ADAPTIVE MOBILE AD-HOC NETWORK (AMAN): A QOS FRAMEWORK FOR MOBILE AD-HOC NETWORKS

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ABSTRACT
Quality of Service (QoS) support for Mobile Ad-hoc NETworks (MANETs) is a challenging task due to the dynamic topology and limited resources in MANETs, and the QoS model should be the first matter to consider as a system goal. The INSIGNIA framework, ASAP and DiffServ model can provide system-level QoS support for MANETs, but each have pros and cons in service precision and scalability. In this paper, we propose a hybrid QoS model for MANETs, called AMAN, which combines the per-flow granularity of INSIGNIA and ASAP and the per-class granularity of DiffServ, to provide a responsive, scalable, and flexible QoS support for MANETs. The simulation results show that AMAN can achieve effective service differentiation and offer the best QoS to the per-flow service under various mobility conditions.

INTRODUCTION
Mobile ad-hoc networks represent future generation wireless networks, with a high degree of versatility and robustness, capable of being deployed quickly and economically at places lacking any infrastructure. The characteristics of these networks such as bandwidth scarcity and fluctuations, node mobility, hostile working conditions and battery power constraints, have hindered their development. Projected applications of such networks include defense-based, disaster relief operations, commercial applications and sensor networks. Many of these applications require a distinction in the quality of connections being supported in terms of bandwidth availability, end-to-end delay and jitter. As multimedia traffic finds its way into wireless networks, the use of the UDP transport layer protocol alone does not suffice to accommodate the needs of users.

Most multimedia traffic require a more stable throughput for them to be regarded useful. Therefore there is a dire need for a QoS model integrated within the nodes for such applications. The model must be able to distinguish flows based on their QoS needs and have mechanisms that work to meet those requirements. Since there is no central coordinator, the QoS model must operate in a fully distributed manner. The QoS framework should allow layers of the OSI model to interact and cooperate in providing a comprehensive quality of service to the traffic.

We propose a QoS model that differentiates traffic into classes and attempts to provide bandwidth and delay guarantees to flows of highest priority class. The framework relies on its strong adaptation algorithm to give more access to resources for the highest priority class of traffic whilst the least priority traffic cedes its share of bandwidth allocation to the highest priority until the time resources are available.

RELATED WORK
The SWAN (Ahn, 2002) model differentiates traffic into real-time UDP traffic and best effort TCP traffic. It is a stateless and fully distributed model that provides soft QoS assurances to real-time traffic. It uses admission control for real-time traffic, rate control of TCP traffic and ECN congestion control mechanisms to ensure that real-time packets meet QoS bounds. Each node comprises an admission controller that maintains information about the status of the outgoing link in terms of the available bandwidth and amount of congestion. It does this by promiscuously listening to all packet transmissions within its range. The source node sends a probe message to the destination to find the bottleneck bandwidth along the path. If this value is greater than the requirements plus a threshold value, the flow is admitted; otherwise it is rejected and marked as best-effort. All TCP flows are considered as best-effort.

INSIGNIA (Lee, 98), (Lee 2000) is an in-band signaling system that supports adaptive reservation-based services in ad-hoc networks. All the control information is carried in-band with the data and encoded using the IP option field in datagrams. The signaling system supports a number of protocol commands that drive fast reservation, fast restoration and an end-to-end adaptation mechanism. This in-band information is snooped as data packets traverse intermediate nodes/routers and used to maintain soft-state reservations in support of flows/micro-flows. To establish reservation-based flows between source-destination pairs, source nodes initiate fast reservations by setting the appropriate fields in the INSIGNIA IP option field before forwarding packets. Reservation packets (i.e. data packet with the appropriate IP option set) traverse intermediate nodes, executing admission control modules, allocating resources and establishing soft-state reservation at all intermediate nodes between source-destination pairs. The reservations need to be periodically refreshed by the packets of the flows. In the event of a change in the path resulting
from movement of the nodes, the first packet along the new path makes fresh reservations along this path thereby performing a fast restoration. Reservations made along the old path are removed on a timeout. Flows in the network are expected to be adaptive to bandwidth availability. A flow that was allocated a MAX amount of bandwidth initially could be downgraded to a MIN amount or even to best-effort in the event of rerouting of a flow or if network conditions change. ASAP (Xue, 2003) is an adaptive reservation QoS protocol. When a flow requires service, it is soft-reserved first and later hard reserved. When the route has been established the resources are then hard-reserved to the flow. ASAP employs an adaptation method that will allow some flows to release bandwidth if the allocated bandwidth is more than their required minimum. It also has a route repair mechanism that allows self-healing by finding alternative routes when a route is broken, which happens frequently in wireless networks. ASAP adaptation helps to stabilise the throughput of flows in wireless ad-hoc networks.

