

PERFORMANCE EVALUATION OF UDP MULTIMEDIA TRAFFIC FLOWS IN SATELLITE – WLAN INTEGRATED PATHS^(*)

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Abstract

In this paper, we present a set of experimental results, which show the behaviour of UDP (User Datagram Protocol) traffic flows, with respect to QoS (Quality of Service) requirements, in a basic Satellite – MANET (Mobile Ad hoc NETWORKS) testbed. The testbed is constituted by a set of portable computers, interconnected by WLANs, and with a remote host through a satellite path. The packet loss, the data jitter, and the packet delay are investigated both for Constant Bit Rate (CBR) flows, and for a real video application.

Index Terms: Performance evaluation, QoS, Delay, Jitter, UDP, Satellite, Skyplex Data, WLAN, MANET

1. Introduction

Natural and man-made disasters, like earthquakes, floods, storms, structural collapses, etc., pose a challenge to public emergency services. In order to cope with such disasters in a fast and coordinated manner, communications between rescue squads, both among themselves and outside the assisted zone, play a critical role. In the hours and even days following these events, communications are often limited, due to the damages caused by the disaster to land connections or because the event occurred in an area without infrastructures.

Wireless communications are the reply to these needs; wireless networks are the easy, fast, and intuitive way for providing the first communication means for the depicted scenarios. In particular, MANET (Mobile Ad hoc NETWORKS) [1] is the topology generally contemplated in these situations, in which handheld devices or notebooks use wireless ad-hoc networks for communications between each other and with a special node, which is a gateway for outside communications, through a satellite link.

Given such a network, we assume that user data are flows derived from multimedia and real-time applications, like voice calls, video streaming, and video conferencing, which make use of UDP (User Datagram Protocol) transport protocol.

In this paper, we present a set of experimental results, which show the behaviour of UDP traffic flows in a basic MANET testbed developed at ISTI. The testbed is constituted by a set of portable computers and handsets, interconnected among them in wireless mode, and a Skyplex Data satellite link [2][3]. The portable computer that acts as a gateway between the ad-hoc network and the Skyplex box is a Debian Linux box (kernel 2.6.8, Celeron 1.133 GHz with 256 MB of RAM).

Wireless LANs [4][5] have the advantage of low delivery delays, but they have drawbacks such as the high channel errors due to multiple paths and data collisions. Satellite

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links have an inherent broadcast facility, but they suffer from high delivery delays and atmospheric adverse conditions, which may worsen the Signal to Noise Ratio (SNR). Thus, the whole network, made up of WLAN nodes and the satellite link, is not a trivial environment for QoS (Quality of Service) requirements of the multimedia flows.

The packet loss, the data jitter and the end-to-end delivery delay are separately measured in both the WLAN and the satellite link; then, these three parameters are evaluated as total, combined effects on the hybrid wireless network considered. The traffic flows used are both a simple CBR (Constant Bit Rate) generator, characterized by the size of the IP datagram packets and the packet generation time interval, and a multimedia and real-world video application. The investigation aims at evaluating the QoS performance of UDP traffic flows, both in unicast and in broadcast/multicast transmission mode. Delivery delays, from the application layer's point of view, are finally calculated, which are useful for estimating the buffer's sizes of the receiving applications.

2. Testbed configuration

The testbed configuration of our transmission experiments is depicted in Fig. 1.

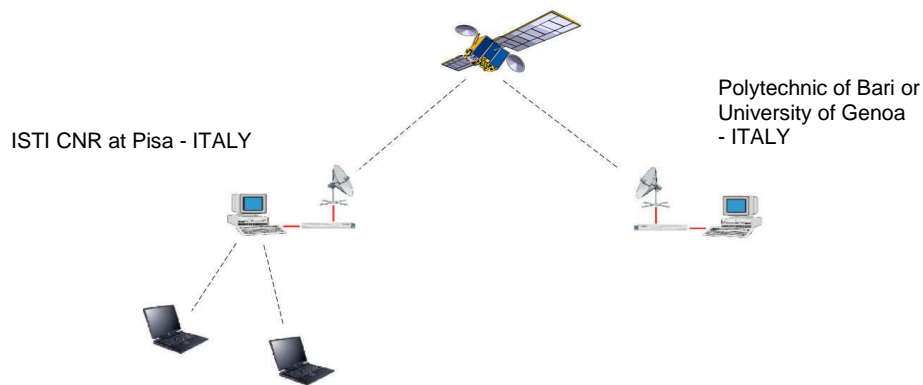


Figure 1 – Testbed environment.

