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INSIGNIA

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Abstract

This document specifies INSIGNIA, an in-band signaling system for supporting quality of service (QOS) in mobile ad hoc networks. The term `in-band signaling` refers to the fact that control information is carried along with data in IP packets. We argue that in-band signaling is more suitable than explicit out-of-band approaches (e.g., RSVP) when supporting end-to-end quality of service in highly dynamic environments such as mobile ad hoc networks where network topology, node connectivity and end-to-end quality of service are strongly time-varying. INSIGNIA is designed to support the delivery of adaptive real-time services and includes fast session/flow/ microflow reservation, restoration and adaptation algorithms between source/destination pairs. In this memo we discuss how INSIGNIA fits into our broader vision of a wireless flow management model for mobile ad hoc networks and how it interfaces to the proposed MANET Working Group routing algorithms and IMEP specification.

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1. INTRODUCTION

The introduction of real-time audio, video and data services into mobile ad hoc networks presents number of technical barriers that are due to the time-varying nature of the network topology, node connectivity and end-to-end quality of service (QOS). In such networks, mobile nodes function as hosts and routers. As hosts they represent source and destination nodes in the network while as routers they represent intermediate nodes between a source and

destination providing store-and-forward services to neighboring nodes. The wireless topology that interconnects mobile hosts/routers can change rapidly in unpredictable ways or remain relatively static over long periods of time. Another technical issue that needs to be addressed is associated with the wireless link level performance. Mobile ad hoc networks are bandwidth constrained and time-varying due to radio link characteristics and impairments.

The end-to-end communications abstraction between two communicating mobile hosts can be viewed as a complex channel. Due to node mobility and wireless link impairments, user-to-user sessions may need to be rerouted in the network while preserving the session connectivity and quality. Network algorithms need to be strongly adaptive and responsive to the time-varying and location dependent topological changes, resource availability, quality of service degradation and session connectivity.

In order to provide adaptive quality of service support for real-time service in mobile ad hoc networks, 'flow-states' (i.e., reservation states at nodes associated with flows or microflows) need to be managed. A flow needs to be established, restored, adapted and removed over the course of a user-to-user session in response to time-varying topology, connectivity and end-to-end quality of service conditions.

Since wireless and computational resources are limited in mobile ad hoc networks, any signaling overhead needed for wireless flow management must be kept to a bare minimum. Future signaling systems should be capable of restoring reservations and associated flow-states along a new path in response to topological changes with minimum noticeable degradation at the user session level.

This memo provides an overview of wireless flow management model that supports the delivery of adaptive real-time services in dynamic mobile ad hoc networks. A key component of wireless flow management is INSIGNIA, an in-band signaling system that supports fast flow reservation, restoration and adaptation algorithms that are specifically designed to deliver adaptive real-time services in mobile ad hoc networking environments. INSIGNIA is designed to be lightweight and highly responsive to changes in network topology, node connectivity and end-to-end quality of service conditions.

1.1 TERMINOLOGY

Mobile Ad Hoc Networks:
Represent autonomous distributed systems that comprise a number of mobile nodes connected by wireless links forming arbitrary time-varying wireless network topologies [20].

Adaptive real-time flows:
This type of flow represents delay sensitive traffic, e.g., voice and video which can sustain some loss. Real time data flows are assumed to be somewhat loss tolerant and delay sensitive. These types of flows typically require flow setup procedures, resource reservation provided by INSIGNIA.

Microflows:
Micro flows represent short-lived flows, e.g. web style client/server interactions that comprises a limited train of data packets. These types of flows may require resource assurances in the network and, therefore, typically require some form of in-band support for fast resource allocation. We use the terms session/flow and microflow interchangeably. INSIGNIA has been designed to transparently support the requirements of both flows and microflows in mobile ad hoc networks.

Flow Setup:
A Source initiates a flow set up by transmitting a request packet

with its minimum and maximum bandwidth requirements. Intermediate mobiles receiving request packets, processes the requests and forward them to the next appropriate mobile host. A flow setup is complete when a source receives a QOS report from its peer destination.

Restoration:
When a reserved flow is rerouted and its associated states (e.g., reservation) are successfully created along the new route. Three types of restoration (viz. `max to max`, `max to min` and `min to max`) may be observed along the new path.

Enhancement Layer (EL) Degradation:
When a reserved flow is rerouted and its EL restoration fails, then a flow/sessions enhancement layer packets are degraded to best effort service. In a such case, only base layer (BL) packets are forwarded/received as reserved packets.

Flow Degradation:
When a reserved flow is rerouted and both EL and BL restoration fails. No resource allocation or associated states are created and all packets are treated as best effort after re-routing.

Adaptation:
When EL degradation persists for an unacceptable period, a destination mobile notifies its source to drop the EL packets at the source host (scaling down). The destination can also initiates an EL resource recovery (scaling up) procedure when a monitored flow state at the destination indicate that sufficient resources exist along the path to support a better quality level.

