Characterization of MPEG-4 Traffic over IEEE 802.11b Wireless LANs*

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Abstract

Several traffic characterization studies have been performed on wireless LANs with the main objective of realizing good and accurate models, in particular to model the errors in the wireless channel. In this paper we are more interested in the effects of those errors on the higher layer protocol. Using two freely available tools to send and receive real-time streams and collect and analyze traces, we send MPEG-4 encoded video frames over a 11 Mbps, 802.11b wireless LAN to characterize the errors in the channel and the effect of those errors on the quality of the movie. We performed experiment considering three distances from the access point (10, 50 and 75 ft. away) and four packet sizes (500, 750, 1000 and 1500 bytes). We found that a tradeoff exists between the packet size and the amount of information lost. Small packets affect B and/or P frames most of the time and when they affect I frames the amount of information lost is minimal. On the other hand, small packets also produce bigger error bursts, affecting I frames more. Packets of 750 bytes are a good compromise. In addition, we found that the distribution of the error length and error-free length in number of packets is similar to those found in the former 2 Mbps wireless LAN.

1. Introduction

Wireless LANs have become very popular in many scenarios because they are very simple, convenient and cheap. Nowadays, we find wireless LANs in businesses, museums, libraries, and factories and in many other places where this technology is the only solution for cabling problems, cost, or flexibility reasons. The cost of wireless LANs have decreased so drastically that many households, hotels, apartment buildings, airports and the like have already installed such networks. An example of a common configuration at home is the connection of the wireless access point to a high-speed cable modem or ADSL connection.

Normally, wireless networks are attached to the wired infrastructure so that wireless users are also connected to the corporate network and/or the Internet. Wireless users will use the same business mission critical applications and all other types of applications they are used to run over wired networks. Furthermore, wireless users expect their applications to run as if they were wired connected. However, wireless networks are different, and several factors make them more challenging to satisfy those users' demands. Wireless networks are lossy in nature and challenged by other radio propagation and mobility factors, therefore, applications don't usually perform as good as in wired environments. As a result, it is important to have a deeper knowledge about these networks, its issues and limitations, and the performance characteristics.

Network applications are different in nature and affected differently depending on the type of communication problems. For instance, data applications are very sensitive to packet losses but not that sensitive to packet delays. On the other hand, delay is very important for voice and video applications but they can tolerate some losses [5]. In this paper we present a traffic characterization study of video traffic over wireless LANs at the packet and application levels. First, we characterize the errors at the packet level. Even though other studies have characterized the errors in wireless LANs before, they have all used older wireless LANs technology such as the known WaveLAN at 2 Mbps. Second, we investigate the effect of those errors on video applications; we want to give a good idea of how much harm those errors cause on applications, in particular on MPEG-4 video encoded applications. And third, we also characterize the delay jitter of the video traffic. This is a very important parameter for buffer dimensioning purposes and to detect anomalies. We focus on video applications because of the stringent QoS requirements that they impose on the network, in terms of bandwidth, delay and losses.

The paper is organized as follows: Section 2 presents the related work on traffic characterization in wireless LANs

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and a description of MPEG-4. The test bed, tools and settings we used in our experiments are presented in Section 3. Our main findings are shown in Section 4. Finally, in Section 5 we present our conclusions and areas of further research.

