Adaptive Polling List Arrangement Scheme for Voice Transmission with PCF in Wireless LANs

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Abstract—Polling based PCF is the optional channel access mode in MAC sub-layer of IEEE 802.11 WLAN. The detail of polling list arrangement is not defined in standards, and a traditional Round Robin (RR) polling scheme is inefficient for packetized voice transmission. This paper proposes two adaptive polling list arrangement schemes in order to decrease the average delay of voice packets, by means of reducing the possibility of null polls. One scheme is called Dynamic Descending Array (DDA), which resets the polling array after each beacon at the beginning of contention free period, in a descending order according to the number of packets queued in stations' buffers. The other scheme combines RR and our DDA to further avoid waiting too long for some station, which is termed as Hybrid DDA and RR (HDR). The improvement of DDA and HDR on delay performance of our schemes is testified in dissimilar simulation scenarios, which assume different wireless channel quality, network scale, traffic load and polling access policies etc. It is shown that the proposed DDA and HDR schemes outperform RR scheme from the delay viewpoint. What’s more, HDR works extremely well with gated access policy, when the signal-to-noise ratio of wireless channel is low and the network traffic load is high.

I. INTRODUCTION

The IEEE 802.11 wireless local area network (WLAN) [1] is gaining popularity for data applications in campus networks. While the use of 802.11 LANs for Internet applications, most commercially available offerings only implement the 802.11 mode of operation that supports data services, called Distributed Coordination Function (DCF) mode, and not the second 802.11 mode of operation, designed for real-time services, called the Point Coordination Function (PCF) [2].

DCF is contention based channel access mode, where wireless terminals contend for the shared medium in a distributed manner according to the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocols. In the case of PCF, however, the access point (AP) of Basic Service Set (BSS) coordinate the channel access among stations by using a centralized polling mechanism. PCF is more suitable for time-sensitive traffic delivery [3], as it avoids contention during contention free period (CFP) and reduces contention in contention period (CP). Voice transmission as the most basic form of human communication has been spread out from the classical telephone oriented networks (POTS) to the packet oriented networks like the Internet (Voice-over-IP, VoIP). Packetized voice services in WLAN hence, may be supported best with the PCF mode.

M. Veeraraghavan et al. [2] designed and analyzed a system that uses the polling mode for interactive voice traffic, concluding that more voice calls can be accommodated with larger inter-poll periods. E. Ziouva et al. [4] examined an IEEE 802.11 BSS network performance in terms of maximum number of supported conversations and minimum bandwidth available for data traffic. But both [3] and [4] did not take the impact of polling list into account, adopting fixed list in analysis. Besides, the assumption in [3,4] that voice packets were generated every contention free period repetition (CFPR) interval was far from reality, as human speech is alternated between talkspurt and silence instead of being constant bit rate (CBR). Silence detection and cyclic shift polling were proposed to increase the capacity for voice calls in [5]. However, the authors did not describe the process of detection. Some other enhanced polling strategies [6-8] were brought forward to increase the performance of PCF mode: But none of them consider the wireless channel characteristic and packet retransmission issue in PCF, which greatly affect the system performance.

This work proposes two adaptive polling list arrangement schemes in order to decrease the average delay of voice packets, by means of reducing the possibility of null polls. One scheme is called Dynamic Descending Array (DDA), which resets the polling array after each beacon at the beginning of contention free period, in a descending order according to the number of packets queued in stations' buffers. The other scheme combines round robin (RR) and our DDA to further avoid waiting too long for some station, which is termed as Hybrid DDA and RR (HDR). Extensive simulation results are collected to compare our DDA and HDR with RR schemes. The improvement on delay performance of our schemes is tested in dissimilar scenarios, which assume different indoor wireless channel quality, network scale, traffic load and polling access policies etc.

The structure of the paper is as follows. Section II briefly introduces the PCF mode of IEEE 802.11 standards, including the traditional RR polling mechanism. After analyzing the speech characteristic and the inefficiency of RR polling in Section III, our DDA and HDR schemes are described in detail. Simulation results for performance enhancement evaluation by our schemes are presented in Section IV. Finally Section V gives the conclusions.

II. IEEE 802.11 PCF

PCF is an optional capability of IEEE 802.11 MAC sub-layer, which is connection-oriented. It is based on polling and provides contention-free services enabling polled stations to transmit without contending for the shared channel. The function of point coordinator (PC) is performed by AP within each BSS. Stations within the BSS that are capable of operation in the CFP are known as CF_Aware stations. The
method by which polling lists are maintained and the polling sequence is determined by the PCF is left unspecified.

