TECHNICAL RESEARCH REPORT

INORA- A Unified Signaling cum Routing Mechanism for QoS Support in Mobile Adhoc Networks

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INORA - A Unified Signaling cum Routing Mechanism for QoS Support in Mobile Adhoc Networks

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Abstract

Mobile Adhoc NETworks(MANET) are characterized by bandwidth constrained wireless links, multiple hops and highly dynamic topologies. Providing QoS support in MANETs, thus is a challenging task. This paper presents the design, implementation and evaluation of INORA, which is a network layer QoS support mechanism which makes use of the INSIGNIA[1] inband signaling mechanism and TORA[4] routing protocol for MANETs. TORA provides multiple routes between a given source and destination. We present an effective coupling between TORA and INSIGNIA to get routes that are "best-able" to provide QoS requirements for a flow. INORA also combines congestion control with routing.

1 Introduction

Mobile Adhoc Networks are infrastrureless networks of mobile nodes connected by wireless links. The topology of the mobile adhoc network changes with time due to mobility of nodes. The channel conditions of the wireless medium are also time-varying. Providing quality of service (QoS) support for the delivery of real-time audio, video and data in mobile adhoc networks thus, presents a number of technical challenges. Mobile adhoc networks can be quite large, which makes the problem of network control very difficult. In fixed-wired networks, most QoS schemes use hard-state resource reservations and explicit *connection-establishment* and *connection teardown* mechanisms. Dynamically changing topology of mobile adhoc networks due to mobility of the nodes calls for the soft-state reservation[1] of resources across the network for providing QoS suppport, as against hard-state reservations in wired networks. QoS support can be provided at the MAC layer(Eg. MACA/PR[8]) or at the network layer[5][1][9].

2 Approaches to network layer QoS support in Mobile Adhoc Networks

Various network layer mechanisms have been proposed for QoS support in mobile adhoc networks. They can be be broadly categorized as the following depending on the degree of coupling between the QoS resource mechanisms and routing protocol.

1. QoS Routing
2. QoS signaling with no interaction between the QoS mechanism and the routing protocol.
3. QoS signaling with interation between the QoS resource mechanism and the routing protocol.

QoS Routing QoS routing protocols search for routes with sufficient resources for the QoS requirements. QoS routing protocols work with the resource management mechanisms to establish paths through the network that meet end-to-end QoS requirements, such as delay or jitter bounds, bandwidth demand.[10]

E.g.: CEDAR[5]

Here, the QoS provision mechanism is intrincically tied to the routing protocol. QoS Routing is difficult in MANETs.

Firstly, the overhead of QoS routing is too high for the bandwidth limited MANETs because there needs to be some mechanism for a mobile node to store and update link information.

Secondly, because of the dynamic nature of MANETs, maintaining precise link information is very difficult.

Thirdly, the traditional meaning that the required QoS should be maintained once a feasible path is estabished is no longer true. The reserved resource may not be guaranteed because of the mobility-caused path breakage or power depletion of the mobile hosts.

QoS Signaling QoS signaling is used to reserve and release resources, set up, tear down and renegotiate flows in the network. Soft-state reservations are better in mobile adhoc networks, because of the highly dynamic conditions in the network. [2]

QoS Signaling without interaction between the QoS mechanism and the routing protocol The signaling mechanism can be operated independent of the routing protocol. The routing protocol provides the route between the source and destination of a flow. The signaling protocol establishes resources along the route chosen by the routing protocol. Here, the routing protocol is completely decoupled from the signaling mechanism.

E.g. INSIGNIA[1][2]

QoS Signaling with interaction between the QoS mechanism and the routing protocol Here, there is a loose coupling between the QoS mechanism and routing protcol. The coupling is looser than in *QoS Routing.* The routing protocol provides a route between the source and destination of the flow. The signaling mechanism provides feedback to the routing protocol regarding the route chosen and asks the routing protocol for alternate routes if the route provided doesn't satisfy the QoS requirements. The INORA (INSIGNIA+TORA) scheme that is presented in this paper belongs to this category. In INORA, INSIGNIA makes a callback to TORA asking for alternate routes when the current route fails to meet the QoS requirements. TORA is a good choice for the routing protocol in this case. This is because, TORA operates by creating a routing structure called a *Directed Acyclic Graph* (DAG), which gives multiple routes from a source to the destination.