2 Related Work

Traffic characterization is a well-studied field, in particular over wired networks. Internet traffic dynamics were very well studied in [9] including out-of-order delivery of packets, pattern of packet losses and the distribution of the duration of the losses and packet transit delays. In [10], the authors evaluated packet traces in wide area networks to investigate whether the arrival process of FTP connections and TELNET packet arrivals corresponded to the commonly used Poisson arrival process. In [7], the authors studied traces to show that the distribution of the packet interarrival times is not exponentially distributed and that the traffic exhibits self-similarity. Video traffic has been studied over 10 and 100 Mbps Ethernet LANs characterizing the quality of the video in term of glitches [11]. In wireless networks, [2] characterizes the throughput, average delay, jitter, frame error rate, IP loss rate and other parameters for UDP traffic over 802.11b wireless LANs. In [8], the error length and error-free length distributions were provided characterizing the loss behavior of the AT&T WaveLAN. The study shows average packet error rates of 2 to 3% and correlated errors. However, neither study relates the effects of the errors to the applications in current wireless networks. Here, we provide insights about how those errors affect the quality of the MPEG-4 encoded video. In addition, we make use of a trace-based approach to characterize the errors at the packet level to verify those results on the new generation of wireless LANs, the 11 Mbps IEEE 802.11b standard.

MPEG stands for Moving Pictures Experts Group, an International Standards Organization group formed to standardize audio and video compression. Three MPEG standards exist, MPEG-1, MPEG-2 and MPEG-4. MPEG-1 was designed with the idea of storing moving pictures and audio on Compact Disks at a low bit rate. MPEG-2 has become very popular because it has been used as the compression mechanism for DVB and DVD. In contrast to MPEG-1 and MPEG-2, MPEG-4 is object-based. MPEG-4 objects are part of a scene which can be accessed or manipulated independently. MPEG-4 achieves higher compression ratios than MPEG-2 and has better coding tools, making it more suitable for the Internet and wireless delivery of applications [12]. The MPEG standard defines four distinct pictures encoding: Intra-coded Picture (I-Picture), Predictive-Coded Picture (P-Picture), Bidirectional-Predictive-Coded Picture (B-Picture) and DC-Coded Picture (D-Picture). The I-Picture is coded using information only from the picture itself. The P-Picture is coded using motion compensation prediction in reference to a previous I-Picture or another P-Picture. B-Picture is coded in reference to either previous or future I-Pictures or P-Pictures. Finally, the D-Picture stores the DC component of each DCT block. The I, B and P pictures are arranged in a periodic pattern known as a Group of Pictures (GOP). Figure 1 shows the GOP of MPEG-4 video that we used in our experiments, and the relationships among pictures. The MPEG-4 Group of Pictures (GOP) is made of 12 frames in the following order: IBBPBBPBBPBB. The first two B pictures (2 and 3) are bidirectionally coded using the past frame (I frame 1) and the future frame P (frame 4). Therefore, each B picture is encoded based on the previous and following I and/or P pictures. P pictures on the other hand are dependent of previous I or P pictures.It is worth mentioning that due to these dependencies the decoding order will be different from the encoding order. The P frame 4 must be decoded before B frames 2 and 3, and I frame 1 (the last I frame) before B frames 11 and 12. If the MPEG-4 sequence is transmitted over the network, the actual transmission order should be 1, 4, 2, 3, 7, 5, 6, 10, 8, 9, 1, 11, and 12. From the graph and the explanation above about the dependencies, it is easy to conclude that I-Pictures are the most important ones since they contain the actual video content and all other pictures are error-coded based on the I frames.

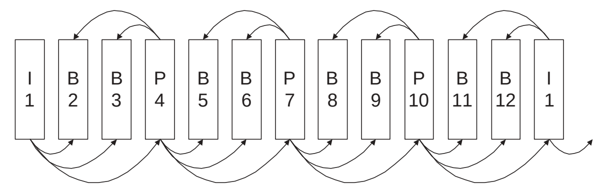

Figure 1. Group of Pictures of MPEG-4 frame sequence and dependencies used in our experiments

3 Testbed, Tools and Settings

The test bed used in our experiments is shown in Figure 2. We employed two hosts for our experimental setup. The first host is the only PC connected in an Fast Ethernet switched network and the second host is the only laptop in a wireless LAN. We used an isolated Fast Ethernet segment to make sure no packet losses occur in the wired portion of the network. This assures that only wireless media related

