Evaluation of Jumboframes Feasibility in LTE Access Networks

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***Abstract*—Long Term Evolution (LTE) represents the cutting-edge broadband wireless access technology in providing ubiquitous and simultaneous connectivity to many users. This paper evaluates the impact that packets breaking the 1500 bytes legacy value, called Jumboframes, have in LTE networks, by exploiting and extending the network stack in the ns-3 simulator. We first provide an overview about the key features of LTE starting from a physical layer perspective, to logical functions like the adaptive modulation and coding scheme, together with a detailed description of the Radio Link Control (RLC) segmentation capabilities. A comparative evaluation is performed based on diverse network configuration criteria, such as user position, density and mobility. We aim at assessing the benefits and caveats that derive from Jumboframes usage in LTE networks. Moreover, a novel cross-layer approach is proposed to mitigate the effect of rapid buffer saturation, due to the transmission of oversized packets with scarce radio resources. To conclude, we test our framework through the analysis of realistic video traces.**

***Index Terms*—LTE, Jumboframes, network simulator, video delivery, RLC functionalities.**

I. Introduction & Related Work

The increased usage of mobile phones that connect to a plethora of on-line services and multimedia content is placing the capacity of mobile operators under stringent requirements. In addition, the different nature of the kind of traffic traversing the wireless medium, shared by thousands of concurrent users, further creates complex scenarios, particularly when any disruption to the bandwidth performance is easily perceived by the user (e.g., video traffic).

For these reasons, mobile operators have started to research novel approaches, which aim to tackle these performance requirements under increasingly complex scenarios. A main course of action by standardization bodies, such as the 3GPP, has led to the enhancement of the mechanisms composing the radio access of the cellular networks. Examples of the effects introduced by such mechanisms are the reduction of packet loss and the increase of throughput in outer zones of the coverage area [1]. Similarly, the 3GPP is also acknowledging the usage of other mechanisms acting in different functional areas of the Evolved Packet Core (EPC). For example, the increasing number of cellular users connected on-line has motivated the interest in capitalizing on available non-3GPP accesses such as WLAN. Towards that end, different offloading mechanisms, where the mobile operator is able to provide discovery, routing and flow information about both 3GPP and non-3GPP accesses, are being defined and employed [2].

As such, these considerations further pave the way for the definition and experimentation of novel mechanisms, aiming to optimize user experience for mobile users looking for rich content, such as video. A typical assessment factor of the performance of an access network is its throughput capability. As of today, wired fiber optic links are one of the fastest networking technologies available. In fact, the throughputs made available by these environments [3] have motivated the increment of the frame size parameter, the Maximum Transmission Unit (MTU), which before was associated to a 1500 bytes legacy value from early Ethernet deployments. Taking advantage of the inherently better fiber optic links performance and reliability, the increase of the MTU parameter reduces the number of packets sent by enforcing less fragmentation, while at the same time reducing overhead and CPU processing since fewer packet headers need to be analyzed by the network stack.

The usage of these larger packets, deemed Jumboframes, has been amply studied in the past, and different analyses on the performance impact in TCP [4] have been presented. Likewise, such evaluations have also targeted the shortcomings of not just the MTU increase itself (e.g., different MTU values on the path [5], burst drop, delay jitter and application sensitivity [6]), but also its impact on other mechanisms relying on the legacy MTU value (e.g., IP packets Total Length fields and their CRC limit [7]). However, wired links have not been the only technologies evolving in this direction. For example, [9] has explored the impact of Jumboframes in WLANs with a real testbed, showing benefits in terms of throughput in different scenarios. In particular, the authors highlighted the fact that the wireless medium dynamics and shared access of its contention-based access mechanism not only exacerbate the previously mentioned shortcomings of large frame usage, but it also creates new issues on medium fairness usage and end-user experience performance. As such, resilience mechanisms, such as partial frame size selection, packet recovery and rate adaptation, need to be employed in order to circumvent these issues.