3 Overview of INSIGNIA signaling system

The INSIGNIA[2] inband signaling system plays an important role in establishing, adapting, restoring and terminating end-to-end reservations for flows. INSIGNIA is designed to be light-weight in terms of the amount of bandwidth consumed for network control. It operates by setting up soft-state reservations for a flow across the path from the source of the flow to the destination of the flow in a mobile adhoc network. INSIGNIA uses the IP Options field in the IP header to convey the signaling information. See fig.1. The following are the IP options fields:

- **Service Mode:** When a source node wants to establish a reserved QoS flow to a destination node, it sets the RES bit of the INSIGNIA IP option service mode of a data packet and sends the packet toward the destination. On reception of a RES packet, the intermediate nodes execute *admission control* to accept or deny the request. When a node accepts a reservation request, resources are committed and subsequent packets are scheduled accordingly. If the reservation is denied, packets are treated as *best effort mode* (BE) packets.
- **Payload Type:** This option carries an indication of the payload type, which identifies whether the packet is of the type *base QoS* (BQ) or *enhanced QoS* (EQ)[2]
- **Bandwidth Request:** The bandwidth request allows us to specify its maximum (MAX) and minimum (MIN) bandwidth requirements for

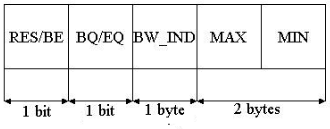

Figure 1: INSIGNIA IP options

adaptive services. During request establishment, the bandwidth indicator reflects the resource availability at the intermediate nodes along the path between source-destination pairs of different flows.

3.1 Admission Control

A source of a QoS flow sets out data packets with its service mode IP options field set to RES. All the intermediate nodes which receive packets with their *service mode* field set to RES perform admission control. At the first node where the admission control fails, the service mode is changed to BE (best effort).

Admission control failure occurs either of the following occurs:

- The node is unable to allocate atleast the minimum required bandwidth (BW_{min}) for the flow.
- There is congestion at the node, i.e the queue-size at the node has exceeded a threshold.($Q > Q_{th}$)

In fig.2, we illustrate the connectivity of a MANET with a graph. The source of a QoS flow is node 1. The destination is node 5. Let the path given by the routing protocol be $1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 5$. node 4 is the first node at which an admission control failure occurs because of either of the conditions mentioned above. The reserved flow turns into a *best effort* flow.

3.2 QoS Reporting

QoS reporting is used to inform source nodes of the ongoing status of the flows. Destination nodes actively monitor ongowing flows, inspecting the *status information* (e.g. Bandwidth Indicator) and *measured delivered QoS* (e.g packet loss, throughput etc.). Although the QoS reports are basically generated periodically according to the sensitvity of application, QoS reports are sent immediately when required. The source, on the reception of a QoS report indicating a flow degrade from *reserved* to *best effort* flow may downgrade the flow. Here the feedback is end-to-end from the source to destination. INSIGNIA doesn't take any help from the network with regard to redirecting the flow along routes which are able to provide the required QoS guarantees. In INORA (See section 4) we describe a mechanism that takes help from the network and the feedback about the capability of intermediate nodes to admit flows is given to the routing protocols on a hop-by-hop basis.

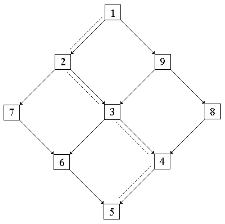

Figure 2: INSIGNIA-Admission Control fails at node 4

4 INORA

In INORA, we make use of feedback on a per-hop basis to direct the flow along route that is able to provide the QoS requirements of the flow. We make use of the INSIGNIA in-band signaling system and TORA[4] routing protocol in the INORA scheme.

TORA operates by creating a *Directed Acyclic Graph* (DAG) rooted at the destination. We use this routing structure to direct the flow through routes that are able to provide the resources for the flow according to the QoS requirements of the flow. We present two schemes under the INORA framework.

1. Coarse feedback scheme.
2. Fine feedback scheme.

4.1 Coarse Feedback Scheme

The operations of the coarse-feedback scheme of INORA are described illustrated through the following example :

Consider a QoS flow being initiated with node 1 as th source and node 5 as the destination.

