802.11 WLAN MAC Layer Modeling

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Abstract

In the standardized 802.11 protocol for Wireless Local Area Networks by the IEEE, an interesting and very useful model arises. This EO Markov Model [1]. incorporates as its primary medium access control (MAC) technique, the distribution coordination function (DCF). In this report, we consider a revised version of this EO Markov Model, investigate it analytically and graphically. We also concentrate on the role of certain principal parameters on the system efficiency, exploring the interrelationships with other model parameters through simulations and validating these results with network simulation realizations from the NS2 Network Simulator.

1. Introduction

As technology becomes more integrated into our daily lives, much more research effort and involvement are further required and fostered/encouraged. Thus, relevant applications utilizing a wireless network framework such as the recently engineered Voice Over Internet Protocol (VOIP) to the older and more common employments in the basic wireless internet access now demand greater introspection into the models on which they are based. A general representation of a network system is given in the figure below

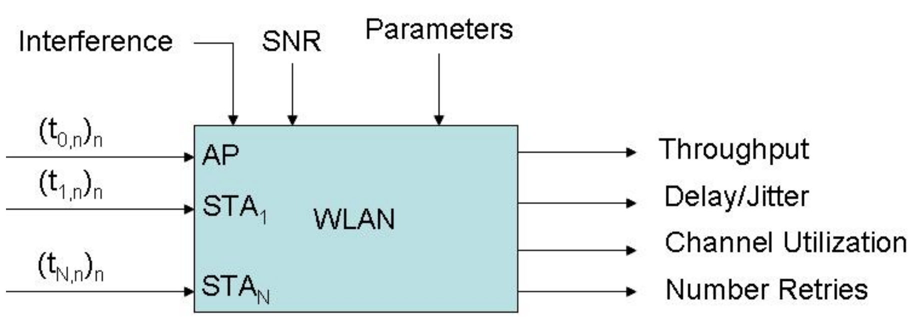

Figure 1: General representation

The above figure describes a universal structure of a network model with a single Access Point (AP) and several Stations on which we focus in this report. Here $(t_{i,j})_j$ represents the arrival times of information packet j in to station i (with the AP standardized as station 0). Similar to any multi-unit system, we expect some sort of communication or correspondence between the different stations given by the Interference through the wireless local area network (WLAN). The bottom two layers of a WLAN device consist of a MAC layer and a Physical layer and their performance are defined by the Signal Noise Ratio (SNR) and a set of other parameters. The overall performance of such a system is governed by measurements such as its Throughput, Delay/Jitter, Channel Utilization (Average busy medium time), Service time and Number of retries to name a few.

