Dynamic Scheduling of PCF Traffic In An Unstable Wireless LAN

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Abstract

IEEE 802.11 MAC protocol PCF is intended to facilitate real time traffic, however, the performance of PCF is highly affected by conditions on the WLAN and it has unnecessary overhead. To address these problems, we propose an aging priority scheduling algorithm and a dynamic adaptation algorithm to vary the PCF interval based on the traffic and reduce the overhead. Simulation results show our algorithms are efficient and suitable for PCF traffic.

Keywords 802.11, PCF, MAC Scheduling

1. Introduction And Related Work

Wireless LANs are becoming increasingly popular for providing real time service. Studies have shown that Internet traffic can be periodically busy under regular loads [1,2,3], however, protocols currently in use are better suited to steady traffic flows. Our goal is to improve the efficiency of MAC protocols (thus wireless LANs) by providing a means for adapting to periodic busy and unstable usage patterns [4].

The IEEE 802.11 standard MAC protocol supports two kinds of access methods [5]: DCF (Distributed Coordination Function), PCF (Point Coordination Function). The DCF is designed for asynchronous data transmission by using CSMA/CA and must be implemented in all stations. On the another hand, the PCF is optional and based on polling controlled by a PC (Point Coordinator). Recently, IEEE published two other standards, they are, Extended DCF and HCF (Hybrid Coordination Function). These two access methods together with PCF are intended for transmission of real-time traffic as well as that of asynchronous data traffic. Since PCF has been widely implemented, in this paper, we focus on the PCF. PCF uses round-robin polling. The polling scheme is an important mechanism to guarantee real time traffic. However, it carries a lot of null frame overhead and the structure of the frame will cause performance degradation when traffic and station association patterns are periodically busy. We characterize such a WLAN as unstable.

Complex MAC polling schemes have been proposed to solve the overhead problem. Sharon and Altman [6] proposed STRP, which succeeds in reducing the polling overhead caused by stations having no pending data to transmit. Ranasinghe [7] proposed DDRR instead of basic round-robin scheduling in PCF to provide QoS and showed the impact of different polling strategies on the capacity of 802.11 WLAN. Both of the algorithms effectively improve the polling quality, but they cannot be implemented in the current 802.11 standard without the addition of new management frames and cause additional overhead. C. Coutras[8] proposed to manage the time of polling for each station in handling real time traffic. Yeh et al.[9] proposed a priority-ELF scheme combined with PCF, which checks the priority of the stations, and then the AP polls the stations in the order of the priority from high to low. Suzuki et al.[10] proposed priority-based multimedia transmission with PCF, which gives the priority control to AP or both AP and the stations, and then AP decides whether to poll or not based on the priority of the stations. All of the schemes are sufficient to maintain the QoS of the multimedia traffic. However, they do not consider the effect of the system conditions in an unstable WLAN and the overall performance of PCF.

Current analyses of PCF do not consider the effects of an unstable WLAN. In this paper, we will use Markov Chain model to analyze the performance in an unstable WLAN. MAC layer protocols are reviewed in Section 2. In Section 3, we evaluate and analyze MAC layer performance. In section 4, we propose our aging priority round-robin scheduling algorithm and dynamic adaptation algorithm. Our simulation results are presented in Section 5. We conclude in section 6.

2. The 802.11 MAC Layer Protocols

The MAC architecture is composed of two basic coordination functions: PCF which uses polling and DCF which uses RTS/CTS. The former protocol is part of the infrastructure model, while the latter is part of the ad-hoc model. In PCF, time is divided into super-frames. A super-frame includes contention free period (**CF**) and contention period (**CP**). PCF works in CF. DCF works in the other period.

2.1 Contention Period (CP): DCF With RTS/CTS

The basic DCF is CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance). Carrier sensing is performed using physical carrier sensing (by air interface) as well as virtual carrier sensing. Virtual carrier sensing uses the duration of the packet transmission, which is included in the header of RTS, CTS, and DATA frames. The channel is considered to be busy if either physical or virtual carrier sensing indicates that the channel is busy. When a station wants to transmit a packet, it needs to sense the channel. If the channel is idle in DIFS interval. Then, the station sends a RTS. After it receives a CTS from the receiver, the sender will send a data frame after waiting SIFS. If the sender receives an ACK from the receiver, the transmission is successful. In the meantime, other stations just wait a NAV (Network Allocation Vector) time, which indicates the remaining time of the on-going transmission sessions. Using the duration information in RTS, CTS and Data frames, stations update their NAVs whenever they receive a frame. When the sender finds the medium is busy, the sender waits a back-off window. The length of the back-off window is considered to be a counter. The station will try to retransmit when the counter reaches zero.