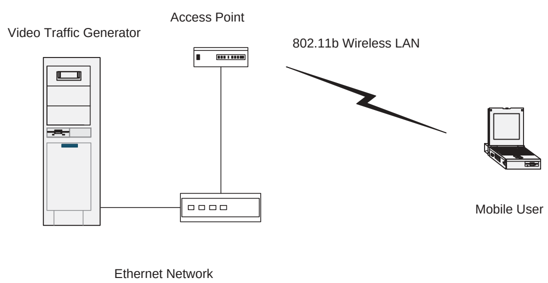

Figure 2. The experimental environment

losses will occur, which is what we want to characterize. The wireless LAN utilized corresponds to the IEEE 802.11b standard. It runs at up to 11 Mbps in the license-free 2.4Ghz band and implements the well-know Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) Medium Access Control (MAC) protocol [1]. At the physical layer, this wireless LAN utilizes Direct Sequence Spread Spectrum (DSSS) and Complementary Code Keying (CCK) modulation for high and medium transmit rates. In a closed office environment, like the one we worked in, the radio characteristics limit the transmission rate of 11 Mbps to a range of up to 80 ft. Both hosts ran the Linux OS, kernel version 2.4.3. We used the frame length trace of high quality MPEG-4 video of the Jurassic Park movie for all our tests [4]. This is similar to the approach used in [13], [8], and [3] for performing measurement and evaluation of wireless network characteristics.

The RUDE and CRUDE applications [6] were installed in the video traffic generator and mobile computer, respectively. RUDE stands for Real-time UDP Data Emiter and CRUDE for Collector for RUDE. The rate of transmission of the UDP packets was controlled based on the frame generation rate of MPEG-4 video (25 frames/sec). We added the picture type and end of picture delimiter fields in each packet being transmitted by RUDE. The output trace files generated also contain the characteristics of the wireless network during the tests. The analysis of the effect of the network physical and MAC layer characteristics over MPEG-4, at the application layer, is an issue of our future research. No modifications to the wireless interface of the mobile hosts were made. With RUDE we load the MPEG-4 video trace and transmit it over the network. On the mobile computer CRUDE receives the packets transmitted by RUDE and stores a trace for each transmission. The traces can then be used by any other application to process and plot the results. Traces were collected for different packet sizes and distances from the access point. We ran the experiments using packets sizes of 500, 750, 1000 and 1500 bytes and distances of 10, 50 and 75 ft away from the access point, with no other data over the wireless network. Although this represents an idealistic scenario, it describes the pure behavior of the wireless media and serves as the base case for comparisons under different scenarios.

4 Experiment Results

In this section we present and explain the most important results obtained. In Figures 3 and 4 we present the Inverse of the Cumulative Density Function ($1 - CDF$) of the error length (and error-free length) in number of packets ($P \quad [error \quad (free) \quad length > x]$) when the mobile unit is 75 ft away from the access point using packet sizes of 500, 750, 1000 and 1500 bytes, respectively. We chose to include only the results from the traces 75 ft away from the access point because they are the most interesting ones as the user is only 5 ft away from the maximum theoretical range. In this case we found more errors than in the 10 and 50 ft away cases. In the case of the error length distribution, these curves say that as the packet size is decreased the probability of having a burst of errors of the same size decreases. For instance, the probability of having a burst greater than 10 errors with a packet size of 500 bytes is around 0.15 while it is reduced to 0.002 if we used packets of 1500 bytes. In the worst case of using packets of 500 bytes, around 50% of the bursts are equal or less than 4 packets. This number increases to around 90% when using 1500 bytes packets. In the case of the error-free length distribution, the probability of having an error-free burst greater than 100 packets is still around 22%. Our curves look very similar to the ones presented in [8] in two aspects. First, they also present three different segments to be fitted individually, two straight lines and one concave curve, saying that a simple geometric model will not capture the real loss behavior. We didn't pursue the curve fitting though. We are more interested in knowing the effect of those errors on the video stream. Second, the values pretty much match, in other words, the probability of finding an error burst or error-free burst of 4 packets is quite similar.

