A Qualitative Comparison of Active Layered Multicast Adaptation Protocol and Resource Reservation Protocol

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Abstract

This work involves the comparison of two multicast congestion control protocols: Resource Reservation Protocol (RSVP) and Active Layered Multicast Adaptation Protocol (ALMA). ALMA is an Active Network (AN) based protocol "which focuses on the implication of microeconomic theory to bandwidth adaptation;"[4] whereas RSVP reserves a resource at a given quality for the duration of the application to mitigate congestion. The aim of the work is to assess the AN based multicast congestion control protocol, by revealing its advantages and drawbacks. Performance evaluation properties of the two congestion control protocols such as speed, TCP friendliness and implementation issues are discussed. We conclude that RSVP is the better of the two approaches and ALMA needs further development before it can be deployed in the real world.

1. Introduction

Congestion is the process where too many packets are present in the network, thus causing performance degradation. When the number of packets inserted by a sender is within the capacity of the network, the number delivered is proportional to the number sent (even when within capacity, packets could be dropped due to other factors, for example, if a receiving Ethernet station is offline, the packets cannot be delivered. Hence, we used the term proportional and not equal). However, as the traffic increases, the routers may no longer be able to cope and they can begin losing packets. At extremely high traffic, performance collapses completely and almost no packets are delivered (called congestion collapse). Network congestion is likely to increase with the increase in the number of users and applications over time. This makes congestion control an extremely important topic for today's Internet.

Certain applications, like a distributed database system, require widely separated processes to work together in groups. The members of the group often need to communicate the same information to several other members within the group. For large groups, a point-to-point communication strategy can be expensive, and for networks significantly larger than the interested groups, the broadcasting alternative might not be appropriate either (because of undue stress on the network or the message might be confidential and should not be free to be read by all machines). Such applications use multicasting instead, wherein a message is sent to groups of a well-defined size but small compared to the network as a whole. Applications, like Television and Cable systems where several audio and video transmissions are subscribed to by a group of receivers, each of whom can view any station and switch stations at any given time, rely heavily on multicasting [9].

Traditionally, a multicast application makes reservation requests for a certain level of quality. Once the network determines that sufficient resources are available to accommodate such requests, it guarantees the service quality throughout the lifetime of the application, by scheduling the packets from these applications with higher priority inside the network switches and routers [1]. However, congestion control in these applications is complex, because unlike point-to-point communication, groups in a multicast application can change membership dynamically, such as people changing from a ‘sports’ to a ‘music’ station. Furthermore, the approach of a sender reserving the resources in advance would require each sender to track all entries and exits of the receivers and to regenerate the spanning tree at each change. For applications like cable television with millions of subscribers, this type of approach would not work at all. However, several protocols in existence today can handle such environments. This paper provides a qualitative comparison of two such multicast protocols: an active congestion control protocol, Active Layered Multicast Adaptation (ALMA), and a non-active congestion control protocol, Resource ReSerVation Protocol (RSVP).

The importance of this comparison lies in the fact that although Active Networks were introduced some ten years ago, they have yet to be adopted for use in the Internet. The objective here is to compare the advantages and disadvantages of ALMA (Because ALMA is based on Active Networks) with RSVP to demonstrate whether Active Networks are better for Congestion Control. Because RSVP is an industry-accepted and proven protocol [11], if we can show the advantages of ALMA over RSVP, it could bring the deployment of Active Networks one-step closer to reality.

2. Active Networks

In a traditional network, the user data bits traverse the network without modification and the computational requirements of the network are extremely limited, e.g., header processing in packet-switched networks and signaling in connection-oriented networks. In an Active Network, the computational ability of the network is greatly expanded to allow the network to perform customized computation on the network traffic, user data, etc. Two different mechanisms are used to create this new computational capability. First is the use of active nodes, where the routers or switches in the network are enhanced in order to perform customized computations on the messages flowing through them, e.g., a “trace” program on an active router could record operational statistics for every packet that is processed through it. Second is the use of active packets, which contain miniature programs that are executed at each router they traverse, e.g., a “health of a system” program could be embedded in the active packet and execute every time it passes through a node, thus providing the receiver with “health of a system” statistics along with the original packet contents. Furthermore, an active packet may invoke a pre-defined program method or plant new ones within network nodes.
[15]. Finally, active packets can be combined with active nodes to perform desired operations [8, 3].

