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# Implementing and Evaluating Improved MAC Efficiency Through Payload Extension in 802.11n Networks

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*Abstract*—**Currently, the default size of Internet packets is set at a legacy value of 1500 bytes, since Ethernet was the dominant connection technology. Increasing this size, and thus using larger frames, brings several advantages such as less header overhead and CPU processing. However, the transmission of larger frames also raises several issues impacting data transmission, such as packet loss. With the increase in performance gained from recent wireless technology advances, solutions, such as Frame Aggregation, begin to exploit this increased bandwidth. However, the legacy value is still the dominant one.**

**This paper evaluates the feasibility of increasing the Maximum Transfer Unit for a more efficient data transfer and bandwidth consumption in wireless 802.11n networks. We focus particularly in the experimental implementation and evaluation of the usage of Jumbo-Frames between an Access Point and the connected nodes, featuring a modified kernel that allows the usage of larger payloads, via enhancements to the existing wireless kernel modules. Network performance parameters including bandwidth usage, delay and packet losses are used to assess the benefits and drawbacks of the usage of Jumbo Frames in the wireless medium. Obtained results show that a more efficient medium usage can be achieved by increasing the payload size, when compared with standardized aggregation mechanisms. In addition, the measured packet losses decrease due to a considerable reduction on the number of packets sent for the same bandwidth consumption. To conclude, we perform an evaluation of the proposed enhancement in wireless video streaming scenarios and evaluate the performance gains that such module enables.**

*Index Terms*—**Wireless Networks, Jumbo Frames, Network Management, Network Performance.**

## I. Introduction

Packets compose the information units flowing on the Internet that allow connected hosts to retrieve and exchange different types of content and informations. In the last years, we have witnessed a continuous increase on the capacity and performance of network links, fuelled by contributions from novel connecting technologies, such as fibre optics. This increase in performance allowed the consideration of larger packet sizes, beyond the universal value of 1500 bytes historically set by the mainstream Ethernet technology [1], which were hindering an efficient usage of the novel technologies network link capacity.

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Jumbo Frames (JF) emerged as a solution to this issue and can be defined as packets whose size is larger than the widely deployed default value of 1500 bytes. The use of such frames allows more efficient data transfers by enhancing the throughput while reducing the overhead caused by processing several packets with distinct headers. In addition, the usage of JF allows a more efficient usage of the available bandwidth, optimizes information and content transfer between different hosts. However, the usage of JF also also raises several implementation issues. For lossy links, the amount of information lost when packet losses occur is exacerbated due to the increase in data sent over each JF packets.

Currently, we are also witnessing a large increase in wireless technologies performance, with Long Term Evolution (LTE) [2] cellular links from the 3GPP providing download speeds over 10Mbps over mass-user wide-area deployments, and IEEE 802.11n [3] reaching speeds up to 100Mbps in smaller areas and less users. This performance increase has prompted for the development of novel packetization techniques, such as aggregation [4]. However, this technique, although allowing a larger amount of information to be sent in a large block, it still limits individual packet size to the 1500 bytes legacy value. As such, fueled by current wireless technology performance increases, the base is set to evaluate the performance of JFs in current deployments.

This paper provides a research overview of current packetization mechanisms applied to WLAN technologies, focusing on wireless JFs and aggregation. It presents a payload extension mechanisms in 802.11 networks, detailing its implementation and its impact through the analysis networking aspects that are affected by the deployment of large datagrams. In addition, it improves over current JFs research in WLAN networks, by experimentally deploying and verifying frames with payload sizes up to 4KB, thus already addressing the limitation reported in [6]. The evaluation is performed in terms of throughput, packet loss and delay and the obtained results are compared with existing aggregation techniques. In addition, it proposes a kernel enhancement module which can be easily deployed in any Linux machine in order to enable the usage of larger datagrams on the target machine. To conclude, this paper also presents an evaluation of the usage of JF in video streaming in wireless networks. In particular, we try to evaluate the performance gains in terms of reduction of the number of exchanged packets between server and receiving client. In this manner, we aim at achieving a more efficient usage of the wireless medium in order to allow more efficient video streaming schemes.