We also plotted the Probability Density Function of the error length in number of packets from the same set of traces. From the Figures 5, 6, 7, and 8 we can obtain our first conclusion. As the packet size is increased the pdf is simplified having a fewer number of beans with higher probability. These results are totally expected because as the packet size increases the channel errors affect fewer number of packets.

To analyze the effect of the channel errors in the MPEG-4 video stream we proceed as follows. First, from the error length graphs we obtain the length of most error bursts in number of packets. Then, we analyze those bursts individually to know what type of MPEG-4 frames they affect the most. Finally, we analyze those packets and frames even further to know how much information on average the MPEG-4 frames lose.

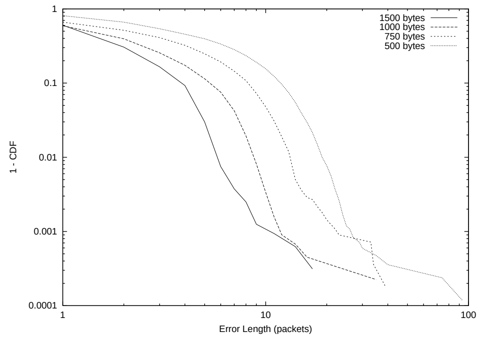

Figure 3. Inverse CDF of the error length for packet sizes of 500, 750, 1000 and 1500 bytes, 75 ft away from the access point

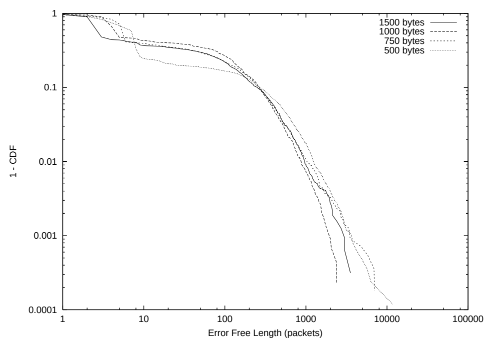

Figure 4. Inverse CDF of the error-free length for packet sizes of 500, 750, 1000 and 1500 bytes, 75 ft away from the access point

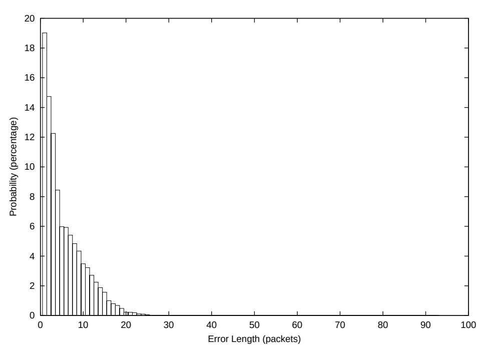

Figure 5. Error length distribution using a packet size of 500 bytes being 75 ft away from the access point

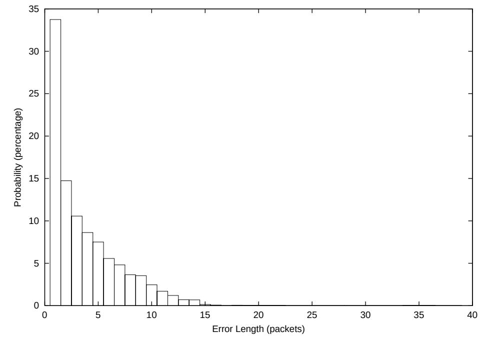

Figure 6. Error length distribution using a packet size of 750 bytes being 75 ft away from the access point

