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

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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 networking. MANETs are being used in numerous application domains from emergency rescue and relief to wireless sensor networks. Quality of Service (QoS) provisioning in MANETs is of utmost importance in order to support real-time communications (such as audio and video) over MANETs. However, QoS provisioning in highly mobile wireless networks such as MANETs is a very challenging problem compared to provisioning of QoS in wired IP networks. The main reasons behind this being unpredictable node mobility, wireless multi-hop communication, contention for wireless channel access, limited battery power and range of mobile devices as well as the absence of a central coordination authority in MANETs. This paper presents the current state of the art in MANET QoS Provisioning schemes at Routing, Transport and Medium Access Layers as well as the MANET QoS Signaling and Provisioning Models. Previous surveys have only looked at QoS provisioning models, signaling and routing. This paper presents a complete survey of the challenges and recent protocols being developed for QoS provisioning in MANET across multiple network layers as well as the various QoS signaling and QoS models being developed for MANETs.

Keywords

Quality of Service, Mobile Ad hoc Network, IntServ, DiffServ, Wireless Networks, Routing.

I. INTRODUCTION

The Internet was originally developed to offer only "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.

According to RFC2386 [1], QoS is a set of service requirements (such as latency, jitter, and packet loss) to be met by the network while transporting a flow of data traffic. A flow is a packet stream from a source to a destination with an associated QoS requirement. A QoS model is a mechanism for achieving and provisioning of QoS. IETF has developed two of the main QoS provisioning models in the Internet: (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.

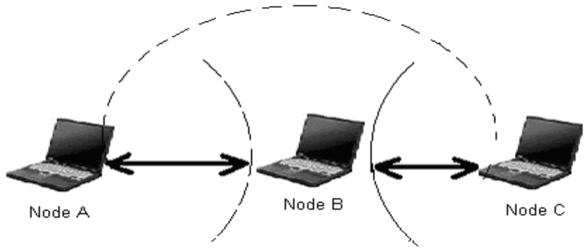

Figure 1. Example of Ad hoc Network

The last decade brought widespread use of wireless networks connecting mobile devices to the internet, creating the need for supporting real-time communication applications on such highly mobile networks. Within the wireless networks domain, wireless mobile ad hoc networks have become very popular. A Mobile Ad Hoc network (MANET) [4] is a collection of mobile nodes like PDAs and laptops which dynamically form a temporary network, without using any existing network infrastructure (wireless access points or base-stations) as shown in figure 1. The only infrastructure is the wireless interfaces on the devices themselves. If the wireless nodes are not within wireless range of each other, communication requires multi-hop routing. 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 consumes large portion of the scarce network capacity for exchanging huge chunks of routing table data. This reduces the available capacity of the network for actual communication. Reactive or on-demand routing [6] on the other hand launches a route discovery every time a route needs to be established. This requires the actual communication to be delayed until the route is determined. The key advantages offered by MANET are as follow:

i. Rapidly deployable: There is no need for backhaul wiring and infrastructure support to setup a MANET. This makes the deployment and operation of MANET relatively easy and less expensive compared to infrastructure networks such as cellular or wired networks.
ii. Self-organising and self-configuring – MANET support mobility, addition of new nodes, and configuration and maintenance are relatively easy due

to MANETs self-configuration and self-organising features.

iii. Self-healing – As MANETs usually have multiple and redundant paths, they are inherently more robust as they can avoid creation of bottleneck links and communication disruption due to single points of failure.

iv. Coverage Extension and scalability – Since MANETs make use of multi-hop routing, the range of wireless nodes can be significantly extended. This avoids creation of shadow regions which are sometimes present in cellular networks (in large halls or buildings and subways).

v. Low transmission power – As the messages are routing in a multi-hop fashion, the transmission power of the source node can be reduced, since the wireless signal only needs to reach the next hop (not the final destination), while still being able to communicate with a far away wireless device.

MANETs have become increasingly popular recently, firstly due to their autonomic and infrastructure-less properties of dynamic self-organising, self-configuration, 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 increasing number of wireless devices joining the network. However, 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 including satellite mesh 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].

QoS provisioning in MANETs is very important in order to support real-time communications such as audio and video. However, provisioning of communication QoS over wireless networks is far more challenging than for wired networks because of variability of wireless links, the lack of any central coordination authority (for QoS and channel assignment), node mobility, limited battery power, multi hop communication and contention for accessing the wireless channel. The main requirements for a QoS Model for MANETs are as follows:-

i. *Minimal overhead* –The wireless link capacity, battery and computational resources in a wireless multi-hop network are quite limited. Therefore a QoS model for wireless multi-hop networks should minimise the signalling overhead as well as the computational overhead entailed in provisioning of QoS.

ii. *Robustness* – QoS models should be capable of handling frequent route failures and dynamically changing network. The QoS model should have mechanisms to adapt to the changing topology without creating bottlenecks, in a fast and efficient manner.

iii. *Fairness* – The QoS resources should be shared in a fair manner among the wireless clients, and misbehaving nodes should not be allowed to make use of the network's resources without relaying packets for other nodes.