2.2 Contention Free Period (CF)

PCF uses a centralized contention-free polling access method to facilitate real time services. It is done by software called point coordinator **(PC)** in the Access Point (**AP**). It performs polling for stations that are capable of being polled. Before a PCF polling cycle, AP contends with other stations in DCF, but AP only needs to wait a PIFS, which is shorter than DIFS. Because of the priority, no other senders would interrupt AP. To prevent starvation of stations that are not allowed to send during the CF, the CP is at least long enough to transmit one Maximum MAC protocol data Unit (MMPDU). The 802.11 standard does not specify a mechanism for adjusting the relative length of CF and CP. After a station finishes 802.11 association with an AP in CP, the AP gives an association id (AID) to it and puts it in the polling queue based on the station's AID**.** The AP maintains the polling list that specifies the order in which stations are to be polled. The AP polls the stations in a round-robin fashion. If there is no pending data transmission, the station either responds with a null frame containing no payload or does not respond. If the AP does not get a response from the station, then the AP may re-poll the station after PIFS interval instead of SIFS interval, which is the normal interval between any two pollings and shorter than PIFS. If the CF terminates before all stations have been polled, the polling queue is resumed at the next station in the following CF cycle.

2.3 Motivation

When all stations have pending data, sequential polling provides ordered channel access and reduces collisions. However, in an unstable WLAN, two conditions may occur: 1) Only a few stations have pending data (active stations) and the rest are silent (silent stations), which are stations sending null frames or not responding at all. 2) Many stations join or leave the WLAN at the same time causing a large number of association and disassociation requests. In the first condition, the silent stations include two parts: a) They do not have data because of periodically busy traffic patterns. b) They decide to disassociate, which also contributes to the second condition. The 802.11 polling mechanism causes significant overhead under these conditions. It adds unnecessary delay for stations with data, due to unsuccessful poll attempts for silent stations. We call the overhead caused by null frame or no response to be null frame overhead. Furthermore, since all stations in the WLAN contend in the CP and the stations in the polling queue are allowed to send management frames or control frames only in the CP, the degree of contention in the CP increases. The stations which want to associate, might not be able to connect with the WLAN immediately. The stations which want to disassociate, might not be able to disconnect with the WLAN immediately and they will be polled needlessly by the AP in the next CF. All these stations will contend in the next CP again, thus further increasing contention. Next, we analyze how the two situations degrade the performance in the CF and the CP.

3. Evaluation Of WLAN Performance

We define two metrics: **Throughput** (the number of packets that can pass through in a fixed time) and **Delay time** (the interval from the time a user requests a service to the time the service is granted). We calculate the two metrics for each of the two parts of the super-frame, CF and CP.

3.1 Throughput Scp And Delay Time Tcp Of CP

S_{CP}: We use the Markov chain analysis method to examine the performance of DCF. The Markov chain model is based on binary slotted exponential back-off window which is used by Bianchi et al. [11] and Wu et al. [12]. However, in our analysis, we consider both the retry and retry limits to analyze the back-off window automaton machine. Therefore, a more complete Markov Chain model is proposed in this paper. We assume n fixed stations contending in the WLAN. Let b(t) be the stochastic process representing the back-off time counter for a given station. The b(t) decrements at the beginning of each slot time. Thus, b(t) will become b(t-1) at the beginning of the next time slot. Slot time is referred to as the constant value, σ. Let s(t) be the stochastic process representing the back-off stage (0,…, m) of the station at time t. We assume each packet collides with constant and independent probability, p. So, the bi-dimensional process {s(t), b(t)} belongs to a discrete-time Markov chain, Figure 2 is the automaton machine for back-off window.

