Bandwidth Management Framework for IP based Mobile Ad Hoc Networks

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Abstract

In mobile ad hoc networks (MANETs) the wireless links are error prone in nature and the mobile devices are highly mobile, therefore traditional Internet QoS protocols like RSVP cannot be easily migrated to the wireless environment. The management of bandwidth is critical to establish session guarantees for traffic flows. This paper examines the challenges of incorporating scalable bandwidth management scheme in a mobile ad hoc network environment with brief description of some proposals that specifically address this problem. It also analyzes a framework coping with the specific issues of MANETs and further proposes an extension to this existing framework for flexible resource allocation and better scalability.

1 Introduction

Bandwidth management in MANETs is much more difficult than in wired networks. In this paper, a scalable QoS framework referred as adaptive bandwidth reservation and pre-allocation QoS architecture (ASAP) has been explained with further extension. This QoS framework draws upon the positive aspects of existing QoS techniques called IntServ [Braden R., et al., 1994] and DiffServ [Blake, S. 1998].

Extended framework includes local repair mechanism which is used to overcome the problems related to the inertness of resource reservations. The reverse path problem is addressed by using dynamic virtual paths and flexible time control increases the efficiency and performance of ASAP. These mechanisms together make this QoS framework scalable to network mobility. The rest of the paper is organized as following.

This paper first does a brief review of some related work in this area. It then introduces to the reader the concepts of MANET, QoS and QoS models in MANETs. It then discusses how traditional QoS techniques fail to scale well in MANETs. It also discusses some schemes that have been specifically designed to address the provision of QoS (specifically) bandwidth in MANET. The paper then critically evaluates these proposals. Finally, it presents an extension to a QoS signaling protocol for flexible resource allocation and better efficiency.

2 Related Work

Bandwidth management in mobile ad hoc networks is not new. Several schemes have been proposed, such as [Charles. E., et al., 2000] has extended the basic ad hoc on-demand distance vector (AODV) routing protocols to provide QoS support. Other proposals like INSIGNIA [Farkas K., et al., 2006] and flexible QoS model for mobile ad hoc network (FQMM) [Xiao, H., et al., 2000] use a reservation oriented approach and keep per-flow state information at the mobile nodes. SWAN [Gahng-Seop Ahn., et al., 2002] use a stateless feedback based mechanism to achieve soft real-time services. All of these QoS architectures work at the networking layer or above so they make little use of information which is available at the lower layers. However, most signaling schemes were not designed with the survivability in mind and are highly vulnerable to fault occurrences.

The focus of this paper is on real time applications to determine which individual QoS mechanism is helpful in reducing latency, jitter and packet loss in MANETs.

3 Mobile Ad Hoc Network (MANET) Introduction

A mobile ad hoc network [Corson, S., Macker, J. 1999] is a self-configuring network of mobile devices connected by wireless links. Nodes in mobile ad-hoc network are free to move and organize themselves in an arbitrary fashion. Each user is free to roam about while communicating with others. The path between each pair of the users may have multiple links and the radio between them can be heterogeneous. This allows an association of various links to be a part of the same network.

4 Quality of Service (QoS) Introduction

Quality of Service (QoS) [Ferguson, et al., 1998] refers to the capability of a network to provide better services to selected network traffic. It is measured in terms of guaranteed amount of data which a network transfers from one place to another in a given time slot. In MANETs, its main objective is to achieve a more deterministic network behavior so that information carried by the network can be better delivered and network resources are better utilized, which can be achieved either by raising the priority of a traffic flow or limiting the priority of another flow.

4.1 Need for QoS in MANETs

QoS are needed in order to efficiently utilize network resources by identifying which network traffic is critical and allocate appropriate network resources to support those traffic streams.
Traffic behavior and QoS requirement for different applications vary from application to application. Different applications require different network performance, based on bandwidth needs and latency sensitivity, if higher the latency sensitivity, higher will be the bandwidth requirement; data transfers can have zero tolerances for packet loss and high tolerances for delay and jitter.

