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A novel scheduling approach to concurrent multipath transmission of high definition video in overlay networks

Jiyan Wu [a,*], Bo Cheng [a], Yanlei Shang [a], Jun Huang [b], Junliang Chen [a]

[a] State Key Laboratory of Networking and Switching Technology, Beijing University of Posts and Telecommunications, Beijing 100876, PR China
[b] School of Communication and Information Engineering, Chongqing University of Posts and Telecommunications, Chongqing 400065, PR China

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ABSTRACT

Recent advancements in network infrastructures provide increased opportunities to support video delivery over multiple communication paths. However, the high definition (HD) video transmissions still pose crucial challenges due to the high throughput demands and large-size video frames. Motivated by optimizing the delay performance for concurrent multipath transmission of HD video, we propose a novel scheduling approach dubbed FSWG (*F*rame *S*plitting based on *W*eibull distribution and *G*raph theory) that aims to minimize the end-to-end frame delay while alleviating out-of-order arrivals. First, we analytically construct a delay performance model for HD video streaming in multipath overlay networks based on Weibull distribution and graph theory. Second, we formulate the frame splitting over parallel paths as a constrained optimization problem of minimizing total frame delay and derive its solution based on the water filling algorithm. Third, we design a multipath video transmission system to implement the proposed scheduling approach. The performance evaluation is conducted through extensive simulations in QualNet using H.264 video streaming. Experimental results show that FSWG outperforms the existing schemes in terms of Mean Opinion Score (MOS), Peak Signal-to-Noise Ratio (PSNR), and delay performance metrics.

1. Introduction

During the past few years, we have witnessed the ever-growing popularity of high definition (HD) video services (e.g., video conferencing, remote study and online gaming) over the Internet. The data traffic of video streaming is expected to be the predominant portion of the load imposed on future networks (Cisco company, 2013; Allot, 2010). However, the transmission for HD video streaming is a severely challenging task due to the high throughput demands and stringent delay requirements.

First, the sufficient bandwidth required for delivering stable HD video services mainly ranges from 4 to 25 Mbps (ITU-T Recommendation, 2003). In most cases, a single communication path is not capable of completely supporting such data transmissions (Liao et al., 2012; Han et al., 2011; Chebrolu and Rao, 2006). Second, the real-time HD video services impose stringent delay requirements on the transmission tasks. Since the receiver displays the received video continuously, each frame is associated with a decoding deadline. Whenever the delay experienced by a frame exceeds the corresponding decoding deadline, the frame is considered to be lost. The ITU-T G.114 (Kamiyama et al., 2011) recommendation suggests that the one-way transmission delay should not exceed 150 ms to achieve excellent media quality.

The increasing availability of multiple communication paths between end devices provides new opportunities to address the above issues. Concurrent multipath transmission (Liao et al., 2012, 2008) is considered to be a promising solution for supporting video delivery, since it can substantially increase the throughput and reliability to improve streaming media quality. The overall architecture of a multipath video streaming system is presented in Fig. 1. To minimize the total frame delay, which consists of end-to-end transmission latency and out-of-order recovery time, the following issues should be seriously considered: (1) how to schedule the video frames to minimize the end-to-end transmission delay, and (2) how to alleviate the frame out-of-order arrival that incurs additional recovery time. Recent studies (Han et al., 2011; Chebrolu and Rao, 2006; Jurca and Frossard, 2007; Song and Zhuang, 2012) on multipath video streaming have already moved towards solving the above challenging problems. However, in the context of HD video traffic, a critical issue that remains to be addressed is the large-size video frames.

To state the challenging problem, we collect the statistics of video frame size from HD video sequences by encoding them with the standard H.264 reference software JM 18.2. The video sequences used are in HD 1080 format (1920 × 1080) downloaded

* Corresponding author. Tel.: +86 1061198029.
E-mail addresses: wujiyan@126.com (J. Wu), chengbo@bupt.edu.cn (B. Cheng), shangyl@bupt.edu.cn (Y. Shang), xiaoniuadmin@gmail.com (J. Huang), chjl@bupt.edu.cn (J. Chen).

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from http://media.xiph.org/video/derf: (1) *blue sky*, (2) *river bed*, and (3) *station*. According to http://en.wikipedia.org/wiki/Bit_rate, we choose the bit rates 4, 8 and 15 Mbps, which represent typical encoding rate of HD video applications. Figure 2 presents the frame-size statistics of all the video sequences listed above.

The results include the probability density function (PDF), mean and peak values of video frame size. Even in the lowest encoding rate of 4 Mbps, the mean value of video frame size is approximately 20 kB. There is a clear trend that the ratio of large-size video frames continues to rise with the increase in the encoding rate. Such is also the case in mean and peak values of video frame size. Based on the statistics and analysis, we can arrive at conclusion that large-size frame is a generic characteristic of HD video and the delay constraints for such frames may be easily violated during the transmission.

We propose to split and schedule the generated large-size frames over multipath networks at application layer. Taking advantage of the multihoming (Goldenberg et al., 2004; Thompson et al., 2004) capability of end devices, a multipath transmission scheme can exploit the fractional bandwidth available in different communication paths. Although multiple paths may be simultaneously available for multihomed devices, it becomes challenging if none has sufficient bandwidth to accommodate the HD video streaming.

