A QUANTITATIVE ANALYSIS OF HANDOVER TIME AT MAC LAYER FOR WIRELESS MOBILE NETWORKS

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ABSTRACT

Extensive studies have been carried out for reducing the handover time of wireless mobile network at medium access control (MAC) layer. However, none of them show the impact of reduced handover time on the overall performance of wireless mobile networks. This paper presents a quantitative analysis to show the impact of reduced handover time on the performance of wireless mobile networks. The proposed quantitative model incorporates many critical performance parameters involve in reducing the handover time for wireless mobile networks. In addition, we analyze the use of active scanning technique with comparatively shorter beacon interval time in a handoff process. Our experiments verify that the active scanning can reduce the overall handover time at MAC layer if comparatively shorter beacon intervals are utilized for packet transmission. The performance measures adopted in this paper for experimental verifications are network throughput under different network loads.

KEYWORDS

Handover time, medium access control, detection phase latency time, wireless mobile networks

1. INTRODUCTION

A Handoff occurs in IEEE 802.11b when a mobile station moves beyond the radio range of one access point (AP) and enters in another coverage area at the MAC layer. During the handoff, management frames are exchanged between the station (STA) and the AP. Consequently, there is a latency involved in the handoff process during which the STA is unable to send or receive traffic. On the other hand, our measurements are not only shown that the latencies are very high but also shown that they vary significantly for the same configuration of stations and AP. In this paper, we use *full scan handoff* to denote the original active handoff scheme of the wireless card which scans all channels consecutively in the discovery phase. Most improvements to the active scan handoff strive to scan fewer channels. This is called as *selective scan handoff*. The authors of [1] proposed a MAC layer fast handoff. They use selective scan to record the scan results in the "AP cache" for future use. However, in the case of incorrect cached information, the handoff latency is the same as that of the full scan handoff. Recently, a fast scan handoff scheme is proposed [2]. Instead of broadcasting the probe request frame to all APs, the probe request frame is sent to a specific AP who will be the sole responder. However, this scheme needs to change both the wireless mobile stations and the AP.

2. MATHEMATICAL MODEL FOR REDUCING THE HANDOVER TIME

This section presents a mathematical model that incorporates many critical performance measurements to show the impact of reduced handover time on wireless mobile networks. The performance of the cells permits the use of the real time services when the MAC scheduler is modified [3]. However, our study focuses on the optimization of the second method. We have observed in our measurements that stations firstly assume collision and retransmit several times. If transmission remains unsuccessful, then radio fading is assumed and the link is probed by sending probe requests.

We present an argument that stations must start the search phase as soon as collision can be excluded as reason for failure. If the actual reason was a temporary signal fading, the selected AP's search would likely be the current one and the handoff will not be executed. Thus, a key factor in our detection algorithm is the number of collisions that a frame can suffer before it is transmitted.

2.1.Proposed Mathematical Model for the Collision Detection and Avoidance

We use the probability distribution function (PDF) to approximate the number of collisions for both saturated and non-saturated cases. The proposed probabilistic approach assumes that the STAs must start the search phase as soon as collision can be excluded as reason for failure. If the actual reason was a temporary signal fading, the selected AP after the search would likely be the current one and the handoff will not be executed. According to PDF, if we assume that a random variable X represents a collision per frame transmission, then X should lie within a certain range representing by R . We assume that the value of R belongs to an interval of two values representing as V_{MIN} and V_{MAX} . This argument leads us to the following mathematical expression:

$$X \in \{V_{MIN}, V_{MAX}\} \text{ where } R \xrightarrow{\in} \{V_{MIN}, V_{MAX}\} \quad (1)$$

By further extending (1), we can approximate the probability that X lies in the ideal interval:

$$P(X) \in \{V_{MIN}, V_{MAX}\} = F|V_{MAX}| - F|V_{MIN}| \quad (2)$$

Where F represents the PDF and P is the probability that X lies within the defined interval for collision avoidance. Based on (1) and (2), one can produce the PDF for the collision avoidance as shown in (3):

$$R \to F_R(R) = P\{X \le R\} \quad (3)$$

If we further assume that the system consists of K users, then (1) and (3) be used to approximate the probability of collision per frame transmission. In other words, by reversing the order of probabilities given in (1) and (3) with respect to the ideal range shown in (2), we can approximate the number of total collisions as follows.

$$P\{X \le R\} = \sum_{j=0}^{R} (1-P)\, P^{i} \; @ (1-P)^{R+1} \tag{4}$$

where the sign " @" represents the estimated value and the term $(1-P)^{R+1}$ can be considered as a normalization term to ensure that the probability of each random backoff time follows a valid PDF.