The wireless path at ISTI is made up of notebooks (Celeron 1.133 GHz with 256 MB of RAM) equipped with a Debian Linux operating system (kernel 2.6.8). The wireless link is assured by wireless PCMCIA network cards of different manufacturers (CNet CNWLC-811 IEEE802.11b for transmission, Conceptronic C54RC IEEE802.11g for reception), always operating with the standard DCF (Distributed Contention Function) [4] contention access mode at a rate of 11 Mbps, and acting as traffic sources. Another Linux host acts as a gateway between the WLAN network and the Skyplex box, and forwards packets towards the satellite.

The satellite link is a Ka channel of the Eutelsat HotBird™6 satellite, which uses the technology known as Skyplex Data [2][3][6]. This is an IP-based satellite network derived from the DVB-RCS [7], and it is used here in a standard point-to-point (for unicast traffic) and point-to-multi-point (for multicast traffic) topology.

We have used remote Linux hosts hosted at the Polytechnic of Bari and at University of Genoa, alternatively, as traffic sinks on the other side of the satellite link.

In unicast transmissions, WLAN cards use standard IEEE802.11 settings; in particular, the DCF Retry Limit value is set to 7 for every outgoing MAC frame, i.e. up to 7 transmission retries are performed in case of unacknowledged frames. In multicast transmissions, the value of the Retry Limit is zero, i.e. the frame is transmitted only once a time, regardless its good reception.

3. The Measurements

In the first phase, UDP packets have been generated by a simple CBR traffic generator written in C, in order to test the single WLAN or the satellite links, and to investigate their basic performance. About 24 hours of measures has been performed both on the satellite channel and on the WLAN channel, with single tests of 45 minutes each. In a second phase a real world MPEG-4 video stream has been transmitted by means of the software VLC (Video Lan Client) on the full WLAN and satellite path.

A software in C has been developed with the purpose of tracking and collecting packets in the cardinal points of the path, i.e. at the WLAN source, at the satellite gateway, and at the remote sink. This software runs on Linux in user mode, so the collected statistics refer to the application's layer. All the time measures (the end-to-end jitter and delay) have the precision of the Linux kernel clock. The *gettimeofday()* system call has been used; it returns ms time figures from the Linux System Time, making use of the wall-clock time.

We gathered our measurements with the notebooks located in fixed indoor positions, at about 10 meters apart from the satellite gateway, separated by thin walls and doors, and with people working around involved in the common activities of an office environment.

We carried out several measurement campaigns, with CBR traffic at different transmission rates, varying both the packet lengths and their inter-generation time. It is well known that WLAN communication's performance widely change according to the environment, people's presence and movements; thus, we present here only the most representative tests of the common situation observed, and we introduce a way for deriving Retry 0 transmission performance from the Retry 7 ones, so that a direct comparison is possible between the two WLAN operating modes.

Every test presented in this work lasts 45 minutes; every packet generated has its own sequence number; for all packets that travel through the three cardinal points of observation of the network, the software sniffs pieces of information like the sequence number, the packet length and the transit time. Each packet may experience a different transmission delay, so a jitter, defined as the difference between two transmission delays, is induced on the packet arrival time [8][9]. By definition, in every single hop, the first packet received has a null jitter, while the n^{th} packet (transmitted at the time $t_{TX,n}$ and received at the time $t_{RX,n}$) has the jitter $j_{n,1}$ given by

$$j_{n,1} = (t_{RX,n} - t_{RX,1}) - (t_{TX,n} - t_{TX,1}) \quad (1)$$

i.e. the jitter $j_{n,1}$ is referred to the transmission delay of the first packet, because this is comfortable for the delay calculation.