Adaptation Policy:
Describes the bandwidth adaptation characteristics of a flow and the actions to be taken based on the observed network conditions experienced by a flow and its ability to adapt to those conditions. The decision to trigger adaptation mechanisms (i.e., scaling flows up/down)is based on application-specific adaptation policy.

Adaptation Handler:
A module that stores the adaptation policy that interacts with

flow monitoring and QOS report modules.

Monitoring Module:
A module that keeps track of the incoming INSIGNIA flow state. Typically the packet type, resource availability and QOS are periodically monitored.

QOS reports:
These are periodic messages that are generated by destinations to inform peer sources of reception state/status of adaptive real-time flows. The periodicity depends on the sensitivity of a flow. Best effort flows do not, typically, generate QOS reports.

Soft-state management:
Each mobile host creates, stores and updates the state information for each adaptive real-time flow and its reservation status. This state information requires subsequent packets to refresh the flow state otherwise the flow state is considered old and automatically removed after a soft-state interval.

Soft-state timer:
The soft-state timer value defines the holding time for real-time reservation state for adaptive real-time flows/flows. If the mobile soft-state is not refreshed within the soft-state timer interval then the state is automatically removed. (Note that the treatment of flows and microflows may differ in terms of the setting of this state variable. Typically, flows would call for extremely fast reservation and release that may be more aggressive than the dynamics and timescales associated with longer lived flows. This issue is under experimentation and for further study.)

1.2 ASSUMPTIONS

INSIGNIA assumes that link status sensing and access schemes are provided by lower layer entities/protocols.

2. A WIRELESS FLOW MANAGEMENT MODEL FOR MOBILE AD HOC NETWORKING

The goal of wireless flow management is to support the delivery of adaptive real-time services in mobile ad hoc hosts under time-

varying conditions. An adaptive service model allows packet audio, video and real-time data applications to specify their maximum and minimum bandwidth needs. INSIGNIA plays a central role in the resources allocation and management between source and destination mobiles. Based on availability of end-to-end resources, wireless flow management attempts to provide assurances for the minimum or maximum bandwidth needs depending of resource availability. In addition to supporting adaptive real-time services the service model also supports IP best-effort packet delivery.

```
              adaptive mobile
                applications
                     ^
+---------------------------------------------------------------+
|                    |                                          |
|  +---------------+ | +------------------+      +------------+ |
|  | MANET routing | | |     INSIGNIA     |<---> | admission  | |
|  |   protocol    | | |                  |      | control    | |
|  +---------------+ | +------------------+      +------------+ |
|       |    \        |   |      |      |              |        |
|       |     \       |   |      |    control          |        |
|  ---------   \      |   |  ---------  |          ---------    |
|   routing     \     |   |   mobile    |           channel     |
|    table       \    |   |  soft-state |            state      |
|  ---------      \   |   |  ---------  |          ---------    |
|          \      \  | signal /  \     | packet    /   \        |
|           \      \ v  -ing /    \    | drop     /     \       |
|            \ +-------------+      +------------+        \      |
|   +-----+   \|  packet     |      |  packet    |     +-----+  |
===>| MAC |===>| forwarding  |======>| scheduling|====>| MAC |===>
|   +-----+    +-------------+      +------------+     +-----+  |
|IP packet in               data packets          IP packet out|
+---------------------------------------------------------------+
```

Figure 1. Wireless Flow Management Model at a Mobile Host/Router

Realizing wireless flow management in mobile ad hoc networks presents a number of technical challenges. First, flows and microflows should be rapidly established without the penalty of a round trip delay and with minimal overhead due to signaling. Second, active flows should be maintained and restored in case of routing changes or link failure. Wireless flow management should be capable of rapidly responding to dynamic topology changes by adapting and re-establishing affected flows with minimal service disruption. Third, flow-state set up during flow establishment should be automatically removed when an application session terminates. Flow-state should also be automatically removed at routers no longer on the new path after re-routing has occurred due to topological changes.

The main modules of the wireless flow management model are illustrated in Figure 1).

2.1 PACKET FORWARDING MODULE

The packet forwarding module [15] classifies incoming packets and forwards them to the appropriate module (viz. MANET routing, INSIGNIA, local applications, wireless packet scheduling modules). Signaling messages are processed by INSIGNIA and data packets delivered locally or forwarded to the packet scheduling module.

2.2 ROUTING MODULE

The routing module dynamically tracks changes in ad hoc network topology making the routing table visible (via APIs) to all intermediate packet forwarding module (e.g., INSIGNIA, packet forwarding). Wireless flow management assumes the availability of MANET routing protocol [2] (e.g. Temporally Ordered Routing Algorithm (TORA) [1], Dynamic Source Routing [7], Zone Routing Protocol [5], Ad Hoc On demand Distance Vector Routing Protocol [6]).

2.3 INSIGNIA MODULE

The INSIGNIA module establishes, restores, adapts and tears down real-time flows. Flow restoration algorithms respond to dynamic route changes due to mobility. Adaptation algorithms respond to changes in available bandwidth. Based on an in-band signaling approach that explicitly carries control information in the IP packet header, flows can be rapidly established, restored, adapted and released in response wireless impairments and topology changes. Because of this dynamic environment, network state management is based on soft-state [3], which is well suited to managing reservation flow-state in mobile ad hoc networks.