2. Previous Work - Midterm Work

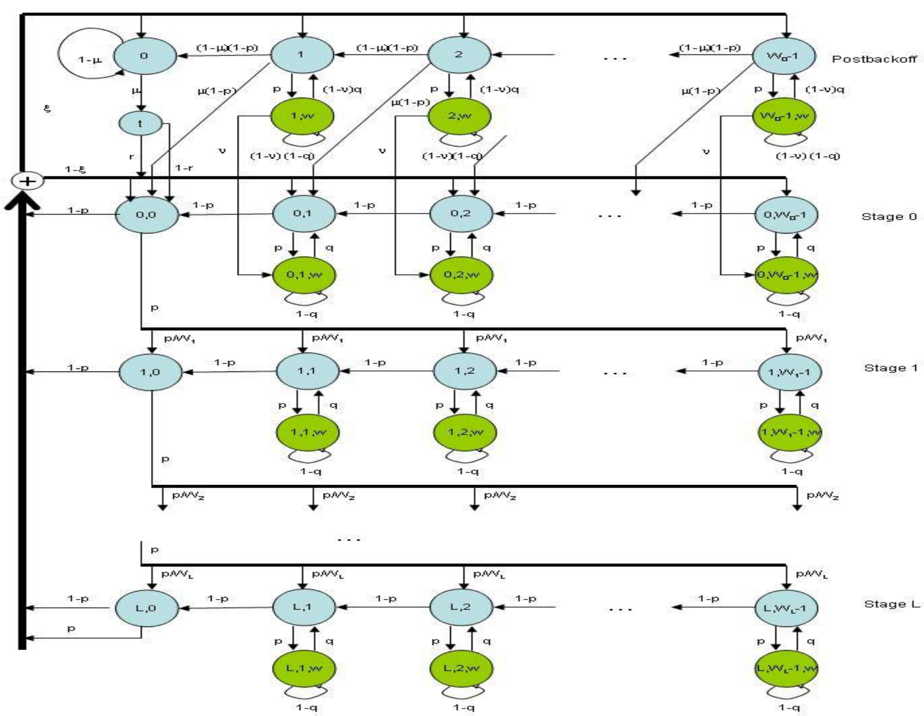

Figure 2: Transition state diagram

We commence our analysis by examining the transition state diagram of the modified EO Markov model given in Figure 2. The possible states here are: (b, k), (b, k, w), (k) and (k, w). The value of b is representative of the stage (i.e. the current number of retries). At each packet transmission, the back-off time k is a random integer generated uniformly between $(0, W_b - 1)$. W is called the contention window whose value depends on the number of retries. At the first transmission attempt, W_0 is set to CW_{min}, the minimum contention window. After each unsuccessful transmission attempt, W is doubled up to the correspondingly maximum contention window CW_{max}. On the other hand L denotes the maximum number of retries permitted. [2]. Finally, w is indicative of the waiting state.

The transmitting probabilities portrayed in the state diagram are defined as follows:

p = Prob(Unsuccessful transmission)

q = Prob(Medium is free during waiting time)

r = Prob(Medium busy during DIFS while in state t)

μ = Prob(A packet arrives during a slot time)

ν = Prob(Packet arrival during the waiting time)

ξ = Prob(Empty MAC Queue at the end of a transmission)

An example of the simulation of the above model is shown in Figure 3a and Figure 3b. Figure 3a portrays the activities in the Application, MAC as well as the Physical layers of a station. Whereas Figure 3b shows the corresponding state of affairs in the AP.

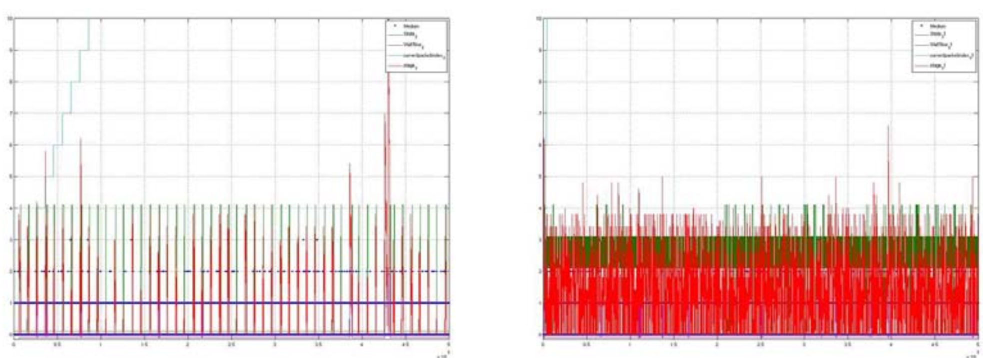

Figure 3: An Example of simulations for a station and the AP respectively

2.1. Theoretical Analysis

Let us consider the equilibrium stationary probabilities of states (b, k), (b, k, w), (k) and (k, w) corresponding to $\pi_{b,k}$, $\pi_{b,k,w}$, π_k and $\pi_{k,w}$.

Given the sub-diagram of the transition state diagram below,

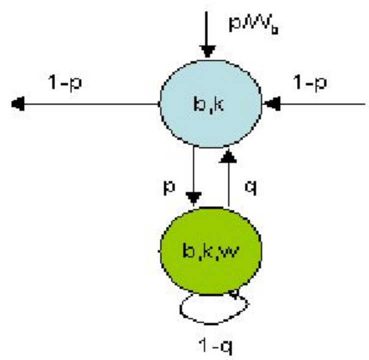

Figure 4: Sub transition diagram

$$\pi_{b,k} = \frac{p}{W_b}\pi_{b-1,0} + (1-p)\pi_{b,k+1} + q\pi_{b,k,w} \quad \text{, where} \quad 1 \le b \le L; 1 \le k \le W_b - 1$$

$$\pi_{b,k,w} \;=\; p\pi_{b,k} + (1-q)\pi_{b,k,w} \quad \text{, where} \quad 1 \le b \le L; 0 \le k \le W_b - 1$$