In PCF, a wireless channel has a superframe structure [1]. Each superframe consists of a CFP and CP. The length of superframe is defined as CFPR interval. The CPFR interval is used to determine the frequency with which the PCF occurs. At the beginning of every CFP, the AP sends a beacon frame to all wireless stations after the AP confirms that the medium is idle for a point inter frame space (PIFS). Note that a PIFS period is smaller than a distributed inter frame space (DIFS) period but larger than a short inter frame space (SIFS) period. So the start of a new CFP will not interrupt the acknowledgement for received packets, while at the same time AP is able to gain the control of channel in precedence over other stations to implement PCF mode. The beacon frame contains the information on the maximum duration of the CFP (Max_CFP_Duration). All stations can then set their network allocation vector (NAV) not to send any packet during CFP. The Max_CFP_Duration is a manageable parameter. At a minimum, time must be allotted for at least one MPDU to be transmitted during the CP.

During the CFP, the AP poll each station in its polling list by sending a DATA+CF-Poll frame or a CF-Poll frame. If a wireless station receives the former, it can respond to the AP after a SIFS period with a DATA+CF-ACK frame or a CF-ACK frame. The AP then replies with a DATA+CF-ACK+CF-Poll frame or a CF-ACK+CF-Poll frame. If a station receives a CF-Poll frame from the AP, it can send back with a DATA frame or Null frame. The AP basically continues to poll each station fixed and circularly until the time reaches the Max_CFP_Duration, which is the operation mechanism of RR polling. However, the AP can also terminate the CFP ahead of schedule by sending a CF-End frame.

III. ADAPTIVE POLLING LIST ARRANGEMENT

A. Talkspurt-silence alternation of voice traffic

We concentrate on the transmission of voice as the basic form of human communications in this work. In recent years VoIP aware applications have been emerged based on the Realtime Transport Protocol (RTP) and UDP/IP. This adds an overall overhead of at least 68 bytes to every voice packet. (Without options. IP header is 20 bytes, UDP header is 8 bytes and RTP header is 40 bytes.) The size of overhead is comparable with voice frames. For example, if ITU G 711a-Law codec (64 kbps) is used with 10 ms of audio data per RTP packet, the audio data is only 80 bytes. As a result, a BSS of IEEE 802.11b infrastructure network using DCF is low efficient to handle large number of VoIP calls [9]. For the sake of satisfying capacity and voice packet delay performance, PCF is inevitable.

Normally, users tend to stop their conversation, listen to their counterparts and restart their conversations. The effect is known as the talkspurt-silence alternation, and the behavior is independent from the codec used and is modeled by a two-state Markov chain as shown in Fig. 1 [7]. The model is actually ON/OFF stochastic process. The ON (talkspurt) and OFF (silence) periods are exponentially distributed with mean values $1/\alpha$ and $1/\beta$, respectively. During talkspurt periods an audio flow is represented as an isochronous source with fixed inter-arrival time $T$ that are determined by the audio codec. In other words, the packet generation rate $\lambda$ is fixed. During silence period, nevertheless, no packet is generated.

The talkspurt-silence alternation characteristic of audio traffic make round robin polling mechanism not efficient at all. The reason is that the AP will neither add or delete station IDs in its polling list, nor change the sequence according to which stations are polled. As a result, if a certain audio source enters silence period, the AP continues to poll it though the station responds NULL frame each time. This will cause valuable bandwidth wastage and incurs unnecessary delay to other stations in talkspurt state.

B. DDA and HDR schemes

Round robin polling mechanism could not adapt to the variety of traffic source, hence the efficiency is quite low and packet delay could not be effectively decreased. We firstly propose to dynamically arrange the stations in polling list at the beginning of each CFP. Instead of fixing the polling sequence according to ascending IDs, i.e., $1, 2, 3, \ldots$ the AP rearranges the polling list in an descending order according to the number of packets queued in all stations. The scheme is designed to reduce the possibility of null poll as much as possible. At the same time, though all the packets must be delivered, it is good to offer access preference to stations that have more packets waiting in queue. This is due to the inevitable inter-poll "overhead", which includes PIFS, CF-Poll frame and so on. Take a simplest case as an instance: if there are two stations in polling list, the former has one packet waiting and the latter has ten. The packet size is constant so the processing time is constant, without taking the retransmission into account at present. If the former station is polled firstly, all the ten packets of the second station have to wait for inter-poll-"overhead", which increase average medium access delay. On the contrary, if the latter station is served ahead of the former, the inter-poll overhead only affect the delay of one packet. In this case, the average packet delay of whole system is decreased. Our system is more complex than this example, but the principle is the same. By letting stations with more packets waiting in queue access the channel firstly, the scheme is effective to decrease average packet one-way delay. This adaptive polling arrangement scheme is named as Dynamic Descending Array (DDA).