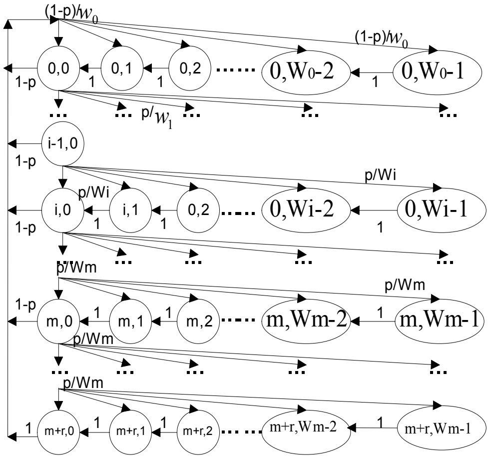


Figure 2 Markov Chain model of back-off window

The back-off window [11] is chosen from [0, CW], where $CW_{min} \leq CW \leq CW_{max.}$ CW_{min} is 32× σμs (σ is a slot time). CW_{max} is 1024× σμs. CW is randomly chosen from 0 to $2^m \times CWmin-1$, where $0 \leq m \leq 5$ and m is the parameter that denotes the stage of the back-off window and is incremented every time a station cannot access the media. It is not incremented further when m=5. We consider each state transition probability from stage one to stage m ($5 \leq m$) then back to stage zero. So, the only non-null one-step transition probabilities are shown in equation (1) with the notation:

$P\{i_1, k_1 | i_0, k_0\} = P\{s(t+1)=i_1, b(t+1)=k_1 | s(t)=i_0, b(t)=k_0\}$

These state transition probabilities account for: (1) At the beginning of each slot time, the back-off counter is decreased, which works from stage 0 to stage m. (2) From stage 1 to stage m, a new packet following a successful packet transmission starts with stage 0. (3) After an unsuccessful transmission, the back-off stage increases by one. (4) Once the back-off stage reaches the value m, it is not increased in subsequent packet transmissions. (5) The system is reset to stage 0, after it fails to retransmit several times(r times) in stage m, which improves the stability of the access protocol under high-load conditions [6]. This last step is not considered in previous models [12,13].

$$\begin{cases} P\{i,k|i,k+1\}=1 & k\in[0,w_i-2] \quad i\in[0,m] \\ P\{0,k|i,0\}=(1-p)/w_0 & k\in[0,w_0-1] \quad i\in(0,m+r] \\ P\{i,k|i-1,0\}=p/w_i & k\in[0,w_i-1] \quad i\in(0,m) \\ P\{m+j,k|m+j-1,0\}=p/w_m & j\in[0,r] \quad k\in[0,w_m-1] \\ P\{0,k|m+r,0\}=1/w_0 & k\in[0.w_0-1] \end{cases} \tag{1}$$

Let $b_{i,k}=\lim_{t\to\infty}P\{s(t)=i, b(t)=k\}$, $i\in[0,m]$, $k\in[0, W_i-1]$ be the stationary distribution of the chain.

First note that: $b_{i-1,0}\times p=b_{i,0}$ $0<i<m+r$ (2)

So, we have $b_{i,0}=p^i b_{0,0}$ (3)

$$b_{i,k}=\frac{w_i-k}{w_i}\begin{cases}(1-p)\sum_{j=0}^{m+r-1}b_{j,0}+b_{m+r,0} & i=0 \\ pb_{i-1,0} & 0<i<m+r-1\end{cases} \tag{4}$$

Using the fact that $(1-p)\sum_{i=0}^{m+r-1}b_{i,0}+b_{m+r,0}=b_{0,0}$, equation (4) can be re-written as

$$b_{i,k}=\begin{cases}\frac{w_i-k}{w_i}b_{i,0} & i\in[0,m] \quad k\in[0,w_i-1] \\ \frac{w_m-k}{w_m}b_{i,0} & i\in(m,m+r] \quad k\in[0,w_m-1]\end{cases} \tag{5}$$

