IEEE802.11 WIRELESS NETWORK UNDER AGGRESSIVE MOBILITY SCENARIOS

Pierpaolo Bergamo, Daniela Maniezzo, Kung Yao
Electrical Engineering Department
University of California, Los Angeles, CA 90095
{pbergamo, maniezzo, yao}@ee.ucla.edu

Matteo Cesana, Giovanni Pau, Mario Gerla
Computer Science Department
University of California, Los Angeles, CA 90095
{cesana, gpau, gerla}@cs.ucla.edu

Don Whiteman
NASA-Dryden Flight Research Center
Edwards, CA 93523
donald.e.whiteman@nasa.gov

ABSTRACT

Wireless LAN (WLAN) has been extensively deployed in commercial, scientific and home applications due to the availability of low-cost wireless Network Interace Cards (NICs) based on the IEEE802.11 standard. The purpose of this work is to study experimentally the behavior of an IEEE802.11 wireless network when the nodes are characterized by mobility up to the speed of 240 km/h. This study leads to the understanding of the survivability and the performance of a connection under various aggressive mobility conditions. These studies may be adapted for data telemetry from mobile airborne nodes to fixed networks or between airborne nodes.

INTRODUCTION

Since its birth in the 70s, Wireless LAN technology has become increasingly popular in the network industry. Wireless LANs have been devised to provide ubiquitous communication capabilities and information access to nomadic users. A nomadic user roams around and wants to be granted with “anywhere anytime” connectivity (e.g., employees of the same company visiting different branches) [1][2].

The WLAN technology was standardized for the first time in 1997 by IEEE within the IEEE802.11 standard which specifies the features of the Medium Access Control (MAC) and of the Physical layer [3]. This standard is implemented in almost all available WLAN devices.

While the IEEE802.11 standard supports client mobility, it was originally devised to replicate in a wireless fashion the structures of the wired Local Area Networks (LANs). Only recently the idea of utilizing IEEE802.11 technology for high mobility scenarios has been taken into account and the range of WLAN based applications has been enriched.

In [4] authors analyzed the performance of an IEEE802.11b system under different propagation and mobility scenarios, even though the performance is only related to an inter-vehicular communication.

Another feasible application of IEEE802.11 technology is telemetry. The idea is to equip aircraft and/or cars with IEEE802.11 enabled devices which communicate data with a fixed backbone infrastructure. In [5], authors developed their own frequency hopping transceiver working at 900 MHz for telemetry purposes. In [6], the project of using a WiFi-like network for military telemetry applications is presented and discussed. In that paper, the authors focused on aspects like frequency selection and network security. Another interesting work is [7], in which it is assured through analytical considerations that these kinds of transceivers can guarantee an impressive tolerance to high speeds.

Our work can be considered an extension of the work in [4] because we extend the measurements for telemetry purposes, and a proof of the work [7], because in some sense we demonstrate the good performance of this technology, which was considered only by analytical means. A better understanding of the IEEE802.11 performance in various mobility and propagation scenarios is the final goal of this work.

EQUIPMENT DESCRIPTION AND SOFTWARE TOOLS

Depending on the experiment we performed, one or more cars equipped with IEEE802.11b hardware (bridge, access point or client adapter) and laptops were used for the traffic generation and data collection. We used Intel [8] Pentium IV based laptops running Iperf [9] for traffic generation and transport layer statistics. In several experiments, two 5.2 dBi gain outdoor Cisco [10] AIR-ANT2505 omnidirectional antennas were connected to a Cisco Aironet BR340 bridge configured according to the experimental requirements. The Cisco bridge was connected to the laptop using a Ethernet cable.

The MAC layer statistics collection was performed using a self-made wireless sniffer, named EMS (El Mirage Sniffer). The sniffer was developed at Computer Science and Electrical Engineering Departments of UCLA. It is written in C language, by using the pcap [11] library. We wrote our own sniffer to conduct actual performance evaluation. Note that a wireless sniffer could or could not get all the packets sent from a source to a destination and vice-versa. So we built a program able to collect statistics, without making a huge dump of the traffic, and able to reconstruct (if possible) the statistics of the missed traffic. This is performed by using information in IEEE802.11 headers. The program can run on a simple PDA with an IEEE802.11b card.

