A Flexible Quality of Service Model for Mobile Ad-Hoc Networks

Hannan XIAO[1], Winston K.G. SEAH[2]†, Anthony LO[2] and Kee Chaing CHUA[2]

[1]Dept of Electrical Engineering
National University of Singapore
10 Kent Ridge Crescent
Singapore 119260
engp8803@nus.edu.sg

[2]Centre for Wireless Communications*
20 Science Park Road, #02-34/37 TeleTech Park
Singapore Science Park II
Singapore 117674
{winston, loanthony, chuakc}@cwc.nus.edu.sg

Abstract – Quality of service (QoS) support in Mobile Ad-hoc NETworks (MANETs) is a challenging task. Most of the proposals in the literature only address certain aspects of the QoS support, e.g., QoS routing, QoS medium access control (MAC) and resource reservation. However, none of them proposes a QoS model for MANETs. Meanwhile, two QoS models have been proposed for the Internet, viz., the Integrated Services (IntServ) model and the Differentiated Services (DiffServ) model, but these models are aimed for wired networks.

In this paper, we propose a flexible QoS model for MANETs (FQMM) which considers the characteristics of MANETs and combines the high quality QoS of IntServ and service differentiation of DiffServ. Salient features of FQMM include: dynamics roles of nodes, hybrid provisioning and adaptive conditioning. Preliminary simulation results show that FQMM achieves better performance in terms of throughput and service differentiation than the best-effort model.

I. Introduction

A Mobile Ad-hoc NETwork (MANET) is a collection of wireless mobile nodes dynamically forming a temporary network without the use of any existing network infrastructure or centralized administration. MANETs have their own advantages such as high robustness and easy to setup despite the resource constraints like limited bandwidth and power. Typical applications of MANETs are in tactical networking and disaster recovery operations. Recently, the rising popularity of multimedia applications among end users in various networks and the potential usage of MANETs in civilian life have led to research interest in providing QoS support in MANETs.

As pointed out in [5], it is a huge challenge to provide QoS in MANETs. A network's ability to provide a specified quality of service between a set of endpoints depends upon the inherent performance properties such as delay, throughput, loss rate, error rate of the links and nodes, the traffic load within the network, and the control algorithms operating at different layers of the network [12]. In MANETs, the quality of a wireless link (e.g., its capacity or signal-to-noise ratio) is apt to be highly variable and the environmental conditions influencing the wireless link at a particular time are not likely to be known completely or in advance. Furthermore, node mobility and dynamic network infrastructure make the problem more complex. In the literature, researchers work on certain aspects of QoS in MANET including QoS routing [12], QoS MAC [9] and resource reservation [8]. While the proposed protocols are sufficient to meet the QoS needs under certain assumptions, none of them proposes a QoS model for MANETs.

We argue that a QoS model for MANETs should first consider the features of MANETs, e.g., dynamic topology, time-varying link capacity and limited power. In addition, as the applications of MANETs in the civilian sector become more and more popular, we assume that MANETs will be seamlessly connected to the Internet in the future. Therefore, the QoS model for MANETs should also consider the existing QoS architectures for the Internet.

Based on these assumptions, we propose a flexible QoS model for MANETs (FQMM) after investigating in detail the applicability of both IntServ and DiffServ with respect to the characteristics of MANETs. Our proposed model has the following features: nodes have dynamic roles, a hybrid provisioning scheme that combines the per-flow granularity in IntServ and per-class granularity in DiffServ, and a relative and adaptive traffic profile to maintain consistent differentiation between traffic types and keep up with the dynamics of the network. QoS routing and resource management are also discussed and throughput is studied as a main QoS parameter through simulation.

II. IntServ, DiffServ and MANETs

This section discusses the applicability of IntServ and DiffServ in MANETs.

A. IntServ and MANETs

The idea behind IntServ [2] is borrowed from the paradigm of the telephony world and B-ISDN, i.e.,

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† Corresponding author.

