

PERFORMANCE OF MOBILE AD HOC NETWORKING ROUTING PROTOCOLS IN REALISTIC SCENARIOS

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ABSTRACT

This paper presents a comprehensive study on the performance of common MANET (mobile ad hoc network) routing protocols under realistic network scenarios. The routing protocols used in this study include AODV, DSR, OLSR, OSPFv2 and ZRP, which comprise a good mix of reactive, proactive and hybrid protocols.

The paper evaluates these protocols under simulation scenarios based on an actual exercise carried out under the DARPA FCS Communications Program. Mobility of the nodes was simulated using GPS logs from the field exercise. Traffic is simulated using a model of the traffic generation tool that drove traffic in the live exercise, and reads the same script files.

The simulation results produced by QualNet are first validated against the corresponding measurements taken from the exercise, and several network configuration parameters are then varied to examine the performance of these protocols under "what-if" scenarios. This simulation study together with its post analysis shows the performance of each protocol under specific conditions both quantitatively and qualitatively.

INTRODUCTION

The first part of this paper provides a simulator validation via throughput comparisons between the live exercise's reported results and those produced by QualNet simulation runs. The validation base scenario is a four hour simulation that involves live exercises with 19 mobile nodes and a base station. The nodes follow a dual counter rotating ring mobility pattern comprising of an inner loop and an outer loop. There are 5 inner loop nodes and 14 outer loop nodes. The outer loop nodes rotate clockwise whereas the inner loop nodes rotate counter-clockwise.

The second part of the paper utilizes QualNet simulation runs to conduct a protocol comparison of AODV, DSR, OLSR, OSPFv2, and ZRP, on the identical network scenario. We provide analytical results that allow us to compare the relative performance of these MANET routing protocols in delivering the five traffic types that were present in the live exercise.

QualNet's analysis capabilities allow the modeler to analyze the quantitative performance of protocols in terms of control overhead, route acquisition delay, and route acquisition success rate. Qualitative protocol performance can be measured in terms of packet delivery ratio, latency, and jitter of data packets. It can also provide statistical data on protocol performance when subject to increasing network size, increasing number of hops between sources and destinations, node density, network load, number of source and destination pairs, and increasing mobility.

ROUTING ALGORITHMS

Open Shortest Path First (OSPF)¹ routing represents a traditional wired routing protocol. It is a link state algorithm that distributes the state of links in the network between the routers. These routers use the link state information to construct a shortest path tree to all destinations, installing the destinations, associated cost and the next hop to reach those destinations in the IP forwarding table.

On demand routing protocols such, as Ad hoc On-demand Distance Vector (AODV)² routing and Dynamic Source Routing (DSR)³, are more suited for ad hoc environments than traditional wired routing protocols, because they

¹ The intra-domain routing protocol OSPF version 2 as described in the latest RFC 2328

² Implementation according to IETF Internet Draft 9 of AODV (draft-ietf-manet-aodv-09.txt)

³ Implementation according to IETF Internet Draft 7 of DSR (draft-ietf-manet-dsr-07.txt)

dynamically find routes when necessary, thereby greatly reducing route storage. Since on demand routing protocols only save route information as needed, they should be more adaptable to large network populations and ever changing network topologies. However, such adaptability comes at a cost: namely the introduction of latency in searching for routes, increased routing control overhead for increased network load, and the loss of control over path quality.

Optimized Link State Routing (OLSR)⁴ protocol is a link state protocol designed for the challenges of the ad hoc network. The protocol utilizes multipoint relays (MPRs) which are a subset of the total number of nodes, which forward broadcast messages during the flooding process. Link state information is generated only by nodes elected as MPRs, and the link state updates need not include total link state information.

The Zone Routing Protocol (ZRP)⁵ is a hybrid framework composed of a proactive link state routing protocol, which manages routes within the configured radius (zone), and a reactive routing protocol that requests routes for destinations outside the zone. This configurable radius needs to be tailored to the target network scenario, but blends the advantages of each routing style.

Our definition of performance is the level to which a routing protocol provides applications with high throughput and low end-to-end delay, relative to the network scenario. Furthermore, the routing protocol itself must use minimal routing control overhead and exhibit high packet delivery ratio (which correlates to high application throughput).