Since it's difficult to synchronize the clocks of the observation points and every clock has its own drift, we assumed linear clocks' drift. A linear correction has thus been adopted along with every interval of 12 consecutive hours of measures. In short, the slope of the linear part of the jitter drift, caused by the different clocks' drift of the transmitting and receiving side, has been calculated for such intervals, and a linear correction proportional to the time was applied at every $j_{n,1}$. Then, an offset O is added to the jitter values so calculated in order to obtain the packet delay values D_n given by

$$D_n = j_{n,1} + O \quad \ni \quad D_{hop} = \min_n \{D_n\} \quad (2)$$

so that the minimum delay obtained is equal to the minimum delay of the hop D_{hop} , measured as the half of the minimum round trip time of 1000 *Ping* packets, sent with the same size and inter-generation time of the analyzed packets.

Furthermore, continuous jitter calculation, as specified by RTP protocol in [10], is evaluated as

$$J_n = J_{n-1} + \frac{|j_{n,n-1}| - J_{n-1}}{16} \quad (3)$$

where the difference between transmission delays $j_{n,n-1}$ is referred to consecutive packets. Hereafter, when we speak about packet jitter we refer to J_n defined in (3).

3.1. The satellite path

Figure 2 shows the packet delay of a CBR traffic realized with UDP packets of 1000 bytes (IP header included) and packet inter-generation time of 20 ms (which results in a 400 kbps rate), relatively to the satellite link only. The figure shows a packet delay quite regular and concentrated, except for rare peaks, where the system seems to recover after a sort of bad situation. It is worth pointing out that the satellite used performs on board processing, and the transponder is shared in TDMA (Time Division Multiple Access) mode with other users. Figure 3 presents the CDF (Cumulative Distribution Function) of the packet delay. Figures 4 and 5 show the details of the delay spread and the peaks of the packet delay, respectively. In particular, Fig. 5 shows what happens when packets are not transmitted on the satellite path, for less than 1 s interval. When the transmission resumes, the delay has accumulated and the situation recovers in about 5 s. This phenomenon has been observed in all the satellite tests.

The satellite channel has resulted to be almost error-free; very few losses have been observed so that is not possible to give a precise value of the packet loss. No single packet errors have been registered and this is probably due to the peculiarity of the Skyplex architecture. Error bursts of 2 or 3 consecutive packets have rather been observed.

The minimum delay D_{hop} measured on the satellite path has been 0.284619 s; Table I shows the mean and standard deviation of the packet delay and the mean packet jitter.

	Packet loss [probability]	Packet delay [s]		Mean jitter [s]
		Mean	Standard deviation	
Satellite	-	0.334329	0.104579	0.0133456
WLAN Retry 0	3.33×10^{-1}	0.000912	0.000094	0.000028
WLAN Retry 7	4.82×10^{-4}	0.001379	0.001080	0.000669
WLAN "Retry 0" emulated	2.12×10^{-1}	0.000978	0.000091	0.000022

Table I – Packet loss, packet delay and packet jitter statistics of the satellite and WLAN transmissions, relative to 45' of CBR traffic presented in Fig. 2, 6 and 9.

3.2. The WLAN path

Figure 6 shows the packet delay on the WLAN alone, when the above described CBR traffic is transmitted with Retry 0 (suitable for multicast/broadcast transmissions). The delay is quite constant and delimited by a narrow band. Figures 7 and 8 show the length of the packet error bursts during the test. The statistics relevant to this test are shown in Table I.

Figure 9 is analogous to Fig. 6, but with Retry 7 (suitable for unicast transmissions). It is plain that the different bands in which the delays of the packets are gathered correspond to the retries the WLAN MAC layer operates. As shown in Table I, the mean and standard deviation of the packet delay for WLAN Retry 7 test is greater than the Retry 0 one, while the packet loss benefits from the retries. This is evidenced in Fig. 10, in which the packet error bursts' length for the Retry 7 test is shown, and in Fig. 11, in which the PMF (Probability Mass Function) of the packet error length for Retry 0 and Retry 7 tests are compared each other. In Fig. 12 the CDFs for the packet delay of Retry 0 and Retry 7 tests are compared.