The remainder of this paper is structured as follows. Section II presents the state of the art on JFs and IEEE 802.11n aggregation procedures. This is followed by Section III where our JFs framework, implemented over a modified Linux kernel, is described. Section IV provides experimental results comparing our JFs approach with 802.11n aggregation techniques. Finally, the paper concludes in Section V.

## II. State-of-the-art

In this section we present a thorough analysis of the existing work on JFs, exploring aspects related to JFs deployment and frame aggregation approaches.

### *A. Jumbo Frames Deployment*

JF deployment performance in WLAN environments was already addressed before. Optimal settings of the maximum packet size are addressed in [5] where a theoretical analysis of the effect of the MTU size on wireless network performance is performed. Such analysis, based on a distortion model, performs an estimation of video traffic quality based on metrics such as the average frame peak signal-to-noise ration (PSNR). The optimal MTU can then be expressed as a function of the two previously mentioned variables in a given wireless channel. The authors conclude that under poor channel conditions a small MTU is expected to have a better performance while under good channel conditions, large packets perform better. In [6], the authors propose the use of Fast Resilient Jumbo frames (FRJ) for optimizing wireless performance and resilience, tackling important aspects such as frame size selection, partial packet recovery and rate adaptation. In this manner, the authors are able to achieve robustness and performance increases in wireless LANs. The authors evaluated their approach by performing testbed experiments in which the MadWifi driver [7] and the Click toolkit [8] were used to implement the proposed approach. Several rate adaptation schemes with different frame sizes (1500 and 3000 bytes) were implemented and compared with the approach proposed in the paper. The comparison is performed in single and multiple (2 to 8) flows environments and the authors evaluate the throughput, data rate and medium fairness and conclude that the proposed approach enhances the three mentioned evaluation parameters. However, due to hardware limitations pointed out by the authors, they were only able to achieve JFs up to 3000 bytes.

In addition, it was observed that, due to the high variability of the wireless medium conditions, most of the available research work on JF was applied into wired connection scenarios. As such, in order to fully grasp current proposals for JF deployment research, we have also analyzed a set of key contributions in these environments. In [9], a discussion on the effect of the Ethernet maximum frame payload size of 1500 bytes on IPv4 and IPv6 traffic is provided. The authors used real IPv4 traffic and by using simple assumptions transformed this traffic into IPv6 and evaluated the overhead created. The authors concluded that using an MTU of 9KB allows a decrease of 40% on the number of generated packets.

In [10] the authors presented a case study for "super jumbo frames" (SJFs) experiments conducted prior to and at Supercomputing 2005, for up-to-64000 Bytes path MTU. The authors state that an increase in average pMTU and MSS is one of the overall simplest mechanisms to change the boundary conditions of Internet network traffic. However, no error recovery mechanisms were proposed and the authors only analyzed the network throughput and did not analyze errors caused by the increase of the MTU. An interesting approach, presented in [11], proposed an aggregation scheme for enabling a higher utilization of larger packets performed at the ingress node of a network domain, to packets with the same exit point. In this manner, core router scalability was improved by maximizing the number of large packets transversing a network domain while minimizing the number of packets that need to be processed. For evaluating the proposed approach, the authors captured the outbound traffic of a university campus and applied their aggregation mechanisms which enabled a reduction on the number of exchanged packets while enabling a higher throughput and a better utilization of the bandwidth of the network connections. On the other hand, medium fairness decreased while the end-to-end delay and jitter increased.

In [12], the usage of JFs in a Quality of Service (QoS) mechanism based on priority for Multiple Multicast IPTV Streams is evaluated. By using JFs, the authors aim to enhance the throughput of each multicast stream. The NS3 network simulator was used to measure HD-IPTV performance with regard to QoS parameters such as delay and throughput. Different number of users of multicast streams were simulated and the authors concluded that the average delay for the multicast streams with JFs is lower than the delay of multicast streams without JFs. In addition, the throughputs of multicast streams with JFs are slightly higher than that of those without JFs.