In this scenario, the routing protocols must be robust with respect to channel noise interference, multiple paths between sources and destinations, number of hops between the source and destination, and a high amount of mobility related link changes. The routing protocol must handle the large network load in addition to its own control packet overheads.

REALISTIC SCENARIOS

The base scenario is a 4 hour simulation based on live exercises with 19 mobile nodes and a base station. We used IEEE 802.11b WaveLAN radios with omni

⁴ Port of INRIA implementation of IETF Internet Draft 3 (draft-ietf-manet-olsr-03.txt) of OLSR in C for Linux.

⁵ Implementation according to IETF Internet Draft 4 of ZRP (draft-ietf-manet-zone-zrp-04.txt), Draft 1 of IARP (draft-ietf-manet-zone-iarp-01.txt), Draft 2 of IERP (draft-ietf-manet-zone-ierp-02.txt), and Draft 2 of BRP (draft-ietf-manet-zone-brp-02.txt)

directional antennas, mobility from the GPS logs of the live exercises, and a port of the traffic generator from the exercise to drive traffic generation in the QualNet model.

The nodes follow a dual counter rotating ring mobility pattern comprising of an inner loop and an outer loop. There are 5 inner loop nodes and 14 outer loop nodes. The outer loop nodes rotate clockwise whereas the inner loop nodes rotate counter-clockwise.

The traffic generated falls into five categories. The first is High Rate traffic, either 120 kbps or 200 kbps of 1 KB packets, depending on the source/destination pair throughout the entire simulation. The second is High Rate Report traffic, from four of the mobile nodes to the base station, with an average of 40 kbps of 1 KB packets, beginning at 900 seconds into the simulation and continuing to simulation end. The third is Bidirectional traffic, averaging 40 kbps between randomly selected node pairs, for 300 seconds each flow. There are 69 such flows throughout the course of the exercise. Finally, there are 15 Low Rate Report traffic sessions, with mobile nodes sending 100 byte packets to the fixed base station at an average of 0.8 kbps throughout the simulation run.

SIMULATOR VALIDATION

The traffic generator produces a log of the received throughput over time in kbps. We present an example of the generated graphs that are indicative of the level of conformance between the field measurements and the QualNet runs for each category of traffic. The first is an example of High Rate traffic between nodes 14 and 13.

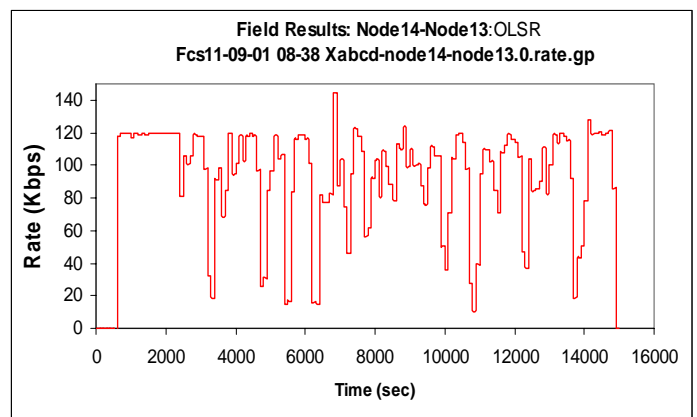


Figure 1. Field Results of Node14-Node13 Throughput using OLSR

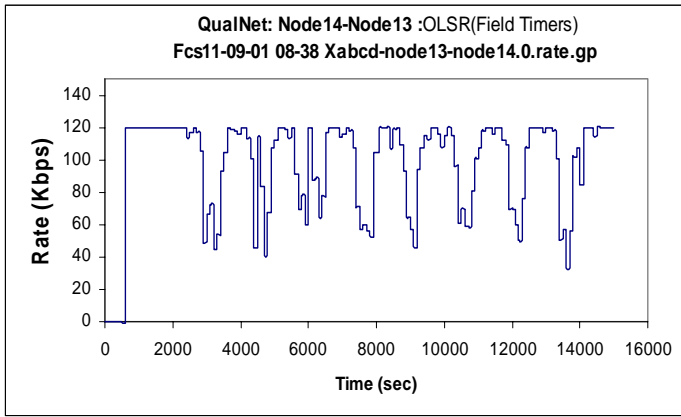


Figure 2. QualNet Simulated Results of Node14-Node13 Throughput using OLSR

The QualNet run shows somewhat less variability in this flow than the field exercise, but tracks reasonably closely in maximum throughput and the times during which reduced throughput are noted.

