Ad Hoc Networks 80 (2018) 1–15

Contents lists available at ScienceDirect

Ad Hoc Networks

journal homepage: www.elsevier.com/locate/adhoc

AD^3-GLaM: A cooperative distributed QoE-based approach for SVC video streaming over wireless mesh networks

Tran Anh Quang Pham[a,*], Kamal Deep Singh[b], Juan Antonio Rodríguez-Aguilar[c], Gauthier Picard[d], Kandaraj Piamrat[e], Jesús Cerquides[c], César Viho[a]

[a] IRISA, University of Rennes 1, Campus de Beaulieu, Rennes 35042, France
[b] Laboratoire Hubert Curien, Université de Saint-Etienne, Jean Monnet, Saint-Etienne F-42000, France
[c] IIIA-CSIC, Campus de la UAB, Bellaterra, Barcelona, Spain
[d] Laboratoire Hubert Curien, University of Lyon, MINES Saint-Etienne, Saint Etienne F-42023, France
[e] LS2N, University of Nantes, Nantes, France

ARTICLE INFO

Article history:
Received 26 July 2017
Revised 29 June 2018
Accepted 8 July 2018
Available online 10 July 2018

Keywords:
QoE
SVC video streaming
Distributed
Wireless mesh networks

ABSTRACT

We study the routing problem of scalable video coding video streaming over wireless mesh networks. In contrast to most of the conventional routing algorithms, our proposal focuses on optimizing users' satisfaction. The mean opinion score –an indicator of quality of experience (QoE) in video streaming– is utilized to assess the quality of routes in wireless mesh networks. The objective is to optimize the overall user experience in the network. Conventional routing approaches do not consider QoE and are not optimal with respect to user experience. Moreover, some centralized approaches are not scalable and require significant computational resources. The latter disadvantage can be overcome using distributed approaches. This paper presents a QoE-based cooperative distributed routing approach. Among distributed cooperative optimization schemes, AD^3 is highlighted as one of the most efficient because of its fast convergence. The contributions of this paper are as follows: we encode the original problem into a factor graph and optimize the number of exchanged messages; we propose a partially distributed routing scheme based on OLSR and AD^3; and we propose a distributed decoding algorithm in order to find a feasible solution. Our thorough simulation results confirm the advantages of the proposed scheme.

1. Introduction

The recent rapid growth of wireless networks has led to the development of various wireless applications that are widely used in our modern lives, in various domains such as military, commerce, entertainment, etc. Moreover, the number of wireless Internet users has been drastically increasing [1]. Furthermore, wireless local area network (WLAN) communication interfaces can be found on most devices nowadays. Consequently, wireless devices can connect to one another and form wireless mesh networks (WMNs). Recent works in the literature have proposed interesting applications which confirm the benefits of adopting WMNs [2–5]. The abundance of wireless links can be exploited in several scenarios. For example, wireless mesh networking can be utilized to maintain connections in disaster recovery scenarios, when conventional infrastructure networks are unavailable.

Video streaming is one of the most popular services on the Internet and its traffic accounts for 70%–82% of all Internet traffic [6]. Scalable video coding (SVC) is an extension of the H.264/MPEG-4 AVC video compression standard. It enhances flexibility of video streaming over inherently unstable wireless networks [7]. The major advantage of SVC is its capability of decoding a stream with partially received data [8]. The more layers a client can receive, the better the video quality. The video quality measurement can be obtained either using objective or subjective approaches. The subjective approaches are based on evaluations done by real humans. Thus, they are more correlated to users' experience than objective approaches, which are based on network-oriented metrics. Regarding subjective quality-assessment methods, the International Telecommunication Union (ITU) recommends the Mean Opinion Score (MOS) metric [9]. MOS can be divided into five levels corresponding to the users' perception: 5 (Excellent), 4 (Good), 3 (Fair), 2 (Poor), 1 (Bad). MOS is a good measure of quality, but it requires a lot of resources and cannot be obtained automatically. A hybrid Quality of Experience (QoE) evaluation method, named Pseudo-Subjective Quality Assessment (PSQA), was proposed in [10] to es-

* Corresponding author.
E-mail address: quang.pham-tran-anh@irisa.fr (T.A.Q. Pham).

https://doi.org/10.1016/j.adhoc.2018.07.005
1570-8705/

timate users' experience in real-time. The most recent version of PSQA for SVC was introduced in [11].

In WMNs, traffic flows may have to traverse through multiple relaying nodes until reaching the destination. That can deteriorate the performance as well as the quality of some applications, especially video streaming ones. Determining the end-to-end path that can enhance user experience is the most important task in WMNs. Because of the aforementioned advantages of SVC and QoE metrics and the importance of routing in WMNs, we study QoE-based routing problem for SVC video streaming over WMNs in this paper. A use-case of this scenario is video streaming in rural areas where the cellular networks may not be available or may have insufficient coverage. Thanks to the wide-spread of wired networks, the dwellings may be equipped with gateways (GWs) connecting to the Internet through high speed connections. Consequently, WMNs with multiple GWs are considered in this study.