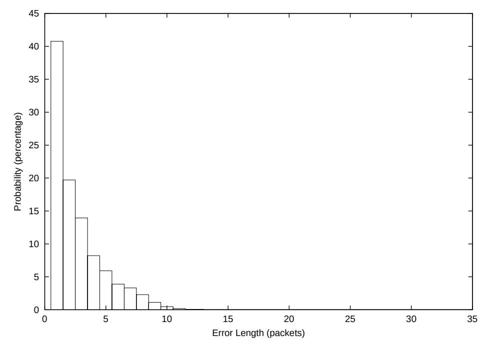

Figure 7. Error length distribution using a packet size of 1000 bytes being 75 ft away from the access point

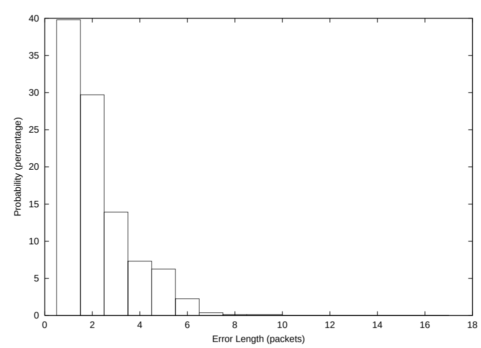

Figure 8. Error length distribution using a packet size of 1500 bytes being 75 ft away from the access point

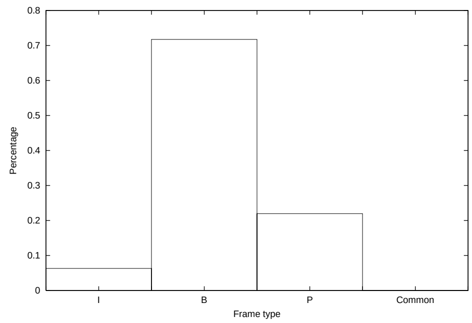

Figure 9. MPEG-4 frames affected by error bursts made of one packet, when the access point is 75 ft away and packets are 500 bytes long

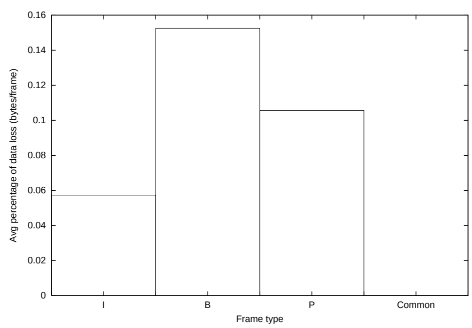

Figure 10. Mean amount of bytes affected in I, B and P frames by error bursts made of one packet, when the access point is 75 ft away and packets are 500 bytes long

From Figure˜refel75 it can be seen that in the worst case (packet 500 bytes long) 50% of the error bursts are made of 4 packets or less. As a result, we chose to analyze the error bursts made of one, two, three and four consecutive packets.

Figure 9 shows what type of MPEG-4 frames are affected the most by error bursts of length one packet when packets are 500 bytes long. It is clear that when only one packet is in error, B frames are most likely to be affected. In fact, 71% of the frames affected are B frames, 22% are P frames and only 6% are I frames. This is good news because, as we said earlier, I frames are the most important ones.

Similar graphs were plotted for the rest of the cases but are not presented here as they present very similar trends. However, we decided to tabulate all the results. Table 1 includes the percentage of MPEG-4 frames affected by error bursts made of one, two, three and four packets when we used packets of 500, 750, 1000 and 1500 bytes. From the table, similar conclusions can be made. In general, B frames are affected the most, followed by P frames and I frames. Furthermore, it is clear that the best performance is achieved with the smallest packet size. (The fewest number of I frames were affected when we used 500 bytes packets.) It is also possible that packets within an error burst affect more than one and different frames. We added a fourth column (**C**ommon) to indicate this situation along with the type of frames affected in parenthesis. As shown, I frames are also the less affected frames, although not significantly. Not shown in the table are all the cases where the error burst length is greater than four. It is worth mentioning that the trend exhibited in Table 1 reverses as the number of consecutive packets lost in one burst increases. For instance, for the 500 bytes packets case, if we consider an error burst of 22 packets, 62% of them affect I frames, 25% P frames, and 13% B frames with no combinations. This result was somehow expected since I frames are the largest, and larger packets will have higher probability to affect those frames. Fortunately, the probability of having error burst of that length is very small as seen in Figures 3 and 4.

