Ad hoc On-Demand Distance-Vector Routing Scalability

Sung-Ju Lee[a] *sjlee@hpl.hp.com*
Elizabeth M. Belding-Royer[b] *ebelding@cs.ucsb.edu*
Charles E. Perkins[c] *charliep@iprg.nokia.com*
[a] Internet Systems & Storage Lab, Hewlett-Packard Laboratories, Palo Alto, CA, USA
[b] Department of Computer Science, University of California, Santa Barbara, CA, USA
[c] Communications System Laboratory, Nokia Research Center, Mountain View, CA, USA

As mobile networking continues to experience increasing popularity, the need to connect large numbers of wireless devices will become more prevalent. Many recent proposals for ad hoc routing have certain characteristics which may limit their scalability to large networks. This paper examines five different combinations of modifications which may be incorporated into virtually any on-demand protocol in order to improve its scalability. The scalability of current on-demand routing protocols is evaluated through the selection of a representative from this class of protocols. The performance of the un-modified on-demand protocol is compared against that of it combined with each of the scalability modifications. Each scheme's behavior is analyzed in networks as large as 10,000 nodes through detailed simulation. Based on the observations, conclusions are drawn as to the expected scalability improvement which can be achieved by each modification.

I. Introduction

Recent advances in the portability, power, and capabilities of wireless devices and applications have resulted in the proliferation and increased popularity of these devices. As the number of users continues to grow, wireless routing protocols will be required to scale to increasingly larger populations of nodes. Conference networking scenarios can require the formation of networks on the order of tens to hundreds of nodes, while many military applications can involve thousands to tens of thousands of nodes. Furthermore, as the deployment of wireless networks becomes more widespread, new applications may encourage the formation of large ad hoc networks. For instance, sensor networks may include thousands of sensors which must be able to self-configure and establish routes. Similarly, military battlefield operations often require the formation of ad hoc networks containing hundreds to thousands of soldiers and personnel.

This paper evaluates the scaling potential of on-demand ad hoc routing protocols by comparing a base routing protocol with the performance of it combined with various modifications. The Ad hoc On-Demand Distance Vector (AODV) Routing protocol is used as a representative of on-demand routing protocols. The scalability of AODV is investigated by evaluating its performance in networks as large as 10,000 nodes. Then, three methods for improving the scalability of ad hoc routing protocols are described and integrated into the AODV protocol for their evaluation. The modifications include an expanding ring search (AODV-ERS) for route discoveries initiated by a source node, a query localization protocol (AODV-QL) which also attempts to prevent the flooding of route requests, and the local repair (AODV-LR) of link breaks in active routes. Further, the methods for preventing discovery floods are each in turn combined with the local repair mechanism, to yield a total of five possible improvement algorithms. Each of these modification combinations is evaluated, through detailed simulation, in networks of up to 10,000 nodes, and compared with the results achieved by the un-modified AODV protocol. The purpose was to study the routing behavior of on-demand routing protocols in large scale networks, and investigate how enhancement strategies affect the performance. The contribution of this work is the analysis of the scalability characteristics of the AODV routing protocol, the addressing of the possible problems of on-demand routing in large networks, and the presentation of results and insights that suggest future directions of research for scalable ad hoc routing protocols.

Due to the space limit, we present only the partial results of our study. Readers are referred to [1] for the extended version of this work.

II. Simulations

The simulations used to evaluate the scalability of AODV and its modifications were implemented within the GloMoSim library. The simulations model networks between 50 and 10,000 mobile hosts placed randomly within the simulation area. The room size for each simulation was chosen so as to keep the node density approximately constant in the different size networks. A free space propagation model with a threshold cutoff was used in the experiments. The IEEE 802.11 MAC protocol with Distributed Coordination Function (DCF) is used as the MAC layer in the experiments. A traffic generator was developed to simulate constant bit rate sources. The size of data payload is 512 bytes. Twenty data sessions with randomly selected sources and destinations are simulated. Each source transmits data packets at a rate of four packets/sec. The random waypoint model is utilized as the mobility model. The minimum speed for the simulations is 0 m/s while the maximum speed is 10 m/s. The selected pause time is 30 seconds.