This paper evaluates the state of the art in provisioning, signalling and routing for ensuring good QoS 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 discusses the recent trends in MANET QoS developments and future areas of research in QoS provisioning for MANETs as well as draws some important conclusions.

II. CHALLENGES IN QOS PROVISIONING FOR MANET

QoS provisioning in highly mobile wireless multi-hop networks such as MANETs is very challenging compared to wired networks because of various difficulties associated with these types of networks. Some of these problems have been addressed in the QoS models for MANETs however a lot of problems remain unresolved.

2.1 Wireless Communication Medium Related Problems

i. ***Capacity Constraints:*** Wireless bandwidth is generally scarce and expensive to own [11]. Furthermore, clients in multi-hop wireless networks are generally equipped with a single wireless interface only, further limiting the communications capacity of these nodes.

ii. ***Unreliable Communication Medium:*** The wireless medium used for communication in multi-hop wireless networks is prone to errors due to interference noise generated from transmissions of other wireless devices in the vicinity as well as multi-path fading effects [12]. This makes it extremely challenging to provide any guaranteed packet delivery.

iii. ***Unpredictable Channel Access Delay:*** As there is no centralised controller in a multi-hop wireless network, media access control is based on a distributed mechanism random back offs. This leads to the difficulty in calculating and guaranteeing tight delay bounds generally required for real-time communication.

iv. ***Inaccurate Bandwidth Estimation:*** Available wireless channel bandwidth at a mesh client or router is difficult to be accurately determined, as it is affected by a number of factors, including the traffic load in the wireless transmission and sensing range, node mobility, as well as the general variability of wireless links.

2.1 Network Related Limitations and Problems Node

i. ***Mobility and Dynamic Topology:*** The client nodes in multi-hop wireless networks are generally mobile, resulting in routing information to become stale relatively quickly. Furthermore, battery powered wireless clients acting as relays could randomly turn off due to battery exhaustion. These topological changes may require QoS path re-establishment. If the rate of topology changes is higher than the speed of QoS path re-establishment, it would be virtually impossible to provide QoS.

ii. ***Absence of Centralised QoS Control:*** In a multi-hop wireless networks there is no centralised controller which keeps track of client nodes location, allocation of resources and QoS management. Therefore, QoS provisioning has to be done in a distributed fashion, which is much more challenging than for a centralised network.

iii. ***Network Heterogeneity:*** Another key challenge in QoS provisioning is the high level of heterogeneity present in multi-hop wireless networks. Mesh routers differ from mesh clients considerably in terms of level of mobility as well resource availability. For example, mesh routers are typically equipped with multiple radios, giving them a higher aggregate communication capacity than single radio mesh clients.

2.3 Qos Model Related Considerations

i. ***QoS Route Selection and Querying Problem:*** Most multi-hop protocols such as AODV [6] make use of control packets such as RREQ (Route Request) for route discovery and selection. However, such control packets have different properties than actual data packets. For example, RREQ packets are generally given priority in transmission and processing at intermediate nodes and are much smaller in size than actual data packets which can be of varied length. This may lead to selection of paths which are composed of unstable or congested wireless links [13].

ii. ***Varied QoS Requirements:*** The QoS requirements in multi-hop wireless networks are highly varied and dependent on the particular application scenario, and it is therefore difficult to develop one single standard for QoS provisioning to cover all these varying requirements. For example, a sensor network deployed to identify a toxic leak in an industrial unit might prioritize high reliability, while a disaster relief and response network may put a higher importance on least amount of delay and route discovery latency in order to promptly alert first responders and paramedics [14].

iii. ***False Admission Control Problem in Stateless QoS Models:*** Since in a multi-hop wireless network, there is no centralised QoS controller, multiple flows may send probe messages to check current bandwidth availability at the same time. If the QoS model is stateless, then the intermediate nodes will not keep track of reservations and probes. This may result into a situation where multiple flows (sharing a common path or intermediate node) send probe messages simultaneously and each source may receive a response indicating that resources are available, when in fact they might not [15].

2.4 Multi Layer QoS Provisioning Problem

In comparison to wired networks, QoS provisioning in a MANET is a Multi Layer problem. In wired networks QoS provisioning is generally accomplished at the Transport and Routing Layers. However, in a MANET, all the network layers need to participate in QoS provisioning. The physical layer must be able to quickly adapt to changing Wireless Channel characteristics. The Medium Access layer needs to minimise packet collisions and ensure fair channel access and reliable data communication in a distributed channel assignment scenario. Network layer need to determine data communication paths on-demand which can fulfil the QoS requirements in a dynamic network topology. The Transport layer needs to take care of the packet loss and large delay and delay jitter associated with frequent path failures in MANETs. Finally the Application layer needs to be able to adapt quickly to packet loss, delay, out of sequence delivery of packets in order to ensure QoS.