The next set of graphs shows the reported throughput for High Rate Report traffic between node 15 and the base station:

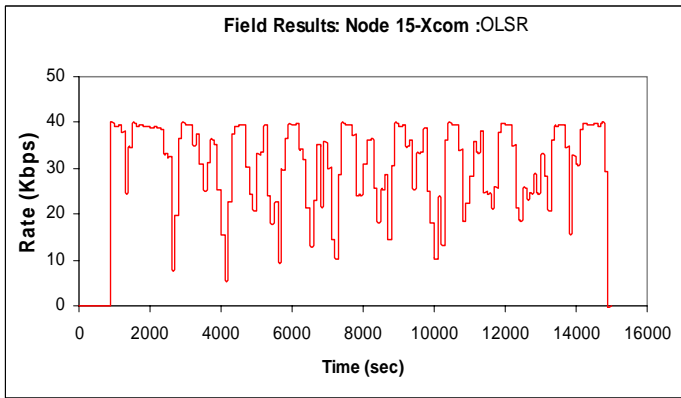


Figure 3. Field Results of Node15-XCom Node Throughput using OLSR

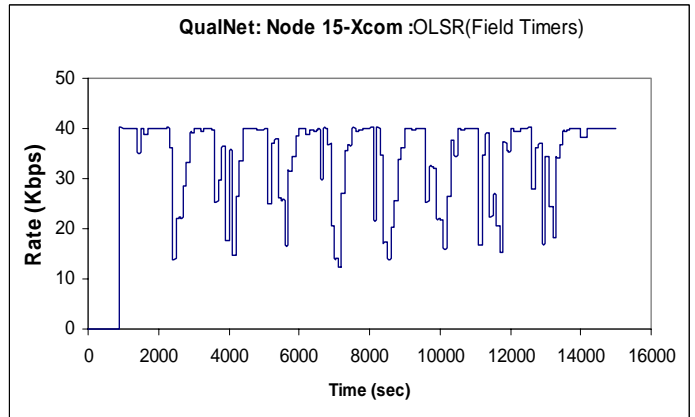


Figure 4. QualNet Simulated Results of Node15-XCom Node Throughput using OLSR

Again, the QualNet run is showing less variability, but tracking at a similar level on the timing of lowered throughputs. Even though the traffic generators produce packets at the same rate in QualNet and during the field exercise, we do not expect a perfect match because of differences due to propagation modeling, and differences in the random number streams used by QualNet and the live exercise for MAC backoff timers, etc.

The third set shows throughput at node 16 for the Bidirectional traffic class.

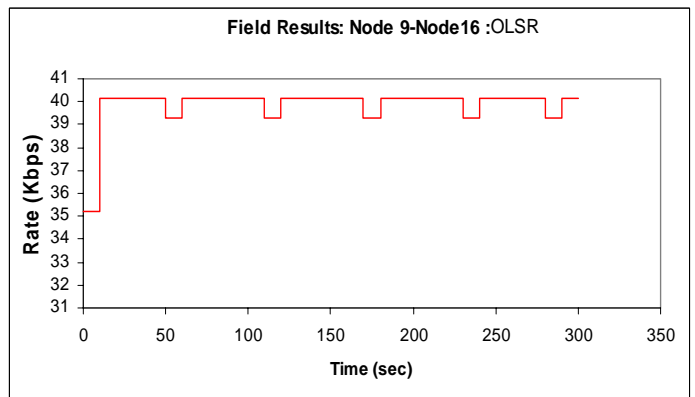


Figure 5. Field Results of Node9-Node16 Throughput using OLSR

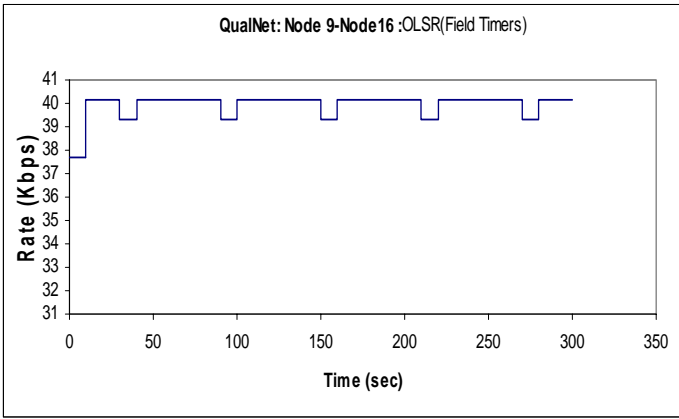


Figure 6. QualNet Simulated Results of Node9-Node16 Throughput using OLSR

This set of data shows the closest match between QualNet and the live exercise, as these were two nodes within one hop of each other, sending for a relatively small amount of time.