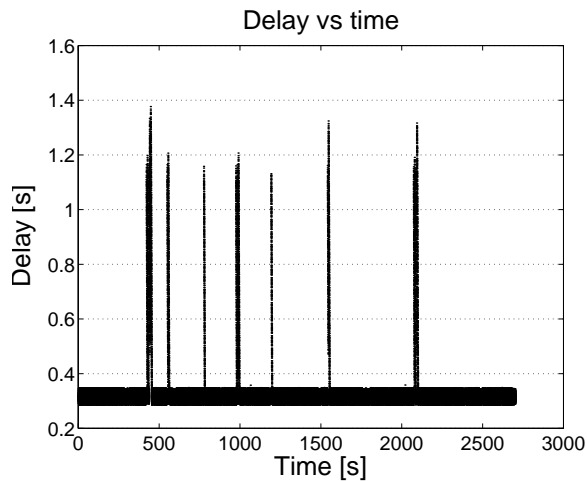


Figure 2 – Packet delay for the satellite channel observed in 45' of transmissions.

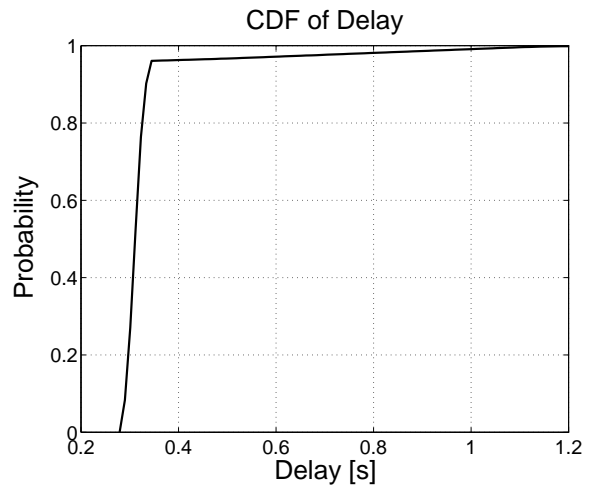


Figure 3 – CDF of packet delay for data in Fig. 2.

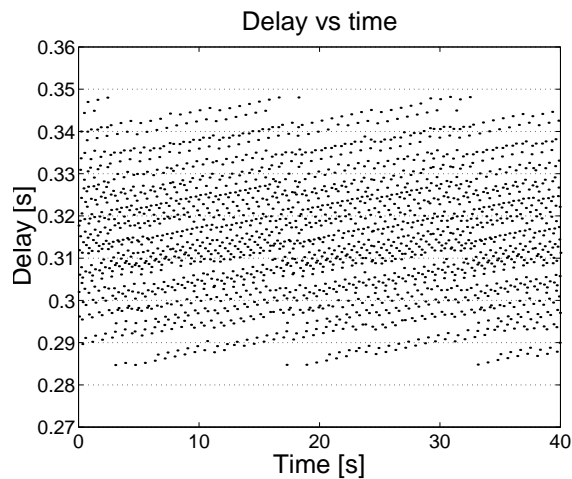


Figure 4 – Details of first 40 s in Fig. 1.

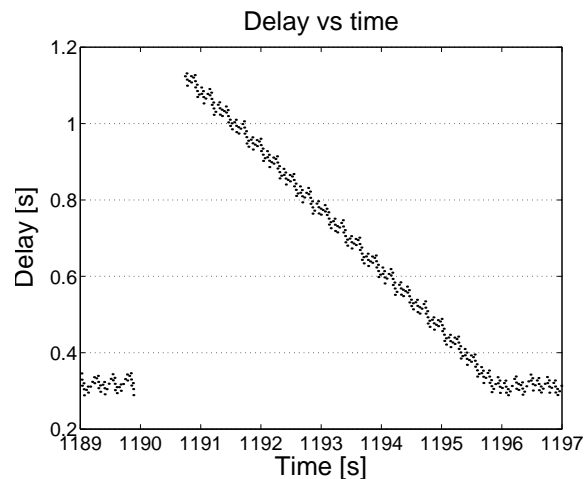


Figure 5 – Details of a delay peak in Fig. 1.

It is important to notice that WLAN channel's performances widely change due to radio multipaths and environment variations, and the WLAN Retry 0 and Retry 7 tests shown are not really comparable. In fact in other Retry 7 tests very heavy packet losses have been found as well.