4.2 Quality of Service Models

The QoS model specifies the architecture in which certain services can be provided in the network to deliver services needed by specific network traffic.

Three basic levels of end-to-end QoS can be provided across a heterogeneous network,
Best-effort service: Best-effort service is basic connectivity with no guarantee.
Differentiated service: DiffServ [Blake, S. 1998] is also called soft QoS. Some network traffic is treated better than the rest which is provided by traffic classification.
Integrated service: IntServ [Braden R., et al., 1994] is also called hard QoS. This is an absolute reservation of network resources for specific traffic.

4.3 Why Existing QoS models fail in MANET environment

IntServ in MANET [Xiao H., et al., 2003]
The IntServ model is not suitable for MANETs due to following shortcomings in MANET environments:
Scalability: IntServ provides per-flow granularity, so the amount of state information increases proportionally with the number of flows. This results in a storage and processing overhead on routers, which is the scalability problem of IntServ.
Signaling: Signaling protocols have three phases: connection establishment, connection maintenance and connection teardown. In highly dynamic networks this is not promising approach since routes may change very quickly and the adaptation process of protocols using a complex handshake mechanism would just be too slow. Moreover, the signaling overhead is a potential problem as well.

DiffServ in MANET [Xiao H., et al., 2003]
The main drawbacks of DiffServ approach in MANETs are:
SLA (Service Level Agreement): DiffServ is based on the concept of SLA's. SLA is a contract between a customer and its Internet Service Provider (ISP) which specifies the forwarding service the customer will receive. The SLA includes traffic conditioning rules. Traffic conditioners are placed at the nodes where the traffic originates. They are responsible for re-marking the traffic streams, discarding or shaping packets according to the traffic profile. In mobile ad hoc topology there is no obvious scheme for the mobile nodes to negotiate the traffic rules therefore making SLAs is difficult in MANETs.
Ambiguous core network: In DiffServ, traffic classification and conditioning has to be done at the boundary nodes. This makes QoS provisioning much easier in the core of the network. In MANETs, there is no specific core network because every node is a potential sender, receiver and router.

4.4 QoS Models for MANETs

I. Flexible QoS Model for Mobile Ad Hoc Network: FQMM

FQMM [Farkas K., et al., 2006] [Xiao, H., et al., 2000] is a QoS model for mobile ad hoc networks which is designed for small to medium sized MANETs, using a flat nonhierarchical topology. It defines three types of nodes exactly as are in DiffServ:

- Ingress node: A mobile node that sends data.
- Interior nodes: The nodes that forward data to the other nodes.
- Egress node: It is a destination node.

The basic idea behind FQQM is that it uses a hybrid per-flow and per-class provisioning policy. In this scheme, traffic of the highest priority is given per-flow provisioning while other traffic with lower priority classes are given per-class provisioning. Like DiffServ, FQMM has service differentiation; the per-class granularity can be improved to per-flow granularity for certain classes of high priority traffic. However, it is difficult to offer per flow granularity to all the traffic in a MANET due to bandwidth limitation and other constraints. Thus, this hybrid scheme combines the per-flow granularity of IntServ and per-class granularity of DiffServ.

This QoS model is flexible because of the following features:

- Nodes have dynamic roles.
- The provisioning policies are hybrid and flexible.
- FQMM can be combined in a flexible manner to meet different network conditions and QoS requirements.

Problems of FQMM in MANETs

In FQMM, as both IntServ and DiffServ schemes are separately used for different priority classes. Therefore, the drawbacks related to IntServ and DiffServ remain to be a drawback in FQMM as well. Although it is attractive model for MANETs but still has following major problems:

- Without an explicit control on the number of services with per-flow granularity, the scalability problem still exists.
- FQMM may not be able to satisfy hard QoS requirements, due to its DiffServ behavior in ingress nodes.