2.4 ADMISSION CONTROL MODULE

The admission control module is responsible for allocating bandwidth to flows based on the maximum/minimum bandwidth requested. Once resources have been allocated they are periodically refreshed by a mobile soft-state mechanism through the reception of data packets. Admission control testing is based on the measured channel capacity/utilization and requested bandwidth. To keep the protocol simple and lightweight, new reservation requests do not affect existing flow reservations. Rerouted or new flows may be degraded if resources are unavailable.

2.5 PACKET SCHEDULING MODULE

The packet scheduling module responds to location dependent channel conditions experienced in wireless networks [22]. The scheduling mechanism is implementation and QOS model dependent. Currently, we have implemented a simple Weighted Round-Robin (WRR) service discipline which takes location dependent channel conditions into account. It should be noted that a wide variety of scheduling disciplines can be used to realize the packet scheduling module.

2.6 MEDIUM ACCESS CONTROLLER MODULE

The medium access controller module (possibly) provides quality of service driven access to the shared wireless media for adaptive real-time services and best-effort services. The wireless flow management is designed to be transparent to any underlying media access control protocols. However, the performance of the MANET is strongly coupled to the provisioning of QOS support at the MAC layer. Nevertheless, our approach is to investigate the performance of INSIGNIA using both non QOS-capable and QOS-capable MACs.

3. INSIGNIA PROTOCOL

Mobile ad hoc signaling systems should be lightweight in terms of the amount of bandwidth they consume and be capable of reacting to fast network dynamics close to call/session and packet transmission time scales. Future signaling systems should be highly responsive to flow re-routing and be capable of re-establishing active reservations along the new path with minimum disruption to on-going services.

In-band signaling systems are capable of operating close to packet transmission time scales and are therefore well suited toward managing fast time-scale dynamics found in mobile ad hoc environments. In contrast, out-of-band signaling systems (e.g. Internet's RSVP, ATM's UNI, etc.) are incapable of responding to such fast time-scale dynamics. Based on an in-band approach, INSIGNIA is designed to restore 'flow-state' (i.e., a reservation) in response to topology changes within the interval of two consecutive IP packets under ideal conditions.

3.1 IP OPTIONS

To establish an adaptive real-time flows, INSIGNIA uses a new IP option to setup, restore and adapt resources between source-destination pairs. When intermediate nodes receive packets with the these IP options set they attempt to reserve, restore or adapt resources forwarding date packets toward the destination.

By coding control information in the INSIGNIA IP option (in each IP

header), we support the notion of in-band control which we believe is called for to support QOS in ad-hoc mobile networks. The INSIGNIA IP option supports flow reservation, restoration and adaptation control. Best effort and adaptive real-time services are supported by INSIGNIA and are indicated by the reservation mode and service type fields in the IP options as illustrated in Figure 2. Flows are represented as having a discrete base layer (BL) with a minimum bandwidth and an enhancement layer, which requires the maximum bandwidth. This characterization is commonly used for multi-resolution traffic (e.g., MPEG audio and video) and more generally for real-time data that has discrete max-min requirements.

```
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version| IHL |Type of Service|        Total Length             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|       Identification        |Flags|     Fragment Offset       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Time to Live |    Protocol   |        Header Checksum         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Source Address                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Destination Address                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

```
  |     Options (Used for INSIGNIA IP Options)     |     Padding    |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                       Figure 2a.  IP Header


  reservation   payload                bandwidth request
  mode          indicator
      0      1     2      3    4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9
  +-------+----+----+-------+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |REQ/RES|RT/BE|BL/EL|max/min| max_bandwidth | min_bandwidth |
  +-------+----+----+-------+-------------+---------------+
          service     bandwidth
          type        indicator
  |<----->|<--->|<--->|<----->|<------------------------------>|
   1 bit  1 bit 1 bit  1 bit            16 bits