AN emerged as one of the possible solutions to several problems identified with today’s networks, such as the difficulty of introducing new technology efficiently and easily, poor performance of the existing network due to required support for legacy systems, and the inherent computational limitation of the networks. AN is a collection of several strategies developed to address these issues and has been part of ongoing discussion within the broad DARPA research community since early 1994 [16].

3. Active Layered Multicast Adaptation

ALMA is a multicast protocol implemented as an Active Application. The active network is used as a mechanism to obtain resource information that is translated using the simplified economic principles of offer and demand to make the price indicate the availability of a given resource.

ALMA is a layered multicast protocol where the source data stream is encoded hierarchically and then divided into multiple streams representing layers of successively detailed data. Coding and stripping data into n cumulative layers \( L_1, \ldots, L_n \) simply means that each subset \( \{ L_1, \ldots, L_i \} \leq n \) encompasses the same content but with an increase in the quality as \( i \) increases. This kind of coding is well suited for audio and video applications. For instance, a video codec can encode the signal in a base layer and enhancements in the higher layers. In this case, each subset \( \{ L_1, \ldots, L_i \} \) covers the same content and the higher number of layers we have, the higher quality video signal we obtain. Thus, it is more important to ensure delivery of lower layers than higher layers [17]. ALMA’s layered transmission is similar to a conventional layered transmission, except with customizable active packets, it is possible to use a potentially large number of layers.

In ALMA, a receiver subscribes to a data stream via a subscribe packet (active packet). The subscribe packet specifies the number of layers corresponding to the quality a receiver wishes to obtain (also called the subscription level), and the source address from which it wishes to obtain the stream(s). No group addresses are used and the receiver subscribes directly to the source. Once the subscription is successful, a receiver may begin to receive data from the sender. The data is carried from the sender to the receiver(s) via data packets (active packets). Each data packet has an associated “budget” based on the importance of the data it carries. Because higher layers have less priority than a lower layer, the data packets carrying data from a higher layer have a smaller budget value than a data packet carrying data from a lower layer.

Each link that the data passes through has an associated cost based on the average load on that link. An example of the formulae used is a convex increasing function, which forces a sharp rise in price for highly loaded links to prevent further allocation of the bandwidth (Figure 1):

\[
Price = 1000\sqrt{(1.01/(1.01\text{-load})-1000}
\]

![Figure 1. An example budget function to be applied to each layer (top), and the price function maintained by the node interfaces (bottom)](image)

The congestion control mechanism can be summarized as follows: When a data packet comes across a link, if the price of the link does not fit within the budget of the data packet, the packet is filtered out of the system before it can be sent out on that link. During any hike in link prices (reacting to a rise in the level of congestion), the higher layer data packets are discarded before lower layer packets. Data packets also prune from the multicast tree those branches that have persistent congestion [10]. After such pruning due to congestion, the number of layers a destination receives might be different from its desired subscription level. To overcome this issue, receivers monitor the number of layers they get and if the level is not what is desired, they spawn subscribe packets to probe for additional bandwidth. This combination of responsibilities means that the decision load is always distributed, with the active nodes deciding on pruning and the receiver nodes deciding on probing [10].