II. INSIGNIA

INSIGNIA [Farkas K., et al, 2006] is a signaling protocol which is specially designed for MANETs. INSIGNIA supports algorithms like fast flow reservation, restoration and adaptation; which are designed to deliver adaptive real-time service. INSIGNIA implements an in-band approach by encapsulating some control signals in the IP option of every data packet, which is now called INSIGNIA option. Moreover flow state information is kept in every node and this information is refreshed periodically.

INSIGNIA offers one-pass reservation. When a source node requests to establish a reservation to a destination node it sets the reservation (RES) mode bit in the INSIGNIA IP option service mode of a data packet and forwards that data packet toward the destination node. The bandwidth request field allows source node to specify its maximum and minimum bandwidth requirements. On reception of a RES intermediate routing nodes execute admission control to accept or deny the request. When a node accepts a request, resources are dedicated and packets are scheduled accordingly. If the reservation is denied, packets are treated as best effort mode packets.

Although INSIGNIA presents very promising approach to QoS support in MANETs but the system still lacks a few essential features:

- The most frequently mentioned drawback of INSIGNIA is scalability problem due to the flow state information which is kept within the nodes of a certain path.
- Bandwidth usage in INSIGNIA is not efficient. The extra reservation on the path from the sending node to the bottleneck is a waste of bandwidth. MANET’s topology changing will make this reservation waste propagate frequently.
- INSIGNIA imposes a major processing overhead on the network as there is no mechanism to dynamically change the frequency by which control signals are inserted into the data packets.
- INSIGNIA offers only two bandwidth levels to be used, MINIMUM and MAXIMUM. A better approach would be needed in order to satisfy application requirements and to fully utilize the available resources.

III. Adaptive Bandwidth Reservation and Pre-allocation QoS Architecture: ASAP

ASAP [Jianbo Xue, 2003] provides adaptive QoS support to real time applications in infrastructure based wireless IP networks. The purpose of this analysis is to extend the ASAP framework which can be used in mobile ad hoc networks.

Soft/Hard Reservation

In ASAP architecture, a new reservation concept, soft/hard reservation is introduced for efficient resource allocation. Soft reservation can be considered as the claim of a traffic flow for a certain bandwidth to be used in future. Hard reservation enables a traffic flow to exclusively reserve some bandwidth.

The actual reservation mechanism is two pass based. When a new real-time flow is about to start, a soft reservation request is sent first. If there are enough resources available, the requested bandwidth will be soft reserved for that flow. After a soft reservation is established, the end node sends a hard reservation message requesting the same amount of bandwidth. This hard reservation will remove all the traffic occupying the corresponding soft reserved bandwidth. So after a hard reservation, the QoS traffic can immediately start running with its necessary QoS support.

Introducing these two kinds of reservations is to achieve good performance in QoS monitoring.

Adaptive QoS Monitoring

QoS monitoring packets periodically investigates the QoS situation on every node within a certain path. Hard reservation messages are sent whenever the end-to-end QoS changes. Monitoring interval can be changed dynamically. For example more frequent monitoring is needed, if the network is unstable, in order to adapt to bandwidth fluctuations. If the network is stable, processing overhead can be saved by keeping the monitoring rate low.

ASAP Signaling System

ASAP also provides efficient in-band signaling for resource reservation, management, adaptation and releasing. The signaling is designed to produce minimum possible overhead and to provide maximum flexibility.

Problems of ASAP in MANETs

Although ASAP makes use of in-band signaling and fast adaptation but the protocol still fails to meet some MANET specific demands. Few problems of ASAP in a mobile ad hoc environment are:

- Flow Restoration Problem
- Reverse Path Problem
- Lost Hard-Reservation Messages

Ad Hoc Extensions for ASAP

Based on above listed shortcomings ASAP needs to be extended which can provide fast flow restoration and short reaction time to topology changes. To achieve this following new mechanisms are identified:

- Local Repair
- Dynamic Virtual Path
- Flexible Timing Control
- Congestion Control

