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Overlay multi-hop FEC scheme for video streaming ☆

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Abstract

Overlay networks offer promising capabilities for video streaming, due to their support for application-layer processing at the overlay forwarding nodes. In this paper, we focus on the problem of providing lightweight support at *selected* intermediate overlay forwarding nodes to achieve increased error resilience on a *single* overlay path for video streaming. We propose a novel *overlay multi-hop forward error correction* (OM-FEC) scheme that provides FEC encoding/decoding capabilities at intermediate nodes in the overlay path. Based on the network conditions, the end-to-end overlay path is partitioned into segments, and appropriate FEC codes are applied over those segments. Architecturally, this flexible design lies between the end-to-end and hop-by-hop paradigms, and we argue that it is well suited to peer-based overlay networks. We evaluate our work by both simulations and controlled Planet-Lab network experiments. These evaluations show that OM-FEC can outperform a pure end-to-end strategy up to 10–15 dB in terms of video peak signal-to-noise ratio (PSNR), and can be much more efficient than a heavyweight hop-by-hop strategy.

keywords: Peer-to-peer networks; Overlay networks; Video streaming; Forward error correction

1. Introduction

Most recently, peer-to-peer (P2P) architectures and overlay networks are gaining attention. Padmanabhan et al. [16] discussed the problem of distributing media content, both live and on demand, to a large number of receivers in a scalable way. They propose a solution called CoopNet for content distribution that combines aspects of infrastructure and P2P-based content distribution, wherein clients

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cooperate to distribute content, thereby alleviating the load on the server. CoopNet builds multiple distribution trees spanning the source and all the receivers, for its multiple description coded media content. Yeo et al. [25] propose an application-level multicast overlay using peering technology and a lightweight gossip (active probing) mechanism to monitor prevailing network conditions and improve tree robustness. Clients can dynamically switch to other parents if they experience a poor QoS. In [6], Chu et al. explore the possibility of video conferencing using an overlay multicast architecture. Their constructed overlay-spanning tree is optimized according to measurements of available bandwidth and latency among users, and can be modified by the addition of good links and the dropping of the poor links. The main goal of a resilient overlay network (RON) [1] is to enable a group of nodes to communicate with each other in the face of problems with the underlying Internet paths connecting them. RON detects such problems by aggressively probing and monitoring the paths connecting its nodes. If the underlying Internet path is the best one, that path is used and no other RON node is involved in the forwarding path. If the Internet path is not the best one, RON will forward the packet by way of other RON nodes.

Providing high-quality video streaming over the current best-effort Internet is a challenging problem due to video's characteristics such as high bit-rate, delay variation sensitivity, and loss sensitivity. Streaming video and other media have been intensively studied in the past several years. From the channel coding perspective, forward error correction (FEC) schemes are considered to protect packets from channel losses, at the expense of increased bit-rate. A Reed–Solomon (RS) code based unequal error protection scheme in conjunction with scalable video coding was proposed by Horn et al. in [9], where different FEC codes are applied to video base layer and enhancement layer according to channel conditions. Tan and Zakhor [23] proposed a layered FEC scheme as an error control mechanism in a layered multicast framework. By organizing FEC into multiple layers, receivers can obtain different levels of protection commensurate with their respective channel conditions. Distributed video streaming using multiple servers and FEC was proposed by Nguyen and Zakhor [13,14] and Kim et al [12]. In [14], all packets are protected by fixed FEC codes and the proposed rate allocation algorithm adjusts the transmission rates of all senders in order to minimize the probability of lost packets. In [12], the optimal amount of redundancy is applied to each bitplane for sub-streams using a bitplane-wise unequal error protection algorithm.

Performance characteristics of peer-based overlay networks are likely to be very different and highly variable with respect to the traditional Internet or even managed overlay networks. However, their massive diversity, i.e. multiple overlay paths that can be harnessed, can compensate for the performance variability of any one path [2,3]. In addition, lightweight support at intermediate nodes can improve single path performance. In this paper, we focus on the latter problem and propose a novel overlay multi-hop FEC (OM-FEC) scheme for video streaming over peer-based overlay networks. The OM-FEC scheme dynamically partitions the end-to-end overlay path into segments according to its error characteristic, and provides appropriate error resilience over each segment. Here, we do not focus on overlay path construction and routing problems. Rather, we assume a peer-based overlay path has been pre-constructed and we focus on how to efficiently utilize it. We will henceforth use the term "overlay path" to denote the constructed path over a P2P network.

1.1. Scope and assumptions

Most prior work on video over P2P/overlay networks has focused on massive video data distribution or video conferencing using application-layer multicast. In contrast, our objective is to revisit the problem of efficiently utilizing the resources of a *single* overlay path. Our approach operates at small time-scales in the data-plane, and can be combined with overlay routing and topology management approaches that operate in the control-plane and over larger time-scales [1]. In this sense, OM-FEC is complementary to prior work where resilience is provided using overlay routing methods. We assume that we can