In-Home Online Entertainment: Analyzing the Impact of the Wireless MAC-Transport Protocols Interference

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***Abstract*— Online entertainment is now possible at home by means of a plethora of ubiquitous services that can be provided based on wireless technologies such as, for instance, the common Wi-Fi IEEE802.11g network technology. Yet a scarce attention has been devoted to study the impact of wireless MAC layer design choices on the the native Internet transport protocols (e.g., TCP, UDP) during the distribution of in-house entertainment contents. We show that the current setting of the maximum number of retransmissions and the queue size in the IEEE802.11 protocol not necessarily corresponds to the optimal choice in this context. Based on the obtained results, we also provide directions in order to find the most efficient MAC layer setting.**

I. INTRODUCTION

Home networking is still in its jurassic era and is usually limited to few PCs and electronic equipment located in different rooms of the house, yet the vision for the near future includes many devices networked within a single household and connected to the Internet [1].

In this context, entertainment is going to play a major role among the various applications that might be run at home and its heart is represented by the *media-center* [2]. Analysts define media centers as devices that store all of a consumer's digital content (such as, music files, home video, digital images, etc.) in a unique location, allowing it to be enjoyed from multiple locations within the house. It is expected that media centers will expand their features becoming, within few years, the engine of the home network, thus controlling the whole home connectivity [3].

Indeed, as the availability of those digital entertainment devices is increasing rapidly, the need for interconnecting them is felt as ever more urgent, as well as the necessity to extend the reach of entertainment centers to the wireless domain. In the today's market, IEEE802.11[1] based wireless LANs are emerging as the best candidate to lead the "home networks" revolution providing wireless connectivity and advanced functions in terms of flexibility, security and throughput to support new emerging entertainment applications ranging from networked games to in-house digital audio/video distribution and live conferencing etc. [4]. In this context, technical standards are currently being defined that address both the methods of wired/wireless interconnection and the means to guarantee a full interoperability between digital entertainment appliances. Yet not much work has been done in the direction of understanding how can the Internet native language (i.e. the TCP/IP protocol) take over this complex scenario for efficiently delivering digital contents to entertainment devices, and which is the impact of diverse MAC layer settings over the Internet native transport protocols (e.g. TCP, UDP) during the distribution of in-house entertainment.

For these reasons, we are aimed at studying several realistic home networking scenarios for entertainment over IEEE802.11g networks. In particular, we focus our attention on the cross-layer interactions between transport and mac layer when digital contents are distributed to entertainment devices. We then propose a fine tuning of the currently deployed off-the-shelf low-cost wireless gateways thus achieving the best possible tradeoff between the different types of traffic patterns that may exist during the activity of entertainment distribution in an average home network.

This paper is organized as follows. Section II briefly recalls related work, while in section III we design several home networking scenarios. A brief introduction to the IEEE802.11 MAC Layer is given in section IV as an introductory basis to sections V and VI where our NS-2 based experiments and results are presented and discussed. Section VII, finally, concludes this paper with our final remarks.

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[1]Currently the IEEE802.11 based WLAN offers two different transmission rates: (i) 11Mbit/s (IEEE802.11b) and (ii) 54Mbit/s (IEEE802.11g/a). The next generation the IEEE802.11n, based on MIMO technologies, designed to support a transmission rate of 100Mbit/s has been already announced and should be available by the end of 2006.

II. Related Work

In recent years, many researchers have focused their studies on the problems that TCP encounters in a wireless environment [5]. Experimenting TCP and UDP over IEEE802.11 with different signal levels, Nam et al. showed that without retransmission implemented at the link layer, loss rates become unacceptable for any application [6] [7]. The claim that MAC layer retransmissions improve TCP performance is confirmed by Xylomenos and Polyzos, who experimented TCP and UDP on a WLAN and analyzed their behavior with different interfaces and bidirectional TCP traffic [8]. On the other hand, a high number of repeated retransmissions can cause TCP to timeout anyway and retransmit the same data as the MAC layer. Moreover, MAC retransmissions can be wasteful and potentially harmful for time-sensitive applications, such as real time video or audio over UDP.

