Power Efficient Multipolling Mechanism for Next Generation Wireless LANs

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***Abstract*— As the Wireless LAN (WLAN) becomes prevalent, users are demanding more and more features such as high throughput and low power consumption. To provide higher channel efficiency, contention-based multipolling mechanism was proposed to improve the single polling and contention-free multipolling mechanisms. However, when this medium access control (MAC) protocol is used, wireless stations would need to spend much time in overhearing which tends to waste energy and reduce battery lifetime. We propose a power efficient multipolling mechanism to arrange wireless stations into groups and put them into sleep mode when other stations are transmitting. From the simulation results, we find the proposed mechanism can address the issue of overhearing while also keeping the flexibility and high channel efficiency properties.**

I. Introduction

Over the past few years, the world has become increasingly mobile. Wireless LAN (WLAN), due to its mobility, ease of deployment and flexibility, has become a prevailing technology in the broadband wireless access networking. We can enjoy the freedom and convenience of connecting to the Internet with portable computing devices on the campus, at home, or in coffee shops.

The IEEE 802.11 standard document [1] defines the medium access control (MAC) layer and the physical (PHY) layer specifications. The mandatory distributed coordination function (DCF) in 802.11 uses contention-based access scheme to provide fair, easy and robust wireless connectivity. However, due to high overhead for the MAC/PHY operations, the throughput performance of 802.11 is much worse than the underlying PHY transmission rate. It has been proved in [3] that by simply increasing the PHY rate without reducing the MAC/PHY overhead, the throughput is bounded below 100 Mbps. Therefore, enhancement in the 802.11 MAC protocol is necessary. Despite the goal to provide QoS in WLAN, IEEE 802.11e [2] also defines some features which can improve the channel efficiency. The introduction of transmission opportunity (TXOP), Block Ack, and direct link protocol (DLP) can be utilized to reduce some MAC operation overhead. In [4], [5], and [6], ordered-contention multipolling mechanisms were proposed to further reduce overhead and increase channel efficiency.

Additionally, since most wireless devices are battery powered, reducing power consumptions of wireless network interface cards (WNICs) is also important. Many techniques have been proposed to reduce WNIC power consumption, such as transmitting power control and MAC-level power management (PM). Regarding the PM method, powering down the transceiver can lead to great power savings. In [7], the major sources of energy waste of shared medium wireless networks were listed: *collision*, *overhearing*, *control (packet) overhead*, and *idle listening*. Among these, overhearing means that a station (STA) receives and decodes packets that are not destined to itself. Control (packet) overhead is necessary to maintain MAC operations normally. However, it increases the active time and power consumption of STAs when transmitting, receiving control packets or experiencing some backoff deferral. A well designed power efficient MAC protocol should try to remove these sources of power consumption. Some MAC schemes used in other wireless networks like [7] and [8] were proposed to achieve these goals.

From observation, we find that avoiding collision and reducing unnecessary protocol overhead are major challenges to improve both channel efficiency and power conservation. Hence, during MAC protocol designing, it is reasonable to take these two issues into account. The above-mentioned high channel efficiency MAC mechanisms of [4], [5] and [6] use centrally coordinated contention method to reduce control packet overhead when compared with the polling scheme provided in 802.11. However, they still have the problem of overhearing during operations.

In this paper, we propose a new MAC scheme called Power Efficient Multipolling (PE-Multipoll) which puts wireless STAs into doze mode when they are not scheduled to transmit or receive. Since the source of overhearing problem is removed, the time spent in active mode for a wireless STA is reduced dramatically. From analysis and simulation results, we find that the proposed mechanism can retain the advantage of high channel efficiency and flexibility while also achieving the goal of power conservation.

II. Related Works

A. Power Management of WLAN

Typically, WNICs have two active modes – receive and transmit – and two low-power modes – doze and off. In active modes, the amplifiers of RF circuit need to lift a signal before

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transmission or to lift the received signal to an appreciable level after reception. It is the most power hungry components of RF systems of WLAN [9]. The doze mode consumes much less power because the RF circuitry is turned off and can be entered and exited in a very short time (e.g. 0.8ms). The off mode means that the WNIC is shut down and takes longer time to return to active modes (e.g. 60ms) [10].

