國立交通大學

網路工程研究所

碩士論文

適用於 IEEE 802.11 無線區域網路電話系統中之省電傳送機制

Energy-Efficient Transmission Mechanism for VoIP over IEEE 802.11 WLAN

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中 華 民 國 九 十 六 年 六 月

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碩 士 論 文

A Thesis

Submitted to Institute of Network Engineering

College of Computer Science

National Chiao Tung University

in partial Fulfillment of the Requirements

for the Degree of

Master

in

Computer Science

June 2007

Hsinchu, Taiwan, Republic of China

中華民國九十六年六月

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國立交通大學網路工程研究所碩士班

Abstract (in Chinese)

無線區域網路電話(Voice over IP over WLAN, VoWLAN)為公眾與私人無線區域網路系統中一項重要的應用服務。然而，這樣的服務面臨了手持裝置耗電與系統能支援的最大使用者數目(VoWLAN Capacity)有限等技術挑戰，因此使得大規模的商業化佈建緩慢。在本研究中，我們針對 IEEE 802.11 無線區域網路電話系統提出了一個跨層的省電傳送機制，此機制考量語音封包可以忍受某種程度封包遺失(packet loss)的特性，並且根據目前語音封包遺失率，動態的停用媒體存取控制層(MAC)對於語音封包的回應封包(Acknowledgement)。在此機制下，可以縮短手持裝置傳送與接收封包所需的時間與對應消耗的能量。模擬結果說明瞭本機制可以在通話品質被保證的情況下，大幅的改善無線區域網路手持裝置的耗電情形，以及無線區域網路電話系統所能支援的最大使用者數目。

Energy-Efficient Transmission Mechanism for VoIP over IEEE 802.11 WLAN

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Abstract (in English)

Voice over IP (VoIP) over WLAN (VoWLAN) is an important application for public and private WLANs. However, VoWLAN systems suffer from various technical challenges such as power consumption of WLAN stations (STAs) and VoWLAN capacity issues, making the commercial deployment of large-scale VoWLAN services problematic. This study presents a cross-layer and energy-efficient mechanism for transmitting VoIP packets over IEEE 802.11 WLANs. The proposed mechanism considers the characteristics of VoIP that can tolerate some packet loss, and dynamically disables the medium access control (MAC) layer acknowledgement for voice packets according to the packet loss rate. In doing so, the time and energy consumed to transmit and receive voice packets for a VoWLAN STA can be reduced. Simulation results demonstrate that the mechanism significantly improves the energy efficiency of a VoWLAN STA and WLAN utilization while the voice quality can be also guaranteed.

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Acknowledgements

這篇論文可以順利完成，首先要感謝的人是我的指導教授，曹孝櫟老師。老師是我在大學做專題期間一直到碩士班畢業的指導教授，也是影響我很深遠的人。在研究的指導上，老師一直十分的栽培我，讓我有參與大型程式競賽、申請專利、出國參加研討會這些其他碩士班學生可能沒有的經歷。而我在畢業後能到自己理想的公司工作，這一切到要歸功於我的老師。而在待人處事上，老師也一直告訴我們要用積極進取的態度面對生活，因為如此，讓我能有正確的價值觀來面對壓力與挑戰的到來。老師謝謝您，因為您才有今天的我。

接著我要感謝實驗室夥伴們。謝謝建明學長、誌謙學長、一正學長、宥霖學長在我研究過程中給予我的諸多建議，讓我在思考上可以趨於完備。謝謝彥筑、雅筑、政龍、名杰在平日中對我的砥礪，這讓我有不斷努力下去的動力。謝謝建臻學弟、家祥學弟、世永學弟常常陪我留在實驗室熬夜奮鬥。謝謝你們。

最後我要感謝一直支持我的家人。謝謝爸爸、媽媽、姊姊、哥哥願意當我的避風港，讓我在遇到壓力時總是能得到紓解。謝謝女朋友乃瑛的默默陪伴，因為妳讓我不管作任何事情都很有衝勁。

Chapter 1. Introduction

Extensively used in public and private networks, WLAN offers convenient and broadband accesses to mobile Internet services. Having recently attracted significant interest from both academia and industry, Voice over IP (VoIP) over WLAN (VoWLAN) is considered as one of the most important applications for WLANs [1]. However, various technical challenges inhabit VoWLAN systems such as power consumption, mobility management, WLAN utilization and quality of services (QoS), making large-scale VoWLAN services difficult to deploy. Two critical challenges for a VoWLAN system are the VoWLAN capacity, i.e. the number of VoIP sessions that an access point (AP) can support, and the power consumption of a VoWLAN station (STA), i.e. the standby and talk hours of a VoWLAN terminal.

The IEEE 802.11 WLAN adopts Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) for its medium access control (MAC) [2]. The method performs inefficiently when transmitting large numbers of small MAC frames. Unfortunately, voice packets are small, and are generated periodically every 10 ms to 30 ms. Several reports have already indicated that small voice packets significantly reduce the overall WLAN performance, thus limiting a WLAN AP to only support a small number of VoIP sessions [3][4]. To improve the WLAN utilization for transmitting voice packets, previous studies optimized WLAN parameters such as the contention window size and transmission opportunity (TXOP) for voice packets [5][6]. Wang et al. presented a multicast downlink transmission mechanism that aggregates multiple downlink voice packets into one multicast packet, and transmits the packet to a group of VoWLAN STAs [3]. The overheads for inter-frame spacing and contentions between small voice packets are eliminated, and the WLAN utilization is thus improved. However, this mechanism requires VoWLAN STAs to always stay awake to receive downlink multicast packets, and it does not solve the power consumption problem.

Regarding the power consumption issue for a VoWLAN system, Chen et al. evaluated three VoWLAN packet transmission schemes based on the IEEE 802.11 power saving mode (PSM) and IEEE 802.11e automatic power saving delivery (APSD) mode [7][8]. Wang et al. considered the characteristic of voice packets arrivals and suggested to periodically wake up VoWLAN STAs to receive and transmit voice packets [9]. Therefore, a Time Division Multiple Access (TDMA)-like accesses can be achieved for transmitting and receiving voice packets, reducing the energy consumption of VoWLAN STAs. Another important characteristic of voice packets that is not fully elaborated in the design of a VoWLAN transmission scheme is the need for a reliable delivery [10]. Reliable transmission is essential for data packets, but is not always necessary for voice packets, which could tolerate some loss. In this study, a cross-layer and energy-efficient transmission mechanism that differentiates WLAN MAC-layer schemes for voice and non-voice packets is thus proposed. The mechanism dynamically disables the MAC-layer acknowledgment for each transmission attempt of a voice packet according to the current packet loss rate and the target voice quality. By eliminating MAC-layer acknowledgment frames for voice packets, the time and energy consumed by sending and receiving acknowledgement frames are minimized. Therefore, the energy efficiency of a VoWLAN STA and the WLAN utilization are both improved. To realize the proposed idea without modifying the IEEE 802.11 standard, this work adopts WLAN MAC multicasting that does not require the acknowledgement to transmit voice packets. Then, the proposed mechanism can be implemented on the existing WLAN infrastructures merely through software upgrades.

The rest of this thesis is organized as follows. Chapter 2 describes a network architecture for a VoWLAN system and VoWLAN transmission schemes. Next, Chapter 3 presents the design of the proposed mechanism. Chapter 4 discusses the simulation results. Conclusions are finally drawn in Chapter 5.