III. Home Networking Scenarios

The current market is heading toward a wireless house where all the devices (e.g., computers, televisions, intelligent fridges, etc.) are wirelessly connected to the home network and possibly controlled by the media center.

In this context, take, for example, a mid-class american household where a family of four people lives: two teenage kids and the hardworking parents. Each family member presumably owns several networked personal portable devices such as PDAs, MP3 players, game consoles and digital cameras. All these being also connected to the home network.

Based on the market trends, we also consider that all those devices are wirelessly connected[2] to a media center that controls the in house media distribution and provides access to the Internet as well as to the cable television and companies providing external services (e.g., the alarm company). We also assume that several family members will be accessing the household network at the same time according to their work or leisure needs. In particular, for the sake of our study, we consider the following family scenario: (a) one teenager is watching the movie "Star Wars", streaming it from the close-by media entertainment center; (b) the other one is playing with his latest *Massive Multiplayer Online Game* (MMOG) against a crowd of buddies across the Internet; (c) the dad is having a conversation through an IP based video chat; and (d) the mum is downloading the last U2 greatest hit compilation from the Apple iTunes© music store. In the above everyday-life picture is worth noticing that each of the aforementioned employed applications features different requirements in terms of network performance, as well as suffer from very specific problems all due to the best effort nature of the Internet transport protocols.

These are as follows:

- **Video Streaming**. Streaming applications are affected by the jitter phenomenon[3] while are resilient to some packet loss; a network designed mainly for video streaming should minimize the jitter.
- **Video Chat** and **Massive Multiplayer Online Games**. Both this applications require a high degree of interactivity, they greatly suffer from delays and packet jitter while may tolerate some packet loss.
- **iTunes Music download**: A music download activity is typically performed using TCP, hence this type of application is resilient to jitter and delays but decreases the sending rate in presence of losses: it hence does not tolerate any error losses (losses that are not generated because of congestion).

[2]For the purpose of this work we are only considering the IEEE802.11g technology at a nominal rate of 54Mbit/s

[3]The packet Jitter is defined by RFC 2598 as defined jitter as the absolute value of the difference between the arrival times of two adjacent packets minus their departure times, $|(a_j - d_j) - (a_i - d_i)|$.

IV. The IEEE802.11

We consider very important to devote a short section to the 802.11 MAC layer protocol as well as recall its main characteristics as these are probably at the basis of the effects we will analyze in the next section.

The 802.11 MAC layer protocol attempts to face the packet loss problem by implementing its own retransmission scheme [9]. In particular, lost packets are retransmitted after a certain period of time without having received any corresponding ack. Successive retransmissions for the same packet are repeated up to a maximum number of time, which is by default set to 4 in the standard IEEE802.11, or until receiving a successful ack. A backoff mechanism determines the retransmission timeouts.

This scheme hides wireless error losses from the TCP's congestion control mechanism, thus avoiding deleterious multiple reductions of the data sending window. On the other hand, local retransmissions affect packet delivery delay by increasing its variability and thereby affecting time-constrained applications such as audio or video stream.

V. Simulation Environment

In order to analyze in depth our scenario, we have utilized the well known NS-2 network simulator (version ns-2.28) [10]. Our adopted configuration of the nodes and links can be easily visualized by the means of Figure 1. In particular, the house environment is represented by four mobile nodes named N1, N2, N3 and N4, and the Media-Center that incorporates also the Access Point (AP). The MAC layer parameters have been set accordingly to the IEEE802.11g standard. The simulation

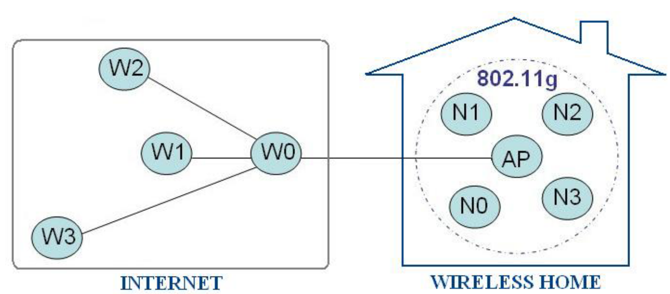

Fig. 1. **Simulated topology.**

Node 1	Node 2	Delay	Capacity	Queue Size
W1	W0	10ms	100Mbps	140pkts
W2	W0	20ms	100Mbps	140pkts
W3	W0	30ms	100Mbps	140pkts
W0	AP	10ms	100Mbps	140pkts