Recognized as a powerful technique also for wireless technologies, this paper aims to design and evaluate the usage of enhanced packetization mechanisms for deployment in LTE

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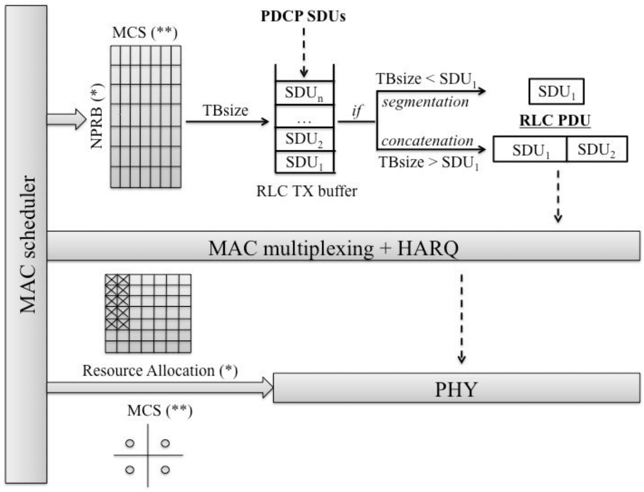

Fig. 1. Overview of the Radio Access mechanisms involved for Jumboframes transmissions in LTE networks.

networks. It is well-know that coordinated-based wireless access technologies (e.g., LTE and LTE Advanced) are strictly coupled with adaptive resilience and medium fairness mechanisms [8]. Therefore, this paper provides a feasibility study evaluation of the opportunistic advantage of using frames of larger size in LTE networks, contributing with a concrete assessment of employing Jumboframes in different scenarios. Unlike [9], the study is more focused on the description of the key aspects of LTE networks (e.g., RLC header) that have a direct impact on Jumboframes implementation, permitting a complete understanding of the addressed problem. Due to the particular complexity of the considered cellular architecture, we study the impact of Jumboframes transmissions using ns-3, a network simulator that permits to evaluate, as well as the wireless access, also the EPC, permitting to perform an overall system evaluation without recurring to a real testbed, as done in [9]. Therefore, the objective of the paper is not only to determine, for specific situations, the validity of using Jumboframes, but also to detect when such behavior enhances the network performance.

This paper is organized as follows. Sec. II provides a description on the LTE system model regarding frame and fragmentation mechanisms related with the paradigm of Jumboframes. In Sec. III, our Jumboframe-enabled LTE framework is analyzed in different scenarios. In particular, Sec. III-A presents a study on the overhead and the buffer status for the LTE architecture without mobility. Mobile users are considered in Sec. III-B with a solution to the problem of buffer saturation. The validation concludes in Sec. III-C with a real-time video transmission. Final considerations are presented in Sec. IV.

II. System Model

The simulation platform used to evaluate Jumboframes feasibility is ns-3, an open source discrete-event network simulator for Internet-based systems, available online at [10]. Our work exploits the module currently under development within the LENA project [11], which comprises the LTE core network, EPC, presented in [12], and the radio access, eUTRAN, detailed in [13] and based on the first LTE simulation framework for ns-3 [14]. The simulator is extensively documented in [15].

We will first provide a description of some key physical aspects and signaling procedures in order to better understand the resource distribution among users in LTE, and the associated resource exploitation, namely modulation and coding scheme (MCS). In fact, as depicted in Fig. 1, the MAC scheduler is in charge of generating an allocation scheme based on the Channel Quality Indicator (CQI) feedbacks; through this map, at each sub-frame, the eNodeB (eNB) reads the number of Resource Blocks (NRB) and the associated MCS assigned to each user in order to determine the packet size to be transmitted and, possibly, perform RLC segmentation or concatenation.

LTE radio spectrum: The frequency axis is subdivided in sub-bands with a carrier frequency raster of 100 kHz, whereas the total transmission bandwidth is expressed in number of Resource Blocks (RB) (e.g., 50 RBs correspond to 10 MHz of bandwidth). The LTE frame is composed of 10 subframes of 1 ms each, for a total duration of 10 ms. Each subframe can be seen as a *time* vs *frequency* grid. Resources in LTE can be allotted to the users in terms of an integer number of RBs, where the RB is the allocation quantum. Each RB is 180 kHz wide in frequency (12 subcarriers, 15 kHz each) and 14 OFDM symbols in time (1 ms).

Channel Model: The propagation conditions defined in Annex B.2 of [16] have been used to generate channel traces for three different scenarios, as shown in Table I.

TABLE I
3GPP PROPAGATION SCENARIOS

Scenario	User speed [kmph]
Pedestrian	0, 3
Vehicular	30, 60
Urban	0, 3, 30, 60

The macroscopic pathloss is based on the Friis free space equation, and the shadowing is modeled as a log-normal distribution with zero mean, and standard deviation 8 dB.

