BLOCK-POLL COORDINATION FUNCTION FOR IMPROVING THROUGHPUT PERFORMANCE IN WIRELESS LANS

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ABSTRACT

IEEE 802.11 DCF shows the inefficient throughput performance, due to the large backoff and collision overheads. We propose the Block-poll coordination function (BCF) to reduce the backoff and collision overheads, thus increasing the aggregate throughput. By introducing a new Block-poll frame which includes a polling bitmap, each station can decide its transmission order, so that the channel access emulates TDMA. In addition, by dividing the polling bitmap into several chunks and transmitting only the changed chunks, the polling overhead can be reduced. The simulation and analysis results show the proposed protocol achieves higher throughput than IEEE 802.11 DCF, while reducing the average delay and the delay jitter values.

1. INTRODUCTION

The IEEE 802.11 wireless LAN [1] technology has matured in the research area as well as in the market. However, as a number of studies have pointed out, the theoretical maximum throughput of IEEE 802.11 DCF is only about three quarters of the link capacity, due to backoff and collision overheads. The backoff overhead is defined as the wasted idle slot time due to the backoff process. When the number of stations is small, collision hardly occurs. However, a lot of time slots are not utilized because of the backoff process. On the other hand, when the number of stations becomes large, collisions can occur more frequently, resulting in the performance degradation. This is referred to as the collision overhead.

The IEEE 802.11 standard optionally defines the controlled access function, Point Coordination Function (PCF), which can increase the throughput by adopting a polling mechanism. The contention free period (CFP) and the contention period (CP) are repeated periodically, and in the CFP, the access point (AP) polls stations in the polling list in a round-robin manner. When the polled station does not have frames to send, it sends a null frame back to the AP to inform the AP that the station has no frame to send. PCF can fully utilize the medium because collisions will not occur in CFP. However, the overhead due to CF-Poll and corresponding ACK frames reduce the overall throughput, particularly when the polled station has no frames to transmit.

In general, the controlled access mechanism shows better performance over the distributed access mechanism. However, the controlled access mechanism still exhibits overheads due to polling. Overall, the distributed access mechanism has backoff and collision overheads, while the controlled access mechanism has polling or slot allocation overheads. Therefore, in order to improve the throughput performance of the IEEE 802.11 MAC protocol, reducing the backoff and collision overheads will be of great significance. We propose the Block-poll coordination function (BCF) for the IEEE 802.11 wireless LANs to reduce such sources of the performance degradation.

This paper is organized as follows. First, we analyze the problems of DCF and introduce related work in Section II. And then we propose BCF in Section III. In Section IV, we evaluate our proposed protocol by numerical analysis and simulation results, and then concluding remarks will be given in Section V.

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2. RELATED WORK

A number of alternative polling algorithms have been proposed to reduce the polling overhead of PCF. [3] is proposed to enable simultaneous polling of the stations in the basic service set (BSS). To reduce the polling overhead occurring when the polled station has no frame to send, it manages the station list with Idle/Active rings and polls stations in the Active ring one after another. When the station in the Active ring does not have a frame to send, it is moved to the Idle ring. Therefore, this approach can reduce the idle slot time of the polled stations with no frames to send. However, it still exhibits the overhead to poll each station in the Active ring one after another.

To be incorporated with IEEE 802.11e [2], the multi-user polling algorithms are proposed ([4], [5], [6], [7]). In [4], each polled station attaches a polling frame that contains the polling message for the remaining polled stations. it reduces failure in receiving the polling frames. However, the redundant polling frames hinder the efficient channel utilization. [5], [6] propose contention-based multi-user polling mechanisms. Under [5], [6], upon receiving the multi-poll frame, each station retrieves the corresponding backoff counter from the polling list and begins the backoff process. These approaches can achieve better channel utilization than PCF. However, they should broadcast the address list of the polling stations. Therefore, when the number of stations in the list increases, the overhead increases accordingly. In addition, for providing the QoS differentiation, many of the multi-polling mechanisms introduce additional overhead, such as transmission opportunity (TXOP). [7] also proposes a multi-polling mechanism, but this work aims at solving the hidden terminal problem. To this end, it introduces the deferring process. It is effective in that it is tailored to prevent the hidden terminal problem. However, such a mechanism hampers the efficient channel utilization.