Therefore, by using the normalization condition for stationary distribution, we have

$$1=\sum_{i=0}^{m}\sum_{k=0}^{w_i-1}b_{i,k}+\sum_{m+1}^{m+r}\sum_{k=0}^{w_m-1}\frac{w_m-k}{w_m}=b_{0,0}\times[(\frac{1-(2p)^{m+1}}{1-2p})w+\frac{1-p^{m+1}}{1-p}+2^m wp^{m+1}\frac{1-p^r}{1-p}+p^{m+1}\frac{1-p^r}{1-p}]$$

$$b_{0,0}=\frac{2(1-2p)(1-p)}{w[(1-(2p)^{m+1})(1-p)+2^m p^{m+1}(1-p^r)(1-2p)]+(1-2p)(1-p^{m+r+1})}$$

Finally, τ will be represented by $b_{i,0}$, which means a packet is transmitted when back-off counter is reduced to be zero.

$$\tau=\sum_{i=0}^{m+r}b_{i,0}=\frac{1-p^{m+r+1}}{1-p}b_{0,0}=\frac{2(1-2p)(1-p^{m+r+1})}{w[(1-(2p)^{m+1})(1-p)+2^m p^{m+1}(1-p^r)(1-2p)]+(1-2p)(1-p^{m+r+1})} \tag{6}$$

We also have $p=1-(1-\tau)^{n-1}$ (7). Next, we will calculate the max throughput of DCF in a slot time based on the τ. Let P_{tr} be the probability that there is at least one transmission in the considered slot time, σ. Further, let P_s be the probability that a transmission is successful. So, P_{tr} and P_s are as follows:

$$P_{tr}=1-(1-\tau)^{n-1} \qquad P_s=\frac{n\tau(1-\tau)^{n-1}}{p_{tr}}=\frac{n\tau(1-\tau)^{n-1}}{1-(1-\tau)^n}$$

The throughput, S_{cp}, can be expressed:

$$S=\frac{E[\text{Payload Information in a slot time}]}{E[\text{Length of a slot time}]}=\frac{p_s p_{tr}E[P]}{(1-p_{tr})\sigma+p_s p_{tr}T_s+(1-p_s)p_{tr}T_c}$$

Here, E[P] is the average packet payload size, so, the average amount of payload information successfully transmitted in a slot time is $P_sP_{tr}E[P]$. Three things could happen in a slot time, σ: a) No packet transmitted, the probability is $(1-P_{tr})\sigma$; b) Exactly one packet transmitted, the probability is $P_sP_{tr}T_s$, where T_s is average length of the packet successfully transmitted in a slot time; and c) More than one packet transmitted, the probability is $(1-P_s)P_{tr}T_c$, where T_c is average length of the packet unsuccessfully transmitted in a slot time. The values E[P], Ts, Tc and σ are expressed with the same time unit when they are calculated in the following sections.

We assume: all the data packets have the same length, all the propagation delays, δ, are the same, and the length of a collision packet is the longer of the two packets that collide. We only consider collisions between two packets and ignore the others. Let H represent the length of the packet header including physical and MAC layer header. We obtain T_s and T_c as follows, which are more complete than [12][13] :

T_s=RTS+δ+SIFS+CTS+δ+SIFS+H+E[P]+δ+SIFS+ACK+ δ+DIFS (8)

T_c= RTS + δ + SIFS + CTS + δ+ SIFS (9)

$$S_{\max}=\frac{p_s p_{tr}E[P]}{(1-p_{tr})\sigma+p_s p_{tr}T_s+(1-p_s)p_{tr}T_c}=\frac{E[P]}{T_s-T_c+(\sigma(1-P_{tr})/P_{tr}+T_c)/P_s} \tag{10}$$

When $\frac{\partial S}{\partial\tau}=0$, based on (10), we get max throughput, S_{max}, in a slot time, σ, at $\tau\approx 1/n\sqrt{T_c/2\sigma}$ (11). Based on equations (6), (7) and (8), we know the max throughput of a slot time depends on system parameters m, W and n (the network size). However, let $k=\sqrt{T_c/2\sigma}$ and $\tau=1/(nk)$, then, when n→∞, we get $P_{tr}\approx 1-e^{-1/k}$ and $P_s\approx 1/k(e^{1/k}-1)$. Therefore, we have approximate max throughput, S_{app}, $S_{app}=E[p]/(T_s+\sigma k+T_c(k(e^{1/k}-1)-1))$ (12).