EXPERIMENT DESCRIPTION

In order to study the effects of aggressive mobility on wireless network performance, we devised a set of measurements in different scenarios. We have selected three propagation scenarios:

- Free space propagation: by free space, we mean that the experiments were performed in the desert area of El Mirage Dry Lake, CA, USA, even though it should not be called “free space” properly, but such an area is completely flat and without plants;
- Highway condition: the experiments were conducted on US Highway 1 in the Palos Verde area (South of Los Angeles);
- Semi-free space propagation: the experiments were performed in a parking lot, in which there are obstacles, such as metallic containers and trees, but they are fixed.

Several sets of experiments have been performed aiming to exploit time-varying problems related to outdoor propagation environments with high speed mobility.

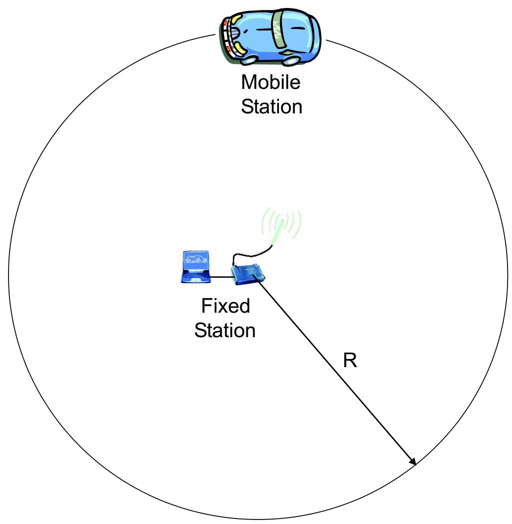

Fig. 1. High Speed Experiments: Circular.

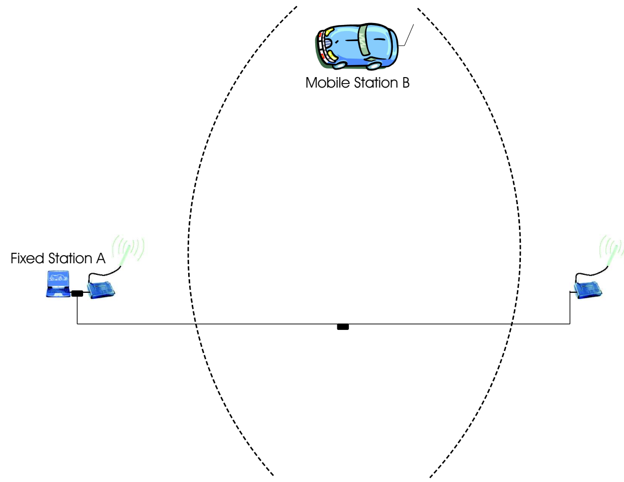

Fig. 2. Handoff Experiments.

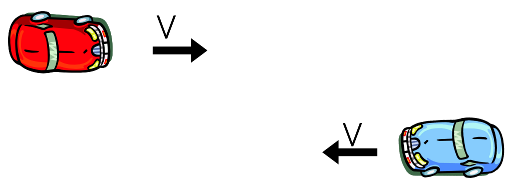

Fig. 3. High Speed Experiments: Straight.

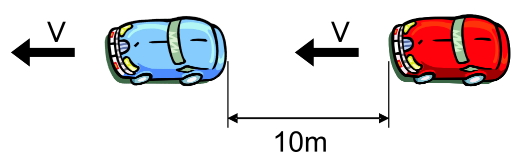

Fig. 4. Follow Experiment with Approximate Zero Relative Speed Between the Cars.

High Speed Experiments

Two sets of experiments were performed:

- *Circular*: Figure 1 shows the experimental setup. A station, equipped with a Cisco bridge with a high gain antenna, is fixed in the center of a circle. The mobile station is moving around the circumference. The experiments were conducted changing the circumference radius and the speed of the mobile station in the free space propagation scenario. We used a GPS system to assure a circular trajectory.
- *Straight*: in those set of experiments, the two cars are moving in opposite directions at predefined speed. The distance between the cars first decreases and then after the meeting point, increases as shown in Figure 3 with the relative speed between the two cars as the sum of the two speeds. Here the focus is on the impact of the relative speed between the two wireless nodes. This set of experiments have been conducted both in free and semi-free space propagation scenarios.