3. PROTOCOL DESCRIPTION

The key concept of BCF is to exploit the advantages of the TDMA MAC protocol and to reduce the polling overhead by introducing the Block-poll frames. We assume the traffic pattern of the wireless LAN users is bursty, which means a user makes use of the wireless LAN for a period of time and stays idle for a while, and then starts using it again. FTP and WWW are the examples of this traffic pattern. We consider this traffic pattern in designing our protocol to reduce the polling overhead.

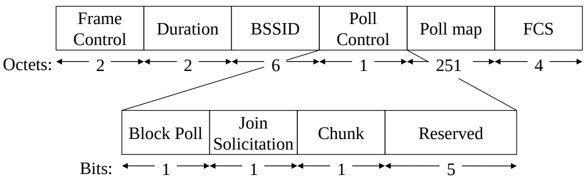


Fig. 1. Block-poll frame format

3.1. Basic Idea

A *Block-poll* frame is broadcasted by the AP to let each station know its transmission order. The Block-poll includes a bitmap (*Poll-map*), which is similar to the traffic indication map (TIM) field in the beacon frame. Each bit in the Poll-map corresponds to the *association identifier (AID)* of each station, and AID zero represents the AP's transmission. The Poll-map is 251 bytes long, so that it can cover up to 2007 non-AP stations. If a bit of a station is set to one in the Poll-map of the Block-poll frame, it is allowed to transmit a frame. Otherwise, it is not allowed to send frames. Fig. 1 shows the frame format of the Block-poll frame, which contains Frame control, Duration, BSSID, Poll Control, Poll-map and FCS fields. Each field is the same as that of the normal MAC header except Poll Control field; the details of the Poll Control field will be given in the next subsection.

BCF uses the controlled access mechanism, so that the AP coordinates the transmissions within the BSS. The AP broadcasts the Block-poll frames every round or every M rounds; here a round means a duration in which every station which is set to one in the Poll-map finishes its transmission. When each station receives the Block-poll frame, if the station is set to one in the Poll-map and also has a frame to send, it sets its backoff counter to the number of preceding "one"s in the Poll-map. For example, if three bits are set to one in the Poll-map before a station's AID bit, then the station sets its backoff counter to three. On the other hand, if the station has nothing to send, it does not set the backoff counter, which causes the assigned time slot (one time slot) to be wasted idle. Finally, if the station's bit in the Poll-map is set to zero, the station is not allowed to access the channel, and hence it does not set the backoff counter.

The station which sets its backoff counter decreases the counter after each idle time slot (in case the medium has been idle), or a DIFS (in case the medium has been busy), as in DCF. When the backoff counter reaches zero, the station transmits a frame. Corresponding ACK transmission is also same as DCF, so that the receiving station replies with the ACK frame after a SIFS period.

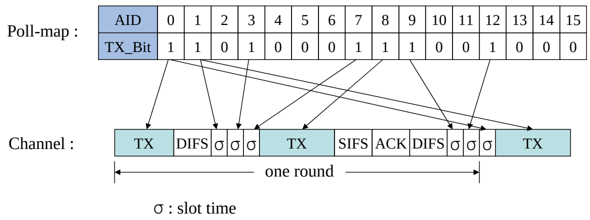


Fig. 2. An example of the BCF operation

When the last station whose transmission bit is set to one in the Poll-map finishes transmission or gives up its slot, the transmission chance goes back to the first station, i.e., the frame transmission is performed in a round-robin manner. Fig. 2 shows an example of the BCF operation. In the figure, AID0 (AP) transmits a frame in its time slot. Because it is a Block-poll message, it is broadcasted. AID1 is the very next station whose bit is set to one; however, it has no frame to send, so that it gives up its time slot. So do AID3 and AID7. In case of AID8, it has a frame to send, thus it transmits a frame in its time slot.