### *B. Frame Aggregation*

The latest 802.11 amendment [3] presents several MAC layer enhancements such as the increase of the payload that can be delivered to each frame. In this manner, 802.11n devices can aggregate several frames for a joint transmission, thus significantly reducing the MAC layer overhead. The standard proposes two frame aggregation approaches, i) Aggregate MAC Service Data Unit (A-MSDU) and, ii) Aggregate MAC Protocol Data Unit (A-MPDU), illustrated in figure 1. The first approach allows different MSDUs, with the same destination, to be sent together in a single MPDU with the maximum length of 7935 bytes, sharing a common MAC header and CRC fields which makes it less resilient to transmission errors. Therefore, when errors occur, the whole packet needs to be retransmitted. On the other hand, the main concept of the latter approach, A-MPDU, is to aggregate several MPDU sub-frames into a single PHY packet of size up to 65536 bytes. The aggregation is performed after the MAC headers are added to each frame which allows each sub-MPDU to

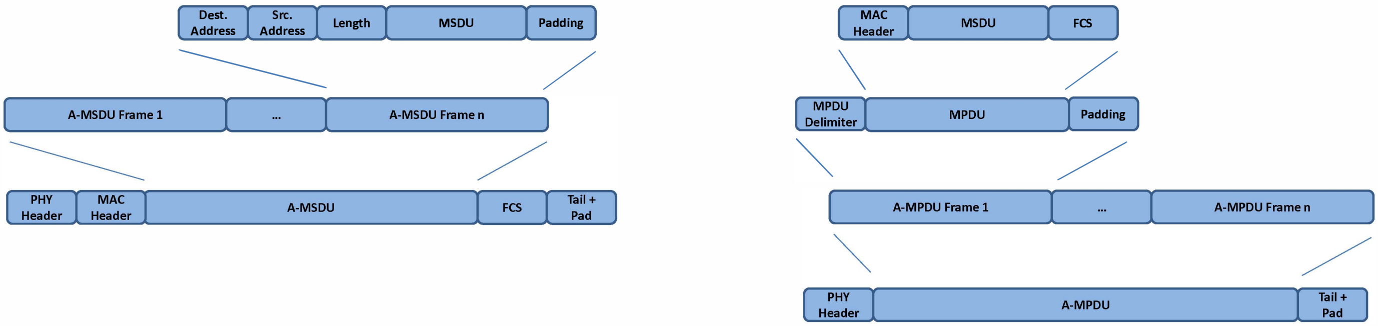


Figure 1. Frame Aggregation schemes proposed in 802.11n.

have its own CRC field. Therefore, this approach is more resilient to transmission errors since the usage of several CRCs fields allows the identification of the sub-MPDU frames that were received with errors which can then be retransmitted. By means of a Block-Acknowledge message, the destination node can inform which sub-frames were received without errors. The sub-MPDU frames received with errors can then be re-transmitted.

An analysis and evaluation of the several MAC enhancements proposed in the 802.11n amendment is presented in [13]. The authors focus their analysis on the two aggregation schemes proposed in the mentioned standard and through extensive simulations, the authors could conclude that these schemes indeed improve significantly the channel efficiency and data throughput. A separate analysis of the aggregation schemes, in distinct scenarios was also performed. This was also analysed in [4], with the authors also proposing an optimal frame size adaptation algorithm with A-MSDU for error-prone channels. The approach consisted in evaluating the network throughput, $L*$, under different BER conditions and with different number of contending stations. The obtained results show that the network throughput was rather insensitive to the number of contending stations while, on the other hand, it was very sensitive to the BER.

Although the standardized aggregation methods already show improvements in performance, they also pave the way for further optimizations, allowing even greater performance gains. A multiple receiver frame aggregation approach for video traffic is proposed in [14]. The main concept of the proposed approach, named Instantaneous Multi-receiver Aggregation (IMA), is to extend the MPDU aggregation scheme to allow the aggregation of MPDUs destined to different hosts. In this manner, the sender sends a broadcast aggregated frame and the different destination hosts respond with a Block-ACK (BACK). Each receiver sends a BACK according to the position of the corresponding frame. If some ACKs are not received, the sender retransmits the the corresponding MPDU, which results in an increase in the number of supported video streams by a factor of 2 or higher.