TABLE I
SIMULATION CONFIGURATION (WIRED LINKS)

From	To	Type	Transport Protocol	Start	End
AP	N0	Movie Stream	UDP	0s	180s
W1	N1	Game Traffic	UDP	45s	180s
N1	W1	Game Traffic	UDP	46s	180s
W2	N2	Video Chat	UDP	90s	180s
N2	W2	Video Chat	UDP	91s	180s
W3	N3	FTP	TCP	135s	180s

TABLE II
SIMULATED APPLICATION LAYER TRAFFIC FLOWS

outcomes showed us that we were able to reach a maximum achievable bandwidth rate of circa 20Mbps. This represents a reasonable value over the declared 54Mbps even in the real world. Focusing on the wired links, their one-way delays and capacities have been configured as listed in Table I, while their queue sizes have been set equal to 140 packets. This value comes out by multiplying the longest RTT with the smallest link capacity on the path (e.g. the bottleneck) which is represented by the 20Mbps effectively available over the wireless link.

As shown in Table II, several kinds of applications have been run over this network topology.

In order to uplift the trustworthiness degree of the simulations, we have exploited real trace files for the movie stream and for the video-chat. Specifically, adopted trace files correspond respectively to high quality MPEG4 Star Wars IV for the movie, and two VBR H.263 Lecture Room-Cam for the video-chat, as can be found in [11].

The parameters characterizing the game-generated traffic have been chosen following the directions provided by scientific literature in this field. Indeed, we can assume that the user in the house is engaged in one of the very popular first person shooter games, e.g. Quake Counter Strike, with other $\tilde{2}5$ players, through the Internet. Hence, to model the traffic generated by this kind of MMOG (packet size and interarrival time), we can use some of the approximations suggested in [12], which are based on real game platform measurements. In particular, in our simulation game events have been generated at client side every 60ms; while the server was transmitting game state updates every 50ms toward the client. Moreover, packet size has been set to 42Bytes and 200Bytes, respectively for client and server generated game packets.

Parameter	Values	Comments
MAC data retransmissions	1, 2, 3, 4	default value = 4
shadowing deviation	7, 9	medium, high
user-AP distance (m)	5, 10	same room, different room
MAC queue size (pkts)	50, 100	common default values

TABLE III
SIMULATION PARAMETERS

Simulation experiments have been replicated to examine the effects generated by differently setting some of the parameters involved in the scenario. Table III lists all the variable parameters in the simulations; each combination of their possible values has been simulated.

In particular, it is worth to conclude this discussion by mentioning our experimental choices with respect to the Shadowing Model, which is a realistic and widely utilized signal fading model available in NS-2.

We followed the directions provided by the official NS-2 manual to represent a home environment partitioned into several rooms. Specifically, in our simulation, the path loss exponent of the Shadowing Model was always set to 4 while the shadowing deviation had alternatively the value of 7 and 9. Transmission signal attenuation grows with the increase of these parameters; we hence expect to face higher percentage of packet losses over the wireless media when setting the shadowing deviation to 9.

VI. EXPERIMENTAL RESULTS

A. FTP Impact on Realtime Entertainment Applications

We have intentionally started the various application flows one after the other in order to progressively notice the impact of the successively incoming and overlapping traffic on the preexisting ones. In particular, we expect to witness increasing delays and jitter in the packets arrival time as we augment the traffic level. However, the bandwidth requirement of the first starting applications in our scenario is well below the effectively available capacity of the IEEE802.11g wireless media. We have hence to wait until the FTP flow takes action, quickly saturating the channel and the queues along the path with its packets, before being able to clearly detect significant variations in the delays and jitter experienced by the various real time flows. This phenomenon is evident in figure 2 where the mobile device was located at 10m from a standard IEEE802.11g AP (having four retransmissions for data packets and queue size set to 50 packets). Moreover, the shadowing deviation in the line-of-sight was set to 9, denoting a hard partitioning of the house.

