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Optimized routing for video streaming in multi-hop wireless networks using analytical capacity estimation

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ABSTRACT

Finding suitable routing paths for video streaming remains a challenging issue for multi-hop wireless networks, and previous studies rely on heuristics such as minimal hops or load-balancing. In this paper, we present an analytical approach that takes cross-layer factors into account and propose a new routing metric based on optimizing a queueing model that considers local loads, interferences and packet droppings. Through periodic traffic monitoring, routing nodes can estimate their capacity analytically, while a messaging protocol then helps establish the most efficient route. Simulation results obtained from using realistic video traffic have shown that our proposed routing metric outperforms existing routing metrics in several aspects.

1. Introduction

Advances in wireless technologies including mobile ad hoc networking and sensor networking have been an enabling factor to novel applications. Particularly, with the widening bandwidth and increasing computing power of wireless devices, video streaming over these multi-hop wireless networks (MWN) has become plausible. Indeed, video streaming over multi-hop wireless network can play an important role in military and civilian services. For example, in a gas leaking area, a battle field, or in an emergency situation such as earthquakes, a combination of wireless video sensors and wireless relay nodes can be dispatched to regions of risk for collecting and transmitting real-time visual information back to a remote base station. The effective routing of video packets through the MWN is however a challenging task. Even for an ad hoc network in a civil setting within an indoor or outdoor environment, various detrimental factors exist, for instance, rain and snow [1]. There is also considerable inter-interference and intra-interference due to contention in the medium access control (MAC) layer between the neighbor nodes [2]. In particular, while interference can be serious for video streams over MWNs without using MAC control signals, such as the Request To Send (RTS) and Clear To Send (CTS) messages in IEEE 802.11, the RTS/CTS mechanism has been shown to be ineffective and can significantly reduce the throughput for video streams over multi-hops [3]. Besides MAC contention, varying channel qualities and limiting battery power of the transmission nodes further pose challenges to the satisfactory streaming of video packets, demanding more adaptive, and cross-layer solutions.

Recently there have been some considerable research attempts targeting at solving this problem. For instance, protocols such as SPEED [4] and MMSPEED [5] have been proposed to provide routing methods for real time applications over wireless networks. Both of them, however, rely on the Global Positioning System (GPS), which may not be available due

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to environmental and resource constraints. The usability of these methods is therefore limited. Load balancing routing methods [6] are studied to optimize routing path searching process on wireless networks by avoiding distributing uneven traffic and bypassing heavy load nodes. There is a potential side effect for load balancing: delay can become unnecessarily long even in an unsaturated wireless network, since the routing path may have to wind a long distance to circumvent heavy-load nodes. The longer routing path not only leads to a higher delay, but also brings potentially more intra- and inter-interference. The trade-off between load balancing and path lengths needs to be studied so as to find a suitable routing path in a WMN.

In this paper, we propose a new routing metric based on an analytical treatment on capacity estimation for WMN nodes. We gauge the current node capacity, i.e., its potential of incorporating more flows, by employing a queueing model that considers the packet arrival rate, current load, and interference-inferred delays. Cross-layer factors are taken into account, since retransmissions caused by MAC contention or noisy interference will affect the processing time of video packets. The new routing metric can hence allow the routing to adapt to both the load of transmitting nodes and their potential interferences. By choosing a routing path with high total node capacity, the proposed routing method can deliver better streaming qualities, and suffer less from heavy load and prolonged delays as shown in our comparative simulation study.

The remainder of this paper is organized as follows. Section 2 briefly reviews recent research papers on load balancing routing path searching. This is followed by introducing our queueing model to be used in Section 3, from which the proposed routing metric called "Analytical Capacity Estimation" (ACE) is derived. The path selection algorithm and the routing protocol are presented in Section 4. After verifying the traffic model using realistic video tracks, we present the simulation results in Section 5. Finally, we conclude our paper with a brief discussion on future directions.

2. Related work

In an IEEE 802.11 based MWN, the discovery of neighbor nodes can be achieved either by exchanging "Hello" messages or by overhearing neighbor nodes' transmission. Various routing metrics have been proposed in the recent literature, but they can be classified into two groups: edge-based routing metrics and vertex-based routing metrics.

Edge-based routing metrics search for a routing path based on the link quality. For instance, ETX [7], ETT [8], WCETT [8] and EAR [9] are all edge-based routing metrics. Maintaining a table with up-to-date characteristics of all edges is not a trivial task for a vertex, as in MWN each vertex may connect to numerous neighbors. This will then become an energy-draining, memory-consuming and time-consuming process for an MWN. For example, an idle node needs to send extra uni-cast messages to measure the link quality in EAR. The extra traffic could aggravate existing congestion in a busy MWN and inevitably result in a shorter life cycle due to the transmission overhead. Due to the asymmetry of link quality, two nodes have to exchange this information two-way so as to estimate the link quality on both directions. Dissemination of these routing messages can trigger a considerable amount of overhead and degrade the overall capacity of the MWN.

Vertex-based routing metrics are relatively simpler. Each node only maintains the metric based on its local information or information gathered from neighbors' "Hello" messages. Overhearing can be used to eliminate the overhead of the "Hello" messages if necessary. The simplest vertex-based metric is the hop count. Ad hoc On-Demand Distance Vector routing (AODV) [10] is a typical hop-count routing protocol. AODV counts the numbers of hops along all possible routing paths during a routing path discovery period and selects the shortest one to deliver the packets. It has however been shown that the performance of shortest path is not necessarily always good because it does not take interference into account [11]. On the other hand, ABR [6] and LBAR [12] choose routing paths based on local metrics such as *route relaying load* or *active path activity*. These are basically the current number of active data paths at a node itself or neighbor nodes. These path-activity based metrics are limited in the sense that they do not consider the different traffic load at network nodes and their interference to each other.

Other research looks into load modeling as it is considered to be helpful in evaluating the potential performance of a node. Load is defined as the average length of the queue at each node monitored over a period. In ALARM [13], each node adds its own load information into the AODV routing request when searching for a routing path. The destination node picks up the routing path with the lowest total load. This way ALARM tries to provide load balancing by avoiding hot-spot nodes, but the examination on neighbor nodes' load alone may cause a route with high interference to be chosen.

Other protocols, such as LARA [14] and NLR [15], incorporate both local and neighbor loads. Each node obtains neighbor nodes' load by exchanging the "Hello" messages. During the routing path discovery process, each node adds both local load and neighbor load into the routing request. The destination node then selects the path with the lowest total load once all the request messages arrive. These protocols therefore tend to avoid busy areas within an MWN, as neighbors' high load will cause MAC contentions and may further result in prolonged delays and even packet drops. On the other hand, researchers also looked into interference-aware routing more from a physical layer perspective, and proposed to use directional antenna [16] and reception probability modeling [17].

Apart from these heuristic solutions, analytical performance modeling in MWNs has been rarely studied. In this article we focus on finding an analytical solution in routing metric design for streaming applications. By working with a queueing model based on the Network layer, we also take system time in lower-layer processes into consideration, which allows us to deal with retransmissions and potential interference between neighbor nodes.