## III. Proposed Approach

In this section we present and discuss our proposed approach. The main concept consists in enabling nodes connected to a 802.11 network to send and receive packets larger

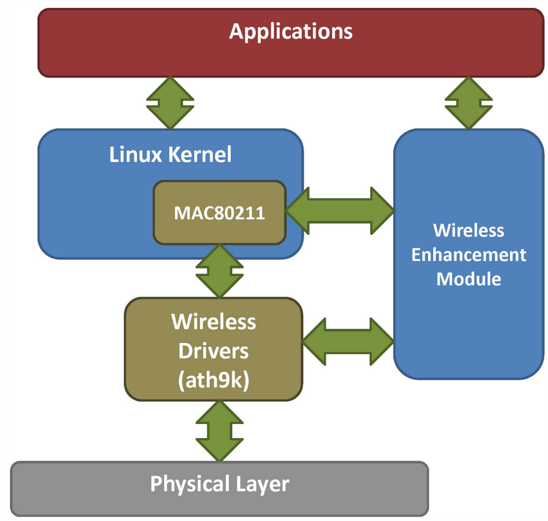


Figure 2. Proposed enhancement module.

than the legacy value of 1500 bytes. In this manner, we implement a payload extension mechanism and evaluate the impact created by such extension in wireless scenarios. This capability was achieved by creating a Wireless Enhancement Module (WEM) extending the necessary Linux kernel modules implementing the 802.11 protocol stack. With such module, we intend to achieve an increase of the effective wireless channel usage and a consequent increase of the global network performance. The proposed module interacts with the kernel of the host machine and with the corresponding drivers of the wireless cards, as shown in figure 2. In this manner, the proposed WEM can tune the whole kernel to send a frame of a selected size, allowing applications to perform an optimized usage of the available network resources. Therefore, we were able to overcome the limitation reported in [4] and generated packets with payloads of size up to 4000 bytes.

With this work focusing on 802.11n networks, the *mac80211* and *ath9k* kernel modules were enhanced to connect and interact with the WEM. Such modules were then installed in the kernel tree. The need for this interaction is associated to the fact these modules prevent the extension of the payload of 802.11 data packets. Therefore, the interaction of the WEM with the existing kernel tree consisted in changing the values of the *IEEE80211_MAX_DATA/_FRAME_LEN* and *IEEE80211_MAX_FRAG_THRESHOLD* constants of the *mac80211* kernel module to the maximum values allowed by the buffers of the used wireless cards. This allows the creation of JF until the MAC layer. However, in order to send such frames, the wireless driver *ath9k* had also to be enhanced and the value of *IEEE80211_MAX_MPDU_LEN* was changed accordingly.

Several issues emerged during this implementation and evaluation work. For instance, the values of the constants controlling the packet and payload sizes of the *ath9k* and *mac80211* kernel modules are constrained to the maximum size of the buffers of wireless cards which can be seen as the ultimate limitation of the proposed module. In addition, since network packets in the Linux kernel are implemented through Socket Buffers (SKB), whose maximum size is related to the PAGE_SIZE used in the kernel, all these values cannot exceed the mentioned PAGE_SIZE as the kernel can not allocate more than one page for a single payload of a received or transmitted packet. Our implementation and evaluation work was then performed within these mentioned constraints. In addition, all the mentioned changes and interaction performed by our proposed kernel WEM must not change the overall behavior and performance of the entire Linux kernel. Intensive tests were then performed to assure that the interaction of the WEM with the kernel of the machines used in our tests did not raise any stability and performance issues in the kernel tree. Finally, the proposed enhancement module can be easily deployed on any Linux host machine.

## IV. RESULTS

This section presents and discusses the results through obtained intensive evaluation tests performed on the AMAzING wireless testbed [15]. This testbed consists of 24 wireless nodes deployed on the rooftop of the building of Institute of Telecommunications (IT), Aveiro pole. Each node is equipped with VIA EDEN 1Ghz CPU and 1GB of RAM. In addition, each node has two 802.11 wireless cards: a 802.11bg Atheros AR5414 and a 802.11bgn Atheros AR9220 and the open-source drivers *ath5k* and *ath9k* are used for controlling the mentioned wireless cards. The distance between each node is of 8 meters and there are several obstacles between the nodes. Our proposed enhancements were deployed on several nodes of the mentioned physical testbed. Intensive tests comprising a 802.11n Access Point and, in a later stage, a wireless video streaming server which connect with both Jumbo (nodes in which the proposed enhancement kernel module was deployed) and non-Jumbo enabled nodes (nodes without the proposed module which, consequently, will use the AMPDU aggregation) connected to it were performed, as depicted in figure 3. The same nodes were used for the different tests but for the non-Jumbo nodes the proposed kernel module was removed. The 802.11n access point was deployed using hostapd [16] with the several High-Throughput[1] parameters used in order to increase the network bandwidth. Several performance tests were performed by exchanging data frames