4. Resource Reservation Protocol

RSVP [5, 6] is an IntServ (Integrated Service) protocol that establishes a quality of service connection between two end hosts. RSVP uses a two-way handshake involving both the end hosts and the intermediate routers. It consists of two types of messages: PATH and RESV. To initialize, a data source sends PATH messages to a multicast group address, where each PATH message is associated to a unique data flow. These messages are intercepted by RSVP-enabled routers in the path, which set up a soft state for the associated data. A soft state consists of the previous hop, the next hop, and traffic characteristic information, and expires after a period unless refreshed explicitly. Once the PATH message reaches a receiver, and if the receiver decides to make a reservation, the receiver sends an RESV message to the sender. The RESV messages are thus the real requests for resource
reservations. The routers in the reverse path merge the messages (from the various interested receivers) as they travel back to the source. Once the messages reach the sender, a reservation tree is established with the sender as the root and the receivers as the leaves. On the way to the sender, the RSVP-enabled routers intercept the RESV messages and if sufficient resources are not available, an RESVERR message is sent back to the receiver (instead of having the RESV message continue towards the source). This error message provides a negative acknowledgement to the receiver and when intercepted by the routers on the return path causes the deletion of any soft states set up on the router previously (for this data flow), thus clearing up the network for future reservations [13].

5. Comparison

Internet users have high expectations and the industry sets its focus on extending the Internet in terms of the services offered. Thus, emerging applications and their enabling technologies continue to require enhanced functionality and fairness within the network. This treatise focuses on how well ALMA and RSVP meet the need for congestion control. The criteria of interest include functional abilities (enhanced functionality), TCP friendliness (fairness in terms of bandwidth), and real-world implementation, all discussed in more detail in the subsequent section. The functional measurement section compares the speed and stability of the two protocols along with any delays and overhead inherent to their design. The challenge for today’s Internet network managers is how to improve the performance of high-bit-rate multimedia applications over relatively slow TCP networks. One of the primary solutions to this problem is to upgrade the network routers with the protocols that provide the speed and stability required by these applications. This makes the functional features of a protocol very important for comparison. The TCP friendliness aspect compares the performance of either protocol when used in a TCP network. The peaceful coexistence of the protocol with TCP and the fairness of resource allocation are required to ensure smooth deployment of the new multicast protocol into the Internet. The implementation criterion deals with implementation and operational issues of the two protocols in real-world networks. This paper will bring out the advantages and disadvantages of both protocols and compare them qualitatively.

5.1 Functional Measurements

In order to evaluate the functionality of ALMA, particularly the speed and stability, the simulation results from [4] are examined, where one sender transmits data to four receivers via three routers (Figure 2).

![Figure 2. A single session ALMA flow [4]](image)

In the session, all receivers not only converge into optimal layers (highest number of layers, required to provide the Quality of Service (QoS), possible within the available bandwidth) quickly but also stay at the optimal layers during the entire simulation thus proving stability of the protocol. Even though the bandwidth of the links is smaller than the data transfer rate, no loss is documented for the entire simulation, thus showing that the links can accommodate the transfer rate and the ALMA mechanism is able to control the congestion.

Any time delays inherent to the design of the protocol will also have a negative effect on the speed of the protocol. In ALMA, when the level of service received by the subscriber is lower than the desired subscription level, the receiving host probes the network for additional bandwidth. This probing process results in a delay from the time that some bandwidth is released to the moment when new flows start to use it. However, this time-delay is a trade-off between how fast a reaction is desired and the amount of resources (bandwidth and active processing) that can be dedicated to the probing process.

In an active network using ALMA, the ALMA protocol maintains the responsibility of forwarding all data packets to all subscribing receivers. In order to provide this functionality, the multicast group information (also called the forwarding state) is stored in the active nodes in the path connecting the sender to the receiver. The amount of information kept in each active node is on the order of the state necessary to maintain one IP multicast, new receivers may join (or leave) the group thus making the protocol as scalable as any other multicast based traditional scheme.