Chapter 2. Network Architecture and Transmission Schemes for VoWLAN Services

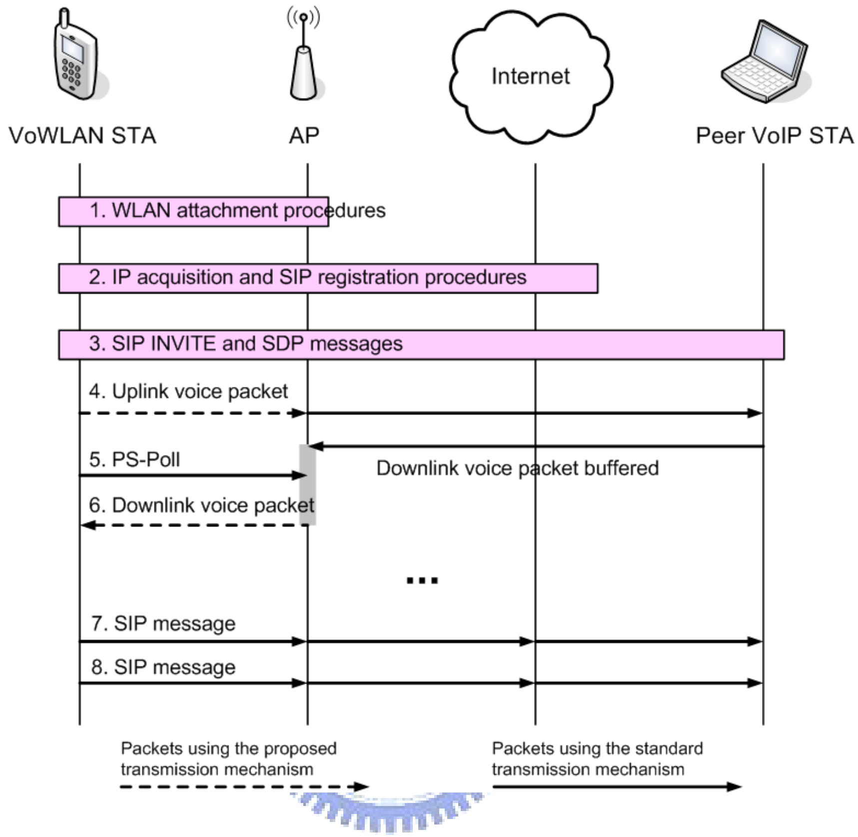


Figure 1. A generic network architecture for a VoWLAN system

Figure 1 illustrates a generic network architecture for a VoWLAN system. A VoWLAN STA is attached to WLAN via an AP, which is further connected to the Internet. A VoWLAN STA can then use call setup protocols such as session initiation protocol (SIP) to establish a VoIP session with a peer STA, which can be a fixed or a mobile node. Two transmission schemes are used to reduce the power consumption of a VoWLAN STA during a VoIP session. The first method, called the PS-Poll transmission scheme, adopts the PSM defined in the IEEE 802.11 standard. According to the PS-Poll transmission scheme, an STA first notifies the WLAN AP to enter the PSM, and stays in the doze state, which consumes much less energy than the WLAN receiving state. If a VoWLAN STA has an uplink voice packet to transmit, it wakes up and sends the packet. After receiving the acknowledgement frame from the AP for the uplink voice packet, the VoWLAN STA sends a PS-Poll frame to retrieve the downlink voice packet buffered on the AP. Normally, an AP first responds with an acknowledgement frame to the PS-Poll frame and, then, transmits a downlink voice packet to the STA. According to IEEE 802.11 specifications, acknowledging a PS-Poll frame is not mandatory, but most existing APs implement the PS-Poll acknowledgement. Finally, the STA receives and acknowledges the downlink voice packet. Figure 2 shows a timing diagram for uplink and downlink voice packet exchange without any packet error and collision based on the PS-Poll transmission scheme.

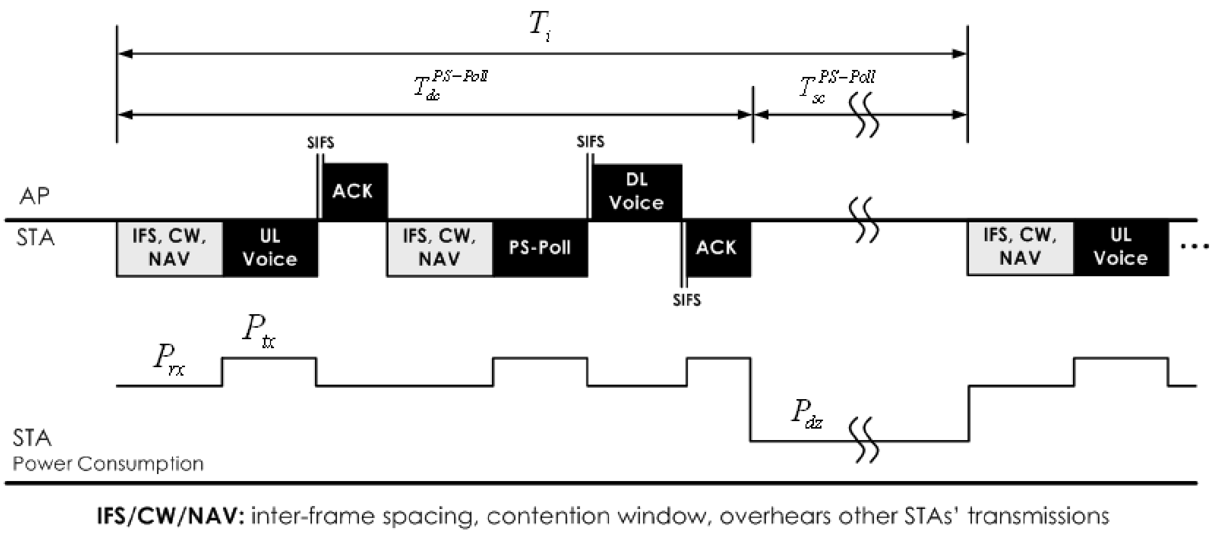


Figure 2. PS-Poll VoWLAN transmission scheme

A duty cycle, $T_{dc}^{PS-Poll}$, refers to the time period for transmitting one uplink and receiving one downlink voice packet for the PS-Poll transmission scheme. Since downlink and uplink voice packets are generated periodically, say every T_i, the sleep period of a VoWLAN STA for every T_i is given by $T_{sc}^{PS-Poll} = T_i - T_{dc}^{PS-Poll}$.This model assumes that the voice codec is a constant bit rate (CBR), and the codecs for uplink and downlink voice packets are symmetric. Figure 2 also illustrates the power consumption of a VoWLAN STA. P_{rx}, P_{tx} and P_{dz} denote the power consumption of a VoWLAN STA during the receiving, transmitting and doze states, respectively. Clearly, a shorter length of a duty cycle a VoWLAN transmission scheme introduces, the less energy a VoWLAN STA spends for transmitting and receiving voice packets and also the less network resources a VoWLAN session consumes.