[1]Channel width of 40Mhz, maximum MSDU of 4000 bytes and Short Guard-Interval for 20 and 40 Mhz channels

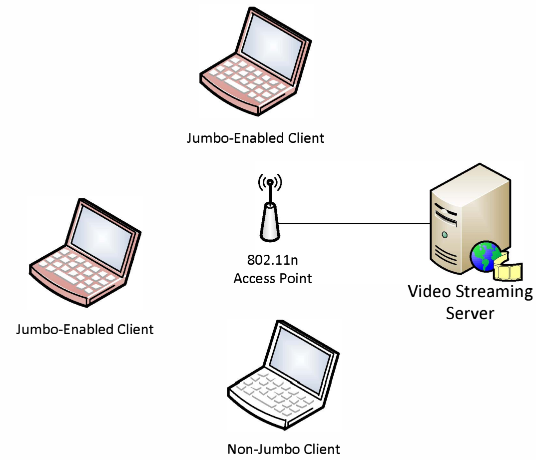


Figure 3. Testbed deployment.

with payloads (measured at the layer 4) of different sizes using the well known network and bandwidth evaluation tool IPerf [17]. Several measurement tests were performed by exchanging UDP traffic between the several used nodes and measuring several performance metrics. A very important aspect of the testbed is that it is deployed on the building of IT Aveiro which is in the campus of the University of Aveiro. Consequently, there are several networks broadcasting their SSIDs and nodes from other wireless networks sending and receiving traffic. The nodes used for evaluating our approach will detect such interferences which affect all the results obtained when performing our evaluation tests. This constitutes a two-fold aspect of the testbed: on one side these interferences affect the performance of our approach while, on the other side, they provide us with a realistic analysis to the obtained results and provide an insight of the real deployment of our proposed module.

Different evaluation metrics were used for analysing the performance gains and possible losses associated to the usage of JFs in wireless networks. Figures 4, 5 and 6 show performance results obtained for bandwidth, packet delay and packet loss, respectively, comparing the performance between WEM and non-WEM enhanced nodes. In the latter case, the driver forces the aggregation scheme proposed in 802.11n standard. The maximum Layer-4 payload sizes used were from 2KBytes to 4KBytes.

Concretely, figure 4 shows the efficient bandwidth a node is able to achieve when increasing the maximum payload size and using JF of different sizes. For nodes using our WEM module featuring JF support we can see that, by increasing the maximum payload size, we can indeed perform a more efficient bandwidth usage. For the same link conditions, the bandwidth a node achieves can increase from around 100 Mbits/sec, for packets of 1500 bytes, to more than 170 Mbits/sec for payload sizes of 4000 bytes. On the other hand, nodes without the WEM and only using the AMPDU aggregation, do not obtain such bandwidth improvements. The results show for non-Jumbo nodes, and the corresponding fluctuations, are related to interferences in the wireless medium. However, such interferences were also present when the tests with Jumbo-nodes were performed which allow us to conclude that the usage of JF enables a higher resilience to such interferences.

Figure 5 depicts the delay variation with the used maximum payload size. A clear increase on the delay can be seen, for both with and without the WEM, when the payload size also increases. Such occurrence was expected since larger packets require more transmission time. On the other hand, the tests performed with nodes transmitting aggregated frames also registered an increase of the transmission delay. However, comparing both approaches, it can be verified that the usage of the enhancement module and the usage of larger frames creates less transmission delay than when fragmenting the different frames and sending them as a part of an AMPDU.

