ASAP: An Adaptive QoS Protocol for Mobile Ad Hoc Networks

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Abstract **— With the increasing widespread use of wireless technologies, the need arises for QoS provisioning mechanisms for multimedia applications in wireless networks. However, to support QoS in mobile ad hoc networks (MANETs) is more challenging than in fixed and last-hop wireless access networks. QoS protocols designed for fixed network, e.g. RSVP, are not applicable in MANETs, because they cannot cope with MANET's highly dynamic topology. Existing QoS frameworks explicitly built for MANETs are not as flexible and efficient as needed. In this paper, we propose a new QoS framework for MANETs– Adaptive Reservation and Pre-allocation Protocol (ASAP). By using two signaling messages, ASAP provides fast and efficient QoS support while maintaining adaptation flexibility and minimizing wasted reservations. Simulation of this framework using AODV [10] illustrates the features and performance of ASAP, and demonstrates the design concepts.**

Keywords **— Mobile Ad Hoc Network, QoS, Adaptation, Resource Reservation, In-band Signaling, Wireless, ASAP**

I. INTRODUCTION

Wireless IP networks are becoming pervasive due to their flexibility and lower cost. As extensions of the fixed network infrastructure, wireless IP networks are expected to support diverse applications currently running on fixed networks, such as real-time multimedia applications.

In order to support real-time applications, QoS models like IntServ [1] and DiffServ [2] have been proposed by the IETF for fixed networks. For instance, RSVP [3], a standard protocol of IntServ, is based on resource reservation. The round-trip signaling between sender and receiver builds up a flow-path and reserves the necessary bandwidth according to the flow's profile and the resources available along the path. By reserving resources along the flow path, RSVP provides efficient QoS guarantees. Unfortunately, in the case of mobile ad hoc networks (MANETs), where paths are constantly changing, RSVP's path-based reservation mechanism is clearly not adequate.

There are three major issues in QoS provisioning for ad hoc networks. First, since the topology of the network is highly dynamic, flow relying on a pre-established path and resource reservation along the path will suffer traffic interruptions due to frequent path changes. A better option is to have reactive QoS treatment coupled with the flow instead of the proactive QoS approach proposed in RSVP. Second, QoS parameters like throughput or latency are time-variant. Throughput can dramatically change in a short time due to radio interference or movement of hosts. The QoS mechanism needs to be adaptive, even when confronted with rapidly changing environments, in order to provide relatively stable QoS guarantees. Third, a MANET has less communication bandwidth, smaller processing and power capacity than a fixed network. Given the limited resources, the QoS mechanism and signaling should not exhaust these resources.

Currently, work on QoS in wireless networks mostly focuses on improving RSVP to suit last-hop wireless access networks. For instance, MRSVP [4] and HMRSVP [5] use excessive reservations in all neighboring cells so that QoS can be maintained in whichever cell the mobile hosts might move to. An alternative solution is to find the nearest-common router (NCR), locally repair the path from the NCR and the new access point, and restore the original QoS on the new path. Such schemes are used in LRSVP [6] and [7]. Although these attempts address some QoS issues in wireless environments, RSVP-similar QoS models cannot entirely cope with the needs of QoS provisioning in mobile ad hoc networks.

INSIGNIA [8] is one of the noteworthy QoS frameworks for MANETs. The main goal of INSIGNIA is to provide adaptive QoS guarantees for real-time traffic. It adopts in-band signaling to piggyback control information into the IP header of traffic so that resource reservation and QoS treatment can be provided along the flow, without the need of a pre-established flow path. INSIGNIA considers two optional QoS levels: base QoS and enhanced QoS. Flow traffic carries MIN/MAX bandwidth requests in the packet headers. In each hop, the flow reserves bandwidth to meet MIN/MAX request. At a bottleneck, a hop where only MIN or best effort QoS can be supported, all the hops preceding the bottleneck will adjust their reservation to no more than the bottleneck's QoS. Finally, base QoS or enhanced QoS traffic will be sent by the sender upon receiving a QoS report from the receiver indicating the total bandwidth reserved along the path.

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the same procedure, but only updates SoftBW if the reserved amount is less than the original amount in SoftBW. When the receiver gets SR message, it knows that the available bandwidth equals the value of SoftBW. It then replies with an HR message with SetBW equal SoftBW in the SR message, so that each intermediate host can switch its soft reserved bandwidth to a hard reservation. It also marks SoftBW/HardBW fields in the message, releases the extra reservation if it exists, and updates its flow table. Upon receiving the HR message, the sender can start the flow with a speed matching the reserved bandwidth.

The reason of combining soft and hard reservation is to avoid the waste of extra reservations in hosts other than the bottleneck, a problem that occurs in INSIGNIA.