Instead, for most part of the packets of the Retry 7 test, it is easy to discriminate the packets received at the first try performed by the IEEE 802.11 MAC protocol from those received at subsequent retries, by simply watching the delay experienced by each packet. If the Retry would be set to 0, all packets transmitted with retries would have been lost. Thus, it is possible for the Retry 7 test to go back and to roughly achieve what it would be happened in the same situation, if the Retry would be set to 0. Figure 13 shows the CDF of packet delay for the WLAN channel with Retry 7 compared to the one obtained for the first try only of the same transmission (for the purpose, packets with delay less than or equal to 0.002134 s have been considered first try packets). Table I shows the packet loss, the mean packet delay, its standard deviation, and the mean packet jitter of this comparable "Retry 0" emulated transmissions.

The minimum delay D_{hop} measured on the WLAN path has been 0.000883 s.

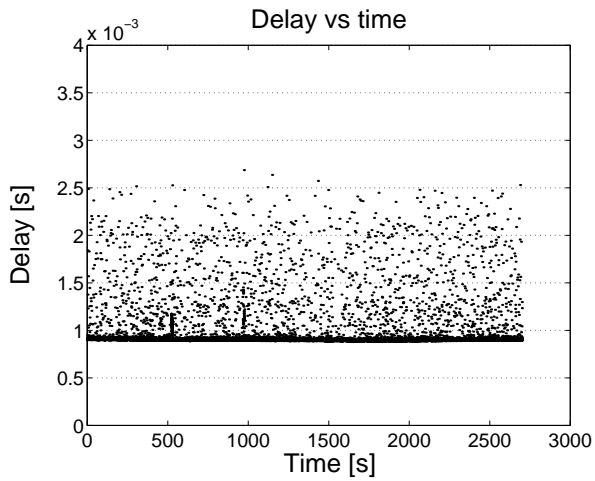


Figure 6 – Packet delay for the WLAN channel with Retry 0 observed in 45' of transmissions.

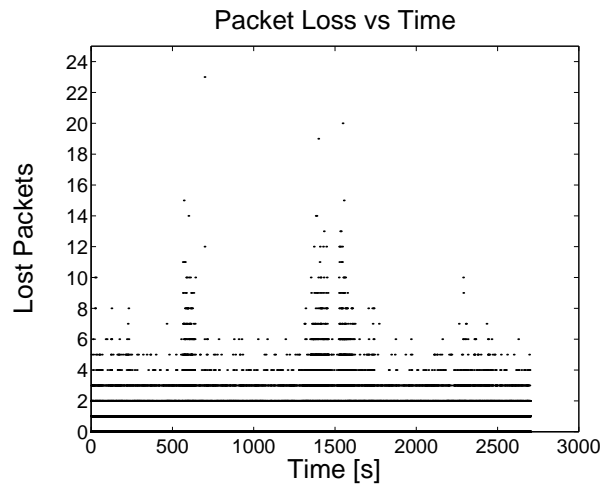


Figure 7 – Lost packets for WLAN transmissions with Retry 0 in the test of Fig. 6.

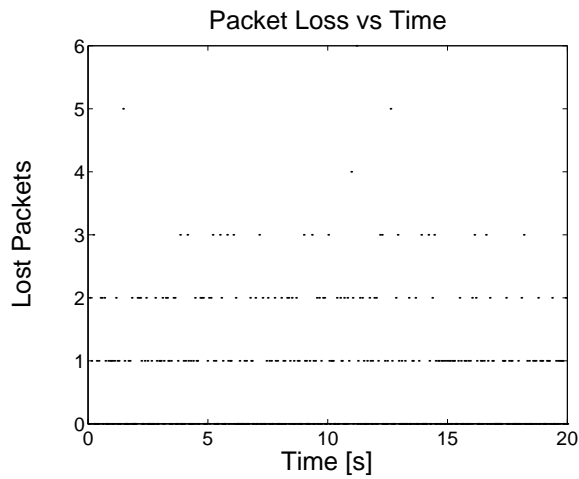


Figure 8 – Details of first 20 s of Fig. 7.

