Dynamic Packet Size Selection for 802.11 Inter-Vehicular Video Communications

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Abstract

This paper focuses on improving the performance of video communications in inter-vehicular environments using the 802.11 ad hoc network protocol. We present the results of transmission experiments between two cars equipped with 802.11 standard devices in two typical driving scenarios, urban and highway, showing the characteristics of each scenario in terms of link availability and SNR for different bitrates and packetization policies. Moreover, we also evaluate the video quality at the receiver by means of the PSNR distortion measure, showing that the best packetization policy depends on the scenario. On the basis of these results, we design an adaptive algorithm which dynamically varies the video packet size to improve the efficiency of the video transmission. Results show that consistent perceptual quality gains in terms of PSNR value (up to about 3 dB) can be achieved with respect to a fixed-policy transmission technique.

1 Introduction

The presence of wireless devices on public and private vehicles is expected to rapidly increase in the next few years. For instance, some airplanes and trains already allow internet access using the 802.11 protocol by on board passengers, and several cars include an intra-vehicular wireless platform that allows easy integration of various devices, such as mobile phones, with the on board systems.

For the specific case of the automotive industry, inter-vehicular wireless communications are also expected to gain popularity in the next few years, as shown by the numerous research projects which are currently under development (e.g. [1, 6, 7]), Potential applications of inter-vehicular communications include, for instance, multi-vehicle-based visual processing of road information, multi-vehicle radar systems for obstacle avoidance and automatic driving. Inter-vehicular networks will also make a new class of applications possible, for instance 'swarm' communications among cars traveling along the same road, network gaming among passengers of adjacent cars and virtual meetings among coworkers traveling in different vehicles.

Protocols such as WAVE and its ancestor DSRC [3, 12, 13] have been lately proposed to address the issue of inter-vehicular communications, but these solutions require the development of new standards and devices, hence their deployment will take some time. In the meantime, several researchers are studying the applicability of currently available wireless networking protocols, such as the widely used 802.11 Wireless Local Area Network standard, to inter-vehicular communications.

Few efforts have been devoted so far to study and simulate 802.11 inter-vehicular networks, due to the relative novelty of the application. Some works focused on simulations to assess the performance of inter-vehicular transmissions compared with other access schemes such as UTRA TDD ad hoc [11]. Others addressed networking issues such as routing specifically for the inter-vehicular scenario [19]. However, few experimental results of 802.11-based inter-vehicular transmissions have been presented. Transmission experiments between two cars equipped with an external antenna have been presented in [17]; in this work, the performance of a generic UDP data transmission is evaluated by means of the Signal-to-Noise Ratio and throughput in different driving scenarios. Other works focused on vehicles communicating with a roadside access point [15].

The main contribution of this paper is to present results of multimedia transmission experiments between vehicles using the 802.11b wireless standard in different traffic conditions and scenarios, as a function of the main multimedia encoding parameters such as the bitrate and the packet size. In the first part of the paper we analyze the performance of plain video transmission experiments. Then, building on these results, we design an heuristic algorithm to improve the video quality performance at the receiver based on adapting the packet size to the characteristics of the particular driving scenario. During the experiments we moni-

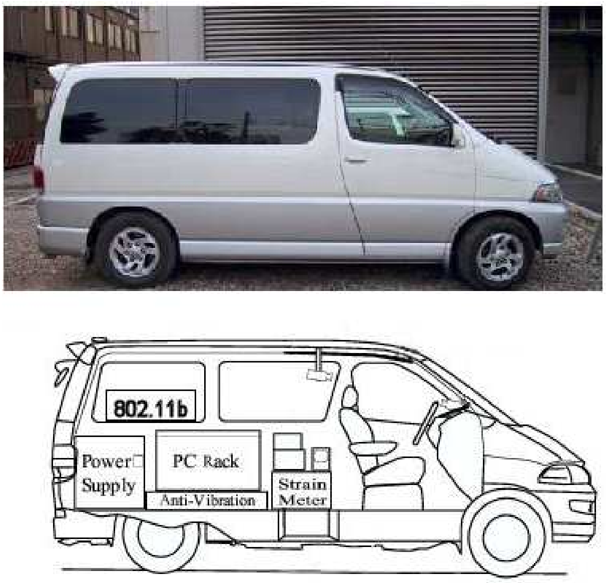

Figure 1. Data collection vehicle used during the experiment.

tored different performance metrics, such as the packet loss rate, the link availability and the received SNR, as well as the perceptual video quality of the transmission using the PSNR distortion measure.