1. Let the DAG created by TORA be as illustrated in fig.3
2. Let 1 → 2 → 3 → 4 → 5 be the path chosen by the TORA routing protocol.(See fig. 3)
3. INSIGNIA tries to establish soft-state reservations for the QoS flow along the path. Node 4 is the first node at which admission control for the flow fails, (because of either condition mentioned in section 3.1Node 4 sends an out-of-band *Admission Control Failure* (ACF) message to its previous hop (node 3).(See fig.4)
4. Node 3 realizes that the next hop 4 is not good for the current flow and re-routes the flow through another downstream neighbor (node 6) provided by TORA. (See fig.5)
5. If node 6 is able to admit the flow, the flow gets the required reservations all along the path. The new path would be 1 → 2 → 3 → 6 → 5(See fig.5)
6. If node 6 is unable to admit the flow, it sends an ACF message to node 3(its previous hop).(See fig.6)
7. Node 3 realizes that it has exhausted all the downstream neighbors that it was provided by TORA. So, it sends a Cumulative *Admission Control Failure* message to its previous hop (node 2), indicating that none of its downstream neighbors can accommodate the flow.(See fig.7)
8. Node 2 now, tries with its other down-stream neighbors for the possibility of a path that can give the required reservations to the flow.

The following things can be noted:

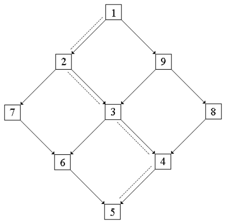

Figure 3: INORA Coarse-Feedback
node 4 is a bottle-neck node. Admission Control Fails at 4

- As a result of this scheme, it is possible that different flows between the same source and destination pair can take different routes, as can be seen from fig.8, that to go from node 1 to node 5, flow 1 takes the path 1 → 2 → 3 → 4 → 5 and flow 2 takes the path 1 → 2 → 3 → 6 → 5
- While INORA is trying to find a good route for the flow following admission control failure at an intermediate node, the packets are transmitted as *best effort* (BE) packets from the source to the destination. It should also be noted that there is no interruption in the transmission of a flow that has not been able to find a route in which resources have been reserved all the way from the source to the destination.
- Because of the nature of the *Directed Acyclic Graph* (DAG), INORA tries to get a route which satisfies QoS requirements locally. When this fails, the search for a route which satisfies the QoS requirement becomes more global. In the worst case, we would have searched the entire DAG for a QoS route.
- Also, the scope of search for the routes is the DAG. INORA only chooses an appropriate route from the set of routes given by TORA. It doesn't trigger any route-querying mechanism to find new routes which will be good *QoS-wise*.

4.1.1 Implementation Details

When a node X receives an Admission Control Failure (ACF) message from its downstream neighbor Y,

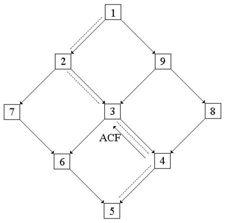

Figure 4: INORA Coarse-Feedback
node 4 sends an out-of-band ACF to the previous hop (node3)

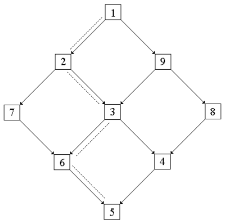

Figure 5: INORA Coarse-Feedback
node 3 redirects the flow to node 6.

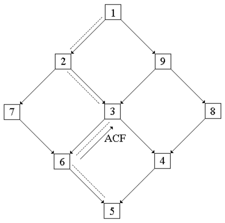

Figure 6: INORA Coarse-Feedback
If node 6 fails to admit the flow, 6 sends an ACF message to 3

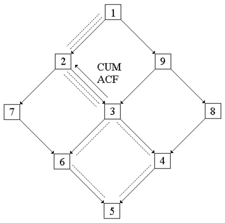

Figure 7: INORA Coarse-Feedback
node 3, having exhausted all its next-hops, sends an a cumulative ACF to its previous hop 2.

