EVALUATION OF MULTI-RADIO EXTENSIONS TO DSR FOR WIRELESS MULTI-HOP NETWORKS

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Abstract: Performance on multi-hop networks suffers from limited throughput capacity and poor scalability problems as the network size or density increases (Gupta and Kumar, 2000). One way to alleviate these problems is to equip each node with multiple radios. As hardware cost drops, this approach becomes more and more appealing and feasible. By tuning radios into non-interfering channels, the wireless spectrum can be more efficiently utilized, thus enhancing the whole network performance. This work extensively evaluates Dynamic Source Routing Protocol(DSR) (Johnson and Maltz, 1996) for multi-radio multi-hop networks. Through simulations, DSR with multi-radio extensions exhibits an overall performance improvement for throughput, packet delivery rate and latency.

1 INTRODUCTION

Unlike traditional wireless networks, a multi-hop network is a collection of independent wireless nodes that establish a network normally without any pre-established infrastructure. Each node can transmit data packets to other nodes within its radio range, and forward packets on behalf of other nodes.

Despite their flexibility and convenience to support diverse applications (Cordeiro and Agrawal, 2002), multi-hop networks are not yet widely deployed since they perform poorly as the number of nodes and/or hops increases (Gupta and Kumar, 2000). The poor performance mainly results from the inability of a wireless radio to transmit and to receive at the same time. Such a weakness halves the forwarding node capacity; in addition, simultaneous transmissions on the same frequency channel and the sub-optimal MAC back-off mechanisms exacerbate the limited capacity problem.

Many approaches have been proposed to alleviate the capacity problem. One approach is to explore directional antennas (Ko et al., 2000; Choudhury and Vaidya, 2002). Since directional antennas are able to focus energy in a given direction, they have some advantages over omni-directional antennas in multi-hop networks, such as less interference, longer transmission range and the increasing potential for spatial reuse, etc. Such features result in higher multi-hop capacity and better connectivity. However, replacing omni-directional antennas with directional ones will not fully exploit all the advantages. A number of adjustments are required at each layer of the networking protocol stack to accommodate directional antennas (e.g. broadcast problem, discovery of neighbors, etc).

Another approach consists of using multiple channels for each node. For example, the widely deployed IEEE802.11b standard supports 3 non-overlapping channels without interference. Users in infrastructure-based wireless networks already successfully exploit the multi-channel feature: different access points are assigned to different channels such that neighboring cells communicate on non-overlapping channels concurrently. Such channel assignment results in lower interferences and higher capacity (Lee et al., 2002; Tzamaloukas and Garcia-Luna-Aceves, 2001). However, this method cannot be applied “as is” to multi-hop wireless networks since neighboring nodes must communicate on the channel with same frequency. Some researchers suggest al-

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lowing each node to use multiple channels following a hopping sequence (Tyamaloukas and Garcia-Luna-Aceves, 2000). Receiver and sender nodes will follow some channel hopping sequence till they lock on a common channel. Unfortunately, a non-negligible switching latency (especially for off-the-shelf wireless network interfaces (Inc., 2004)) would negatively impact the performance.

Due to ever decreasing hardware cost, the switching latency can be eliminated by equipping each node with multiple radios: the radios on each node would be tuned on multiple non-overlapping channels, thus wireless nodes can send and receive independently and simultaneously on multiple channels. Therefore, with multiple radios on each node, the available spectrum could be more efficiently shared. However, after adding one or more radios to each node in multi-hop networks, routing data packets becomes more challenging in such scenarios. Although most well-known multi-hop routing algorithms have been so far extensively studied in case of mono radio nodes (Boukerche, 2004; Broch et al., 1998), far fewer studies exist for evaluating their performance when nodes are configured with multiple radios (Pirzada et al., 2006).

Some other research works also investigated the multi-radio nodes effect but most of them focus on the link-quality routing protocols and new routing metric such as (R. Draves and Zill, 2004; Couto et al., 2003). On the contrary, our work only extends Dynamic Source Routing(DSR) (Johnson and Maltz, 1996) to take advantage of multi radio feature and evaluates the ***Raw*** performance improvement due to multi-radio in multi-hop networks.