The random backoff time will be discussed later in detail. In addition, *R* will be any real number representing the number of STAs ready to transmit the frames. The range of *R* is provided in (2). In order to derive a generic equation that includes both detection and avoidance, we can now combine our four equations that yield the following result:

$$P\{X \le R\} = \sum_{j=0}^{P\{X \le R\}} (1-P)\, P^{i} \; @ (1-P)^{F_R(R)=P\{X \le R\}+1} \tag{5}$$

Equation (5) consists of both the probability of detection and collision avoidance characteristics.

For the sake of simulation, we assume that there are *n* numbers of STAs that are transmitting a fixed packet size of typically 40 bytes using an ideal channel. Fig. 1 shows a regular case of packet transmission when only a limited number of users are transmitting at one time. In addition, for Fig. 1 we run our simulation multiple times for different values of *n*.

In order to address the worst case scenario, we consider *n* number of STAs with an additional assumption that all STAs have data to transmit all the time via an ideal channel (i.e., the standard IEEE 802.11 MAC [1]) as shown in Fig. 2. It should be noted in Fig. 2 that the probability of collision increases as we increase the probability of transmission per frame. However, the performance degradation was small compared to the increase in probability of

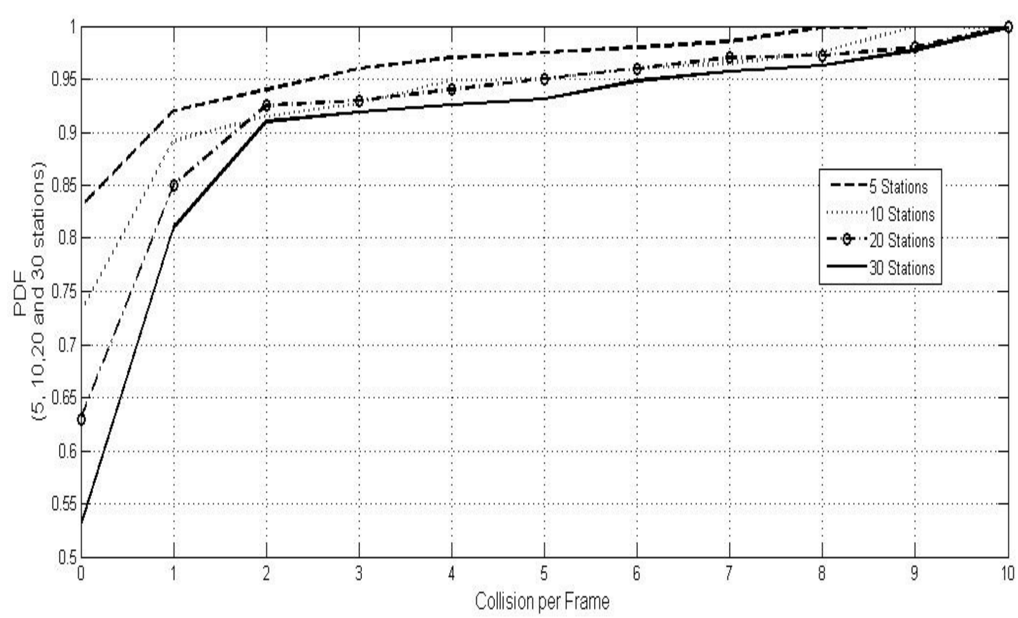

Figure 1. PDF versus number of collision per frame with ideal channel condition for a non-saturated condition