The existing routing schemes can be categorized into two groups: centralized [12–16] and distributed [17–19]. The centralized routing algorithms contain a centralized entity. The centralized controller is able to characterize the whole network and determine the global optimal or sufficiently sub-optimal routing solutions. In contrast, the distributed routing algorithms allow nodes to find out the local optimal solutions based on their knowledge. Centralized schemes can provide high quality routing solutions, however, they also have some disadvantages, such as high requirements in terms of computational resources, high calculation time, etc. Conventional distributed schemes can deal with large-scale network, but its routing configuration is far from the optimal solution.

Alternating Directions Dual Decomposition (AD^3) [20], an algorithm proposed in the realm of the machine learning literature, has been empirically shown to outperform state-of-the-art message-passing algorithms on a wide variety of large-scale problems. Furthermore, existing machine learning approaches that have been particularly designed for routing come with high cost in terms of time [21], e.g., thousands of seconds, which is far above our requirements. Nonetheless, the applicability of AD^3 to distributedly solve an optimization problem poses non-trivial challenges: (1) an encoding of the optimization problem as a so-called factor graph, a graph-based structure, that guarantees the efficient computation of messages by AD^3; (2) the operation of AD^3 in a distributed manner; and (3) the *decoding* of the solution (using LP relaxation of the optimisation problem) obtained by AD^3 into a feasible solution.

Here we address the above challenges through the following contributions:

- We cast the routing problem in WMNs as an optimization problem.
- We provide an encoding of the optimization problem as a factor graph. The encoding employs AD^3 computationally-efficient factors in order to guarantee efficient computation.
- We formulate and solve a factor and variable assignment problem in order to optimize the number of messages exchanged by GWs.
- We propose a scheme that is based on combining the well-known OLSR, to gather information about the network, with AD^3, to solve the optimization problem in a distributed manner.
- We design a distributed decoding algorithm to convert the solution output by AD^3 into a feasible solution.

The rest of this paper is organized as follows. Section 2 provides related works. Section 3 outlines the whole proposed scheme. Section 4 provides mathematical descriptions of multi-channel WMNs under time constraints. In Section 5, we demonstrate how to convert the optimization problem into a factor graph and solve it with AD^3. A joint variable and factor assignment problem is also studied in this section. Subsequently, the output is decoded by the GLaM algorithm, which is presented in Section 6. Simulation results are presented and discussed in Section 7. Finally, Section 8 concludes the paper.

2. Related work

In WMNs, routing is one of the important elements that impacts the overall performance. Therefore, several routing algorithms have been proposed and are discussed in this section.

2.1. Centralized vs. distributed routing algorithms

We categorize existing routing algorithms into two major types: centralized and distributed. With distributed algorithms, each entity takes decisions independently, based on the local information available. Ad-hoc On-Demand Distant Vector (AODV) [22] and Optimized Link State Routing Protocol (OLSR) [23] are the most well-known protocols in this type. Both of them determine the path to a destination based on the number of hops. The main difference is that OLSR maintains a routing table at every node while AODV creates and maintains the routes when they are needed. OLSR is more efficient in high density networks [24]. A multipath extension of OLSR was presented in [25]. Multiple end-to-end paths are determined explicitly at the source by Multipath Dijkstra Algorithm. Though the routes in MPOLSR are not computed distributedly, the distributed selection of Multipoint relays (MPRs) puts MPOLSR into decentralized group. Another variant of OLSR, named cross-layer QoS-aware routing protocol on OLSR (CLQ-OLSR), has been introduced in [26]. Two sets of routing mechanisms were implemented, physical modified OLSR protocol (M-OLSR) and logical routing, by constructing multi-layer virtual logical mapping over physical topology. Physical M-OLSR protocol is responsible for routing table construction and bandwidth estimation on best-effort interface, while logical routing on real-time interfaces computes the optimized logical path using topology and bandwidth information. Every node in CLQ-OLSR estimates the available bandwidth on each associated channel. Each node disseminates the information of topology and available bandwidth to other nodes through HELLO and TC messages. The optimized logical path could be computed using the topology and bandwidth information. CLQ-OLSR outperforms OLSR [23] and multichannel-OLSR [27] in terms of average packet delivery rate, delay, and jitter. Above routing algorithms consider some QoS parameters, however, they did not take video specific parameters into account. Consequently, the routing configurations of these algorithms do not provide optimal performance for video streaming services. Whereas, such video specific parameters are considered in our work. Furthermore, some routing protocols are unable to provide the optimal solutions as shown in Section 7.

In [28], the algorithm assigns different paths and different transport layer protocols to different types of frames. The I-frames and inter-frames are conveyed by TCP and UDP respectively. The paths for I-frames are determined by adopting TCP-ETX routing metric while inter-frames are transported through the shortest path. Although this scheme is able to enhance the reliability, it does not consider user experience. A novel routing algorithm, called Quality of Experience (QoE) Q-learning based Adaptive Routing (QQAR), was presented in [29]. QQAR takes experience of users into account. QoE measurement is integrated into routing paradigm in order to enable adaptive and evolutionary capabilities of the system. QQAR utilizes PSQA tool for QoE evaluation and Q-Learning algorithm for determining the paths. The simulations confirmed that QQRA outperforms other traditional approaches in terms of MOS. The algorithm was not designed for wireless net-