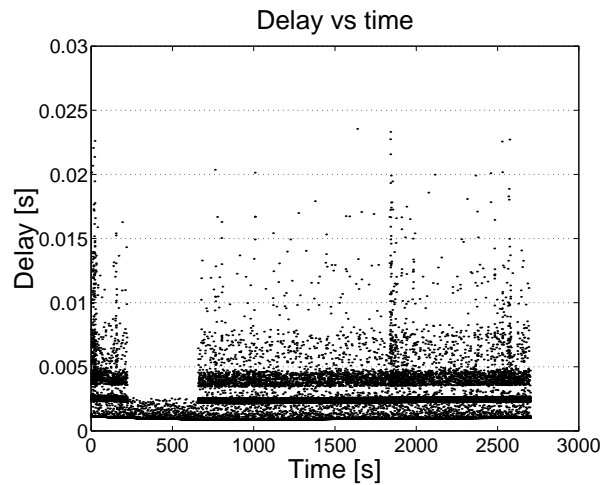


Figure 9 – Typical trend of packet delay for the WLAN channel with Retry 7 observed in 45' of transmissions.

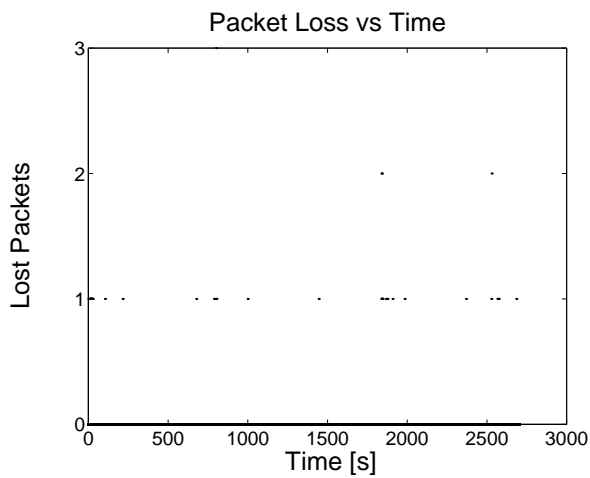


Figure 10 – Lost packets for WLAN transmissions with Retry 7 in the test of Fig. 9.

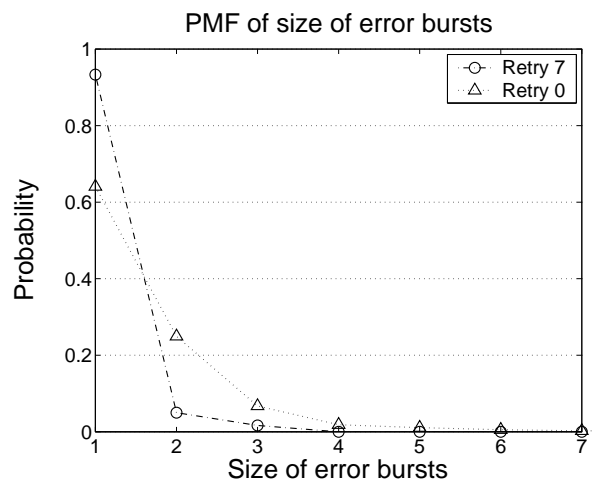


Figure 11 – PMF of the error burst length for WLAN transmissions.

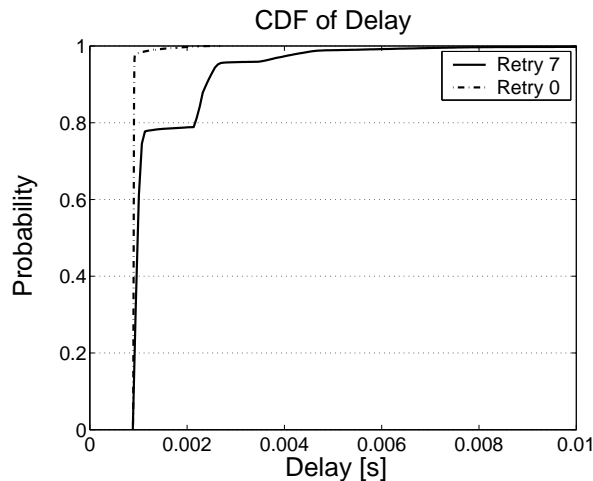


Figure 12 – CDF of packet delay for WLAN transmissions.