CQI feedback: Prior to transmission, each eNB broadcasts a signaling pilot sequence. All the users within its coverage area decode it, and generate a list of CQI on a per RB basis, in order to provide the eNB with an overall quality information snapshot. CQI feedback [17] represents an indication of the data rate that can be supported by the channel for allocation and scheduling purposes. In LENA, the generation of CQI feedback is done according to the primitives specified in [18].

Scheduling & Resource Allocation: The MAC layer scheduler is in charge of generating specific structures called Data Control Indication, which are then transmitted by the eNB through the Physical Downlink Control Channel to the connected users, in order to provide them with a resource allocation map in every sub-frame. These control messages contain information such as the MCS to be used, selected with the Adaptive Modulation and Coding scheme, the associated Transport Block (TB) size as defined in [19], and the allocation bitmap which identifies the RBs that will carry the data transmitted by the eNB to each user. To achieve a good fairness level, we adopted a Round-Robin scheduler: at each allocation

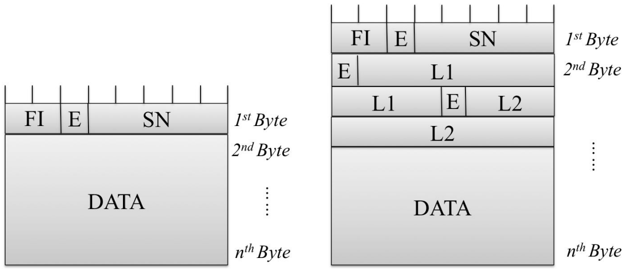

Fig. 2. RLC PDU example: 1 single SDU (left), 2 concatenated SDUs (right).

step, the resources are equally distributed among the users.

RLC segmentation/concatenation: As shown in Fig. 1, depending on the channel conditions and the adopted scheduling strategy, a user might be allotted a number of resources that enable the transmission of multiple Segment Data Units (SDU) (i.e., *concatenation*); conversely, the SDU has to be split (i.e., *segmentation*). Generally speaking, the overhead plays a fundamental role for the evaluation of Jumboframes, so we focus on the LTE-specific guidelines defined in [20]. The RLC mode selected for our simulations is Unacknowledged (UM).[1]

As shown in Fig. 2, the RLC header of a Packet Data Unit (PDU) containing more than one SDU is more complex. Additional fields, as described below, are introduced to describe the packet concatenation structure.

- FI (Framing Information): the first bit indicates whether the first byte of the Data field is the first byte of an RLC SDU, whereas the second bit indicates whether the last byte of the Data field corresponds to the last byte of an RLC SDU.
- E (Extension): when this field is set to 1, it means that a new RLC SDU will be included in the current PDU;
- SN (Sequence Number): indicates the sequence number of the current PDU;
- LI_i (Length Indicator): represents the Data field size of the *i*–th SDU, in Bytes.

III. Jumboframes Evaluation Framework

Jumboframes in ns-3 are enabled by appropriately setting to 10 KB the MTU i) in the application server (*udp-client*[2]), ii) in the internet (*point-to-point-helper*), and iii) in the LTE core network (*epc-helper*). In the application server, Jumboframes are generated with packets of 9 KB, whereas the traditional frames have 1 KB long packets. We take into account the delivery of three files with different sizes: 4.5, 45 and 450 MB.

A. Feasibility Study

In order to provide an adequate insight about Jumboframes impact in LTE networks, we configure different simulation scenarios characterized by diverse number of users and their location. The variability offered by these parameters permits to highlight the interplay between the RLC segmentation/concatenation mechanism, the size of RLC PDU and the number of RBs assigned by the MAC scheduler to each user.

1) User-location: The considered scenario is composed of 3 users located at different distances from the eNB: 200, 1000, and 2000 m away, respectively. Each user perceives highly different channel conditions, resulting in a diverse bandwidth utilization (i.e., different MCS value). The downlink flow is designed in a way that, in each sub-frame, the transmission queues are always full (i.e., backlogged). As shown in Fig. 3, UE1, that corresponds to the user in the proximity of the eNB, is the first one that completes its download, thanks to the better assigned resources exploitation. The usage of Jumboframes slightly outperforms the traditional approach in terms of transmission time reduction (3%). It is interesting to note the large overhead savings of Jumbo with respect to normal frames usage (87%) shown in Fig. 4, where the total amount of overhead (i.e., UDP, IP and RLC) is depicted for the transmission of a 450 MB file. This is due to the reduced amount of RLC concatenation performed by the eNB to adapt the incoming Jumboframe to the reserved region assigned by the MAC scheduler to each user. In fact, in addition to the higher level headers such as UDP and IP, each transmitted packet presents an RLC header whose size relies on the fragmentation/concatenation performed at the RLC level (see Fig. 1): the more RLC operations are accomplished the bigger is the RLC header. Thus, the lower amount of overhead required by Jumboframes permits to reduce the processing complexity with respect to the normal frames case, as illustrated in Fig. 5. Here, the depicted distributions collect the different RLC header lengths used by the eNB to transmit all the RLC PDUs for each user in the case of the 450 MB file delivery. For example, in case of Jumboframes (gray bars), UE1 (the user with the best channel conditions) transmits