B. Shadowing and Distance impact to TCP Throughput

The distance between the AP and the mobile device represents an important factor in determining the transmission quality, especially in a partitioned environment as a house. In fact, figure 3 shows that, positioning the mobile device at a distance of 5m from the AP, the maximum throughput achievable by the FTP application is already obtained when utilizing only two retransmissions at the MAC layer. The quality of the transmission signal also depends on the impediments that it may encounter along its path between the AP and the mobile device. We compare now a house environment constituted by medium level partitions (parameter set to 7), with another one

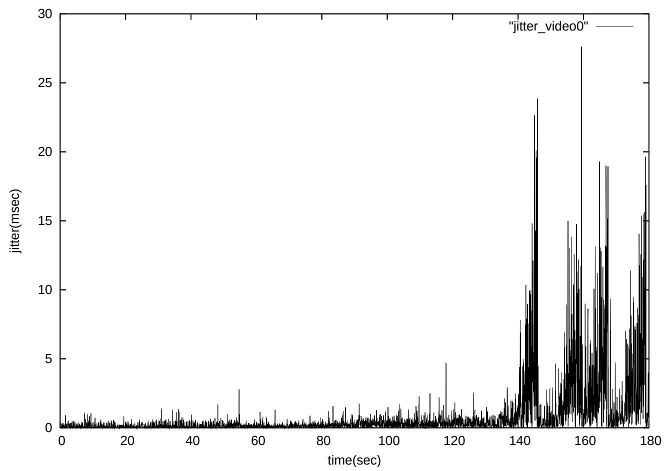

Fig. 2. **Example of movie streaming jitter.**

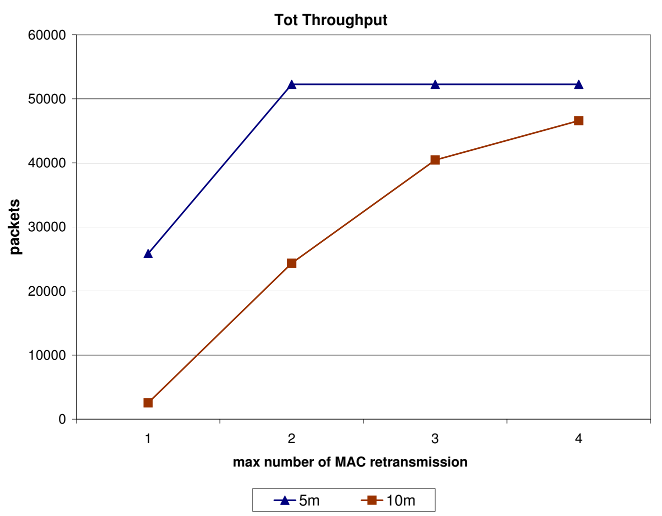

Fig. 3. **FTP total throughput with different user-AP distances; shadowing deviation = 9, MAC queue size = 50pkts.**

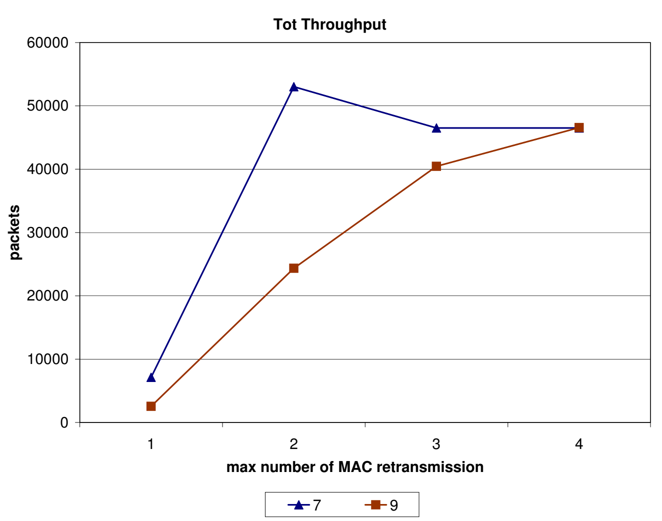

Fig. 4. **FTP total throughput with different shadowing deviation values; distance from the AP = 10m, MAC queue size = 50pkts.**