To maximize battery lifetime, the PM function should put STAs into doze mode as long as they are idle. The IEEE 802.11 standard specifies a PM function using a contention based power-save polling (PS-Poll) method to improve power efficiency. However, the performance of packet latency and channel efficiency are bad when this scheme is implemented.

B. Contention-Based Multipolling Mechanism

The idea of "ordered contention" was first proposed in [4]. The polling frames of the polling scheme used in IEEE 802.11 or IEEE 802.11e can be treated as overhead which lowers channel efficiency. Therefore, the authors designed a multipolling mechanism named Contention Period Multipoll (CP-Multipoll) to solve the problem. The basic idea is that in the multipoll frame, access point (AP) announces the channel access order of STAs in the polling list via different backoff value assignments. After getting the notification, all STAs set their backoff counter and start to count down if the medium is sensed to be idle for Short Inter Frame Space (SIFS) which is shorter than DCF IFS (DIFS) used by legacy STAs. If the medium is busy, STAs need to freeze the counter and set their network allocation vector (NAV). When the backoff counter reaches zero, the STA has the right to initiate its transmission.

The CP-Multipoll mechanism has the property that for continuous and periodic traffic, the constant polling frames used in 802.11 or 802.11e can be avoided. When getting the right of medium access, the scheduled STA can hold it flexibly depending on the size of locally buffered data as long as the required time does not exceed TXOP limit. Besides, if some STAs do not respond due to failure of receiving the multipoll frame or do not fully utilize the TXOP, other scheduled STAs will detect the idleness of channel and advance their transmissions. Therefore, the channel can be fully utilized with very few control packet overhead.

However, since the operations of ordered contention require the cooperation of all scheduled STAs, STAs which have not yet finished their transmission cannot enter doze mode because they need to update their NAV value during others' transmission and correctly decrease backoff value when the medium is idle. Therefore, STAs of later order in the polling list will suffer much overhearing before they can access the medium. This situation could be worse when STA density is high and traffic load is heavy.

III. Power Efficient Multipolling Mechanism

In this section, we present a Power Efficient Multipolling mechanism which aims to alleviate the problem of overhearing suffered by CP-Multipoll. In exchange it accepts some performance degradation in channel efficiency which can be traded off with the required active time.

A. Mechanism Design

According to [7], we know that the best way to avoid interference and overhearing is to put STAs into sleep. We focus on infrastructure WLAN where AP takes the responsibility of scheduling. The basic idea of PE-Multipoll is to notify wake-up time and access order for every scheduled STA so that STAs can remain in doze mode most of time and access the channel by a modified ordered contention.

Assume that there are n scheduled STAs in the basic service set (BSS) which are partitioned into K groups by the AP. The group i is composed of m_i STAs and $\sum_{i=1}^{K} m_i = n$. The members of group i are assigned the same wake-up time WT_i which is set to the estimated required time of group 1 to group $(i-1)$. The jth scheduled STAs in the polling list is assigned backoff value bt_j. The detailed tasks performed by the AP and scheduled STAs are described below.

1) AP: The AP receives reservation requests from STAs during contention periods (CPs). After admission test according to the information provided in reservation requests, the AP maintains a polling list and announces PE-Multipoll frame after beacon or at scheduled time every scheduled service interval (SI). The frame format of PE-Multipoll is shown in Fig. 1. Each STA in the polling list has its corresponding poll record. The number of poll records is indicated in the Record Count field. The Poll Record field contains the information of the association identifier (AID) in the BSS, the assigned backoff value in units of slot time, the wake-up time relative to the receiving time of this PE-Multipoll frame, and the maximal duration of an aggregate TXOP for a specified STA.

Octets: 2	2	6	1	6 × RecordCount				4
Frame Control	Duration /ID	BSSID	Record Count	Poll Record (6 octets)				FCS
			(0-255)	AID (2 octets)	Backoff (1 octets)	Wake-up time (2 octets)	TXOP Limit (1 octets)	

Fig. 1. Frame format of PE-Multipoll.

