Quality of Service for Mobile Ad-hoc Networks: an Overview

Rafael Guimarães, Julián Morillo, Llorenç Cerdà, José-M Barceló and Jorge García

Technical University of Catalonia
Computer Architecture Department
Jordi Girona 1-3
E-08034 Barcelona, Spain
{rafael.guimaraes,jmorillo,llorenc,joseb,jorge}@ac.upc.es

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1 Introduction

Mobile Ad-hoc NETworks (MANETs) are multi-hop ad-hoc wireless networks in which there are no backbone infrastructure. Each Mobile Node (MN) acts either as a host generating flows or being the destination of flows from other MN or as a router forwarding flows directed to other MN. Due to the unpredictable location and mobility of MNs in MANETs, classical routing protocols used on wired networks are not suitable for MANETs. Protocols defined for ad hoc networks are classified as reactive protocols and proactive protocols. Reactive protocols are characterized by MNs acquiring and maintaining routes on demand, while proactive protocols are characterized by all MNs maintaining routes to all destinations all the time. Examples of reactive protocols are DSR (Dynamic Source Routing) [5], and AODV (Ad hoc On-demand Distance Vector) [3]. Examples of proactive protocols are OLSR (Optimized Link State Routing Protocol) [17], and TBRPF (Topology Dissemination Based on Reverse-Path Forwarding) [15].All these protocols have been analyzed and compared in several papers. The main conclusion on these comparisons is that none of them is the best for all environments. Depending on several aspects such as mobility, load of the network, diameter of the network, etc, a protocol may behave better than other.

For obtaining QoS (Quality of Service) on a MANET, it is not sufficient to provide a basic routing functionality. Other aspects should also be taken into consideration such as *bandwidth constraints* due generally to a shared media, *dynamic topology* since MNs are mobile and the topology may change and *power consumption* due to limited batteries.

For wired networks there are two approaches to obtain QoS: an *over-provisioning* and *network traffic engineering*. Over-provisioning consists of the network operator offering a huge amount of resources such that the network can accommodate all the demanding applications. Instead, network traffic engineering classifies ongoing connections and treats them according to a set of established rules. Two proposals belonging to this class has been done inside the IETF: Integrated Services (IntServ) [2] and Differentiated Services (DiffServ) [1].

IntServ is a reservation-oriented method where users request for the QoS parameters they need. The Resource reSerVation Protocol (RSVP) [14] has been proposed by IETF to setup resource reservations for IntServ. Opposite to IntServ, DiffServ is a reservation-less method. Using DiffServ, service providers offer a set of differentiated classes of QoS to their customers to support various types of applications. IPv4 TOS octet or the IPv6 Traffic Class octet is used to mark a packet to receive a particular QoS class.

In general, the specific aspects of MANETS make the wire-based QoS models not appropriate for MANETs. Over-provisioning, for instance, may not be possible because resources are scarce. IntServ/RSVP may require unaffordable storage and processing for MNs, and signaling overhead. Diffserv on the other hand, is a lightweight overhead model that may be more suitable for MANETs.

However, Diffserv organization in customers and service providers does not fit the distributed nature of MANETs. These have motivated numerous QoS proposals targeted to MANETs.

In the rest of the chapter we shall present some representative QoS proposals for MANETs that have been presented in the literature. We have classified them in *Reservation-Less* and *Reservation-Oriented* Approaches. By Reservation-Less we shall refer to that proposals targeted to lightweight QoS protocols. These proposals typically take ideas similar to the DiffServ approach, minimizing the state information kept by the network to achieve QoS. On the contrary, by Reservation-Oriented we shall refer to those proposals designed to achieve higher degree of QoS guarantees, typically by using reservation mechanisms and by keeping some flow state information at the MNs, thus, using similar ideas to the IntServ approach.

2 Reservation-Less Approaches

2.1 Load-Balancing Schemes

The simplest QoS mechanism that have been proposed for ad-hoc networks can be considered has load-balancing schemes. Two of these proposals are [9] and [7], the former has been proposed for AODV and the later for OLSR. The basic idea behind these approaches consists of the MNs estimating the available bandwidth. This is done by means of measurements at the MNs of the transmission time of the packets and activity periods. Using AODV, an additional field is added to the Route Requests packets (RREQ) to propagate the measurements when a new route is searched. This information is taken into account by the destination before sending the Route Reply (RREP) packet. In case of OLSR, the MNs propagate the available bandwidth together with the topology to the rest of the network. This information is used by the Shortest Path First (SPF) algorithm when searching for a new route.