Ramraj (2010) presented a bandwidth management protocol to demonstrate fair bandwidth sharing between nodes. One node is identified as the bandwidth manager and the bandwidth management protocol is invoked at flow establishment, flow teardown and when bandwidth adaptation is required. When the bandwidth manager node is inaccessible, a new manager node is elected. In our proposed approach we differ with Ramraj (2010) by performing the bandwidth management on all nodes so that we remove the problem of single point of failure. Pattanayak (2009) proposed a distributed cluster scheme for MANETs, in harsh environments, based on the concept of survivability to support QoS requirements and to protect bandwidth efficiently. With the incorporation of clustering algorithms in survivability technology, they employ a simple network configuration and expect to reduce occurrences of faults in MANETs. In (Bushehri, 2014), the author proposed a reliability aware scheme in which clients rank service providers on their reliability and response time. They use a Hidden Markov Model for the service selection and choose the best service providers whilst avoiding poor providers; this managed to lower violations of the client service level agreement. We need a framework that optimizes assignment of bandwidth to flows according to the type and priority of traffic. The types of traffic have to be multiple unlike in some of the other frameworks which classify traffic into two classes only.

PROPOSED QoS FRAMEWORK
This section describes the proposed framework architecture, AMAN whose proposed architecture is illustrated in figure 1. The proposed QoS architecture has five basic modules namely Bandwidth Estimation, Bandwidth Adaptation, Congestion Control, Admission Control and Reservation. The implementation of the proposed traffic management scheme is supposed to fulfill these requirements:

i. Admission of a new flow into the network if there is enough bandwidth to carry the flow without interfering with other ongoing traffic.

ii. Increase in the available bandwidth by reducing the allocation of other ongoing applications in order to incorporate a new flow.

iii. Deny of a new flow, whose requested bandwidth is greater than the available bandwidth after Bandwidth Adaptation has been done.

Traffic Differentiation
For traffic differentiation we adopt the DiffServ model, (Nichols, 1998), for classification and marking packets. DiffServ provides QoS by dividing traffic into a number of classes and allocating network resources on per class basis. The class is marked directly on the packet in the 6 bit DiffServ Code Point (DSCP) field, which is part of the original type of service (ToS) field in the IPV4 header. The DiffServ field is split into the 6-bit DSCP field and a 2-bit field which is used for Explicit Congestion Notification (ECN) mechanisms.

We propose assigning priorities to different types of traffic, which are going to affect the treatment of traffic at nodes. We adopt the CISCO QoS Baseline as our classification model (Szigeti, 2013), see Table 1.

![Traffic Management Framework Architecture](image)

**Figure 1: Traffic Management Framework Architecture**

<table>
<thead>
<tr>
<th>Bits</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>DiffServ Field</td>
<td>DSCP</td>
<td>DSCP</td>
<td>DSCP</td>
<td>DSCP</td>
<td>DSCP</td>
<td>DSCP</td>
<td>DSCP</td>
<td>ECN</td>
</tr>
<tr>
<td>Function</td>
<td>Class Selector</td>
<td>Drop Probability</td>
<td>0</td>
<td>ECN</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 2: The functions of Differentiated Services (DS) bits in class creation**