having more unfavorable partitions to wireless transmissions (parameter set to 9). Figure 4 confirms our expectations by showing us the throughput gain achievable in the first case. However, figure 4 also reports a case where having just two retransmissions at the MAC layer produces a higher total throughput than utilizing a greater number. This apparent paradox has instead a rational explanation. First, we should remember that IEEE802.11 has a limited buffer for transmissions and retransmissions. Second, the game and the video-chat applications generate some reverse traffic that shares path and networking resources with the acknowledgment (ack) packets generated by TCP as transport protocol under the FTP application. When the channel is fully utilized, some acks get lost and may cause timeouts. Figure 5 and figure 6 refers to the same configuration of figure 4 and present the congestion window, the slow start threshold and the bandwidth delay product of the underlying TCP flow. They show a higher frequency of timeouts when the traffic level is more elevated and, moreover, represent one of the several situations, all with different simulative configuration, where we have encountered this reverse traffic problem.

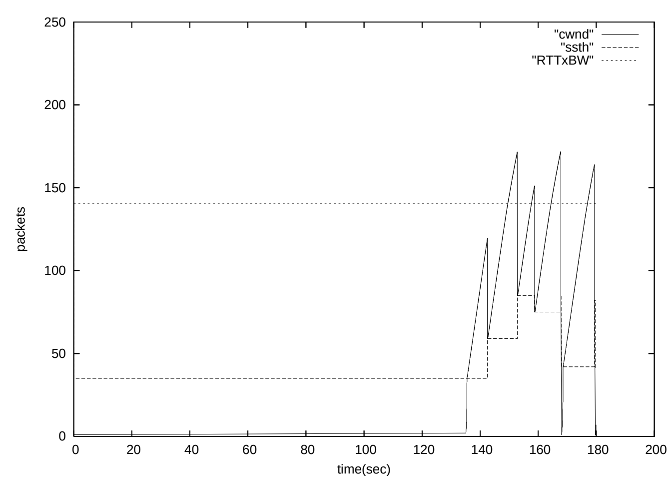

Fig. 5. **Example of TCP congestion window; max MAC retr = 2.**

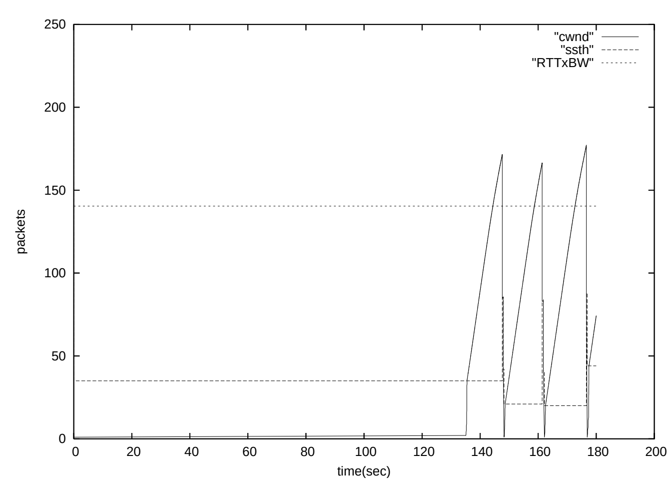

Fig. 6. **Example of TCP congestion window; max MAC retr = 3.**

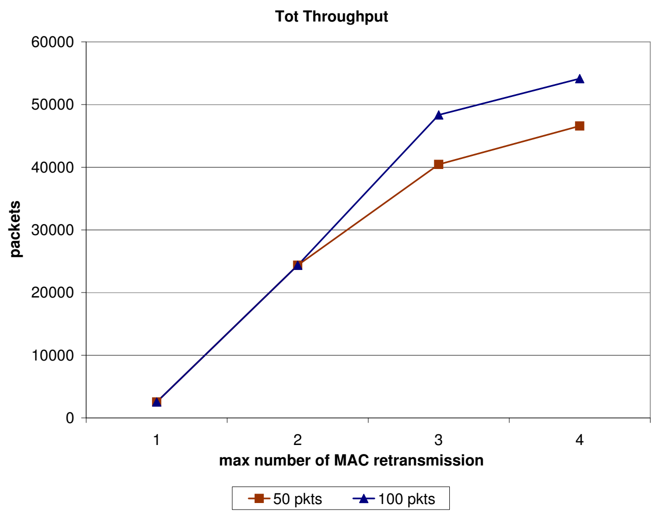

Fig. 7. **FTP total throughput with different MAC queue sizes; distance from the AP = 10m, shadowing deviation = 9.**

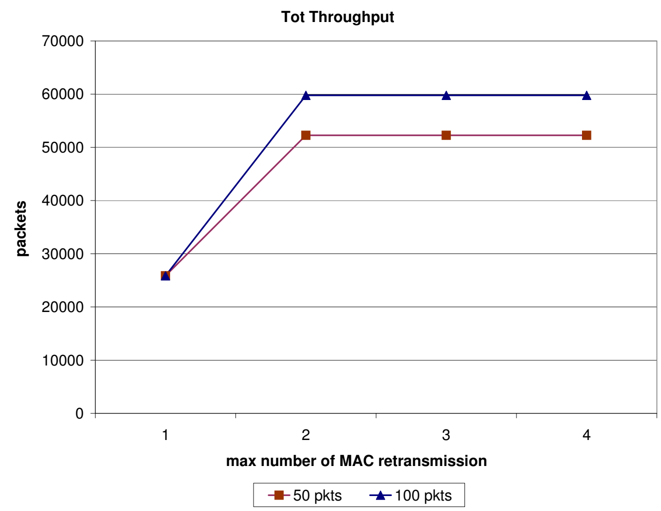

Fig. 8. **FTP total throughput with different MAC queue sizes; distance from the AP = 5m, shadowing deviation = 9.**

C. MAC Layer Queue Size and Retransmissions: Performance Tradeoffs

Finally we intend to highlight the impact of having different queue sizes and maximum number of retransmissions at the MAC layer on the performance of the various types of traffic present in our considered scenario. Starting with the first parameter, figure 7 and figure 8 confirm that having larger queue size helps TCP in achieving higher throughputs. However, there is no difference in the achieved throughput when wireless losses, not recovered via MAC retransmissions, are frequent enough to keep the TCP transmission rates low and hence never have the possibility to utilize more than 50 queue slots.

