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IEEE 802.11 무선랜의 Power Save Multi-Poll 동작의 수학적 성능 분석

(Numerical Analysis of Power Save Multi-poll Operation in IEEE 802.11 WLANs)

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요 약 본 논문에서 802.11 무선랜의 Power Save Multi-Poll (PSMP) 동작에 대한 성능을 수학적으로 분석한다. 수학적 분석을 통하여 우리는 전체 동작 시간 중 전력 소비에 사용되는 시간을 구함으로써 전력 소비 효율을 얻는다. 수학적 분석을 통하여 PSMP 동작의 효율성을 예측할 수 있다.

핵심주제어 : IEEE 802.11 무선랜, 전력 절약, 전력

Abstract In this paper, We Numerically Analyze the Performance of the 802.11 Power Save Multi-Poll (PSMP) Operation. From the Analysis, we have Power Saving Efficiency Indicating how much time is Used for Power Consumption Over the Entire Operation Time. Consequently, we can Estimate the Operational Efficiency of the PSMP Operation.

Key Words : IEEE 802.11 WLANs, Power Save, Power Management.

1. Introduction

In IEEE 802.11 Wireless Local Area Networks (WLANs), STAtions (STAs) with Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) may experience difficulty in achieving satisfactory Quality-of-Service (QoS) for delay-sensitive traffic since CSMA/CA was not designed to guarantee exact timing for packet transmissions. Accordingly, it becomes necessary to develop a new policy for the service. The Power Save Multi-Poll (PSMP) operation was designed to support power saving operation guaranteeing high QoS requirements in the 802.11 WLANs[1]. The Access Points (APs) with the PSMP operation can schedule transmission opportunities for uplink and/or downlink traffic in a centralized manner.

The PSMP operation provides two benefits: (1) the scheduling information of the PSMP is utilized for STAs to power down their transceiver, thus saving power consumption while they are not scheduled to receive/transmit data frames, i.e., packets. (2) The PSMP AP can completely rules the

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schedules considering STAs' QoS requirements without contention based channel access so that it is possible to serve the STAs with highly qualified services.

We numerically analyze the PSMP operation in terms of the power saving efficiency. The power saving efficiency is measured with the power saving factor[2,3]. It is a metric obtained by dividing the time for sleeping by overall operation time. This paper is certainly helpful for the industry since today's WLAN STAs are always suffering from short lifetime due to the limitation of battery capacity including PDAs and smart phones[4]. It is also important to user experiences[5,6]. This paper is organized as follows: in Section II, we explain the detailed PSMP operation, and then, discuss how to manage it. In Section III, we derive the equations regarding the PSMP operation with respect to power saving factor. In Section IV, we show the numerical analysis results and Section V concludes the paper.

2. Power Save Multi-Poll Operation

In the 802.11 WLANs, APs with PSMP operation schedule packet transmission opportunities for the associated STAs in a centralized manner. Fig. 1 shows an example of the PSMP operation. In this figure, the AP transmits initial PSMP frame containing the information regarding STAs' transmission and reception time instances. The initial PSMPs are broadcast periodically in every service period denoted by T_P. The AP and the STAs transmit their frames back to back with Short Inter-Frame Space (SIFS) interval in turn during allowed transmission periods. Thanks to the scheduling information in a PSMP, STAs may power down their transceiver except the duration where they are scheduled to receive and transmit packets, thus reducing power consumption. Additionally, STAs access wireless channel without contention according to the scheduling information in the PSMP so that highly stringent QoS requirements can be successfully provided.

In this figure, random variables t_A, t_I and t_P indicate active, inactive, and PSMP service period. The probability density functions (pdfs) for the random variables are $f_A(t)$, $f_I(t)$ and $f_P(t)$. Random variable $t_S^{(l)}$, where $l \geq 0$, is used to represent each PSMP sequence from initial PSMP sequence. The PSMP AP and the STAs transmit/receive packets during the active period while the STAs power down their transceiver during the sleeping period.