The final set shows Low Rate Report traffic received by the base station from node 13.

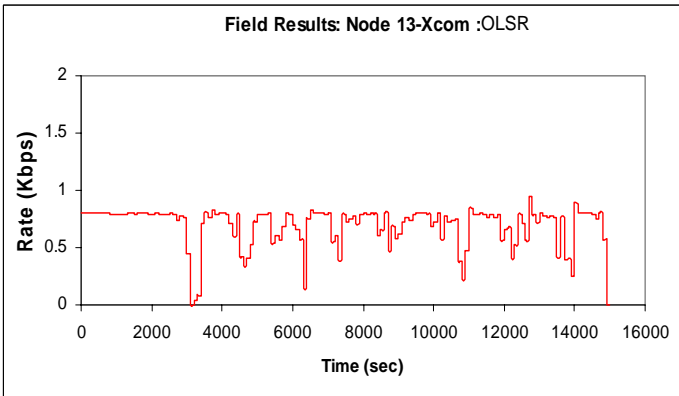


Figure 7. Field Results of Node13-XCom Node Throughput using OLSR

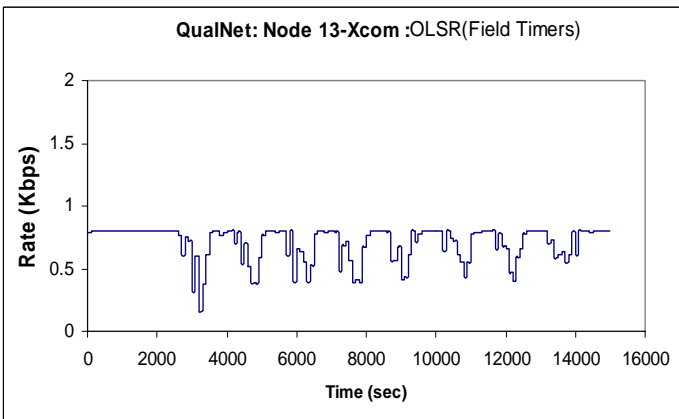


Figure 8. QualNet Simulated Results of Node13-XCom Node Throughput using OLSR

As with the first two types of traffic, we are seeing correlation between the QualNet and field experimental results, with reduced variability on the QualNet side. Another potential contributor to this reduced variability is the absence of fading effects, and interference from sources other than the radios themselves (vehicles, power lines, buildings, etc.).

PROTOCOL COMPARISON

The QualNet network simulator was used to generate the following graphs, which illustrate the comparison between the Field measurements (using OLSR), and the QualNet simulated runs using OLSR, AODV, OSPFv2, and ZRP, with their default parameter settings. These are aggregate percentages of packet receptions for each node pair that participated in the traffic type.

The first graph shows the results for High Rate traffic. These connections are either 120 kbps or 200 kbps flows of 1 KB packets, depending on the source/destination pair, transmitting throughout the entire simulation.