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adopting a virtual circuit connection mechanism. The Resource ReSerVation Protocol (RSVP) is used as a signaling protocol to setup and maintain the virtual connections. Routers apply corresponding resource management schemes, e.g., Class Based Queueing (CBQ) to support the QoS specifications of the connection. Based on these mechanisms, IntServ provides quantitative QoS for every flow[‡]. The pros and cons of the IntServ approach in MANETs are enumerated below.

Scalability: IntServ provides per-flow granularity, so the amount of state information increases proportionally with the number of flows. This results in a huge storage and processing overhead on routers, which is the well-known scalability problem of IntServ. The scalability problem is less likely to occur in current MANETs considering the small number of flows, the limited size of the network and the bandwidth of the wireless link. On the other hand, as fast radios and efficient low bandwidth compression technology develop rapidly, the emergence of high speed and large size MANETs with plenty of applications is foreseeable. Then, the pure IntServ approach for MANETs will inevitably meet the scalability problem as in high speed fixed networks today.

Signaling: Signaling protocols generally contain three phases: connection establishment, connection tear-down and connection maintenance. Corson[5] predicts that a larger percentage of link capacity will be allocated to control overhead in a network with smaller and time-varying aggregate network capacity. For MANETs with dynamic topology and link capacities, the overheads of connection maintenance usually outweigh the initial cost of establishing the connection. Therefore, RSVP-like signaling is not practical in MANETs.

Router mechanisms: IntServ imposes high requirement on routers. All routers must have the four basic components: RSVP, admission control routine, classifier, and packet scheduler. Consequently, the processing overheads of routers are high which is undesirable in power-constrained MANETs.

B. DiffServ and MANETs

The tenet of DiffServ [1] is to use a relative-priority scheme to soften the hard requirements of hard QoS models like ATM and IntServ. At the boundary of the network, traffic entering a network is classified, conditioned and assigned to different behaviour aggregates by marking the DiffServ codepoint (DSCP) field in the IP packet header. Within the core of the network, packets are forwarded according to the per-hop behaviour (PHB) associated with the DSCP. Implicit reservation is done in the form of the service level agreement which is agreed between users and network providers. DiffServ provides qualitative QoS for aggregate flows. The pros and cons of the DiffServ approach for MANETs are enumerated as follows.

Node functionality: DiffServ is designed to overcome the difficulty in implementing and deploying IntServ and RSVP in the Internet backbone. The size of MANETs is not comparable with that of the backbone, but the functionalities of nodes in MANETs are analogous with those of routers in the Internet backbone. The role of each node in MANETs is twofold, host and router/switch. As a router, a node routes packets for other nodes as what the backbone routers do in the Internet. Hence, a MANET is similar to a backbone network in the sense of the functionalities of nodes. Intuitively, this similarity implies a potential usage of the DiffServ approach in MANETs.

Timescale: DiffServ is aimed to provide service differentiation among traffic aggregates to customers over a long timescale. In MANETs, mobility and link capacity reach some steady state over a long timescale despite the instantaneous changes in topology and bandwidth conditions. It is difficult to provide short timescale QoS by trying to keeping up with the time-varying conditions but it should be possible to provide QoS on a long timescale for MANETs as DiffServ does for the Internet.

Interior nodes: DiffServ is lightweight in interior nodes as it does away with per-flow states and signaling at every hop. In MANETs, keeping the protocol lightweight in interior nodes is important since putting too heavy load on a temporary forwarding node which is moving is unwise.

Services: Premium Service [11] is supposed to provide low loss, low latency, low jitter and end-to-end assured bandwidth service like a virtual least line. Such a virtual least line is hard to maintain due to the dynamics of MANETs. On the other hand, Assured Service (AS) [4] is aimed to provide guaranteed, or at least, expected throughput for applications and it is easy to implement. AS is attractive when throughput is chosen as an important QoS parameter for MANETs. In addition, AS is more qualitative-oriented than quantitative-oriented [7] and it is not easy, if not impossible to provide much quantitative QoS in MANETs with the physical constraints. Therefore, AS has a potential usage in MANETs.