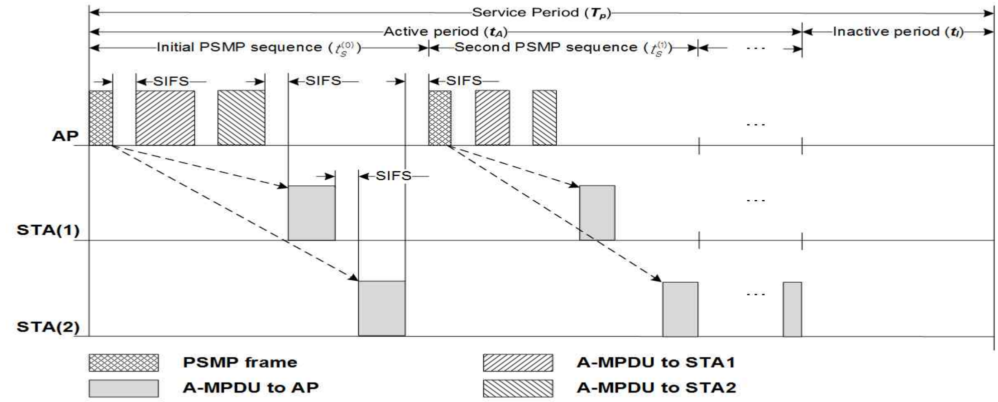

Fig. 1 An example of PSMP Operation.

3. Numerical Analysis

We make several assumptions for our analysis as follows: (1) we consider that there exist N STAs under PSMP operation so that each STA is indexed by n, where 0 ≤ n < N. (2) Random variable $t_X^{(n)}$ represents packet transmission time when the AP sends a packet to STA(n). It follows general distribution. Its pdf and cumulative density function (cdf) are denoted by $f_X^{(n)}(t)$ and $F_X^{(n)}(t)$, respectively. Also, the expectation $E[t_X^{(n)}]$ is simply denoted by $\tau_D^{(n)}$. (3) Packet arrivals destined for STA (n) are exponentially distributed with the expectation of $\lambda_D^{(n)}$. First, we derive the power saving factor indicating the ratio between sleeping time and overall operation time.

Basically, the PSMP AP buffers the packets arriving during inactive period, and then forwards them in the subsequent service period. For this reason, we derive the average number of new packet arrivals destined for STA(n) during inactive period t_I. Since packet arrival intervals are exponentially distributed, it is true that the number of packet arrivals follow Poisson distribution. From this feature, we can define Z transform function $\alpha_D^{(n)}(z)$ of the number of downlink packet arrivals toward STA(n) for random variable t_I by:

$$\begin{aligned}\alpha_D^{(n)}(z) &= \int_0^\infty \sum_{m=0}^{\infty} \frac{(\lambda_D^{(n)}t)^m}{m!} e^{-\lambda_D^{(n)}t} z^m f_I(t)dt \\ &= \int_0^\infty e^{-\lambda_D^{(n)}t} \sum_{m=0}^{\infty} \frac{(\lambda_D^{(n)}tz)^m}{m!} f_I(t)dt \\ &= \int_0^\infty e^{-(\lambda_D^{(n)}-\lambda_D^{(n)}z)t} f_I(t)dt \\ &= F_I^*(\lambda_D^{(n)}-\lambda_D^{(n)}z) \qquad (1)\end{aligned}$$

where $F_I^*(z)$ is the Laplace transform of $f_I(t)$. Since inter-packet arrival intervals are independent, identically distributed (i.i.d.), we have:

$$\alpha_D(z) = \sum_{n=0}^{N-1} \alpha_D^{(n)}(z) = \sum_{n=0}^{N-1} F_I^*(\lambda_D^{(n)} - \lambda_D^{(n)}z). \quad (2)$$

From this equation, we can have the expected number of packets which the PSMP AP buffers at the beginning of active period by:

$$\begin{aligned}-\frac{d\alpha_D(z)}{dz}\Big|_{z=1} &= -\sum_{n=0}^{N-1} \frac{dF_I^*(\lambda_D^{(n)} - \lambda_D^{(n)}z)}{dz}\Big|_{z=1} \\ &= \sum_{n=0}^{N-1} \lambda_D^{(n)} E[t_I]. \qquad (3)\end{aligned}$$