Note that AP assigns the same wake-up time WT_i to all STAs belong to group i. The reason that STAs are divided into different wake up groups is to reduce the chance of channel idleness. Besides, since the wireless medium is shared, the possible multi-destination frame aggregation scheme as proposed in [6] can be exploited to further increase the channel efficiency.

In order to be backward compatible, AP can send a CTS frame to itself to set NAV of all STAs to create a scheduled access phase (SAP) to avoid interference. Therefore, legacy STAs will not interfere with the transmissions in SAP and can enter doze mode while other STAs should remain awake to check the following PE-Multipoll frame and update their NAV. During the SAP, the AP prepares the downlink traffic for each scheduled STA according to the order maintained in the polling list. Note that when AP transmits data frames or ACKs to STAs, it should notify the order of the on-going transmitting STA in the QoS Control field of the MAC header and pending data information via the More Data bit. After the transmission of all scheduled STAs, AP will transmit a CTS frame with zero duration to itself again to release the channel. The remaining time not controlled by AP will become CPs. CPs are still necessary for association operations, connection reservations, or access of legacy STAs.

2) Scheduled STA: STAs should first reserve its transmission via traffic specification (TSPEC) in Add Traffic Stream (ADDTS) frames during CPs. After it is admitted by the AP, it should wait for the notification of PE-Multipoll frame and achieve synchronization by checking beacon frames. A scheduled STA should maintain and adhere to notified information such as SI, backoff value, wake-up time and TXOP limit. The assigned backoff value is also its access order.

When an STA wakes up at the scheduled time, its backoff value count down process begins after the channel is sensed idle for SIFS period. If the channel continues to be idle for a slot time, it decreases the backoff value by one. Otherwise, it stops the counter. When the channel is busy, it sets the NAV to the Duration value in the received frame and gets the access order of the on-going STA. The obtained on-going STA's access order can be utilized to adjust the backoff value held by an STA according to the difference of the STA's access order and the obtained one. When backoff value reaches zero, the STA transmits an uplink frame to initiate its TXOP.

Each STA can hold the medium flexibly depending on the buffer status as long as the required time does not exceed the TXOP limit. When the frame exchanges are finished, the STAs can enter the doze mode till the transmission time of next PE-Multipoll frame. It is set to the receiving time of PE-Multipoll plus the value of SI of the BSS.

3) Backoff Value Assignment: The policy of the backoff value assignment depends on the approach used to deal with hidden node problem. We assume that the jamming approach proposed in [5] is adopted. As a result, the backoff value (in units of slot time) bt_j of STA with access order j follows the rule: $bt_1 = 0$ and $bt_j = bt_{j-1} + 1$ for $j \geq 2$. To avoid interference from overlapping BSS in the vicinity, the APs should not use the same frequency band. Otherwise, the transmission time of interfering STAs should be separated via the coordination of APs which are in charge of scheduling (this may be achieved by the measurement information discussed in the IEEE 802.11k [11]).

4) Calculation of Wake-Up Time and TXOP Limit: In our current study, we use the average required time of each STA to be a reference of setting the wake-up time. After gathering the requests from STAs, the AP first determines the value of SI as the method provided by the referenced scheduler in [2]. To calculate the required TXOP of a specified TS, the AP uses the parameters obtained from TSPEC: Mean Data Rate (ρ), Nominal MAC Service Data Unit Size (L), the Scheduled Service Interval (*SI*), Physical Transmission Rate (*R*), and per packet Overhead in time units (*O* = *2* × *SIFS* + *ACK* + *MAC header* + *PHY header*). Assume that STA j has k TSs. The scheduler first calculates the average number of MSDUs for TS l generated during an SI.

$$N_l = \left\lceil \frac{\rho_l \cdot SI}{L_l} \right\rceil, \text{where } \lceil\ \rceil \text{ is the ceiling function.} \quad (1)$$

