Spatially Disjoint Multipath Routing Protocol without Location Information

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***Abstract*—Multipath routing permits the discovery and use of multiple paths between a source and a destination. We develop a distributed on-demand multipath routing protocol for MANETs capable of finding spatially disjoint paths without location information. The use of spatially disjoint routes in multipath routing is important due to the non-interfering nature of the paths. This enables applications such as load-balancing, bandwidth aggregation, secure communications and multimedia transmission. Most of the proposed multipath protocols for MANETs focus on reliability and are not adequate for these types of applications because of *route coupling* between alternate paths. We propose Spatially Disjoint Multipath Routing (SDMR) protocol, capable of finding multiple paths in one route discovery, measuring the distance between them and choosing paths with most separation. SDMR is evaluated through simulation.**

I. Introduction and Motivation

Various multipath routing protocols for MANETs have been proposed [1]–[5]. Most focus on providing fault tolerance, i.e. the capability of switching to alternate routes when a route fails. They only find link or node-disjoint paths, which in practice are spatially close to each other. When alternate paths are used simultaneously for load-balancing, data packets are distributed over the available paths, thereby improving the network utilization and end-to-end delay. For effective load balancing, the problem of *route coupling* arising from interference between alternate paths has to be addressed [5]–[9].

The developed SDMR protocol discovers multiple paths between two endpoints in one route discovery and measures the distance between the paths. It does not rely on previous knowledge of the topology or location information. The route discovery mechanism enables the discovery of paths that traverse all geographical regions (not only shortest routes).

II. SDMR

The basic concept of SDMR is as follows. A source node S that needs spatially disjoint paths to a destination D initiates a route discovery and receives a partial graph of the connectivity of the network (similar to link-state routing protocols). S then uses this graph to choose the most disjoint paths from a set of calculated paths between itself and D. In SDMR link-state is only sent to a source node, and only nodes which are in *valid* paths from S to D send it.

A. Protocol operation

Due to drastic space limitations, we can only briefly outline the operation of the protocol. The missing details can be found in [10].

By exchanging HELLO messages, nodes know their 1-hop and 2-hop neighbors, and select their Multipoint Relays (MPRs).

When a source node S needs spatially disjoint paths to a destination D it sends a *Route Request* (RREQ). The RREQ is flooded through the network using MPRs. The complete route to the source is recorded in RREQs by intermediate nodes. Because D must receive a set of reverse paths that traverse all geographical regions of the network, intermediate nodes forward multiple RREQs, but with certain restrictions to limit overhead.

In the *Route Reply* (RREP) phase, the link-state (1-hop neighborhood) of all nodes in the reverse paths has to be sent to S, so that it can build a partial graph of the network to compute spatially disjoint paths. Because D doesn't know this information, it sends RREPs to the source through the reverse paths and intermediate nodes include their 1-hop neighbors in the RREPs. It is not necessary for RREPs to traverse the complete set of original reverse paths RP_1. Because nodes know their 2-hop neighbors it is possible to compute a smaller set of reverse paths RP_2 such that by sending RREPs along the paths in RP_2 the 1-hop neighbors of all nodes in RP_1 can be received by the source. We use a heuristic algorithm to compute RP_2.

When S receives all RREPs it builds a partial graph of the network with the received neighborhood information. S computes a set of candidate paths between S and D doing breadth-first search (applying certain restrictions). Finally, the source chooses the pair of most disjoint paths and routes packets using source routing.

The distance between two paths p_i and p_j is measured as a weighted average of the distance of nodes of p_i to p_j. Nodes closer to endpoints receive less weight. The distance d_k of a node n_k of p_i to p_j is the minimum distance in hops from n_k to a node of p_j. d_k ranges from 0 to 3. Distance is 0 if n_k is common to both paths and is 3 if there are three or more

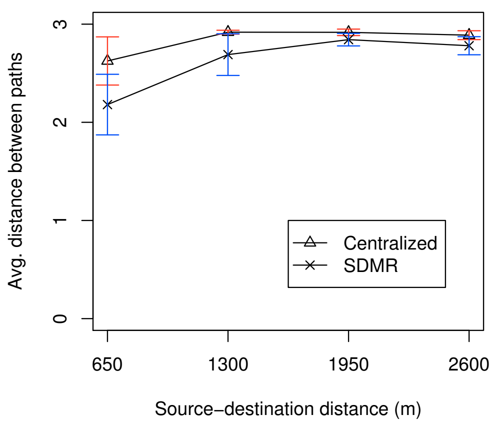

Fig. 1. Comparison of path distance between SDMR and centralized algorithm.

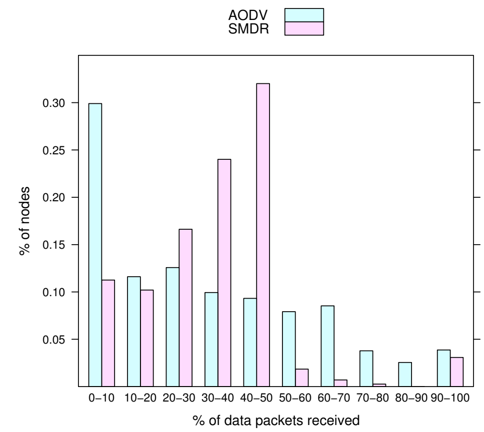

Fig. 2. Histograms of data packet reception. Under ten scenarios of 2000m x 2000m, 120 nodes and source-destination distance of 2600m.

hops from n_k to p_j. The distance between two paths p_i and p_j is calculated as:

$$distance(p_i, p_j) = \sum_{k=1}^{l} d_k \times w_k \quad ; \quad \sum_{k=1}^{l} w_k = 1 \qquad (1)$$

III. Performance Evaluation

We evaluate the capacity of SDMR of finding spatially disjoint paths using the ns-2 simulator. Scenarios consist of static networks of 120 nodes placed randomly in a 2000 x 2000 meter area.

First we study the optimality of the protocol by comparing the distances between paths found by SDMR and paths found by a centralized algorithm with complete topology information. Fig. 1 shows these results. As we can see, SDMR closely follows the behavior of the centralized approach. Path distance is measured following eq. 1.

In a second set of tests we evaluate the effectiveness of spatial separation with SDMR. For a transmission scenario with one source-destination pair, we compare the percentage of session packets nodes in the network can intercept when AODV and SDMR are used. SDMR distributes data packets along two disjoint paths in round-robin fashion. AODV uses a unicast route. We count the number of data packets every node receives, including nodes along routes used. Fig. 2 shows the percentage of nodes receiving a percentage of session packets. We can see that in SDMR substantially less nodes receive more than 50% of the session, compared to AODV. The effect of routing along disjoint paths in SDMR is that there are much more nodes receiving between 40-50% of the session: the session is evenly distributed along two paths, and the nodes along these paths and their neighbors can receive these packets. In AODV, since packets are routed along one path, less nodes will be able to overhear data packets, but in SDMR less nodes are able to overhear more than 50% of the packets. This may be particularly relevant for some applications such as enhanced security.

IV. Future Work

For future work we will study the possibility of optimizing the protocol in order to reduce route discovery overhead while maintaining a similar separation between paths found.

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