In the same way as Eqs. (1)-(3), we can derive average number of uplink packets toward AP from STAs. Remind that the downlink/uplink packet transmissions toward individual STAs/an AP are spaced with T_{SIFS}, and hence the expectation of initial PSMP sequence is derived by:

$$\begin{aligned}E[t_S^{(0)}] &= \sum_{n=0}^{N-1} \rho_D^{(n)} E[t_I] + \sum_{n=0}^{N-1} \rho_U^{(n)} E[t_I] \\ &\quad + T_{PSMP} + 2(N+1)T_{SIFS} \\ &= \sum_{n=0}^{N-1} \rho^{(n)} E[t_I] + T_C \qquad (4)\end{aligned}$$

where $\rho^{(n)} = \rho_D^{(n)} + \rho_U^{(n)}$ and $T_c = T_{PSMP} + 2(N+1)T_{SIFS}$. From our assumption that the number of packets arriving for $t_S^{(l-1)}$ follows Poisson distribution, we can derive the expected number of packet arrivals at the PSMP AP toward a STA(n) by:

$$\sum_{n=0}^{n-1}\int_{0}^{\infty}\sum_{m=0}^{\infty} m(\frac{(\lambda_D^{(n)}t)^m}{m!})e^{\lambda_D^{(n)}}f_{t_S^{(l-1)}}(t)dt$$
$$=\sum_{n=0}^{N-1}\int_{0}^{\infty}\lambda_D^{(n)}tf_{t_s^{(l-1)}}(t)dt$$
$$=\sum_{n=0}^{N-1}\lambda_D^{(n)}E[t_s^{(l-1)}]=Et_S^{(l-1)}]\,(\sum_{n=0}^{N-1}\lambda_D^{(n)}). \qquad (5)$$

Similarly, we have the average number of uplink packets of STA(n) for lth PSMP sequence by $E[t_S^{(l-1)}](\sum_{n=0}^{N-1}\lambda_U^{(n)})$. From this equation, the expected duration of the lth PSMP sequence is derived by:

$$E[t_S^{(l)}]=E[t_S^{(l-1)}]\sum_{n=0}^{N-1}\rho^{(n)}+Tc$$
$$=E[t_I](\sum_{n=0}^{N-1}\rho^{(n)})^{l+1}+Tc\sum_{i=0}^{l}(\sum_{n=0}^{N-1}\rho^{(n)})^i \qquad (6)$$

In the steady state, the active period is the sum of the PSMP sequences in the service period. However, the number of PSMP sequences depends on how to manage the packets arriving during PSMP sequences. In other words, since the beginning instances for STAs′ uplink and downlink transmissions are announced by each PSMP frame, it is not possible to transmit the packets arriving during ongoing transmission times immediately after the completion of ongoing packet transmissions. For this reason, two options remain, i.e., we can defer the packet transmissions for the packets arriving during a PSMP sequence until its subsequent PSMP sequence or its next service period. In either case, letting L be the number of total PSMP sequences for the service period in the steady state, the average active period $E[t_A]$ is obtained by:

$$E[t_A]=\sum_{l=0}^{L=1}E[t_s^{(l)}]. \qquad (7)$$

From the PSMP operation, it is always satisfied that $T_P=t_A+t_I$ so that we can have $E[T_P]=E[t_A]+E[t_I]$. From this equation and Eq. (7), we can rearrange $E[T_P]$ by:

$$E[T_P]=E[t_{A]}+E[t_I]$$
$$=\sum_{l=0}^{L-1}E[t_S^{(l)}]+E[t_I]$$
$$=E[t_I](1+\sum_{l=0}^{L-1}(\sum_{n=0}^{N-1}\rho^{(n)})^{l+1})+$$
$$T_c\sum_{l=0}^{L-1}\sum_{i=0}^{l}(\sum_{n=0}^{N-1}\rho^{(n)})^i \qquad (8)$$

