Opportunistic Scheduling and Rate Adaptation for Scalable Broadcast Video Streaming

Daniele Munaretto

Department of Information Engineering
University of Padova
Padova, Italy
Consortio Ferrara Ricerche
Ferrara, Italy
E-mail: munaretto@dei.unipd.it

Abstract—In this work we propose an adaptation framework where video packets are opportunistically scheduled for broadcast/multicast media streaming applications. The scheduling mechanism operates based on the average and instantaneous user distributions and radio link channel quality, information obtained through the cellular uplink channel. In our framework we use H.264 Scalable Video Coding (SVC) to generate multiple independent streams or scalable sub-streams, further split into video packets, which are opportunistically scheduled with the goal of maximizing the average quality of service for the end user. Based on the design of our delivery system, we finally foresee practical implementations of efficient scheduling algorithms for broadcast video delivery over next generation cellular networks.

Keywords—scalable video coding; opportunistic scheduling; broadcast streaming;

I. INTRODUCTION

In the next generation cellular networks, video streaming is seen as the killer application in terms of data traffic share. Standard broadcast video transmission schemes (MBMS, [1], [2]), designed to deliver the same video contents to multiple users in the same area, are calibrated on the end user with worst channel conditions. This turns into providing robust transmissions to ensure a base video quality to this user, while affecting the video quality perceived by users that potentially benefit from receiving the same video flow at a higher rate, i.e. with better video quality. Prior work shows that encoding a video in multiple video layers, for instance by using H.264 SVC [3], is beneficial for delivering videos to a heterogeneous set of users. In SVC, three dimensions of scalability are offered in order to overcome different channel conditions (quality or SNR and temporal scalability), screen sizes and device capabilities (spatial scalability) of users, [4]. Further flexibility in broadcast systems is gained at the base station when using different modulation and coding (MC) schemes at the physical layer, and by exploiting the scheduling flexibility offered by the MAC layer in LTE cellular networks. For instance, a low quality video stream (in SVC, the base layer), encoded at a low bit-rate can be broadcast with an appropriate MC so that all users in the cell correctly receive the packets and play the video, no matter what their channel conditions are, while an additional high quality video stream (in SVC, enhancement layer), encoded at high bit-rate, can be broadcast at a higher MC, and hence can be decoded only by users with good channel conditions.

We now assume that packets of each individual stream/substream use a dedicated queue inside the base station. In this context, the base station requires a scheduling mechanism which decides at each time instant which stream to schedule for transmission. Hence, in this work we propose an opportunistic and flexible scheduling scheme based on the instantaneous user distribution, the users’ channel quality, and the MC schemes decided for each available stream, to properly select the queue from which packets must be sent into the channel with high priority. This allows the delivery of simultaneous sub-streams to different quality-based classes of users in an efficient way, exploiting the instantaneous variation of the users channel conditions to increase the overall users perceived video quality.

The remainder of the work is organized as follows. Prior work is described in Section II and our delivery architecture is presented in Section III. We conclude with planned research activities in Section IV.

II. RELATED WORK

Prior art relevant to our work focuses on three main aspects. First, in the case of unicast wireless transmissions, opportunistic schedulers are presented which act upon the instantaneous changes of the channel conditions of the active users [5]–[7]. The scheduler then schedules for transmission packets for the user experiencing the best channel conditions at a given time instant. Furthermore, fairness issues may be taken into account in order to mitigate the problem of user starvation, in case a user experiences a bad channel for a long period. Solutions concentrate mostly on the idea of defining fairness metrics among active users, and keeping history information about prior scheduling decisions. In general, the type of content being scheduled, and its relative importance among users, is not taken into consideration.
Second, the problem of opportunistic scheduling is addressed in broadcast scenarios [8]. The type of content usually matters in this context and so does the user preference for a given piece of content. The opportunistic scheduling decision is based on the user preferences/content popularity, and takes into account various constraints, e.g., transmission or storage capacity. From this point of view, the presented scheduling solutions function at a different layer, i.e., the application or control plane, and optimize the type of content that is transmitted at a coarse level. These solutions do not take into account the instantaneous channel variations perceived by the wireless users, and do not attempt an optimization of the channel resource allocation on fine grained time intervals in order to make the wireless transmission process more efficient.

Finally, the third related area concentrates around the problem of optimizing the resource allocation at the application and network/MAC layer [9]–[11]. Usually algorithms are defined in order to choose the right application rate and adaptive modulation and coding scheme in order to maximize/minimize a given metric. These algorithms perform on a coarser time scale, and usually assume average channel conditions and application metrics. While the output of such algorithms can be used as input to our proposed innovation, our opportunistic scheduling mechanism is independent of the existence of such algorithms.