**Admission Control**
A new call for transmission will need to be admitted at each and every node in a path from source and a destination of
the call. This can only happen if the requested bandwidth of the new flow is smaller than the available bandwidth. Figure 3 below demonstrates what happens in the Admission Control Module. When a call for transmission is made by a new flow, its requested bandwidth (MinBw) is compared with the available bandwidth (AVbw). If the requested bandwidth is smaller than the available bandwidth then the flow is automatically admitted, otherwise the Bandwidth Adaptation Module is invoked to try to release extra bandwidth being used by other flows so that enough resources are freed to allow the new flow. The Adaptation module returns a modified (AVbw) available bandwidth value which is a sum of the old AVbw value together with the released bandwidth (RLbw) values. If the new value of available bandwidth is greater than the minimum requirement of the new flow, then it will be admitted, else the flow will be denied.

Table 1: Cisco QoS Baseline Classification, Marking, and Mapping Recommendations

<table>
<thead>
<tr>
<th>Application</th>
<th>Binary DSCP</th>
<th>CLASS OF SERVICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP Routing</td>
<td>110000</td>
<td>6</td>
</tr>
<tr>
<td>Voice</td>
<td>101110</td>
<td>5</td>
</tr>
<tr>
<td>Interactive Video</td>
<td>100010</td>
<td>4</td>
</tr>
<tr>
<td>Streaming Video</td>
<td>100000</td>
<td>4</td>
</tr>
<tr>
<td>Locally Defined</td>
<td>011010</td>
<td>3</td>
</tr>
<tr>
<td>Mission Critical Data</td>
<td>011000</td>
<td>3</td>
</tr>
<tr>
<td>Call Signalling</td>
<td>010010</td>
<td>2</td>
</tr>
<tr>
<td>Transactional Data</td>
<td>010000</td>
<td>2</td>
</tr>
<tr>
<td>Network Management</td>
<td>010000</td>
<td>2</td>
</tr>
<tr>
<td>Bulk Data</td>
<td>001010</td>
<td>1</td>
</tr>
<tr>
<td>Scavenger</td>
<td>001000</td>
<td>1</td>
</tr>
<tr>
<td>Best Effort</td>
<td>000000</td>
<td>0</td>
</tr>
</tbody>
</table>

QoS Signalling Method

AMAN is an in-band signalling system it uses the packet’s header to carry all its control information. In case of IPv6 this information can be transmitted within the base header and/or within any extension headers. AMAN uses the eight bits of the CLASS field to transmit its Message Type indicator and congestion notification. The IPv6 Hop-by-Hop options extension header will carry the request for reservation (RES), the minimum and maximum required bandwidth (MinBw and MaxBw) and the bandwidth reserved by a node for the specific flow (ActualBw). The QoS option has four fields, the reservation indicator (RES), Minimum and Maximum bandwidth fields (MinBw and MaxBw) and the Actual allocated bandwidth field (ActualBw).

The RES bit is set to 1 if the source is seeking a reservation for a new flow. At every intermediate node, there is an admission control procedure to ascertain whether the resources available can sustain a new flow without hindering ongoing communications. When the available bandwidth is not enough, then an intermediate node should not admit a new flow, otherwise it will interfere with on-going flows whilst it does not meet its own minimum requirements.

Figure 4: Signalling messages embedded in the IPv6 Header

When the source node initiates a new flow, it fills all the fields with data and forwards the packet to the next node. Every intermediate node checks the MinBw and ActualBw and compares them with its AvailBw. If there are enough resources (that is AvailBw > MinBw), and if the ActualBw from the previous node is greater than AvailBw, the ActualBw field is updated to AvailBw otherwise the field is not changed. Every node in the network keep a QoS table to store the flow label, source address, DSCP and bandwidth allocated to the flow. Various values of ActualBw are reserved at various nodes along the path. This means that, for some time, there would be over-reservation of resources at some nodes. This is corrected by unicast a RES report (QR) packet from destination node to the source node showing the bottleneck bandwidth for the flow. Figure 5 shows a source S sending data to destination D along a
certain path selected by the routing protocol. The bottleneck for the path is 150 Mbps at node X. Node D sends a RES report (QR 150) packet to the source node showing the bottleneck bandwidth. The RES report message does not have to follow the same path as the reservation message since this may not be possible in MANETs. The source will then change the ActualBw field to 150 Mbps and change the RES field to 0. All the nodes receiving the packets will now allocate this new value and release extra bandwidth they had allocated.