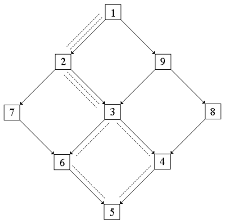

Figure 8: INORA Coarse-Feedback
Different flows between same source-destination pair can take different routes

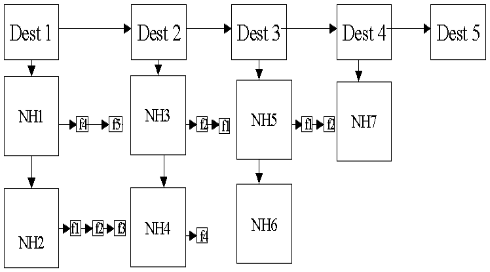

Figure 9: TORA Routing Table in INORA

it blacklists the downstream neighbor Y. Associated with the black-list entry, is a timer, which makes sure that the downstream neighbor Y is black-listed long enough. The node Y must be black-listed for the expected period of time required by INORA to search for a QoS route. This time is $O(E)$, where E is the number of links in the network at any given time. The TORA routing table is restructured in INORA as shown in fig.9

Associated with every destination, there is a list of next hops which is created by TORA. With the feedback that TORA receives from INSIGNIA in INORA, TORA associates the *next-hops* with the flows that they are suitable for. So, a routing look-up in INORA is based on the ordered pair $(destination, flow)$. If TORA doesn't have the information about the best route for the given flow, the routing look-up is just based on the destination. In that case, TORA gives the downstream neighbor with the least *Height*[4]metric. If any of the nodes is not INORA aware, normal operations of INSIGNIA and TORA continue.

4.2 Class-Based Fine Feedback Scheme

In this scheme, we divide the (BW_{min}, BW_{max}) interval into N classes, where BW_{min} is the minimum bandwidth required by a flow and BW_{max} is the maximum bandwidth required by the QoS flow. The IP options field in the IP header which carries the INSIGNIA information, now carries an additional *class* field. This field signifies the amount of bandwidth that has been allocated for the flow along the path.

The operation of the protocol is illustrated by the following example:

Consider a QoS flow being initiated with node 1 as the source and node 5 as the destination, with minimum bandwidth requirement BW_{min} and maximum bandwidth requirement BW_{max}. Let the flow be admitted with class m $(m < N)$ at node 1.

1. Let the DAG created by TORA be as shown in fig.10
2. Let $1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 5$ be the path chosen by the routing protocol.(See fig. 10)
3. INSIGNIA tries to establish soft-state reservations for the QoS flow along the path.
4. Node 2 is able to admit the flow with class m as was requested by its previous upstream hop, node 1.
5. Suppose that node 3 has admitted the flow with class l, but has not been able to allocate the bandwidth of class m, as requested by its previous hop 2.$(l < m)$ (See fig.11)
6. Node 3 now, sends an *Admission Report message* $(AR(l))$ to the upstream previous hop(node 2), indicating its ability to give *class* l bandwidth to the flow.(See fig. 11)
7. Node 2 splits the flow in the ratio of l to $m - l$ and forwards the flow to node 3 and node 7 respectively, in that ratio. This means that the flow of class m has been split into two flows of class l and $m - l$ and is forwarded to nodes 3 and 7 respectively.(See fig. 12)
8. Suppose that node 7 is unable to give *class* $(m - l)$ as requested by the upstream previous hop 2, but is only able to give class n $(n < m - l)$. 7 sends an Admission Report message $(AR(n))$ to the upstream previous hop , node 2.(See fig.13)
9. Now node 2, realizing that its downstream neighbors have been unable to give the *class* m, which it was requested, informs its ability to give a class $l + n$ $(l + n < m)$ by sending a cumulative *Admission Report* $AR(l + n)$ to its previous hop 1. (See fig. 14)
10. Now, node 1 tries to find another downstream neighbor, which might be able to accommodate the flow with class $(m - (l + n))$

The following things can be noted:

- When a node is unable to admit a flow, either due to its inability to give the flow the requested minimum bandwidth or due to congestion at a node, it is not able to allocate the minimum bandwidth BW_{min} required by the flow, the *Admission Control Failure* messages as in the *coarse-feedback* scheme described in section 4.1are sent. So, the *fine-feedback scheme* is a super-set of the *coarse-feedback scheme*.
- *Fine-feedback scheme*, like the *coarse-feedback scheme* first tries to search for a QoS route, which can give the requested bandwidth *class* locally. The search becomes more global if it is not able to find the QoS route which gives the required cumulative class locally.
- A single flow can get split, and the packets can take different routes from the source to the destination. (See fig.15)

4.2.1 Implementation Details

Consider the example mentioned in 4.2. When node 2 receives an $AR(l)$ from node 3 and $AR(n)$ from node