With all the promising aspects of MANETs with DiffServ, it is still not straightforward to adopt the DiffServ approach in MANETs since DiffServ is designed for fixed and relatively high speed networks. It is also desirable to incorporate suitable QoS features provided by IntServ into MANETs. The following section describes a QoS model for MANETs which takes into consideration the above items.

[‡] A flow is an application session between a sender and a receiver

III. FQMM

A. Model

Currently, FQMM is for small to medium size MANETs, with less than 50 nodes, using a flat non-hierarchical topology. It defines three kinds of nodes as in DiffServ. An ingress node is a mobile node that sends data. Interior nodes are the nodes that forward data for other nodes. An egress node is a destination node. For example, in Fig. 1, eight nodes are moving about and a route is established for communication from node M1 to M6. When data is sent from M1 to M6, M1 behaves as an ingress node – classifying, marking and policing packets. Nodes M3, M4 and M5, along the route from M1 to M6, behave as interior nodes forwarding data via certain PHB defined by the DSCP. M6 is the egress node which is the destination of the traffic. In this model, a MANET represents one DiffServ domain where traffic is always generated by applications running on an ingress node and terminate in an egress node.

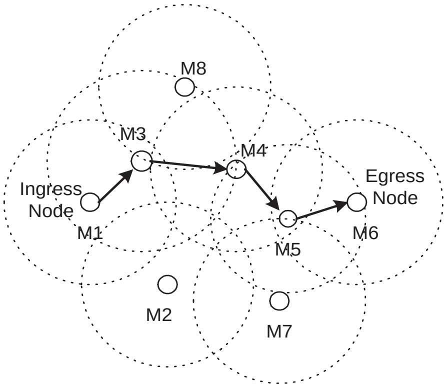

Figure 1: Scenario 1

When nodes move about, another topology may form as shown in Fig. 2. In this scenario, there are two connections: one is from M1 to M6, the other is from M8 to M2, and the roles of the nodes are listed in Table 1. As illustrated, the nodes have dynamic roles in FQMM.

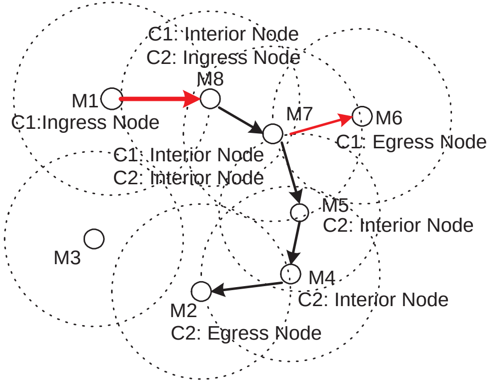

Figure 2: Scenario 2

B. Provisioning

Provisioning refers to the determination and allocation of resources needed at various points in the network. In the current Internet, provisioning is at a high level, quite coarse, and generally based on the estimation of the scale and utilization of the network. In IntServ, the provisioning policy is to realize ideal per-flow granularity by RSVP signaling along the route and reserving sufficient resources. Provisioning in DiffServ is per-class based with static provisioning performed by human agents on behalf of ISPs or users, or dynamic provisioning by signaling or measurement.

Connection	Ingress Node	Interior Node	Egress Node
C1	M1	M8, M7	M6
C2	M8	M7, M5, M4	M2

Table 1: Roles of Nodes in FQMM (Scenario 2)

We propose a hybrid per-flow and per-class provisioning scheme for FQMM. In such a scheme, traffic of highest priority is given per-flow provisioning while other priority classes are given per-class provisioning. Although like DiffServ, FQMM has service differentiation, we can improve the per-class granularity of DiffServ to per-flow granularity for certain classes of traffic since the traffic load in a MANET is much lesser compared to the backbone of the Internet. However, it is difficult to provide per-flow granularity to all the traffic in a MANET due to bandwidth limitation and other constraints. Hence, we try to preserve the per-flow granularity for a small portion of traffic in MANET, given that a large amount of the traffic belong to other classes. Since the states of per-flow granularity come from only a small fraction of the traffic, the scalability problem in IntServ does not exist. Therefore, this hybrid scheme combines the per-flow granularity in IntServ and per-class granularity in DiffServ.