2.2 Courtesy Piggybacking

The Courtesy Piggybacking [10] is a proposal that intends to avoid the bandwidth starvation suffered by low priority traffic on service differentiated systems. In these systems, whenever high priority traffic is intense, the low priority traffic may not be transmitted at all, since it keeps waiting for the "never ending´´ transmission of high-priority traffic.

The idea of this proposal is to piggyback low priority traffic into the high priority traffic whenever there is a free space. This free space may be when a MAC frame is not completely filled by the high priority data – this may happen when data is fragmented and the last fragment is shorter than the MAC frame or when available high priority data is not enough to fill a MAC frame. Whenever this happens, this unused "free space´´ may be used to piggyback low priority traffic.

This approach is completely independent of the service differentiation scheme and the routing algorithm used. It is designed in a cross-layer way, so that the MAC layer may have access to network layer information, to fill its frame with low priority data.

2.3 SWAN

The SWAN Project [6] proposes a feedback-based mechanism to provide soft real-time services and service differentiation on stateless wireless ad-hoc networks. It uses rate control for UDP and TCP best-effort traffic and admission control on the sender for UDP real-time traffic.

Instead of depending of signaling and state information, SWAN uses feedback information from the network. By measuring MAC delays, it automatically configures the rate control mechanism and, by measuring the rate of real-time flows that passes through its neighbors, it evaluates the amount of bandwidth that are still available for new real-time connections, thus configuring the admission control.

Whenever a node suffers from QoS degradation, it marks every forwarded packet with an Explicit Congestion Notification (ECN) flag. The destination of a packet marked with ECN should notify the source of the flow, so that it blocks transmission or adapts it to the new conditions.

SWAN is a simple and effective solution. By avoiding signaling, it simplifies the whole architecture and provides a solution that, although not being able to guarantee the QoS needs of each flow for the whole session, provides a differentiation between real-time and best-effort, prioritizing the former.

3 Reservation-Oriented Approaches

3.1 INSIGNIA

INSIGNIA [16] consists on an in-band signaling protocol in contrast with out-of-band signaling protocols as RSVP. This means that signaling information related to QoS mechanisms is encapsulated in data packets, making this approach easy and "lightweight´´. This implies that there are no special packets for doing the signaling. INSIGNIA is just the signaling protocol and a routing protocol, such as DSR, AODV, OLSR or TBRPF, is still needed.

INSIGNIA supports fast flow reservation, restoration and adaptation algorithms that are specifically designed to deliver adaptive real-time service in MANETs. It encapsulates control signals in an IP option of every data packet which is called INSIGNIA option.

3.2 Flexible QoS Model for MANETs (FQMM)

FQMM [8] is a QoS model specifically designed for MANETs that combines both IntServ and Diffserv mechanisms. Basically, it proposes a hybrid provisioning scheme that combines the per-flow granularity of IntServ and per-class granularity of DiffServ, and a relative and adaptive traffic profile to maintain consistent differentiation between traffic types and keep up with the dynamics of the network.

Trying to exploit the best of both approaches, FQMM provides QoS differently according to the traffic priority. Per-flow provisioning is given for high-priority traffic while per-class provisioning is given for other traffic priorities. Classification is made at the source node and QoS provisioning is made on every node along the path.

3.3 CEDAR

Most routing algorithms designed for ad-hoc networks assume that every node behave as edges of the flows (source and destination) and as routers. This means that every node must maintain the state of the network and must exchange this information with every other node. In proactive algorithms, this information is exchanged periodically while in reactive algorithms, it is exchanged on demand.

Trying to avoid all this overhead, the *Core Extraction Distributed Ad hoc Routing* (CEDAR) [12] algorithm proposes the election of core network that are responsible for all the route computation.

A set of nodes is dynamically elected to form the core of the network, so that each of them maintains the local topology of the nodes that belongs to its domain. The core nodes propagate information about bandwidth availability on the stable links of the core network and keep information about dynamic and low-bandwidth links. By doing this, all route computations are restricted to the core nodes.