Now that we know which frames are affected the most one additional question remains. How much information is lost? In other words, when a frame is affected, is it lost completely or barely affected? Figure 10 is meant to address this question. Following with the example of error bursts of one packet, packets 500 bytes long, and 75 ft away from the access point, the figure shows the average amount of bytes that are affected in I, B and P frames related to the frame size. As it can be seen, every time an I frame is affected by a burst of one packet I frames lose about 6% of the data, P frames lose about 10%, and B frames lose around 15% of the data. This is again goods news. Not only I frames are the less affected by the bursts of errors but also they lose the less amount of bytes. Table 2 shows all the cases, or the average percentage of bytes affected in I, B and P frames by error lengths of one, two, three and four packets using packet sizes of 500, 750, 1000 and 1500 bytes. From the table we can see that as the length of the burst increases so does the amount of data affected; this is a totally expected behavior. The same behavior is observed when the packet size is increased. The combination column shows the weighted average of the amount of data lost in all affected frames. However, it does show in what proportion are individual frames affected. Table 3, answers that question, showing the amount of affected bytes in I, P, and B frames everytime a burst of one, two, three, or four packets affect more than one type of frame. As it can be seen, I frames are barely affected, followed by P and B frames respectively.

Finalizing with the example and looking at all the results presented in the tables, the main conclusion is that video traffic over this particular type of wireless LAN is less affected when using small packet sizes, in our experiments packets of 500 bytes. However, we also know that as we decrease the packet size we also increase the probability

Burst Length	Pkt Size = 500 bytes				Pkt Size = 750 bytes				Pkt Size = 1000 bytes				Pkt Size = 1500 bytes			
	I	P	B	C	I	P	B	C	I	P	B	C	I	P	B	C
One Pkt	6.4	22.3	71.2	0.0	11.8	25.98	62.2	0.0	10.7	22.3	66.3	0.0	6.4	25.4	68.1	0.0
Two Pkts	4.1	12.8	63.3	19.7 (IBP)	5.4	16.1	54.14	24.3 (IBP)	4.22	13.5	59.4	22.8 (IBP)	4.9	15.4	59.2	20.5 (IBP)
Three Pkts	6.0	21.14	63.9	8.9 (IBP)	4.6	18.7	64.8	11.9 (IBP)	5.6	23.1	66.1	5.2 (IBP)	15.5	37.3	41.8	5.3(IBP)
Four Pkts	2.9	25.63	69.4	1.9 (IBP)	2.7	18.12	76.3	2.9 (IBP)	3.0	40.0	57.0	0.0	20.9	40.1	37.2	1.7 (BP)

Table 1. Percentage of MPEG-4 frames affected by error bursts of length one, two, three and four packets of length 500, 750, 1000 and 1500 bytes when the mobile unit is 75 ft away from the access point

Burst Length	Pkt Size = 500 bytes				Pkt Size = 750 bytes				Pkt Size = 1000 bytes				Pkt Size = 1500 bytes			
	I	P	B	C	I	P	B	C	I	P	B	C	I	P	B	C
One Pkt	5.7	10.5	14.9	0.0	9.4	17.3	23.4	0.0	12.9	21.7	26.7	0.0	19.1	32.3	36.7	0.0
Two Pkts	13.7	22.6	25.2	15.2(IBP)	17.5	28.3	28.6	20.3(IBP)	23.5	30.9	33.2	27.1(IBP)	31.6	39.8	42.0	33.0(IBP)
Three Pkts	17.9	29.0	33.7	20.2(IBP)	25.9	33.3	37.2	33.8(IBP)	31.1	39.14	42.6	28.6(IBP)	48.0	50.3	54.3	39.4(IBP)
Four Pkts	21.2	39.1	41.3	28.7(IBP)	36.4	39.4	42.3	39.2(IBP)	43.6	47.7	50.8	0.0	54.8	57.4	59.4	31.0(BP)

Table 2. Average percentage of bytes affected in I, B and P frames by error lengths of one, two, three and four packets using packet sizes of 500, 750, 1000 and 1500 bytes and being 75 ft away from the access point.

