Multipath Source Routing in Wireless Ad Hoc Networks

Lei Wang, Lianfang Zhang, Yantai Shu and Miao Dong
Department of Computer Science, Tianjin University
Tianjin 300072, China
w-lei@excite.com

Tel.: +86-22-27404394 ext. 681, Fax: +86-22-27404544
Oliver W.W. Yang
School of Information Technology and Engineering, University of Ottawa
Ottawa, Ontario, Canada, K1N 6N5
Tel.: (613) 562-5800 ext 6210, Fax: (613) 562-5175
yang@site.uottawa.ca

Abstract —In this paper, we propose a new multipath routing protocol for ad hoc wireless networks — Multipath Source Routing (MSR), which is based on DSR (Dynamic Source Routing). MSR extends DSR's Route Discovery and Route Maintenance mechanism to deal with multipath routing. Based on the measurement of RTT, we propose a scheme to distribute load between multiple paths. The simulation results show that our approach improves the throughput of TCP and UDP and the packet delivery ratio, and reduces the end-to-end delay and the queue size, while adding little overhead. As a result, MSR decreases the network congestion quite well.

Key words: Multipath Routing, Source Routing, Wireless Ad Hoc Network

1. Introduction

An ad hoc or multihop mobile wireless network is an infrastructureless network with no fixed routers, hosts, or wireless base stations. In ad hoc wireless networks, a remote mobile node interconnection is achieved via peer level multihopping technique. This implies that the interconnection topology can change dynamically, giving rise to many challenging research issues. In this environment, ad hoc routing is critical and has to be supported before any applications can be deployed for ad hoc mobile networks.

Congestion at the links and in the routers is the main cause of large delays in the Internet; the same is true in wireless ad hoc networks where bandwidths are always very limited. Routing protocols used in conventional wired networks (e.g., Bellman-Ford and link state) are not well suited for the mobile environment due to the considerable overhead produced by periodic route update messages and their slow convergence to topological changes. Also, all the Internet routing protocols in use today rely on single-path routing algorithms, which not only under-utilize resources, but also cannot cope with congestion and link breakage. It is because that all traffic for a destination should be routed through a single successor and when that link becomes congested or broken its whole traffic has to be rerouted, which is more time consuming in wireless networks. If link costs are made functions of congestion or delays, routing table entries can become unstable in single-path routing protocols. Multipath routing can overcome this problem; however, maintaining alternative paths requires much more routing table space and computation, especially for pre-computation based routing algorithms in large networks.

Many ad hoc routing protocols have been proposed recently, such as DSDV [1], TORA [11], DSR [3, 8], and AODV [2]. However, they are all single-path based. In this paper, we propose a new approach for multipath routing in ad hoc wireless networks — Multipath Source Routing (MSR), which is based on DSR (Dynamic Source Routing).

The rest of this paper is organized as follows. Section 2 gives a brief introduction to DSR protocol. Section 3 presents the MSR protocol. In section 4, the performance comparisons between MSR and DSR are discussed. We give the conclusion in section 5.

2. Dynamic Source Routing

DSR[8] uses source routing instead of hop-by-hop packet routing. Each data packet carries the complete path from source to destination as a sequence of IP addresses. The main benefit of source routing is that intermediate nodes need not keep route information because the path is explicitly specified in the data packet. DSR is on-demand based, that is, it

0-7803-5957-7/00/$10.00 © 2000 IEEE

does not require any kind of periodic message to be sent. The source routing mechanism, coupled with the on-demand nature of this protocol, eliminates the need for the periodic route advertisement and neighbor detection packets present in other protocols.

The DSR protocol consists of two mechanisms: Route Discovery and Route Maintenance. When a source has a data packet to send but does not have any routing information to the destination, the source initiates a route discovery. To establish a route, the source floods a route request message with a unique request ID. When this request message reaches the destination or a node that has route information to the destination, it sends a route reply message containing path information back to the source. The "route cache" maintained at each node records routes the node has learned and overheard over time to reduce overhead generated by a route discovery phase.

Route Maintenance is the mechanism by which a packet's sender S detects if the network topology has changed such that it can no longer use its route to the destination D because two nodes listed in the route have moved out of range of each other. When Route Maintenance indicates a source route is broken, S is notified with a ROUTE ERROR packet. The sender S can then attempt to use any other route to D already in its cache or can invoke Route Discovery again to find a new route.

