

Using Probabilistic Multipath Routing to Improve Route Stability in MANETs

Fabian Rump
University of Bonn
rumpf@cs.uni-bonn.de

Sascha Alexander Jopen
Fraunhofer FKIE
sascha.jopen@fkie.fraunhofer.de

Matthias Frank
University of Bonn
matthew@cs.uni-bonn.de

Abstract—Many MANET routing protocols do not perform well in dense scenarios with high network load. In these situations, we can observe a high level of route instability, which is often called “route flapping”. In this paper we present the PRIME routing protocol, which uses a probabilistic multipath forwarding process to increase route stability in dense scenarios with high network load. We describe the routing protocol and propose different scenarios to evaluate the protocol performance. We compare the behavior of our protocol with the well-known OLSR and AODV protocols in those scenarios. The evaluation results show that the PRIME routing protocol does in fact have a positive impact on route stability and can improve the overall network performance in situations with high network load.

I. INTRODUCTION

Mobile Ad-Hoc Networks (MANETs) are self-organizing networks without a centralized infrastructure and depend on the cooperation between the participating nodes. Specifically, a MANET node may need to forward packets of other nodes in order to transport the packets to a destination node. In addition MANET routing protocols must deal with the constraints specific to MANETs, such as frequently changing topology, limited energy and low processing power.

Most well-known MANET routing protocols use a deterministic strategy to discover routes to a destination node and then use this route until the route breaks or a better route is discovered. In scenarios where high load is present between two communicating nodes, this behaviour can lead to an undesirable situation where the MANET routing protocol is frequently switching between multiple available routes even though the topology of the network did not change, which may result in uneven load distribution, network instability and reduced traffic throughput [7]. This problem is often denoted as “route flapping” [9]. Route flapping can be a significant problem, since it affects not only the end-to-end network performance but can also lead to imbalanced use of the resources on the MANET nodes.

To overcome this problem, the participating nodes should share the network traffic among the available links in a different way. Instead of selecting only one route, multiple routes could be used in parallel. This approach is generally called multipath routing and has been studied before. However, most of the proposed solutions employ rather complex computations to find and maintain the available routes, which may be unfavorable given the limited processing power of MANET nodes.

In contrast to the previously proposed solutions we have found a simpler approach which is still able to reduce the effects of route stability in scenarios with high network load. To achieve this, we use a weighted probabilistic forwarding mechanism. Specifically, we propose the PRIME (Probabilistic Routing In Mobile Environments) routing protocol, which is a proactive distance-vector based protocol for MANETs. We will show that PRIME can significantly improve the stability of routes in high load scenarios.

By improving route stability we obtain a better network performance: If a route changes or breaks down completely for a short period of time, dropouts in the transmission occur. Reducing the number of route changes improves the end-to-end packet delivery characteristics. Hence for applications such as video streams or voice calls we get a more stable application performance if the route instability is minimized. Furthermore the load generated on the forwarding nodes will be distributed more evenly, which is a desirable effect regarding the limited node resources.

The remainder of this paper is structured as follows: In Section II we give an overview about related work in the area of multipath routing in MANETs. We will describe the proposed PRIME routing protocol in Section III. The environment and scenarios used to evaluate the proposed protocol are detailed in Section IV. The evaluation results are presented in section V. Finally, we will conclude the paper and give a brief overview about future work in Section VI.

II. RELATED WORK

A. Singlepath routing protocols

In order to compare our results with well-known singlepath routing protocols, we will refer to the OLSR and AODV protocols in our evaluation. The Optimized Link State Routing (OLSR) [1] protocol basically works by sending out beacon packets in regular intervals to detect other nodes inside the transmission range of a node. The neighborhood information of each node is then disseminated inside the network. Routes can be obtained from that information by calculating the shortest path to each destination. Ad-hoc On-demand Distance Vector Routing (AODV) [8] uses route request (RREQ) packets. RREQs are sent as broadcast packets and are replicated by other nodes until the RREQ reaches the destination node. This route is then sent back to the source node with a route reply (RREP) packet. If a link between two nodes that is part

of an active route breaks, a route error (RERR) packet is sent. The involved nodes can then try to find another route to the destination.

B. Routing metrics

Routing metrics are used to differentiate between the quality of the available paths. The OLSR and AODV protocols use the hop count metric ([1], [8]) and might prefer a route over a weak link only because the route is shorter than the other available routes. This may lead to route instability when high load is inflicted on that link [3]. To improve the route stability in such scenarios, De Couto et. al. proposed the Expected Transmission Count (ETX) metric [2] which takes into account the quality of each link. Thus in theory a routing protocol using the ETX metric should be able to select stable routes. However, recent studies of the performance of ETX conducted by Tran et. al. [11] indicate that the link quality estimation is negatively affected by high network load. Hence, the performance of ETX may degrade significantly under high load conditions. This shows that changing the routing metric is generally not sufficient to improve route stability in high load scenarios.

C. Multipath routing protocols

To mitigate the effects of route instability, different solutions to employ multipath routing in MANETs have been proposed. A common approach is to compute multiple node-disjoint or edge-disjoint paths. One example is Split Multipath Routing (SMR) introduced by Lee et al. [5]. In SMR, similar to the AODV protocol, RREQ packets are propagated from a source node through the network until one or multiple copies of the RREQ packet reach the destination node. For each replicated RREQ packet, the forwarding path is recorded in the header. Thus, if a destination node received multiple copies of the packet with different paths, it may compute multiple disjoint paths. Depending on the number of nodes in the network, this computation is rather complex. Additionally, the number of available paths is limited and the complete route discovery process has to be repeated when the network topology changes.

