modifications to existing hardware.

The paper is organized as follows: Section II and III present the existing 802.11 MAC protocol and the proposed PPR algorithm respectively. A definition of fairness and a method of evaluating it are presented in Section IV. Sections V and VI present our simulation model and our simulation results respectively. Finally, in Sections VII and VIII, we discuss our results and present our conclusion.

II. 802.11 MAC Protocol

The 802.11 MAC protocol provides asynchronous, time-bounded, and contention-free access control via the Distributed Coordination Function (DCF) and the Point Coordination Function (PCF) [1]. DCF, the basic channel access method, is based on contention (random access), whereas PCF uses a centralized polling mechanism in which a point coordinator determines which station has the right to transmit. Since commercially available wireless cards do not currently support PCF, we focus only on DCF in this paper.

The DCF, summarized in Fig. 1, uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) to prevent collisions in the wireless environment. When a station has a data packet to transmit, it first senses the channel to determine whether another station is transmitting. When the channel is found to be idle for a time interval greater than or equal to the distributed interframe space (DIFS), the station can proceed to transmit the data frame. If the channel is found to be busy, the station waits for the channel to become idle and then initiates the backoff timer, which is decremented when the channel is sensed as idle, stopped when a transmission is detected on the channel, and reactivated when the channel is sensed as idle again [2]. When the backoff timer reaches zero, the station transmits its packet. The value at which the backoff timer is set is uniformly selected from the interval (0, CW-1), where CW is the contention window whose size, 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 known as binary exponential backoff, or BEB.

CSMA/CA, unlike the CSMA/CD (Carrier Sense Multiple Access with Collision Detection) used in wired Ethernet, relies on a positive acknowledgement mechanism to ensure that the destination station has received the sent packet. Immediately after packet has been successfully transmitted, the receiving station sends out an acknowledgement frame (ACK) after a time interval called short interframe space (SIFS), which is smaller than DIFS. If the ACK frame is not received by the transmitting station, a collision is assumed to have taken place and a retransmission attempt occurs.

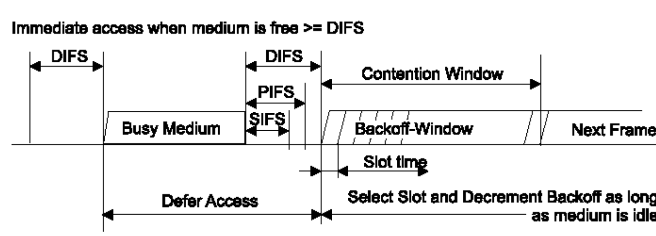

Fig. 1. 802.11 DCF MAC protocol operation

The addition of a RTS/CTS (Request-to-Send and Clear-to-Send respectively) mechanism can be used to solve the hidden-terminal problem.

III. Fairness

When the throughput of any two stations is not equal, we say that the network is unfair. Thus, in an ideal network, every station should transmit an equal amount of data at equal rates. A more precise method of evaluating fairness involves defining a quantity known as the fairness index (*FI*), which is expressed in the following equation [3]:

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

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 $FI = 1$.

The resetting of CW to CW_{min} after each successful transmission in the BEB algorithm 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 [4].

In developing a new algorithm to replace BEB, we seek to achieve a fairness index that is smaller and closer to 1 than that of BEB.

IV. 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. We achieve this through probabilistically controlling the contention window to "punish" a station possessing a small CW and winning the contention by doubling its CW. On the other hand, if a station has lost the contention on consecutive transmissions, we assign a probability with which it has a chance to reduce its CW to CW_{min}. Reducing the CW to CW_{min} "releases" the station from having a high probability of losing the rest of the contention races. Hence we name our algorithm, Probabilistic Punishment and Release (PPR).

Algorithm – Probabilistic Punishment and Release (PPR)

```
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 × 2
              Else
                  CW_new = CW_min
          Case CW_2
              // 40% chance of punishment
              If (Random < 40)
                  CW_new = CW_old × 2
              Else
                  CW_new = CW_min
          Case CW_3
              // 20% chance of punishment
              If (Random < 20)
                  CW_new = CW_old × 2
              Else
                  CW_new = CW_min
Else   // we experienced a collision
  If (CW_old < CW_threshold)
      // similar to BEB algorithm
      CW_new = CW_old × 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 × 2
          Case CW_5
              // 40% chance of release
              If (Random < 40)
                  CW_new = CW_min
              Else
                  CW_new = CW_old × 2
          Case CW_6
              // 80% chance of release
              If (Random < 80)
                  CW_new = CW_min
              Else
        CW_new = CW_old × 2
```

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 $CW_1 < CW_2 < CW_3 < CW_{threshold} < CW_4 < CW_5 < CW_6$.