A reasonable cell size was selected in order to avoid the renegotiation of the link speed according to the current network conditions of IEEE802.11b. Thus, we set the link speed to the fixed rate of 2 Mbit/s for all our experiments. In particular, the following traffic conditions were used:

- 128 kbit/s UDP (User Datagram Protocol) traffic (light load);
- 1 Mbit/s UDP traffic (medium/high load).

Following Experiments

In this set of experiments, two cars are equipped with a laptop connected to a wireless bridge each and the 5.2 dBi gain antenna described above. One car follows the other as shown in Figure 4 with an approximate zero relative speed and an approximate distance of 20 m between the two cars. Experiments were performed at different absolute speeds in a highway and free space scenarios. This set of tests aims to study the efficiency of the IEEE802.11 in a typical case of group mobility where wireless nodes move with relative speed near to zero. As in the first set of experiments, we set the link speed to the fixed rate of 2 Mbit/s. These are the data considered rates:

- 128 kbit/s UDP traffic (light load);
- 1 Mbit/s UDP traffic (medium/high load).

Handoff Experiments

The IEEE802.11 standard includes mechanisms to allow a client to roam among multiple Access Points (APs) or bridges, that can be operating on the same or separate channels. Each AP transmits a beacon signal every T_{beacon} second (in our experiments $T_{beacon} = 100ms$). The beacon includes a time stamp for client synchronization, a traffic indication map, an indication of supported data rates and other parameters. Roaming clients use the beacon to gauge the strength of their existing connection to an AP. If the signal is judged too low,the roaming station can attempt to associate itself to a new AP. The roaming station first performs a scanning function to locate a new AP on the same or a different channel. The client can send probes to a number of APs and receive probe responses from each to select the most suitable AP. Upon finding the strongest signal, the client sends a reassociation request to the new AP. The AP will accept and acknowledge the request to complete the handoff procedure.
During the handoff procedure, the exchanging of management packets and the eventual scanning on other channels cause a latency in which the client is unable to send or receive traffic.

The purpose of this set of experiments is to understand the performance in terms of loss packet due to the handoff with high mobility. In particular, we evaluated the network performance in terms of throughput and delay when the mobile station is traveling across two cells at speeds up to 120 km/h. Figure 2 shows the setup of the experiments. The two fixed station are two wireless Cisco Aironet AP340 access points wired connected (through a Ethernet cable using some repeaters). The distance between the two station is 600m and with this distance we have a maximum overlapping zone of 70m (at 30mW as transmission power, 2Mbit/s, the transmission range in free space scenario is about 370m). We made two type of experiments:

- Access Points in the same channel,
- Access Points in different non-overlapping channels.

The laptop A is the fixed station and it is wired connected with the Access Points. The laptop B equipped with a Cisco AIR-PCM350 card (PCMCIA) is the mobile station moving through the two cells. The wireless card was always in line of sight with the two access points. We tried both laptop A and B as the receiver of the communication. For this experiment, we considered 128 kbit/s and 1 Mbit/s UDP traffic generation rate. The considered propagation environment was freespace.

In Table I all the conditions and parameters of the measures are reported.

The traffic load is generated using Iperf which also permits the collection of statistics indices, such as:

Experiment Type	Propagation	Bit Rate	Generation Rate	Speed
Circular	Free Space	$2Mbit/s$	$128kbit/s$, $1Mbit/s$	up to $130km/h$
Straight	Free Space	$2Mbit/s$	$128kbit/s$, $1Mbit/s$	up to $240km/h$
Straight	Semi-free Space	$2Mbit/s$	$128kbit/s$, $1Mbit/s$	$100km/h$
Following	Free Space	$2Mbit/s$	$128kbit/s$, $1Mbit/s$	up to $130km/h$
Following	Highway	$2Mbit/s$	$128kbit/s$, $1Mbit/s$	$100km/h$
Handoff	Free space	$2Mbit/s$	$128kbit/s$, $1Mbit/s$	$100km/h$

TABLE I

EXPERIMENT PARAMETERS AND SCENARIOS.