The energy consumed by applying the PS-Poll transmission scheme during a duty cycle, $E_{dc}^{PS-Poll}$, is defined as $E_{dc}^{PS-Poll} = E_{ul}^{PS-Poll} + E_{dl}^{PS-Poll}$, where $E_{ul}^{PS-Poll}$ and $E_{dl}^{PS-Poll}$ denote the energy consumed when transmitting one uplink and one downlink voice packet, respectively. According to Wang's study [11], $E_{ul}^{PS-Poll}$ and $E_{dl}^{PS-Poll}$ can be further rewritten as:

$E_{ul}^{PS-Poll} = E\_BK^{PS-Poll} + E\_FR_{ul}^{PS-Poll} + E\_SU_{ul}^{PS-Poll}$, and

$E_{dl}^{PS-Poll} = E\_BK^{PS-Poll} + E\_FR_{dl}^{PS-Poll} + E\_SU_{dl}^{PS-Poll}$.

Above equations assume there is no packet loss due to packet collision or packet error during the transmission. $E\_BK^{PS-Poll}$ denotes the energy consumption for a VoWLAN STA in the WLAN MAC contention window. $E\_FR_{ul}^{PS-Poll}$ and $E\_FR_{dl}^{PS-Poll}$ denote the energy consumption for a VoWLAN STA that overhears other STAs' transmissions. $E\_SU_{ul}^{PS-Poll}$ and $E\_SU_{dl}^{PS-Poll}$ represent the energy consumption for a VoWLAN STA successfully transmitting an uplink and receiving a downlink voice packet respectively.

Assuming that the average number of transmissions overheard by a VoWLAN STA during a contention window period is given by $N_t^{PS-Poll}$, and that the VoWLAN STA consumes P_{rx} during the overhearing period, the energy consumption due to the VoWLAN STA overhearing the other VoWLAN STAs' transmissions during a contention window period can be calculated as

$$E\_FR_{ul}^{PS-Poll} = E\_FR_{dl}^{PS-Poll} = N_t^{PS-Poll} \times P_{rx} \times \left(\frac{T_{ul-success}^{PS-Poll} + T_{dl-success}^{PS-Poll}}{2} \right).$$

The overhearing probabilities for downlink and uplink transmissions assume equal. The parameters $T_{ul-success}^{PS-Poll}$ and $T_{dl-success}^{PS-Poll}$ denote the time periods for each successful transmission of an uplink and downlink voice packet adopting the PS-Poll transmission scheme, given by

$T_{ul-success}^{PS-Poll} = T_{difs} + T_{ul-voice} + T_{sifs} + T_{ack}$, and

$T_{dl-success}^{PS-Poll} = T_{difs} + T_{PS-Poll} + T_{sifs} + T_{dl-voice} + T_{sifs} + T_{ack}$,

where T_{difs}, T_{sifs}, $T_{ul-voice}$, $T_{dl-voice}$, T_{ack}, and $T_{PS-Poll}$ represent the time periods for the DCF Inter Frame Spacing (DIFS), Short Inter Frame Spacing (SIFS), the transmission of an uplink voice packet, a downlink voice packet, an acknowledgement frame and a PS-Poll frame, respectively. The energy consumption for a VoWLAN STA to transmit an uplink and to receive a downlink voice packet for the PS-Poll transmission scheme, i.e. $E\_SU_{ul}^{PS-Poll}$ and $E\_SU_{dl}^{PS-Poll}$, can be denoted as

$E\_SU_{ul}^{PS-Poll} = P_{rx} \times (T_{difs} + T_{sifs} + T_{ack}) + P_{tx} \times T_{ul-voice}$, and

$E\_SU_{dl}^{PS-Poll} = P_{rx} \times (T_{difs} + T_{sifs} + T_{dl-voice} + T_{sifs}) + P_{tx} \times (T_{PS-Poll} + T_{ack})$.

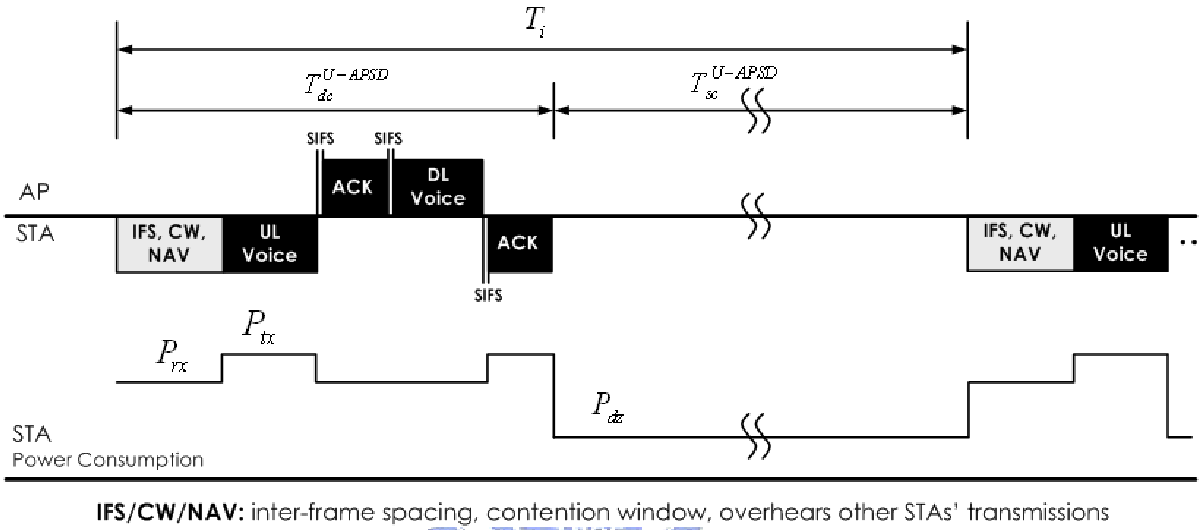


Figure 3. U-APSD VoWLAN transmission scheme

The second method adopts the APSD mechanism defined in the IEEE 802.11e [8]. The APSD improves the IEEE 802.11 PSM by averting the PS-Poll procedure. An uplink voice packet can be configured as a frame to trigger a service period, which is used to transmit downlink packets. Figure 3 shows an example of an unscheduled-APSD (U-APSD) transmitting a downlink and uplink voice packet. An STA is initially in the doze state. Once an STA has an uplink voice packet to send, it wakes up and transmits the packet. The AP responds with an acknowledgment frame to the uplink voice packet, starts the downlink service period, and then transmits a downlink voice packet to the STA. This approach avoids the PS-Poll procedure, shortens the duty cycle, and reduces the power consumption of a VoWLAN STA.

Chapter 3. Energy-Efficient Transmission Mechanism

3.1. Design of the Proposed Mechanism

The proposed transmission mechanism considers the characteristics of voice packets, and differentiates voice and non-voice packets in the WLAN MAC transmission. The initial idea behind the proposed mechanism is to disable the MAC layer acknowledgement for voice packets, and to minimize the overheads for performing acknowledgements. However, to disable the MAC acknowledgement for voice packets, lost packets cannot be detected and retransmitted, and the voice quality may degrade. Therefore, the proposed mechanism is improved herein by dynamically turning the MAC-layer acknowledgement on and off for each transmission attempt of a voice packet, depending on the WLAN packet loss condition and the target voice quality. If packet error and loss rarely occur, then the MAC-layer acknowledgment for a voice packet is turned off, which improves the efficiency of network and energy. Conversely, while the packet loss rate increases, the MAC-layer acknowledgement for voice packets is turned on to ensure the voice quality.