V. Simulation Model

To study the performance of PPR against BEB in 802.11 WLANs, we simulate it using OPNET Modeler 9.1 [5]. We evaluate the performance of BEB and PPR using two real-time application scenarios: voice over IP and video conferencing.

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 video stations only in the video conferencing 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. Each station runs only one bi-directional voice session over UDP/IP.

For the video conferencing scenario, we assume that the bit rate is 512 kbps and the frame rate is 25 frames/sec. We also assume that the packet sizes are exponentially distributed.

VI. SIMULATION RESULTS

In our simulations, each scenario is an independent basic service set with *n* stations having the same pre-defined fair share. We assume that no hidden stations are present, and therefore the stations do not use the RTS/CTS mechanism prior to the transmission. 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. Fig. 2 illustrates PPR's increased improvement in fairness over BEB as the number of stations increases.

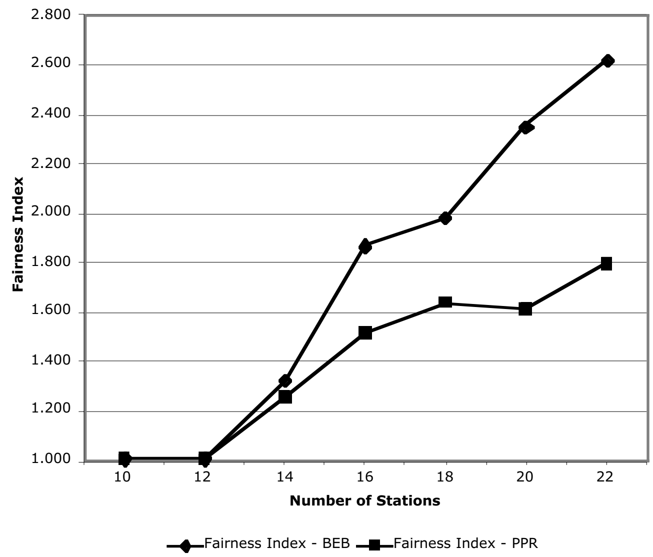

Fig. 2. Fairness index for voice

We also observe a higher total throughput in the network, as shown in Fig. 3, when PPR is compared against BEB in long-term simulations. For voice traffic, performance is often also measured in terms of delay and jitter, which are shown in Fig. 4 and 5. (In this paper, we define jitter to be the delay variance.) Since PPR adjusts the CW better than BEB, resulting in an efficient channel access, delay and jitter are slightly lower. The results are obtained from a long simulation time, which demonstrates that PPR improves fairness without sacrificing other important areas of network performance.