Using the default system parameters in Table 1 for DSSS 802.11, we compare S_{max} with S_{app} in table 2. They are not affected by the network size, n, in a saturated WLAN. Therefore, the throughput of CP will not degrade by increased number of stations contending for the media. Therefore, the limited length of a CP will limited the throughput in a CP. Furthermore, due to the limited time in CP, some new stations can not be associated and put in the polling queue immediately. Thus, the throughput of CF will potentially degrade. Since silent stations in CF will not increase the throughput of a CF, the effective way to increase the throughput of CP is to extend the length of CP when the unstable conditions happen.

Parameter	Symbol	Value
SIFS	SIFS	10µs
DIFS	DIFS	50 µs
Slot time	Slot	20 µs
Propagation dalay	δ	1 µs
Header (MAC+PHY)	H	416bits
ACK	ACK	112bits
RTS	RTS	160bits
CTS	CTS	112bits
Packet Payload	P	8224bits
CF-Poll size	Tpoll	160bits
Channel B/W	bw	1Mbps

Table1.Default Parameter

n	Smax	Sapp
10	0.8201	0.8142
15	0.8196	0.8123
20	0.8161	0.8113
25	0.8107	0.8107
30	0.8041	0.8103

Table2 Max throughput

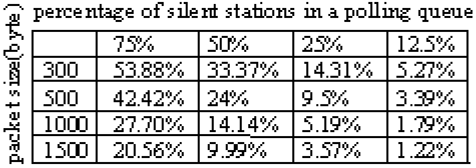
T_{CP}: Based on a Markov chain model described in [14], we see that T_{CP} depends on the length of B (back-off stage), Ts and Tc.

Therefore, the only way to reduce T_{cp} is to decrease contention by increasing the CP. See details in [14].

3.2 Throughput S_{CF} And Delay Time T_{CF} Of CF

S_{CF}: Whenever AP polls silent stations, the time to poll, the time to respond with null frame or no response, and the transmission time is all overhead (recall the description of CF in section 2.2). To simplify, we assume all silent stations respond to the polling with null frames. The silent stations include stations with periodic data traffic (sometimes it does not have data to send) or disassociating stations. Let N be the total number of stations in a WLAN, p_{null} be the fraction of stations having no pending data. Then, polling overhead O_{null} is $p_{null} \times N \times T_{PollNull}$. $T_{PollNull}$ is the overhead time due to polls of silent stations: $T_{PollNull} = T_{poll} + T_{null} + 2\times SIFS$, where T_{poll} and T_{null} is time to send poll and null frame respectively. We assume every station responds with the same length data P_{size} taking time T_{data} and use the default parameters in Table 1. The successful polling time is $T_{PollSuccess} = T_{poll} + T_{data} + T_{ACK} + 3\times SIFS$, where T_{ACK} is the time to send a acknowledge frame. We calculate the percentage of overhead as ratio of $T_{PollNull}$ to CF duration. Table 3 shows the overhead with respect to silent stations and packet sizes. The higher the percent of silent stations in a polling queue, the higher the percent of overhead in the traffic, so the throughput of S_{CF} will be degraded.

T_{CF}: The AP must contend in CP to start the polling cycle. The shortest time delay is T_{PIFS} . If the medium is busy, the AP has to wait T_{start}, which is $\sum_{j=0}^{n}(T_{PIFS}+K(m,j))$. k(m,j) is chosen from 0 to $2^m\times CW_{min}-1$ (recall the back-off window description). Here, j is the number of times the medium is checked and $0\leq j \leq n$; where $m = j$ when $0\leq j \leq 5$ and $m = 5$ when $5\leq j \leq n$. The T_{CF} of a station in CF depends on its order in the polling sequence, which is expressed as $T_{star}+T_{Beacon}+K_{station}\times(2T_{SIFS}+T_{poll}+T_{response})$, where T_{Beacon} is the time used by beacon frame, $K_{station}$ is the station's AID and $T_{response}$ is the time to response. When silent stations are in the polling queue, the active stations must wait longer to be polled by the AP. Therefore, the effective way to increase S_{CF} and reduce T_{CF} is to have the AP not poll silent stations in the polling queue.



percentage of silent stations in a polling queue

packet size(byte)	75%	50%	25%	12.5%
300	53.88%	33.37%	14.31%	5.27%
500	42.42%	24%	9.5%	3.39%
1000	27.70%	14.14%	5.19%	1.79%
1500	20.56%	9.99%	3.57%	1.22%

Table 3. Percent of overhead in a CF traffic

3.3 Analysis

Real time applications require the max delay for data frames to be bounded. A station having pending data needs to be guaranteed a connection with AP. However, based on the analysis above, we can see that performance of an unstable WLAN will degrade under the unstable conditions. Thus, the effective way to improve performance is to not poll silent stations and extend the length of CP to an appropriate value when unstable conditions occur to allow more stations to connect to the WLAN.

