# Performance Analysis of IEEE 802.11 IBSS Power Save Mode using a Discrete-Time Markov Model

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## ABSTRACT

The power management algorithm in the IEEE 802.11 standard for Independent Basic Service Set (IBSS) mode is an important field of research for power constrained wireless devices. This paper presents an overall analysis of a data frame transmission together with the corresponding ATIM frame transmission using a Markov chain model. The impact of network size on the throughput of the IEEE 802.11 DCF in Power Save Mode (PSM) is analysed and the theoretical results are validated using simulation.

**Categories and Subject Descriptors:** C.2.1[Network Architecture and Design]: Wireless communication

**General Terms:** Performance

**Keywords:** Markov model, PSM, ATIM frame, throughput analysis

## 1. INTRODUCTION

The IEEE 802.11 standard [2] defines the PSM scheme to manage power using ATIM-BI cycle. Several medium access control (MAC) protocols [4, 3] have been designed for wireless LANs to further improve the power consumption over standard algorithms. Zheng *et al.* [7] propose an analytical study of the IEEE 802.11 power save mode using the transient analysis techniques. The ATIM frame and data frame transmission depend on the CSMA/CA mechanism specified in the IEEE 802.11 DCF [2]. The analysis depends on the assumption of packet arrival rate, which is highly dynamic in real environments. To the best of our knowledge, the performance analysis of data communication in IBSS PSM using Markov model is not available in existing literature. In our earlier paper [6], a discrete time Markov model was presented to calculate the probability that an ATIM frame is transmitted successfully. In this paper, the work in [6] is extended by combining the analysis of the ATIM window and data window transmission as a whole. The analytical work is also verified with simulation results.



## 2. MODELING AND ANALYSIS

The network under consideration has $n$ number of stations with every station having backlog data. In 802.11 PSM the time is divided in beacon intervals. Every beacon interval is divided in ATIM window and data window. The stations that have successfully transmitted an ATIM frame within the ATIM window compete to transmit a data frame in the rest of the beacon interval. If a station is unable to transmit an ATIM frame during the ATIM window, e.g., due to contention with another station or ending of the ATIM window, the data frame is buffered and an attempt is made to transmit an ATIM frame during the next ATIM window. A station may discard data frames which are buffered for an excessive amount of time. It may be noted that in the IEEE 802.11 standard [2] neither the retry limit nor the condition for discarding the ATIM frame have been specified. However, the paper [3] defined the retry limit of three for an ATIM frame transmission within an ATIM window and up to three BIs. Similarly, the data frames can be dropped if the retry limit is exceeded for data transmission. In [7] the authors have explained by theoretical analysis and simulation results that a single data window is sufficient to successfully transmit a data frame after transmitting an ATIM frame successfully in the ATIM window.

Consider stochastic processes $s(t)$ representing the backoff stage, $b(t)$ representing the backoff counter and $a(t)$ representing the backoff layer (the beacon interval number counting down from 2 to 0) at time $t$. A discrete time Markov model for data transmission in PSM is presented in Fig. 1. The state $(G)$ is a dummy state. In Fig. 1, $p_a$ and $p_d$ are conditional collision probabilities in the ATIM window and data window, respectively. Assume that $q_a$ is the probability that the ATIM window ends when a station is attempting to transmit an ATIM frame. Similarly $q_d$ is the probability that the data window ends while an attempt to transmit a data frame is going on.

### 2.1 Model analysis

Let $b^{'}_{i,j,k}$ and $b^{''}_{i,j}$ be the stationary distributions of the Markov chain for the ATIM and data windows, respectively. To obtain a closed-form solutions for the Markov chain presented in Fig. 1, iterative equation (3) and equation (4) are