Figure 1 shows each scheme's throughput performance, where throughput is calculated to be the number of data bytes delivered to destination hosts. The figure shows that

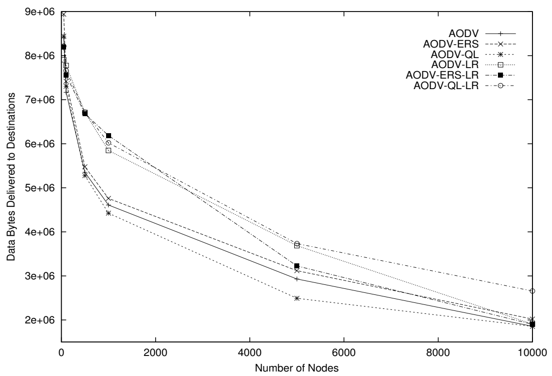

Figure 1: Throughput.

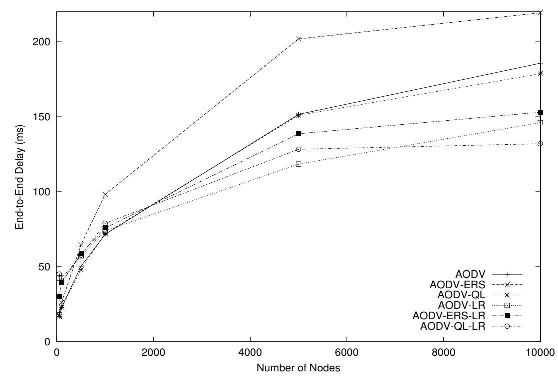

Figure 2: End-to-end delay.

the ability of the protocols to deliver packets to their destination degrades as the network size becomes larger. The path length is greater in larger networks because the simulation area and the number of nodes increase while the average number of neighbors is kept relatively constant. Routes are more prone to disconnections in mobile networks when path lengths are longer. Because any link failure along the path results in the inability of the source to reach the destination, longer routes have a greater probability of route disconnection than shorter hop routes. An increased route length in larger multihop networks is a characteristic not only of on-demand routing protocols, but any routing protocols. We observed that performing route repair locally improves throughput. Since nodes closer to the destination than the source re-initiate route discovery, new routes are repaired more quickly and fewer data packets are dropped. It is interesting to note that AODV-QL has the poorest throughput. The main purpose of query localization is to exploit node locality and reduce the number of routing message transmissions. Localizing the query, however, has the risk of not being able to establish the route.

The end-to-end delay for packet delivery of each protocol is reported in Figure 2. Schemes that utilize the local repair technique have shorter delays. Protocols in which sources initiate route repair have longer end-to-end delays because of longer route re-establishment latency. To recover a broken route, a RERR packet must first be delivered from the node upstream of the broken link to the source of the route. The RREQ must then be broadcast from the source to the destination, and a RREP consequently has to be transmitted back to the source. Data packets are buffered at the source node during this process and this duration of time adds to the end-to-end delay. In local repair schemes, on the other hand, the node upstream of the disconnected link initiates an immediate route reconstruction. Since route rediscovery is done locally, less time is needed to search for and obtain a new route. Local repair schemes can, therefore, yield shorter delays. Note that AODV-ERS has the longest delay because a route may not be built in the initial attempt (i.e., TTL = 1 or last known hop count of the route). Among local repair schemes, AODV-ERS-LR has the longest delay for the same reason.

III. Conclusion

This paper has evaluated the scalability of on-demand ad hoc routing protocols by selecting a representative from this set of protocols and simulating it in networks of up to 10,000 nodes. To improve the performance of on-demand protocols in large networks, five combinations of modification have been separately incorporated into an on-demand protocol, and their respective performance has been studied. It has been shown that the use of local repair is beneficial in increasing the number of data packets that reach their destinations. Expanding ring search and query localization techniques seem to further reduce the amount of control overhead generated by the protocol, by limiting the number of nodes affected by route discoveries.

While the performance improvements of the modifications have only been demonstrated with the AODV protocol, we believe that other on-demand ad hoc routing protocols will show similar improvements when incorporated with the modifications we studied. To verify this belief, however, remains as future work.

Scalability in ad hoc mobile networks is inherently difficult due to the mobility of the nodes and the transience of network links. Work on large-scale ad hoc networks is likely to uncover techniques that would be valuable for stabilizing routing protocols in the Internet at large, leading to faster route convergence and reduced route flaps. Creating ad hoc routing protocols which experience minimal performance degradation when used in increasingly large networks is a challenge, and there remains a significant amount of work to reach this goal.

References

[1] S.-J. Lee, E. M. Belding-Royer, and C. E. Perkins, “Scalability Study of the Ad Hoc On-Demand Distance-Vector Routing Protocol,” *International Journal of Network Management*, vol. 13, no. 2, March 2003.