From this equation, we have $E[t_I]$ and $E[t_A]$ by:

$$E[t_i]=\frac{T_P-T_c\sum_{l=0}^{L-1}\sum_{i=0}^{l}(\sum_{n=0}^{N-1}\rho^{(n)})^i}{1+\sum_{l=0}^{L-1}(\sum_{n=0}^{N-1}\rho^{(n)})^{l+1}}, \qquad (9)$$
$$E[t_A]=\frac{T_P-T_c\sum_{l=0}^{L-1}\sum_{i=0}^{l}(\sum_{n=0}^{N-1}\rho^{(n)})^i}{\sum_{l=0}^{L-1}(\sum_{n=0}^{N-1}\rho^{(n)})^{l+1}}, \qquad (10)$$

Each PSMP STA does not need to stay awake while other PSMP STAs are receiving buffered packets. For this reason, our concern should be the power saving factor for each STA. In initial PSMP sequence, STA(n) stays awake to receive the buffered packets during $E[t_I]$. From Eq.(4), the average time duration, in which STA(n) should be awake for the packet receptions, is derived by $\rho^{(n)}E[t_I]$. In the second PSMP sequence, the average awake time duration is given by $\rho^{(n)}E[t_S^{(0)}]$. Therefore, we have the STA(n)′s average awake time in lth PSMP sequence by

$\rho^{(n)}E[t_S^{(l-1)}]$. In this way, we derive the overall average awake time for the STA(n) by $\rho^{(n)}(E[t_I)+\sum_{l=0}^{L-1}E[t_S^{(l)}])$. From Eqs. (6), (8), and (9), the power saving factor for the STA(n) is finally derived by:

$$\frac{\rho^{(n)}(E[t_I])+\sum_{l=0}^{L-1}E[t_S^{(l)}])}{E[T_P]} \qquad (11)$$

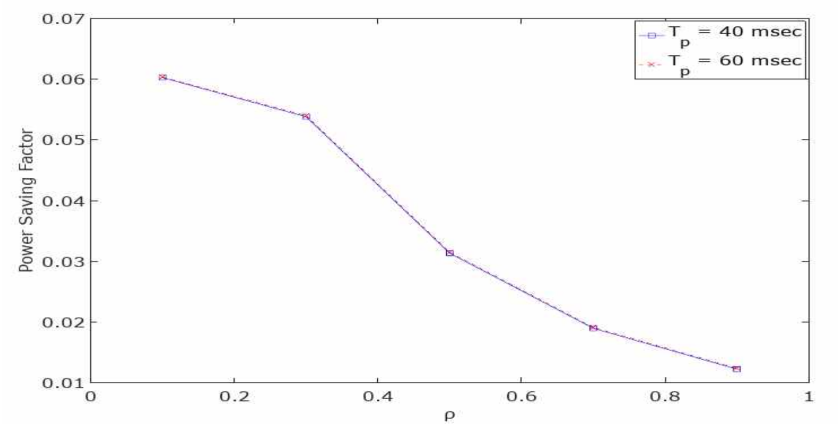

Fig. 2 Performance evaluation results.

4. Performance Evaluation

Table 1 Parameters

Parameter	value	Parameter	value
N	5	SIFS time	10 μs
L	3	DIFS time	34 μs

We evaluate the performance of the PSM according the Eq. (11). For our evaluation, we set the parameter values shown Table 1. Fig. 2 shows the analytical results depending on Tp. In this figure we can recognize that the power saving factor decreases depending on the offered load since AP should stay awake in order to send traffic in proportion to the load. However, there are slight differences according to different T_P values. Overall, we can observe PSMP efficiency is not so good due to the fact that the power saving factor is not better than 0.1. Nevertheless, the PSMP can be useful for other STAs, which do not attend the PSMP operation, since they can have the exact scheduling information regarding how long time they can sleep.

5. Conclusions

We have numerically analyzed the power saving efficiency of the PSMP operation by introducing power saving factor. In future, we will continue to validate our numerical analysis by comparing simulation results for more concrete analysis.

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