This paper is organized as follows. Section 2 describes the 802.11 inter-vehicular transmission scenario, while Section 3 illustrates the codec setup for video streaming including the packetization policies. Section 4 presents the results of plain video transmission experiments in various conditions, showing the influence of the packetization policy on the performance. In Section 5 the proposed dynamic packet size selection algorithm is described, while the corresponding performance results are reported in Section 6. Finally conclusions are drawn in Section 7.

2 Inter-Vehicular Transmission Scenario

We performed transmission experiments between two vehicles in different environments, at various speeds and inter-vehicle distances. The first vehicle, a van (Figure 1) donated by Toyota Corp. to Nagoya University for the CIAIR Project [2], carries a laptop with one PCMCIA 802.11b card (device #1). The second vehicle is a car which carries another laptop equipped with two 802.11b wireless cards (#2 and #3).

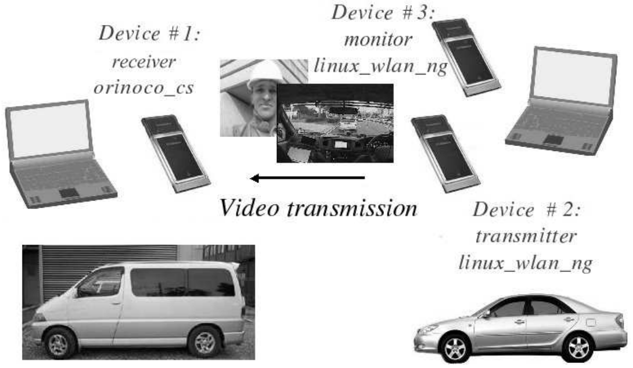

Figure 2. The experimental testbed. The video flow is transmitted from the car to the van.

Figure 2 shows our experimental video streaming testbed. Device #1 acts as the video receiver while Device #2 is the video transmitter. Both devices operates using the 802.11 ad hoc mode, i.e. without relaying on any access point. Device #3 is used to monitor the transmission between the two devices. This device has been configured to operate in monitor mode, thus it records all the traffic, including MAC acknowledgment packets, and it is useful to determine packet losses and SNR information. We used a third card for monitoring because enabling the monitor mode on Device #1 or #2 would prevent them from operating communications normally, hence the need of a separate card. Both laptops run the Linux kernel version 2.4. The main characteristics of the wireless devices including the drivers are listed in Table 1. All devices have been set to use the RTS/CTS mechanism and the MAC-level ARQ retry limit is set to the default value (eight).

No external antenna has been used, because we decided to test a scenario composed by portable devices which do not need complex set-up operations, such as placing an external antenna. For instance, they could simply be a PDA equipped with a wireless network interface.

We used the software known as *ethereal* [4], which is based on the *libpcap* library [8], to monitor the wireless communications. All wireless devices used during the ex-

Table 1. Main characteristics of the wireless nodes.

Device ID	#1	#2	#3
Function	Receiver	Transmitter	Monitor
Interface	PCMCIA	PCMCIA	USB
Card type	802.11b	802.11b	802.11b
Manufacturer	Buffalo	Asus	D-Link
Model	Melco	WL-100	DWL-120
Driver name	Orinoco_cs	Wlan_ng	Wlan_ng

Table 2. Main characteristics of the test video sequences.

Sequence	*foreman*		*foreman*		*paris*	
Resolution	QCIF (176×144)		QCIF (176×144)		CIF (352×288)	
Frame rate (fps)	10		15		20	
Target bitrate (kbit/s)	150		300		600	
Flow ID	**S1**	**L1**	**S2**	**L2**	**S3**	**L3**
Maximum packet size (bytes)	560	750	560	750	750	1200
PSNR (Y) (dB)	37.51	37.54	40.78	40.66	35.68	35.68
Actual bitrate (kbit/s)	148.5	151.2	304.5	300.8	607.2	594.0
Total number of packets	1050	780	2010	1500	1050	780
Packet frequency (packets/s)	35	26	67	50	100	62
Amount of padding (%)	17.94	23.31	13.04	18.43	13.84	13.63

periments are based on the Prism II chipset [5]. These chipsets, with the appropriate kernel support [10], can also report the received signal quality for the captured packets. This required to enable the *raw dumping* and *prism header* features in both the ethereal software and the driver module, so that the signal quality could be read and stored. We measured the received SNR at both devices #1 and #3.