4. Our Scheduling and Adaptation Algorithms

We propose: 1) An aging priority round-robin algorithm to schedule MAC polling in CF, which reduces overhead caused by silent stations. 2) A dynamic adaptation algorithm to dynamically adjust the length of CF and CP in a super-frame. Both of the algorithms can be easily implemented in the AP and do not add any additional overhead to 802.11 frames.

```
Notations:
SQ: the queue for the silent stations;
SQ.name: the order of a silent station in the SQ;
SQ.age: the time a silent station stays in the SQ;
SQ.send: 1(send data or RTS in CP) or 0(keep silent in CP);
AT: the max time of a silent station stays in SQ.
AQ: the queue for the active stations;
AQ.name: the order of a active station in the AQ
AQ.send: 1(send data in CF) or 0(silent when be polled)
Schedule()
Begin:
1.Check SQ before the AP polls
For i =0, n
  If (SQ[i].send = 1) or (SQ[i].send = 0 and SQ[i].age>=AT)
    remove it from the SQ, reorder SQ and  put it in the end of the AQ
    AQ[end].name=end
    AQ[end].send=0
    end++
  If SQ[i].send = 0 and SQ[i].age<AT
   keep it in SQ
   SQ[i].age++
EndFor
2. the AP Polls the stations in the AQ
For i =0, n
  the AP polls AQ[i]
  If AQ[i].send = 1
    keep it in AQ
  If AQ[i].send = 0
   remove it from AQ, reorder AQ and  put it in the end of SQ
   SQ[end].name=end
   SQ[end].send=0
   SQ[end].age=0
   end++
 EndFor
EndBegin
```

Figure 4 Aging Priority Round-Robin Scheduling

4.1 Aging Priority Round-Robin Scheduling

We define two terms: **Silent queue,** which contains silent stations that will not be polled in the CF and **Active queue**, which contains active stations that will be polled in the CF.

At first, all polled stations are put in the active queue so they will be polled during the CF(recall the description of CF in section 2.1). If the station responds with a data frame, it will be kept in the active queue, which means it will be polled in the next CF duration. If a station responds with a null frame or does not respond at all, it is considered a silent station and will be put into the silent queue, which means it may not be polled in next CF duration. Instead, the AP polls the next station in active queue after SIFS. The priority of stations in the silent queue is slowly increased so that they will be moved to the active queue after a time in the silent queue. All the stations can contend in CP. If a station in the silent queue sends RTS or data during the CP, it will be put back into the active queue. Otherwise, the station stays in its current queue. Figure 4 is the pseudo code of our aging priority round-robin scheduling algorithm. Active stations have priority over silent stations, which facilitates reliable real time service.

Notations:

MaxCF: the max length of CF, which is (BeaconPeriod*DTIMPeriod*CFRate)-(MMPDU+2*SIFS+2*slot+8*ACK).

MinCF: the min length of CF, which is (BeaconPeriod*DTIMPeriod*CFRate)-(3*MMPDU+2*SIFS+2*slot+8*ACK).

MaxCP: the max length of CP, which is (3*MMPDU+2*SIFS+2*slot+8*ACK).

MinCP: the min length of CP, which is (3*MMPDU+2*SIFS+2*slot+8*ACK).