For RSVP, the results of two simulations from [12] where one RSVP sender communicates with two RSVP receiver hosts via one RSVP router are examined. In the first simulation, a videoconference application (Vic) is tested on a network overloaded with background noise traffic. It is observed that the Vic windows on the receivers are less distorted during a reserved session than a non-reserved session, thus demonstrating RSVP’s ability to mitigate congestion and maintain QoS. In the second simulation, two RSVP sessions and two NonRSVP sessions are established with the same transmission rates of 100pkt/sec and 200pkt/sec. It is observed that the packet transmission rate of the two RSVP sessions is 87.787pkt/sec and 169.903pkt/sec and that of the two NonRSVP sessions is 27.21pkt/sec and 68.85pkt/sec. This demonstration of reserved traffic having a higher transmission rate than the non-reserved traffic further proves RSVP’s ability to provide enhanced QoS.

Like the active protocol, RSVP has time delays inherent in its design that affect the speed of the protocol. RSVP experiences an initiation delay (effective time to establish a reservation) equal to the interval between the time when the first PATH message is sent from the source LAN segment to the time the first RESV message is received at the source LAN segment. It also experiences a queuing delay caused by the packet-scheduling overhead when the network has a high number of real-time sessions. Real-time packet scheduling is required once the reservation states have been established in the routers in order to schedule the packets in the transmission queue associated with each output link to ensure that the real-time performance guarantee is met for the time. This overhead increases with the number of real-time sessions, because the packet scheduler cannot keep up with the
packet arrival rate. As a result, each real-time packet incurs extra queuing delay [1]. RSVP is also scalable to large networks due to the dynamic nature of the soft state mechanism. The soft state mechanism is the automatic invalidation of the reservation states installed on the network devices after a period, unless refreshed explicitly. This allows the recycling of the reserved nodes without their being explicitly freed by the reservations. This management of reserved resources optimizes the use of network nodes for the new reservations, thus allowing the protocol to scale for large multicast groups.

5.2 TCP friendliness

For this paper, the friendliness measure will be described as the ability of the protocol to improve TCP performance when put in a network together with TCP traffic. The performance improvement can be in the form of extra bandwidth or more bits per second for TCP in conjunction with the multicasting protocol [4][2]. The third simulation by Sari and Djemame [4], deals with the mix of a single ALMA session and two TCP flows (Figure 3). Both sessions (TCP and ALMA) are started at the beginning of their experiment with a rate set to 100 Kb/s. With the bottleneck link’s bandwidth set to 300 kb/s, the subscription level of the sender is set to the highest value (available in the simulation) of 17 layers in order to stress test the system.

Figure 3. A single ALMA session and two competing TCP flows [4]

In order to assess the friendliness of the ALMA protocol, Sari and Djemame calculated a ratio of the average throughput of ALMA over the average throughput of TCP to give a friendliness index of 1.048. However, for ALMA to be TCP friendly, the ratio has to be less than or equal to one, so they concluded that ALMA is unfriendly towards TCP because it uses more bandwidth during the simulations.

The research work by Jun, Zhihong, and Zhenming from Beijing University of Posts & Telecommunications was used to evaluate the TCP friendliness characteristics of RSVP. In an effort to improve the Quality of Service (QoS) of the Internet, the researchers performed a detailed analysis of TCP over RSVP [2]. Their simulation was based on the fact that as a reliable end-to-end protocol, TCP requires an acknowledgement (ACK) packet from the receiver to the sender, once every so many data packets have been received. Thus, the transmitting speed of TCP depends on the transmitting speed of the ACK packets, which are affected by any bottlenecks in the path linking senders and receivers. Because RSVP is a unidirectional protocol, it can reserve resource for the forward data packets, but if the ACK stream is treated with a different profile by the network, RSVP cannot guarantee resource for the ACK packets on the reverse trips. The simulation entailed six TCP streams, Server1 to Client1 with RSVP, and the other five server-client connections without RSVP. Thus in the reverse path, ACKs for the TCP RSVP connection had to compete with six forward TCP data streams. The throughput of both TCP with RSVP and TCP without RSVP was calculated and tabulated in Table 1. As demonstrated, the throughputs of both sessions are almost equal, thus stating that RSVP has no positive effect on the throughput of TCP due to the congestion of the reverse path. We calculated the average friendliness index as 1.014 thus showing that the RSVP protocol is unfriendly towards the TCP protocol.