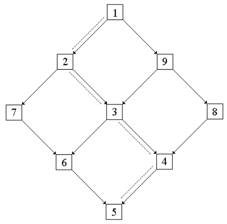

Figure 10: INORA Fine-Feedback
node 3 has admitted the flow with class l, but is not able to give the bandwidth-class that the node 2 (previous hop) is able to give, say m, $m > l$

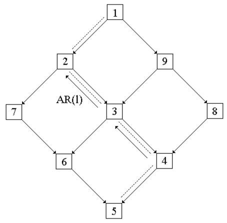

Figure 11: INORA Fine-Feedback
node 3 sends Admission Report $AR(l)$ to previous hop (node 2)

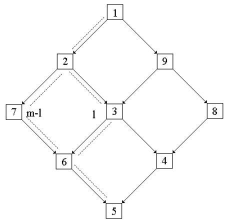

Figure 12: INORA Fine-Feedback
node 2 splits the flow among the next hops, 7 and 3 in the ratio $m - l$ to l

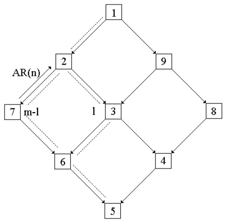

Figure 13: INORA Fine-Feedback
node 7 is unable to give $m - l$, but only $n < m - l$. It sends $AR(n)$ upstream

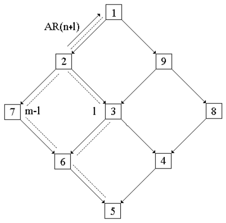

Figure 14: INORA Fine-Feedback
node 2 sends $AR(n+l)$ indicating the bandwidth that it can support

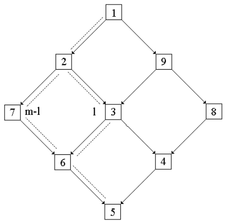

Figure 15: INORA Fine-Feedback
A single flow gets split and takes different paths to the destination

7, indicating the ability of the downstream neighbors to give class n and class l to the flow as against the requested class m $(l + n < m)$, node 2 makes a note of the class, that each downstream neighbor has been able to allocate in the *Class Allocation List* and associates timers with those entries. The TORA routing tables here, are similar to the *coarse-feedback scheme* as illustrated in fig. *9.* There is an additional *class* field in the *flow* entries of the routing table. The routing table look-ups are made on the basis of the ordered 3-tuple $(destination, flow, class_{req})$ where

destination stands for the destination for which we are looking up routes.

$flow$ stands for the flow for which we are looking up routes.

$class_{req}$ stands for the bandwidth class requested by the flow.

5 Simulations

We performed *ns-2* simulations to evaluate the INORA framework. The INSIGNIA code was obtained from COMET group, Columbia University [11]. The TORA *ns-2* code from CSHCN, University of Maryland[12] was used. We made modifications to the INSIGNIA and TORA code to incorporate the INORA scheme. CMU Monarch wireless extensions [13]for *ns-2* were used. We ran experiments with the INORA schemes(*coarse-feedback* and *fine-feedback*), and the original INSIGNIA and TORA, running independent of each other without the feedback. In the INORA *fine-feedback scheme,* we chose the number of classes, $N = 5$

Our simulation scenario is a $1500mX500m$ rectangular grid with 50 mobile nodes. The node mobility follows *Random Way-point Model.* The nodes move with speeds uniformly distributed between 0-40m/s. We have 10 flows, 3 of which have QoS requirements and the remaining 7 flows don't have QoS requirements. The sources generate CBR traffic. The simulations have been run for a simulation time of 300sec. We considered two different scenarios. Scenario B has QoS sources transmitting at a higher data rate and the QoS flows have a higher reservation requirements.

