Delay-constrained streaming in hybrid cellular and cooperative ad hoc networks

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ABSTRACT

Wireless real-time video is frequently used in multimedia applications to provide interactive mobile streaming services. However, delivering real-time video when a cluster of adjacent smartphones attempts to access the same content is challenging because the existing schemes are not fully compatible with limited cellular resources under stringent delay constraints. When the resources of a cellular network are shared by many clients, the available bandwidth allocated to each device is inevitably insufficient. This inadequacy also leads to large end-to-end delays, which degrades video quality. To address the problem, we propose a cooperative scheme called delay-constrained streaming in hybrid networks (DCSHN), which focuses on effective real-time traffic with delay constraints, i.e., goodput. First, a mathematical model is introduced to describe the maximization problem of goodput utility when a group of devices is watching the same real-time video. Second, a data-flow distribution mechanism is developed to obtain a close-to-optimal result to the optimization problem with fast convergence for efficient online operation. Then, a prototype on the Android platform involving real-time video encoded with the H.264 codec is constructed to test the performance. The real-world test shows that the proposed approach yields reasonably improved outcomes, including a better video peak signal-to-noise ratio (PSNR), end-to-end delay, and goodput.

1. Introduction

The demand for video streaming on mobile devices, particularly smartphones, represents a large share of the market and has the potential for growth in the next few years. According to a marketing investigation by Cisco [1], video streaming accounted for 55% of the total usage of mobile traffic in 2015, and its share is predicted to be as high as 75% by the end of 2020. This enormous growth imposes heavy loads on capacity-limited cellular networks. In addition to the consumption of bandwidth resources, real-time streaming services, which are sensitive to video jitter, also require a certain timeliness [2]. The real-time video, which is similar to multiplayer online games and Internet telephony, is one of the applications with timing constraints on the delivery of data. In such applications, old messages quickly become stale, so that getting new messages is preferred to resending lost messages. However, due to path congestion and unreliability [3,4], large end-to-end delays and packet losses can significantly degrade the Quality of Experience (QoE) of real-time video services. The competition between users for limited network resources becomes even worse in crowded places, e.g., a group of friends who desire to watch a live soccer match together on their smartphones. In fact, 50% of YouTube consumers between the ages of 18 and 34 years watch video clips together with friends in person [5].

Unfortunately, current cellular networks are designed for unicast services and do not natively support multicast and broadcast. Consequently, transmitting video content to many mobile users over cellular networks can lead to network congestion and large end-to-end delays. This network capacity issue may be partially addressed [6] by deploying more cellular base stations or supporting the Multimedia Broadcast Multicast Service (MBMS) [7]. However, new network infrastructure entails additional costs, and the modifications might not be fully compatible with existing smartphones. Hence, disseminating real-time videos to many mobile users simultaneously remains a challenge.

This study considers video transmission in hybrid cellular and cooperative ad hoc networks. Each mobile device can access two networks simultaneously through the cellular and WiFi interfaces. The cellular interface is leveraged to connect to the video server and download streaming data. The WiFi interface is utilized to communicate with group members and share data via local ad hoc networks. Thus, the bottleneck of cellular bandwidth is alleviated by the aggregation of the network resources, which also reduces the expenses paid to cellular service providers.

To realize the above functionalities, this paper extends the literature...
on developing a cooperative scheme called delay-constrained streaming in hybrid networks (DCSHN), as shown in Fig. 1. Distinct from previous studies, a mathematical model is presented to optimize the goodput performance of real-time traffic. Delay-sensitive services always focus on the goodput performance, which is an application-level measurement. Since all out-of-date packets are dropped, goodput differs from throughput, as it indicates the amount of data received successfully by the destination by a requested deadline. The video server is used to allocate video data to different sub-flows according to the path statuses of the cellular-communication connections and the delay constraint requested by the video application. After fetching from the remote server, the group exchanges data via the ad hoc network based on the WiFi technique. The proposed scheme aims to maximize the goodput utility of the entire group while adapting to the fluctuations of the network condition and satisfying the delay requirement of the video application.

The contributions of the paper are summarized as follows:

- We introduce a mathematical model to demonstrate the maximization problem of goodput utility of an adjacent group who are watching the same real-time stream using different radio interfaces concurrently.
- We propose a data-flow distribution mechanism that utilizes the hybrid cellular and cooperative ad hoc networks to save cellular bandwidth and reduce the expense while satisfying the delay constraint.
- The prototype proposed on the Android platform implements the mechanism and actualizes a Device-to-Device (D2D) broadcast scheme to evaluate the system performance in a real-world environment.
- Experimental results involving real-time video encoded with the H.264 codec demonstrate the following:
  - DCSHN reduces the average end-to-end delay by up to 99.5 and 75.9 ms compared to Green and Cooperative DASH (GDASH) [9] and Earliest Delivery Path First (EDPF) [10], respectively.
  - DCSHN increases the average goodput by up to 395 and 360 Kbps compared to GDASH and EDPF, respectively.
  - DCSHN increases the sum of the goodput utility function by up to 535 and 13,433 Kbps compared to GDASH and EDPF, respectively.
  - DCSHN improves the average video Peak Signal-to-Noise Ratio (PSNR) by up to 3.1 and 2.8 dB compared to GDASH and EDPF, respectively.

The remainder of this paper is organized as follows. In Section 2, we briefly survey and discuss the works related to this research. In Section 3, we discuss the statement of the problem and the design of the system model. The implementation of the proposed DCSHN mechanism is described in Section 4. Section 5 provides a performance evaluation on a real-world testbed, and conclusions are given in Section 6.

2. Related work

The problem of video transmission over hybrid cellular and ad hoc networks has been studied by several research groups. Do et al. [6] studied the problem of optimally choosing mobile devices that will serve as gateways from the cellular network to the ad hoc network. A system is proposed to determine the ad hoc routes and the delivered layers from the gateways to individual devices. To run in real time, even for large hybrid networks, a greedy algorithm called THS is introduced to reduce the time complexity while achieving close-to-optimum video quality. In the system proposed in [11], smartphones are grouped into collaborative clusters according to a low-complexity clustering algorithm. In each cluster, there is a cluster head who receives the data on the long-range LTE links, and the LTE scheduling is considered. Once the content is received, a multicasting scheme is deployed to forward the content to other cluster members using the short-range wireless communication technology. Hua et al. [12] formulated a resource-allocation problem to balance the system-wide and worst-case video qualities of all viewers at a 3G cell. A flooding routing protocol considering each users effective distance to the base station is used to discover neighbors and a heuristic algorithm is employed to forward streaming content in the ad hoc network. The aforementioned works always select a cluster head as the gateway, and D2D communication is
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