Ratio: the number of stations associating to the number of stations associated, or silent stations to active stations;

```
Dynamic Adaption()
Begin
   If ratio > 1/2
      If CF > MinCF
         CF = CF-MMPDU;
         CP = CP+MMPDU;
   If ratio < 1/2
      If CF < MaxCF
         CF = CF+MMPDU;
         CP = CP-MMPDU;
EndBegin
```

Figure 5 Dynamic Adaptation algorithm

4.2 Dynamic Adaptation Algorithm

The beacon frame in the beginning of CF contains the max length of CF. Due to the network load, the AP may not start a super-frame as soon as possible. However, AP guarantees the CP is long enough to send a MMPDU (one window). Therefore, the length of a super-frame may vary. Since the performance of polling is always better than DCF under normal conditions, to fully use the polling mechanism, the length of CF usually is set to be the maximum and the length of CP is set to be the minimum. The lengths of a super-frame, CF and CP are all fixed at system initialization. However, when many stations associate or disassociate at the same time, the contention in the CP increases. In addition, because of our scheduling algorithm, stations in the silent queue might contend in the CP more frequently than they would have if they remained in the polling queue. Recall section 3.1, we verify the solution is to extend the length of CP when the contention level is high. We define two dynamic windows, for the length of the CF and CP respectively. If the ratio of the number of stations trying to associate to the number of stations already associated is more than ½, or if the ratio of silent stations to active stations is more than ½, then the WLAN is an unstable WLAN. The value of the ratio is determined heuristically from table 3. If the ratio is less than ½, we make the window of CF longer and the window of CP shorter unless it is already at the minimum length. Figure 5 is the pseudo code of dynamic adaptation algorithm.

5. Simulation

Our simulations are built on network simulator NS-2[13]. We first show the effect of null frame overhead caused by the periodically busy traffic and disassociation request) along with the contention in CP caused by a large number of associations on the throughput and delay time in the standard 802.11. This gives us a baseline for comparison with our algorithms. We use CBR applications as traffic generators. The throughput and delay time are calculated from valid CBR packets that reach their destination. All the simulations set the data packet rate to be 448kbps, size to be 512 bytes and use 50 stations. The length of a super-frame is ten MMPDU and the min duration of CP is one MMPDU. All simulation results are the average of 20 runs. Each simulation lasts for 100 simulation seconds, which is sufficient for measuring at steady state.

5.1 Effect Of Periodically Busy Traffic

Figure 6 shows the effect of periodically busy traffic causing null frame overhead on the throughput of PCF. The x-axis indicates the number of stations in the polling queue. That is, there are 10 stations, 20 stations, 30 stations, 40 stations and 50 stations in the polling queue respectively. Stations not in the polling queue can only contend in the CP. PCF (Steady) means that the CBR traffic is steady and all the stations in the polling queue are active stations. PCF (Periodic Busy) means that every CBR traffic generator has data to send in every another 0.5 second. As shown in Figure 6 PCF (Steady), the throughput increases with the increase in the number of stations in the polling queue. However, the throughput of PCF (Periodic Busy) decreases with the increase in the number of stations in the polling queue. This is because stations in the polling queue that are silent will respond to polls with null frames. With more stations in the polling queue, there are more silent stations.

Figure 7 shows the effect of periodically busy traffic causing null frame overhead on the per packet delay time of PCF. The results show the per packet delay time increasing with the increase in the number of no-data stations in the polling queue and reaching the minimum when polling queue is filled with active stations. From the simulations, we know that this traffic will caused null frame overhead which will reduce the throughput and increase the per packet delay time of a WLAN.