Figure 5: Fast reservation showing reservation request and reservation report for bottleneck bandwidth.

Re-routing (Fast restoration).

Reservation-based flows are often rerouted within the lifetime of ongoing sessions due to node mobility, as illustrated in Figure 6. A node moves out of radio contact and the flow is re-routed through mobile node Y. The minimum reservation is immediately restored along the new path, while reservations along the old path are timed out and automatically removed and there is no change along the common path.

Figure 6: Fast restoration showing how an intermediate node help find new routes when a link is broken by mobility.

Rerouting active flows involves the MANET routing protocol (to determine new routes), admission control, and resource reservation for nodes along the “new path.” Soft-state timers are continually refreshed and reservations maintained as long as packets associated with a particular flow are periodically received at intermediate routing nodes between source-destination pairs.

Bandwidth Adaptation

Adaptation ensures that a new flow can be admitted by accepting bandwidth released by other applications already in the network. Figure 7 illustrates the bandwidth adaptation algorithm. When the request for adaptation arrives, the priorities of ongoing applications are checked to get the flow with the least priority. The adaptation module must degrade the least priority flows to their minimum required bandwidth in order to free resources for the new flow. The module must be able to calculate the amount of bandwidth to be released by low priority flows before degrading them. If the highest priority flow asks for resources when the remaining resources are not enough, then we have to pause some of the least priority traffic to release resources.

Figure 7: Bandwidth Adaptation Algorithm

In case of network congestion notification, we can adapt the ongoing flows to reduce the allocations until the channel is no longer congested. The destination node informs the source of this congestion through a QoS report and the source scales down the transmission rate of flows to MinBw starting with the least priority. If congestion persists, then flows will be paused starting with the least priority flow. More flows will be stopped until the system has been restored to a non-congested state. We call this the panic mode. After a random back-off time a source with a throttled or paused flow can attempt to increase or re-admit the traffic flow. Node mobility or session dynamics may cause a flow routed via Y to be scaled up from minimum to maximum required service.

PERFORMANCE MODELLING OF AMAN

AMAN was evaluated through simulation. The system is written in C++ code that consists of several functions which will be called to perform different tasks including computing the available bandwidth. The code consists of a data structure called flows with five attributes namely:

- Flow Prioriity – Every flow is given a randomised priority value to resemble different real-time traffic, with the flow with the lowest value having the highest priority.
- **Flow ID/Address** - Each flow that enters the network has a Flow ID to uniquely identify all the flows in the network and also to keep track of the flows which were reduced to required minimum during bandwidth adaptation.

- **Reserved Bandwidth (RBW)** - When the flow is admitted into the network it is given its required bandwidth and this becomes the Reserved Bandwidth (RBW).

- **Required Minimum Bandwidth (RQmin)** - This is the minimum required bandwidth requirements of a flow in the network.

- **Releasable Bandwidth (RLBW)** - This is the difference between the reserved bandwidth and the required minimum. The bandwidth that can be released for other new flows to be admitted.

All these values will be randomised for the sake of the experimental studies. This random behaviour tries to mimic the random nature of traffic arriving and leaving the node. An array of up to 100 flows is defined and this will be used for different flows in the simulations. The Channel Capacity is assumed to be 2Mbps. A new flow will go through admission control, reservation and sometimes it might have to go through bandwidth adaptation first if the available bandwidth is not sufficient. As the simulations are run the results are written to output files where data was extracted for analysis. A flow can be admitted without need for adaptation, admitted after some adaptation has been done or denied admission even when adaptation has been done.

