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QoS routing with traffic distribution in mobile ad hoc networks

Gabriel Ioan Ivascu, Samuel Pierre, Alejandro Quintero *

Mobile Computing and Networking Research Laboratory (LARIM), Department of Computer Engineering, École Polytechnique de Montréal, C.P. 6079, succ. Centre-Ville, Montréal, Que., Canada H3C 3A7

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ABSTRACT

Mobile ad hoc networks (MANETs) follow a unique organizational and behavioral logic. MANETs' characteristics such as their dynamic topology coupled with the characteristics of the wireless communication medium make Quality of Service provisioning a difficult challenge. This paper presents a new approach based on a mobile routing backbone for supporting Quality of Service (QoS) in MANETs. In real-life MANETs, nodes will possess different communication capabilities and processing characteristics. Hence, we aim to identify those nodes whose capabilities and characteristics will enable them to take part in the mobile routing backbone and efficiently participate in the routing process. Moreover, the route discovery mechanism we developed for the mobile routing backbone dynamically distributes traffic within the network according to current network traffic levels and nodes' processing loads. Simulation results show that our solution improves network throughput and packet delivery ratio by directing traffic through lowly congested regions of the network that are rich in resources. Moreover, our protocol incurs lower communication overheads than AODV (ad hoc on-demand distance vector routing protocol) when searching for routes in the network.

1. Introduction

The emergence of real-time and multimedia applications and the widespread use of wireless and mobile devices have generated the need to provide Quality of Service (QoS) support in wireless and mobile networking environments [7]. Unfortunately, attempts to adapt QoS solutions developed for the Internet do not generally have great success [5,7]. This is due to the fact that Internet-based solutions were not designed to cope with constraints such as user mobility, high-error rates and scarce bandwidth found in the wireless communication environment. Moreover, over-provisioning as it is done in wired networks by adding resources to the network to cope with increasing demand is not possible in the wireless environment where resources are constrained and finite. Hence, to achieve the goal of providing high-quality services in next-generation wireless networks, it is necessary to implement new techniques that can guarantee QoS when considering the limitations imposed both by the end-user and the network.

This paper presents a new approach called *quality* of service mobile routing backbone over AODV (QMRB-AODV) for supporting QoS in mobile ad hoc networks. Our method makes use of a mobile routing backbone to dynamically distribute traffic within the network and to select the route that can support best a QoS connection between a source and its destination. Nodes in real-life mobile ad hoc networks (MANETs) are heterogeneous and have different characteristics. Based on these characteristics, our solution classifies nodes in a MANET as either QoS routing nodes, simple routing nodes that route packets through the network without providing special service provisions or transceiver nodes, that send and receive packets but cannot relay them. A mobile routing backbone is created using all nodes having routing capabilities. QoS support is realized by relaying packets having special requirements to nodes rich in resources and connected through stable links. To avoid starvation of best-effort packets both types of routing nodes have forwarding capabilities. The main advantage of QMRB-AODV is a better use of the available bandwidth by distributing the traffic through the network and by reducing the number of control messages needed to establish a route from a source node to a destination node.

The remainder of this paper is organized as follows. Section 2 presents an overview of QoS in mobile ad hoc networks. Section 3 describes our approach to improve QoS support in MANETs, presents the QoS mobile routing backbone and the routing algorithm used to discover new routes in the network; the routing mechanism has been integrated in the AODV (ad hoc on-demand distance vector) protocol and its performance evaluated by simulation. Simulation and results are discussed in Section 4. Finally, Section 5 concludes the paper.

2. Quality of service in mobile ad hoc networks

QoS is a collection of characteristics or constraints that a connection must guarantee to meet the requirements of an application

* Corresponding author. Tel.: +1 514 340 3240x5077; fax: +1 514 340 3240.
E-mail addresses: gabriel-ioan.ivascu@polymtl.ca (G.I. Ivascu), samuel.pierre@polymtl.ca (S. Pierre), Alejandro.Quintero@polymtl.ca (A. Quintero).

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[19]. A connection can be characterized by a set of measurable requirements such as minimum bandwidth, maximum delay, maximum delay variance (jitter), and maximum packet loss rate. After accepting a connection request from the user, the network has to ensure that the requirements of the user's flow are met throughout the duration of the connection [5].

In a mobile wireless communication environment the problem of guaranteeing QoS to users or applications is more complex than in a wired communication environment. Furthermore, the characteristics of mobile ad hoc networks complicate QoS support: the communication medium is unreliable and error-prone, bandwidth is often limited which limits the use of control messages, nodes are free to join, move or leave the network at any moment, making the topology entirely dynamic and unpredictable, battery energy as well processing power are generally low [4,24]. Moreover, for the MANET to retain its efficiency, the protocols at various layers may need to self-tune to adjust to environment, traffic and mission changes [8].

QoS support may be provided in many ways and at different layers of the networking stack. In the link layer, QoS MAC (medium access control) protocols attempt to offer a fair access to the communication medium to frames having particular service requirements. Several approaches are presented in [1,20]. However, the support provided by MAC protocols is limited to the neighborhood where the medium is shared and hence, they cannot offer end-to-end QoS support.