We explore the problem by designing a framework dubbed FSWG (Frame Splitting based on Weibull distribution and Graph theory), which jointly exploits frame splitting and multipath transmission to minimize total frame delay. Unlike other transport-layer or network-layer solutions which may sacrifice compatibility with the pervasive TCP/IP suite, the proposed application-layer scheduling approach is easier to be implemented in real systems. The contributions of this paper can be summarized in the following.

- We analytically design a framework for HD video transmission in multipath overlay networks based on Weibull distribution and graph theory. Then, we construct a delay performance model for each fragment dispatched onto different paths.
- Based on the delay performance model, we formulate the frame splitting over multiple communication paths as a constrained optimization problem of minimizing the total frame delay. The water filling algorithm is employed to derive the solution and obtain the dynamic frame splitting ratio for each communication path.
- We evaluate the performance of the proposed FSWG through extensive simulations in QualNet with H.264 video streaming. Experimental results show that FSWG outperforms the existing models in terms of MOS (Mean Opinion Score), PSNR (Peak Signal-to-Noise Ratio), total frame delay, end-to-end video frame delay, and probability of out-of-order arrivals. Furthermore, the network overhead of FSWG introduced by frame splitting is tiny compared to the input video traffic.

The remainder of this paper is organized as follows. Section 2 briefly reviews and discusses the related research work. In Section 3, we present the problem formulation and solution procedure. Section 4 describes the system design of the proposed FSWG scheduling approach in detail. Performance evaluation is provided in Section 5 and conclusion remarks are given in Section 6. The basic notations used in this paper are listed in Table 1.

2. Related work

Video delivery over multiple communication paths has attracted considerable research attentions recently. The general reviews can be found in Apostolopoulos and Trott (2004) and Ramaboli et al. (2012). Most of the existing scheduling approaches are based on the video frame or GoP (Group of Pictures) level and the performance they mainly focus on is throughput. For live streaming video applications, delay is another key performance metric along with throughput to achieve excellent quality (Bobarshad et al., 2010).

The Earliest Delivery Path First (EDPF) (Chebrolu and Rao, 2006) algorithm takes into account the available bandwidth, propagation delay, and packet size for estimating the arrival time.

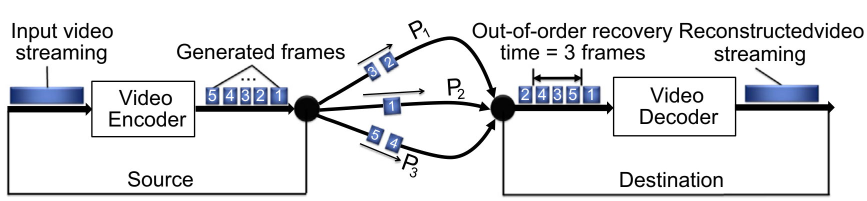
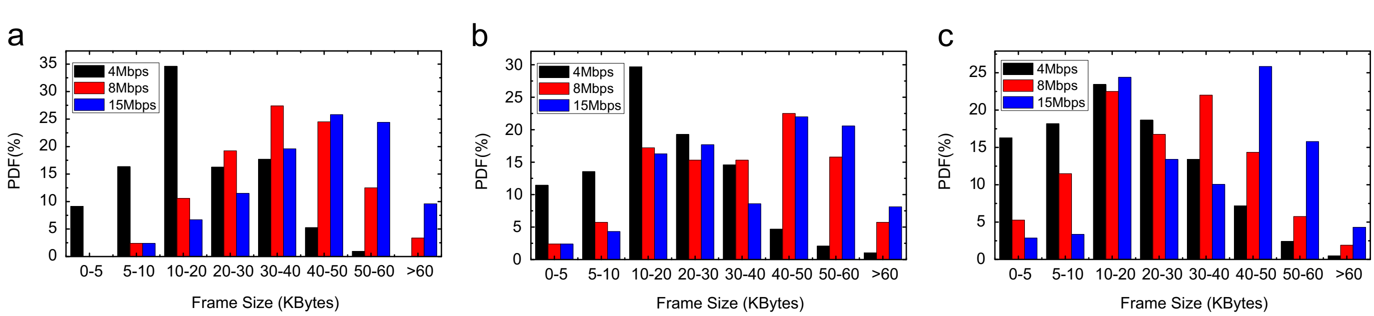


Fig. 1. A multipath video streaming system with three paths between the source (*S*) and destination (*D*) nodes. Due to the path diversity (e.g. available bandwidth and propagation delay) and variations in video frame size, the scheduled packets may arrive at *D* out-of-order and it induces additional recovery time.



Video Sequence	Bit Rate = 4 Mbps		Bit Rate = 8 Mbps		Bit Rate = 15 Mbps	
	Mean	Peak	Mean	Peak	Mean	Peak
blue sky	19579	59004	36018	71841	42270	73029
river bed	20374	61546	34665	71951	36687	72145
station	19062	65284	27007	65560	34252	65980

Fig. 2. Frame size statistics of three HD video sequences: (1) blue sky, (2) river bed, and (3) station.