Table 1. RSVP simulation results (extended data from [2] with the friendliness index measure)

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>Throughput (bits/sec)</th>
<th>Friendliness Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>With RSVP</td>
<td>No RSVP</td>
<td></td>
</tr>
<tr>
<td>360</td>
<td>4187</td>
<td>4030</td>
</tr>
<tr>
<td>576</td>
<td>6522</td>
<td>6305</td>
</tr>
<tr>
<td>1224</td>
<td>8612</td>
<td>8563</td>
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<td>9601</td>
<td>9549</td>
</tr>
<tr>
<td>3024</td>
<td>9807</td>
<td>9766</td>
</tr>
<tr>
<td>3564</td>
<td>9927</td>
<td>9892</td>
</tr>
</tbody>
</table>

5.3 Implementation issues

ALMA is not protocol-independent because it requires network specific information to be provided by the active routers and active packets in an active network. Hence, for ALMA, a pure AN environment where all packets and nodes are active is required, thus severely limiting the deployment of the protocol in current networks. Even though there are methodologies discussed in [14] that enable us to migrate to a mixed scenario of active and non-active nodes while at the same time keeping a pure AN abstraction, ALMA is unable to run on a purely classical non-active network.

On the other hand, an advantage of being based on active networks is that ALMA is an adaptive protocol, where all routes adapt to the availability of the resources. Therefore, the QoS is not based on a particular (reserved) route but on the layered communication (data streams) such that a change in route has no effect on the guaranteed QoS. However, the layered communication also makes it difficult to establish a good pricing structure because the amount of multicast forwarding state left in the nodes (detailed in section 3) does not increase with the number of layers. Therefore, it becomes difficult to separate the resource used by the different layers and thus difficult to assign a cost to the use of the resource.

Security is also a major challenge for an Active protocol, as accessible programmability creates numerous opportunities for damage. For example, the point at which programmability is exposed through the loading and execution of code in network devices needs to be crafted carefully to insure security [7]. Additionally, no known commercial routers support ALMA or Active protocols because the technology is predominantly in the research stage.
RSVP was designed to work with any routing protocol as long as the underlying protocol provides the required QoS. Protocols like ATM or IP with integrated services, very easily satisfy these requirements. Routing itself has some underlying issues because it is separate from admission control and therefore if the route changes, reservations must be re-made along the new route. These new reservations take time to set up or they might fail after setup. There are associated predicaments with using primary and secondary routes. For example, even if the secondary routes have enough bandwidth, they are still unusable when the primary routes do not have adequate bandwidth if other QoS criteria cannot be maintained throughout the new routes.

Another aspect of RSVP is that merging of flows in a commercial network makes it difficult to decide who pays for the service. The concern can be explained with the following example. Consider two distinct flows:

- **Flow 1**: Low delay, Low Bandwidth
- **Flow 2**: High Delay, high bandwidth

With RSVP, if a path with low delay and high bandwidth was available, the flows could be merged because the path would satisfy both flow 1 and 2, but it may cost much more (to the provider) than maintaining the two separate flows. Because the two users have asked for separate characteristics, developing a *pricing structure* that is fair to the users, cost-effective to the provider, and allows the merging of the flows under the price constraints of the system, becomes a commercial challenge.

Additionally RSVP is not widely available protocol even though Cisco routers have RSVP support [11] and a RSVP demon is available from USc ISI to run on Solaris and BSD Net 2 derivatives.