3 H.264 Video Streaming

The state-of-the-art video coding standard known as ITU-T H.264 [14] has been employed for video compression. This standard is designed to decouple the coding aspects from the bitstream adaptation to the particular characteristics of the transmission channel. The part of the standard that deals with the coding aspects is called Video Coding Layer (VCL), while the other is the Network Adaptation Layer (NAL). In our experiments we used the NAL designed to transport the compressed data over the IP network [21].

We employed the video coding software known as JM 6.1e [16], modified to be robust to packet losses. A temporal concealment has been implemented, so that the content corresponding to a lost packet is replaced with the same area in the previous frame, that is already stored in the decoder picture buffer. Packet losses can be detected at the decoder by means of the RTP sequence number. We coded the standard video sequences known as *foreman* (QCIF format) and *paris* (CIF format) using different bitrates and packet sizes, as shown in Table 2. A total of six different RTP video flows have been generated, with different characteristics in terms of bitrate and packet size. For simplicity's sake, the packet size was kept constant for each particular transmission experiment to simplify the interaction with the client/server software suite that we used to perform the transmission experiments. For this reason, sometimes the video encoder could not completely fill the packets. The amount of padding is shown in the last row of Table 2.

We used the *rude/crude* packet generation suite [9] to perform the transmission experiments. This suite is a complete and open source client/server solution to generate customized UDP streams. Several flows, whose characteristics are reported in Table 2, have been transmitted during the experiments. The transmission of each flow has been repeated 50 times to achieve statistically significant results.

Two different packetization policies have been used for each target bitrate. The flows denoted by S are characterized by a small maximum packet size and consequently a relatively high packet rate, and vice versa for the other flows (denoted by L). We used two different packetization policies because we expect that the performance of the transmission will noticeably vary depending on the driving scenario, as confirmed by the results in the next section.

4 Inter-Vehicular Video Streaming Experiments

We conducted a measurement campaign in two typical driving scenarios, referred to as *highway* and *urban*, characterized by different vehicular mobility and traffic density.

In the *highway* scenario the speed limit is 55 mph. Stops are not frequent and are caused only by traffic lights. We did not experience any traffic jam. During this part of the experiment, we drove out of Nagoya city, heading to Motoyama and back, at moderate speed, and stopping infrequently. In this scenario sometimes the wireless devices could not communicate with each other, due to the high distance between the two cars.

In the *urban* scenario the average speed is low, less than 15 mph. Stop caused by traffic jams and traffic lights are frequent, while the distance between the two cars is on average smaller than in the previous case. In this part of the experiment we drove downtown Nagoya at low speed and with many cars around and between the wireless devices. Com-

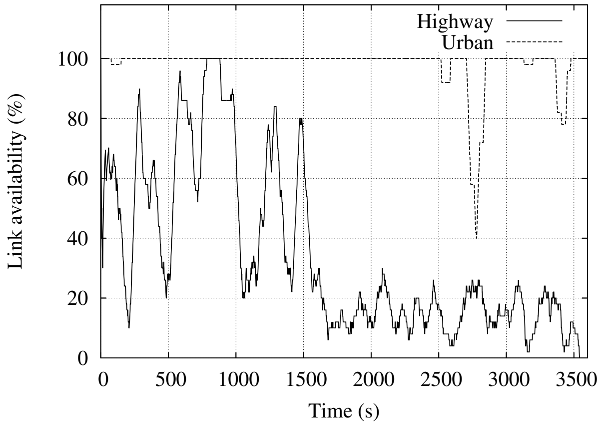

Figure 3. Link availability as a function of time for both the highway and urban scenarios. Values are averaged on a ten-second window.

munication problems happened when the two cars were at opposite sides of an intersection or other cars were located between the two.

4.1 Channel Characteristics

The first result is that the two scenarios differ in terms of link availability and SNR at the receiver. In particular the main difference between the two scenarios is given by the different amount of time in which the link is available. The link availability is determined by means of the beacon frames. We set each device to transmit one beacon frame every second, and we compute the link availability as the ratio between the number of received beacon frames over the number of transmitted ones for a given temporal window. Figure 3 shows the link availability as a function of time for the two scenarios while Table 3 summarizes the average values of link availability. In the urban scenario Devices #1 and #2 can communicate for over 97% of the time, because the cars are next to each other and proceed at low speed. In the highway scenario, instead, link is available for less than half of the time. To this regard, an external antenna could considerably increase the communication range of the wireless devices.