Where by convention, $\pi_{b,W_b} = 0$

In the case where $k = W_b - 1$, we get

$$\pi_{b,k} = \frac{p}{W_b}\pi_{b-1,0} + q\pi_{b,k,w}$$

From the above equations, we can solve recursively to get:

$$\pi_{b,k,w} = \frac{p}{q}\pi_{b,k}$$

In a similar sense we can derive all other stationary probabilities of the respective states.

$$\pi_{b,k} = \frac{(W_b - k)p}{W_b(1-p)}\pi_{b-1,0}$$

$$\begin{aligned} \Rightarrow \pi_{b,0} &= (W_b - 1 + 1)\frac{p}{W_b}\pi_{b-1,0} \\ &= p^2\pi_{b-2,0} \\ &\vdots \\ &= p^b\pi_{0,0} \end{aligned}$$

If $\pi_{0,0} = x$, then

$$\pi_{b,0} = p^b x$$

$$\pi_{b,k,w} = \frac{p}{q}\pi_{b,k}$$

$$\pi_{b,k} = \frac{(W_b - k)}{W_b}\frac{p}{(1-p)}p^{b-1}x$$

Now in the Postbackoff stage,

Let π_s be the stationary probability of $\bigoplus$, if we consider $\bigoplus$ a state s.

$$\begin{aligned} \pi_s &= (1-p)x + (1-p)px + \ldots + (1-p)p^L x + pp^L x \\ &= (1-p^{L+1})x + p^{L+1}x \\ &= x \end{aligned}$$

By similar analysis of the state diagram,

$$\pi_k = \frac{\xi}{W_0}\pi_s + (1-\mu)(1-p)\pi_{k+1} + q(1-\nu)\pi_{k,w}$$

$$\pi_{k,w} = p\pi_k + (1-\nu)(1-q)\pi_{k,w}$$

$$\Rightarrow \pi_{k,w} = \frac{p}{1-(1-\nu)(1-q)}\pi_k$$

So,

$$\left[1 - \frac{q(1-\nu)p}{1-(1-\nu)(1-q)}\right]\pi_k \;=\; \frac{\xi}{W_0}x + (1-\mu)(1-p)\pi_{k+1}$$

$$\Rightarrow \pi_k = \frac{1-(1-\nu)(1-q)}{1-(1-\nu)(1-q+pq)}\frac{\xi}{W_0}x + \frac{1-(1-\nu)(1-q)}{1-(1-\nu)(1-q+pq)}(1-\mu)(1-p)\pi_{k+1}$$

Let

$$\alpha = \frac{1-(1-\nu)(1-q)}{1-(1-\nu)(1-q+pq)}\frac{\xi}{W_0}$$

and

$$\beta = \frac{1-(1-\nu)(1-q)}{1-(1-\nu)(1-q+pq)}(1-\mu)(1-p)$$

Then

$$\pi_k = \alpha x + \beta\pi_{k+1}$$

Given $\pi_k = c_k x$

$\Rightarrow c_k x = \alpha x + \beta c_{k+1} x$

$\Rightarrow c_k = \alpha + \beta c_{k+1}$

$\Rightarrow c_{W_0-1} = \alpha + \alpha\beta = \alpha(1+\beta)$

$\vdots$

$\Rightarrow c_{W_0-k} = \alpha(1+\beta+\ldots+\beta^{k-1}) = \alpha\frac{1-\beta^k}{1-\beta}$

Thus we have,

$$\pi_k \;=\; \alpha\frac{1-\beta^{W_0-k}}{1-\beta}x$$

$$\pi_{k,w} = \frac{p}{1-(1-\mu)(1-q)}\pi_k$$

Since

$$1 \equiv \sum_{\text{state}} \pi_{\text{state}}$$

and

$$\pi_{\text{state}} = c(\text{state}, \mu, \nu, \xi, p, q, r)x$$

we obtain the $\pi_{0,0}$:

$$x = \frac{1}{\sum_{\text{state}} c(\text{state}, \mu, \nu, \xi, p, q, r)}$$

Then we get all the long term probabilities.