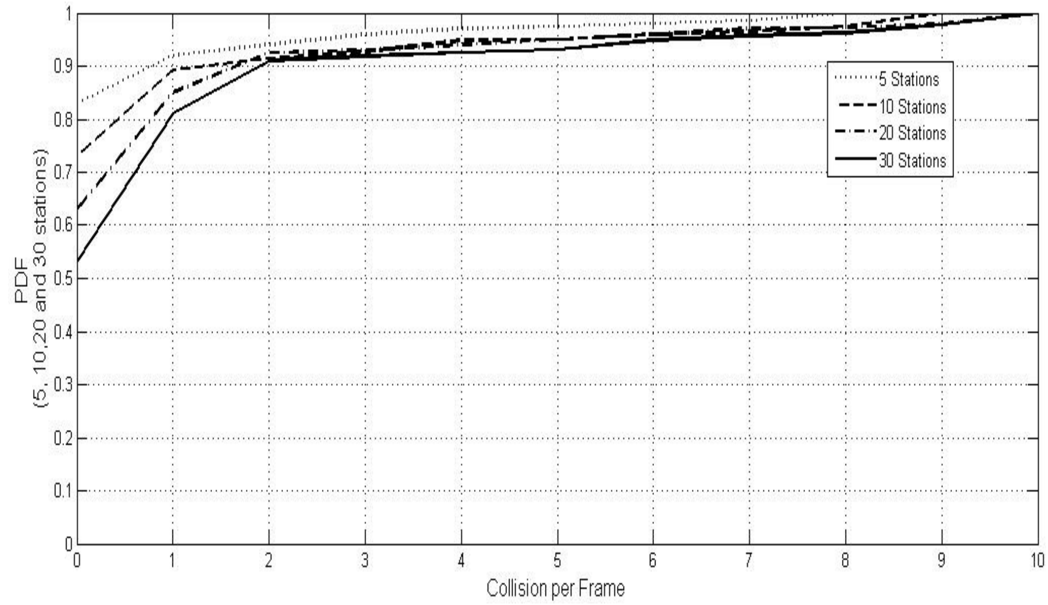

Figure 2. PDF versus number of collision per frame with ideal channel condition for a saturated condition

packet transmission.

Fig. 1 shows that three consecutive collisions is a rare event, even in saturation as shown in Fig. 2. This implies that there is no need to explicitly probe the link. The same conditions that we used throughout our measurements, this time would be around 3 ms, which are approximately leads to 300.

In order to compute the minimum channel time, we follow the classical theory of Slotted Aloha protocol [4]. That is, each STA listens to the channel before the transmission of the frames. If the channel is busy, it defers the transmission with a certain probability. On the other hand, if the channel is free for a certain time (called DIFS, Distributed Inter Frame Space, in the standard [3]), then the STA can transmit the frames.

In addition, when the channel is busy, each node waits for a random amount of time and then periodically listen the channel to find possible DIFS. This random wait-time can be considered as a random backoff time that each node needs to experience during the high contention. Since each STA can only transmit during a certain slot, this random backoff time is, therefore, a multiple of slot times. In addition, we also assume that there is no propagation time and response generation time involve in the computation of minimum channel time. The above discussion leads us to the following mathematical expression:

$$Min_{(CT)} \geq (DIFS) + (RB_{Time} \times S_{Time}) \qquad (6)$$

where $Min_{(CT)}$ referees to minimum channel time, DIFS, RB_{Time} represents *random backoff time,* and the parameter S_{Time} indicates the length of the slot. We can approximate the ideal range of $Min_{(CT)}$ as follows: $AP_R \geq Min_{(CT)} \geq DIFS$

Next, we need to compute the values of *maximum channel time* which might work as the upper threshold value. Since 10 STAs per cell seem to be an adequate number to achieve a good cell throughput [5], we have simulated the different beacon interval with OPNET to figure out the suitable max channel time. Based on our experiments, we conclude that the best value for *maximum channel time is* 10 milliseconds. The last step is to compute the *total search time*. According to the IEEE standard [1], each STA requires to scan all available channels during active scan. The available channels include both busy channels *(B)* and free channels *(F)*. Also, the time to scan a busy channel is not necessarily the same as to scan a free channel. This, therefore, leads us to a simple mathematical expression for the total search time: $SE_{Time} = T_B(B) + T_F(F)$ where the left hand side of this expression represents the total search time, and T_B and T_F represents the time required to scan a busy and free channels, respectively.

The last step is to compute the *maximum channel time* and the total search time. The available channels include both busy channels *(B)* and free channels *(F)*. The total search time will be based on the total time required to scan both busy and free channels. This leads to the following equation:

$$T_B = \left(2P_{(Delay)}\right) + \left(Max_{(CT)}\right), T_F = \left(2P_{(Delay)}\right) + \left(Min_{(CT)}\right) \tag{7}$$

If we assume that we have an ideal minimum time for scanning free channels, then the following mathematical expressions must be true:

$$\begin{aligned} T_B &= \left(2P_{(Delay)}\right) + \left(Max_{(CT)}\right) \\ T_F &= \left(2P_{(Delay)}\right) + \left(DIFS\right) + \left(RB_{Time} \times S_{Time}\right) \end{aligned} \tag{8}$$

$$\begin{aligned} SE_{Time} = &\left[\left(2P_{(Delay)}\right) + \left(Max_{(CT)}\right)(B)\right] \\ &+ \left[\left(2P_{(Delay)}\right) + \left(DIFS\right) + \left(RB_{Time} \times S_{Time}\right)(F)\right] \end{aligned} \tag{9}$$

The above *minimum channel time* and the *maximum channel time* provides the best searching result as compared to the current network cards provides. Specifically, we can use (9) to approximate the total scanning time involves in the search phase. Next section shows the effect of our proposed mathematical model in terms of load balancing, throughput, and transmission delay.

3. PERFORMANCE ANALYSIS OF THE PROPOSED MATHEMATICAL MODEL

The performance measures adopted in this paper are network load, throughput, and the media access delay. The system is modeled in OPNET for both lightly and heavily loaded networks. Fig. 3 is based on our mathematical derivation that simulates the *search-timer* for the *Min-Channel*. The result of this simulation should fall between 670ms and 1024ms. The lowest threshold value has been derived from standard industry and IEEE has given the constant factors [1]. The upper threshold value, however, is suggested based on the maximum latency involved in the given wireless mobile network.