By applying the PS-Poll transmission scheme shown in Figure 1, a VoWLAN STA transmits an uplink voice packet, and then uses a PS-Poll frame to retrieve a downlink voice packet on the AP. In addition to voice packets, an AP and STA may exchange non-voice packets such as SIP messages. The proposed design requires a WLAN AP to be upgraded to understand SIP and session description protocol (SDP), so that an AP can distinguish voice packets and non-voice packets. For an uplink voice packet transmission such as Step 4 in Figure 1, a MAC-layer transmission counter, given by N_r^{ul}, is associated with each uplink voice packet, where N_r^{ul} denotes the maximum number of MAC-layer transmission attempts for an uplink voice packet. Similarly, N_r^{dl} is associated with downlink voice packets such as Step 6 in Figure 1. N_r^{ul} and N_r^{dl} are dynamically adjusted based on the current packet loss rate, and the target voice quality that a VoIP session sets. N_r^{ul} and N_r^{dl} are negotiated by an AP and STA, and are stored on both sides. For instance, if $N_r^{ul} = 1$, then an uplink voice packet is sent only once, and does not need to be acknowledged. Since N_r^{ul} is stored on both the STA and AP, the STA knows that the packet will not be acknowledged, so the STA can return to sleep or perform the next packet transmission without waiting for the acknowledgement frame. Therefore, the STA can save the time and energy to receive acknowledgement frames from the AP. Similarly, for a downlink packet transmission, the STA can conserve energy by not sending an acknowledgement frame for a downlink voice packet. Hence, the overheads to perform the MAC acknowledgement for voice packets are eliminated, and both the energy efficiency and WLAN utilization can be improved. If $N_r^{ul} = 2$, then the uplink voice packet that is sent at the first time needs an acknowledgement from the AP. If the AP receives the packet, it acknowledges the uplink voice packet, and the transmission is complete. Otherwise, if the STA does not receive the acknowledgement from the AP, the STA detects the packet loss and resends the uplink voice packet again. Since $N_r^{ul} = 2$, the resent voice packet does not need the MAC acknowledgement. The STA proceeds for the next transmission or returns to sleep after resending the voice packet. Restated, the STA sends the uplink voice packet at most $N_r^{ul} - 1$ times that require the MAC-layer acknowledgement. The packet resent at the N_r^{ul} time needs not be acknowledged. Clearly, increasing the values of N_r^{ul} and N_r^{dl} generally improves the voice quality, but also increases the radio resource and energy consumption for a VoWLAN session. The method to determine N_r^{ul} and N_r^{dl} is discussed later in this section. Non-voice packets such as SIP messages and PS-Poll frames, which are important packets and need to be reliably delivered, are transmitted by the standard WLAN MAC mechanism.

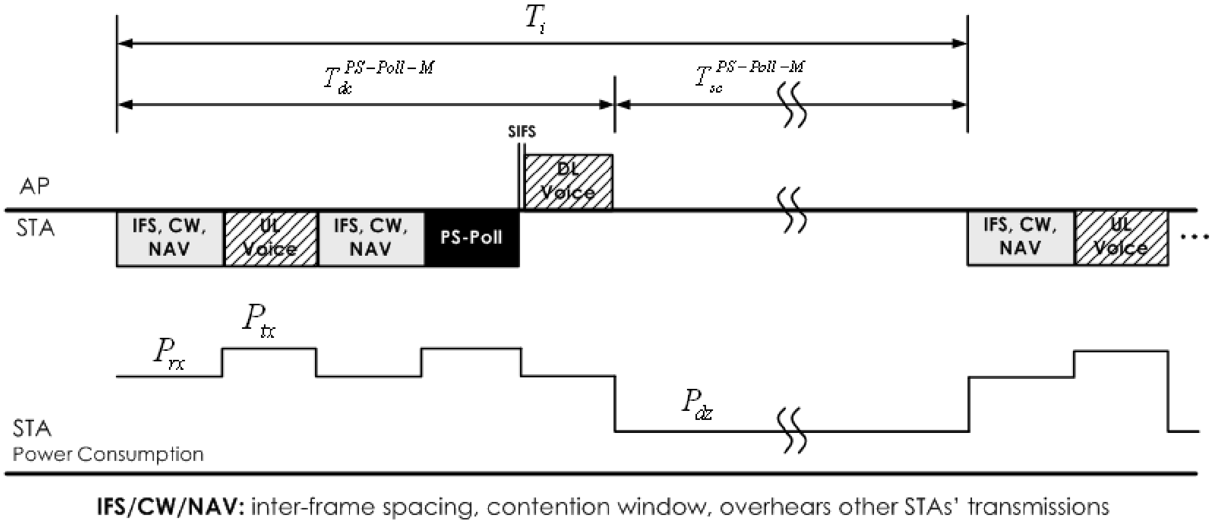


Figure 4. The proposed mechanism applied to the PS-Poll scheme

Figure 4 shows a timing diagram of the proposed method applied to the PS-Poll transmission scheme, where both $N_r^{ul} = 1$ and $N_r^{dl} = 1$, i.e. voice packets are neither acknowledged nor retransmitted. Comparing Figure 2 and Figure 4 reveals that sending packets without acknowledgement frames significantly reduces the length of a duty cycle. This is because the length of an acknowledgement frame is nearly equal to that of a small voice packet. Then, the energy consumption of a VoWLAN STA for an uplink and downlink transmission by applying the proposed mechanism to the PS-Poll scheme, denoted as $E_{ul}^{PS-Poll-M}$ and $E_{dl}^{PS-Poll-M}$ respectively, become

$$E_{ul}^{PS-Poll-M} = E\_BK^{PS-Poll-M} + E\_FR_{ul}^{PS-Poll-M} + E\_SU_{ul}^{PS-Poll-M}, \text{ and}$$

$$E_{dl}^{PS-Poll-M} = E\_BK^{PS-Poll-M} + E\_FR_{dl}^{PS-Poll-M} + E\_SU_{dl}^{PS-Poll-M}.$$

$E\_FR_{ul}^{PS-Poll-M}$, $E\_FR_{dl}^{PS-Poll-M}$, $E\_SU_{ul}^{PS-Poll-M}$, and $E\_SU_{dl}^{PS-Poll-M}$ are further defined as

$$E\_FR_{ul}^{PS-Poll-M} = E\_FR_{dl}^{PS-Poll-M} = N_t^{PS-Poll-M} \times P_{rx} \times \left(\frac{T_{ul-success}^{PS-Poll-M} + T_{dl-success}^{PS-Poll-M}}{2} \right).$$

$$T_{ul-success}^{PS-Poll-M} = T_{difs} + T_{ul-voice}, \text{ and}$$

$$T_{dl-success}^{PS-Poll-M} = T_{difs} + T_{PS-Poll} + T_{sifs} + T_{dl-voice}.$$

$$E\_SU_{ul}^{PS-Poll-M} = P_{rx} \times T_{difs} + P_{tx} \times T_{ul-voice}, \text{ and}$$

$$E\_SU_{dl}^{PS-Poll-M} = P_{rx} \times \left(T_{difs} + T_{sifs} + T_{dl-voice} \right) + P_{tx} \times T_{PS-Poll}.$$