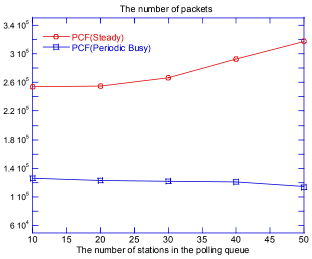


Figure 6 Throughput

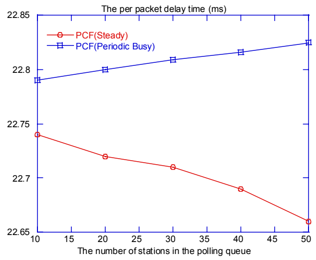


Figure 7 Average delay time

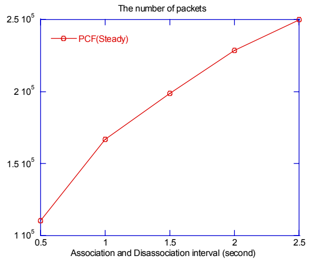


Figure 8 Throughput

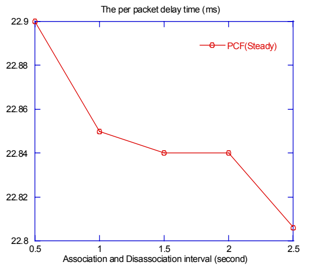


Figure 9 Average delay time

5.2 Effect of Disassociations And Associations

Since we want to show the effect of disassociations and associations, we use steady CBR traffic (PCF (Steady)) since we do not need to consider the effect of null frame overhead. All stations are active and in the polling queue at the beginning of the simulation. These active stations become silent stations only when they want to disassociate from the WLAN. The x-axis indicates the time interval with which every station disassociates with the AP and then re-associates immediately with the AP. So, we generate an unstable WLAN with a large number of associations and disassociations.

In Figure 8, the throughput increases when disassociation requests and association attempts are less frequent. In Figure 9, the per packet delay time decreases when disassociation requests and association attempts are less frequent. This is because: 1) null frames from disassociating stations cause null frames in CF and contention in CP; 2) new associations add more contention in CP. Though more contention in CP will not effect the max performance of CP, some stations have to wait until the next CP to associate or disassociate, because they are limited by the length of CP, which reduces the performance.

5.3 Simulation Results Using Our Algorithms

Figure 10 shows the throughput for three different algorithms as a function of the number of stations in the polling queue. In each simulation, every CBR traffic generator sends data in every another 0.5 second and every station disassociates with the WLAN in every 0.5 second and then re-associates immediately. The x-axis shows the number of stations in the polling queue (recall the description of x-axis in section 5.1). Stations not in the polling queue only contend in the CP.

The first algorithm PCF (Periodic Busy, Dis) uses the standard polling mechanism as defined in 802.11. When two unstable system conditions coexist, both the throughput and delay time will be heavily affected. The second algorithm PCF (Aging) shows the effect of using our aging priority round-robin polling mechanism. The overhead caused by silent stations from periodically busy traffic or disassociating requests will be avoided. The third algorithm, PCF (Aging, Dynamic) shows the effect of using both our aging priority round-robin along with the dynamic adaptation to change the length of the CP.

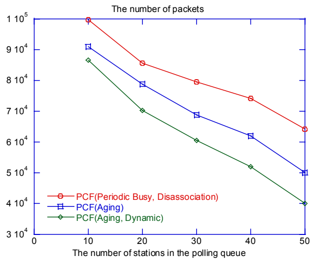


Figure 10 Throughput

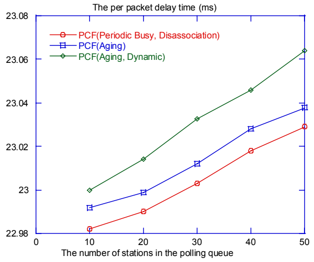


Figure 11 Average delay time

Figure 10 and 11 show that the throughput and delay time reach the maximum and minimum respectively when both of our algorithms used. The performance of the WLAN in PCF (Aging), that uses one of our algorithms is better than in PCF (Periodic Busy, Dis). When the size of the polling queue is 50 stations in Figure 10, the throughput improvement is 20%. The performance of PCF (Aging, Dynamic) is always better than PCF (Aging) under the conditions in our simulation. The throughput improvement for 50 stations in the polling queue is 33% compared with PCF (Periodic Busy, Dis). Our algorithms produce a less dramatic improvement in the delay time. This is because we have calculated average delay time for all stations, and the delay time for the active stations decreases but the delay time for the silent stations may increase. The reduction in delay time is 2.6% for 50 stations using the combined algorithms. Our algorithms show better results in a more unstable WLAN, however, even WLANs that suffer only temporary instability could benefit from our algorithms.

6. Conclusions

The null frame overhead caused by silent stations and contention caused by a large number of associations and disassociations in an unstable WLAN degrades performance. To resolve these problems, we proposed an aging priority round-robin algorithm to schedule MAC polling and a dynamic adaptation algorithm to change the length of CF and CP. Active stations have priority over silent stations. By polling only active stations, the CP can be lengthened to facilitate associating and disassociating stations. Simulation results show that our algorithms can improve throughput by as much as 33% and reduce delay time thus benefiting PCF traffic.

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