In this way, the transmission order of each station is determined by the bit set in the Poll-map. As a consequence, the wasted time can be reduced significantly because there cannot be a collision within the BSS. Since we already assume that the users' traffic pattern is bursty, we can also assume *temporal locality* of the Poll-map, i.e., the Poll-map would not change frequently over time. Hereby, the Block-poll frame does not have to be transmitted every round, which can reduce the overhead of the Block-poll frame.

Chunk #	AID	0	1	2	3	...	Chunk #	AID	2004	2005	2006	2007
0	TX_Bit	1	1	0	0		251	TX_Bit	1	0	0	0

Fig. 3. An example of the chunk-based Poll-map

3.2. Chunk-based Block-poll Design

Although the Block-poll frame is not transmitted every round, it is a fixed overhead. In other words, the size of the Block-poll frame is not dependant on the number of stations in the BSS because it carries a bitmap, not a list. Thus, if the number of stations is small, the overhead of the Block-poll frame becomes relatively large. Therefore, we propose a *Chunk-based* Poll-map in order to reduce the overhead of the Poll-map. As in Fig. 3, the Poll-map is divided into several chunks, each of which marks its chunk number and contains K TX bits. If the traffic pattern shows temporal locality, the Poll-map does not change frequently; only a few stations switch between Active/Idle modes over a certain time. Therefore, transmitting only the changed chunks will significantly reduce the overhead of the Block-poll frame.

Normally, the AP broadcasts only the changed chunks, and for the Poll-map synchronization, it transmits the full Poll-map every M rounds or triggered by some events, such as the association/disassociation of the newly joined station. In this case, Chunk bit of Poll Control field in the Block-poll frame header is set to zero to indicate the full bitmap is transmitted. Otherwise, Chunk bit is set to one, to indicate only a few chunks are included.

3.3. Join/Leave operation

In terms of the Poll-map management, the AP periodically (every M rounds) broadcasts the *Join-solicitation* frame, which also contains a bitmap (*Inverted-Poll-map*) that is the inverse of the Poll-map in the Block-poll frame. This is to allow the idle stations to participate in Block-poll. Therefore the Poll-map is inverted in the Join-solicitation message. A station which has been set to zero in the Poll-map will be set to one in the Inverted-Poll-map. If this station has a frame to send, it will reply to this message with any pending frame. The transmission order is the same as the case of the Block-poll. Thus, the station sets its backoff counter to the number of preceding stations whose bit is set to one in the Inverted-Poll-map.

Table 1. Poll Control field of the Block-poll frame

BP	JS	Ch	Meaning
1	0	0	Block-poll frame with full Poll-map
1	0	1	Block-poll frame with Chunks
0	1	0	Join-Solicitation frame

By setting the Join-solicitation bit to one in Poll Control field of the Block-poll frame, the AP broadcasts the Join-solicitation frame. (The meaning of the bits in Poll Control field is shown in Table I.) When the station sends a frame in its assigned slot time, its AID bit will be set to one in the Poll-map afterwards. On the other hand, if the station has nothing to send, it can give up its opportunity by sending no frame.

When a station whose bit is set to one in the Poll-map does not have a frame to send, it will transmit no frame in its time slot. The AP keeps track of whether each station transmits any frame in its time slot or not. If a station gives up its time slot for *M* consecutive chances, it is excluded from the Poll-map. And then the changed Poll-map (or chunk) is transmitted at the next Block-poll transmission. This is also on the assumption of temporal locality of the traffic pattern, which implies the station will not transmit frames for a while after then.

3.4. Discussion

3.4.1. Poll-map Synchronization

All the bits in the Poll-map is maintained in every station, so that the Poll-map synchronization is a critical issue in BCF. If a station has a stale poll-map, collisions can occur, which will severely deteriorate the performance of BCF. Therefore, the AP transmits the Block-poll frame every M rounds to synchronize the Poll-map of each station even though the Poll-map has not changed. Ideally, collision cannot occur in BCF, however, the frame transmission in the overlapping BSSs can cause collisions. In this case, two collided stations waste the medium for a transmission time, but other stations can transmit frames correctly afterwards. In BCF, the collided station does not perform exponential backoff. Also, BCF does not employ Extended Inter-Frame Space (EIFS) because the EIFS operation of some stations can damage the transmission order. Likewise, there is no difference in the BCF operation in case of transmission failure due to the channel error.