Local Repair

A local repair [Xue J., et al., 2003] is triggered by a soft reservation message. Upon receiving a soft reservation message the node reserves some bandwidth within the specified range and updates table entries as usual. Before passing the message to the next hop the node checks whether its actual hard reservation corresponds to the hard reservation specified within the received message or not. If both values are equal nothing has to be done and the soft reservation message is sent along the path. In case, if the actual hard reservation specified is smaller than its own hard reservation for that flow, the node releases additional reservation, otherwise, if the specified value is greater than its own, the node tries to allocate additional resources. Both releasing and allocation of bandwidth has to be done with respect to the range and the amount of soft reserved bandwidth for that flow.

```
receiving_message (SR ) ;
soft_reserving_and_updating_tables (SR.MinBW , SR .MaxBW) ;
if ( HardResvBW < SR . HardBW) {
        if ( SoftResvBW > = SR. HardBW _ HardResvBW ) {
                hard_reserving (SR. HardBW _ HardResvBW ) ;
```

```
        }
        elseif ( SoftResvBW > 0 ) {
                hard_reserving (
        SoftResvBW ) ;
        }
}
else {
        hard_releasing ( HardResvBW _
SR . HardBW ) ;
}
```

Dynamic Virtual Path

Unsymmetrical routes and links causing difficulties for hard reservation messages to follow the reverse path, established during soft reservation can be addressed by dynamic virtual path mechanism [Xue J., et al., 2003]. This can be achieved by adding a hop count field to the hard reservation message that is reset on every node and incremented on every other. In addition to this, a global MAXHOPCOUNT constant is defined. If, this hop count reaches MAXHOPCOUNT on a certain node the hard reservation message is not processed any further and will be sent to the source node specified within the flowID of the message. As the hard reservation message will be received by the source node, the node updates its QoS entry for that flow by setting actualSoft and actualHard to the corresponding values within the message. The subsequent soft reservation message will then trigger a local repair in order to switch any soft reserved bandwidth into hard reservation on all the remaining nodes.

Flexible Timing Control

In ASAP, there are two timing parameters which are related to the efficiency and performance of ASAP; the SR (Soft Reservation) sending interval and the soft state time-out period. The interval between SR messages is critical in determining the speed with which ASAP adapts changes. This time interval 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. The soft state time-out period must be coherent with the SR interval. The SR interval should not be smaller than the timeout period in order to keep the flow path alive. And the timeout 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 broken paths alive for a long time, thereby preventing other traffic from accessing those resources.

Congestion Control

In mobile ad hoc networks for better bandwidth management we also need congestion control which can be done by detecting it and reducing transmission rate.

In MANETs, the queue length is not a valid indication of congestion. We need to detect congestion in a node's neighborhood by monitoring the wireless channel utilization ratio. This information can be obtained by defining a threshold value, and when the channel utilization ratio is larger than this threshold, we can assume that this node's neighborhood is getting congested.

By examining the channel usage of a node, we are able to take into account the activities of both the node itself and its surrounding neighbors and therefore obtain a good approximation of the bandwidth usage. The channel utilization ratio is defined as the fraction of time within which a node is sensing the channel as being utilized. Normally a wireless radio has four states; (1) Busy state, (2) Carrier sensing channel busy, (3) Virtual carrier sensing busy and (4) idle state. Among the four states, the states (1), (2) and (3) can be treated as busy state and (4) as the idle state. Each node will constantly monitor the channel state changes and record the time period that the radio is in each state. For each time period, we then calculate the channel utilization ratio.

5 Conclusion

Three major problems of using ASAP in MANETs were presented in the paper that were related to flow restoration, reverse path and lost hard reservation messages. Thereafter, the paper identified and explained a solution to address these specific problems. To be specific, a local repair mechanism is used to overcome the problems related to the inertness of two pass based reservations like the big latency during flow restorations. The reverse path problem is addressed by using dynamic virtual paths while flexible timing control and congestion control will help in improving efficiency and performance of ASAP.

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