It can be evident in Fig. 3 that below 670ms there is no significant improvement. However, for such a short period of time (i.e., below 670ms), it would likely decrease the overall network efficiency. This is due to the fact that below 670ms, it is more likely that channels will be more quickly declared as empty channels where as the maximum latency time will gradually increase

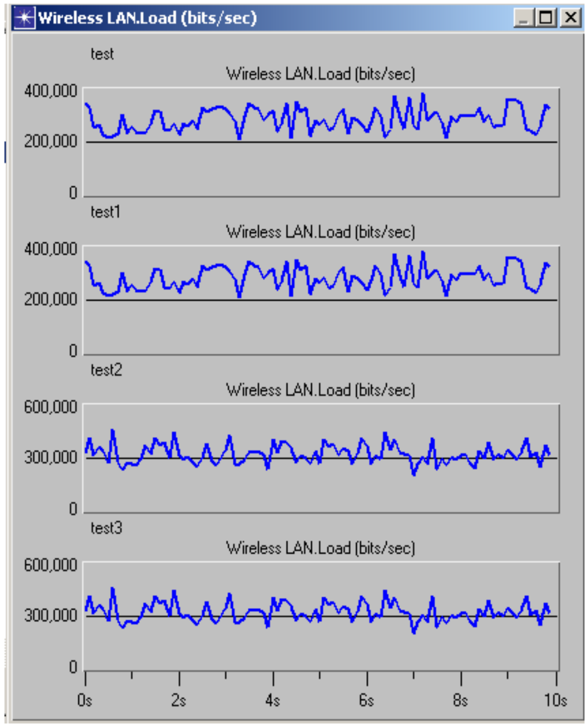

Figure 3. Network load with different values of beacon interval versus time

resulting in overall poor performance of the network. It should also be noted in Fig. 3 that as we increase the minimum threshold to 1024ms, this increases the overall network traffic.

Fig. 4 shows a comparison of throughput versus network traffic. It can be clearly seen in Fig. 4 that as we linearly increase the network traffic, the overall throughput of the system decreases. In other words, an increase in *minimum channel time* becomes one of the reasons for a decrease in overall network throughput. It should also be noted that the results of Fig. 4 is not only the experimental verification of the results of Fig. 3 but also provide some better and technical insight in the increase of throughput. In addition, the overall system throughput decreases sharply, however, it makes some spikes during the random intervals. It can be evident in Fig. 4 that the overall throughput increases significantly with respect to the varying network load represented in Fig. 3.

4. CONCLUSION

In this paper, we have proposed a mathematical model that can be used to effectively reduce the handover time of WLAN at MAC layer. Specifically, we proposed a mathematical model for collision detection and avoidance as well as for search phase. Our simulation results verify that the utilization of probabilistic approach with the active scanning yields lower latency for each detection and search phases provided that if we utilize the appropriate values of some critical parameters such as the beacon interval, minimum and the maximum search times. Both simulation and numerical results of this paper demonstrate that the reduced handover time at MAC layer provides better load balancing, high throughput, and minimum frame transmission delay.

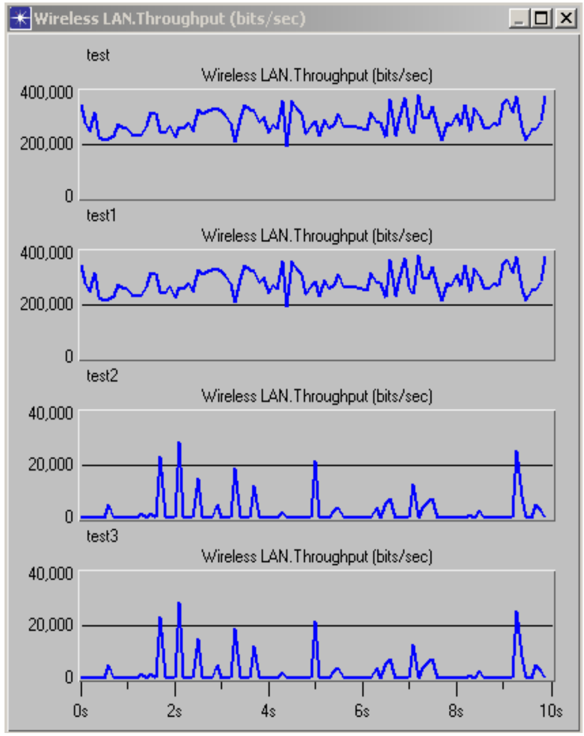

Figure 4. WLAN throughput versus probe request/response transmission time

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