We also measured the SNR values when the link is available. Values are reported in Table 3. The average SNR when the link is available in the highway scenario is about 22.5 dB, more than 3 dB compared to the urban scenario. This fact can be explained as follows. In the highway scenario cars cause very little communication problems because they are not close as in the urban scenario. Moreover, potentially interfering devices (e.g. access points) are not as frequent as in the urban scenario. When driving in the urban scenario, instead, the number of interfering objects increases; thus we expect that the average SNR of the communication channel is lower, as confirmed by the value in Table 3.

The strong variations experienced, in terms of link availability and SNR, suggest that the optimal packetization policy should be different when environmental changes happen, to take advantage of the different bit error probability [18] which depends on the SNR at the receiver. In particular, in the urban scenario we expect that a transmission policy which privileges small packet sizes (S) results in lower error rates compared with the large packet size policy (L). In the highway scenario, instead, we expect that the transmission policy L performs better for the opposite reasons. Despite the lower link availability, in fact, the relatively high SNR value allows the error-free transmission of larger packets, leading to a greater throughput when the link is available. Moreover, it is better to exploit the channel as much as possible when the link is available because the devices can communicate for less than 34% of the time (as shown in Table 3).

4.2 Analysis of the Transmission Performance

In this section we present the performance of video streaming in the urban and highway scenarios, analyzing both network metrics such as the packet loss rate and the goodput value, and video quality measures such as the Peak Signal-to-Noise Ratio (PSNR) and its variance.

In Figure 4 the packet loss rate of each transmission experiment in the urban scenario is presented using box-plots, which are useful to analyze the statistical distribution of the data. Each box-plot represents the distribution of packet loss rate obtained with 50 transmission experiments of the same flow. The line in the middle of the box indicates the median value, the upper and lower bounds of the box indicate the third and first quartile respectively (Q3 and Q1), that is, 50% of the values lay inside the box. The external lines extend until the adjacent values (as defined in [20]) and they denote the distance between the upper adjacent value and Q_3 (upper line) and between the lower adjacent value and Q_1 (lower line). The upper adjacent value (AV_u) is the largest observed value which satisfies the inequality $AV_u \leq Q_3 + 1.5r$ where $r = Q_3 - Q_1$ is the inter-quartile difference. Analogously, the lower adjacent value (AV_l) is

Table 3. Average link availability and SNR.

Scenario	Average link availability	Average SNR when link is available
Highway	33.98 %	22.49 dB
Urban	97.78 %	19.14 dB

Table 4. Packet loss rate, goodput and perceptual quality values for all flows.

Highway scenario				
Flow ID	Packet loss rate (%)	Goodput (kbit/s)	PSNR (dB)	PSNR std. dev. (dB)
S1	9.13	139.1	32.42	7.95
L1	6.95	141.8	33.41	5.75
S2	15.79	246.9	32.53	10.29
L2	6.63	273.5	36.54	7.32
S3	21.34	460.9	26.42	4.92
L3	12.20	510.3	31.37	5.31

Urban scenario				
Flow ID	Packet loss rate (%)	Goodput (kbit/s)	PSNR (dB)	PSNR std. dev. (dB)
S1	1.95	150.1	35.87	3.93
L1	5.45	144.0	33.77	5.71
S2	8.84	267.2	33.57	7.75
L2	10.06	263.5	33.77	8.47
S3	7.64	541.2	32.89	3.76
L3	8.70	530.7	32.49	4.34

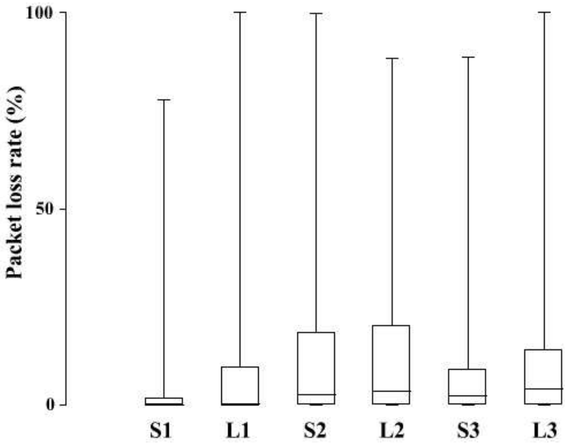

Figure 4. Raw packet loss rate data for the urban scenario presented with box-plots. The line in the middle of the box indicates the median value, the upper and lower bounds of the box indicate the third and first quartile respectively (Q_3 and Q_1) and the external lines extend until the adjacent values.

the smallest observed value which satisfies the inequality $AV_l \geq Q_1 - 1.5r$.