C. Conditioning

A traffic conditioner is put at the ingress node where the traffic originates. It polices the traffic according to the traffic profile after a valid route is found. Components of the conditioner include traffic profile, meter, marker and dropper. Traffic profile is important because it decides the policy of other components which change the configuration according to the traffic profile.

We propose a relative and adaptive differentiation traffic profile for FQMM. The goal of such a traffic profile is to keep consistent differentiation between sessions which could be per flow or per aggregate of flows and to adapt to the dynamics of the network. For FQMM, we found that absolute traffic profile is not applicable since the effective bandwidth of a wireless link between nodes is time-varying. Thus, we defined the traffic profile as the relative percentage of the effective link capacity, in order to keep the differentiation between classes predictable and consistent under the dynamics of the network. In addition, the profile should be adaptive to the dynamics. When a token bucket is used as the traffic profiler, the parameters of the token bucket profiler of a certain session i are as follows:

$$r_i = T_i \times C_t \times R, \qquad i \subseteq \{1..N\} \qquad (1)$$

$$l_i = B_i \times C_t \times L, \qquad i \subseteq \{1..N\} \qquad (2)$$

where r_i is the token generation rate, l_i is the token bucket length, T_i and B_i are parameters related to the relative target rate of the traffic source i which could be one flow or one aggregate, C_t is a parameter that expresses the dynamic fluctuations of the effective link capacity, and R and L are constants.

From the above equations, the traffic profile is consistent in terms of relative differentiation between classes and adaptive to the network dynamics. We have chosen bandwidth allocation as the relative differentiation parameter, leaving other parameters such as queueing delay and loss rate to be considered later.

D. QoS routing and resource management

Routing protocols for MANETs like Dynamic Source Routing (DSR) [3] provide only best-effort routing, i.e., the connectivity of the route. However, best-effort routing is not enough in supporting QoS. Additional constraints should be considered to provide the required service. Constraints on routing protocol should be consistent with the provisioning policy. For example, per-class provisioning requires that all routers along the determined route should assure that traffic of a certain class injected into the route not be greater than the total percentage of bandwidth assigned in the traffic profile.

To support QoS routing, an additional QoS check is executed after the best-effort routing protocol has found routes. A route is valid if it passes the checking; otherwise it is invalid. If multiple valid routes are found, the best one or a random one can be chosen. It may be more efficient if we consider the QoS constraints together with routing protocol, i.e., designing a QoS routing protocol. In FQMM, we use existing routing protocols already provided in the literature [3], since designing a QoS routing protocol is not in our current scope of work.

The most critical resource of concern is the wireless link capacity. The objective of resource management in our model is to get the highest link utilization while conforming to the provisioning constraints. Link bandwidth sharing and buffer allocation are two important aspects of resource management. The former is done by the scheduler which decides the opportunities of flows for link access and the latter holds the valid packets when necessary and drop some packets from the buffer in case of network congestion. Together they achieve the target QoS requirements.

Different scheduling schemes have been proposed in the literature from the simplest FIFO to other complex schemes. Several researchers have also investigated the problem of how to adapt the packet fair queueing algorithms to wireless networks [10]. While the proposed solution is for a cellular wireless network model, it is not clear whether the same solution can be applied directly to MANETs. We will first study the performance of existing scheduling and buffer allocation approaches in FQMM and then find a suitable resource management scheme for the model.

IV. Preliminary Simulation Study

The *NS* simulator was used in the simulation study. Eight nodes form a small FQMM in a 1000×1000 meter square (cf. Fig. 1, Fig. 2). All nodes communicate with identical, half-duplex wireless radio that are modeled after the commercially available IEEE 802.11-based WaveLan wireless radios which have a bandwidth of 2Mbps and a nominal transmission radius of 250m. Each node moves according to the *random waypoint* mobility model and runs the DSR routing protocol [3].

