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Performance evaluation of Application Layer Joint Coding solutions for video transmissions between Mobile Devices over the Internet of Things

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A B S T R A C T

In the Internet of Things (IoT) era with the wide employment of Mobile Devices (MDs), the distribution of video streams is continuously increasing and specific solutions for transmissions between mobiles are needed. In this paper, we provide the performance comparison, through emulations, among Application Layer Joint Coding approaches for videos over channels whose conditions change over time. The proposed analysis highlights that the video streaming over such critical channels is practicable, from the Quality of Experience (QoE) viewpoint, only if source and channel coding are both adaptively applied to the video transmissions.

1. Introduction

In the last years, due to the great widespread of the Mobile Devices (MDs) that characterize the so called Internet of Things (IoT), the need for a reliable and fast communication arises. For examples, the next fifth generation (5G) network moves in this direction by adapting itself to the requested applications. To achieve this goal, 5G network must have the following characteristics: *(i)* highly flexible and intelligent; *(ii)* have a spectrum management scheme; *(iii)* expected to improve efficiency while decreasing the cost; *(iv)* introduce flexible bandwidth allocation based on the demands of users.

Even though spectrum, bandwidth, coverage and transmission rate will be extended in particular with the introduction of 5G networks, channel reliability could be not granted in critical areas such as rural zones or mountains with long tunnels and high canyons (also urban) in which run cars or high-speed trains may experience a not optimal channel availability. Such channel outage, may occur while the vehicle crosses through areas characterized by severe fading conditions (e.g., tunnels). This is a very critical issue when dealing with real-time services (such as video streaming), which experience possibly long (on the order of several seconds) interruptions, thus causing highly negative performance impairments (service disruption) in terms of the end user point of view [1].

In addition, frequent handover across cells greatly increases the possibility of service interruptions, and the problem is prominent for multimedia communications that demand both high-throughput and continuous connections [2].

This paper tackles the problem of video streaming in areas where networks experience channel outage and in which users are in mobility (*e.g.*, inside a moving car or on a high-speed train). The solution proposed in this work is to employ Application-Layer Joint Coding (ALJC) techniques to mitigate channel outage so to provide good quality video streaming even in severe conditions. Indeed, ALJC guarantees flexibility and easy-reconfigurability, in addition to the recovering capabilities of the code itself. From a practical viewpoint, video streams are compressed and protected so to guarantee a good perceived video quality and, at the same time, limit the offered load to the network as done in [3] and extended in [4]. In this paper we compare three different approaches: *(i)* Static ALJC (*Static*), *(ii)* Adaptive ALJC (*Adaptive*) and *(iii)* Fully Adaptive ALJC (*Fully Adaptive*). *Static* provides low compression jointly with a low protection. Both of these parameters are fixed. *Adaptive* employs very high compression while the video streams protec-

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tion varies along with the channel conditions. Finally, *Fully Adaptive* allows both protection and compression to follow the channel conditions.

In more detail, the contribution of this paper are listed below:

- we provide the performance comparison, through emulations, among the aforementioned techniques *Static, Adaptive* and *Fully Adaptive* over critical channels and
- the analysis of the feasibility of video transmissions over critical channels from/to Mobile Devices: from the results, we prove that it is practicable only if a *Fully Adaptive* ALJC solution is applied.

The remainder of this paper is structured as follows: in Section 2 an overview of the related work in the literature is provided; Section 3 details the considered conditions and the three proposed ALJC approaches while Section 4 shows and describes the obtained numerical results. Finally, conclusions are drawn.

2. Related work

The aim of the Application-Layer Joint Coding (ALJC) techniques analyzed in this paper is to mitigate channel outage so as to provide good quality video streaming even in severe conditions. The concepts on which these solutions are based are well suited for different kinds of cellular technologies, since, notwithstanding the remarkable differences in terms of latency and capacity, they are all more or less subject to outages, when it comes to challenging environments. In particular, if we think about the *2G* cellular framework, *GPRS* technology enabled data transmission with data rates in the range {56-115 kbit/s}, which are hardly compatible with a quality video streaming domain application [5]. The development of the *third generation* technology introduced higher throughputs and lower latency, providing up to 2 Mb/s bandwidth. This new approach allowed users to exploit the cellular network also for next generation applications such as video and audio streaming. With the advent of *4G – LTE*, the data rates were increased even more. A typical *Long Term Evolution* framework can reach up to 300 Mb/s download speed, providing an ideal latency lower than 10 ms.