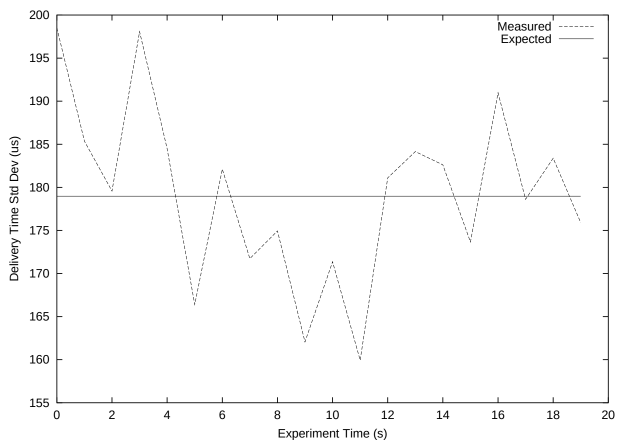

Fig. 5. Measured Standard Deviation of Backoff Time (128kbit/s, circular, 130km/h)

- Packet Loss: number of corrupted packets;
- Delay Jitter: computed by the server as the difference between the server's receiving time and the client's sending time.

At the MAC layer, the statistics collected with EMS and the quantities of interest include:

- Packet loss rate;
- Number of retransmissions before correct delivery of a frame;
- Jitter in transmission time.

Since we are trying to obtain the performance in various conditions in a peer to peer communication, we have disabled the RTS/CTS control packets handshake of IEEE802.11 protocol. In general, this optional protocol is used in the presence of hidden terminals [12], i.e., when there are nodes out of range of each other which try to transmit to a common neighbor at the same time.

RESULTS

Free space propagation

In the free space propagation scenario, IEEE802.11 is very robust to speed variations. We have tested speeds up to 130 km/h in the *circular* scenario (see Figure 1, we changed the radius R from 300m to 500m), up to 120 km/h each car (240 km/h absolute) in the *straight* scenario (see Figure 3), and

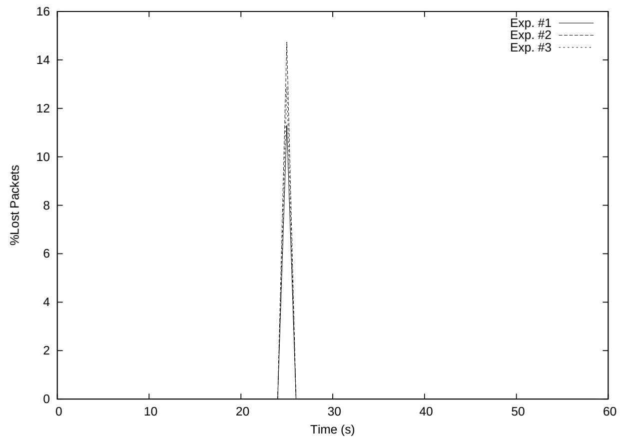

Fig. 6. Handoff - % Lost Packets vs. Measure Time.

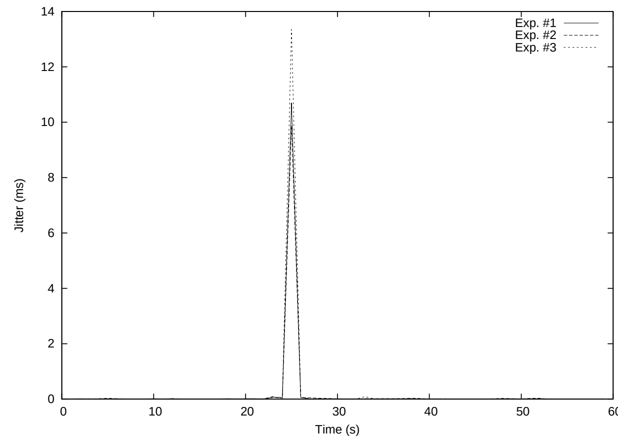

Fig. 7. Handoff - Jitter vs. Measure Time.