A commonly accepted empirical rule, first proposed by Tukey [20], has been used to check if potential outliers are present. If the length of the lines external to the box is more than 1.5 times the inter-quartile range (i.e. the height of the box) outliers probably exist. Figure 4 therefore shows that most of the samples whose packet loss rate is about 100% are potential outliers.

To unveil those possible outliers, we used the well-known Tchebyshev's inequality. By using this method we do not make any specific assumption on the statistical distribution of the data. Tchebyshev's inequality states that the probability Π_s for any sample s to be more than ι times σ far away from the mean is

$$\Pi_s < \frac{1}{\iota^2} \tag{1}$$

We used an interval of 95%, which is a reasonable value for experimental statistics, to decide which samples will be discarded, that is, the probability of the sample is less than $\overline{\Pi}_s$, where

$$\overline{\Pi}_s = \frac{100 - 95}{100} \cdot \frac{1}{2}. \tag{2}$$

The factor 1/2 is due to the symmetry of the Tchebyshev's distribution. Let ι_{cr} be the *critical value* of ι, that is, the value which satisfies Equation (1) for the chosen $\overline{\Pi}_s$. The critical value ι_{cr} is equal to 6.32. Samples whose standard deviation is greater than $\iota_{cr} \cdot \sigma$ have been discarded.

Table 4 presents the values of packet loss rate measured when transmitting the six flows in the two considered scenarios, after discarding the outliers with the previously described method. The packet loss rate and goodput values in

Table 4 show that the packetization policy S (small packets) experiences lower error rates than the policy L (large packets) in the urban scenario and vice versa for the highway scenario. Clearly, the goodput values present the same behavior. Note that the goodput shown in the table is defined as the amount of useful bits received (excluding retransmissions). The different behavior of the two packetization policies is clearer in the highway scenario, where switching from policy S to L increases the goodput up to 10%. In this scenario the low link availability causes packet dropping at the transmitter due to MAC-level timeout expiration; therefore, given a certain amount of data to transmit, it is better to create a lower number of large packets than a high number of small packets. In the urban scenario, instead, the nearly constant availability of the channel leads to lower packet loss rates because the loss rate due to MAC-level timeout expiration is negligible. Given a certain SNR, therefore, the packet loss rate is only function of the number of bits in the packet. This leads to smaller differences in goodput (about 2-4%, see the S- and L-flows of the urban scenario in Table 4).

We also evaluated the perceptual quality experienced by the user at the receiver, in terms of PSNR. Although the PSNR may not be the best estimator of the users' mean opinion, it is a widely accepted measure and it facilitates comparisons with other works. Results are shown in the last two columns of Table 4. Gains up to 5 dB in perceived video quality are possible in the highway scenario if the best packetization policy L (large packets) is chosen (see flows S3 and L3). In the urban scenario, as previously explained, the best packetization policy consists in sending small packets, but in this scenario the differences between the two transmission policies, although they can be significant (more than 2 dB when transmitting at 150 kbit/s), are generally smaller due to the lower average packet loss rate. It is also worth noting that, regardless of the scenario, the standard deviation values are always lower if the best packetization policy is chosen, that is, PSNR values are more consistent with positive effects on the overall quality perceived by the user.

5 The Adaptive Algorithm

The results of the transmission experiments presented in the previous section suggest that it is possible to increase the video quality adapting the packet size to the instantaneous driving conditions. Hence we propose to design an algorithm which discriminates between the two considered scenarios, i.e. urban and highway. As shown in Section 4.1, those scenarios present very different characteristics in terms of the link availability value (LA). Hence we designed an algorithm which tracks the mean LA value to determine the scenario, then it accordingly decides which is the best transmission strategy. Every second the algorithm evaluates the mean LA value on a thirty-second temporal window, and then it decides which is the best transmission policy to use, i.e. the maximum packet size parameter of the video encoder. A threshold value equal to 95% of link availability has been empirically determined on the basis of the data shown in Figure 3. The pseudocode of the algorithm is reported in Table 5.

