Ad Hoc Networks 13 (2014) 575–597

Contents lists available at ScienceDirect

Ad Hoc Networks

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

Agent-based Multi-Service Routing for Polar-orbit LEO broadband satellite networks

Yuan Rao [a,b,*], Jun Zhu [a], Chang-an Yuan [b], Zhao-hui Jiang [a], Lei-yang Fu [a], Xing Shao [c], Ru-chuan Wang [c]

[a] College of Information and Computer Science, Anhui Agricultural University, Hefei, Anhui 230036, China
[b] Science Computing and Intelligent Information Processing of Guangxi Higher Education Key Laboratory, Guangxi Teachers Education University, Nanning, Guangxi 530023, China
[c] Jiangsu High Technology Research Key Laboratory for Wireless Sensor Networks, Nanjing University of Posts and Telecommunications, Nanjing, Jiangsu 210003, China

ARTICLE INFO

Article history:
Received 17 July 2012
Received in revised form 11 June 2013
Accepted 17 October 2013
Available online 26 October 2013

Keywords:
Agent
Multi-service
Routing
Broadband
Polar-orbit LEO satellite networks

ABSTRACT

There exist essential requirements for providing service differentiation in the next-generation networks. In this paper, AMSR (Agent-based Multi-Service Routing) is proposed and evaluated for Polar-orbit LEO broadband satellite networks. AMSR forwards best-effort traffic in a distribute manner using three factors: unfair traffic distribution, link utilization level and constellation geometry characteristics. Meanwhile, AMSR employs an on-demand source routing method, called agent-based inter-satellite link QoS routing (AIQR), to implement QoS routing in space. In AIQR, agent migrates based on best-effort forwarding to gather QoS routing information, and determines QoS path considering both call duration and the periodic changes in network topology. Moreover, with protecting ongoing communication in mind, a gradual rerouting strategy is introduced to deal with user-to-satellite and satellite-to-satellite handover. Through simulations on an Iridium-like system, AMSR is shown to achieve better QoS guarantee and more effective service differentiation as well as lower overhead compared with the previously proposed methods. Especially, simulation results thoroughly reveal AMSR's handover performance in terms of latency and hop count, rerouting frequency and overhead. Additionally, the credits and further research of this study are pointed out.

1. Introduction

The next generation of the wireless communications is particularly important for providing the broadband global information services and mobile e-applications (m-applications) in support of anytime, anywhere, and any required quality of service (QoS) capabilities in a low-cost way [1,2]. As an ideal component for the next-generation Internet, LEO broadband satellite networks will be called to support a bunch of applications in the future. Similar to traditional Internet, the applications undergone in next generation network can be roughly categorized into three types: delay-sensitive, bandwidth-sensitive and no specific QoS constraints. This highlights a need for providing service differentiation in the future network. In the context of multi-service, different data packets might have different importance. For packets belonging to urgent mission, the network should make more effort to deliver them. In addition, due to the possibility of offering a solution for broadband access to geographically dispersed mass users, satellite networks are expected to be an essential component of the next-generation network. They can provide service for all kinds of users located in various areas, especially rural, remote, and difficult for access regions on the earth's surface.

* Corresponding author at: College of Information and Computer Science, Anhui Agricultural University, Hefei, Anhui 230036, China. Tel./fax: +86 551 65786623.

E-mail address: ry9925@gmail.com (Y. Rao).

1570-8705/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.adhoc.2013.10.009

So far, the numerous routing schemes have been proposed for satellite networks [3,4]. However, most of these existing routing schemes provide either best-effort [5–9] or single traffic class optimization, such as, end-to-end delay, packet loss ratio and hop count [10–13]. To play its due role in the future, the broadband satellite communication systems must have the ability to provide differential service. In this context, it is imperative for the future broadband satellite systems to optimize resource usage and satisfy diverse performance requirements by taking into account different traffic class parameters and network dynamics. According to the orbit altitude, there are low earth orbit (LEO), medium earth orbit (MEO) and geostationary earth orbit (GEO) satellite networks. LEO satellite network shows lower communication delay and transmission loss when compared to MEO/GEO satellite networks. Moreover, LEO systems increase the potential frequency reuse by dividing the satellite footprint into cells, each one corresponding to a specific beam of the satellite antenna radiation pattern. Thus, service differentiation in LEO satellite networks is an interesting research area. Because of its deployment feasibility, the multi-service routing in Polar-orbit LEO satellite systems has become more appealing.