To further increase the polling efficiency, we also propose another scheme called HDR (Hybrid DDA and RR). As the name itself denotes, the scheme combines the idea of DDA
and round robin. At the start of CFP, that is, after the beacon frame, all stations report to AP the number of packets queued in buffer. The AP then sequentially polls stations in a temporary list. The temporary polling list includes the stations with non-zero queued packets, and the IDs are arranged as DDA does. That is, the sequence is a descending order according to the number of packets in each station's buffer. The AP polls stations in a cyclic manner. However, distinct with RR, once all the packets in queue of a certain station is delivered (including retransmission), the station is removed from polling list. Furthermore, in order to avoid waiting too long for those stations not in the original temporary list, the HDR will initiate traditional RR polling when the size of temporary list diminishes to zero. Because it is possible that those stations start generating voice packets during CFP after beacon frame, the new generated packets could not be delivered until Max_CFP_Duration later if RR polling is not initialized.

What's more, there are different access policies in a polling system, namely, gated access policy, exhaustive access policy and limited-N access policy [12, 13]. Gated policy means that, upon receiving the polling message from AP, the station is permitted to send all packets stored in its buffer until that time. The case of an exhaustive policy works on a different principle. Upon the reception of polling message, the station will transmit all packets that have been stored in its buffer until that time, as well as packets arriving during the time that the channel remains allocated to the terminal. Hence, the AP will not poll the next station until the buffer of current station has been completely emptied. However, in a limited-N policy, each station could transmit $N$ packets at most when polled by AP. The performance of our DDA and HDR schemes will be compared with RR scheme in simulations, considering these access policies.

IV. PERFORMANCE ENHANCEMENT EVALUATION

A. Simulation description

a) Indoor wireless channel modeling

As in [10], we assume the carrier frequency and the channel bit rate are such that frequency selective effects can be neglected. Hence, the wireless environment in our simulation strictly holds for flat fading situation. We incorporate the wireless channel characteristic into simulation by modeling the channel with a two-dimensional Markov chain [10]. The Markov model has two states related, namely, GOOD and BAD. We assume a packet error rate equal to one is associated to the BAD state, and no errors are made when in the GOOD state. So if the channel state is BAD at the transmission instant of some packet, the packet must be retransmitted. The channel characteristic is represented with SNR and $s_a$ where SNR denotes the averaged (over the fluctuations due to fading) signal-to-noise ratio at the receiver (either a station or AP). The SNR value is related with parameter $P_0$ in the Markov model according to equation (6) in [11]. In this paper, the physical channel is simulated based on the above theoretical characterization. For the sake of brevity, the detailed analysis of channel model is omitted. Interested readers may refer to [10] [11] for details concerning all the description.

b) System parameters

We use Matlab and Microsoft Visual C++ to simulate our DDA and HDR. The mapping from SNR to channel state and packet state (error or correct), as well as voice traffic source, are generated with Matlab and stored in files. Visual C++, on the other hand, simulates the whole polling process during CFP. Since DCF operation is not the focus of this work, we assume minimum CP according to IEEE 802.11 standard [1] and computed as [4]. We consider only uplink voice transmission using PCF, while DCF supports both up and down links. So average packet delay (one-way) is our concern, which is the time lapsed since packet generation till reception by AP successfully. Overlapping BSS issue is out of the scope of this paper, and the propagation delay and hidden station are negligible. Moreover, beacon interval is assumed to be the same with CFR interval, hence the AP generates beacon only once in each superframe.

Direct Sequence Spread Spectrum (DSSS) 802.11 WLAN parameters [1] are used in simulation, with other important parameters as shown in Table I.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean value of voice ON period</td>
<td>375 ms</td>
</tr>
<tr>
<td>Mean value of voice OFF period</td>
<td>625 ms</td>
</tr>
<tr>
<td>Voice frame size (payload)</td>
<td>160 bits</td>
</tr>
<tr>
<td>Channel bit rate</td>
<td>11 Mbps</td>
</tr>
<tr>
<td>UDP + IP header</td>
<td>28 octets</td>
</tr>
<tr>
<td>MAC header</td>
<td>34 octets</td>
</tr>
<tr>
<td>Physical header</td>
<td>24 octets</td>
</tr>
<tr>
<td>Beacon</td>
<td>106 octets</td>
</tr>
<tr>
<td>CF-Poll, CF-Ack+CF-Poll, CF-Ack, Null</td>
<td>34 octets</td>
</tr>
<tr>
<td>RTS, CF-End, CF-Ack+CF-End</td>
<td>20 octets</td>
</tr>
<tr>
<td>Ack,CTS</td>
<td>14 octets</td>
</tr>
<tr>
<td>SIFS</td>
<td>10 us</td>
</tr>
<tr>
<td>PIFS</td>
<td>30 us</td>
</tr>
<tr>
<td>DIFS</td>
<td>50 us</td>
</tr>
<tr>
<td>Slot time</td>
<td>20 us</td>
</tr>
</tbody>
</table>