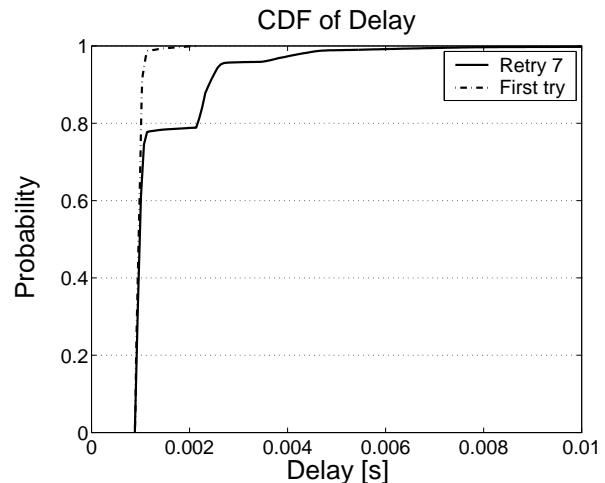


Figure 13 – CDF of packet delay for the WLAN channel with Retry 7, and for the first MAC try only.

3.3. MPEG video transmission on the full path (WLAN and satellite)

A transmission of a real MPEG-4 video stream has been performed over the full WLAN and satellite path. The VLC software [11] has been used as source: it generates UDP packets of a fixed size of 1344 bytes (IP header included), with a variable inter-generation time. Further 4 bytes have been added to each of the generated packets, for tracking purposes. The transmission lasted 45', and 160402 packets was generated, achieving a mean throughput of 640.7 kbps. The WLAN hop operated in the Retry 0 mode, emulating a multicast or broadcast transmission, within a low noise channel.

Table II shows the packet loss, the mean packet delay, its standard deviation, and the mean jitter measured in each hop, and the ones resulted in the total path.

	Packet loss [probability]	Packet delay [s]		Mean jitter [s]
		Mean	Standard deviation	
WLAN (Retry 0)	4.00×10^{-2}	0.000940	0.000231	0.000021
Satellite	-	0.367103	0.196004	0.010863
Full path	4.00×10^{-2}	0.367946	0.196004	0.010864

Table II – Statistics of the full path transmission, relative to 45' of a real video streaming.

Figures 14, 15, and 16 show the behaviour of the packet delay, the CDF of the packet delay, and the packet jitter for the full path streaming, respectively. Most of delay and jitter is due to the satellite hop. Figure 17 shows the number of lost packets in the full path; losses are fully due to the WLAN hop.

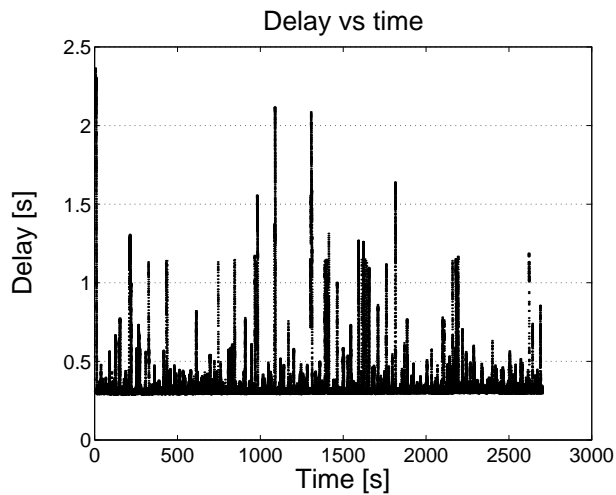


Figure 14 – Packet delay for the full path in 45' of real video streaming.