The decrease in energy consumption per duty cycle from adopting the proposed mechanism for the PS-Poll scheme is thus obtained:

$$\Delta E_{dc}^{PS-Poll} = E_{ul}^{PS-Poll} + E_{dl}^{PS-Poll} - E_{ul}^{PS-Poll-M} - E_{dl}^{PS-Poll-M} \qquad \text{(A)}$$

Assume that the PS-Poll scheme with and without the proposed mechanism suffers the same numbers of overhearing transmissions, i.e. $N_t^{PS-Poll} = N_t^{PS-Poll-M}$. Additionally, the WLAN MAC contention windows for the PS-Poll transmission scheme with and without the proposed mechanism are assumed to be equal, i.e. $E\_BK^{PS-Poll} = E\_BK^{PS-Poll-M}$. Then, Equation (A) can be rewritten as

$$\begin{aligned}\Delta E_{dc}^{PS-Poll} &= \left(E\_SU_{ul}^{PS-Poll} - E\_SU_{ul}^{PS-Poll-M} + E\_SU_{dl}^{PS-Poll} - E\_SU_{dl}^{PS-Poll-M}\right) + \\ &\quad \left(E\_FR_{ul}^{PS-Poll} - E\_FR_{ul}^{PS-Poll-M} + E\_FR_{dl}^{PS-Poll} - E\_FR_{dl}^{PS-Poll-M}\right) \\ &= \left[P_{rx} \times \left(T_{sifs} + T_{ack} + T_{sifs}\right) + P_{tx} \times T_{ack}\right] + \\ &\quad \left[N_t^{PS-Poll} \times P_{rx} \times \left(T_{sifs} + T_{ack}\right)\right] \qquad \text{(B)}\end{aligned}$$

Equation (B) reveals that the performance improvement by applying the proposed mechanism comes not only from the elimination of acknowledgement frames for downlink and uplink voice packets, but also from reducing the length of the period that a VoWLAN STA overhears the other VoWLAN STAs' transmissions.

This proposed mechanism can also be applied to the U-APSD transmission scheme, eliminating the acknowledgement frame for downlink voice packets. Notably, the uplink voice packet in the U-APSD scheme is used to trigger download packet transmissions. Therefore, the proposed design categorizes the important uplink voice packets as non-voice packets in the U-APSD scheme, and processes them by using the standard MAC transmission scheme to prevent the packet loss.

3.2. The Maximum Numbers of Transmission Attempts for Voice Packets

Disabling MAC-layer acknowledgement may introduce packet loss which degrades the voice qualities. First, the contention window of each voice packet transmission does not increase when sending packets over WLANs without the MAC-layer acknowledgement. The probability of collisions rises when the number of VoWLAN sessions increases. Second, the WLAN channel error also introduces packet loss. To reduce packet loss and maintain voice quality, the proposed transmission mechanism defines the maximum numbers of transmission attempts for each uplink and downlink voice packet, which are denoted as N_r^{ul} and N_r^{dl} respectively. N_r^{ul} controls the uplink packet loss caused by uplink packet collision and packet error, while N_r^{dl} controls the loss rate for downlink voice packets. Notably, $N_r^{dl} \neq N_r^{ul}$, since collision never occurs for transmitting downlink voice packets guarded by a PS-Poll frame for the PS-Poll scheme, or by an uplink trigger frame for the U-APSD scheme. Hence, N_r^{dl} is only used to reduce packet loss caused by WLAN channel error. A VoWLAN system must set a target voice quality in terms of the packet loss rate. If the loss rates of the downlink and uplink voice packets reach that predefined values, then N_r^{ul} and N_r^{dl} increase to improve the downlink and uplink voice qualities. Conversely, N_r^{ul} and N_r^{dl} are decreased to reduce the energy consumption when the packet loss rate is low. Typically, the target packet loss rate is set to 1–2% for a VoWLAN application [12]. Another issue is measuring the packet loss rate. A possible solution is to implement a sender-report and receiver-report mechanism like real-time control protocol (RTCP) between an AP and VoWLAN STAs [13]. The sender and receiver reports containing the number of voice packet sent and received by an AP and STA are periodically exchanged to obtain the current downlink and uplink packet loss rates.

3.3. Implementation Issues

To apply the proposed mechanism to the IEEE 802.11 standard, the WLAN MAC multicasting that does not require acknowledgement from peers can be adopted to transmit voice packets without acknowledgement frames. A VoWLAN STA, say STA *i*, is configured with two MAC addresses, one unicast address, MAC STA*i*, and one multicast address, MAC M*i*. The WLAN MAC frame with a unicast address as the destination MAC address is used to send non-voice packets, and the WLAN MAC frame with a multicast address as the destination MAC address is used to send voice packets between an AP and STA. First, a VoWLAN STA associates itself with an AP using its unicast MAC address. The AP and STA then set up a shared multicast MAC address, by either implicitly producing MAC multicast address from the STA's unicast address, or explicitly exchanging a message between the STA and AP to configure a new multicast MAC address. The multicast address is only shared by the AP and STA, and not with other STAs. Restated, each STA has its own unicast MAC address, and its own multicast address which is shared by the AP for uplink and downlink voice packet transmission. A multicast address is used as the destination MAC address of voice packets only because the MAC multicast frame does not need an acknowledgement frame from the receiver, but the multicast frame has no intent to be sent to a group of STAs. If $N_r^{ul} > 1$ or $N_r^{dl} > 1$, then the first $N_r^{ul} - 1$ or $N_r^{dl} - 1$ transmission attempts for a voice packet use the unicast MAC address, implying that the packet needs to be acknowledged. The multicast MAC address is used at the N_r^{ul} and N_r^{dl} time transmission to avoid the MAC acknowledgement. This design enables the proposed mechanism to be implemented in the existing WLAN infrastructure through only software upgrades.

Chapter 4. Simulation Results

Simulations were conducted to evaluate the WLAN performance and the energy consumption of a VoWLAN STA for different packet transmission schemes. The VoWLAN simulation environment comprised an AP and several VoWLAN STAs, which established VoIP sessions and exchanged voice packets with wired-line nodes in the same subnet. Table 1 summarizes the simulation parameters.