Whenever a node needs to establish a connection to another node, it contacts the core node of its domain. This core node computes a core path to the destination domain and uses this core path as a directional guideline for the establishment of a short stable admissible QoS route from the source to the destination.

3.4 Quality of Service for Ad hoc On-Demand Distance Vector

This approach [13] is based on, and is suitable only for, AODV. It consists simply on including a QoS Object extension on the Route Request (RREQ) and Router Reply (RREP) messages which specifies bandwidth and/or delay parameters, during the phase of route discovery.

A node will become a hop on the route only if it can meet the requirements specified in the RREQ. If, once the route is already established, a node realizes that the QoS requirements can not be sustained for a certain flow, the node must originate an ICMP QOS_LOST message back to the source.

There are two similar mechanisms for guaranteeing maximum delay and minimum available bandwidth on a path. For guaranteeing delay, every time a node receives a RREQ, it subtracts from the delay value carried by RREQ the NODE_TRAVERSAL_TIME, which is the time required by a node to process the RREQ. If the result is negative, the packet is discarded, since the delay requirement can not be accomplished for this route. For guaranteeing bandwidth, the value carried by the RREQ is compared to the available link capacity. If the available link capacity is lower, the packet is discarded. When the destination node replies with a RREP, each node forwarding the RREP compares the bandwidth field in the RREP and its own link capacity and maintains the minimum of the two in the Bandwidth field of the RREP before forwarding the RREP.

3.5 Cansever et al

In [4] the authors look for the formulae to estimate the available bandwidth in an ad-hoc network using shared links. To do so, each node may do the following calculation:

$$MUB_i = C_i - \sum_j l_{ij}, \forall j \in \text{Neighborhood of } i \tag{1}$$

where MUB_i means the maximum unused bandwidth, C_i is the capacity of the node and l_{ij} is the total traffic between nodes i and j.

But, since the traffic between neighbors of a node also interfere, these traffics must also be taken into consideration to calculate the maximum available bandwidth (MAB_i), what leads us to:

$$MAB_i = MUB_i - \sum_j \sum_k l_{jk}, \forall j \in \text{Neighborhood of } i, \forall k \in \text{Neighborhood of } j \tag{2}$$

The MAC protocol must support regulated access to the media and also random access (CSMA-CA) for about 10% of the time. In the random access period, all nodes broadcast their MUB and their local bandwidth requests. Now that all nodes are aware of their neighbors traffic demands, a simple algorithm may allocate time slots among the neighbors in proportion to their demands.

When using a reactive routing protocol, such as AODV or DSR, the MAB may be used to elect a path that fulfills the QoS needs of a flow. The Route Request (RREQ) messages checks the available bandwidth to be sure that the flow may pass through the node (if not, the RREQ is discarded). During the reverse path establishment (Route Reply), the resources may be then reserved.

The previous formulas, however, may not guarantee a correct calculation of the available bandwidth in the general case. In [11] it is shown that available bandwidth can be computed if the nodes know not only l_{ij}, but the MAB_i computed by their neighbors. Then, the available bandwidth AB_i to allocate new reservations at MN$_i$ is given by:

$$AB_i = \min\{MAB_i, MAB_j\}, \forall j \in \text{Neighborhood of } i \tag{3}$$

3.6 Ad hoc QoS on-demand routing (AQOR)

AQOR [18] provides a strategy for dynamically constructing paths between mobile nodes that form a MANET, providing QoS guarantees, so the protocol signaling allows for both route discovery and end-to-end QoS reservation (minimum bandwidth and maximum delay). The protocol is designed for shared links (without TDMA) which makes more difficult to handle problems related to available/used bandwidth and delays. AQOR presents some mechanisms to solve these problems in an efficient manner. By using the proposed mechanisms it is possible to make an admission control of flows based on the available resources (bandwidth and end-to-end delay), and to easily apply fast recovery on QoS violation situations.

The protocol works in several ways to allow QoS routing: neighbor discovery and maintenance, route exploring, route registering (for explored routes), a bandwidth reservation mechanism based on the arrival of the first packet of a flow, releasing of registered resources (but not reserved), a loop-free routing mechanism and the already mentioned mechanisms for admission control and bandwidth calculation.