Extensive simulations are conducted to show that DSR with multi-radio extensions is very efficient for high traffic loads and exhibits a high delivery rate as well as a lower latency.

The rest of the paper is organized as follows: Section 2 briefly introduces the basic DSR scheme and describes our extensions to DSR to take advantage of the multi-radio nodes. Section 3 outlines the simulation settings. And Section 4 demonstrates and analyzes the experiment results. Finally, Section 5 concludes the paper.

2 EXTENDED DYNAMIC SOURCE ROUTING

Routing protocols for multi-hop networks are normally classified as *reactive* (or On demand) and *proactive* (Royer and Toh, 1999) protocols. Reactive routing protocols (e.g. AODV (Perkins and Royer, 1999), DSR (Johnson and Maltz, 1996)) create and maintain a route between a pair source-destination only when the source node needs to send packets to the destination node; In contrast, proactive routing protocols (e.g. OLSR (Clausen et al., 2003), STAR (Garcia-Luna-Aceves and Spohn, 1999)) require wireless nodes maintain routing tables for all nodes on the network.

Source IP	Request ID	Destination IP	RouteRecord Series

Figure 1: Simple RREQ Packet Format.

Broch et. al (Broch et al., 1998) evaluated multiple ad hoc routing protocols and concluded that Dynamic Source Routing (DSR) (Johnson and Maltz, 1996) is one of the best in terms of resources consumption in single radio multi-hop network. While DSR has been extensively studied in single radio networks, there is no work to our knowledge that evaluates its performance directly over multi-radio multi-hop networks. Thus this work extends DSR to work with multi-radio nodes scenarios and evaluates the performance of such extensions through extensive simulations.

DSR (Johnson and Maltz, 1996) is a reactive routing protocol specially designed for wireless multi-hop networks and it is based on the concept of source routing as the source node specifies in the packet's header the sequence of nodes to reach the destination.

The basic idea of DSR routing protocol lies in its route discovery process. When a source node *S* intends to communicate with a destination node *D* whose route is unknown, the source node *S* initializes a route discovery process by flooding out a route request packet (RREQ) to all its neighbors (RREQ simple format is illustrated in Figure 1). On receiving a RREQ packet, node *A* checks the destination address in RREQ packet's header: if *A* is the target node, it returns a route reply packet (RREP) to the initiator node *S* by following the path which is typically the reverse of RREQ Route-Record field. RREP will contain the sequence of nodes on the path from source *S* to target *D*; Otherwise, node *A* is just one intermediate node, thus node *A* caches the RREQ packet, appends its own address to the RREQ's Route-Record field, and rebroadcasts the updated RREQ. Node *A* discards the RREQ packet in case the same RREQ packet has already been previously received. After the source *S* receives RREP, it caches the route to send subsequent data packets to the specific destination node.

When a node is configured with more than one radio, radio indices are needed to make DSR aware of the existence of multiple radios. Figure 2 shows a simple network scenario with four nodes, in which

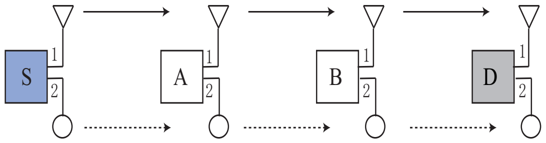

Figure 2: Simple Multi-radio multi-hop network.

Figure 3: Modified RREQ Packet Format.

every node has two independent radios (respectively represented by a triangle and a circle). The radios on each node are set to different non-overlapping channels such that they can independently work without any interferences. Since each node may have one or more radios in the multi-radio network, the route for a given path must include the radio index information to each hop. So on Figure 2, one possible path should be specified as: [(S,1)-(A,2)-(B,1)-D] where 1 and 2 indicate the radio index on each node.

Therefore some slight changes should be made to traditional single radio DSR in order to perform properly in multi-radio scenarios: each node needs to broadcast RREQ packets on all its radios; when an intermediate node gets the RREQ packets from any of its radios, the node should append not only its own address, but also the radio index to the route record to indicate on which radio it recieves the RREQ packet. As shown on Figure 3, a radio index field is added to DSR RREQ packet header.

