Challenges and Recent Advances in QoS Provisioning, Signaling, Routing and MAC protocols for MANETs

Shivanajay Marwaha Jadwiga Indulska Marius Portmann

The University of Queensland, School of Information Technology and Electrical Engineering (ITEE)
and National ICT Australia (NICTA), Queensland Research Laboratory (QRL)
Brisbane, QLD 4072
Australia
{smarwaha, jaga, marius}@itee.uq.edu.au

Abstract – **Mobile Ad hoc Networks (MANET), which comprise of mobile nodes connected wirelessly, are emerging as a very important technology for future generation of wireless mobile and ubiquitous computing. MANETs are being used in numerous application domains from emergency rescue and relief to wireless sensor networks. To support real-time communications (such as audio and video) over MANETs, new Quality of Service (QoS) provisioning mechanisms need to be developed. There are many challenges in QoS provisioning for MANETs such as dynamically changing topology, wireless capacity limitations, heterogeneous network environment, limited battery power etc. Previous QoS surveys in MANET have only looked at QoS provisioning models, singaling and routing. This paper presents a complete survey of the challenges and current state of the art of MANET QoS Routing, Signaling and MAC protocols as well as the various MANET QoS models that are being developed.**

I. INTRODUCTION

The Internet was originally developed to offer "best effort" communication services, wherein all data was to be treated equally without any Quality of Service (QoS) bounds or guarantees regarding delivery. However, with the emergence of real-time communication such as Voice over Internet Protocol (VoIP) and video streaming, e.g. Video on Demand (VoD), strict QoS requirements have been put on the Internet in terms of delay, jitter and throughput. This led to the development of the present day QoS models that can support required communication QoS on the Internet.

QoS is defined as a set of bounds such as latency, jitter, throughput and packet loss to be maintained by the network for a particular data flow [1]. There are two main QoS provisioning models in the Internet that have been developed by IETF: (i) Integrated services (IntServ) [2] and (ii) Differentiated services (DiffServ) [3]. The stateful IntServ, which maintains per-flow reservation state at QoS network entities, has a greater level of accuracy and a finer level of granularity. The stateless DiffServ does not maintain per-flow reservation state at QoS network entities and only relies on coarse classification and differential treatment of traffic.

Within the last couple of years there has been a tremendous increase in the use of wireless networks which have provided internet connectivity to mobile devices, creating the need for supporting real-time communication applications on highly mobile network environments. Within the wireless networks domain, Mobile Ad hoc networks (MANET) have become very popular. A MANET [4] is a network of mobile nodes, for example PDAs and laptops, connected wirelessly, without using any network infrastructure, such as wireless access points, routers or base-stations, as shown in "Fig. 1". If the wireless nodes are not within wireless range of each other, end-to-end communication requires multi-hop routing of data packets.

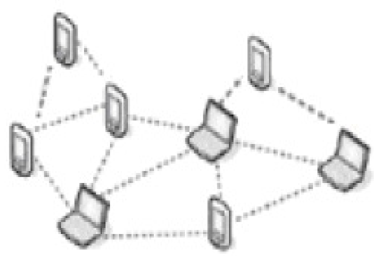

Figure 1. Example of an Ad hoc Network

There are two main routing approaches in MANETs: (i) proactive [5] and (ii) reactive routing [6]. Proactive routing schemes [5] continuously update the routing tables of mobile nodes. This approach consumes large bandwidth to update routing information leading to reduction in the available capacity of the wireless network for actual data communications. Reactive or on-demand routing protocols [6] on the other hand launch an expanding ring search (route discovery phase) every time a route needs to be established. This requires the actual communication to be delayed until the route from the source to the destination is discovered, which may be very long if the network is size is large.

MANETs have become increasingly popular recently, firstly due to their autonomic and infrastructure-less properties of dynamically self-organising, self-configuring, self-adapting, self-healing and robustness. Secondly, the conventional infrastructure-based WLANs and Wireless Metropolitan Area Networks (WMANs) do not scale well with the target coverage area and the ever increasing number of wireless devices joining the networks. MANETs have the unique ability to extend the range of wireless LANs and MANs without additional infrastructure cost.

MANET deployments cover a variety of application domains such as satellite multi-hop networks [7], public safety applications (including disaster relief and emergency response), intelligent transportation systems [8], metropolitan area networks, building automation [9] as well as providing wireless network coverage to remote and inaccessible regions (mountains, deserts and rural areas) [10].