In addition from the transition state diagram, we can see that:

Prob [packet dropped due to collision] $= p^{L+1}$

and also,

Exact # of retries	0	1	2	...	b	...	L
Probability	$1-p$	$p(1-p)$	$p^2(1-p)$	...	$p^b(1-p)$	...	$p^L(1-p)+p^Lp$

$\Rightarrow$ Avg # of retries = $\frac{p}{1-p}(1-p^L)$

3. Results

In this section we consider the simulations performed on the model developed on MATLAB and that processed on the real network simulator, NS2. We coded our prescribed model in MATLAB, considering the models allowing for one and two number of retries respectively. In addition, we also separate the statistics of the data generated for the stations form the Access Point. We expected the results of the average number of retries and the probability of a packet dropped due to collision to verify our theoretical derivations in the previous section. Whereas for the coding performed in NS2, we conformed the network simulator by scripts to a set of parameters that correspond to our theoretical model and generate trace files. This NS2 generates two main types of trace files: output.tr which records progress in the model and output.nam which monitors the progress in order to generate an animation of the system. These trace files are then read and analyzed to generate results we hope to match our theoretically derived ones.

3.1. Results of Model Simulations in MATLAB

Here, we keep track of the sum of the number of packets dropped by collision, the total number of packets successfully transmitted and the number of times each packet was tried to be retransmitted (i.e. number of retries). Then the Probability of a packet being dropped due to collision can be calculated as:

$$\frac{\text{total number of packets dropped by collision}}{\text{total number of packets dropped by collision} + \text{total number of packets successfully transmitted}}$$

Similarly, Average number of retries $=$

$$\frac{\text{total number of retries} + \text{total number of packets dropped by collision}}{\text{total number of packets dropped by collision} + \text{total number of packets successfully transmitted}}$$

After iterating the simulation about 50 times and averaging the statistics, we get Figure 5.

Figure 5 below(where for $L = 1$ i.e. when one retry is allowed) shows the correlation between the probability of unsuccessful transmission between the stations and the AP. Note however that when the number of retries increased to two (L = 2), the unsuccessful transmission probability dropped from the case with L = 1 for the stations while that of the AP remains roughly the same. This can be explained by the fact that since the AP tends to be quite more busy in terms of the transmission it has to do, the number of retries increase by one has no visible increase in the likelihood of success and as such, the probability remains about the same.

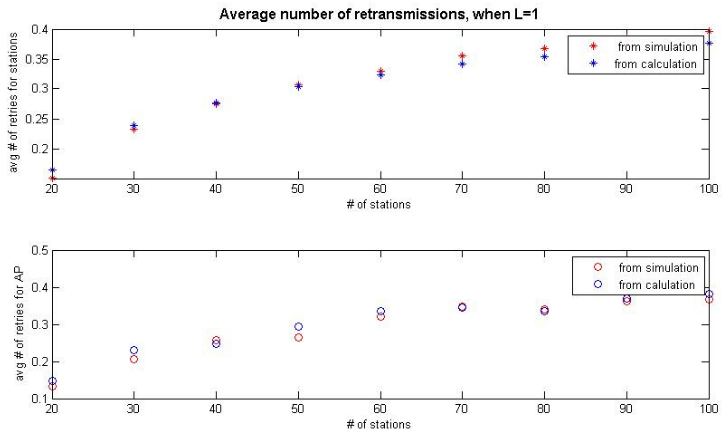

Figure 5: Results of p
(interarrival packet time = 10ms , simulation time = 500 ms, slot time = 20ms)

From the graphs below, we see that our results do indeed match those developed theoretically.