Four one-way TCP Reno sessions are generated between the eight nodes randomly to transfer FTP bulk data. TCP is chosen because it is used in MANETs to support common Internet applications, e.g., FTP. In addition, we are interested in potential AS usage in MANETs, and AS is usually studied together with TCP [6, 7]. TCP packet size is 1460 bytes and window size is 8 packets. Simulations are run for 300 seconds and the TCP sessions start randomly in the first 5 seconds unless otherwise indicated. For each individual TCP connection, (cf. Table. 1), a token bucket profiler is used in the ingress node and Random Early Drop (RED) with *In/Out* (RIO) [4] buffer management scheme is used in the ingress node, interior nodes and egress node.

Relative bandwidth service differentiation [13] is used. The target rate of each session is a certain percentage of the effective wireless link capacity which varies due to node mobility, traffic load dynamics, channel fading, and other related factors. We show the results of the upper and lower bound cases of provisioning here, i.e., 100% and 0% of the effective link capacity in this paper. Five scenarios are considered and the target rates of sessions in each scenario are listed in Table 2.

Scenario	Session1	Session2	Session3	Session4
#0	0%	0%	0%	0%
#1	100%	0%	0%	0%
#2	0%	100%	0 %	0%
#3	0%	0%	100%	0%
#4	0%	0%	0%	100%

Table 2: Target rates of sessions in the five scenarios

Simulations are run over the same mobility model and connection pattern for the five different scenarios. Throughput of each TCP session in different scenarios is shown in Fig. 3. In scenario #0, all packets are marked as OUT by the token bucket profiler since the target rate is zero, therefore the model becomes a best-effort model. The results in this scenario are used for comparison. The changes of throughput in other scenarios compared with those in scenario #0 are listed in Table 3.

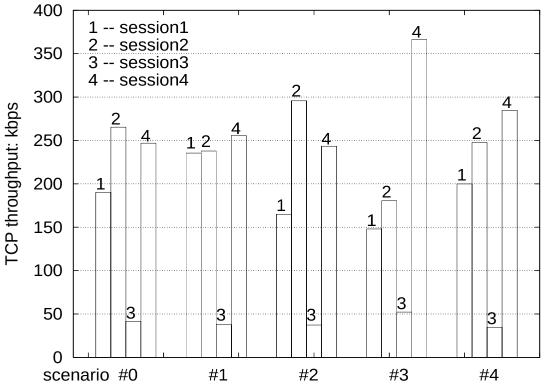

Figure 3: Throughput in the five scenarios

Scenario	Session1	Session2	Session3	Session4
#1	+23.8%	-10.2%	-9.1%	+3.6%
#2	-13.3%	+11.1%	-10.0%	-1.4%
#3	-22.2%	-31.2%	+25.5%	+48.8%
#4	+5.1%	-6.7%	-16.6%	+15.4%

Table 3: Throughput in scenario #1, #2, #3 and #4 compared with that in scenario #0

Fig. 3 and Table 3 show that the throughput of session 1 increases 23.8% in scenario #1, from that in scenario #0. This is because session 1 is given a target rate of 100% of the effective link capacity, so packets from session 1 are marked as IN and packets from other three sessions are marked as OUT since their target rate is zero. The RIO scheme drops less IN packets than OUT packets in case of congestion. Therefore, session 1 gets a higher throughput than that in scenario #0, which is a best-effort model. Such an increase is observed in scenario #2, #3 and #4 too.

It is also shown that session i gets the highest throughput in scenario #i except for session 4. The throughput of session 4 in scenario #3 is even higher than in scenario #4. This is due to the capture behavior of TCP in wireless multihop networks [6]; session 4 somehow captures a lot of bandwidth from session 1 and session 2.

V. Summary

We have described FQMM, a flexible QoS model for MANETs. To our knowledge, this was the first such QoS model proposed for MANETs. We presented a hybrid provisioning scheme and a relative and adaptive traffic profile. We also discussed the issues of resource management and QoS routing in FQMM. Preliminary simulation results on the upper and lower bound cases of provisioning show that FQMM achieves better performance in terms of throughput and service differentiation than the best-effort model. In the future, we will work on more complex cases and design an efficient way to estimate the effective link capacity since this parameter is important in both the provisioning and conditioning schemes.

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