The key advantages offered by MANETs are as follow. MANETs can be set-up quickly as they do not need any infrastructure such as wiring or base stations etc. MANETs can also configure and organise themselves without any manual intervention required, for example when new nodes join or leave the network or when two MANETs merge. Also, if a path breaks, alternate paths can be discovered quickly thereby alleviating any service disruptions due to single points of failure. Lastly, the source node does not need to send the packets at very high transmission power, as the packet only needs to reach the next hop and not the final destination. This also allows frequency to be re-used by other wireless devices in the MANET outside the transmission and reception range.

To be able to support the real-time voice and video communications over MANETs, novel QoS provisioning mechanisms need to be developed. However, there are many problems in providing QoS in MANETs in comparison to static wired networks due to many reasons as described in section 2.

This paper evaluates the state of the art in QoS provisioning, signaling, routing and Medium Access Control in MANETs. These approaches range from QoS models aiming to provide hard or soft QoS guarantees, to mechanisms that improve the network performance (e.g. through QoS based routing) and therefore improve the QoS provided by the network. The structure of the paper is as follows. Section 2 provides a description of challenges in provisioning QoS in MANETs. Section 3 provides a brief overview of the QoS provisioning models developed for MANETs, followed by section 4 which presents the QoS routing algorithms for MANET. Section 5 presents the QoS signaling mechanisms and Section 6 describes the recent advances in Medium Access Control schemes for MANET QoS. Section 7 presents the concluding remarks on the recent trends in MANET QoS developments and future areas of research in QoS provisioning for MANETs.

II. MANET QoS PROVISIONING PROBLEMS

QoS provisioning in MANETs is very difficult compared to wired networks due to many problems. Some of the main QoS provisioning and maintenance problems in MANETs are as follows.

Bandwidth limitation and estimation: The wireless bandwidth and capacity in MANETs is scarce [11] and the channel is not reliable as it is affected by interference, noise as well as multi-path fading [12]. Furthermore, there is a problem is of bandwidth estimation in MANETs, wherein one cannot precisely estimate the bandwidth that is available at a node as it varies a lot based on mobility of the node, other wireless devices transmitting in the vicinity etc.

Node Mobility and Heterogeneity: The nodes in MANETs are mobile and hence the topology keeps changing continuously. This leads to route failures occurring frequently. The nodes in a MANET can also have many different characteristics such as different number of wireless interfaces, battery capacities, node mobility patterns etc.

QoS Probing Problem : Yet another problem is that of QoS Route Selection in MANETs, wherein RREQ packets are used for QoS route discovery, which have different properties compared to actual data packets leading to selection of of non-optimal paths [13]. Lastly, if the QoS model is stateless, there also can be a false admission control problem in MANETs. This happens when multiple flows send probe messages to check QoS on a particular path at the same time. As the QoS model is stateless, intermediate nodes do not store information of previous probes leading to a situation where multiple flows (sharing a common path or intermediate node) may receive the result of a probe message that the resources are available, but in fact that are not [18].

MANET Application dependant QoS Requirements: QoS requirements also vary a lot in different types of MANETs and multi-hop networks [14], therefore one standardised MANET QoS solution may not work very well in all MANET applications.

III. MANET QoS MODELS

There are a few QoS models specifically developed for MANETs. While some MANET QoS models [16, 17] use a hybrid of IntServ [2] and DiffServ [3] approaches, others [18] make use of rate-control mechanisms such as Explicit Congestion Notification (ECN) [19].

A. Hybrid IntServ and DiffServ QoS Models for MANETs

A couple of the QoS models developed for MANETs utilise IntServ [2] and DiffServ [3] in a hybrid fashion. Flexible QoS Model for MANETs (FQMM) [16] is one such QoS model. It defines three types of nodes in a MANET: (i) an ingress node that is the data sender, (ii) an egress node that is the destination or endpoint of communication, and (iii) an interior node that forwards or relays the data to other interior nodes or the egress node. A traffic conditioning scheme is used at each ingress router. IntServ is used for the highest priority traffic, and the remaining data traffic is handled with a DiffServ type QoS mechanism. The traffic conditioner which marks, discards and shapes packets is placed on the ingress node [16]. The assumption in FQMM is that, the traffic belonging to the highest priority class is of a smaller proportion; thereby the scalability problem of IntServ may not be an issue in FQMM.

The advantage of FQMM model is that it is relatively simple, and it borrows from the existing QoS models in traditional wired IP networks. The disadvantage of FQMM is that as the network size increases, so will the high priority traffic receiving per-flow QoS treatment and the cost of the associated per-flow state management in FQMM. This may lead to the scalability problems of IntServ. A node may also misbehave at it has to apply traffic conditioning on itself. The traffic conditioning algorithm may also increase complexity of the wireless nodes in a MANET.