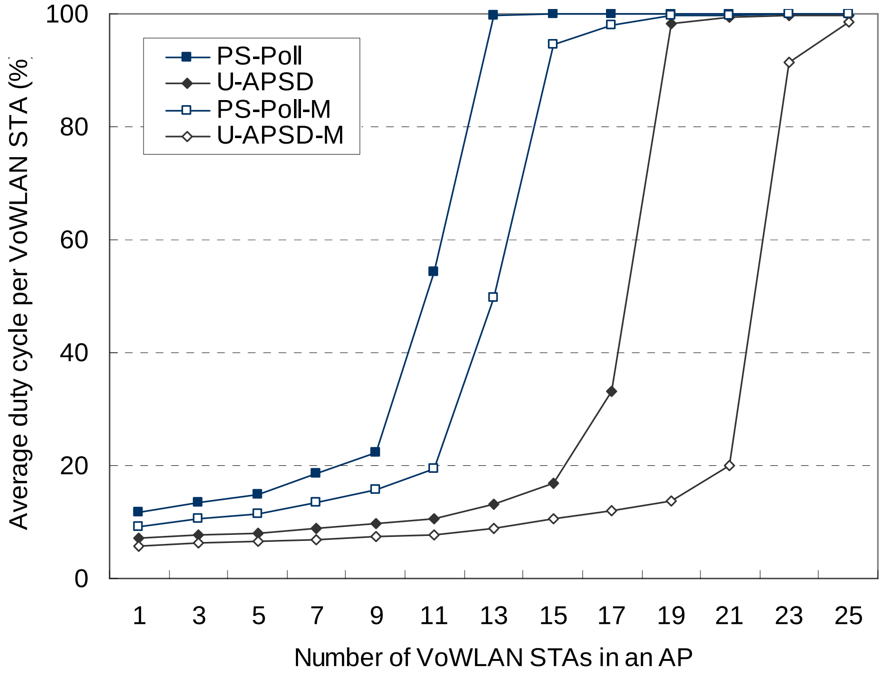
Table 1. Simulation parameters

Parameters of Voice codec		
	GSM	G.711
Bit rate	13.2 kbps	64 kbps
Framing interval	20 ms	20 ms
Payload	33 bytes	160 bytes
Parameters of the WLAN MAC accesses		
	802.11b	802.11g
SIFS/DIFS/Slot time	10 μs/50 μs/20 μs	10 μs/28 μs/9 μs
PHY preamble + header	192 μs	20 μs
PS-Poll/ACK	80 μs/56 μs	27 μs/19 μs
CWmin/CWmax	32/1024	16/1024
Parameters of the power consumption of a WLAN interface (ORiNOCO PC Gold, IEEE 802.11b) [14]		
P_{tx} / P_{rx}	1400 mW/950 mW	
P_{dz}	60 mW	
Bit Error Rates (BERs)		
WLAN channel conditions	1.0e-5/1.0e-4	

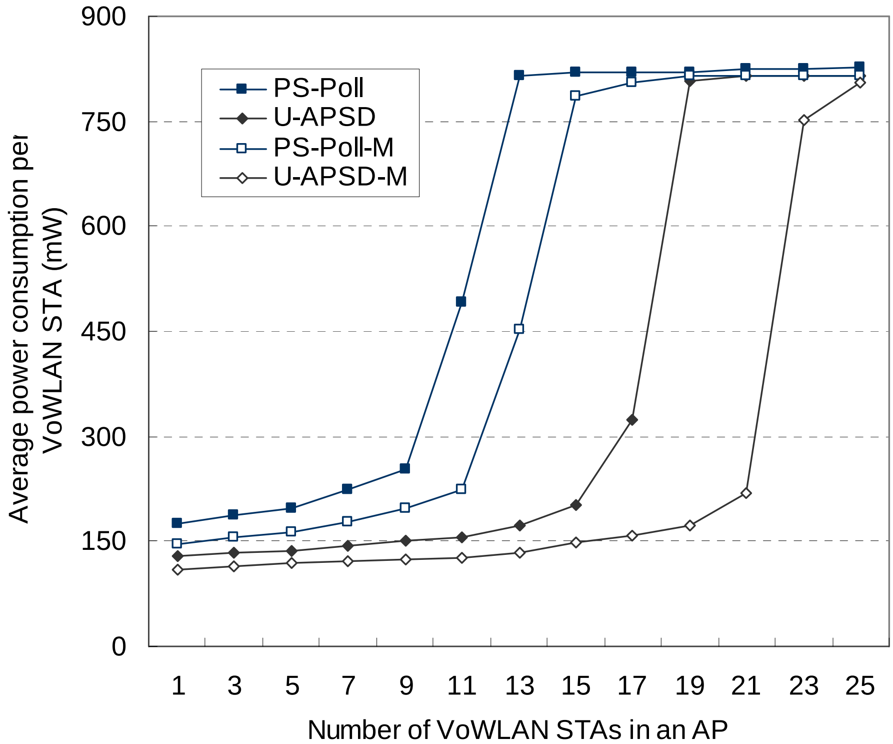
The length of a duty cycle, energy consumption, packet loss rate, and packet delay for a

VoWLAN STA by adopting the PS-Poll, U-APSD, PS-Poll with the proposed mechanism (denoted as PS-Poll-M) and U-ASD with the proposed mechanism (denoted as U-APSD-M) were first evaluated. The first simulation used the IEEE 802.11b and GSM voice codec, and assumed a good WLAN channel condition, i.e. BER = 1.0e-5. Figure 5(a) shows the average duty cycle per VoWLAN STA under different numbers of concurrent VoWLAN STAs in an AP. The y-axis of Figure 5(a) shows the length of a duty cycle over a voice framing interval which indicates the percentage of time that a VoWLAN STA must stay awake to transmit one uplink and one downlink voice packet every voice framing interval. A larger percentage of a duty cycle per voice framing interval implies that more energy is consumed for a VoWLAN STA. Figure 5(a) indicates increasing the number of concurrent VoWLAN STAs in an AP also increases the average duty cycle per VoWLAN STA, because a VoWLAN STA needs to spend more time contending the WLAN channel when more concurrent VoWLAN STAs are served by an AP. The figure illustrates that while the number of VoWLAN STAs in an AP is 1, the PS-Poll and U-APSD transmission schemes with the proposed mechanism decrease by about 10% length of a duty cycle than the transmission schemes without the proposed mechanism. This performance improvement is gained only by eliminating acknowledgement frames. The performance improvement from applying the proposed mechanism grows as the number of concurrent VoWLAN STAs in an AP increases. This is because that a VoWLAN STA usually has to wait for other VoWLAN STAs' transmissions while the AP is serving many VoWLAN

STAs. The proposed mechanism reduces the transmission time of voice packets, and hence, significantly reduces the average length of an overhearing period while the WLAN load becomes heavy. For instance, the average duty cycle per VoWLAN STA for the PS-Poll and PS-Poll-M schemes when supporting 9 concurrent VoWLAN STAs are 4.48 ms and 3.16 ms respectively. The proposed mechanism reduces the duty cycle by about 29%. The average duty cycles for the U-APSD and U-APSD-M schemes are 1.96 ms and 1.48 ms respectively, indicating a reduction of about 24% when adopting the proposed mechanism for the case that 9 VoWLAN STAs are served by an AP. The simulation results reveal that the proposed method removes the acknowledgement frames for voice packets, thus shortening each duty cycle, which also reduces the WLAN channel waiting time while a VoWLAN STA tries to transmit a voice packet. To evaluate the improvement of energy consumption, the energy consumption of a VoWLAN STA using various transmission schemes was investigated. ORiNOCO PC Gold Card is used for this simulation [14]. Figure 5(b) shows the corresponding energy consumption of Figure 5(a). The proposed mechanism reduced the average energy consumption of PS-Poll and U-APSD by about 23% and 17%, respectively, while an AP is serving 9 concurrent VoWLAN STAs.