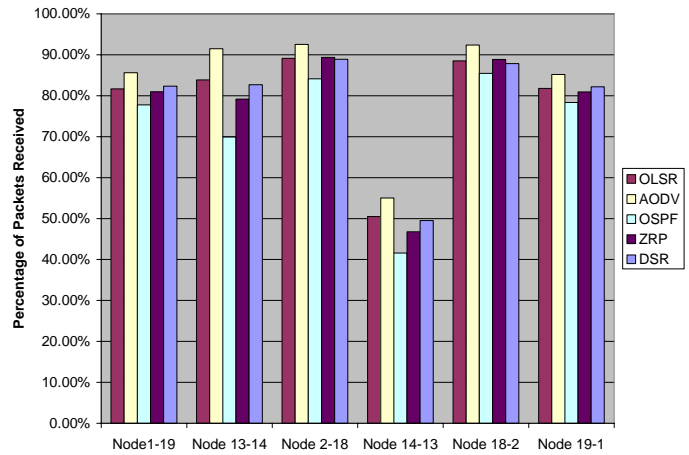


Figure 9. QualNet Simulated High Rate Flow Throughputs

The graph demonstrates that AODV has an edge over the other protocols in successfully delivering data to receivers. However AODV, this graph does not depict the control overhead comparison between protocols, or the latency experienced by these flows. DSR, OLSR, and ZRP are close behind, and OSPFv2, as a traditional wired protocol, trails slightly on all flows. However, none of the protocols are dramatically worse than AODV on delivering high traffic flows. This set of traffic results is important because they represent the highest bandwidth flows in the scenario.

The second graph shows a subset of the 69 bidirectional flows. These flows 40 kbps between randomly selected node pairs, for 300 seconds each flow.

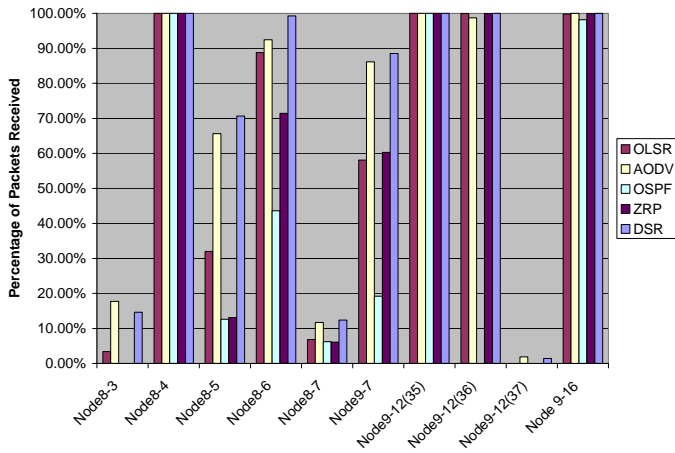


Figure 10. QualNet Simulated Bidirectional Flow Throughputs

This graph highlights the fact that on-demand routing, represented by DSR and AODV was the clear victor in the packet delivery statistic. DSR and AODV were the only routing protocols able to deliver packets in all flows (albeit very few between nodes 9 and 12, flow #37), and delivered more packets for all pairs except one in this sample. ZRP appears to be the next most successful, which further suggests that on-demand routing is most suited to these particular flows. OSPFv2 was unsuccessful in delivering any packets between three of the node pairs, and is a distant last place.

The next graph shows the packet reception percentages for High Rate Report traffic, averaging 40 Kbps between four nodes and the base station.

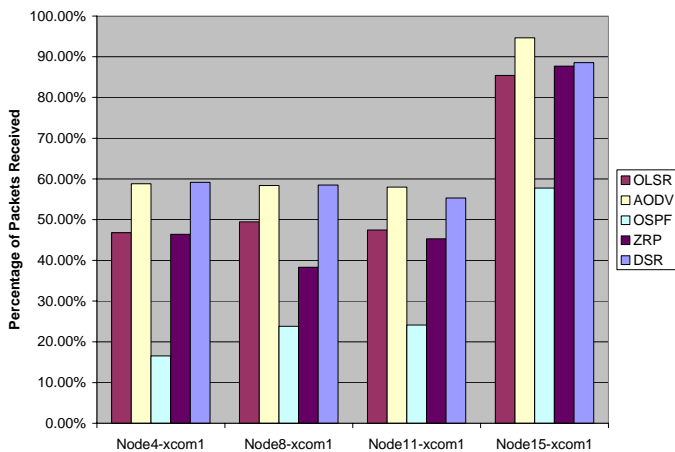


Figure 11. QualNet Simulated High Rate Report Flow Throughputs

This graph continues to demonstrate that OSPFv2, in an unmodified form, is not suited to the realistic scenario we used. AODV and DSR lead the pack, with OLSR and

ZRP measurably behind. However, as a proactive link state protocol, OLSR does not demonstrate the convergence difficulties of OSPFv2, and may be a suitable alternative if low route acquisition latencies are important.

The next graph shows the results for the 15 Low Rate Report traffic sessions, with mobile nodes sending 100 byte packets to the base station at an average of 0.8 kbps throughout the simulation run.