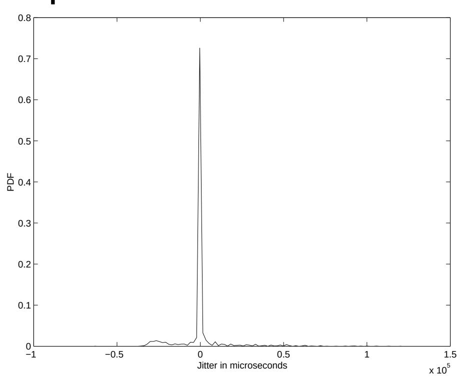

Figure 11. Delay variation (jitter) distribution for I frames when the access point is 75 ft away and packets are 500 bytes long

of having bigger bursts of errors (compare Figures 5, 6, 7, and 8) with the implication that bigger bursts affect I frames more. As a result, our final recommendation is to use packets of 750 bytes as they offer the best compromise.

Finally, in Figure 11, we provide the distribution of the delay variation for the I-frames. This is an important parameter for playout buffer dimensioning at the receiver. Figures of I frame jitter for the other cases are very similar and are not plotted here.

5 Conclusions and Further Research

In this paper we analyze the effect that impairments common in wireless channels have on MPEG-4 encoded video frames when transmitted over an 802.11b wireless LAN. The main conclusion is that I frames, the most important frames in MPEG encoded files, are rarely affected, in particular if we used small packet sizes (in our case, packets 500 bytes long). Furthermore, the amount of information lost from those frames in those cases is really small compared to B and P frames. However, small packets produce larger error bursts and they affect I frames more. A good compromise then is to use 750 bytes packets. We also characterize the errors at the packet level and find that most of the time the error burst is less or equal to 4 packets. Furthermore, comparing our results with past results of similar experiments over a 2 Mbps wireless LAN we find similar distributions for the error length and error-free length, and those distributions don't follow the geometric distribution that is usually used when modeling these channels analytically. Finally, we also plot the distribution of the jitter of I frames, results that are quite useful for playout buffer dimensioning and to detect anomalies. Further work goes in several directions. First, we will fit the error length and error-free length distributions to find the exact distribution and be able to model the errors analytically. Second, we will characterize the errors in the MPEG-4 frames according to macroblocks or slices and try to establish a good metric to express the quality of the video from the user point of view. Third, we will perform more experiments under different network conditions such as changing the load, moving the mobile computer, etc. Finally, we will use these experiments and test bed to characterize more anomalies, which we will use for software testing.

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Burst Length	Pkt Size = 500 bytes			Pkt Size = 750 bytes			Pkt Size = 1000 bytes			Pkt Size = 1500 bytes		
	I	P	B	I	P	B	I	P	B	I	P	B
One Pkt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Two Pkts	1.7	11.13	19.5	2.3	14.65	26.42	4.2	35.1	18.9	4.6	23.9	41.1
Three Pkts	3.6	12.71	28.46	5.3	23.8	42.7	4.2	20.8	36.5	8.6	27.3	45.7
Four Pkts	3.0	23.11	34.15	5.5	25.7	50.7	0.0	0.0	0.0	0.0	66.3	54.16

Table 3. Average percentage of bytes affected in the combinations of I, B and P frames by error lengths of one, two, three and four packets using packet sizes of 500, 750, 1000 and 1500 bytes and being 75 ft away from the access point.

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