3. MSR

We propose a multipath routing protocol MSR, which is based on DSR. MSR also uses source routing. Multipath routing can increase application performance by giving applications the freedom to use multiple paths within the same path service. On the other hand, maintaining alternative paths requires more routing table space and computation overload. However, some DSR's characteristics can suppress these disadvantages. First, Source Routing is so flexible that messages can be forwarded on arbitrary paths, which makes it very easy to dispatch messages to multiple paths without demanding path calculation in the intermediate hops. Second, the on-demand nature of DSR reduces the routing storage greatly.

There are three elements necessary to make multipath network viable: (i) appropriate paths calculated between nodes, (ii) efficient packet forwarding on calculated paths, and (iii) effective end-host usage of multiple paths. The three issues in MSR are addressed as follows.

3.1 Path finding

DSR's route discovery mechanism whereby multiple paths can be returned is employed in MSR. All the routes discovered are stored in the route cache with a unique route index for each. So it is easy for us to pick multiple paths from the cache. In multipath routing, path independence is an import property, because the more independent a path set, the more aggregate physical resources the set offers between a node pair (because those resources are not shared), and the less likely the performance of one path affects the performances of other paths. To achieve high path independent, the disjoint paths are preferred in MSR.

3.2 Loop-free problem

As the route is part of the packet itself, routing loops, either short- or long-lived, cannot be formed as they can be immediately detected and eliminated.

3.3 Packet forwarding and load balancing

Since MSR uses source routing, packet forwarding in the intermediate nodes does nothing but forwarding the packet as the route in its header indicated, adding no further processing complexity than that in DSR. All the work for path calculation is done in the source hosts. Then, for MSR, there are some works of load balancing to do in the source nodes. In our experiment, a special table containing multiple path information to the specific destination is built, as illustrated as follows.

```
struct mul_dest
{
        int index ;
        ID Dest;
        float Delay;
        float Weight;
                ...
};
```

Dest is the destination of a route. *Index* is the current index of the route in DSR's route cache that has a destination to *Dest*. *Delay* is the current estimate of the round-trip time. *Weight* is a per-destination based load distribution weight between all the routes that have the same destination. *Weight* is in terms of the number of packets to be sent consecutively on the same route every time. We choose the weight W_i^j (i is the index of the route to j) according to a heuristic equation (3-1):

$$W_i^j = \mathrm{Min}_j\left(\left\lceil \frac{d_{\max}^j}{d_i^j} \right\rceil, U\right) \times R \qquad (3\text{-}1)$$

where $d_{\max}^j$ is the maximum delay of all the routes to the same destination, d_i^j is the delay of route with index i, and R is a factor to control the switching frequency between routes. U is a bound value to insure that W_i^j should not to be too large. The larger the R's value, the less frequently the switching happens and the less processing overload of searching and positioning an entry in the mul_dest table. When choosing R, the IFQ[1] buffer's size should also be taken into considerations. In our experiment (IFQ size is 50), R is set to 1.

To aid the load balancing, a probing mechanism is employed. An RTT measurement tool for DSR and MSR in simulation, `SRping` is developed to get the RTT between two arbitrary nodes. When distributing the load, the weighted-round-robin scheduling strategy is used.

Probing is also an enhancement to the DSR Route maintenance mechanism. Normally, in DSR, a link breakage can be notified only when a Route Error message is returned. However, in wireless mobile environment, it has a nontrivial chance that the Route Error message can not reach the original sender successfully. Although, "as a last resort, a bit in the packet header could be included to allow a host transmitting a packet to request an explicit acknowledgement from the next-hop receiver"[3], probing one path constantly only to test its validity is not cost effective.

3.4 Optimization

An option can also be added to the MSR for optimization, allowing the packets on the fly to be rescheduled in the intermediate nodes according to their local multipath load distributing processes, if the intermediate nodes have paths to destination and they would like to do so. This forms the cascaded multipath routing, which makes full use of network resources without additional network overhead. When the intermediate node refills the remaining path (from current hop to the destination) to the packet head, one check is necessary to insure the loop-freedom. That is, the remaining path should not contain any node that has present in the path before. When a route error happens, it always needs a packet salvaging [8] process in the hop where the error was detected. If this node is heavily loaded, there will be a bursty traffic switching to the only alternative route in DSR, which is not what we want. However, this could be eased if multipath routing is used.