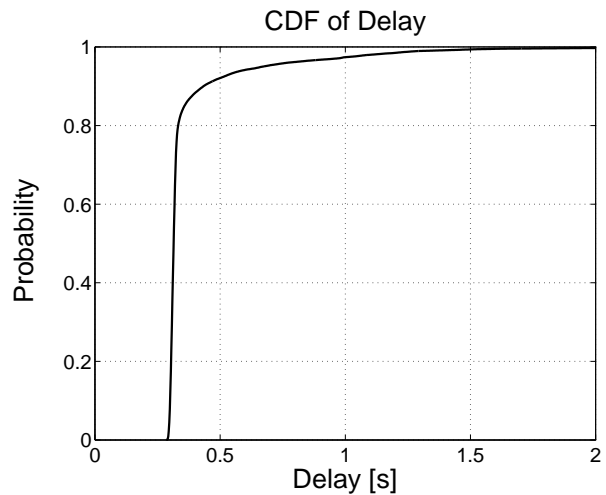


Figure 15 – CDF of packet delay for data in Fig. 14.

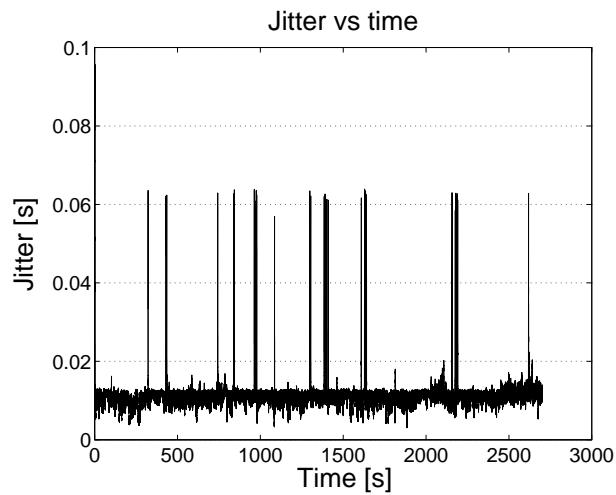


Figure 16 – Packet jitter for the full path video stream.

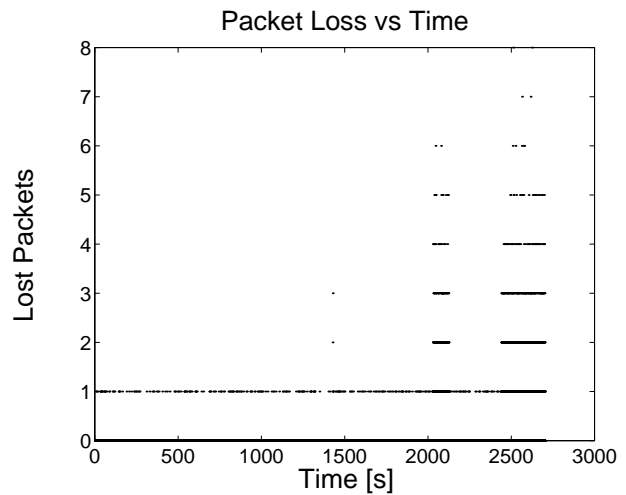


Figure 17 – Lost packets for the full path video stream.

4. Conclusions

An integrated WLAN-satellite testbed has been developed, and UDP transmissions have been performed both with CBR traffic and with a real video stream. The number of lost packets, the packets' delay and their jitter have been measured.

In the end, the resulting packet loss of this hybrid network topology is fully due to the losses in the WLAN hops, while most of the delay and the jitter comes from the satellite hop.

The QoS of multimedia and real-time transmissions over this kind of network topology is severely tried, because the negative effects of each hop are summed in the full path.

A buffer of few seconds located at the receive application, according to our experimental results, is required to fully absorb the jitter, thus guaranteeing the quality of multimedia non real-time streams. Furthermore, it would be better to implement, in the WLAN hops, a different loss recovery strategy. In fact, although the Retry 7 mode improves the safety of transmitted packets, it is not suitable for multicast and broadcast transmissions. Adaptive Forward Error Correction (FEC) techniques, such as erasure codes, could be used in the WLAN hops for multicast transmissions. Such a technique could improve the packet safety with the trade-off of a wider bandwidth occupancy and an increase in the packets' delivery time. This topic will be investigated in a future research. As it is well known the delay

introduced by the satellite channel can be the biggest problem for real-time interactive applications.

The investigation and the behaviour of TCP flows within the hybrid topology here described is another interesting research topic.

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