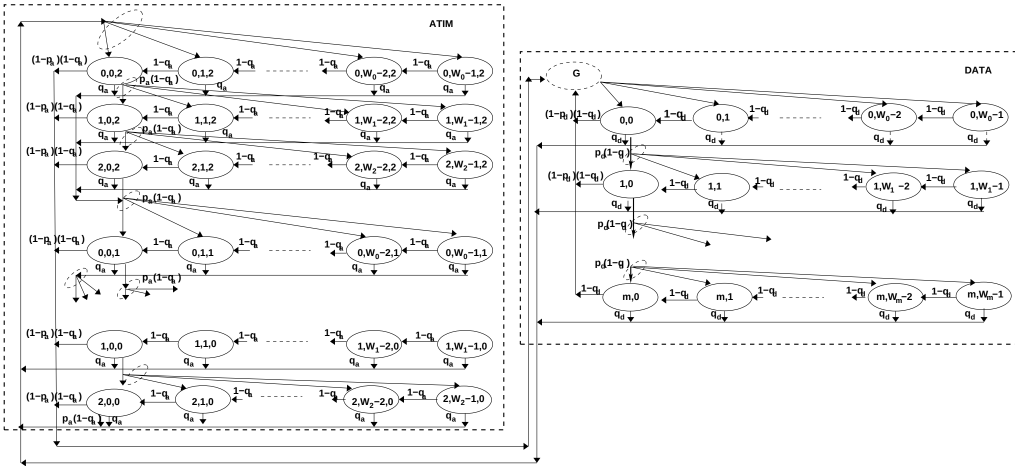


**Figure 1: Markov model for data frame transmission in power save mode.**

$$b^{'}_{i,j,k} = \begin{cases} q_d \sum_{i=0}^{m} \sum_{j=1}^{W_i-1} b^{''}_{m,j} + q_a \sum_{i=0}^{2} b^{'}_{i,0,0} + p_a(1-q_a) b^{'}_{2,0,0}, & i=0, j=W_0-1, k=2; \\ q_d \sum_{i=0}^{m} \sum_{j=1}^{W_i-1} b^{''}_{m,j} + q_a \sum_{i=0}^{2} b^{'}_{i,0,0} + p_a(1-q_a) b^{'}_{2,0,0} \times \sum_{l=0}^{W_0-(j+1)} (1-q)^l, & i=0, j\in[0,W_0-2], k=2; \\ \frac{1}{W_i}[p_a(1-q_a) b^{'}_{2,0,k+1} + \sum_{i=0}^{2} \sum_{j=0}^{W_i-1} b^{'}_{i,j,k+1}], & i=0, j=W_0-1, k\in[0,1]; \\ \frac{1}{W_i}[p_a(1-q_a) b^{'}_{2,0,k+1} + \sum_{i=0}^{2} \sum_{j=0}^{W_i-1} b^{'}_{i,j,k+1}] \times \sum_{l=0}^{W_0-(j+1)} (1-q)^l, & i=0, j\in[0,W_0-2], k\in[0,1]; \\ \frac{p_a(1-q_a)}{W_i} \times \sum_{l=0}^{W_i-(j+1)} (1-q_a)^l b^{'}_{i-1,0,a}, & i\in[1,2], j\in[0,W_i-1], \\ & k\in[0,2] \end{cases} \tag{1}$$

$$b^{''}_{i,j} = \begin{cases} \frac{1}{W_0}[(1-p_a)(1-q_a) \sum_{k=0}^{2} \sum_{i=0}^{2} b^{'}_{i,0,k} + \\ (1-p_d)(1-q_d) \sum_{i=0}^{m-1} b^{''}_{i,0} + (1-q_a) b^{''}_{m,0}], & i=0, j=W_0-1; \\ \frac{1}{W_0}[(1-p_a)(1-q_a) \sum_{k=0}^{2} \sum_{i=0}^{2} b^{'}_{i,0,k} + \\ (1-p_d)(1-q_d) \sum_{i=0}^{m-1} b^{''}_{i,0} + (1-q_a) b^{''}_{m,0}] \times \sum_{l=0}^{W_0-(j+1)} (1-q)^j, & i=0, j\in[0,W_0-2]; \\ \frac{p_d(1-q_d)}{W_i} \times \sum_{l=0}^{W_i-(j+1)} (1-q_d)^l b^{''}_{i-1,0}, & i\in[1,m], j\in[0,W_i-1], \end{cases} \tag{2}$$

used,

$$b^{'}_{i,0,k} = \frac{p_a(1-q_a)}{W_i} \sum_{l=0}^{W_i-1} (1-q_a)^l b^{'}_{i-1,0,k} \quad 0 < i \le 2 \tag{3}$$

$$b^{''}_{i,0} = \frac{p_d(1-q_d)}{W_i} \sum_{l=0}^{W_i-1} (1-q_d)^l b^{''}_{i-1,0} \quad 0 < i \le m \tag{4}$$

Considering this as a regular chain, for each $j \in [0, W_i - 1]$ and $k \in [0, 2]$, equation (1) and equation (2) can be derived.

Let $\tau_a$ be the probability that a station transmits an ATIM frame in a randomly chosen slot, which can be derived as,

$$\tau_a = \sum_{i=0}^{2} \sum_{k=0}^{2} b^{'}_{i,0,k} \tag{5}$$

Accordingly, the relation between $p_a$ and $\tau_a$ can be written as,

$$p_a = 1 - (1-\tau_a)^{(n-1)}. \tag{6}$$

where $n$ is the number of stations in a network. The value of $\tau_a$, $p_a$ can be solved numerically using fixed point iteration on equation ( 5) and equation (6). The probability of successful transmission of an ATIM frame, $P_{as}$, can be calculated as,

$$P_{as} = \frac{n\tau_a(1-\tau_a)^{(n-1)}}{1-(1-\tau_a)^n}. \tag{7}$$

Similarly, the probability of successful transmission of data frame in the data window, $\tau_d$, can be represented as:

$$\tau_d = \sum_{i=0}^{m} b^{''}_{i,0} \tag{8}$$

The quantity $n \times P_{as}$ denotes the expected number of active communication pairs in the data window after the completion of the ATIM window. Accordingly, the relation between $p_d$ and $\tau_d$ is

$$p_d = 1 - (1-\tau_d)^{(n \times P_{as}-1)}. \tag{9}$$

Let $P_{tr}$ be the probability that there is at least one data frame transmission in the considered slot. $P_{ds}$ denotes the probability of successful transmission of a data frame. $P_{tr}$ and $P_{ds}$ are joint probability values given by,

$$P_{tr} = 1 - (1-\tau_d)^{n \times P_{as}} \tag{10}$$

$$P_{ds} = \frac{n \times P_{as}\tau_d(1-\tau_d)^{(n \times P_{as}-1)}}{P_{tr}}. \tag{11}$$