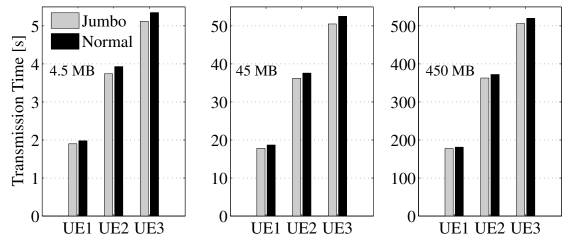

Fig. 3. Transmission time of three files with different sizes ($\{4.5, 45, 450\}$ MB) for three users. Gray and black lines represent Jumbo and normal frames, respectively.

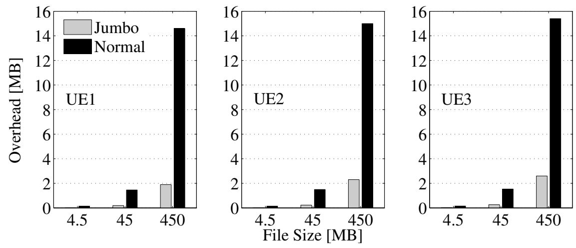

Fig. 4. Total overhead sent during the transmission of the 450 MB file for Jumbo and normal frames.

[1]Please note that in LTE there are two more RLC modes: Transparent Mode (TM), and Acknowledged Mode (AM). Please refer to [20] for further details.

[2]The UDP client represents a UDP packet generator, where it is possible to set the generation rate and the packet size.

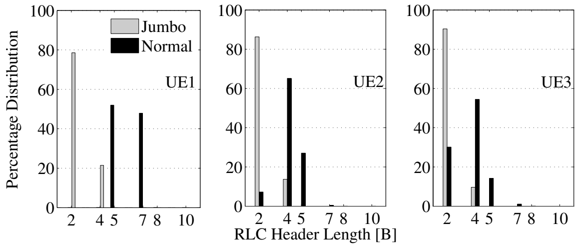

Fig. 5. Comparison of RLC Header length expressed in Bytes between Jumbo (gray bars) and normal (black bars) frames for the 450 MB file delivery.

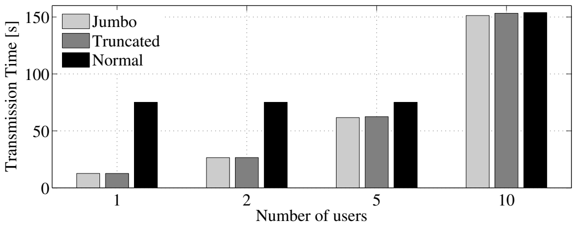

Fig. 6. Transmission time for Jumbo, *truncated* Jumbo and normal frames as a function of the number of users served.

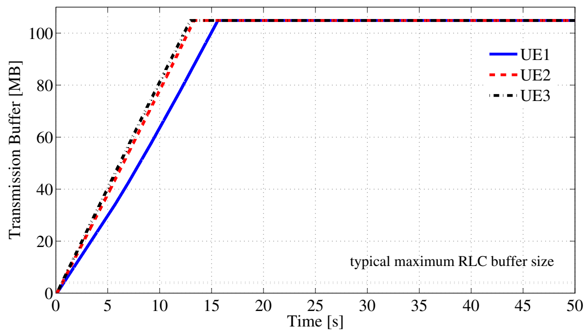

Fig. 7. Status of the RLC transmission buffer for Jumboframes transmissions. The typical size of the buffer is depicted for comparison.