Another model which is similar to FQMM is Complete and Efficient QoS Model for MANETs (CEQMM) [17], which too combines the IntServ and DiffServ models for provisioning of QoS in MANETs. In contrast to FQMM which does not define the use of any particular QoS routing protocol, CEQMM specifically specifies the QoS Optimized Link State Routing (QOLSR) protocol [21]. Multi-metric routing criteria are supported using IntServ for the highest priority flows, and DiffServ for the remaining flows [17]. Since CEQMM is based on QOLSR, it spends a lot of battery power and network resources for exchanging routing data. This may be a limitation for small battery constrained wireless devices.

B. Stateless QoS Model for MANETs

Service Differentiation in Stateless Wireless Ad hoc networks (SWAN) [18] offers a stateless QoS model for MANETs. It does not require intermediate nodes to maintain per-flow reservation states. It differentiates real- time and best effort packets (which do not require any QoS bounds or guarantees) and shapes only the best-effort packets using a leaky bucket traffic shaper. To check if the required bandwidth is available on a path, a probe message is sent to the destination. In SWAN, ECN [19] is used, which was originally proposed for Transmission Control Protocol (TCP) flows to be utilised for loss sensitive data traffic only.

The advantage of SWAN is that being stateless; there is no need for state maintenance at intermediate nodes from source to destination as well as IntServ type periodic refresh messages. As there is no state maintained at the intermediate nodes, if two source nodes simultaneously were to send probe messages, they would both get the result of the probe message that the resources are available, when in fact they might not be as both the probe messages may have traversed the same node or subsection of a path. In order to alleviate this problem the intermediate node will mark the packet header with a Congestion Experienced (CE) flag, which signifies to the destination to inform the source to discover a new path. This solution will solve the false admission problem partially, but the re-establishment may cause large latency and jitter for real time flows, especially if this process occurs multiple times in quick succession. The protocol also suffers from high singaling if there are frequent flow re-establishments.

IV. MANET QoS ROUTING

QoS routing is a specialised routing scheme which finds a network path that satisfies a particular set of QoS requirements. QoS routing in MANETs is difficult because of the constantly changing network topology and link capacity as discussed in Section 3. As a result, it is very challenging to maintain up-to-date routing and network information in such highly mobile and dynamic wireless networks. A few promising techniques for QoS routing in MANETs have been proposed, which try to achieve satisfactory QoS performance. In this section, some of these QoS routing schemes [21, 22 and 23] are presented.

A. CEDAR

Core Extraction Distributed Ad hoc Routing (CEDAR) [21] is a QoS routing protocol for MANETs which uses available bandwidth as a criteria for route selection. It uses a clustered network architecture approach and reactive route discovery. CEDAR has three key components:

Core extraction: First, a set of nodes are dynamically selected to form a network core (self-organizing routing infrastructure) in a distributed fashion that is used to maintain the local topology information and perform route calculations.

Link state propagation: Information about the stable and high bandwidth links is sent to all of the core nodes. However, information of non-stable or low bandwidth links is kept local.

QoS Route Computation: First, a path comprising of core nodes is found from the source to the destination's domain. Then using this core path, partial QoS paths are found from source domain to the domain of the farthest possible node in the core path. This node is then used as the source for the next iteration of the algorithm to find the path which can satisfy the QoS required. Concatenation of these partial paths provides an end-to-end QoS path.

Frequent link-state propagation and the proactive core path discovery in CEDAR [21] can cause high network overhead. Furthermore, it is possible that core nodes could become a bottleneck in the network as most of the data traffic would be routed through them.

B. Ticket-Based Probing

Ticket-Based Probing (TBP) [22] is a multi-path QoS routing scheme for MANETs. In TBP, a ticket means the permission to search/probe for a single path. A source node issues the number of tickets in a route discovery equal to the number of paths it wants to search, wherein a probe message can split at an intermediate node, if it has more than one ticket. In TBP to achieve maximum level of redundancy, QoS resource reservation is done on more than one path and every packet from source to destination is routed along each of these paths. In the second type of redundancy in TBP, QoS resource reservations are done along multiple paths; however, only one path is used as the primary path, while the rest serve as backup paths. In the third type, resources are reserved on the primary path only, even though multiple paths may be established.

Although TBP limits the amount of flooding of control messages, the computation of the number of tickets, issued at the source node is based on unclear heuristics [24]. Resource reservation on backup paths in TBP reduces resource availability for other flows.