3.4.2. Association/Probe

BCF does not have the contention period, so that the association of a new station is relatively difficult. The same situation happens with the Probe-request message. For these cases, the AP attaches empty chunks at the end of the Poll-map, whose numbers exceed the AID range so that the time slots can be reserved to the association process or Probe-request messages. The un-associated station can send a message in these time slots by randomly choosing a slot. This frame can collide with other association or Probe-request messages, but it will hardly occur because such message can rarely occur simultaneously in a round.

3.4.3. QoS differentiation

Although IEEE 802.11e EDCA [2] provides per-flow QoS features, the service providers may want to provide the per-station QoS differentiation. In BCF, it is simply handled by employing the unicast-polling mechanism of PCF. The premium users can notify its service level in the authentication process, and the AP adds the station in the unicast-polling list. The AP gives more transmission opportunities to the station by polling it with PIFS access. Because the unicast-polling is performed with PIFS access, this operation does not affect the operation of the Block-poll.

4. PERFORMANCE EVALUATION

In order to evaluate the performance of BCF, we perform analysis as well as simulations. We compare the throughput, the delay, and the delay jitter with those of DCF, not PCF or other multi-polling mechanisms, since those mechanisms cannot work without extra contention periods; BCF does not require any additional contention period. We consider two traffic patterns: the saturated traffic, and the burst traffic.

4.1. Throughput Analysis

4.1.1. Saturated traffic

The throughput analysis of DCF under the saturated traffic is given in [8]. This study uses the Markov chain model and calculates the theoretical maximum throughput of IEEE 802.11 DCF. From the analysis, the aggregate throughput, T_P, is derived as follows, where Π_s, Π_c, Π_σ, n, and τ denote the channel state probabilities of a successful transmission, a collision, and an idle slot, and the number of stations, and the transmission probability, respectively. T_s and T_c stand for the time spent in the successful transmission and collision respectively, which are borrowed from [8].

$$
\begin{aligned}
T_P &= \frac{\Pi_s}{\Pi_s T_s + \Pi_c T_c + \Pi_\sigma \sigma} \\
\Pi_\sigma &= (1-\tau)^n \\
\Pi_s &= n\tau(1-\tau)^{n-1} \\
\Pi_c &= 1 - \Pi_\sigma - \Pi_s
\end{aligned}
$$

In case of BCF, if the traffic is saturated, the aggregate throughput can be simply estimated by calculating the number of transmitted payloads over M consecutive rounds. In the equations below, M, N, $E[P]$, H_d, and H_b denote the number of rounds for single Block-poll frame transmission, number of stations, the average payload size, the size of the data frame header (both MAC and PHY), the sum of the Block-poll and the Join-solicitation headers, respectively. Also, T_P, T_T, and T_{CO} denote the aggregate throughput ratio, the time for frame transmission, and the control overhead, respectively. In this scenario, because every station has frames to send, only the headers of the Block-Poll and Join-solicitation frames are transmitted; i.e., there is no mode change among stations and hence the Poll-map is not transmitted. In the equation below, the overhead of H_b is fixed, so that the more the stations, the more the aggregate throughput. Particularly as the number of stations and the number of rounds per Block-Poll transmission are increased, the header overhead becomes negligible.

$$T_P = \frac{T_T}{T_T + T_{CO}}$$
$$T_T = E[P] \cdot M \cdot N$$
$$T_{CO} = (H_d + DIFS + SIFS + ACK) \cdot M \cdot N + H_b$$

4.1.2. *Burst traffic*

We assume the traffic state switches from the active state to the idle state periodically, for simplicity. Let τ_A and τ_I be the active duration and the idle duration of the burst traffic, respectively. Then, we can assume that only $\frac{\tau_A}{\tau_A+\tau_I}$ of total contending nodes in the saturated traffic case are involved in contention. Assuming this, we can approximately estimate the the aggregate throughput of DCF in the burst traffic case.