The normalized system throughput, $S$, can be written as,

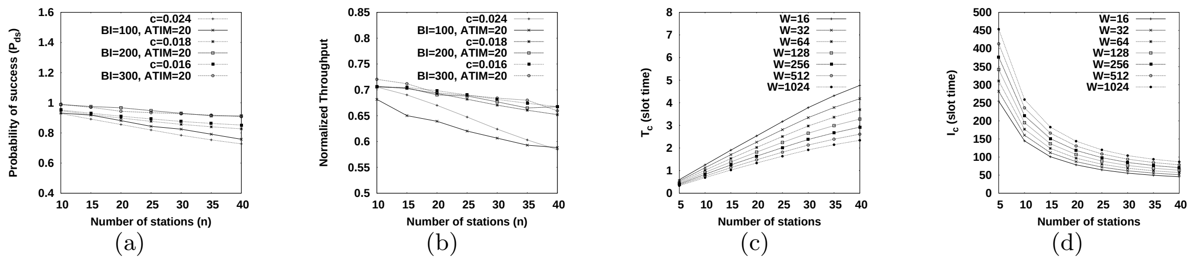


**Figure 2: (a)Conditional probability of success for data frame transmission, (b)Throughput of 802.11 PSM for different node sizes,(c)Average number of slot times wasted in packet collision ($T_c$), per successful packet transmission,(d)Average number of idle slot times per successful packet transmission ($I_c$8)**

$$S = \frac{P_{ds} P_{tr} E[p]}{(1 - P_{tr})\sigma + P_{ds} P_{tr} T_s + (1 - P_{ds}) P_{tr} T_c}.$$

Where $E[p] = P$ is the average payload, $T_s$ and $T_c$ are the average time the channel is used for successful transmission or a collision respectively, and $\sigma$ is the idle slot time.

# 3. SIMULATION RESULT AND ANALYSIS

The proposed theoretical model is validated using simulation results obtained from Qualnet 5.0.1 network simulator [5]. All stations are assumed to be within single hop distance. The throughput for the basic access in IEEE 802.11 DCF in power save mode is calculated under the Direct Sequence Spread Spectrum (DSSS) physical layer [2].

As the ATIM window size is smaller than the data window (normally the ATIM window size is 20ms for maximum performance [4]), the value of $q_a$ can be considered as a constant. In this paper, $q_a$ is assumed to be 0.002. The probability $q_d$ depends on number of active stations in data window. Considering number of active stations in data window is proportional to $n \times P_{as}$, we can assume,

$$q_d = c \times n \times P_{as} \tag{12}$$

where $c$ is the proportionality constant. The value of $c$ depends on the size of the data window.

Fig. 2(a) shows the probability of successful transmission of a data frame after successfully transmitting an ATIM frame against the number of nodes. Fig. 2(b) presents the throughput against the number of nodes. From the figures, it can be noted that for a particular set of ATIM, data window and $c$, the simulation results are at par with the theoretical results.

It can also be noted that the throughput obtained from the proposed model is marginally less than the one obtained from Bianchi's model [1], whereas the probability of success is very high. This is because of the ATIM window overhead in IEEE 802.11 PSM which is not considered in Bianchi's analysis. This justification is given in Fig. 2(c) and Fig. 2(d) that show the theoretical analysis obtained using $q_d = 0.018 \times n \times P_{as}$. Fig. 2(c) presents the average number of slot times wasted in packet collision per successful packet transmission in data window, for different values of contention window. This graph shows that the channel time wasted due to collision in data window is very low compared to the results obtained in Bianchi's analysis [1].

The average number of idle slots per successful packet transmission is more than in Bianchi's analysis [1], as shown in Fig. 2(d). This is because of the overhead due to ATIM transmission. The nodes which cannot send ATIM frames successfully in the ATIM window, have to stay idle for the rest of the beacon interval, which increases the average number of idle slots per successful packet transmission. This increase in the idle channel time impacts total network throughput, and the network throughput degrades in case of IEEE 802.11 DCF in power save mode.

# 4. CONCLUSIONS

An analytical model based on a Markov chain is presented in this paper for the transmission of ATIM and data frames in IEEE 802.11 DCF power save mode. The success probability of a data frame, following the successful transmission of an ATIM frame is used to calculate the throughput of the IEEE 802.11 DCF in power save mode. Simulation results justify the theoretical analysis.

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