C. QoS over AODV

In QAODV [23] a source node will specify the QoS parameters in the RREQ packet and every intermediate node will check whether or not it can support that QoS. As QAODV [23] is based on reactive routing [5], it incurs less control overhead compared with proactive approaches.

V. MANET QoS SIGNALING

If the QoS approach is based on resource reservation such as in the IntServ [2] model, a singaling protocol is required to propagate QoS reservation messages and establish appropriate QoS reservations.

In the In-band Singaling system for supporting QoS in MANET (INSIGNIA) [24, 25], the IP option of every packet is used to carry the singaling control which is called INSIGNIA option [24, 25]. Since it is a per-flow based protocol, each flow state is managed individually over an end-to-end session in response to topology and end-to-end QoS condition changes. INSIGNIA uses a soft-state method to maintain its state information. Bandwidth is allocated to a particular flow if the QoS resource requirements of that flow can be satisfied. Otherwise, if the required resources are not available, the flow will be downgraded to a best-effort service.

To be able to respond quickly to topology changes and varying end-to-end QoS conditions, INSIGNIA uses QoS reports to inform the source node of the status of its real-time flows. The destination node actively monitors the received flows and calculates QoS statistics such as loss rate, delay, and throughput. The reports are sent back to the source node periodically. The source node can take appropriate steps in order to adapt to the changing network conditions.

VI. MANET QoS MAC

Medium Access Control (MAC) Protocol for providing MANET QoS must ensure higher priority is given to real-time traffic in the transmission queue and reliably transport data traffic over the shared wireless medium under rapidly changing conditions.

Priority queuing is used in IEEE 802.11e [26]. IEEE 802.11e [26] uses Enhanced Distributed Coordination Function (EDCF) which has 4 queues, each with a different access category (3 being the highest and 0 as the lowest) as shown in "Fig. 2". Higher priority queue are permitted to transmit when there is a collision among the queues and the lower priority queue is forced to perform a collision response. Three service differentiation mechanisms are used in IEEE 802.11e: (i) Arbitrary Inter-Frame Spaces (AIFS); (ii) Contention Window (CW) sizes and; (iii) medium occupancy limits. Channel access among different priority traffic can be differentiated using these mechanisms.

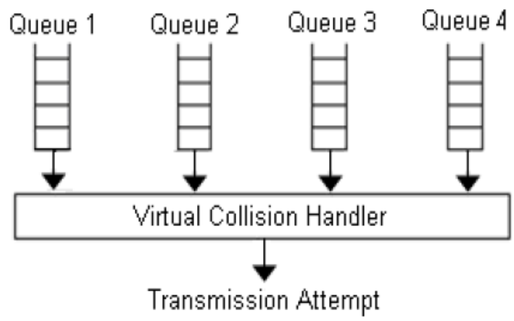

Figure 2. Multiple transmission Queues in IEEE 802.11e

The Adaptive EDCF (AEDCF) scheme [27] proposes improvements over EDCF, wherein channel collision rate is used in adjusting the CW size dynamically.

The size of the CW after a successful transmission is reset by EDCF. This process assumes that the contention level has dropped down. Contention level however often varies at a smaller rate; this can leads to high amount of collisions and retransmissions. Maintaining a high value of CW increases delay on the other hand. In order to balance this trade-off Conditioned Enhanced Distributed Coordination Function (CEDCF) [15] proposes a CW decrease mechanism based on the dynamic channel state. CEDCF [15] proposes CW adjustment based on the fast decrease EDCF mechanism [26] if there are not that many wireless medium contentions; and adjusted according to the adaptive approach AEDCF [27] if the channel is congested.

VII. CONCLUSION

Provisioning of Quality of Service (QoS) to support voice and video applications is crucial in MANET, as multimedia communications is becoming one of the key applications of MANETs. However, QoS provisioning and maintenance in highly dynamic wireless networks such as MANETs is a very challenging problem due to factors such as continuously changing network topology, limitations of wireless channel capacity, link variability, multi-hop communication paths etc as mentioned in Section 2.

Most of the QoS provisioning models in MANETs support Integrated Services [2] type of approach. This seems to be because the size of the MANET networks and the number of reserved flows are not as large as in the wired internet. Furthermore, routing in MANETs is performed in a proactive manner before the start of every communication flow [6]. Therefore, the QoS reservation and probe information can be easily piggybacked on the route discovery packets, tremendously reducing QoS reservation and singaling protocol overhead in MANETs, unlike wired internet where routing and QoS signaling are generally performed separately.

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