                    Figure 2b. INSIGNIA IP Options
```

3.2 RERSERVATION MODE

To establish an adaptive real-time flow, a source node sets the request (REQ) bit in the IP option of a data packet to initiate a reservation request. On reception of a REQ packet, the intermediate nodes execute admission control and accept or deny the request. If the request is accepted, resources are committed and subsequent

packets are scheduled accordingly. Otherwise, packets are treated as best effort packets if resources are unavailable.

Packets that are received by nodes with their reservation mode set to reserved (RES) indicate that the session has previously passed admission control and resources have been reserved. In the case where a RES packet is received and no resources have been allocated the admission controller immediately attempts to make a reservation. This condition commonly occurs when reserved flows are rerouted during the lifetime of an active session due to mobility of sources, intermediate router nodes or destinations.

3.3 SERVICE TYPE

The interpretation of the service type, which indicates either a real-time (RT) or best-effort (BE) packet, is dependent on the reservation mode. A packet with the reservation mode set to REQ and service type to RT is attempting to setup a real-time flow with the bandwidth requirements of the flow specified in the bandwidth request field. A packet with RES/RT set indicates that an end-to-end reservation has previously been established. A RES/RT packet service may be degraded to RES/BE service if the flow is rerouted along a new path when insufficient resources were available on the new path.

A best effort packet sets the reservation mode to REQ as default and the service type to BE requiring no resource reservation to be made in the network. Reception of a RES/BE by a destination node indicates an active adaptive real-time flow was degraded to BE due to insufficient resource availability after rerouting to a new path.

3.4 PAYLOAD INDICATOR

The payload field indicates the type of packet being transported. INSIGNIA supports two types of payload, i.e., base (BL) and enhancement layers (EL). The semantics of the adaptive real-time services are related to the payload type and resource availability. Base and enhancement layers can be assured via distributed end-to-end admission control and resource reservation. Maximum bandwidth reservation is required to support both base and enhancement layers of a flow whereas only minimum bandwidth reservation is required to support the base layer. When a flow with minimum reservation receives a EL packet in reserved mode (RES/RT) set, it indicates either the reservations for EL has been restored at the bottleneck node or an adaptation (scale-up) has been occurred.

3.5 BANDWIDTH INDICATOR

The bandwidth indicator represents the potential resource availability for a flow/session along its current path between a source and destination pair. In this respect the bandwidth indicator represents the prospective resource availability to an application

which will change over time. This does not, however, represent an actual resource reservation but the potential for one to succeed give the current indication. The bandwidth indicator is carried in each packet and can be therefore viewed as a dynamic state variable that can be updated by any mobile host on the current path. Based on its value it represents a good bandwidth hint that resources are available along the current path to meet the flows minimum or maximum needs. In this capacity the bandwidth indicator plays an important role during the flow setup phase and, more importantly, during the adaptation phase.

During flow setup the bandwidth indicator represents the resource availability along the chosen setup route. Reception of setup request packets with the bandwidth indicator bit set to MAX indicates that all nodes en-route have sufficient resources to support the maximum bandwidth requested. In contrast, a packet with the bandwidth indicator set to MIN implies that at least one of the intermediate nodes (known as the bottlenecked mobile host) between the source and destination has insufficient bandwidth resources to meet the maximum needs (if specified); however, reception of a packet with the bandwidth indicator set to MIN does indicate that all nodes can support the minimum bandwidth requirement. In this case, only the base layer reservation is acknowledged as having been successful established via QOS reporting (see Section 4.2). QOS reporting between the destination and source can be used to force the source to 'drop' enhancement layers. In this case the source would only forward the BL packets toward the destination in reserved mode. Any enhancement layer packets would be forwarded as best-effort packets. This action has the benefit of releasing an 'partial reservations' for the enhancement layer that may exist between a bottlenecked mobile host and the destination. We will discuss the issue of 'partial reservations' (which may occur in all phases of INSIGNIA operation)in the sections of flow setup, restoration and adaptation.

The bandwidth indicator is also utilized for restoring the reservation for EL if previously degraded to best effort service. In order to accomplish scaling up adaptation, the adaptation handler resident at destination should monitors a flow's resource availability (by monitoring the bandwidth indicator) and, based on the adaptation policy, initiate a 'scale up' operation using a QOS report.

3.6 BANDWIDTH REQUEST

The bandwidth request allows a source to specify its maximum (MAX) and minimum (MIN) bandwidth requirements for adaptive real-time service support. This assumes that the source has selected the RT service type. A source may also simply specify a minimum or a maximum bandwidth requirement. For adaptive real-time services the base layer is supported by the MIN bandwidth whereas the MAX bandwidth supports the delivery of the base and enhancement layers between a source and destination pair.

4. INSIGNIA OPERATIONS

The IP option and operations support the delivery of adaptive real-time services to mobile hosts. These operations collectively define the foundation of the INSIGNIA system and include flow setup, flow restoration, soft-state management, adaptation and QOS reporting.

Once a flow has been established between a source-destination pair, QOS reports are used to inform the source of the progress of the delivered packet quality at the destination. Node mobility may trigger topology changes. In this case the MANET routing protocol may provide alternative or new path information to destination, in which case, INSIGNIA would attempt to restore reservations at all nodes on the new path through the restoration operation. Moreover, adaptation may be triggered to adjust a flow to match resources availability found on the new path. Managing the network state, while responding to these network dynamics, is handled by a soft-state management mechanism in INSIGNIA. In the following sections, each of the INSIGNIA operations are outlined.

4.1 FLOW SETUP

To establish adaptive real-time flows, source nodes set the appropriate fields in the IP option before forwarding 'reservation request' packets toward destination mobile hosts. A reservation request packet is characterized as having its reservation mode set to REQ, service type set to RT, a valid payload (viz. BL or EL) and a MAX/MIN bandwidth requirement.

Reservation packets traverse intermediate nodes executing admission control modules, allocating resources and establishing flow-state at all nodes between source-destination pairs. If any intermediate mobile node lacks resources to support the requested flow setup, the appropriate IP option field is changed to indicate this condition (or state).