Furthermore every radio within each node needs to send out a copy of RREQ packet in multi-radio networks. Thus many more RREQ packets will be generated causing more RREQ packet collisions than single radio networks, also at the same time increase the likelihood to lose RREQ packets with good routes information (broadcast packets are not retransmitted when lost). In single radio multi-hop network, DSR forwards only the first RREQ packet and discards further RREQ with the same request id and source address. Here, in multi-radio network, in order to increase the chances to get the shortest routes, the nodes are required to forward RREQ packets more greedily than single radio networks: That is the intermediate node forwards *again* a RREQ packet previously seen as long as the hop count is lower.

Table 1: Experimental Parameter.

Simulation Time	120 Seconds
Simulation Field	1500m*1500m
Propagation Mode	Two-ray Ground
Traffic Mode	CBR
Transmission Range	250 m
Number of Connections	5,10,15,20
Packet Size	1000 bytes
Traffic Interval	30 ms
Interface Queue	50

3 EVALUATION METHODOLOGY

3.1 Experimental Set Up

The efficiency of DSR on a multi-radio network is evaluated using ns-2 simulator. In our simulations, all nodes have the same number of radios and the radios on each node are assigned to different non-overlapping channels. The same channel allocation scheme is used for all wireless nodes.

The experimental multi-hop network consists of 50 nodes which are randomly positioned a field of $1500m^2$. All nodes are configured with two radios tuned to two non-interfering channel. Source node and destination node are randomly selected to start UDP connections. Each UDP connection sends CBR traffic with 1000 byte data packets every 30ms. To test the effect of various traffic loads, the number of connections is varied from 5 to 20 taking values 5, 10, 15, 20. For a given set of parameters, the experiment is repeated for 50 times with different starting time.

The performance metrics are obtained by averaging the results of 50 simulation runs. DSR on single radio network and DSR on multi-radio network are evaluated with same simulation setting. The simulation parameters are summarized in Table 1.

3.2 Comparison Metrics

Average Throughput, Packet Delivery Rate, Average End-to-end Delay, and Average Path Length are the metrics used to evaluate DSR routing protocol on multi-radio networks (Broch et al., 1998):

- Average Throughput measures the total number of data bits successfully received during the unit experimental time.
- Packet Delivery Rate measures the number of end-to-end packets successfully received over the total number of data packets sent.

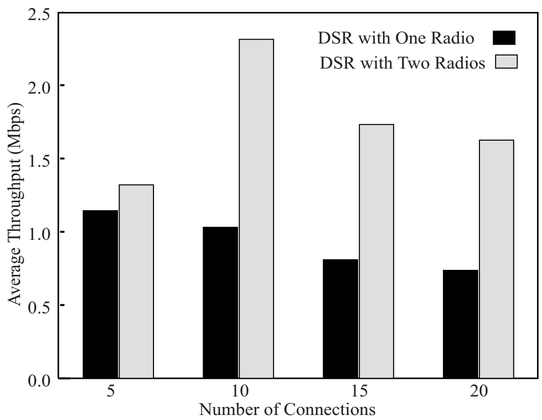

Figure 4: Average Throughput Vs. Connections.

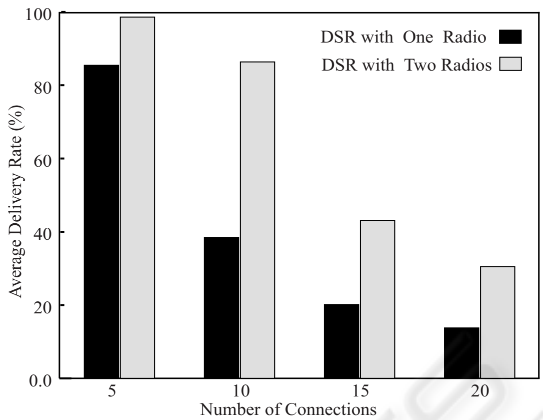

Figure 5: Average Packet Delivery Rate Vs. Connections.

- Average End-to-end Delay measures the average latency time for all successfully received data packets.
- Average Path Length is the average number of hops a packet took to reach its destination.