Then the scheduler calculates the TXOP duration to serve the generated MSDUs and the aggregated TXOP for STA j.

$$TXOP_l = N_l \cdot \left(\frac{L_l}{R_l} + O \right) \quad (2)$$

$$T_j = \sum_{l=1}^{k} TXOP_l \quad (3)$$

Since the aggregated TXOP T is calculated according to the mean data rate, it can be treated as the mean required time of an STA. After obtaining T of each STA in the polling list and the number of STAs in every group, AP computes the average required time G_i of group i by

$$G_i = \sum_{\text{STA } j \in \text{ group } i} \Big(T_j + O' \Big), \text{ where } O' = SIFS + slot. \quad (4)$$

O' stands for the overhead of interval between succeeding STAs. Finally, the wake-up time WT_i of group i is assigned as (WT_1 is set to zero.)

$$WT_i = f \cdot \sum_{w=1}^{i-1} G_w, \text{ where } i > 1 \text{ and } f \in [0, 1]. \quad (5)$$

It is worth to be pointed out that the wake-up time is a trade-off between performance of channel efficiency and active time spent for an STA. Basically, the wake-up factor f is set to 1. However, if the channel efficiency measured by AP is not good enough, f can be adapted to a smaller value to let STAs wake up earlier. As for the calculation of TXOP limit, it can be set to the value calculated by peak data rate of TSPEC with similar procedures.

B. Example

A simple example is shown in Fig. 2 and Fig. 3 which represent the traffic state and power state of STAs separately. In this example, there are two STAs in a group and STAs are initially assigned backoff values which are equal to their access orders. At WT_2, group 2 members (STAs 3 and 4) wake up and start their transmission when their backoff value reaches zero. Since the actual finish time of group 1 is earlier than the wake-up time of group 2, the channel is idle for some period of time. As for time WT_3, the start of transmission for group 3 (STA 5) is postponed by group 2 whose actual finish time is later than the estimated time. Note that when STA 5 wakes up and detects the frame exchanges between STA 4 and AP, it makes backoff value adjustment according to the difference between their access orders (new backoff value $= 5 - 4 = 1$). The legacy STAs using DCF can choose to enter doze mode when they receive the notification from AP to set their NAV.

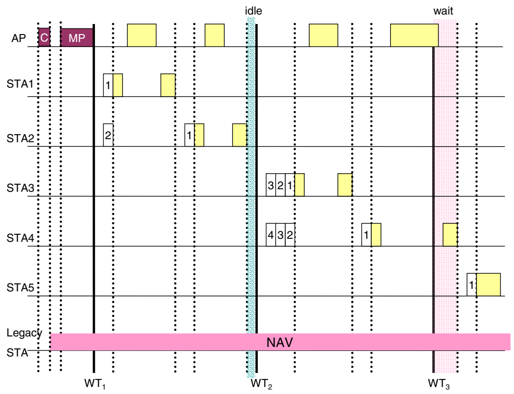

Fig. 2. Example - traffic state of PE-Multipoll (STA 6 is omitted).

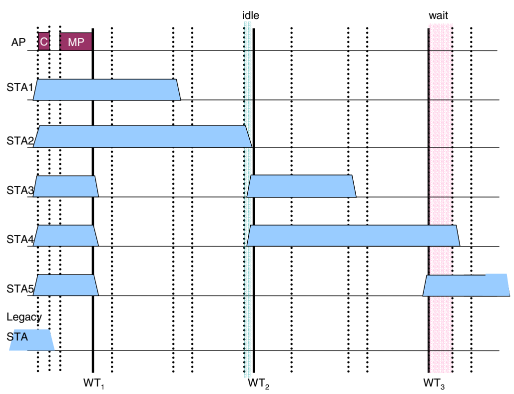

Fig. 3. Example - power state of PE-Multipoll (STA 6 is omitted).

It is not hard to see that if wake-up time assignment is accurate, the channel idle time and the active time spent by an STA can both be reduced. This can enhance the performance of channel efficiency and power conservation.