III QoS MODELS IN MANET

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

3.1 Hybrid IntServ and DiffServ QoS Models for MANETs

Some QoS models developed for MANETs make use of IntServ and DiffServ in a hybrid fashion. Flexible QoS Model for MANETs (FQMM) [16] is such a 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. Also, a traffic conditioning scheme is used at each ingress router. In FQMM, 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].

FQMM assumes that the smaller proportion of the traffic belongs to the highest priority class. Therefore, the scalability problem of IntServ is not an issue in FQMM. The advantage of FQMM model is that it is relatively simple, and it borrows from the existing QoS model concepts in traditional IP networks. However, this approach is only suitable for small sized networks up to around 50 nodes. As the network size increases, so will the high priority traffic receiving per-flow QoS treatment and the cost of the associated state management. This may lead to the well known scalability problems of IntServ. Furthermore, traffic conditioning at the source node bears the possibility of the source node misbehaving to get preferential treatment for its own traffic. Lastly, since every node in MANETs can potentially act as a source, every node therefore needs to run a traffic conditioning algorithm, which might become difficult for mobile devices with limited memory and computational capabilities.

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. Since CEQMM is based on QOLSR, it requires power and network resources for exchanging routing data. This may be a limitation for battery constrained wireless networks such as MANETs.

3.2 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 states. It differentiates real-time and best effort (which do not require any QoS bounds or guarantees) packets and shapes only the best-effort packets using a leaky bucket traffic shaper. Admission control is done at the source using a probe-based scheme, where a probe is sent to the destination to determine ***instantaneous*** bandwidth availability. A probe is sent at the beginning of connection establishment and at the time of reestablishment when the path breaks or congestion is noticed on the path. Real-time sessions are regulated using ECN [19] that was originally proposed for Transmission Control Protocol (TCP) flows (generally loss sensitive data traffic) only.

As SWAN is stateless, there is no need for state maintenance at intermediate nodes and periodic refresh messages. However, since SWAN does not make any resource reservations at the intermediate nodes, a problem of false admission may arise. The problem occurs when multiple source nodes simultaneously send probe messages to check for instantaneous bandwidth along the path between source destination pairs, where the source destination pairs share some common path. In such a case, the source nodes may get a response to their probe message indicating the availability of resource, when in fact they are not. To tackle this problem in SWAN, when an intermediate node experiences congestion, it marks in the header of data packets of all flows with CE (Congestion Experienced). Destination nodes, upon receiving such packets, inform the sources to re-establish the flows. Rather than re-establishing the flows immediately, the source node waits for a random amount of time before initiating the reestablishment process. Although the above process solves the false admission problem, the random waiting time before initiating flow re-establishment may cause large latency in real-time connection establishment, especially if this process occurs multiple times in succession. The approach also suffers from extensive additional signalling overhead due to frequent flow re-establishments.

IV QoS ROUTING IN MANET

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 upto-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.

4.1 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:

i. ***Core extraction:*** First, a set of nodes are dynamically selected to form a ***core*** (self-organizing routing infrastructure) in a distributed fashion that maintains local topology and performs route calculations.
ii. ***Link state propagation:*** Bandwidth availability information of stable high bandwidth links is propagated to all core nodes. Information of dynamic links or low bandwidth is kept local.
iii. ***QoS Route Computation:*** First a core 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 then is used as the source for the next iteration 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 [32] can cause high network overhead. Furthermore, it is quite likely that core nodes could become a bottleneck in the network as most of the data traffic is routed through them.

4.2 Ticket-Based Probing

Ticket-Based Probing (TBP) [22] is a multi-path QoS routing scheme for MANETs which considers a flat routing architecture. In TBP, a ticket is the permission to search for a single path. A probe (for reactive route discovery) is required to carry at least one ticket, but it may consist of more. Therefore, the maximum number of searched paths is bounded by the tickets issued by the source. At the intermediate node, a probe with more than one ticket is allowed to split into multiple tickets. Once the destination node receives the probe message, a possible path is found. In TBP, three-level path redundancy is utilized in case of route failures. The path redundancy scheme establishes multiple routes for the same connection. For the highest level of redundancy, resources are reserved along multiple paths and every packet is routed along each path. In the second level, resources are reserved along multiple paths, but only one is used as the primary path, while the rest serve as backup. In the third level, resources are only reserved on the primary path, even if multiple paths are established.

Although TBP can limit the flooding of control messages, the computation of a suitable number of logical tickets, issued at the source node is based on heuristics [24]. Furthermore, the presence of backup paths (first and second level of redundancy) has an adverse effect on other flows since valuable network resources have to remain reserved for these backup paths. In the last level of redundancy, there might be a long recovery time which may result in a temporary QoS violation [22].