```
   0   1     2      3    4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9
 +---+----+-----+-------+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |REQ| RT |BL/EL|max/min| max_bandwidth | min_bandwidth |
 +---+----+-----+-------+---------------+---------------+
```

Figure 3. INSIGNIA Packet Requesting MAX/MIN reservation

If an intermediate mobile receives a request packet and can only support the minimum requirement then the flow request is degraded to the minimum request at the bottleneck mobile node by resetting the

bandwidth indicator to MIN. Meanwhile the source continues to send reservation requests packets until the destination informs it of the status of flow establishment phase via QOS report (discussed in Section 4.2). Subsequent reservation request packets do not execute admission control but simply refresh existing soft-state reservation.

The establishment of an adaptive real-time flow is illustrated in Figure 4. A source mobile host (M1) issues a flow setup by requesting resource reservation. M2 performs admission control upon reception of the request packet. Resources are allocated if available and the request packet is forwarded to the next mobile (M3). This process is repeated hop by hop until the request packet reaches the destination mobile host (M6). The destination mobile node determines the resource allocation status by checking the service type and current level of service.

When a reservation request is received at the destination node, the INSIGNIA module checks the reservation status. The status of the flow setup is determined by inspecting the bandwidth indication field. If the bandwidth indicator is set to MAX then this implies that all mobile hosts between the source destination have successfully allocated resources to meet the base and enhancement layers bandwidth requirements. On the other hand, a bandwidth indication set to MIN indicates that only the base layer can be currently supported. In this case, all reserved packets with a payload of EL received at the destination have their service level flipped from RT to BE by the bottleneck node. In such case, a partial reservation may exist between the source and bottleneck mobile node. This partial reservation can be viewed as a waste of resources between the source and bottlenecked node (since they go unused) or, as a 'near reservation' where all but the remaining nodes (between the bottlenecked node and the destination) hold reservations. Holding on to these reservations - in effect locking them in - is a 'hedge' against completing the setup phase in the near future. The treatment of 'partial reservations' is still under consideration. Currently, the adaptation process allows the mobile host to clear partial reservations using the adaptation process or leave them in place.