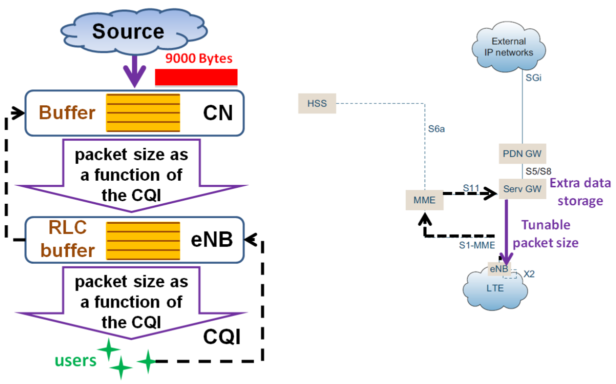

Fig. 8. EPC architecture: ns-3 implementation (left), 3GPP view (right).

PDUs with 2 B RLC header size for slightly 80% of the total transmissions, and 4 B otherwise. On the other hand, by using normal frames, the eNB performs multiple concatenations to produce the RLC PDU suitable for the number of RBs assigned by the MAC scheduler,[3] thus increasing the overall transmission processing complexity. This effect is slightly reduced for the other users, due to the lower number of bits that can be transmitted over the same number of RBs, avoiding complex concatenations between different SDUs.

2) User-density: Here, we vary the density of the users in the cell, aiming to evaluate the Jumboframes performance when the available resources (i.e., RBs) allotted to each user decrease. In particular, we place all the users at the same distance with respect to the eNB and we vary their number from 1 to 10. The packet generation time is equal to the LTE Transmission Time Interval (TTI), that is 1 ms. Thus, a new packet is added to the transmission buffer at each subframe. The download file size is 112.5 MB long. In order to see the impact of Jumboframes in a more realistic scenario, the source is no longer backlogged. Recalling that Jumboframe is constituted of 9 KB and normal frames of 1 KB, we here introduce a third type of frame, named *truncated* Jumboframe. This special version of Jumboframe is made of 9 KB as its precursor, but it undergoes a fragmentation according to the traditional 1500 MTU limit in the EPC. This new classification permits to show the potentiality of Jumboframes when the source admits an extended frame size, but the network cannot sustain a higher MTU limit (1500 B). It can be noted from Fig. 6 that the total transmission of normal frames up to 5 users takes the same amount of time; this is due to the fact that each user can transmit the generated PDU in less than a TTI, thus underutilizing the available bandwidth. On the other hand, concerning the comparison between Jumbo and *truncated* Jumbo frames, we can observe that the transmission time is the same with up to 2 users, while it slightly differs when the number of users increases. With a few users, *truncated* Jumboframes are transmitted in the same amount of time required for the transmission of Jumboframes; in fact, the resources assigned by the MAC scheduler allow to transmit, in each subframe, the additional overhead generated when concatenating more SDUs.

B. Buffer Saturation

We noted above that transmitting bigger frames directly from the source can result in a transmission time and overhead reduction. However, focusing the attention to the status of the RLC transmission buffer as in Fig. 7, it is possible to note the main drawback of Jumboframes transmission in LTE networks: due to the higher amount of information to be sent in the same amount of time, there is a concrete risk of saturation. This figure is obtained by moving the users in opposite directions in order to simulate a continuous change of channel quality. In particular, UE1 leaves its initial position (200 m from the eNB), and approaches the cell-edge (2 km) at a constant speed, and then back to its original position; UE2 moves from an intermediate position (1 km) to the cell edge, and then back to the eNB (200 m); UE3 follows the opposite path of UE1.

To overcome this problem, we propose a dynamic technique that permits to mitigate the congestion by creating a cross-layer interaction between the radio access (i.e., eNB) and the core network (EPC), as depicted in Fig. 8. Thanks to this approach, we can tune the packet size before entering the

[3]In fact, the amount of information that UE1 can receive is higher than the size of a single packet with 1500 B.

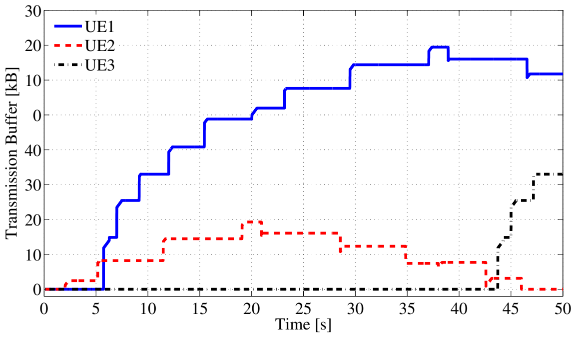

Fig. 9. Status of the RLC transmission buffer for *tuned* frame transmissions during the file delivery.