up to 130 km/h in the *following* scenario (see Figure 4) with 128 kbit/s and 1 Mbit/s as traffic loads, obtaining in all the cases zero retransmissions at the link layer and consequently delay jitter very close to zero (not really equal to zero due to the delay of the processing of the operating system). A transport layer plot of performance is not shown, since it would present flat lines for each index (jitter and packet loss are both equal to zero). As a proof, some results concerning with MAC statistics can be shown. The generated UDP traffic is sent as periodic packets of 1470 bytes (as the default configuration of Iperf). As an example, we consider a traffic generation of 128 kbit/s. One new packet is generated every $t = \{(1470 * 8)bit\}/\{(128 * 1024)bit/s\} = 89722\mu s$. For such length, the transport layer packet is split and sent as a couple of packets at MAC layer. Since IEEE802.11 is based on a CSMA (Carrier Sense Multiple Access) scheme, the variance of the delivery time is a function of the backoff time. The backoff time increases exponentially with the number of the retransmissions. In this case, the packet loss is exactly equal to zero and so there are no retransmissions. The backoff time t_{BO} is uniformly distributed as:

$$t_{BO} = U[0, CW]t_s,$$

where the Contention Window CW is a function of the number of retransmissions (in this case, CW is constant and $CW = CWmin$), $U[a, b]$ is a uniformly distributed variable in the set $[a, b]$ and t_s is the time slot. For IEEE802.11 at 2 Mbit/s with a Direct Sequence spreading modulation, the parameters are

- $CWmin = 31$,
- $t_s = 20\mu s$.

The expected value of t_{BO} is:

$$\overline{t_{BO}} = \frac{CWmin}{2} t_s = 310\mu s,$$

and the standard deviation of t_{BO} is

$$\sigma_{t_{BO}} = \sqrt{\overline{t_{BO}^2} - \overline{t_{BO}}^2} = 178.98\mu s.$$

Since other timings, such as the transmission time of data packets and other frame timings, are deterministic (and known to the layer 2 sniffer), we can compare $\sigma_{t_{BO}}$ to the data obtained by the sniffer (Figure 5). The jitter measured at the MAC layer is effectively close to the expected value. The number of retransmissions and the packet loss were exactly equal to zero.

As far as the *handoff* is concerned, Figures 6 and 7 show the packet loss rate and the jitter, computed at the transport layer. Overall, they show an interesting behavior. As previously described, the packet loss is equal to zero within each cell (free space scenario). When the roaming node disassociates from the first access point to search and to synchronize with the second one, the packet loss rate shows a spike. Unfortunately, this cannot be avoided and it should be considered in a telemetry system which requires an extended coverage area. Each point of the plots is an average performed over 1 second of measurements. With the help of the MAC layer sniffer, we were able to define two distinct phases of the handoff process. The first one is the packet loss due to the fact that the first access point cannot receive data from the roaming node. In this phase, the roaming node tries to send data to the first access point because it is not yet aware that it is out of radio coverage. In Figure 6, the packet loss related to that is shown. This phase requires about $160ms$. After that, a time to associate to the second access point is required. During this time, the wireless adapter buffers the packets coming from the transport layer. So, no more data packets are lost. After about $140ms$, the roaming node is associated to the second access point and it can send over the channel the buffered packets. Thus, the jitter shows a spike in the variance (Figure 7).

Similar measurements were acquired when higher traffic generation rates were considered. In those cases, the percentage of packet loss is about the same (since the time length in which the packets are lost is the same) but the variance is greater. It should be noticed that the wireless adapter has finite memorization capabilities. So, if the generated traffic is too high, the effect is to have some additional loss in the queuing system.

In those measurements, the transmission retry number at the MAC layer was set to zero. Nevertheless, this parameter does not affect the performance, since the backoff time is much smaller than the time in which there is the packet loss. The value of T_{beacon} would probably affect the timings of the handoff time. This topic is currently under investigation.

Same performance were experienced when various areas of overlapping zones of access point radio coverage were considered. If the signal has the sufficient quality to let the handoff, the timings are not really affected by the distances. For the same reasons discussed above, the system performance is not affected by the speed of the mobile user.