4 Conclusions

To cope with specific aspects of MANETS there has been numerous QoS proposals targeted for MANETs. In this chapter we have presented some of representative efforts on this area. The appropriateness of the proposals may depend on the characteristics of a particular MANET: scalability, mobility, power consumption, computational and memory of MNs, etc. In fact, the best QoS approach for each possible scenario it is not yet clear, and it is still a research issue.

References

[1] Differentiated Services (diffserv) IETF Working Group.
`http://www.ietf.org/html.charters/diffserv-charter.html`

[2] Integrated Services (intserv) IETF Working Group.
`http://www.ietf.org/html.charters/intserv-charter.html`

[3] C. Perkins, E. Belding-Royer and S. Daas. RFC 3561: Ad hoc On-Demand Distance Vector Routing, Jul 2003.

[4] Derya H. Cansever, Arnold M. Michelson, and Allen H. Levesque. Quality of service support in mobile ad-hoc IP networks. In *MILCOM 1999 - IEEE Military Communications Conference*, number 1, pages 30–34, Oct 1999.

[5] D. B. Johnson, D. A. Maltz, Y. Hu. DSR-draft: The Dynamic Source Routing Protocol for Mobile Ad Hoc Netowrks (DSR), April 2003.

[6] A. Veres G. Ahn, A.T. Campbell and L. Sun. SWAN: Service Differentiation in Stateless Wireless Ad Hoc Networks. In *Conference on Computer Communications (IEEE Infocom)*, Jun 2002.

[7] K. Al Agha G. Pujolle H. Badis, A. Munaretto. QoS for Ad Hoc Networking Based on Multiple Metrics: Bandwidth and Delay. In *The Fifth IEEE International Conference on Mobile and Wireless Communications Networks (MWCN 2003)*, 2003.

[8] A. Lo H. Xiao, W.K.G. Seah and KC Chua. A Flexible Quality of Service Model for Mobile AdHoc Networks. In *IEEE Vehicular Technology Conference Fall 2000*, pages 445–449, May 2000.

[9] M. Kazantzidis, M. Gerla, and S. Lee. Permissible throughput network for adaptative multimedia in AODV MANETs. In *IEEE ICC 2001*, 2001.

[10] W. Liu and Y. Fang. Courtesy Piggybacking: Supporting Differentiated Services in Multihop Mobile Ad Hoc Networks. In *Conference on Computer Communications (IEEE Infocom)*, 2004.

[11] Ll. Cerdà, J.M. Barceló and J. García. A Reservation Scheme Satisfying Bandwidth QoS Constrains for Ad-hoc Networks. Technical Report UPC-DAC-2004-24, Politechnic University of Catalonia, June 2004.
`http://www.ac.upc.es/recerca/reports`

[12] R. Sivakumar P. Sinha and V. Bharghavan. CEDAR: a Core-Extraction Distributed Ad hoc Routing algorithm. In *Conference on Computer Communications (IEEE Infocom)*, Mar 1999.

[13] C. Perkins and E. Belding-Royer. Quality of Service for Ad hoc On-Demand Distance Vector Routing (work in progress), Oct 2003. draft-perkins-manet-aodvqos-02.txt.

[14] R. Braden, ed. et al. RFC 2205: Resource ReSerVation Protocol (RSVP), Sep 1997.

[15] M. Lewis R. Ogier, F. Templin. RFC 3684: Topology Dissemination Based on Reverse-Path Forwarding (TBRPF), Feb 2004.

[16] X. Zhang S.B. Lee, A. Gahng-Seop and A.T. Campbell. INSIGNIA: An IP-Based Quality of Service Framework for Mobile Ad Hoc Networks. *Journal of Parallel and Distributed Computing (Special issue on Wireless and Mobile Computing and Communications)*, 60(4), 374–406, Apr 2000.

[17] P. Jacquet T. Clausen. RFC 3626: Optimized Link State Routing Protocol (OLSR), Oct 2003.

[18] Q. Xue and A. Ganz. Ad hoc QoS on-demand routing (AQOR) in mobile ad hoc networks. *Journal of Parallel and Distributed Computing*, (63), 154–165, 2003.