Table 5. Pseudocode of the adaptive algorithm.

```
while (true) {
   LA = update_LA_window();
   switch(policy) {
      case S:
         if (LA < 95%)
            switch_to_policy(L);
         break;
      case L:
         if (LA > 95%)
            switch_to_policy(S);
         break;
   }
}
```

6 Results

This section presents the results obtained using the adaptive transmission algorithm described in Section 5. The algorithm has been tested in a time-varying scenario. For about half of the time packets are transmitted in the urban scenario, then the scenario rapidly changes into the highway one, which lasts until the end of the experiment. Three experiments using different video bitrates have been performed. The link availability values as a function of time are shown in Figure 5 for the three experiments. In all of them the heuristic threshold of 95% of link availability appears a reasonable choice.

Table 6. Overall results for each policy in terms of PSNR.

Bitrate (kbit/s)	Transmission Policy		
	Fixed (S)	Fixed (L)	Adaptive
150	35.06	34.38	35.32
300	35.41	36.05	36.11
600	23.88	27.02	27.21

The PSNR values are reported in Table 6. The second and third columns refer to a transmission policy in which the video packet size is decided a priori and is not varied during the experiments, while the last column of Table 6 refers to the proposed adaptive technique, which chooses the best policy (i.e. the packet size) using the algorithm described in Section 5. As expected, the performance is higher than any of the fixed-policy techniques. These results show that the adaptive technique, compared with the fixed-policy techniques, provides performance gains up to 3.3 dB, depending on the bitrate and the considered fixed-policy technique. The gain for the 600 kbit/s transmission also shows that the performance of 802.11 inter-vehicular transmissions may be very sensitive to variations of the packet size, demonstrating that it may be very difficult or impossible to determine a generally valid fixed video packet size. More experiments are, however, needed to validate and further improve the presented technique in different driving conditions.

7 Conclusions

In this paper we presented the results of inter-vehicular video transmission experiments using the 802.11b ad hoc network protocol in two typical driving scenarios, urban and highway. The tests showed that each scenario presents peculiar characteristics in terms of link availability and SNR, which can be used to help in developing more efficient applications. We also evaluated the video quality at the receiver by means of the PSNR distortion measure, showing that the best packetization policy depends on the scenario. Then we exploited those differences to optimize the performance of video transmissions, designing an adaptive algorithm which dynamically chooses the best policy depending on the characteristics of the scenario. Perceptual quality results showed that consistent quality gains in terms of PSNR value (up to 3 dB) can be achieved with respect to a fixed-policy transmission technique.

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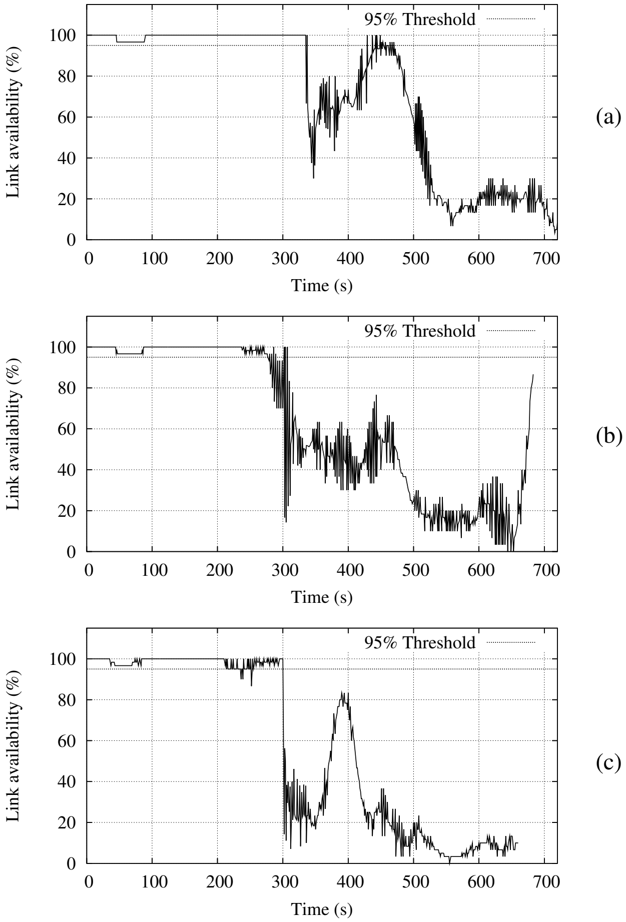

Figure 5. Link availability as a function of time for the three transmission experiments using the adaptive algorithm: at 150 kbit/s (a), at 300 kbit/s (b), at 600 kbit/s (c).

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