In case of BCF, we simplify the model by estimating the duration of the frame transmission, and the Poll-map, and the idle slot overheads in M rounds. In this case, we assume that τ_A and τ_I are much larger than the duration of a round. Therefore, the transmission mode (Active/Idle) of each station does not change frequently in a round. If either the number of rounds per Block-poll frame transmission or the number of stations increases, the aggregate throughput increases accordingly. In the equations below, T_P, T_T, T_I, T_{BO}, and T_{CO} denote the aggregate throughput ratio, the transmission time, the idle time, the time consumed in Block-poll transmission, and the time for the control overhead in M rounds, respectively. Also, K, σ, T_C, and $E[R]$ represent the number of stations in a chunk, the slot time, the transmission time of a chunk, and the estimated duration of each round, respectively.

The analysis results are compared with the simulation results in the next section.

$$T_P = \frac{T_T}{T_T + T_I + T_{BO} + T_{CO}}$$
$$T_T = E[P] \cdot M \cdot N \cdot \frac{\tau_A}{\tau_A+\tau_I}$$
$$T_I = \sigma \cdot M \cdot N \cdot \frac{\tau_I}{\tau_A+\tau_I}$$
$$T_{BO} = \frac{2 \cdot E[R]}{\tau_A+\tau_I} \cdot \left(\frac{N}{K} \cdot T_C\right) \cdot M$$
$$T_{CO} = (H_d + DIFS + SIFS + ACK) \cdot \frac{M \cdot N \cdot \tau_A}{\tau_A+\tau_I} + H_b$$
$$T_C = \left(E[P] \cdot \frac{\tau_A}{\tau_A+\tau_I} + \sigma \cdot \frac{\tau_I}{\tau_A+\tau_I} + \frac{T_{CO}}{M \cdot N}\right) \cdot N$$

4.2. Numerical Results

The simulations are conducted using NS-2 to compare BCF with DCF. The payload size is fixed at 1000 bytes by default, and other simulation parameters are shown in Table II. Although we take only the IEEE 802.11b case in our simulations, the results will be effective to estimate the performance of IEEE 802.11a/g cases.

Table 2. SIMULATION PARAMETERS

SIFS	10 μs
DIFS	50 μs
BasicRate	2 Mbps
DataRate	11 Mbps
PLCP length	192 bits @ 1 Mbps
MAC header (ACK, data)	(14, 28) bytes @ Basic Rate
# of rounds per Block-poll TX (M)	10
# of stations in a Chunk (K)	8

4.2.1. *Saturated traffic*

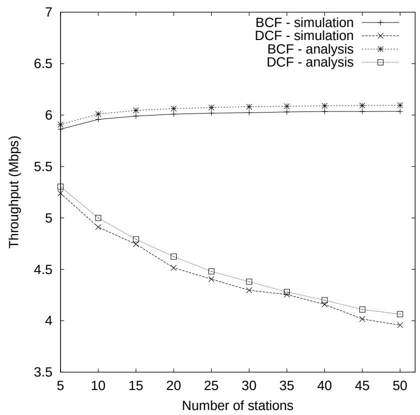
In the saturated traffic scenario, we vary the number of stations from 5 to 50. The aggregate throughput values versus the number of stations of BCF and DCF are plotted in Fig. 4(a). In both the simulation and the analysis results, BCF exhibits slightly increasing throughput with the number of stations. On the other hand, DCF shows the decreasing throughput performance as the number of stations increases. Also, DCF shows the worse throughput performance than BCF. Fig. 4(b) plots the delay values of BCF and DCF. In Fig. 4(b), BCF shows the less delay value than DCF. Also, the standard deviation of the delay is demonstrated in Fig. 4(b), where BCF shows almost constant delay performance, whereas DCF shows much larger delay jitter value. In order to evaluate the theoretical maximum throughput, we measure the throughput with regard to the payload size. The throughput result is shown in Fig. 4(c). Here, the aggregate throughput increases when the payload size increases in both BCF's and DCF's cases. However, as expected, BCF outperforms DCF by a large margin.