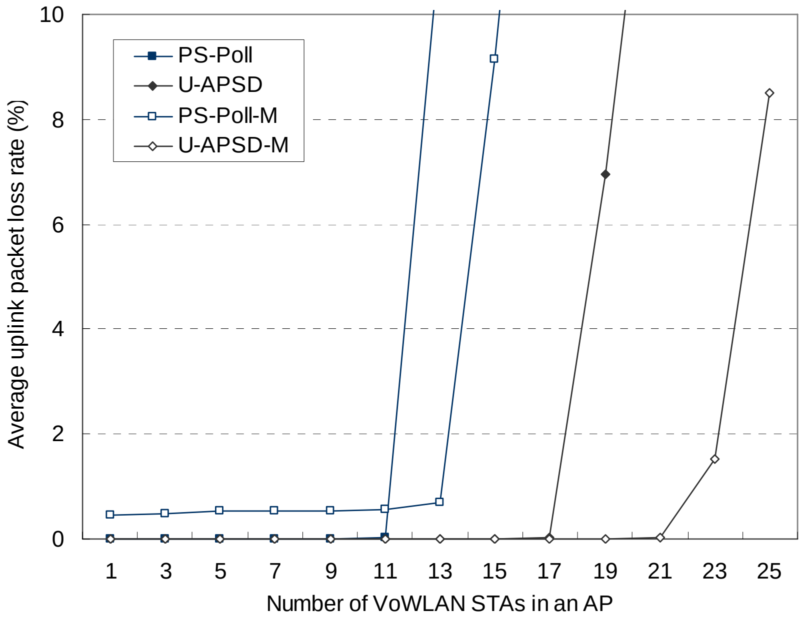
(a)



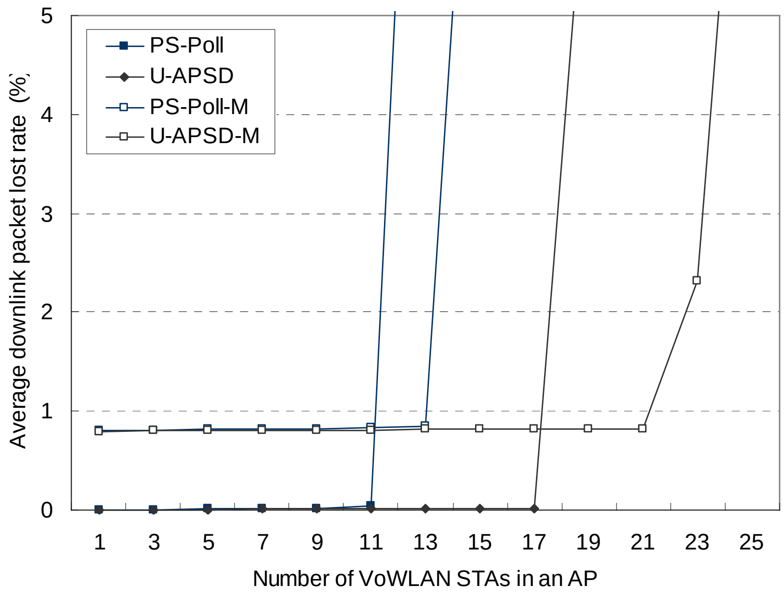
(b)

Figure 5. Aveage duty cycle and enegy consumption for a VoWLAN STA

Voice packets for which acknowledgement frames are not sent might be lost due to packet error or collision, degrading the voice quality. Therefore, the proposed mechanism dynamically adjusts the maximum number of transmission attempts, i.e. N_t^{ul} and N_t^{dl}, for each voice packet based on a target packet loss rate. In the simulations, the maximum permissible packet loss rate was set to 2%. Figure 6 shows the average loss rates for uplink and downlink voice packets by applying different transmission schemes. The simulation results shows that although the packet loss rates of PS-Poll-M and U-APSD-M were slightly higher than those of PS-Poll and U-APSD, the packet loss rates for the proposed transmission mechanism are still less than 1%. The packet delays of different transmission schemes were then investigated. Figure 7 shows the average delay for uplink and downlink voice packets. The figure indicates that the voice packets encounter longer delays as the number of VoWLAN STAs served by an AP increases. This is because that increasing the WLAN load causes more packets to be queued on the AP, increasing the packet delay. Since the proposed mechanism reduces the length of a duty cycle, it increases the maximal number of VoWLAN STAs that can be supported by a WLAN. Simulation results indicate that PS-Poll-M can support two more VoWLAN STAs than the PS-Poll scheme under a 50 ms delay and 2% loss rate constraints for voice packets. U-APSD-M was found to support four more VoWLAN STAs than the U-APSD scheme. Simulation results depicted in Figure 6 and Figure 7 reveal that the proposed mechanism improves the WLAN utilizations of the PS-Poll and U-APSD transmission schemes by about 18% and 24%, respectively and also provides a similar voice quality.

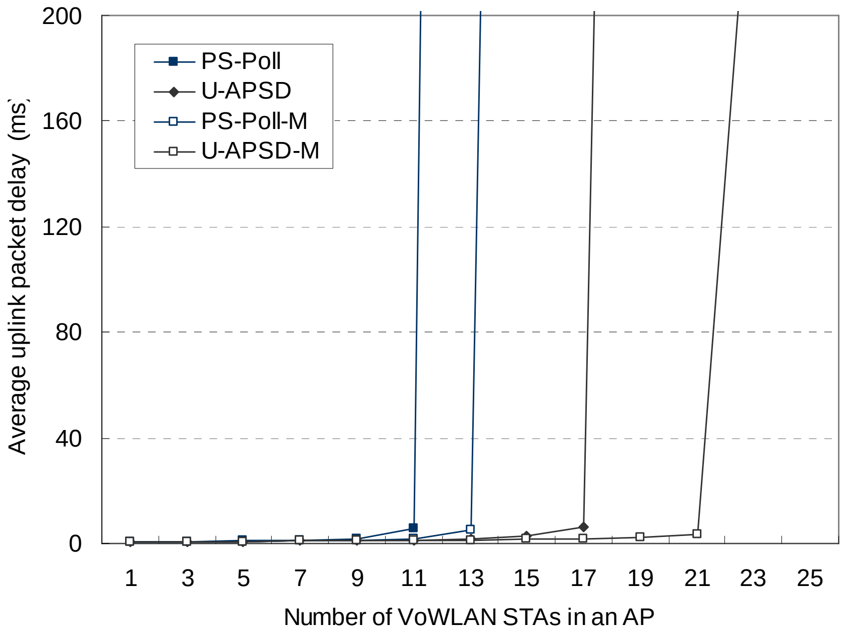


(a)

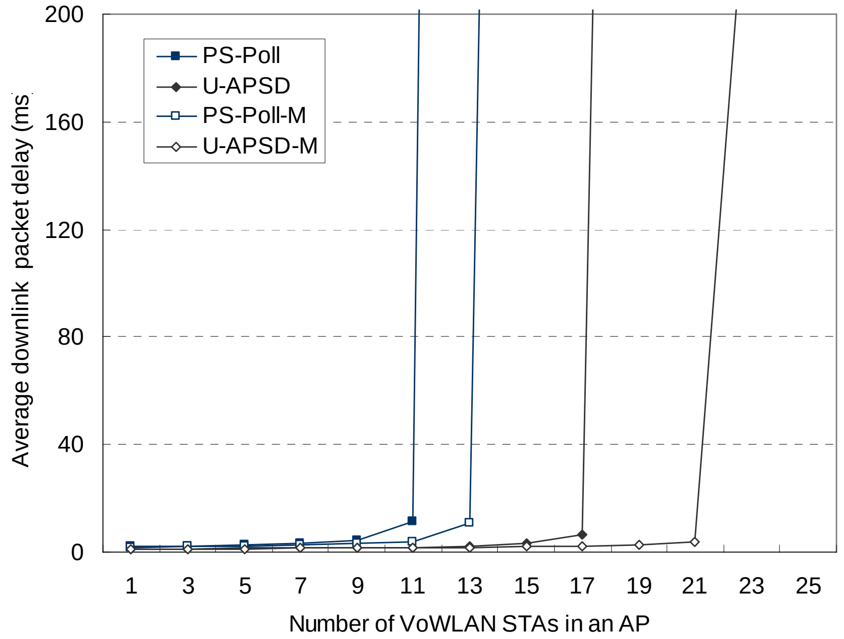


(b)