IV. Performance Evaluation

The average channel efficiency and duty cycle are evaluated in this section. The channel efficiency is defined as the throughput during an SAP and the duty cycle is defined as the percentage of time that STA is in active mode during an SI. The PE-Multipoll is compared with the CP-Multipoll and the polling scheme used in Hybrid Coordination Function (HCF) of 802.11e (named as SinglePoll here). It is assumed that for SinglePoll and CP-Multipoll, the STAs which have finished their frame exchanges can enter doze mode without affecting the operations of original mechanisms.

A. Simulation Environment

The default setting of parameters in simulations is listed in Table I. We use the 802.11a parameters except for the transmission rate. It is assumed that all STAs including AP use the 2×2 Multiple Input Multiple Output (MIMO) and two channel bounding technologies, so the data transmission rate can achieve 216 Mbps while the rate to transmit control or polling packet uses 24 Mbps. We assume that all STAs generate traffic independently with the same model. The traffic

TABLE I
Default Simulation Parameters

SIFS	16 μs
DIFS	34 μs
ACK size	14 *bytes*
PHY rate	216 *Mb/s*
Control rate	24 *Mb/s*
Slot time	9 μs
MAC header	30 *bytes*
SI length	50 ms

STA number n	20
Group size m	2
PE-Mpoll frame	$15 + 6n$ *bytes*
CP-Mpoll frame	$15 + 8n$ *bytes*
Mean data rate	3000 *Kbps*
Standard deviation	100 *Kbps*
Peak data rate	3 + *STD Mbps*
Wake-up factor	1

model used in our simulation is of truncated Gaussian distribution which means that generated data rate varies between zero and peak data rate. All mechanisms serve the equal amount of traffic in every SI during simulations. For PE-Multipoll, group size is set to 2.

B. Simulation Results and Discussion

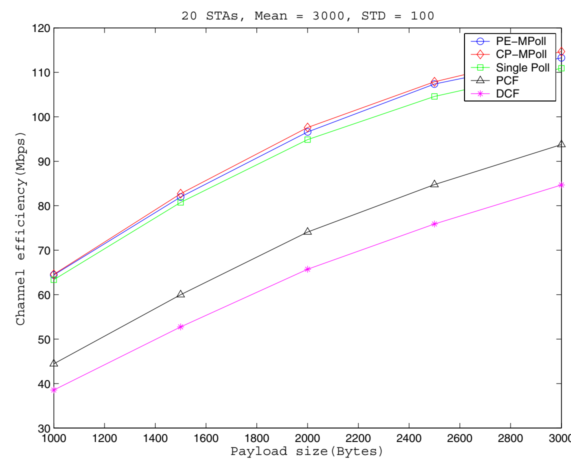

Fig. 4. Channel Efficiency vs. Payload Size.

Fig. 4 presents the channel efficiency of each polling scheme and the maximum achievable channel efficiencies of Point Coordination Function (PCF) and DCF when the standard deviation of traffic model is small (set to 100). The results of DCF and PCF are calculated by referencing the analysis of [3]. In addition, the duty cycles of the polling schemes are shown in Fig. 5. Compared with DCF and PCF, the CP-Multipoll, PE-Multipoll and SinglePoll can transmit multiple packets in a TXOP when getting the medium and hence have better channel efficiencies. The channel efficiency of PE-Multipoll falls between those of the CP-Multipoll and SinglePoll. Since the standard deviation is small, the performance degradation of PE-Multipoll in channel efficiency is small due to the accurate scheduling. As can be seen in Fig. 5, the duty cycle of PE-Multipoll is dramatically smaller than those of CP-Multipoll and SinglePoll.