4.2.2. *Burst traffic*

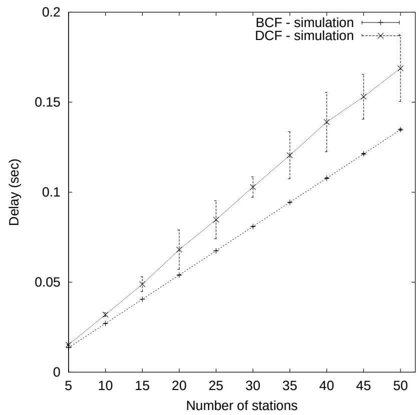
In terms of the burst traffic case, we set the ratio of the active duration to the idle duration to one for simplicity. When the Active/Idle time duration is changed, there is a little difference in the performance of BCF, because, BCF should broadcast the Poll-map change of the active stations. We conduct the simulations of two cases of Active/Idle time durations (T_A=T_I=0.01, 1.0 sec). Figs. 5(a), and 5(b) show the throughput performance of each case. When T_A is 1.0, the aggregate throughput is maintained around 6 Mbps, as in the saturated traffic. However, when T_A is 0.01, the throughput performance of BCF is slightly degraded BCF because the number of changed chunks should be transmitted more frequently. Therefore, in Fig. 5(a), the throughput of BCF is maintained below 6 Mbps. On the other hand, DCF shows almost same results as in the saturated scenario.

5. CONCLUSION

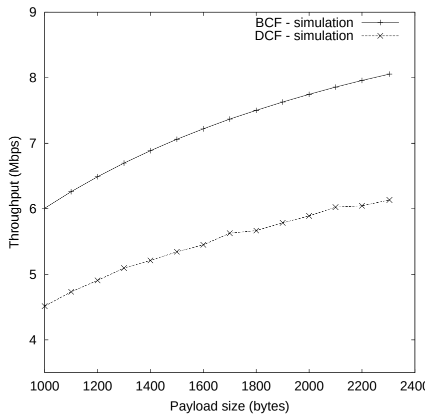
We propose the Block-poll coordination function (BCF) for wireless LANs to enhance the throughput performance of DCF. The polling bitmap in the periodic Block-poll frame coordinates the transmission order of each station in the BSS. The analysis and simulation results show that BCF achieves better throughput and delay performance than DCF. The performance gain of BCF increases as the number of stations becomes large. This is because BCF not only does not suffer from collision but also does not waste the medium time for the backoff process. However, when the network is lightly loaded, BCF does not exhibit better performance than DCF. Our future work will include an analysis of the optimal values for the parameters, such as the number of stations in a *Poll map* and the number of rounds per one *Block Poll* frame.



(a) Aggregate throughput w.r.t. the number of stations

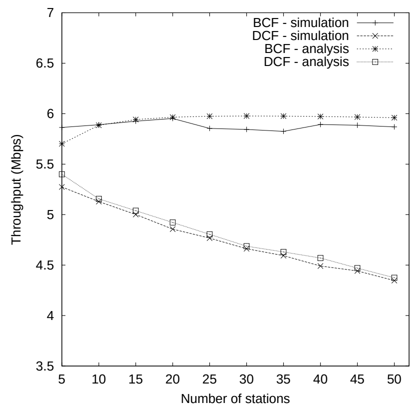


(b) Delay w.r.t. the number of stations

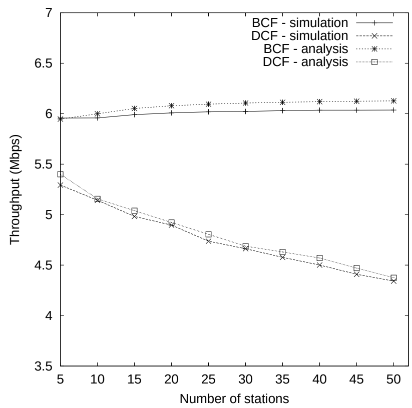


(c) Aggregate throughput w.r.t. the payload size (number of stations = 20)

Fig. 4. Performance comparison in the saturated traffic scenario



(a) Aggregate throughput (T_A=T_I=0.01 sec)



(b) Aggregate throughput (T_A=T_I=1.0 sec)

Fig. 5. Performance comparison in the burst traffic scenario

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