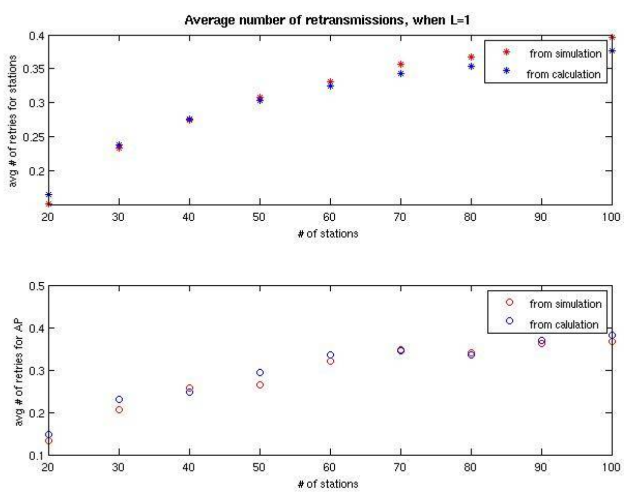

Figure 6: Results of Ave number of retries

3.2. Results of Model Simulation on NS2

The NS2 simulation produces two trace files output.tr and output.nam as previously mentioned. We can use the contents of both files to determine some of the parameters in which we are interested. However, we concentrate here on the output.tr file since it is more detailed. Similar to the MATLAB implemented Markov model in the previous section, we aim to find the parameters p as well as compare the computed average number of retries with that found through simulation. Additionally, we compute the probability that the medium is busy.

In examining the output.tr file, we note that each row of the file corresponds to an event that took place in the simulation and contains over twenty entries describing various aspects of that action. Due to the fact that many of the entries are not relevant for our calculations, we extract the appropriate data. We note that each event involves a packet with a unique packet id -Ii, and each event type is labeled s, r, or d, representing send, receive, or drop respectively. Following the event type in the output.tr file is -t and the time the event began. Furthermore, we observe the node id (represented by -Ni) from which the event is initiated.

The source of the packet and its destination, which are preceded by -Is and -Id, remain unchanged throughout all events that include the unique packet. Also, following -Nl, the output.tr file reveals whether the event is taking place at the level of the agent or the MAC by noting AGT or MAC respectively. We parse this data by first considering all events related to a single packet. From this, we are able to determine the number of retries the packet attempted, whether the packet was dropped from the system as well as whether that was due to collision or overflow.

Figure 7 depicts the results from simulation and verifies the validity of the theoretical results. For this particular case since $L = 1$,$A = \frac{p}{1-p}(1 - p^L)$, hence, $A = p$ where p is the probability of unsuccessful transmission of a packet.

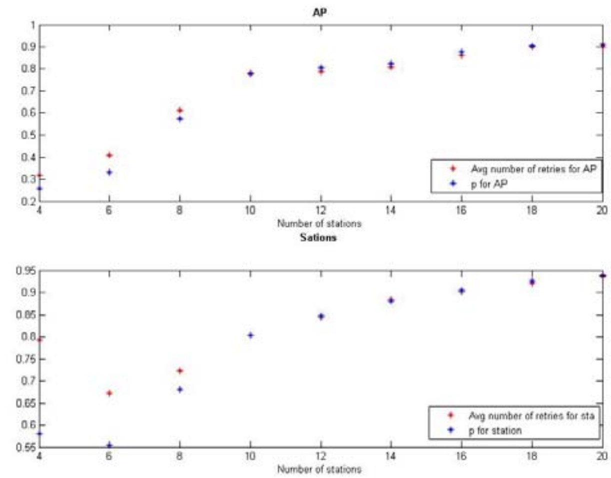

Figure 7: Results of p for AP and stations

The above results hold under a strong assumption of periodicity and synchronization i.e. when all the stations and AP are offset at the same time. But if AP is set to start at a different time than the stations, the Markov model is no longer valid and so the results do not follow the derived mathematical formula.

Figure 8 depicts the average number of retries for the AP for varying period and offset time.It is evident that the Average no of retries do not follow any pattern as they did earlier .