On the other hand, having large queues along the path may augment the total delay time experienced by packets. In fact, each packet waits in queue a time which proportionally grows with the number of anterior packets already present in the same queue at its arrival. In case of intense traffic, queues tend to be congested and hence queuing delays may become a significant component of the global delays experienced by each packet. At the same time, having larger queue size on a link also spreads the range of possible queuing delays that traveling packets may experience on that link (depending on the filling level of the queue). The resulting jitter strongly impact on the performance achieved by real time applications and, in particular, by highly interactive applications as video-chat and MMOG. Statistics of the aforementioned game flow jitters permit a clearer understanding of the performance disparity generated by diverse queue sizes. In particular, table IV refers to the whole simulated duration of the MMOG application, while table V considers only the period when the FTP application is running (from second 135 to second 180).

MMOG applications can bear a maximum delay of 150ms between the generation of an event and its propagation to all the players in the Internet. A scalable architecture exploiting mirrored game servers and an efficient synchronization scheme to uplift the interactivity level has been proposed in [13].

Jitter	50 pkts	100 pkts
maximum (ms)	33.740	108.36
average (ms)	1.306	2.041
variance	7.360	22.079
pkts received	2658	2658

TABLE IV
GAMING FLOW JITTER: STATISTICS FOR VARIOUS MAC LAYER QUEUE SIZES; CONSIDERED PERIOD = [0-180S], MAX MAC RETR = 4, SHADOWING DEVIATION = 9

Jitter	50 pkts	100 pkts
maximum (ms)	33.740	108.36
average (ms)	3.056	5.229
variance	16.665	49.470
pkts received	899	899

TABLE V
GAMING FLOW JITTER: STATISTICS FOR VARIOUS MAC LAYER QUEUE SIZES; CONSIDERED PERIOD = [135-180S], MAX MAC RETR = 4, SHADOWING DEVIATION = 9

However, the efforts in having a fast synchronization among mirrored game servers may be wasted if the client-server part of the connection introduces exaggerate delays, as may happen with larger MAC layer queue size.