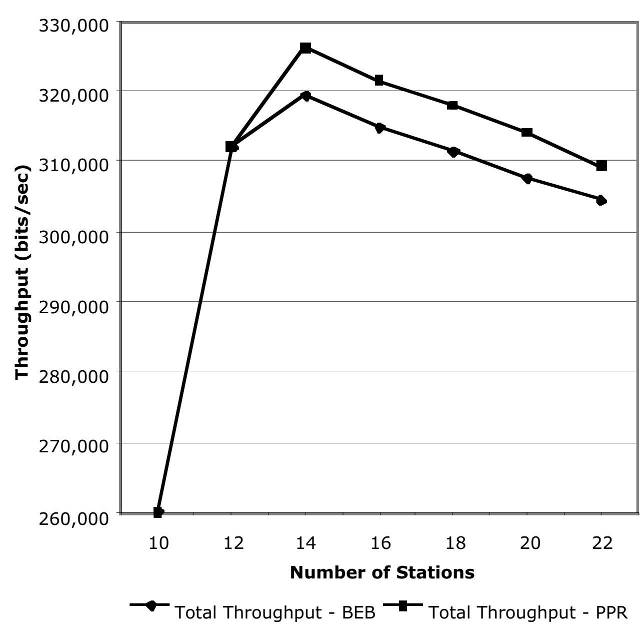

Fig. 3. Total network throughput for voice

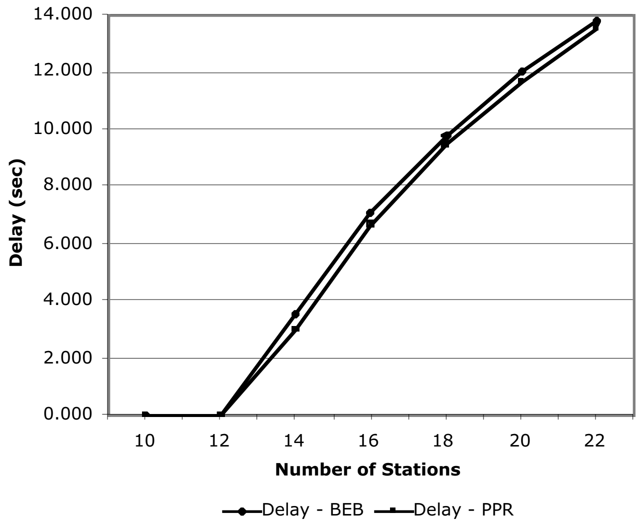

Fig. 4. Delay for voice

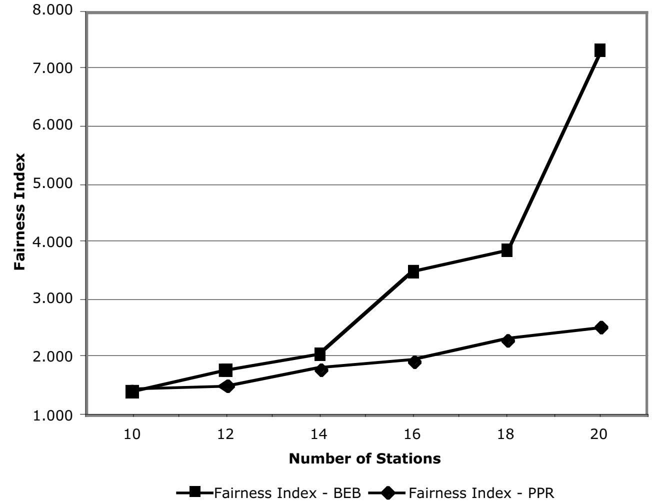

Fig. 6. Fairness index for video

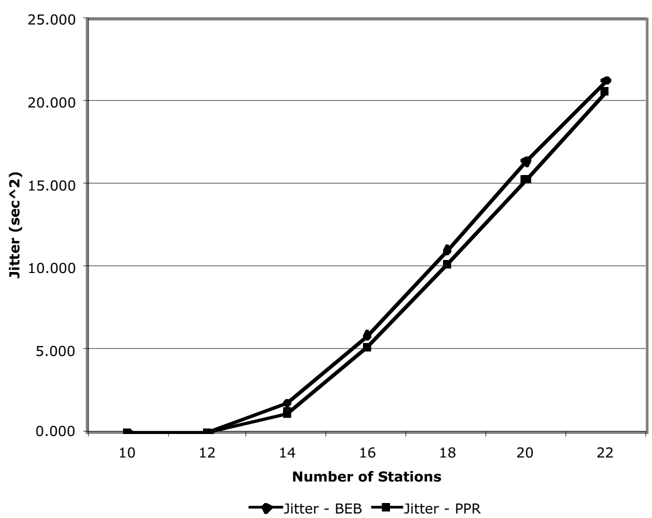

Fig. 5. Jitter for voice

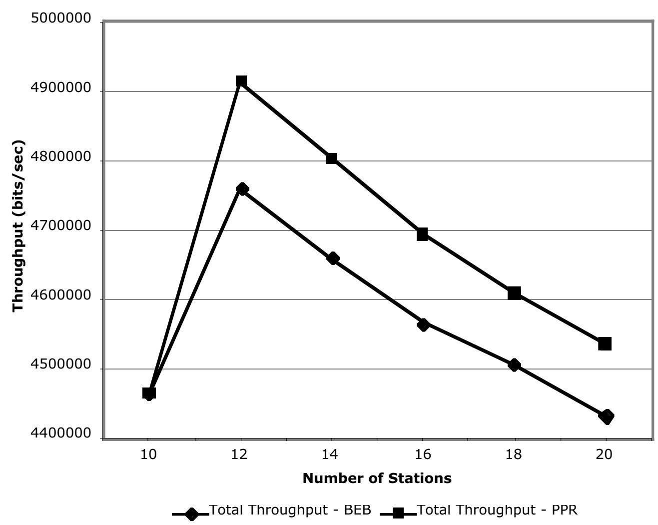

Fig. 7. Total network throughput for video

B. Video Conferencing scenario

In the video conferencing scenario, we observe improvements in fairness as well as the overall throughput of the network when PPR is used instead of BEB, as illustrated in Fig. 6 and 7. Furthermore, we find that delay and jitter, as shown in Fig. 8 and 9, are improved slightly when PPR is employed for contention resolution in the MAC layer instead of BEB. We attribute these improvements to the enhanced channel access method employed by PPR.

