Wireless LAN Access Points as Queuing Systems: Performance Analysis and Service Time

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ABSTRACT
We present a queuing model of wireless LAN (WLAN) access points (APs) for IEEE 802.11b. We use experimentation to obtain our analytic models. The model can be used to analyze and compare the performance of different WLAN APs. We focus on the delay introduced by an AP. The major observations are that the delay to serve a packet travelling from the wireless medium to the wired medium (on the uplink) is less than the delay to serve a packet with same payload but travelling from the wired medium to the wireless medium (on the downlink). A key result is an analytic solution showing that the average service time of a packet is a strictly increasing function of payload.

Categories and Subject Descriptors

General Terms
Performance, Design, and Experimentation.

Keywords
WLAN, AP, IEEE 802.11b, queuing system, service time.

1. INTRODUCTION
Since the approval of the IEEE 802.11b by the IEEE in 1999, the demand for WLAN equipment and networks has witnessed a rapid growth. Today most WLANs use WLAN APs to connect multiple users to a wired backbone network. To provide suitable service, an understanding of the behavior of WLAN APs is essential. The first step is to define the system of interest. Based on our initial experiments, we model the WLAN AP as a queuing system. We are not aware of any study that has looked at the WLAN AP as a point of reference to be modeled as a queuing system. The advantages of our model are manifold; ranging from the ability to compare the performance of different APs, to the simple parameterization of service time. The key result is an analytic model for the average service time of a packet travelling through the WLAN AP in terms of payload.

2. QUEUING MODEL
In our investigation, we seek to model the delay processing in the WLAN AP. A set of assumptions were made. We isolate the AP and define two events: arrival and departure (figure 1). The parameters of interest are the arrival time and the departure time.

Since the number of packets inside the system changes when a packet arrives or when a packet departs, i.e. at separate points in time, then the system is a discrete-event system. The system (figure 1) considers any packet entering the AP, whether coming from the Ethernet side or the WLAN side, as an arriving packet. Similarly, any packet leaving the AP, whether it leaves to the Ethernet medium or to the WLAN medium, is considered a departing packet. The arrival and departure times recorded from experiments have shown that the system can be modeled as a single server system with one FIFS queue (figure 2). We, then, add one more event: entering the server (figure 3), and we define the two system states: waiting and service. The waiting time and the service time of packet \( P_i \) are denoted by \( W_i \) and \( S_i \), respectively, where \( i \) is a positive integer representing the logical identification of the packet with respect to its time of arrival. We define the total delay of a packet, as the response time \( R_i \), to be the time difference between the departure time and the arrival time of a packet, hence \( R_i = W_i + S_i \).

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arrival and the departure times of a packet. To solve this problem, we designed an algorithm that is described in section 3.

3. TEST DESIGN AND ANALYSIS
We send UDP packets to avoid any bits traveling backwards, and we increase the UDP payload by 32 bytes in each experiment. The maximum UDP payload we use is 1472 bytes, because sizes beyond the MTU result in fragmentation [6]. We designed the SSTP (Simple Service Time Producer; figure 4) algorithm to calculate the values of internal-event states: \( W_i \) and \( S_i \).

Table 1. Data file after analysis of measured parameters

<table>
<thead>
<tr>
<th>Packet #</th>
<th>( T_1 )</th>
<th>( T_2 )</th>
<th>Response time</th>
<th>Waiting time</th>
<th>Service time</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_1 )</td>
<td>( T_1 )</td>
<td>( T_2 )</td>
<td>( R_1 )</td>
<td>( W_1 )</td>
<td>( S_1 )</td>
</tr>
<tr>
<td>( P_2 )</td>
<td>( T_1 )</td>
<td>( T_2 )</td>
<td>( R_2 )</td>
<td>( W_2 )</td>
<td>( S_2 )</td>
</tr>
<tr>
<td>( P_3 )</td>
<td>( T_1 )</td>
<td>( T_2 )</td>
<td>( R_3 )</td>
<td>( W_3 )</td>
<td>( S_3 )</td>
</tr>
</tbody>
</table>

Figure 3. Event graph of AP system with enter-service event

Figure 4. SSTP algorithm calculates response time \( (R_i, \text{line } 2) \), waiting time before entering service \( (W_i, \text{lines } 4 \text{ and } 7) \), and service time \( (S_i, \text{lines } 5 \text{ and } 8) \) for each packet \( P_i \).

4. RESULTS
4.1 Response Time
The cumulative probability of the response time shows a piece-wise linear increase with one cutoff point, and it increases with increasing payload for the same utilized bandwidth (figure 5). For the same AP, the uplink service time is less than the downlink service time for packets with identical payloads (table 2).

4.2 Directional Delay
For the same AP, the uplink service time is less than the downlink service time for packets with identical payloads (table 2).

4.3 Service Time Analytic Solution
The discrete-event system allows us to look at the service time values as terms of a sequence. Our analysis showed that the average service time, \( S_n \), can be modeled as presented in equation (1). Since we use a 32B increment in the payload, then the UDP payload is always divisible by 32B, hence, \( n \) is a positive integer.

\[
S_n = S_o + (n-1)r
\]

where, \( S_o \) and \( r \) are different for different APs,

\[
n = \frac{(\text{IP Payload \,(in \, bytes)} - 8B[\text{UDP header}])}{32B}
\]

\[
S_o = \text{service time \,(\mu s) \, for \, packet \, with \, IP \, payload \, of \,(32.n+8)B}
\]

\[
r = \text{incremental difference in \, \mu s \, (calculated \, from \, linear \, regression \, of \, average \, service \, times \, of \, different \, payloads).}
\]

5. WORK IN PROGRESS
We use our model to study the QoS of layered MPEG-4, MPEG-2, MPEG-1, and H.261 streaming applications over WLANs.

6. CONCLUSION
The main purpose was to reveal a mathematical model for wireless LAN access points: a single server, single queue, FIFS system. An interesting result is that the uplink service time is relatively much smaller than the downlink service time. Using our model and test design, one can get an analytic solution of the average service time, which is a linear function of payload.

7. REFERENCES