In any case, the worst jitter is experienced when queues are steadily filled up by the FTP flow. One possible solution to limit this problem consists in bartering part of the FTP throughput with lower queuing delays. This tradeoff can be found also by simply reducing the maximum number of retransmission at the MAC layer. Renouncing to this possibility could bring those delay benefits evidenced in tables VI and VII. MMOG applications can bear a maximum delay of 150ms between the generation of an event and its propagation to all the players in the Internet. A scalable architecture exploiting mirrored game servers and an efficient synchronization scheme to uplift the interactivity level has been proposed in [13]. However, the efforts in having a fast synchronization among mirrored game servers may be wasted

Jitter	50 pkts	100 pkts
maximum (ms)	31.091	44.632
average (ms)	1.045	1.566
variance	4.833	11.034
pkts received	2654	2655

TABLE VI

GAMING FLOW JITTER: STATISTICS FOR VARIOUS MAC LAYER QUEUE SIZES; CONSIDERED PERIOD = [0-180S], MAX MAC RETR = 3, SHADOWING DEVIATION = 9

Jitter	50 pkts	100 pkts
maximum (ms)	31.091	44.632
average (ms)	2.292	3.835
variance	11.502	24.431
pkts received	896	897

TABLE VII

GAMING FLOW JITTER: STATISTICS FOR VARIOUS MAC LAYER QUEUE SIZES; CONSIDERED PERIOD = [135-180S], MAX MAC RETR = 3, SHADOWING DEVIATION = 9

if the client-server part of the connection introduces exaggerate delays, as may happen with larger MAC layer queue size.

In any case, the worst jitter is experienced when queues are steadily filled up by the FTP flow. One possible solution to limit this problem consists in bartering part of the FTP throughput with lower queuing delays. This tradeoff can be found also by simply reducing the maximum number of re-transmission at the MAC layer. Renouncing to this possibility could bring those delay benefits evidenced in tables VI and VII.

Even better jitter average and variance can be gained further diminishing the maximum number of MAC retransmission to 2. However, we advice against this choice, unless placing the device hosting the FTP application closer to the AP or in a house with a better shadowing deviation of the transmitted signal. Otherwise, the FTP throughput descends significantly as can be observed in figure 3 and figure 4.

Summarizing, we can say that a more appropriate configuration of the IEEE802.11g than the traditional one would probably make use of a maximum number of 3 retransmissions, thus guaranteeing a high FTP throughput whilst maintaining a low per-packet delay and jitter. Moreover, when a unique queue is maintained for all the traffic flows, a small size (50 packets) should be preferred.

Alternatively, or even coupled with the above configuration, priority queues could also be used to diminish the delivery time of packets belonging to delay sensitive applications [14].

VII. CONCLUSIONS

In this work, we present a realistic instance of a wireless connected home scenario in which some popular networking entertainment applications are considered. The impact of the underlying wireless technology has been extensively investigated, as well as several other factors that may affect the performance perceived by the final user, in particular:

1) sensitivity of real time entertainment applications to intense concurrent traffic (in the form of big FTP downloads);

2) FTP applications throughput as a function of the distance between the wireless device and the AP, and for different values of the signal shadowing deviation parameter;

3) impact on TCP Time Outs of ACK losses on the reverse wireless LAN channel;

4) tradeoff between FTP performance and interactive applications performance as a function of MAC layer queue size;

5) tradeoff between FTP performance and interactive applications performance as a function of the maximum number of retransmissions at the MAC layer.

We have concluded presenting some factual suggestions on how to tune the IEEE802.11 parameters in order to achieve a more efficient performance tradeoff.

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