2) QoS Monitoring and Adaptation: after a flow path is established, SR messages are periodically inserted into the traffic flow. As each SR message collects QoS information along the flow path, the receiver can keep track of the latest QoS situation and give the sender feedback using HR messages, so that real-time applications can adapt their QoS profile accordingly.

```
receiving_message(SR);
TotalResvBW = SoftResvBW + HardResvBW;
if (TotalResvBW < SR.MaxBW) {
  if (AvailBW >= SR.MaxBW - TotalResvBW) {
    SoftResvBW = SR.MaxBW - HardResvBW;
    soft_Reserving(SR.MaxBW - TotalResvBW);
  } else if (AvailBW > 0) {
    SoftResvBW = SoftResvBW + AvailBW;
    soft_Reserving(AvailBW);
  }
  if (SoftResvBW < SR.SoftBW)
    SR.SoftBW = SoftResvBW;
  if (HardResvBW < SR.HardBW)
    SR.HardBW = HardResvBW;
}
sending_message(SR);
```

The algorithm for processing SR messages in an intermediate host is illustrated in the above pseudo code. When the host receives an SR, it checks whether the existing total reservation for this flow (SoftResvBW and HardResvBW) meets MaxBW. If not, the host tries to make an additional soft reservation out of its free bandwidth (AvailBW) to fill the gap. If successful, it updates SoftBW/HardBW in the IP header accordingly.

If every host on the path makes an additional soft reservation, the receiver will notice that the total bandwidth reserved (sum of SoftBW and HardBW) has increased. Therefore it sends an HR message back to change the reservation state, and the sender can adjust the flow's speed to the new QoS level. The following code explains how the receiver host reacts to an SR:

```
receiving_message(SR);
TotalResvBW = SoftResvBW + HardResvBW;
if (TotalResvBW != SR.SoftBW + SR.HardRW) {
  create_message(HR);
  HR.SetBW = SR.SoftBW + SR.HardBW;
  HR.SoftBW = 0;
  HR.HardBW = 0;
  sending_message(HR);
}
```

Similarly, the sender can scale down the real-time flow transmission in case the flow path changes and less guaranteed bandwidth can be maintained. Intermediate hosts release extra reservations upon receiving the HR message and the sender adapts its flow speed accordingly.

3) Local Path Repairing: ad hoc networks are highly dynamic. The flow path might be frequently broken, as topology and routing information changes. From the point where the path is broken to the receiver end, no QoS can be guaranteed. To re-establish reservation state on this path as fast as possible is a critical aspect when maintaining the QoS of real-time flows in a MANET.

ASAP has a simple but efficient path local repairing mechanism. When a host receives an SR that it has not seen before, and the SR's SoftBW and HardBW are not zero, it realizes that the flow is away from the original path, and it triggers local path reparation. The host will create a new flow entry in the flow table, and make a soft reservation according to MinBW/MaxBW in the SR. This procedure is the same as in the flow setup stage. Then, the host will switch its soft reservation to hard reservation by as much as it is indicated in the HardBW of the SR, and keep the rest as soft reservation. After that, the SR is modified and relayed to the next hop. When SR arrives at the receiver, the broken path has been repaired.

It is quite possible that the QoS provisioning on the new path differs from the original QoS level. Depending on the information collected by the incoming SR messages, the receiver will decide whether to send an HR back to the sender to adapt the QoS guarantees.

4) Flow Releasing: flow releasing can be done either by implicitly time-out of the flow path or by explicitly sending an HR. As all the flow and reservation states are soft-states in ASAP, periodically sending SRs forces hosts to refresh existing states. Simply stopping the flow on the sending side will release the flow path in the next time-out period. An alternative method is to send an HR message with SetBW set to zero, so that each host will release all reservations and erase the flow information upon receiving HR.

C. Flexible Timing Control

In ASAP, there are two timing parameters that are strongly related to the efficiency and performance of ASAP: the SR sending interval and the soft-state time-out period.

The interval between SR messages is critical in determining the speed with which ASAP adapts to changes. A small interval will make ASAP closely follow the QoS changes and quickly adapt to these changes. On the other hand, this may cause excessive messages and high processing load. The selection of this interval can be made flexible according the dynamics of the network. Larger intervals are preferable when the network is relatively stable and has enough resource. A smaller interval is helpful in case of high mobility of network nodes.