4.3 QoS over AODV

A few extensions on Route Request (RREQ) and Route Reply (RREP) messages of the Ad hoc On-demand Distance Vector (AODV) [5] routing protocol have been proposed to support QoS, in *QoS over AODV* (QAODV)

[23] protocol. In this protocol, a mobile host may specify one of two bounds: a maximum delay and minimum bandwidth. Before a node can rebroadcast a route discovery message, it must be capable of meeting the specified QoS requirements. If the requested QoS can no longer be maintained, a node sends a QoS Lost message back to the source. As QAODV [23] is based on reactive routing [5], and incurs less control overhead.

V QoS SIGNALING IN MANETs

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

In the In-band Signalling system for supporting QoS in MANET (INSIGNIA) [24, 25] signalling protocol developed for MANETs, the signalling control information is carried in the IP option of every packet, which is called INSIGNIA option [24, 25]. Since it is per-flow based protocol like RSVP, 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. Coordinating with the admission control module, INSIGNIA allocates bandwidth to the flow if the resource requirements can be satisfied. Otherwise, if the required resources are not available, the flow will be degraded 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 sources 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 to the source node periodically. By using this kind of feedback information, the source node can take corresponding actions to adapt the flows to observed network conditions.

VI QoS MAC IN MANETs

Medium Access Control (MAC) Protocol for providing MANET QoS must minimize packet collisions, allow fair channel access among nodes, provide reliable data transport over shared wireless medium under rapidly changing conditions. Priority queuing is used in IEEE 802.11e [26]. It 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 figure 2. Each queue contends for the channel independent of the others. Collisions among a single station's queues are resolved internally, permitting the higher priority queue to transmit and forcing the lower priority queue to perform a collision response. Different levels of service are provided to each access category through a combination of three service differentiation mechanisms as follows: (i) arbitrary inter-frame spaces (AIFS); (ii) contention window sizes and; (iii) medium occupancy limits. These parameters can be used in order to differentiate the channel access among different priority traffic.

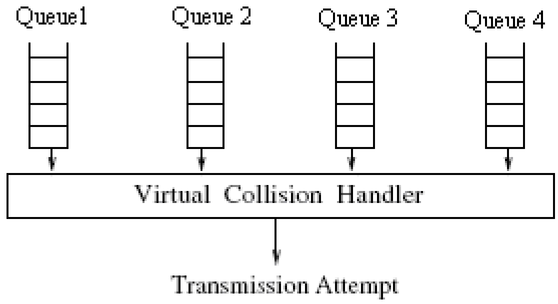

Figure 2. Multiple transmission Queues in IEEE 802.11e

The Adaptive EDCF (AEDCF) scheme [27] has recently been proposed to improve the performance of EDCF. This scheme is based on an old version of EDCF (draft 3.1 [1]). It adjusts the $CW[AC]$ size of each traffic class taking into account the channel collision rate, which improves the total goodput of EDCF (draft 3.1) up to 25%.

With the EDCF the contention window (CW) is reset upon a successful transmission, assuming that the contention level has dropped. This leads to collisions and retransmissions as the contention level is more likely to change slowly. On the other hand, keeping high value of CW increases delay with high back-off values. To optimize this trade-off between fast and slow CW decrease Conditioned Enhanced Distributed Coordination Function (CEDCF) [28] proposes an intermediate CW decrease function that is conditioned by the channel state. If the channel is congested, the size of CW should be adjusted according to the adaptive approach AEDCF. In the other case, when contentions on the medium are negligible, the fast decrease scheme of EDCF is adopted.

VII CONCLUSION

Provisioning of Quality of Service (QoS) to support an voice and video application is crucial in MANET, as multimedia communication is one of the key applications of MANET. However, QoS provisioning in wireless networks especially MANETs is a very challenging problem due to factors such as dynamically changing topology, capacity limitations and link variability, multi-hop communication etc.

This paper presented the QoS provisioning mechanisms being developed for MANETs. As mentioned in Section 2, QoS provisioning in MANETs is a Multi-Layer problem. However, most of the protocols for QoS provisioning that are being developed are single layer approaches. This does not provide a comprehensive solution. One of the areas of future research would be to develop the coordination and communication among the various network layers to achieve QoS in MANETs.

It is also noted that most of the QoS provisioning models in MANETs support Integrated Services. This is because the size of the network and the number of reserved flows are not as large as in the wired internet. Furthermore, the routing in MANETs is performed in a proactive manner before the start of every communication flow. So, the QoS reservation and probe information can be easily piggybacked on the route discovery packets, reducing extra QoS reservation overhead in MANETs.

VIII ACKNOWLEDGEMENTS

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