Obviously, we can obtain the best in terms of performance and user satisfaction when the bandwidth is high and the latency is low. However, all the previous considerations hold true in the case of ideal or good coverage conditions. Indeed, when it comes to challenging areas, user experience is always affected, due to spotted radio coverage or even connectivity outages, and this happens independently of the considered cellular technology. The best possible performance can be obtained when exploiting the upcoming *5G* technology, which provides outstanding characteristics for what concerns delay and throughput. The advent of *5G* opens the door to a new era of telecommunications, where users can benefit from almost real-time communications and data rates that can reach up to 10 Gb/s in download [6]. This new technology enables frameworks such as *Mobile-to-Mobile (M2M)* communications, where our considered ALC solutions best apply. Indeed, an efficient approach to mitigate bad channel state effects with a quick quality recovery is a key feature for a quality user experience in *5G* framework applications.

As stated in [7,8], and in the references therein, two of the most developed topics in the literature in the field have been video streaming and Internet of Things (IoT). The former is a mature topic that has developed into the most voluminous type of data currently traversing the Internet, above 50%. The latter is a topic under development and the merging of the two aspects represent a very interesting issue with numerous applicative implications, such as the video processing at the Fog nodes for urban surveillance [9], but still open. Indeed, the characteristics of the devices and communications channels of the IoT implies limitations to the quality of service offered by the channels. With video streaming applications, in [7] is affirmed that *these limitations have an impact on the type of encoding that can be adopted. Video data, in its original format, is very voluminous, so that compression is a mandatory requirement*. Moreover in that reference, it is discussed the H264 AVC standard as useful solution from the perspective of specific support for error resilience. This solution has been further developed in [10] where the H264 AVC standard was evaluated in case of scalable and non-scalable encoding considered. The proposed analysis has been done testing some video streams in a LoWPANs and considering a static (i.e., with no changes over time) quality level of the wireless channel.

Another inspiring paper in the literature is [11]. It discusses the evaluation of a video streaming mechanism, called DASH, working on top of the Content Centric Networking (CCN) architecture. It has been studied in a suitable IoT scenario but without dynamic channel conditions, typical in case of mobile IoT nodes (i.e., Mobile Devices – MDs). Moreover, the analysis is not provided in terms of user Quality of Experience (QoE) but in terms of Peak Signal to Noise Ratio (PSNR) which cannot not be easily mapped into QoE. A subjective measure of a customer's experience is a key aspect when we consider user-centric services such as video content delivery. A comprehensive investigation on the issues and possible approaches about QoE in the framework of Mobile Social Networks (MSN) is provided in [12]. Also, Liu et al. [13] proposes an interesting solution for the improvement of video transmission in CCNs. In this work authors design a new caching policy for popularity-aware video caching in topology-aware CCN and they employ scalable video coding (SVC) for fast-start video delivery.

To the best of authors' understanding, differently from this paper, in the above mentioned references neither adaptive solutions based on the Application Layer Joint Coding (ALJC) nor a deep QoE performance investigation campaign with challenging channel conditions are proposed.

Concerning the framework of the ALJC in the literature, the work in [14] argues that all the systems can be partitioned into two regions where Application Layer Coding (ALC), i.e., channel coding only, is beneficial and detrimental, respectively. It establishes an asymptotic regime that contains the boundary between these two regions: ALC improves the performance only in systems with low loss probabilities (without coding), and employing such coding in systems with high loss probabilities only degrades the performance. Bisio et al. [4] start from the concepts stated in [14] and presents an heuristic ALJC implemented over smartphones. Differently from this paper, Bisio et al. [4] specifically consider a network with satellite links (with delays compatible with LEO constellations). The works reported in [15] proposes a joint coding solution at the application layer coding assuming that the traffic is generated by Gaussian sources. Mancuso and Bianchi [1] consider the problem of channel outage in a mobility scenario (high-speed train). Differently from our paper, it proposes an elastic buffering devised to decouple the multimedia information retrieval rate on the network backbone from the playout streaming rate at the user terminal.

Kaliszan et al.[16] apply the ALC technique in the arbitrary number of co-channel multicast groups scenario. Luna et al. [17] and Zhang et al. [18] exploit joint source coding to achieve a power-optimized architecture and an energy efficient transmission of a video sequence under delay and quality constraints. Similarly to this paper [19] tries to maximize user perceptions utility in the multi-user wireless video streaming but, differently from our work, it leverages on bandwidth allocation.