access network by relying on the channel feedbacks and the scheduling decision made at the eNB, avoiding saturation at the RLC level. It is to be noted that this technique has been implemented in ns-3 through *c++* programming strategies for evaluation purposes, thus it is not part of a 3GPP compliant structure that should rely on S1 control signaling. A small delay is necessarily introduced during the communication between the eNB and the Service Gateway; if we consider a scenario without mobility, this delay does not affect the transmission buffer because the *tuned* frame size fits with the instantaneous TB size assigned by the scheduler (except for minor multipath channel oscillation). On the other hand, if we introduce mobility, the transmission buffer varies with the speed and where the user is going. In fact, if the user moves closer to the eNB, the delayed channel feedback is more conservative with respect to the actual position; otherwise, if the user is going away from the eNB, the delayed TB size indication overestimates the effective allocatable packet dimension, thus imposing fragmentation, and a consequent increase of the RLC buffer. This behavior is confirmed by Fig. 9, where the RLC transmission buffer of each user is illustrated. The transmission buffer of UE1 increases stepwise (because of quantized CQI levels) and, at around 40 s, it starts decreasing: this is because the user has reached the cell edge, and returns back to its initial position. On the contrary, UE3 initially shows a stable transmission buffer (it starts from the cell-edge and approaches the eNB), then it goes back to its initial position, showing an increase of the RLC buffer. Similarly, UE2 stores extra information at the beginning of the simulation and then reduces the stored data (from the cell-edge the user approaches the eNB), confirming our explanation.

C. Real-Time Video Transmission Evaluation

In this section we present the evaluation of realistic video traces transmitted through Jumbo and normal frames, in order to show the effectiveness of our approach also with real applications, where the size of each frame is variable. To do so, we selected a subset of video packets (16 MB), taken from *Jurassic Park I (H.263 - 256 kbit/s target bit rate)*, downloaded from [23].

The results shown in Figs. 10 and 11 confirm the behavior described in the previous sections. For a low number of users, if compared to the Jumboframes transmission, the additional overhead is transmitted in the same amount of time because

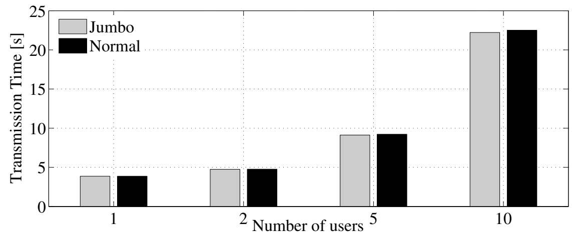

Fig. 10. Transmission time of a part of *Jurassic Park* movie for Jumbo and normal frames as a function of the number of users served.

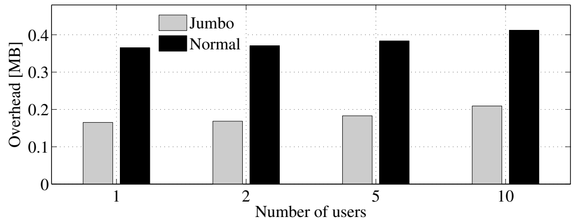

Fig. 11. Total overhead sent during the transmission of a part of *Jurassic Park* movie for Jumbo and normal frames as a function of the number of users served.

of the available resources. Concerning the overhead, we can observe a smaller gain as compared to our example shown in Fig. 4; this is because the size of these time-varying packets is, on average, 4.3 MB.

IV. Conclusion & Future Work

This paper presented a simulation framework for the evaluation of Jumboframes impact in LTE networks. A comparative observation based on diverse network configuration criteria highlighted some benefits and caveats related to this approach. On the one hand, under certain channel and scheduling conditions, we observed a slight transmission time reduction, and a great overhead saving, mainly due to the reduced amount of higher level headers. In addition, Jumboframes permits to further reduce the size of the RLC headers by requiring less segmentation/concatenation mechanisms. On the other hand, scarse resources lead to rapid buffer saturation. In order to mitigate this effect, a cross-layer approach has been proposed, allowing the radio access (i.e., eNB) and core network (EPC) layers to interact and tune the packet size dynamically. We tested our evaluation framework through the analysis of realistic video traces, showing insightful results that confirm the performance impacting trends described throughout the paper. There are many other issues to consider relatively to Jumboframes impact in wireless networks, such as error control techniques, ad-hoc allocation schemes, LTE-A Carrier Aggregation exploitation, and so forth. This work represents a first contribution for the Jumboframes feasibility in LTE networks, paving the way for for further research leveraging future mobile accesses with these enhancing mechanisms.

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