Regarding packet losses, shown in figure 6, we can verify that, for the proposed enhancement module and despite some increase on the losses for payloads of 2000, 2500 and 3500 bytes, the losses associated to larger packets can increase due to interferences in the wireless medium. However, for good link conditions, packet losses are mitigated. This constitutes a very important aspect of our WEM. On the other hand, without our module and sending the frames individually and as part of an AMPDU, can significantly increase packet loss and the consequent occurrence of retransmission. Indeed, as previously mentioned, while performing the measurement tests for both Jumbo and non-Jumbo, there were interferences in the wireless medium. Such interferences create significant packet losses which, as already mentioned, also affect the effective bandwidth usage. In addition, such increase in the packet losses is associated to the fragmentation imposed at layers 2 and 3, which creates an increase on the number of sent packets leading to packet bursts, contributing as well to the increase in transmission errors.

To evaluate the performance gains enabled by the increase of the payload of the packets, we performed several wireless video streaming tests. In these tests, we streamed a 5-seconds HD video between an Access Point (AP) and a connected client. We then counted the number of packets that were sent to stream the video to the client. This procedure was repeated for different payload sizes. The results are depicted in Figure 7 and show that by increasing the size of packets, a significant reduction on the number of packets packets can be achieved. Indeed, by enabling packets with payloads of 4000 bytes, we can reduce the number of sent packets by more than 66%. This indicates that extending the payload of the packets brings several performance gains for wireless video streaming scenarios and that a more efficient usage of the wireless medium can be achieved which can enable more efficient wireless video streaming schemes.

Several lessons emerged from this implementation and evaluation work. To begin with, there are several limitations to the deployment of JFs in both the kernel of operating systems and in the hardware. Some limitations, such as intrinsic definitions in the linux kernel modules and the Abstraction Layer, were effectively addressed. The final barrier was imposed by the definition of the Socket Buffers (SKBuffers) whose maximum size is the PAGE_SIZE of the Linux kernel (set to 4096 bytes)

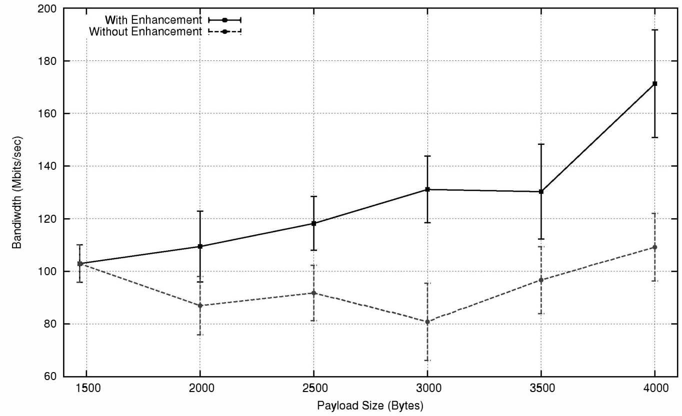


Figure 4. Efficient Bandwidth Usage.

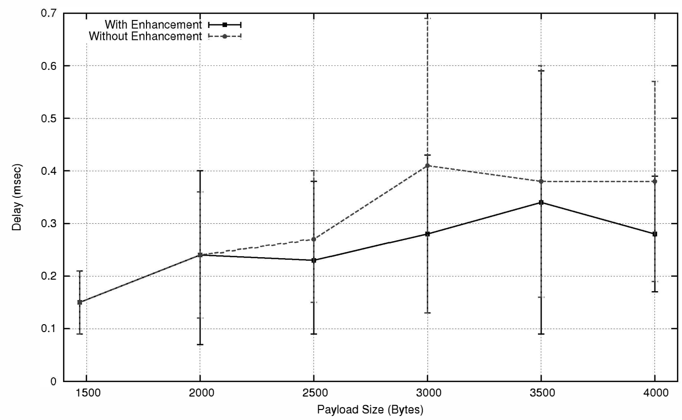


Figure 5. Delay variation.

and consequenly, this value set the maximum payload size to 4000 bytes. Future work includes addressing this issue since the results presented here give a significant stimulus for such work. To conclude, the nature of the wireless medium, with collisions and concurrent transmission, both leading to packet losses, present a significant obstacle to both aggregation and JFs approaches. However, the usage of our proposed module showed that it enables a higher resilience against such issues of the wireless medium.