4 SIMULATION RESULTS

The simulations evaluated the impact of traffic load by varying the number of connections taking values 5, 10, 15, or 20. Promising performance results are obtained with extended DSR for multi-radio nodes.

All plots have the number of connections on the x-axis. Figure 4 plots the average throughput respectively achieved by DSR with single radio nodes and by extended DSR with multi-radio nodes, which illustrates a significant throughput improvement of extended DSR with the multi-radio nodes over DSR with single-radio nodes. The average throughout improvement reaches up to 93% for different connections. As the number of connections increases, the throughput enhancement is more dramatic.

The Packet Delivery Rate is plotted on Figure 5. As illustrated, more data packets are lost as the number of connections increases (traffic load increases). Losses may result from unavailable or incorrect routes, overflow of the buffers, and many other reasons. The Packet Delivery Rate for extended DSR on the multi-radio networks is usually better than DSR on single radio networks regardless of the number of connections.

Figure 6 plots the Average End-to-end delay respectively for DSR with single radio nodes and for extended DSR over multi-radio nodes. The delays significantly vary with the number of connections. As the number of connections increase, medium contention and retransmission increase causing more delay at each hop and more retransmissions. Although the average delay for extended DSR with multi-radio nodes is quite high for heavier traffic load, it remains dramatically lower than with DSR on single radio nodes. On average, the delay is four times smaller.

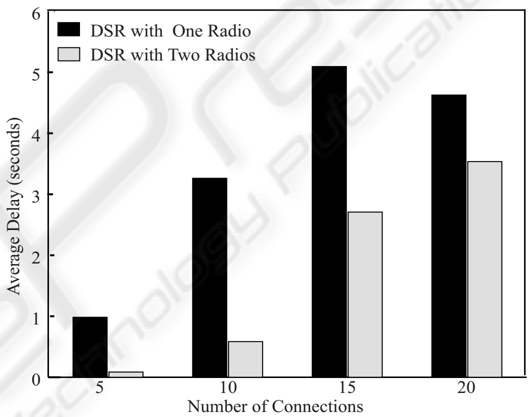

Figure 6: Average Delay Vs. Connections.

Figure 7 plots the Average Path Length. The leftmost column indicates the average shortest hop count that physically existed based on perfect and global knowledge of the network topology. The middle column and the rightmost column display the average hop length respectively taken by extended DSR with multi-radio nodes and DSR with the single radio nodes. Results show that extended DSR with multi-radio nodes finds more often the existing shortest path especially when the number of connections is high.

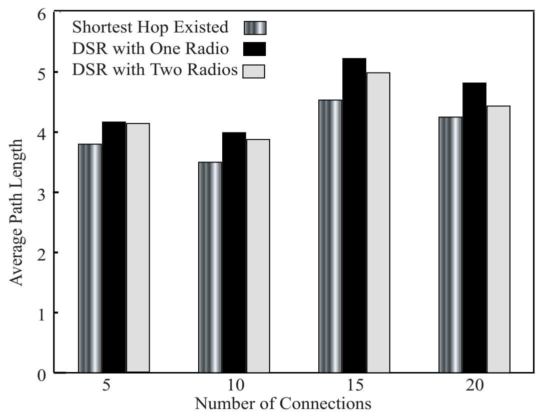

Figure 7: Average Path Length Vs. Connections.

5 CONCLUSIONS AND FUTURE WORK

This work evaluates the Dynamic Source Routing protocol performance on a multi-radio multi-hop network through extensive simulations.

Experimental results show a considerable improvement of overall performance over DSR with single radio nodes in terms of throughput, end-to-end delay, and packet delivery ratio. Therefore, by simply enabling Dynamic Source Routing to work with multi-radio nodes, we can exploit the wireless spectrum more efficiently. However, DSR adopts the shortest hop count to select the routing path, which is quite limited and does not fully take advantage of multi-radio feature in wireless multi-hop networks. It would be of high interest to consider paths with minimal interference and higher throughput. The authors are currently designing a metric similar to the one proposed by Draves and Zill (R. Draves and Zill, 2004) to take into account multiple criteria such as channel conditions and radio interferences.

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