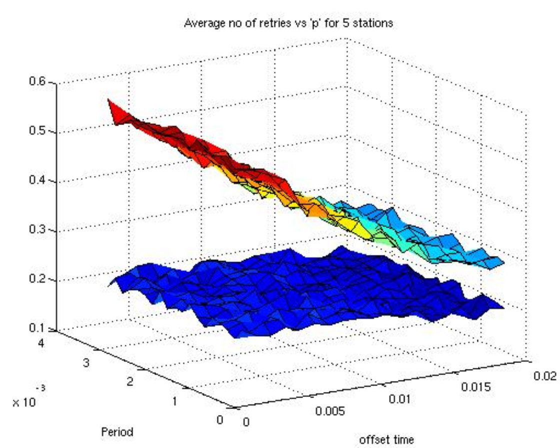

Figure 8: Result of average number of retransmissions

The next figure depicts the average number of retries for stations with varying period and offset time. It is clearly indicated that as the offset time increases the number of retries reduces suggesting less collision and hence a more effective system where the rate of success is higher. A comparison of the two values (Average number of retries and 'p'(for stations)) show that the Markov model breaks down under asynchronization. Hence, changing the offset times is more efficient in reducing the number of collisions in real world network than adjusting the transmission rates.

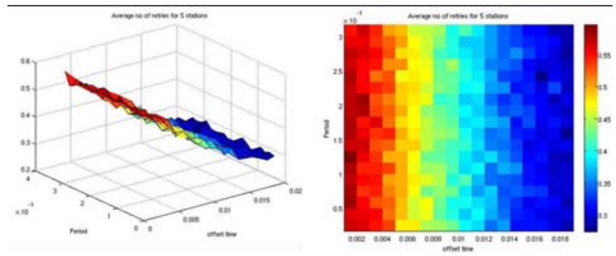

Figure 9: Results of p for AP and stations

Observe from Figure 10 that there is a local maximum for the busy time of medium at a critical point of the number of stations. The number of packets put on the air for transmission increases with the number of stations up until that critical point. Thereafter, the number of stations surpasses the critical point and the medium becomes overwhelmed by the heavy load. Hence, there are more packets dropped than transmitted and so the medium service time decreases. This simulation result matches that of the "real world" performance of a wireless network. Using NS2, we can then simulate the model with one AP station and calculate the number of stations to optimize the system.

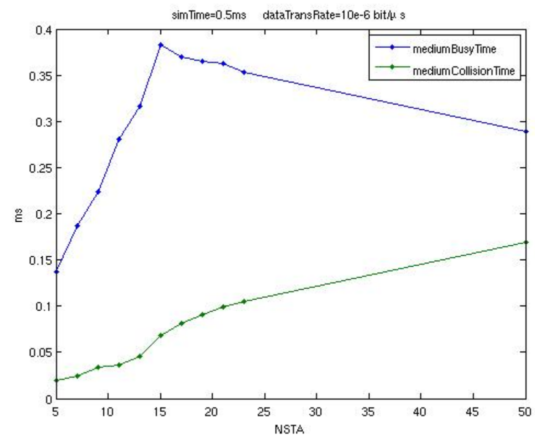

Figure 10: Medium Busyness

4. Summary and Conclusions

We have thus analyzed a modified Markov model (extended from the simple Markov model to include the AIFS mechanism) to compute some basic parameters.The model assumes a finite number of terminals and ideal channel conditions. Analytical results having been compared with the simulation results, show that the Markov model is accurate in predicting the parameters. The asynchronous case with different offset times and different periods is also explored to check for its effect on the average number of retries for AP and the stations. Whence, we conclude that changing the offset time is a good way to reduce the number of collisions.

We also noticed that for simulations with a larger number of stations, the Markov model corresponds to our observations whereas, utilizing a small number of stations in the simulations produce results which tend not be as consistent from what we expect of the the model. This discrepancy is visible in the data derived in the calculations of the collision probability and the average number of retries in the simulations. Moreover such variation reasoning is common during stochastic modeling.

Nevertheless, it is important to note that indeed the 802.11 protocol does sometimes exhibit some forms of instability (saturation)evident while monitoring the throughput value which usually grows until it reaches this value and then starts to decline [3, 4]. Such occurrence is portrayed in Figure 9.

Further work in this area might take the route of analyzing the average service and average wait times from data in the trace output files. In addition, a relationship between these mentioned times would be of interest as well as computation of the through put/delay of such a system. Alternatively, comparing the results for the analytic and simulated model with a configuration of different packet arrival configurations would be of great interest. In fact, the possibilities of further work abound including a possible introduction of a deterministic model for the network.

Acknowledgments

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