Scenario_A: 3 QoS flows generate traffic at a data rate of $81.92.kbps$ The 7 non-QoS flows generate traffic at a data rate of 40.96kbps. The QoS flows ask for a reservation of $BW_{min} = 81.92$ *kbps*, and $BW_{max} = 163.84$ *kbps*

Scenario_B: 3 QoS flows generate traffic at a data rate of 136.533 *kbps*. The 7 non-QoS flows generate traffic at a data rate of 40.96 *kbps*. The QOS flows ask for a reservation of $BW_{min} = 136.533$ *kbps*, $BW_{max} = 273.066$ *kbps*

5.1 Results

We find that INORA with coarse-feedback and fine-feedback schemes gives almost the same packet delivery rate as INSIGNIA and TORA acting without feedback, in both Scenario_A and Scenario_B. (See fig.16 and fig.17)

The average delay on a per-flow basis for QoS flows in Scenario_A is shown in fig.18. The average delay on a per-flow basis for non-QoS flows is shown in fig.19. The average delay on a per-flow basis for QoS flows in scenario_B is shown in fig.20. The average delay on a per-flow basis for non-QoS flows is as shown in fig.21. It can be seen that the delay is flow dependent. The INORA schemes do better *average delay-wise* modally (for more flows) when compared to INSIGNIA and TORA running without interaction. Also, INORA does better when there are higher bandwidth requirements (Scenario_B) than when the flows have lower bandwidth requirements (Scenario_A). The INORA fine-feedback scheme does better when compared to INORA coarse-feedback scheme in Scenario_B.

The plot of average delay vs. simulation time in scenario_A for all data packets (QoS and non-QoS) is as shown in 22. The same plot in Scenario_B is shown in fig.23. In Scenario_B , the INORA fine-feedback scheme does the best, followed by INORA coarse-feedback scheme and then, followed by INSIGNIA and TORA running without feedback.

This shows that as the network gets more heavily loaded, and when the QoS flows have higher bandwidth requirements, having an interaction between the routing protocol and the QoS signaling system gives better performance. Also by using the INORA fine-feedback scheme in higher loaded scenarios, we have good effects of fine-tuned load balancing.

The additional overhead incurred in the INORA schemes over INSIGNIA and TORA running independently of each other for Scenario_A is as shown in fig. 24. The additional overhead incurred in INORA schemes over INSIGNIA and TORA running independently in Scenario_B is as shown in fig. 25. As expected, INORA fine-feedback scheme has larger messaging overhead when compared to the INORA coarse-feedback scheme in both Scenario_A and Scenario_B.

6 Conclusions and Future Work

In this paper, INORA, a QoS support mechanism using INSIGNIA in-band QoS signaling system and TORA routing protocol for adhoc networks has been proposed. The implementation and an evaluation of INORA has also been presented. We have shown by simulations that INORA schemes do well in networks that are heavily-loaded and where the QoS flows have higher bandwidth requirements. In wireless networks, congestion at a wireless node is related to congestion in its one-hop neighborhood. We plan to incorporate a suitable mechanism in INORA to reflect this fact, so that congested neighborhoods can be avoided by QoS flows.

7 Acknowledgements

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References

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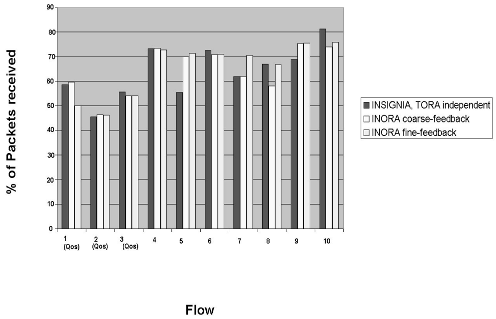

Figure 16: Percentage of Packets delivered(Scenario_A)

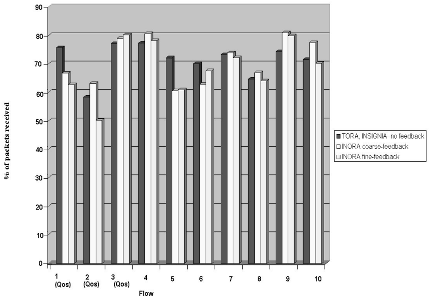

Figure 17: Percentage of packets delivered (Scenario_B)

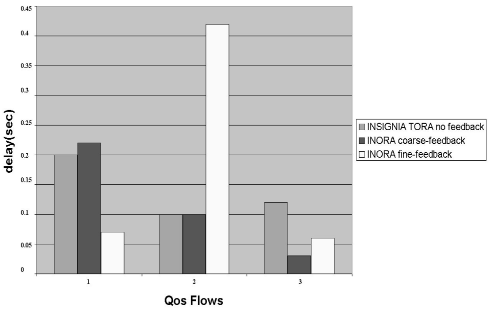

Figure 18: Average Delay of QoS packets (Scenario_A)