4. Performance Evaluation

4.1 Simulation environment

We use *ns* to conduct the simulation. CMU has extended *ns* with some wireless supports, including new elements at the physical, link, and routing layers of the simulation environment. Using these elements, it is possible to construct detailed and accurate simulations of wireless subnets, LANs, or multihop ad hoc networks. For scenario creation, two kinds of scenario files are used. The first is a movement pattern file that describes the movement that all nodes should undergo during the simulation. The second is a communication pattern file that describes the packet workload that is offered to the network layer during the simulation.

Our simulation modeled a network of 50 mobile hosts placed randomly within a 670m×670m area, with a maximum speed of 20m/s and pause time 0, which is a typical movement speed in wireless ad hoc network applications. There were no network partitions throughout the simulation. To evaluate the performance of MSR, we experimented with different application traffic, including CBR and FTP. CBR uses UDP as its transport protocol, and FTP uses TCP.

4.2 Metrics

In performance evaluation, we choose the following metrics:

- *Queue size:* The queue size of IFQ object at each node.

[1] The network stack for a mobilenode consists of a link layer(LL), an ARP module connected to LL, an interface priority queue(IFQ), a MAC layer(MAC), a network interface(netIF), all connected to the channel.[10]

- *Data throughput:* The total number packets received during a measuring interval divided by the measurement interval.
- *Round-trip time*
- *Packet Drop Rate*

Queueing delay is the major component of the overall delay that a packet encounters along its delivery path. We monitored every node's outgoing queue length. By analyzing the dynamics of every node's queue length, the network utilization status can be obtained. Conceptually, the multipath routing models increase network performance by effectively utilizing currently unallocated network resources (links and routers). Therefore, the throughput is expected to be improved.

The end-to-end delay is another metric that we are interested in. We use `SRping` to get the RTTs between two arbitrary nodes. In our experiment, we measure the RTTs according to the communication pattern file in which connections are defined.

Packet drop rate is one of the indicators for network congestion. In wireless environment, due to the physical media and bandwidth limitations, the chance for packet dropping is increased. Therefore, we choose it as one metric.

When evaluating a network routing protocol, control load should also be taken into considerations. There is no more control load in MSR than that in DSR, except for the probing packet transmitted in networks. Since we use unicast, rather than flooding, to test the validity of paths currently used, and the probing interval we choose is very conservative, there is little overload added.

4.3 Simulation Results

Figure 1 presents the average queue size for all 50 hosts. From figure 1, we can see that, in MSR, the packets that should have been queued in the IFQ have been redistributed to other nodes that have light load, through which the traffic is balanced. From figure 2 we can see that MSR achieves higher throughput than DSR almost at every time point, just as we expected. This can be attributed to the fact that the multipath routing effectively utilizes currently unallocated network. From table 1, we can see the packet drop rate has been improved. The reason is that balancing the route load shortens the delay as the chance of congestion is reduced. The RTT measurement average is shown in figure 2. We only measure RTTs between the nodes that have connections defined in the communication file. The results also indicate that the path availability has been improved

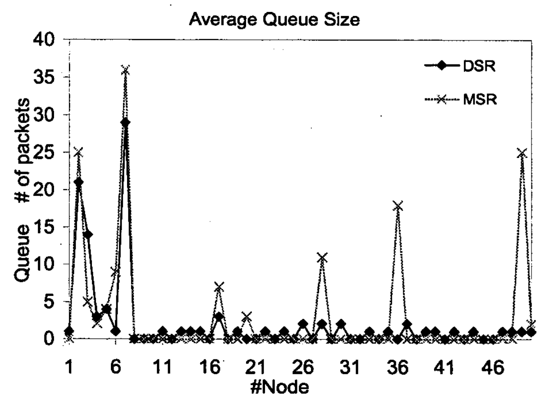

Figure1, Comparison of Queue Size

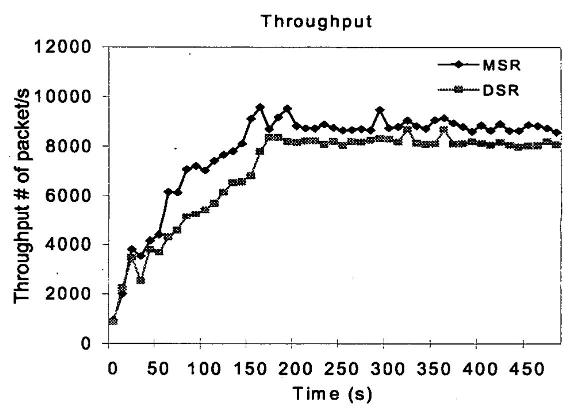

Figure2, Comparison of Throughput

Table 1, Packet drop rate comparison

Exp Seq.	DSR	MSR	Improvement
Exp #1	2.71e-3	1.09e-3	59.78%
Exp #2	8.73e-3	6.09e-3	30.24%
Exp #3	1.87e-3	6.34e-4	66.3%