Highway conditions

If the propagation scenario is not free space, mobility can heavily affect the overall performance. This set of experiments was conducted in a highway. In this case we measured the network performances during the *following* experiments (see Figure 4). The two cars were going in the same direction with speed equal to 100 km/h. Figures 8, 9, 10 and 11 show packet loss rate and jitter for 128 kbit/s of traffic load and for 1 Mbit/s of traffic load respectively. The packet loss and the jitter are heavily affected by the hostile propagation scenario, which involves reflections of trees, buildings and other cars. It should be noted that, during all the experiments, the antennas of the bridges were in line of sight, and so low performance is not due to shadowing phenomena.

The general trend of these measurements shows that a large number of retransmissions can improve the delivery percentage, even though the variance of the delivery time obtains higher values. The key point of these results shows that a telemetry system or any other kind of data transfer based on a reliable transport protocol which perform retransmissions in case of missed acknowledgments such as TCP (Transport

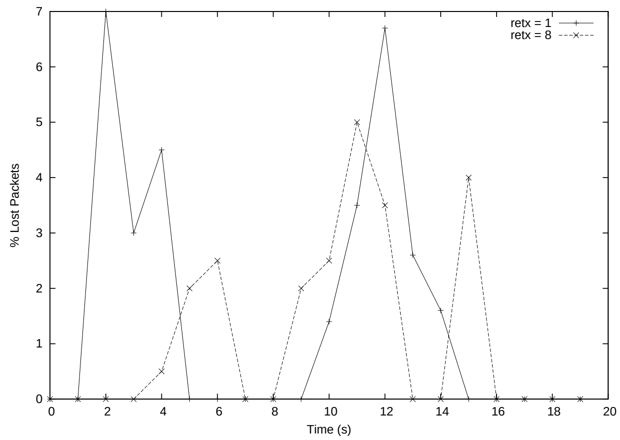

Fig. 8. Highway - Following 128 kbit/s - % Lost Packets vs. Experiment Time.

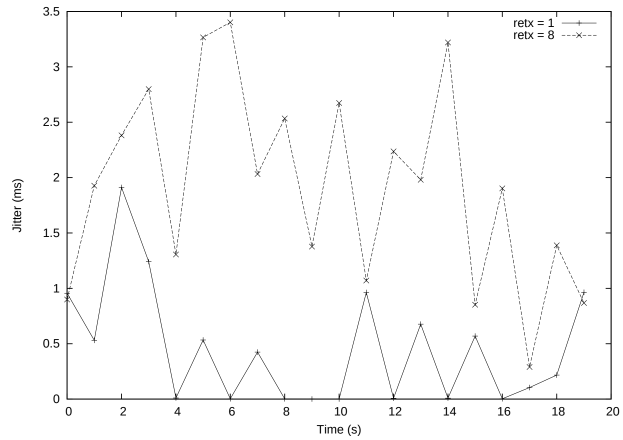

Fig. 9. Highway - Following 128 kbit/s - Jitter vs. Experiment Time.

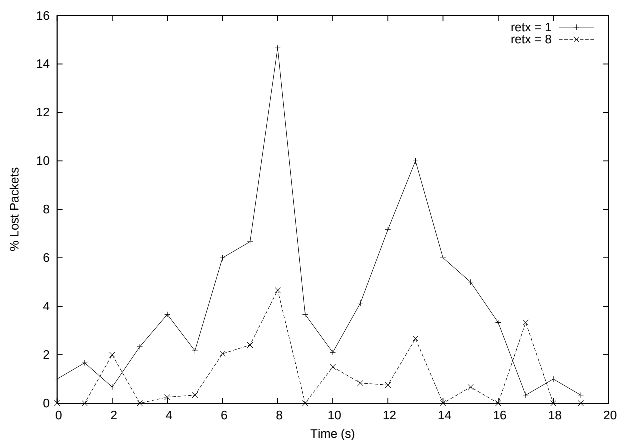

Fig. 10. Highway - Following 1.0 Mbit/s - % Lost Packets vs. Experiment Time.