```
                         +-----+  +-----+
            QOS_REPORT(2)| M9 |---| M8 |\QOS_REPORT(2)
                 +-----+ /+-----+   +-----+ \ +-----+
                 | M2 |/          /       \| M7 |\QOS_REPORT(2)
          REQ(1)/+-----+\        /        +-----+ \+-----+
         +-----+/       \ +-----+/ +-----+         | M6 |
         | M1 |    REQ(1)\| M3 |---| M4 |REQ(1)   /+-----+
         +-----+          +-----+  +-----+\ +-----+/
                             REQ(1)       \| M5 | REQ(1)
                                           +-----+
         Figure 4. INSIGNIA Request Packet and QOS report
```


4.2 QOS REPORTING

QOS reports are used to inform the source of the status of received adaptive real-time flows. Destination nodes actively monitor on-going flows inspecting status information (e.g., bandwidth indication) and calculating QOS statistics (viz. packet loss, delay, out-of-sequence delivery and throughput). QOS reports are periodically sent to source host for the purpose of completing flow establishment and managing adaptations. QOS reporting is application dependent where the periodicity of reports is determined by the application's sensitivity to the delivered QOS. Note that QOS reports do not have to travel on the reverse path toward the source. Typically they will take an alternate route through the ad hoc network as illustrated in Figure 4.

In the case of flow establishment, reception of a reservation request packet with the bandwidth indicator set to MAX (or MIN) indicates that the source's maximum (minimum) reservation has been successfully made en-route. The destination informs the source of this reservation status by setting the bandwidth indicator field with MAX (MIN) in the QOS report, accordingly. The QOS report is a best effort data packet with a payload that comprises of a 'mirror copy' of the INSIGNIA IP option received by the destination, adaptation commands and measured QOS information.

QOS reports are also used as part of on-going adaptation process that responds to mobility and resources changes in the mobile ad hoc network. Periodic QOS reports can be used to inform the source to 'drop' (e.g., drop all EL packets) or 'scale-up' (i.e., transmit EL packets) based on available resources and the adaptation policy of the application. These are the 'adaptation commands'.

4.2.1 QOS REPORT INTERVAL

Since each flow has different sensitivity to QOS, the periodicity of QOS report for each flow should reflect this sensitivity. A flow that is sensitive to service quality requires more frequent QOS report than one that is less sensitive (i.e., more QOS control). A source relates the sensitivity of a flow via setting the TTL value with relatively small value. The destination utilizes the TTL value, requested bandwidth and the adaptation policy to determine the flow's sensitivity to service quality. We are currently investigating the migration of this function to the INSIGNIA IP options field.

4.2.2 QOS PACKET FORMAT

The role of the QOS report is to serve as a simple notification of the satisfaction level perceived by the destination. The QOS report includes a 'mirror copy' of the INSIGNIA IP option, adaptation commands and measured QOS. In fact, the QOS report of INSIGNIA has

the same format as a best effort INSIGNIA data packet. A QOS report has the reservation mode set to RES and service type set to BE. The minimum bandwidth field is set to zeros and maximum bandwidth is set to ones. By doing so, the QOS report can be distinguished from the degraded RES packet. The various packet formats are illustrated in Figure 8.

4.2.3 QOS REPORT DELIVERY

QOS reports should be delivered in a timely fashion. We propose to schedule QOS reports before the transmission of best effort packets but without affecting the performance of reserved flows. The IP option codepoint for QOS reports, even though best effort in service type, set it a side from all other best effort traffic for a 'better than best effort treatment' at intermediate nodes.

4.3 SOFT-STATE MANAGEMENT

Maintaining the quality of service of real time flows in mobile ad hoc network is one of the most challenging aspects that INSIGNIA addresses. Typically, wireline networks requires little QOS or state management where the routes and the reservations remain fixed for the duration of the session/flows. This style of 'hard-state' connection oriented communications guarantees quality of service for the duration of the holding time. However, these techniques are not applicable/valid in mobile ad hoc networks where paths and reservations need to dynamically respond to topology changes in a timely manner over multiple time scales and network dynamics.

Based on the work by Clark [3], 'mobile soft-state' relies on the fact that sources periodically send data messages along the existing path. If a data packet arrives at a mobile router and no reservation exists then admission control and resource reservations are needed to establish soft-state reservations. Subsequent reception of a data packet at a router is used to refresh the soft-state reservation. Thus a mobile host receiving a data packet for an existing reservation reconfirms the reservation over the next time interval. The holding-time for a reservation is based on a soft-state timer interval and not, as in the case of call setup, based on the session duration holding time. If a new packet is not received within a soft-state timer interval, resources are released and flow-states removed automatically without any explicit tear-down messaging.

The soft-state approach is well suited for management of resources in dynamic environment where the path and reservation associated with a flow may change rapidly. The transmission of data packets is strongly coupled to maintenance of flow-states, i.e., reservations. As the route changes in the network, new reservations will be automatically restored by the restoration mechanism provided that resources are available along the new path.

Another benefit of mobile soft-state is that resources allocated during flow establishment are automatically removed when the path changes without any explicit signaling interactions. In-band approaches are flexible and scalable in dealing with a number of difficult mobile ad hoc network issues whereas out-of-band signaling systems need to maintain source route information and respond to topology changes by directly signaling 'affected mobiles' to allocate or free radio resources. In some case, this is impossible to do when using out-of-band signaling techniques if the 'affected router' is out of radio contact from the signaling entity that is attempting to de-allocate resources over the old path.

4.4 FLOW RESTORATION

Flows are often rerouted during the lifetime of sessions due to mobility in mobile ad hoc networks. The goal of flow restoration is to re-establish reservation as fast and efficiently as possible. Rerouting of an active flow involves new admission control and resource reservations for nodes on the new path. Restoration procedures also call for the removal of flow-state at nodes along the old path. In an ideal case, the restoration of flows can be accomplished within the duration of a few consecutive packets because of the in-band nature of INSIGNIA's control.

When a mobile moves out of radio contact and loses connectivity, the forwarding router mobile interacts with the routing module and forwards subsequent packets via the new route. (Note that if the routing table does not have an alternative route toward the destination then the performance of the restoration process is tightly coupled to the performance of the proactive/reactive MANET routing protocol that is operational. This issue is for further study. In [25], however, we implemented INSIGNIA in a mid size ad hoc network using TORA [1] as the routing protocol and discuss performance issues there).

The mobile hosts on a new path receive rerouted packets and inspect their flow state tables. If a reservation does not exist for the rerouted flow then the INSIGNIA module invokes admission control and tries to allocate resources. Note that, if the reserved packets are routed back on to the existing path then the old states are likely to be still valid; hence, the states and reservations are simply refreshed, minimizing any service disruption due to re-rerouting.

Network dynamics may also trigger rerouting with service degradation. When a reserved flow is rerouted to a node where resources are unavailable, the flow is degraded to best effort service. Subsequent downstream nodes receiving these degraded packets make no attempt to attempt to allocate resources or refresh existing soft-state associated with the flow. This results in the automatic removal of any reservation state. In time the reservation may be restored if resources free up at the bottleneck mobile node

or because of the subsequent rerouting allowing the complete restoration of the flow quality. The worst case scenario is that the flow will remain degraded for the duration of the session holding time.

The enhancement layer of a reserved flow with maximum reservation may get degraded during flow restoration if the nodes along the new path can only support the minimum bandwidth requirement. If the degradation of enhancement layer packets persist, it may cause service disruptions and may trigger the destination mobile to invoke an adaptation procedure that force the source node to drop the EL packets. Adaptation details are provided in the following section.

4.5 ADAPTATION

Reception quality of a flow is monitored and based on an application-specific adaptation policy, actions may be taken to adapt the flow to observed network conditions. Actions taken are conditional on the adaptation-policy resident at the destination node, e.g., adaptation policy may chose to maintain the service level under degraded conditions or scale-down flows to their base layers in respond to degraded conditions. Other policy could scale-up flows whenever resources become available. The application is free to program its own adaptation policy that is executed by INSIGNIA through interaction between the destination and source nodes. Details about the adaptation policy API are described in [19].

The adaptation process includes the following adaptation actions:

(1) 'EL degradation' is a network driven action that forwards the EL packets as best effort packets due to lack of resources;
(2) 'Drop enhancement layer' is a destination mobile driven action which requests a source to drop its enhancement layers. This happens when the EL degradation persists beyond an acceptable period; and
(3) 'Scale-up', which requests a source to send its base and/or enhancement layers in reserved mode. This event occurs when a flow has only minimum reservation and the destination learns (through the bandwidth indicator) that the route can accommodate the maximum resource requirement.

The EL degradation is a network driven action whereas the others two actions are driven by an adaptation handler resident at the destination mobile host. Typically, the EL degradation can be observed after rerouting of an adaptive real-time flow. In such an event the EL packets are degraded and forwarded as best effort packets whereas BL packets are forwarded in reserved mode. Note that preference is given to base layers over enhancement layers in the event that reserved packets have to be degraded to best effort.

If the EL degradation persists, a `drop` command may be issued by the adaptation handler at the destination mobile host according to the adaptation policy. The decision to drop the EL packets is facilitated by monitoring the incoming packets. The destination mobile can readily detect the degraded RES packets by reading the IP option fields (where the degraded packets have the format of Figure 5d). Figure 5 illustrates the different modes of INSIGNIA packets.