B. Simulation results

We firstly examine the performance of RR, DDA and HDR schemes under different channel condition. The number of stations is ten, and each generates voice frames every 10 ms during talkspurt. According to the above constant 160 bits payload size assumption, the peak rate of each station is 16 kbps. Other parameters including $s_a$, Max_CFP_Duration and retry limit are also illustrated in Fig. 2. Here, the retry limit is defined as the total transmission times of a packet before dropped by stations. That is, it contains the first transmission and following retransmission due to “bad” channel condition.

Seen from Fig. 2, with the increase of channel SNR value, the average packet delay decreased quickly, no matter which polling scheme is adopted. This is due to the better channel quality and thus less retransmission. The packet delay in the case of exhaustive policy is lower than gated policy, because exhaustive policy makes a station continually transmit packets until buffer becomes empty, which reduces the polling round and all inter-poll “overhead” and is more efficient. Limited policy is not presented here, as its performance is close to...
exhaustive policy under low traffic load condition.) Besides, our DDA and HDR schemes outperform RR scheme in both access policies. The HDR even gains around 33% improvement when SNR of wireless channel is 15 dB and gated policy is used. The reason is that when the channel is error-prone, more packets possibly need retransmission and equivalently increase the network load. Meanwhile, if some station is in talkspurt and the others in silence, the unbalance situation is more serious. RR polling wastes a lot of time in this condition, whereas HDR keeps polling those stations with queued packets so as to decrease the average delay. As for the difference performance between gated and exhaustive policies, gated policy is less efficient with large amount of retransmission, as the stations could only deliver those packets already in buffer before polled by AP. The explanation can be further proved in Fig. 3. When the retry limit becomes larger, the advantages of our DDA and HDR are more prominent.

Simulations are also carried out to investigate the impact of traffic load. We vary the traffic load of each station from 8 kbps to 32 kbps (peak rate in talkspurt) and collect the delay performance with three schemes. The curves are depicted in Fig. 4, which demonstrate that our HDR performs best under high traffic load condition. The reason is the same as explained for low SNR case just now. The performance of limited-5 scheme is presented in Fig. 5, where we can find that with heavier load, the performance of limited policy deteriorates fast. When the peak rate of each ON-OFF source is 32 kbps, the average packet delay with limited-5 policy is even larger than gated policy. However, our HDR scheme still performs excellently in this case.

As shown in Fig. 6, the limit number in limited-N policy, i.e., the N parameter has great impact on delay performance. Smaller N results in larger delay. Fig. 7 presents the simulation results for different network scale. When the number of stations increases, average packet delay becomes larger and our DDA and HDR outperform RR as shown in the figure.

Finally, we simulate the polling process with different Max_CFP_Duration. As depicted in Fig. 8, when the CFP increases from 20 ms to 100 ms, the average packet delay decreases. This is due to the less CP that interrupts the cyclic polling process and adds 5 ms (computed with parameters in Table I according to [4]) to the packet delay every superframe.

![Fig. 2 Average packet delay vs. SNR of wireless channel](image)

![Fig. 3 Average packet delay vs. retry limit](image)

![Fig. 4 Average packet delay vs. traffic load of each station (gated & exhaustive)](image)

![Fig. 5 Average packet delay vs. traffic load of each station (limited-5)](image)
But no matter how long the CFP is, our DDA and HDR schemes behave well.

**V. CONCLUSIONS**

To well support real-time packetized voice services in WLAN, centralized polling based PCF mode is more suitable than contention-based DCF. However, voice source normally alternates between talkspurt and silence. In this case, traditional round robin polling scheme is low efficient, as the AP has to poll every station in its fixed polling list in sequence. This paper proposes two adaptive polling list arrangement schemes to make polling process flexibly. The two schemes, DDA and HDR, set the polling list in descending order according to the number of packets queued in stations at the beginning of every CFP. Combined with round robin concept, HDR further prevents packets from waiting too long. The packets denote those newly generated after beacon frame of stations not in the initial temporary polling list. Extensive simulation results show that the proposed DDA and HDR schemes outperform standard round robin scheme for 802.11 based WLAN that delivers voice traffic, from the delay viewpoint. What's more, HDR works extremely well with gated access policy, when the signal-to-noise ratio of wireless channel is low and the network traffic load is high.

**REFERENCES**