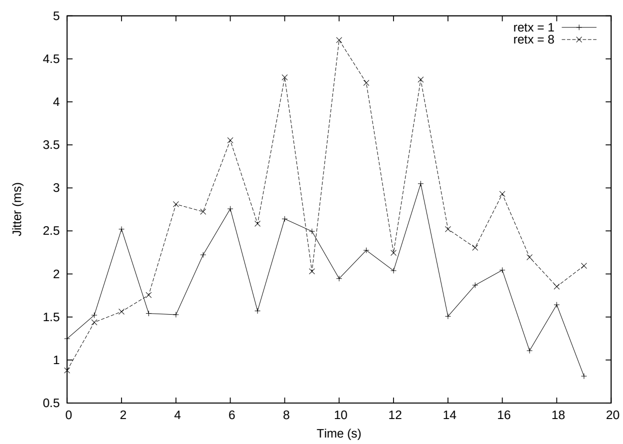

Fig. 11. Highway - Following 1.0 Mbit/s - Jitter vs. Experiment Time.

Control Protocol),cannot be applied to this scenario. As reported in [13], to make TCP work properly, the packet loss should be not over 1%. Even if we consider using a very high number of retransmissions to assure this requirement (if it is possible), the jitter of the communication obtains too high values. This means that TCP is forced to stall because of its mechanisms of link bandwidth adaptation. In fact, TCP transmits a certain number of packets and waits for an acknowledge. This number is called "TCP Window". If no acknowledge is received (in a given time), the TCP Window is drastically reduced. This was introduced for wired scenarios in which the loss of a packet is due to the congestion of the queues of the routers and not to the corruption due to the wireless channel outage, which is, in general, very fast and sudden with respect to routers dropping process. Moreover, this is an optimistic view of the system, since in the reported plots, only a unidirectional traffic from the sender to the receiver is considered. If both the end points are considered to transmit (as in TCP case), more collisions could occur at the MAC layer, and the global throughput, delay and packet loss rate are adversely affected.

A consideration involves the fragmentation of the transport layer packets. In our experiments, the

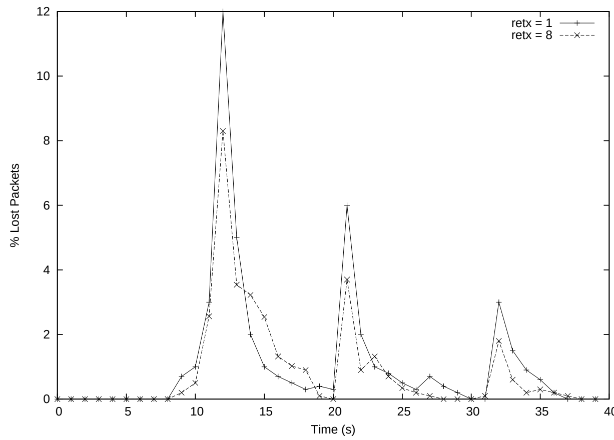

Fig. 12. UDP Traffic 128 kbit/s - % Lost Packets vs. Simulation Time.

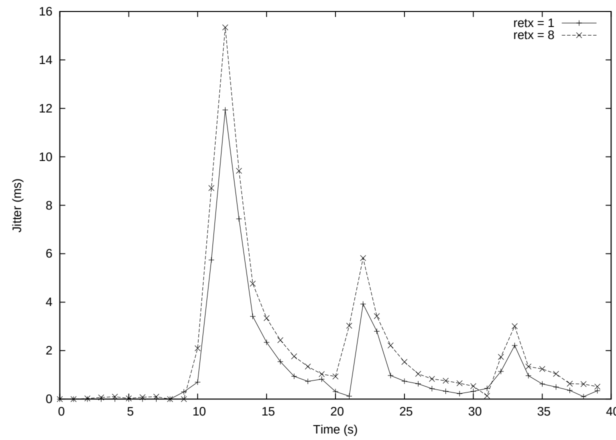

Fig. 13. UDP Traffic 128 kbit/s - Jitter vs. Simulation Time.