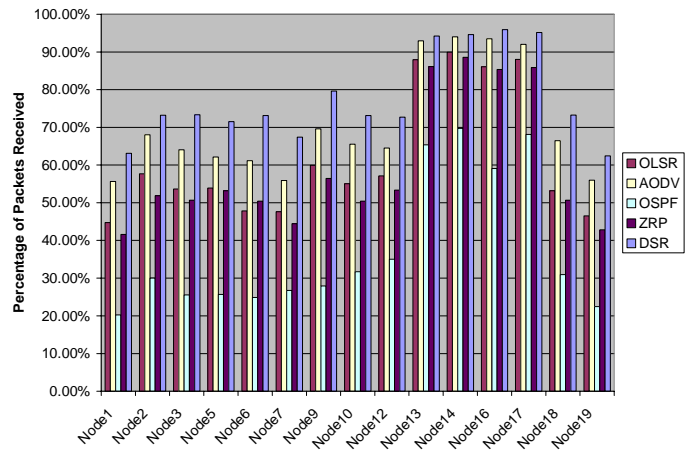


Figure 12. QualNet Simulated Low Rate Report Flow Throughputs

This graph indicates that DSR was more successful than AODV at delivering low data rate report flows (with many source, destination pairs), and that on-demand routing, represented by these two protocols, was the most successful in this scenario. OSPFv2, even with these small data rate flows, lags painfully behind, sometimes delivering less than half the packets of AODV. OLSR performed better than ZRP, making the race for second place difficult to call.

The final graph below illustrates the latency differences between the protocols. It graphs the Packet Delivery Ratio (PDR) on the Y-axis, and the delay in seconds, logarithmically, on the X-axis. Protocols that have similar PDRs may take more or less time, on average, to deliver those packets, and in this comparison, they did.

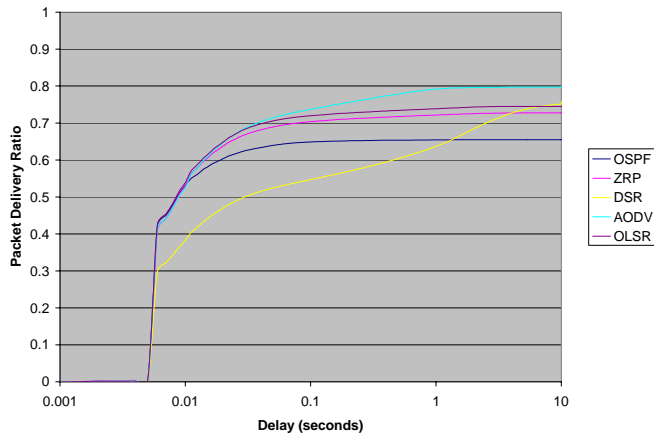


Figure 13. Delay vs. PDR, logarithmic scale

While previous graphs indicated that DSR, OLSR, and ZRP were similarly successful, this graph shows that DSR's packets incurred a significantly larger delay. Only after 7 seconds or so, did DSR catch up and surpass ZRP and OLSR on the PDR.

CONCLUSION

QualNet simulations can be configured to accurately model realistic scenarios in the field with good correlation on the end to end statistics. These simulations can then be extended, or re-run with different parameters, to provide the modeler with the ability to answer additional questions about network performance and optimization, without resorting to costly and time-consuming field exercises.

This paper demonstrates this capability by conducting a performance comparison of several MANET routing protocols using the network and traffic configuration from the live exercise. This comparison shows that the AODV protocol performed the best in this type of scenario, with a slight edge in overall throughput, and a lower overall delay-PDR curve.

It is important to note that these results are specific to the particular network scenario we ran, without parameter tuning. It provides a good indicator of how suited each protocol is, by default, to this type of live exercise, and a good starting point for analysis and parameter experimentation.

We would expect this type of experimentation to yield ZRP parameters that would allow its performance to approach that of AODV, and perhaps scale to larger versions of this scenario with a gentler increase in control overhead, given the hybrid proactive and reactive algorithm. OLSR showed good resilience to a suboptimal

link state situation, where routes are constantly changing as the nodes move in counter-rotating circles and the network picture never permanently converges. DSR incurs some additional delay in its algorithm, but its PDR curve suggests that as the delays in the network grow and the network size scales, it may prove able to deliver larger percentages of traffic.

ACKNOWLEDGEMENTS

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