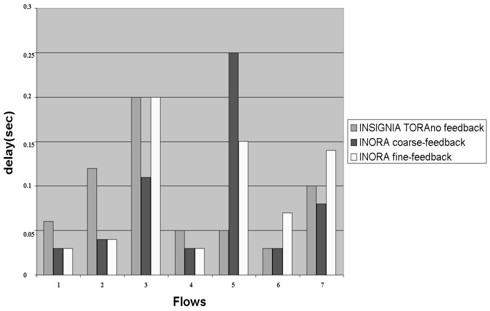

Figure 19: Average Delay of non-QoS packets(Scenario_A)

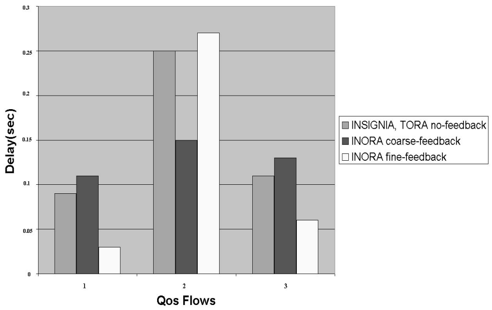

Figure 20: Average Delay of QoS packets(Scenario_B)

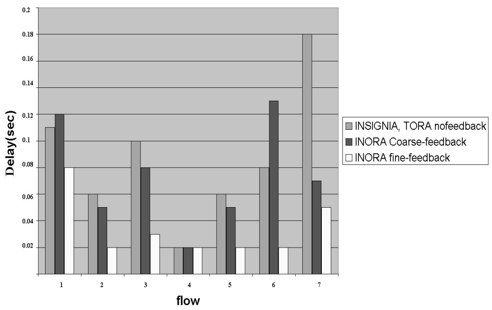

Figure 21: Average Delay of non-QoS packets(Scenario_B)

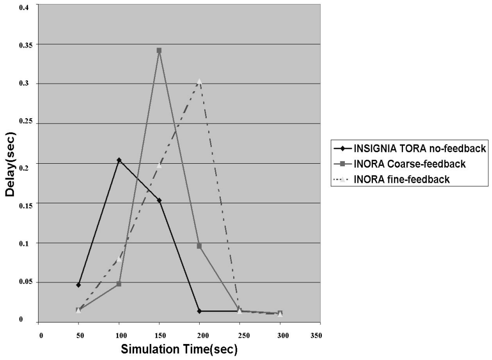

Figure 22: Average Delay of all the packets(Scenario_A)

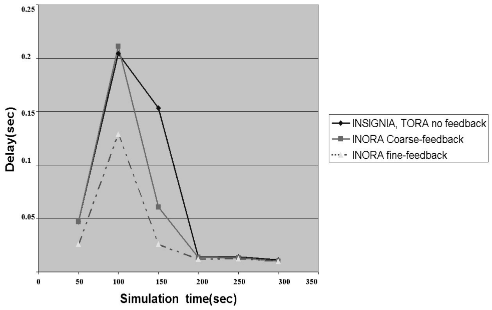

Figure 23: Average Delay of all the packets(Scenario_B)

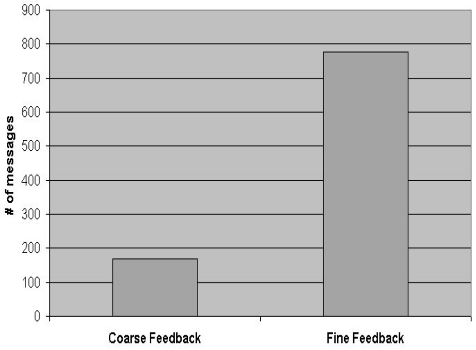

Figure 24: Overhead in INORA(Scenario_A)

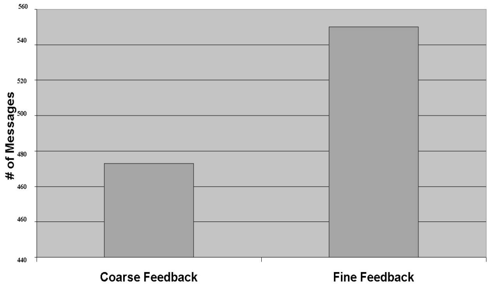

Figure 25: Overhead in INORA(Scenario_B)

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