At the network layer, routing protocols are the main mechanism. Best-effort routing protocols as found in the Internet aim to maximize network performance from an application point of view while minimizing the cost imposed on the network in terms of capacity. There are three classes for such protocols in mobile ad hoc networks. Reactive or on-demand routing protocols create a route between a source and the destination on a per-request basis and are generally well suited to a MANET's dynamic topology. AODV is one of the best-known reactive protocols for ad hoc networks [4,10]. The protocol builds a route to a destination only if a source needs to reach it. Each mobile host operates as a router and routes are obtained as needed with little or no reliance on periodic advertisements. AODV provides loop-free routes even while repairing broken links. Because the protocol does not require global periodic routing advertisements, the demand on the overall available bandwidth is substantially less than in those protocols that necessitate such advertisements. Although AODV does not depend specifically on particular aspects of physical medium across which packets are disseminated, its development has been largely motivated by limited range broadcast media such as those utilized by infrared or radio frequency wireless communications adapters.

Proactive routing protocols are similar to their wired counterparts in the sense that they keep track of routes for all destinations in the network. The routing tables are periodically refreshed to take into account the dynamic behavior of the network. The two main drawbacks with this class of routing protocol are that it generates a high volume of communication overhead needed to keep the routing tables current with topology and they offer poor routing performance when mobile nodes are highly mobile [4,34]. Indeed, proactive protocols fail to respond fast enough to highly dynamic topologies where route failures and changes occur frequently. Finally, there are position-based routing protocols that find routes through the network based on the geographical position of the destination. The position of the destination node can be found either using external information provided by GPS (global positioning system) or through triangulation-like techniques.

As effective as best-effort routing protocols are at finding routes, they cannot efficiently support QoS in MANETs. Indeed, these protocols, by definition, optimize network performance and are not designed to take into account the QoS required by each flow when searching for routes. Thus, efficient QoS support using best-effort protocols can be at best accidental even if resource reservation schemes are used. Abolhasan et al. [6] provide a recent review of routing protocols developed for the ad hoc paradigm.

QoS routing protocols create routes using nodes and links that possess the resources required to fulfill QoS requirements. In other words, this category of routing protocol identifies routes in the network that obey the constraints required by the source application and selects between these routes the one to be used [22]. Further, QoS routing protocols must work together with resource management mechanisms to establish routes through the network that meet end-to-end QoS requirements, such as delay, jitter, available bandwidth, packet loss rate, hop count and path reliability. Finally, routing protocols supporting QoS must also deal with route maintenance. Indeed, since nodes in MANETs are free to move there is a certain probability that route failures may happen due to node mobility.

In [3], Shengming et al. propose a new predictive link metric that can reduce the impact of node mobility on QoS routing. This new metric is integrated in a link caching scheme and implemented in the dynamic source routing (DSR) protocol to provide it with adaptability to changing topologies caused by user mobility. In [18], Shen and Heinzelman present a QoS-aware routing protocol that incorporates an admission control scheme and a feedback scheme to meet the QoS requirements of real-time applications. The novel part of this protocol is the use of the approximate bandwidth estimation to react to network traffic. The protocol implements these schemes by using two bandwidth estimation methods to find the residual bandwidth available at each node.

Du [2] proposes a QoS routing scheme for heterogeneous mobile ad hoc networks based on two classes of nodes. A node can join the routing backbone if it has long transmission range, possesses bandwidth and is reliable. QoS routes are calculated based on bandwidth availability. Moreover, node location information is used to aid routing.

In [14], Conti et al. discuss a lightweight mechanism that enables reliable and efficient forwarding, and that mitigates the effects of adverse situations caused by cooperation misbehavior or network fault conditions. It uses a node's local knowledge to estimate route reliability and multi-path routing to forward packets on the most reliable route. In [23], Shen and Rajagopalan propose an adaptive mechanism called protocol-independent packet delivery improvement service (PIDIS) to recover lost multicast packets. PIDIS provides its packet-delivery improvement services to any multicast routing protocol for mobile ad hoc networks by exploiting the mechanism of swarm intelligence to make intelligent decisions about where to fetch the lost multicast packets. Mottola, Cugola and Picco [29] propose a new content-based routing (CBR) protocol to organize a MANET's nodes in a tree-shaped network. This network organization tolerates frequent topological reconfigurations and minimizes changes that impact the CBR layer exploiting the tree.

Chakrabarti and Kulkarni [15] present a novel way of preserving QoS guarantees in DSR by pre-computing alternate routes to a destination and using these alternate routes when the current route fails. Their method ensures that traffic load is balanced among the alternate routes but also that an appropriate amount of bandwidth will be available for a flow even when nodes move. In [16], Argyriou and Madisetti introduce a novel end-to-end approach for achieving the dual goal of enhanced reliability under path failures, and multi-path load balancing in MANETs. These goals are achieved by fully exploiting the presence of multiple paths. Shen and Thomas [26] propose a unified mechanism for a distributed dynamic management system which aims to maximize QoS and security while maintaining a minimum user acceptable level even as network resource availability changes. In order to achieve this