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Throughput improvement for delay-sensitive video broadcast in wireless mesh networks ☆

Yanan Chang [a,*], Xiaohua Jia [b], Jianqun Cui [a]

[a] Computer School, Central China Normal University, Wuhan, China
[b] Department of Computer Science, City University of Hong Kong, Hong Kong

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ABSTRACT

In this paper, we address the problem of broadcast routing and scheduling of video streaming for delay-sensitive applications in backbone wireless mesh networks. Given a source node and a set of destinations, we aim to build a broadcast tree and compute an optimal schedule such that the throughput for the source to broadcast streaming data to all the destinations is maximized. We divide the whole period for video broadcast into identical time frames and prove that maximizing the throughput can be converted into minimizing the length of a time frame. We propose a three-step method as a solution. Firstly, we build the broadcast tree by defining a new routing metric to select relay nodes. Then we use local search method to adjust the tree structure. Last, we propose a greedy method to schedule concurrent transmissions. Simulations have demonstrated that our method can improve the performance significantly compared with existing methods.

1. Introduction

Wireless mesh network (WMN) is a promising key technology for next generation wireless communications and has recently attracted much attention from both the academic and industrial communities. A wide range of applications for broadband multimedia in WMNs, such as electronic classrooms and webcast, are time-critical [1]. These applications are bandwidth hungry and they impose a stringent requirement on communication delay. Broadcast operation is regarded as a key requirement for such kind of services by simultaneously delivering the same video content to all the receivers. In WMNs, the gateway node usually acts as the source of the broadcast and send packets to all the mesh routers that are connected to it [2]. Thus, to enhance the broadcast efficiency for video streaming in such networks is an important task. In this paper, we study the problem of rate-adaptive broadcast routing and scheduling for video streaming to improve the throughput of delay-sensitive applications in backbone WMNs.

Supporting high-quality broadcast for video streaming over wireless networks is nontrivial. Since we consider rate-adaptation in our system, this is a difficult issue in data broadcasting. On one hand, if we use low data rate to broadcast the packet, more nodes will be covered at the expense of transmission delay. On the other hand, if we include less nodes in a broadcast, the transmission can be done in a much shorter time due to high data rate but it needs more relay nodes for forwarding the packets. The problem is further complicated by inter/intra-flow interference caused by video streaming. For the

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* Corresponding author.
E-mail addresses: ynchang@mail.ccnu.edu.cn (Y. Chang), csjia@cityu.edu.hk (X. Jia), jqcui@126.com (J. Cui).

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sake of smooth video playing at the receiver, the source node usually generates a new packet and broadcasts it to the network at regular intervals. Hence, many different packets will be transmitted in the network simultaneously. The interferences come from not only the transmissions of the same packet on different routing paths but also the transmissions of the different packets along the same routing path. Based on the difficulties mentioned above, it is necessary to design efficient broadcast routing and scheduling method for avoiding inter/intra-flow interference to improve the network performance.

The problem of our concern is as follows. Given the gateway node as the source node and a set of mesh routers as destinations in backbone WMNs, our task is to build a broadcast routing tree and compute an optimal transmission schedule such that the throughput for the source to broadcast streaming data to all the destinations is maximized. We divide the whole period for video broadcast into identical time frames. In each time frame, all the non-leaf nodes in the tree can broadcast a packet to its child nodes successfully without causing interference. With the same transmission scheduling in each time frame, the broadcast of video streaming is of pipelined production. Then the objective of maximizing the total throughput can be converted into minimizing the length of a time frame.

We formulate the problem of minimizing the length of a time frame as a mixed integer quadratically constrained program (MIQCP) and show its NP-hardness. A three-step heuristic method is proposed to tackle this problem. We first define a new routing metric called per receiver delay to build the broadcast routing tree. Then, we do fine adjustment of the tree structure to reduce the interference. Last, we propose a scheduling method by computing the maximum weighted independent set of the conflict graph constructed based on the obtained routing tree in the first step. Even though extensive research has been done on the issue of video broadcast [3–5], to our best knowledge, this is the first work that considers broadcast routing and scheduling for video streaming in the context of rate adaptation.

The rest of the paper is organized as follows. Related work is discussed in Section 2. In Section 3, we present the system model and problem formulation. The proposed broadcast routing and scheduling method is given in Section 4 and simulation results are shown in Section 5. Finally we conclude this paper in Section 6.

2. Related work

Broadcast scheduling is a fundamental problem in multi-hop wireless networks. The objective of a broadcast schedule is to deliver a message from a given source to all the other nodes in the network in a minimum amount of time with the constraint that parallel transmissions cannot interfere with each other [6]. So, far, there have been a growing class of works done to solve the problem of minimum latency broadcast scheduling (MLBS). Gandhi et al. [7] proved the MLBS problem to be NP-complete and then presented an approximation algorithm for one-to-all broadcasting. Their algorithm simultaneously achieves a constant approximation ratio both for the latency as well as the number of transmissions. In [8], the authors studied the problem of minimum latency gossiping (i.e., all-to-all broadcast) in the unit-size message model and the unit disk graph model. They proposed a heuristic algorithm with approximation ratio of 27. In [9], the authors studied the broadcast scheduling in 2D and 3D wireless sensor networks. They devised efficient coloring methods for coloring a hexagonal tiling in 2D plane and a truncated octahedron tiling in 3D space. A latency-efficient broadcast schedule is proposed in [10] by using special geometric properties of independent sets of a broadcast tree to reduce the number of transmissions and the possibility of collision in duty-cycled wireless networks. However, all above works only focus on one packet broadcast scheduling without considering the routing issue.

Rate adaptation is one of the important techniques to improve system performance in wireless networks. The authors in [11] proposed a collision-aware rate adaption scheme, called CARA, to maximize the throughput in wireless local area networks. The main idea of CARA is that the transmitter station can adaptively differentiate frame collisions from frame transmission failures caused by channel errors. In [12], Wong et al. suggested that each sender should select the best data rate and adapt to the channel quality at different time in different locations without explicit information feedback from the receiver. The study of [13] describes the design and implementation of a new routing metric based not only on expected cooperative transmission time but accounts for queueing and backoff delays in the path selection process, with the aim of selecting a minimum end-to-end delay path for multi-rate WMNs. The work in [14] studies the tradeoff between maximizing the average rate utility per user and minimizing the temporal rate variability by considering both rate adaptation and admission control for wireless video streaming. The authors in [15] formulated a generic cross-layer flow-based framework to obtain the achievable throughput rates by jointly optimizing the parameters for multi-path routing, scheduling, rates, transmit powers, and selection of cooperative nodes. They solved the problem optimally to obtain the max–min throughput for the case when cooperation is based on the distributed Alamouti code and networks have a mesh-like topology. Different from above works on unicast transmissions, our work discusses routing, scheduling and rate adaptation for minimizing broadcast latency.

With regard to routing and scheduling, there have several studies done in recent years. Chou et al. studied the problem of realizing low-latency network-wide broadcast in WMNs where a node can dynamically adjust its link-layer multicast rates to its neighbors and proposed efficient routing, multicast grouping and scheduling algorithms to solve the problem [16]. In [17], aiming to minimize both the total transmission delay and the number of transmissions, the authors constructed a breadth-first-search (BFS) tree and presented a distributed scheduling algorithm without taking rate-adaptation into consideration. They also extended the problem to the case of multi-radio, multi-channel and multi-rate WMNs [18]. The study of [19] formulates joint routing and scheduling problem for multi-radio multi-channel mesh and finds concurrent transmission