VII. Discussion

The simulation results show that PPR is a fairer algorithm than BEB. While BEB provides the winning stations with a high chance of continuing to win the contention, PPR offers stations with relatively large CWs a chance to go back to CW_{min} and punishes stations with relatively small CWs. PPR distributes CW sizes more evenly amongst stations in the

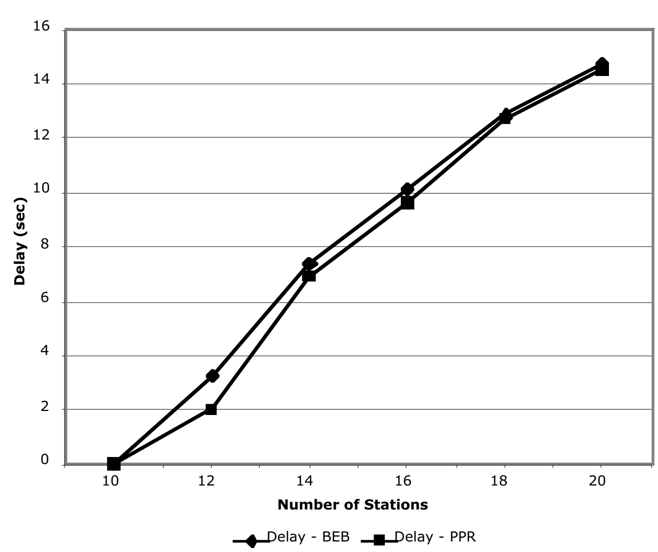

Fig. 8. Delay for video

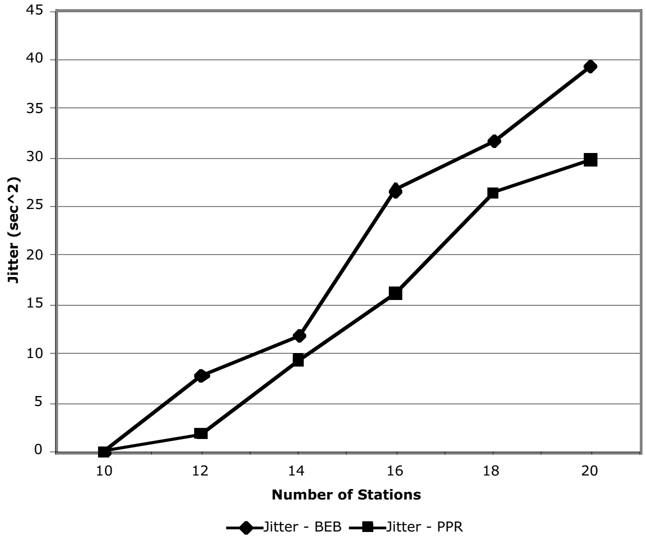

Fig. 9. Jitter for video

short-term, leading to a greater fairness and a more efficient use of the channel. As the number of stations in the network increases, this improvement in becomes more noticeable and pronounced.

The assumption that the network is under heavy traffic load is valid since fairness is only a problem when the channel is busy (when the channel is mostly idle, stations rarely perform backoff as there are few collisions). Although improving the total throughput of the network is not the intent of this paper, we find that using PPR instead of BEB results in a higher overall throughput. Since PPR manages the contention for the channel more effectively, leading to fewer collisions in the wireless medium, the enhancement in fairness does not reduce but rather increases the total throughput of the network.

Especially relevant to delay and jitter-sensitive applications such as voice and video, we find that PPR demonstrates a slight advantage in delay and jitter compared to BEB. As with throughput, these are not the areas we are targeting to enhance, but the results show that the improvements in fairness have no ill effects on the other important areas of wireless LAN performance.

VIII. Conclusion

In this paper, we test our alternative backoff mechanism, which we call the PPR algorithm, against the existing BEB algorithm in an ad-hoc 802.11b wireless network. PPR is based on the novel idea of probabilistically controlling the contention window by assigning a probability that a station is "punished" (CW increased) for possessing small CWs as well as assigning a probability that a station should be "released" (CW reset to CW_{min}) from large CWs. Simulation results on common real-time applications such as voice over IP and video conferencing show that PPR outperforms BEB in all areas of network performance tested: fairness, total network throughput, delay and jitter. Since PPR offers significant improvement to BEB without requiring major modifications of existing physical hardware, it appears to be an effective low-cost alternative to BEB to improve the fairness amongst networking stations competing for the channel.

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