Figure 6. Average loss rates for uplink and downlink voice packets



(a)



(b)

Figure 7. Average delay for uplink and downlink packets

The performance improvement of the proposed mechanism by using the IEEE 802.11b, different voice codecs and BERs was further evaluated. Figure 8 illustrates the length reduction of a duty cycle per VoWLAN STA from applying the proposed mechanism to the PS-Poll and U-APSD schemes. Simulation results indicate that the PS-Poll-M scheme using GSM codec performed better than that using G.711 codec, because the acknowledgement frame introduces relatively more overhead for low bitrate codecs such as GSM than high bit-rate codecs such as G.711. Additionally, the simulation results show that PS-Poll-M performs better at a BER of 1.0e-5 than 10e-4. This is because a poor WLAN channel quality leads to a high packet loss, implying that the proposed methods must increase the maximum number of transmission for voice packets to maintain an acceptable voice quality.

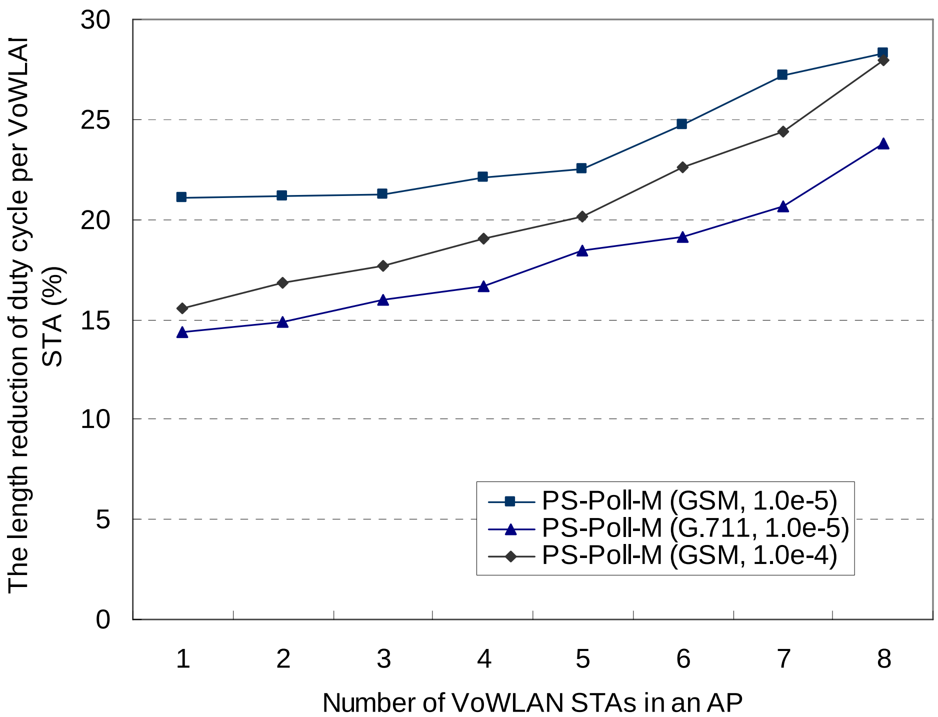


Figure 8. The length reduction of a duty cycle per STA under different codec and BERs

Finally, the performance improvement under different WLAN standards was investigated. Figure 9 shows the average duty cycle per VoWLAN STA when using GSM codec in the IEEE 802.11g with BER = 1.0e-5. While the number of concurrent VoWLAN STAs that can be served by an AP increases, the probability to overhear other STAs' transmission also increases. Therefore, the proposed mechanism that reduces the length of overhearing period efficiently reduces the length of a duty cycle for a VoWLAN STA for high speed WLAN standards. For instance, while 51 concurrent VoWLAN STAs are supported by an IEEE 802.11g AP, the proposed mechanism reduces the average duty cycle of PS-Poll and U-APSD by about 40% and 28%, respectively.

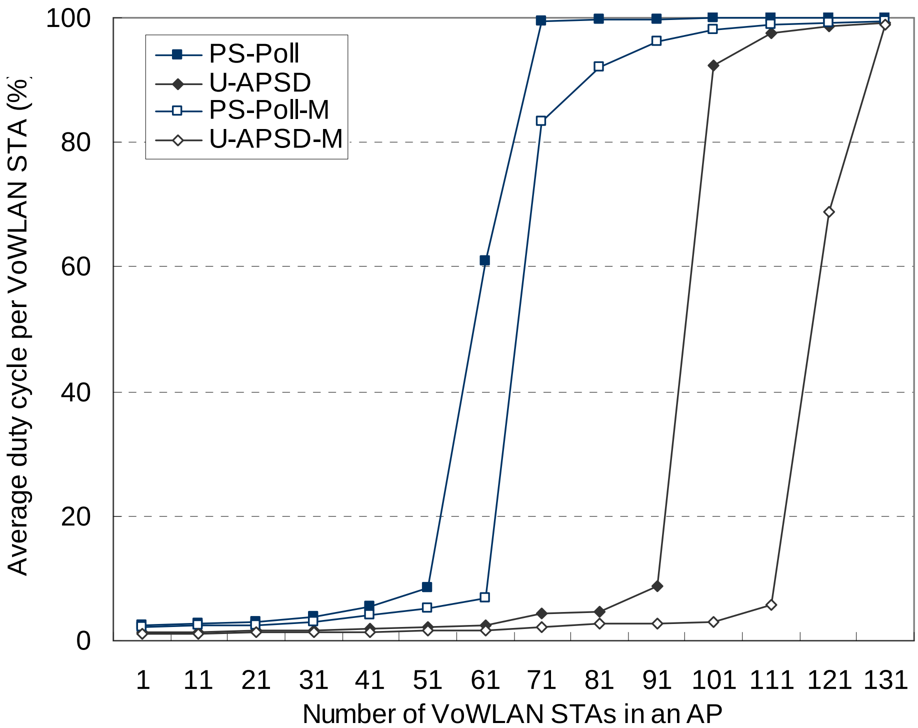


Figure 9. Average duty cycle per VoWALN STA in the IEEE 802.11g environment

Chapter 5. Conclusions

This study presents a cross-layer and energy-efficient transmission mechanism for a VoWLAN system. The mechanism dynamically disables the MAC acknowledgement for each transmission of a voice packet according to the current packet loss rate and the target voice quality, thus reducing the time and the energy consumed by a VoWLAN STA in transmitting and receiving voice packets. Simulation results indicate that the proposed mechanism significantly reduces the energy consumption of a VoWLAN STA, improves the WLAN utilization for transmitting voice packets, and can also guarantee the voice quality. Furthermore, WLAN multicasting is used to transmit voice packets without the MAC acknowledgement, thus enabling the proposed mechanism to be implemented on the existing WLAN infrastructure by software upgrades.

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