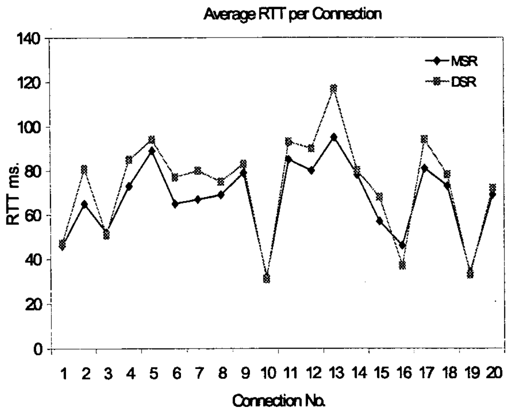

Figure3, Comparison of Average RTT

5. Conclusions

In this paper, a new wireless ad hoc network routing protocol, MSR is presented. Our protocol is a direct descendant of DSR. By incorporating the multipath mechanism into DSR and employing a probing based load balancing mechanism, the throughput, end-to-end delay, and drop rate have been improved greatly. The drawback of MSR may be the processing overload of originating the packets, however, fortunately the computer is becoming more powerful and cheaper. Thus, it may not be the obstacle to the deployment of MSR.

Acknowledgement

This research was supported in part by the National Natural Science Foundation of China (NSFC) under grant No. 69872025, the Natural Science Foundation of Tianjin under grant No. 993800211 and the Natural Sciences and Engineering Research Council of Canada (NSERC) under grant No. OGP0042878.

References

[1]. Charles E. Perkins and Pravin Bhagwat. Highly dynamic Destination Sequenced Distance-Vector routing (DSDV) for mobile computers. In *Proceedings of the SIGCOMM '94*, pages 234–244.

[2]. Charles E. Perkins. Ad Hoc On Demand Distance Vector (AODV) routing Internet-Draft, draft-ietf-manet-aodv-03.txt, June 1999.

[3]. D. B. Johnson and D. A. Maltz, "Dynamic Source Routing in Ad Hoc Wireless Networks," In *Mobile Computing*, edited by Tomasz Imielinski and Hank Korth, Chapter 5, Kluwer Academic Publishers, 1996, pp. 153-181.

[4]. Diamantis Kourkouzelis, Multipath Routing Using Diffusing Computations, *Master Thesis*, 1997.

[5]. Gary R. Wright and W. Richard Stevens. *TCP/IP Illustrated, Volume 2: The Implementation.* Addison-Wesley, Reading, Massachusetts, 1995.

[6]. J. Broch, D. A. Maltz, D. B. Johnson, Y-C. Hu, and J. Jetcheva. A performance comparison of multi-hop wireless ad hoc network routing protocols. In *Proceedings of the 4th International Conference on Mobile Computing and Networking (ACM MOBICOM'98)*, pages 85–97, October 1998.

[7]. Johnny Chen, New Approaches to Routing for Large-Scale Data Networks, *PhD Thesis,* 1998.

[8]. Josh Broch, David Johnson, and David Maltz. The dynamic source routing protocol for mobile ad hoc networks. http://www.ietf.org /internetdrafts/draft-ietf-manet-dsr-03.txt, June 1999. IETF Internet Draft (work in progress).

[9]. Karn, "Improving Round-Trip Time Estimates in Reliable Transport Protocols", In *ACM SIGCOMM*, pages 2–7, August 1987.

[10]. *ns*, Http://mash.cs.berkeley.edu/ns.

[11]. Vincent D. Park and M. Scott Corson. Temporally-Ordered Routing Algorithm (TORA) version 1: Functional specification. Internet-Draft, draft-ietf-manet-tora-spec-00.txt, November 1997. Work in progress.