```
      0   1     2     3   4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9
 +---+----+-----+-----+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |REQ| BE |BL/EL| max | max_bandwidth | min_bandwidth |
 +---+----+-----+-----+---------------+---------------+
          Figure 5a. A Best Effort Packet

      0   1     2     3   4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9
 +---+----+-----+-----+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |REQ| RT |BL/EL| max | max_bandwidth | min_bandwidth |
 +---+----+-----+-----+---------------+---------------+
          Figure 5b. A Request Packet (EL or BL)

 +---+----+-----+-------+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |RES| RT |BL/EL|max/min| max_bandwidth | min_bandwidth |
 +---+----+-----+-------+---------------+---------------+
          Figure 5c. Typical Reserved (RES) Packet (EL or BL)

 +---+----+-----+-----+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |RES| BE |BL/EL| max | max_bandwidth | min_bandwidth |
 +---+----+-----+-----+---------------+---------------+
      Figure 5d. A Degraded RES Packet (EL or BL)

 +---+----+----+-------+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |RES| BE | BL |max/min|1 1 1 1 1 1 1 1|0 0 0 0 0 0 0 0|
 +---+----+----+-------+---------------+---------------+
 |<----------->|       |<----- unique format --------->|
                               a QOS report
       * max/min indicates the accepted service level
          Figure 5e. Format of a QOS report
```

'Dropping' the EL packet at the source removes partial reservations that may exist between a source and bottleneck mobile freeing up resources for other adaptive real-time flows to utilize. It also removes degraded enhancement layer packets from the network which in turn benefits the normal best effort service flows.

INSIGNIA is also equipped with capability to restore the reservation needed for enhancement layers. This process takes advantage of network and session dynamics allowing existing sessions to take advantages of resources released due to re-routing (e.g., resources released along an old path) or session termination. These events may

allow other mobile nodes to take advantage of released resources by scaling up. The bandwidth indicator plays a key role in 'reading' the channels resource availability state in relation to the bandwidth needs of the particular session/flow.

Typically, the scale-up process is invoked when the destination observes sufficient resource have become available along the existing path restore the reservation of an enhancement layer. The decision to scale up is determined by the adaptation policy.

The following example scenario shows an example of a set of states (marked [1] through [7]) observed at the destination illustrating a flow adaptation scenario:

Adaptation Procedures :

```
   [1] Incoming Packets at time t1 with maximum resource allocation
   +---+----+----+-----+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |RES| RT | BL | max | max_bandwidth | min_bandwidth |
   +---+----+----+-----+---------------+---------------+
   +---+----+----+-----+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |RES| RT | EL | max | max_bandwidth | min_bandwidth |
   +---+----+----+-----+---------------+---------------+
                    .
                    .
                    .

   [2] EL packets are degraded due to lack of resources at an
   intermediate mobile node at time t2 and now packet formats become
   +---+----+----+-----+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |RES| RT | BL | min | max_bandwidth | min_bandwidth |
   +---+----+----+-----+---------------+---------------+
   +---+----+----+-----+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |RES| BE | EL | min | max_bandwidth | min_bandwidth |
   +---+----+----+-----+---------------+---------------+
    * Note that EL packet is degraded to a best effort packet
                    .
                    .
```

.

[3] If the degraded EL packets are determined to be not useful for destination mobile host, an EL drop command is issued via QOS report. Upon reception of the QOS report the source transmits only BL packets in reserved mode and do not transmit any EL packets.