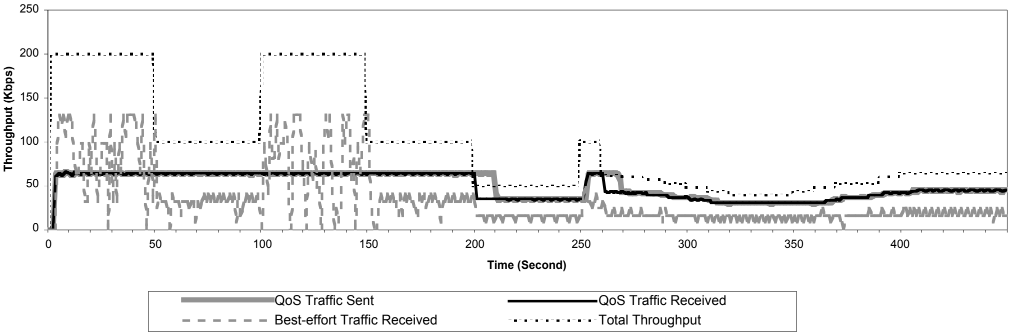

Figure 2. QoS Adaptation Analysis

The soft-state time-out period must be coherent with the SR interval. The SR interval should not be smaller than the time-out period in order to keep the flow path alive. And the time-out period should not go too far beyond the SR interval. The reason is that too large a soft-state time-out will keep reservations on stale or broken paths alive for a long time, thereby preventing other traffic from accessing those resources.

III. SIMULATION AND EVALUATION

Several simulation scenarios have been created with NS2 [9] to evaluate ASAP protocol. The following aspects of ASAP are emphasized:

- QoS adaptation with changes in the quality of wireless link.
- QoS performance under different mobility
- Reservation Efficiency and signaling overhead

A. QoS Adaptation evaluation

In this simulation, a small scenario with 5 nodes is generated. Each node stands still and keeps in a line with 200 meters distance from neighboring nodes. One end generates both QoS flow and best effort traffic, and sends them to the other end. The interval of sending SR messages is 10 seconds. By changing the throughput of the wireless link of one intermediate hop, we can observe how the receiver and sender adapt their flow according to the throughput changes.

As shown in Figure 2, ASAP follows quite well the changes in throughput with only a very small percentage of the traffic missing the QoS guarantees given. The latency in reacting to changes is strongly related to the sending interval of SR messages.

B. QoS Performance

This simulation shows the performance in different mobility circumstances: from a speed of 10km/h (human movement) to 100km/h (car or train movement). We use 20 nodes randomly moving within a 600m*600m area with the specified maximum speed. 12 flows with 16kbps bandwidth are generated by 12 different sender nodes. Each flow has a randomly selected receiver node. Background traffic is randomly generated on 12 randomly selected nodes. The SR sending interval is 1 second. The radio coverage range is 250 meters. As ASAP works regardless of MANET routing protocols, AODV [10] is used to for this simulation.

The total of the QoS packets that violate Guaranteed QoS include two parts: packets treated as best effort and packets that are simply dropped. As the flow bandwidth is quite small comparing to the link throughput, the dropped QoS packets are within a small percentage regardless of mobility. But the amount of packets treated as best effort rather than dropped increases with increasing mobility. This is because the high movement speed leads to a high handover rate that makes the restoration of QoS levels a continuous effort. Even then, the total amount of degraded QoS packets at 100km/h is still within 10%, as shown in Figure 3.

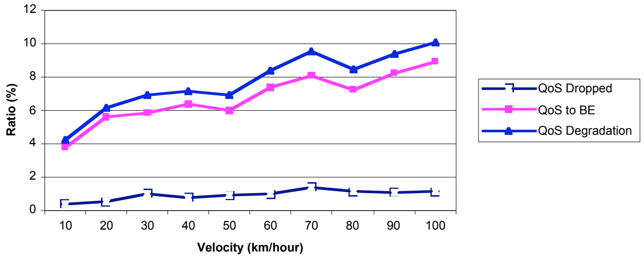

Figure 3. QoS Performance Analysis

C. Reservation Surplus

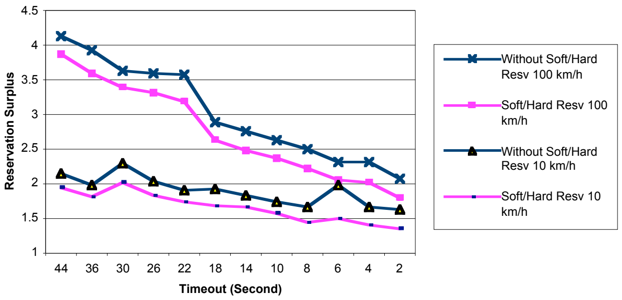

Figure 4. Reservation Surplus Analysis

Reservation surplus is the ratio between the total reserved throughput capacity of the whole network and the total QoS traffic processed (equals the total requested reservation). In the best case, reservation surplus equals 1, when no reservation goes unused.