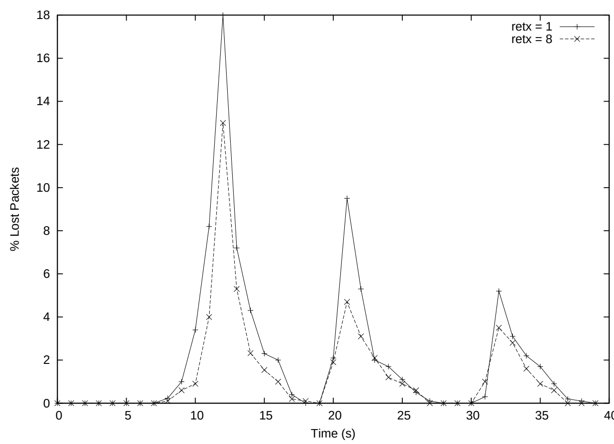

Fig. 14. UDP Traffic 1 Mbit/s - % Lost Packets vs. Simulation Time.

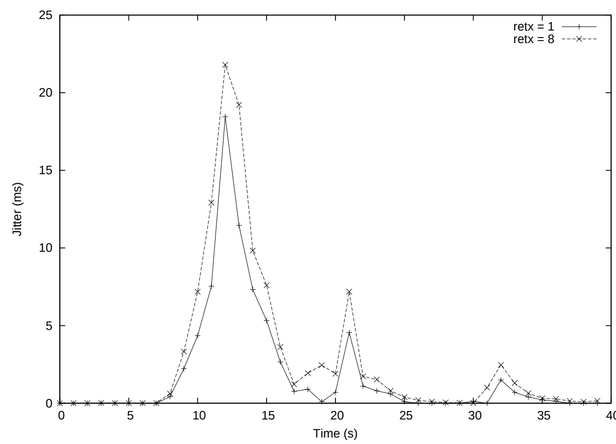

Fig. 15. UDP Traffic 1 Mbit/s - Jitter vs. Simulation Time.

UDP packet was split and sent as a couple of MAC layer packets. This means that if just one MAC packet was discharged, the whole UDP packet is considered lost. On the other hand, too long packets cannot be sent on the channel as a unique MAC packet, because the error probability gets worse. This trade-off, which involves MTU (Maximum Transfer Unit) and fragmentation mechanism, is currently under investigation. As a conclusion of this set of measurements, a telemetry system or a generic communication system cannot so easily be implemented even with soft reliability requirements.

Semi-free space propagation

This set of experiments was performed in a parking lot. In this case we measured jitter and packet loss as function of time in the case of the *straight* experiments with the two cars proceeding at 50 km/h (absolute speed of 100 km/h) in semi-free space scenario. Figures 12, 13, 14, 15 report respectively packet loss rate and jitter with the two different traffic loads, 128 kbit/s and 1 Mbit/s.

In all the results, the jitter is very low except for three peaks well localized in time. This behavior is due to the presence of three obstacles which impaired the propagation over the channel. In the parking lot where we performed the experiments there were a metal container and two trees, which caused a shadowing when the cars were not in the line of sight. In this particular case the measured jitter is in the range of $[0-22]$ms. This is due to the increased number of Layer 2 retransmissions.

The main result of this set of measurements is that the IEEE802.11 equipment tested is very sensitive to scenarios in which terminals lose and re-acquire line of sight very suddenly. In this situation, the packet loss is much higher with respect to the case in which the stations are not in line of sight but fixed.

CONCLUSIONS AND FUTURE WORKS

We showed the behavior and performance of a peer to peer communication based on the IEEE802.11 technology when the nodes are moving at high speeds.

The conclusions are that where the environment is not changing and the performance is not affected by the speed, or at least, by speeds considered in our measurements. In this scenario, IEEE802.11 can be used for telemetry. Nevertheless, some issues related to handoff should be considered if the telemetry system is required to be very reliable.

Schemes that try to make the handoff procedure more reliable will be investigated in the future. In other cases, changing from a line of sight to the lack of a line of sight dramatically affects the performance. This would affect many applications based on TCP, because of the high packet loss and jitter. For this purpose, some new transmission algorithms based on UDP protocol are under investigation and optimization and they will be tested in further measurements.

ACKNOWLEDGEMENT

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