```
+---+----+----+-----+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|RES| RT | BL | min | max_bandwidth | min_bandwidth |
+---+----+----+-----+---------------+---------------+
 * EL packets are not transmitted/received
                    .
                    .
                    .
```


[4] Constant resource availability is detected through the bandwidth indicator at t4 where the received packets indicating the resource availability have the following format.

```
+---+----+----+-----+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|RES| RT | BL | max | max_bandwidth | min_bandwidth |
+---+----+----+-----+---------------+---------------+
 * Currently no EL packets are received.
 * Destination learns from the bandwidth indicator bit (set to max)
   that the current route has the resources available to restore the
   EL packet flow.
                    .
                    .
                    .
```

[5] Through the next QOS report destination informs the source to reinitiate the transmission on EL in RES mode. If the recovery (scale up) is successful, destination receives the following packets.

```
+---+----+----+-----+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|RES| RT | BL | max | max_bandwidth | min_bandwidth |
+---+----+----+-----+---------------+---------------+
+---+----+----+-----+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|RES| BE | EL | max | max_bandwidth | min_bandwidth |
+---+----+----+-----+---------------+---------------+
                                            .
                                            .
                                            .
```

[6] If scale up attempt fails at any mobile node on the route,

destination receives degraded EL packets.

```
+---+----+----+-----+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|RES| RT | BL | min | max_bandwidth | min_bandwidth |
+---+----+----+-----+---------------+---------------+
+---+----+----+-----+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|RES| BE | EL | min | max_bandwidth | min_bandwidth |
+---+----+----+-----+---------------+---------------+
```

[7] If the EL degradation persist after step [6], another drop EL command is issued via following QOS report.

The decision to drop/scale up is entirely up to the application-specific adaptation policy residing at destination mobile. For example a video flow may be sensitive to delays and delivery of constantly changing bandwidth so once enhancement layer packets are dropped, it requires stable resource availability of resources before a scale up decision is made. In the case of real-time data, there may not be any drop command and the application may want to closely follow the dynamics of resource availability. In such case the adaptation policy is quite different from that of a video flow example.

5. NETWORK LAYER FUNCTIONALITY - INTEROPERABILITY WITH IMEP

Since Internet MANET Encapsulation Protocol is a network layer protocol designed to support the operation of many routing algorithms and any other higher layer protocols intended for use in mobile ad hoc networks, INSIGNIA can be fully incorporated with IMEP mechanisms. IMEP will provide mechanisms for supporting link status and neighbor connectivity sensing, lower layer control packet aggregation and encapsulation, one-hop neighbor broadcast (or multicast) reliability, multi-point relaying, network-layer address resolution and provides hooks for inter-router authentication procedures.

IMEP [18] improves overall network performance by reducing the number of network control message broadcasts through encapsulation and aggregation of multiple MANET control messages (e.g. routing protocol packets, acknowledgements, link status sensing messages, network-level address resolution, etc.) into larger IMEP messages.

Usage of the IMEP is desirable because per-message, multiple access delay in contention-based schemes such as CSMA/CA, IEEE 802.11, FAMA etc. is significant, and thus favors the use of fewer, larger messages. It would also be useful in reservation-based, time-slotted access schemes where smaller packets must be aggregated into appropriately-sized IP packets for transmission in a given time slot. Upper layer protocols other than routing may make use of this encapsulation functionality for the same purpose.

Moreover, IMEP will provide the commonality among many network-level routing algorithms. Many algorithms intended for use in a MANET will require common functionality such as link status sensing, security authentication with adjacent mobiles, broadcast reliability of network control messages, etc. This common functionality can be extracted from various protocols and can become generic protocol useful to all. The routing algorithms would also benefit from the common approach to mobile and interface identification and addressing. The IMEP will run at the network layer and will be an adjunct to whichever network routing protocol is using it. Routing control packets will be encapsulated in IMEP messages, which will be further encapsulated into IP packets.

6. SECURITY ISSUES

The MANET computing environment is very different from the ordinary computing environment. In many cases, mobile computers will be connected to the network via wireless links. Such links are particularly vulnerable to passive eavesdropping, active replay attacks, and other active attacks. A stringent authentication and registration processes are required to avoid any malicious users.

Authentication :

The IMEP Authentication object [18] is used to authenticate all IMEP objects. The types of authentication to be supported and specified in a proposed MANET Authentication Architecture under development.

Registration :

Upper layer protocols, i.e., INSIGNIA must register with IMEP prior to use.

7. APPLICATIONS

INSIGNIA can be used as signaling support for small (pico-cell) and large scale mobile networks. Flows and microflows can be supported. Voice, video and real-time data applications can be supported using the INSIGNIA adaptive real-time service. In addition, INSIGNIA networks support traditional best effort services.

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