## V. Conclusions

Internet maximum packet sizes remained constant over the last decades despite significant increases on network links capacities. The legacy value of 1500 bytes as the maximum allowed size was, and still is, associated to the dominance and ubiquity of Ethernet as a connecting technology. However, in recent years, following as well an increase of wireless network performance, and a decrease on the overhead created by fragmenting packets to the mentioned legacy value, several research works analysed the feasibility of using larger packets. These works paved the way to the introduction of frame aggregation in the 802.11n standard.

In this paper we implement a payload extension mechanism and perform its impact evaluation in terms of bandwidth usage, transmission delay and packet losses. The implementation of

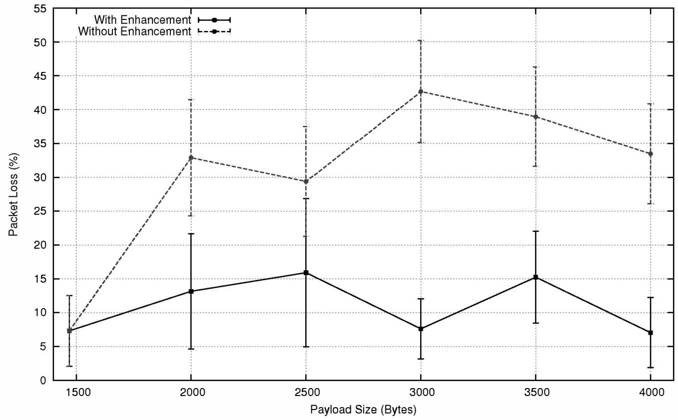


Figure 6. Packet losses.

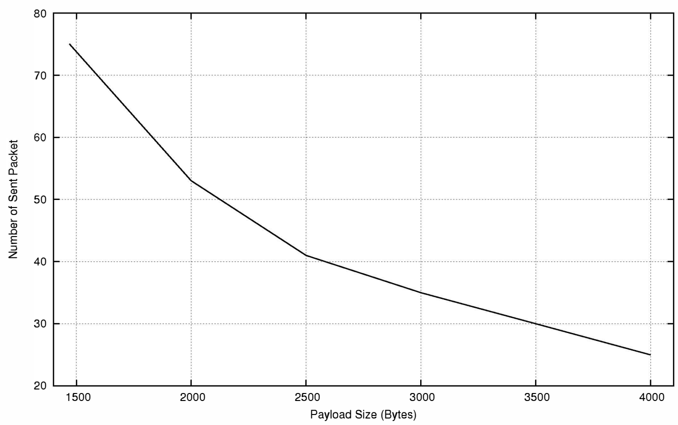


Figure 7. Number of packets required for streaming a 5 seconds HD video.

the proposed extension mechanism was achieved through a kernel module which, by enhancing the existing wireless Linux kernel modules and drivers, allows the increase of the payload in 802.11 packets. This module was deployed on our physical testbed composed of several wireless nodes and intensive tests were performed in order to evaluate the impact of the usage of our extension mechanism in wireless network scenarios. In addition, the performance of our proposed approach was compared to the AMPDU aggregation proposed in the 802.11n standard, in different network metrics. Through intensive tests we can verify that the usage of larger packets brings significant performance benefits. Concretely, nodes can make a more efficient usage of the channel bandwidth and transmit more data while sending less packets, thus increasing throughput while reducing the overhead. However, some performance issues were identified. An increase on the transmission delay was verified, but expected as the maximum packet size increases, but still remaining within tolerable values. Moreover, with the usage of the proposed WEM, an increase on packet loss was also observed but, as shown by our experimental results, under good link conditions such increase does not create a significant drawback. An evaluation of the performance gains enabled by the proposed enhancement for video streaming in wireless networks was also performed. The obtained results showed that a reduction of more than 66% on the number of sent packets can be achieved. Such reduction enables a more efficient usage of the wireless medium for such scenarios and enables novel streaming approaches. As future work, we are currently integrating these mechanisms within the MEDIEVAL framework, allowing real-time evaluation of the wireless network conditions to dynamically adjust JF frame size according to different factors, aiming to optimize video traffic in wireless scenarios.

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