**RESULTS AND FINDINGS**

Data from the simulations help us to deduce various things among of which is to calculate the success rate of bandwidth adaptation in the resource reservation scheme. The success rate of the Bandwidth Adaptation process gives us a rough probability that when a new flow is initiated in a loaded network, the flow is admitted. We compared our results from adaptation simulations with a control experiment without adaptation for the purposes of comparison. We estimate the admission success rate of a scheme as:

$$ S = \frac{\text{No. of flows admitted}}{\text{Total No. of flows}} \times 100\% $$

![Figure 8: Comparison of the success rate of admitting a new flow for a network that does not do bandwidth adaptation to one that does adaptation.](image)

The success rate of the adaptation process is determined by the number of flows admitted after adaptation has taken place, and was found to be 73%. The success rate of a new flow to be admitted without adaptation was found to be 40% as shown in figure 8. This shows primarily that adaptation improves the chance of admitting a new flow by more than 30%. The results shows that most simulations with a new flow’s bandwidth requirements above a certain threshold value (in our case 0.75Mbps) have to undergo the adaptation process despite the size of the network. In this case network size is represented by the number of flows already in the network when a request is done.

The results also show that of those simulations, which required adaptation (22 out of the 30 simulations carried out), most of the simulations with new flow’s requirements above 1Mbps resulted in the new flow being denied admission. These simulation results highlight that the Adaptation process increases the chances of admission of flows that could have been denied by a factor of 0.73 or success rate of 73% as shown by the estimates of the Success rate of a scheme with bandwidth adaptation.
The results in Figure 9 show that the network size is exponentially proportional to the number of flows that have their reservation reduced to their minimum bandwidth requirement. The general trend highlights that as the network size increases the number of flows that will be reduced to working minimum also increases exponentially and this might have a negative effect on the quality of service of the flows reduced. However the performance will remain within acceptable range since the adaptation does not go below the minimum required bandwidth. Under congestion, in case of rerouted flows, adaptation and flow pausing might impact heavily on the network performance since some applications will be forced to stop operation.

Figure 10 shows the relationship between the number of flows in a network and the consumed bandwidth. For the network that does not do adaptation, a small number of nodes will consume a lot of bandwidth. This is attributed to the fact that flows will continue consuming bandwidth close to their maximum requirements, taking no regard to the congestion happening in the network. With adaptation, the network can accept more flows at the same time satisfying their minimum bandwidth requirements.

CONCLUSIONS
In this research we presented a scheme for traffic differentiation and management in Mobile Ad-hoc Networks (MANETs). The proposed scheme is intended to efficiently manage the reservation of bandwidth in MANETs based upon the available bandwidth within the network. The scheme also employs a Bandwidth Adaptation process, which is the novel part of the research, to increase the chances of admission of a new flow into the network. We have discussed in detail how the proposed scheme works and how it increases the available bandwidth in the network by reducing the allocations of other flows to required minimum requirements according to the priorities of the flows. The research also includes an empirical analysis of the behaviour of the scheme by conducting simulations under varying conditions of required bandwidth and priority of new flow, available bandwidth and the size of the network. The results presented for the proposed scheme demonstrates that Bandwidth Adaptation enhances the admission of flows with bandwidth requirements greater than the available bandwidth. Our scheme has an added attribute of a multi-level priority scheme, which treats traffic of various classes differently and gives an advantage to the highest priority traffic. In other schemes like INSIGNIA, ASAP and SWAN, traffic is differentiated into real-time and best-effort traffic only. This does not respect the idea that multimedia traffic that is flourishing in the internet these days have varying characteristics and varying importance. Our framework also differs with ASAP and INSIGNIA in that it does not allow traffic to be degraded to best effort in case of congestion but stop flows that fall below the minimum acceptable bandwidth. This is done to ensure that no multimedia traffic is allowed to flow in the network unless it can be found useful to the end users. The scheme has the potential of coming up with efficient and realistic reservations.
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