Our novel contribution lies on an opportunistic scheduler for media broadcast in wireless environments. Our scheduler takes into account the instantaneous channel conditions of the groups of users subscribed to a particular media stream, and the relative quality difference between the different competing streams. Based on these parameters, at each time instance the scheduler takes the decision on the current stream to be transmitted. To the best of our knowledge, this cross-layer approach, which encompasses media characteristics and instantaneous channel conditions of the users, which affect the size of the user groups accessing each stream, is novel.

III. ARCHITECTURE

In this section we describe our delivery architecture, as shown in Fig. 1. The base station temporarily buffers packets from several video streams in different queues before the transmission on the wireless medium. Each stream is dedicated to a possibly different user group and, depending on the aggregated channel conditions of the group, can be modulated with a possibly different modulation and coding scheme. The user groups can be independent (e.g., in the case of different video streams, one for each user group, or different streams of different quality levels of the same video), or inclusive (e.g., in the case of different scalable sub-streams of the same video, providing different quality levels to different users, grouped according to their channel conditions). For simplicity, we also assume that the aggregated rates of the scheduled streams, given their chosen modulation and coding scheme, do not exceed the channel capacity (e.g., computed per GOP, Group of Pictures). The stream rates and MC schemes associated to each queue are the result of solving an optimization problem, as presented in [12], [13]. The computation is performed periodically, based on average channel conditions of the target users.

The proposed opportunistic mechanism schedules at each time instant the available packets in the transmission queues (Fig. 1). The scheduler is informed about the instantaneous channel quality of each user through the feedback channel (via uplink), and is able to take this information into account in its scheduling decision. For each user group associated to one video stream buffered in one queue at the base station, it computes the instantaneous channel conditions. At each time instant, the scheduler opportunistically schedules for transmission the queue associated to the user group which currently experiences good channel conditions, while at the same time taking into account the relative importance of the content of the queued video streams. In case the associated queue is empty, the scheduler picks the next best user group (with respect to the channel conditions and content). The procedure ensures the efficient use of wireless resources, increasing the possibility of correct reception of the scheduled packets by each user group in case of multiple scheduled video streams, or alternatively increases the overall user perceived video quality in the case of scalable video streaming with multiple enhancement layer sub-streams.

We describe two instances of the same opportunistic scheduler that we plan to implement in our framework. These two approaches differ slightly in the optimization problem and in the scheduling decisions to be taken.

- **Video-quality based instance**: video packets are selected from a specific queue so that the number of users that can receive a video quality layer with a given MC at a certain time instant is maximized. This method enhances the overall video quality of the whole system, by increasing the size of the individual groups of users receiving a specific video layer;

- **Robust opportunistic instance**: the base station selects the packets from the queue as explained above, but instead of maximizing the number of users capable of correct reception by transmitting at the previously established MC, the base station increases the transmission MC, to serve the same number of users but using fewer wireless resources. The new MC is chosen so that the resulting target user group is not smaller than the previously computed one. The potential savings in channel rate by using a higher MC can be used for adopting lower MCs later on in case the channel quality decreases, in other sessions (resource redistribution), to retransmit the most important video packets of the video to increase the probability of correctly receiving
such packets, and to provide additional redundancy (FEC).

IV. FUTURE WORK

In this work we have introduced an adaptation framework for opportunistically scheduling video packets in broadcast/multicast streaming applications. We described the envisioned delivery architecture, focusing our analysis on how to schedule at each time instant video packets in the transmission queues at the base station. Hence, we propose the use of scalable video encoders, such as H.264/SVC [3], designed to address the issue of serving heterogeneous user terminals at the same time.

Two distinct opportunistic scheduling mechanisms were described, where the goal was either to maximize the number of users that can receive a video quality layer with a given QC at a certain time instant or to minimize the wireless resources to be used when serving a target number of end users.

The immediate next steps in our research plan focus on the implementation and the evaluation of the aforementioned scheduling mechanisms by means of simulation and experiment on real video sequences. We plan to consider videos with different characteristics, in terms of application layer data rate, motion activity (dynamic/static videos) and content (simple/complex scenes) [14]. We foresee the use of a set of quality metrics to evaluate the impact of the proposed scheduling solutions on the perceived video quality of the end users, compared to the baseline scheduling mechanisms.

Finally, we plan to design fast and scalable heuristic algorithms to keep the computational complexity of our novel scheduling mechanisms low, in order to fulfill the network constraints and meet the feasibility requirements of a wide set of practical cellular network scenarios.

ACKNOWLEDGEMENT

This work is carried out under the supervision of Prof. M. Zorzi and Dr. L. Badia. It is supported by the MEDIEVAL research project (STREP) of the 7th Framework Programme of the European Commission.

REFERENCES