### 6. Discussion of Comparison Results:

<table>
<thead>
<tr>
<th>Section</th>
<th>ALMA</th>
<th>RSVP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality of Service maintained</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Delays inherent to Design</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>Scalable</td>
<td>Good</td>
<td>Fair</td>
</tr>
<tr>
<td>TCP Friendliness</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>Protocol Independence</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>Pricing Structure</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>Security</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>Commercial Support</td>
<td>Poor</td>
<td>Fair</td>
</tr>
<tr>
<td><strong>Overall</strong></td>
<td>Poor</td>
<td>Fair</td>
</tr>
</tbody>
</table>

Both ALMA and RSVP maintain the Quality of Service required for the multicast session as shown by the simulation results of [4] and [12]. ALMA receives a “Good” rating because of its quick and sustained convergence to optimal layers and we gave RSVP a “Good” rating because of its ability to provide a higher transmission rate to the data traffic when compared to non-reserved data traffic under similar conditions. Both protocols were given a “Poor” rating for time delays inherent to their design: probing delay for ALMA and initiation and queuing delay for RSVP. Both protocols are scalable for large networks, however ALMA’s ability to add new receivers without any change in the states maintained in the active nodes allows it to scale seamlessly, thus earning it a “Good” rating. RSVP earned a “Fair” rating because even though it does an excellent job of managing the soft states in the routers allowing a more efficient use of its resources, it may require the generation of new routes to accommodate the new receivers.

Both protocols were evaluated for TCP friendliness, and required a friendliness index value of less than or equal to one to be TCP friendly. Because ALMA was evaluated at 1.048 and RSVP at 1.014, both protocols were given a “Poor” rating in this category. ALMA also received a “Poor” rating for protocol independence because it requires an active network protocol base to run, whereas the RSVP protocol received a “Good” rating for protocol independence because it was designed to work with any routing protocol as long as the underlying protocol provides the required QoS. Both protocols were given a “Poor” rating for pricing structure because both have design issues that make it difficult to develop a viable economic model to use them commercially. ALMA was give a “Poor” rating for security issues due to the potential security holes at the numerous programmability points brought in by the base active architecture. Because RSVP has no known security issues, at this point it was given a “Good” rating for this category. With ALMA still in the research and design phase, no known commercial products support this protocol earning it a “Poor” rating in this category. RSVP, however, has limited commercial support under Cisco, Sun, and BSD and therefore received a “Fair” rating.

### 7. Conclusion & Summary

The paper compares two major innovations in congestion control: RSVP and ALMA. The purpose of the comparison is to bring out the advantages and disadvantages of an emerging technology ALMA, against a time-honored and tested technology, RSVP, in an attempt to further the development and research of congestion control solutions. Is ALMA really better or does it need more work?

A relative scale of, “Good”, “Fair” and “Poor” was used to rate both protocols under each category. The results of the comparison were tabulated and given one point for a “Good” rating, zero points for “Fair” and negative one point for a “Poor” rating. A negative total value would generate an overall “Poor” rating, a zero value an overall “Fair” rating and a positive value would merit an overall “Good” rating. ALMA, with six “Poor” and two “Good” ratings, earned an overall rating of “Poor”. RSVP, with three “Poor”, three “Good” and two “Fair” ratings, earned an overall rating of “Fair”. Thus, the comparison and evaluation results suggest that RSVP is indeed a better protocol and ALMA needs more work before it can be considered ready for deployment.

Several new research directions were also found during this comparative work, for solution in future paper(s). Because the results of this research provide a conceptual comparison of both protocols, a real-time comparison of RSVP and ALMA using an experimental setup would provide a more detailed look into the advantages and disadvantages of each and is suggested as a research path. Another direction is the comparison of ALMA and the Bi-directional RSVP developed in the works of L. Jun, Y. Zhihong, and L. Zhenming’s “Bi-directional resource reservation for TCP performance improvement” [2]. This modified version of RSVP overcomes the unidirectional limitation of TCP and improves its TCP friendliness, thus affecting one of the major comparison categories of our research. Inability to use either protocol in a commercial network due to the
lack of a realistic pricing structure was also a problem encountered, and research into the development of this pricing strategy is an interesting direction as well.

8. References