In the Polar-orbit LEO satellite systems, the satellites' continuous movement causes the frequent change in the servicing area of a corresponding satellite on the earth. Such change will result in a user-to-satellite handover event. On the other hand, due to the satellite mobility, intra-plane ISLs (Inter Satellite Links) are permanently maintained, whereas inter-plane ISLs must be broken at the higher latitudes of each orbit due to adverse pointing and tracking conditions as the planes cross and are reestablished as the satellites move to lower latitudes. Thus, a satellite-to-satellite handover occurs. As a result, it is a daunting challenge to implement dynamic routing for multi-service in this kind of constellations. In the past decades, several routing schemes proposed looks to cope with multi-class traffic. According to the implementation mechanism, they can be classified into three categories: minimum cost-oriented periodic routing [14–21], constellation geometry-aided distributed routing [22,23] and on-demand routing scheme [24,26,27]. For most of the proposed multi-service routing schemes, there exists a common characteristic in providing service differentiation by introducing new routing metric. However, minimum cost-oriented periodic routing schemes frequently implement complex route updating over entire network, which results in invalid route and entails extremely huge signaling and computation overhead. And, constellation geometry-aided distributed routing schemes may be appropriate only for best-effort traffic. Finally, existing on-demand routing schemes fail to deal with link handover which greatly degrades the routing performance.

Due to the constrained resources onboard, it becomes evident that the designers of this kind of networks will call for routing schemes that would be able to meet the different requirements of performance while keeping complexity and signaling overhead to a minimum at the same time [15]. Additional concern is that the higher system capacity is one essential ingredient in the future satellite network, however, these studies in [14–24,26,27] target the narrowband satellite network. As a remedy, this paper proposes AMSR, an Agent-Based Multi-Service Routing explicitly designed for Polar-orbit LEO broadband satellite networks. While providing better service differentiation as well as low overhead is the primary goal in our design, AMSR achieves good performance with five important factors in mind: unfair traffic distribution, link utilization level, constellation geometry characteristics, call duration and the periodic changes in network topology. The former three factors are used to forward best-effort traffic. All the factors work together to implement QoS routing. These considerations have heightened interest in the possibility of providing efficient multi-service routing. The combination of five factors to provide differentiated service routing is an innovation introduced.

The remainder of this paper is organized as follows. Section 2 gives the previous work on differentiated service and introduces the motivation of this study. Section 3 describes system model. Next, two key parts of the proposed routing scheme are elaborated, best-effort forwarding strategy in Section 4 and agent-based ISL QoS routing in Section 5, respectively. Section 6 gives the performance evaluation. Finally, Section 7 draws conclusions and presents areas of future work.

2. Related work and motivation

Over the past decades, some traffic class dependent routing protocols have been proposed for narrowband satellite networks, and focus on supporting different levels of services. They can be classified into three categories according to their implementation mechanism. In this section, we present the literatures on multi-service routing and discuss recent schemes. We summarize them and explain the motivation of this study at the end of this section.

2.1. Minimum cost-oriented periodic routing

Early studies had mainly focused on minimum cost-oriented periodic routing. To provide service differentiation, TCDR [14,15] employs the periodic scheme for path calculation based on the Dijkstra algorithm along with a link-cost metric that consists of the sum of the propagation and queuing delays for both delay-sensitive and best-effort traffic, while for bandwidth-sensitive traffic the normalized residual bandwidth of the link is considered as the link-cost metric and the Bellman–Ford shortest path algorithm is adopted to compute paths that offer the maximum residual bandwidth within a minimum hop count. To enhance its ability of differentiated service, three separate FIFO queues are implemented for each outgoing link, one for each traffic class. With a queue scheduling policy, different priorities are allocated to the three traffic classes, respectively. However, inter-plane ISLs at higher latitudes becomes heavily loaded in the canonical TCDR [14,15] due to the shorter distance between inter-plane satellites. To cope with this issue, two different strategies are proposed. Mohorcic et al. [16] attempt to control the relative cost of heavily loaded links with respect to lightly loaded