Adaptive packet scheduling for scalable video streaming with network coding

Shenglan Huang*, Ebroul Izquierdo, Pengwei Hao
Queen Mary, University of London, United Kingdom

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Over the last decade, the emergence of new multimedia devices has motivated the research on efficient media streaming mechanisms that adapt to dynamic network conditions and heterogeneous devices’ capabilities. Network coding as a rateless code has been applied to collaborative media streaming applications and brings substantial improvements regarding throughput and delay. However, little attention has been given to the recoverability of encoded data, especially for the streaming with a strict deadline. This in turn leads to severe quality of experience. In this paper, we solve the unrecoverable transmission by proposing a multi-generation packet scheduling problem, which is treated as a video quality maximization problem and solved using dynamic programming algorithm. Experimental results confirm that the proposed algorithm brings better data recoverability and better quality of service in terms of video quality, delivery ratio, lower redundancy rate under different network sizes.

1. Introduction

With the emergence of various multimedia devices such as laptops of smartphones, the scalable data streaming mechanisms have gained great popularity among users. Network users spend significant time in online communication sharing media and watching videos streamed over the Internet. Indeed, multimedia communications are nowadays pervasive and substantial part of modern life. Many research has been studied in the creation of a natural multimedia environment for remote immersive and interpersonal communication, like high-quality 3D video coding or HEVC. With high-quality 3D virtual world and 3D videos, the efficient transmission of data is also the key to success. To achieve the efficient transmission, some researchers combine scalable video coding with network coding [1,2] to adaptively optimize the video transmission over P2P network. Many researchers also study in multi-source streaming tree technologies. However, improving bandwidth efficiency is necessary because better bandwidth resources allocation leads to more useful transmissions and better quality of service for media streaming applications. Therefore, this paper focuses on improving bandwidth efficiency in scalable streaming networks.

Methods such as Fountain codes (Random Linear Network Coding [3], Raptor codes [4], LT codes [5]) have been proposed recently for efficient data delivery in the lossy network. The benefits of Fountain codes is the improvement in delay reduction for live media streaming applications. The traditional scheme for transferring data across an erasure channel is a continuous two-way communication, where senders acquire acknowledgments from receivers to re-transmit error packets. With Fountain Codes, senders can keep transmitting encoded packets to receivers until receivers have enough valid packets to decode the original packets. Raptor codes and LT codes are based on the exclusive or operation and need the complete original data to generate new coded data. Comparatively, RLNC linearly combines packets with random coefficients [6] and can generate new coded data from part of original packets. Therefore, RLNC is more suitable to be used in a distributed system than Raptor codes and LT code. Based on RLNC, Chou et al. [7] proposed a practical network coding scheme for large-scale media streaming. The authors proved that practical network coding could provide significant gains regarding throughput and delay compared with the traditional approach in a distributed network. Many large-scale applications of applying network coding in the field of multimedia streaming [8–10] have also demonstrated benefits in reducing communication delays and facilitating collaboration among nodes. Further, with the development of scalable video coding, some scalable coding methods are combined with RLNC to provide unequal protection for scalable data transmission, such as Expanding Foutain codes [11], Hierarchical network coding [12], and Layered network coding [13].
Peer-to-peer (P2P) networks have been used extensively in multimedia streaming as an effective transmission platform. Many existing commercial P2P networks have shown their success when they are used to transmit files [14] or multicast streaming [15,16]. The advantage of P2P systems is that the network construction is scalable and money-saving [17–19]. Early P2P networks were based on multi-tree structures. Peers immediately push packets to its children nodes when they receive new data. In contrast, swarm-based schemes are proposed [22,23,1]. They allow peers in the swarm-pull scheme to maintain its neighbors and periodically exchanges its buffer-map, which represents the availability of video blocks, with its neighbors. Each peer then fetches packets from its neighbors accordingly [21,16]. By taking advantage of network coding, the mesh-push schemes are proposed [22,23,1]. They allow peers in the swarm-pull schemes to actively push their received packets to its neighbors according to periodically exchanged buffer-maps. When a receiver gets enough encoded packets, it immediately decodes the original packets using Gaussian elimination.

Despite substantial progress in the field, little attention has been given to bandwidth efficiency in the NC-based streaming applications, especially to the NC-based scalable video streaming. Better bandwidth efficiency will result in a better quality of service in multimedia streaming. The bandwidth inefficiency in current NC-based mesh-push scheme is caused by the delay of buffer-map. In the push scheme, there will be a good number of redundant packets already in the transmission pipeline if the delay is considerable. We term this kind of redundant transmission as braking effect. The braking effect is especially severe in scalable video streaming because it happens very frequently due to the layered transmission mechanism. To solve this problem, instead of transmitting layered data, the optimal layer is selected in advance based on the information of video, network bandwidth, and loss rate in advance. Senders then push packets to each receiver based on a distributed multi-sender cooperation algorithm.

The remainder of this paper is organized as follows. In Section 2 we introduce some related works on the packet scheduling problem. In Section 3, we propose the overall system model for the streaming network. Then in Section 4 we describe the proposed scalable streaming system. In Section 7 we present results of some simulation experiments, and in Section 8 we draw some conclusions.

2. Related work

Scalable media streaming refers to the coding technique which fragments a single high-quality media-stream to several layers to provide different quality of experience for different devices. Some papers have proposed the use of NC with SVC. For example, the authors in [12] combines the lower layer first scheduling policy with hierarchical random push network coding. In [24], Nguyen et al. proposed to use a drop-threshold and an add-threshold to find the suitable layer to subscribe based on the buffer-map of receivers. Compared with [12] and the random approach, the uninformative packets rate is relatively low. However, the layer subscription in [12] is fluctuant and inaccurate. In [2], Sanna pointed out the delay of the buffer-map updating will generate braking effect, and brings superfluous transmission. To solve this problem, in [2], they proposed a bandwidth estimation and proactive rate selection algorithm as a plugin component for the random-push packet scheduling policy. In [25], Thomos et al. proposed a rate allocation method to maximize the received video quality. In their scheme, they formulate the bandwidth allocation problem as a distortion optimization function. After that, Huang et al. [23] proposed a joint video quality and delay optimization function. However, both of their works optimize the packet scheduling based on the single generation. Such scheduling policies cannot fully integrate network resources, and maximize the bandwidth efficiencies. Another previous work [26] constructs the cost function for each possible transmitting policy. Then the sender pushes packets according to the rank of cost. Nevertheless, it still cannot avoid the bandwidth inefficiencies caused by these unrecoverable packets. In [27], Thomos proposes to use the Markov decision processes and reinforcement learning approaches to find the possible optimal pushing strategy for a given scheduling region. However, the slow convergence speed and high computational complexity make it less competitive.

Our work departs from the conventional choice of sequential processing of generations and considers the scheduling of several generations simultaneously. The advantage is that the limited bandwidth can be more accurately allocated to multiple generations and layers such that the maximum bandwidth efficiency can be achieved. To achieve the accurate bandwidth scheduling, a multiple generation scheduling problem is proposed firstly, which has been proved to be an NP-complete problem. To solve this problem, we proposed two methods. One algorithm transfers the multi-generation scheduling problem to single generation scheduling problem. The other algorithm solves the multi-generation optimization using a novel dynamic programming algorithm, which can be solved in pseudo-polynomial-time. Based on the selected classes, a distributed packet scheduling algorithm coordinates senders to distribute packets. The scheduling algorithm can effectively avoid the transmission of unrecoverable data, thereby improving the bandwidth efficiency and QoS.

3. System model

In this section, a brief overview of the system is given. Firstly, the definitions of the transmission network are given, and the
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