Fig. 6 shows the comparison of duty cycles versus number of STAs. It is clear that STAs using CP-Multipoll or SinglePoll

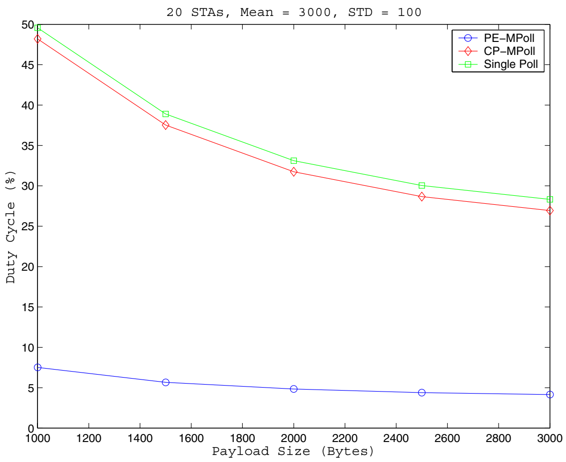

Fig. 5. Duty Cycle vs. Payload Size.

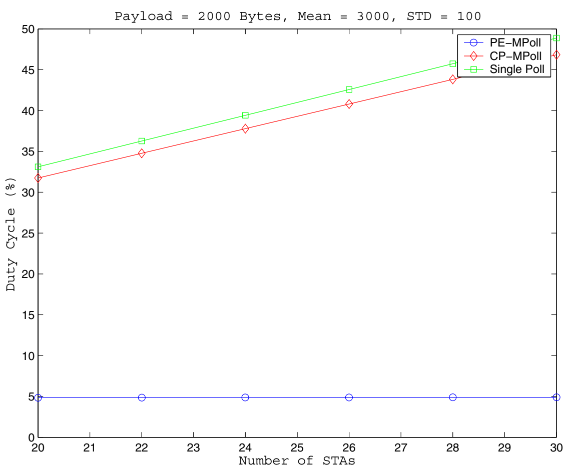

Fig. 6. Duty Cycle vs. Number of STAs.

have to wait for the transmission of other STAs before they can access the channel. Therefore, the more scheduled STAs line up ahead, the more time is wasted in waiting and overhearing. However, the duty cycle of PE-Multipoll is controlled and kept at a value which roughly depends on the group size.

Finally, the effect of wake-up factor is evaluated with a traffic model of high standard deviation of the traffic model (set to 1000) assuming 26 STAs and 2500 bytes payload size. We use the high standard deviation case to evaluate the possible situation that some STAs generate highly bursty traffic. The waiting time indicates the time delayed by the previous groups and the idle time is the time between end of transmission of a group and start of transmission of its succeeding group. When the wake-up factor is set to 1, the channel efficiency of PE-Multipoll is even worse than SinglePoll as shown in Table II. However, as the wake-up factor becomes smaller, the channel efficiency of PE-Multipoll is closer to CP-Multipoll. The price is that STA must be awake earlier to wait for its turn to transmit. Table II reveals that the mean waiting time increases as the wake-up factor decreases. However, at the same time, the mean idle time decreases and thus the channel efficiency improves. For all our studied scenarios, the mean time spent in active mode using PE-Multipoll is still significantly smaller than those using either CP-Multipoll or SinglePoll.

TABLE II
PERFORMANCE COMPARISON OF HIGH VARIATION SCENARIO

Wake-Up Factor	Channel Efficiency (Mbps)	Mean Duty Cycle (%)	Mean Waiting Time (ms)	Mean Idle Time (ms)
1	102.97	5.27	0.5596	0.1283
0.9	107.10	7.18	1.6147	0.0332
0.8	108.16	10.00	3.1490	0.0089
0.7	108.40	13.19	4.8778	0.0027
CP-MPoll	108.47	35.77	N/A	N/A
SPoll	105.01	37.55	N/A	N/A

V. CONCLUSION

This paper presents a PE-Multipoll mechanism which combines the power management and low overhead operations, and is specifically designed for infrastructure WLAN. Wireless STAs can enter sleep mode during a scheduled interval and have flexibility in medium access. With the proposed scheme, the AP can dynamically adjust the wake-up time according to the monitored channel efficiency. Through the simulation results, we find that, with PE-MultiPoll, the time spent in active mode for WLAN devices is largely decreased when compared with other schemes. In the future, we will continue studying the effect of group size and scheduling strategy to further optimize the performance of the proposed PE-Multipoll mechanism.

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