The graph in Figure 4 shows that the reservation surplus of ASAP is correlated to the mobility of hosts and the timeout period of reservation state. Frequent route changes caused by fast movement propagate reservation states in the network. This increases wasted reservation and, therefore, decreases efficiency.

For each combination of the speed (10km/h and 100km/h) and the timeout (2 to 44 seconds), 100 runs have been done in order to gain statistical stability. In Figure 4, two pairs of curves show the reservation surplus of ASAP with and without the Soft/Hard reservation mechanism. For example, when the timeout is 2 seconds and moving speed is 10km/h, the surplus with and without the Soft/Hard reservation mechanism are 1.35 and 1.63 respectively. In this case, by adopting Soft/Hard reservation concept, the surplus decreases 0.28, which implies a reduced reservation of up to 28% of the total requested reservation.

This simulation result shows the reservation surplus without Soft/Hard reservation is higher than it with Soft/Hard reservation mechanism. The average amount of reduced reservation that ASAP spares is around 20-30% comparing to total processed QoS traffic.

D. Signaling Overhead

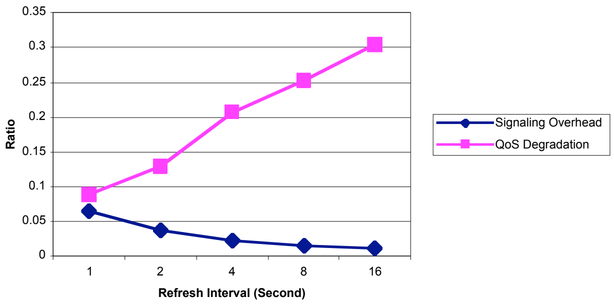

Figure 5. Signaling Overhead Analysis

Obviously the interval sending SR messages affects signaling overhead, the ability of ASAP to react to changes and the QoS traffic.

The smaller the SR interval is, the more signaling overhead, and the higher the processing load. On the other hand, a small SR interval makes ASAP very responsive to routing changes and QoS variation, and minimizes QoS degradation, as illustrated in Figure 5. Adaptively adjusting the SR interval during QoS flow transmission balances the responsiveness of ASAP and minimization of signaling overhead.

IV. CONCLUSION

QoS provisioning in MANETs is very challenging due to the network's highly time-variant characteristics. Based on existing work like the INSIGNIA protocol, ASAP has been designed to further explore QoS provisioning mechanisms and improve existing frameworks. By adopting a Soft/Hard reservation mechanism, ASAP provides very flexible and adaptive QoS support on any QoS level, and maintains reservation efficiency (20-30% less bandwidth reserved comparing to protocols without Soft/Hard mechanism). ASAP has only two signaling messages and involves only simple decision-making. This feature makes ASAP's signaling system elegant and less process-intensive. Furthermore, the local repair mechanism in ASAP facilitates stable and continuous QoS provisioning in case of broken paths.

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REFERENCES

[1] R. Braden, D. Clark, S. Shenker, "Integrated Services in the Internet Architecture: an Overview", *RFC 1633*, June. 1994.

[2] S. Blake, D. Black, M. Carlson, E. Davies, Z. Wang, W. Weiss, "An Architecture for Differentiated Services", *RFC 2475*, Dec. 1998.

[3] R. Braden, L. Zhang, S. Berson, S. Herzog, S. Jamin, "Resource Reservation Protocol (RSVP) – Version 1 Functional Specification", *RFC 2205*, Sep. 1997.

[4] A. Talukdar, B. Badrinath, A. Acharya, "MRSVP: A resource reservation protocol for an integrated services network with mobile hosts," *The Journal of Wireless Networks*, vol. 7, no. 1, 2001.

[5] G. Lee, T. Wang, and C. Tseng, "Resource reservation with pointer forwarding schemes for the mobile RSVP," *IEEE Commun. Lett.*, vol 5, no. 7, l Networks, July 2001.

[6] J. Manner, T. Suihko, M. Kojo, M. Liljeberg, K. Raatikainen, "Localized RSVP" *IETF draft <draft-manner-lrsvp-00.txt>*, May. 2002.

[7] B. Moon, H.Aghvami, "Reliable RSVP path reservation for multimedia communications under an IP micromobility scenario," *IEEE Wireless. Magazine*, Qct. 2002.

[8] S. Lee, A. Campbell, "INSIGNIA: In-band signaling support for QoS in mobile ad hoc networks", *MoMuC 98*, Berlin, Germany, Oct. 1998

[9] Network Simulator 2, http://www.isi.edu/nsnam/ns

[10] C. Perkins, E. Royer, "Ad-hoc On-Demand Distance Vector Routing", *WMCSA 99*, 1999.