A different approach to improve route stability is the combination of multipath routing with QoS mechanisms. The Multipath Dynamic Source Routing protocol (MP-DSR) proposed by Leung et al. [6] is based on calculating the end-to-end reliability by evaluating the quality of the available paths. During the route discovery process, only those paths which satisfy a certain reliability requirement are considered as valid routes. Though the MP-DSR protocol lacks optimization specific to high load scenarios and it is doubtful if the reliability estimation mechanism of the protocol can perform well in such scenarios.

Another QoS-based multipath protocol proposed by Sarma et al. [10] is named SMQR. The SMQR protocol uses hop-by-hop admission control and resource reservation to ensure the proper operation of real-time applications in MANETs. Information about the delay and the bandwidth of the wireless links is obtained through cross-layer interaction. Based on that information, requests for traffic flows with certain delay

and bandwidth requirements can be granted or denied by the MANET nodes. The authors show that SMQR can work well even when several traffic flows are present. However, SMQR is rather complex and requires MAC layer information to work properly.

III. PRIME ROUTING PROTOCOL

PRIME uses a beaconing mechanism to detect other nodes within the transmission range of a MANET node. Each node i maintains a list of neighboring nodes N_i . Initially N_i will be empty. Subsequently, if the node i receives a HELLO message from another node j , it will add a tuple $nt_j = (HT_j, LQ_j, NLQ_j)$ to its neighbor table N_i : HT_j denotes the hold time, which is the maximum time that may pass after the reception of a HELLO message before the entry nt_j will be dropped from N_i . $LQ_j \in (0, 1]$ is the quality of the link between i and j measured at i . It is obtained by monitoring the number of HELLO messages received from j in a specific interval. $NLQ_j \in (0, 1]$ is the quality of the link between i and j measured at j . Obviously this value is initially not known at i . However, i will receive LQ_i from HELLO messages sent by j and can derive $NLQ_j := LQ_i$. Once i has discovered a symmetric neighbor j , it will calculate the distance $d_{i,j}$ according to the definition of the used metric. In theory, any additive metric can be used to derive the distance values. Here we use the ETX metric $d_{i,j} = \frac{1}{LQ_i \times NLQ_j}$. It should be noted that this mechanism is derived from the OLSR beaconing mechanism. However, OLSR uses HELLO messages to detect the 2-hop neighborhood of each node. This is not necessary for the PRIME protocol.

The neighborhood discovery process allows us to find the symmetric 1-hop neighbors of each node. In order to find routes to all other nodes, each node periodically broadcasts topology messages. Each topology message sent by a node i contains a distance vector, i.e. a list of tuples $DV_i = \{(x, d_{i,x}), (y, d_{i,y}), \dots\}$. Initially, the only entry of DV_i will be $(i, 0)$. If node i receives a topology message from j , it will learn the distances $d_{j,x}$ for all neighbors of j . Consequently, i can calculate the distance $d_{i,j} + d_{j,x}$ for each two-hop neighbor reachable via j . At this point, it is important to note that multiple neighbors may have a path to node x . Given a list of neighbors $n_1, \dots, n_m$ with a known distance to x we derive the distance $d_{i,x} = \min_{y \in \{n_1, \dots, n_m\}} d_{i,y} + d_{y,x}$. These derived distances are again included into DV_i . Hence, for each further iteration of the topology message process the node distances are propagated further until at some point the distance information is spread throughout the complete network.

With help of this mechanism, a node s will learn the distance $d_{s,t}$ to each destination node t . Additionally, s will learn $d_{n_1,t}, \dots, d_{n_m,t}$ for all neighbors $n_1, \dots, n_m$. Now we want to find the eligible next hop targets for destination t . Here we use the available distance values to compute a set of directed edges pointing towards t . Specifically, a node determines for each link to a neighbor whether the link is an “outgoing” edge pointing towards t or not by comparing

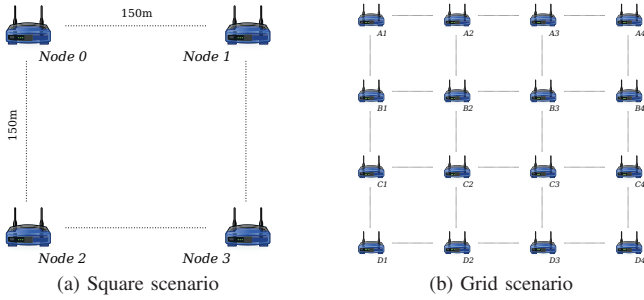


Fig. 1. Scenarios used to evaluate protocol performance

the own distance to the destination node with the distance announced by the neighbor. Only links to neighbors with a lower distance value will be classified as outgoing links and used for forwarding packets.

To achieve a weighted random selection on the list of eligible next hop targets, we can again use the information gained by the link quality detection. For each destination node we calculate the product of the link quality and the neighbor link quality ($LQ_{n_i} \times NLQ_{n_i}$) for all eligible forwarding neighbors $n_1, \dots, n_m$. Using these values, we can draw a random neighbor as the next hop target for each received packet. Thus for a stream of consecutive packets to the same destination node, partially or completely different forwarding paths may be realized.

IV. SIMULATION SETUP

To evaluate the effectiveness of the proposed PRIME routing protocol, we have conducted experimental performance measurements using the ns-3 network simulator [4]. We compare the results of the simulation using the PRIME routing protocol with simulation results of the AODV and OLSR routing protocols in the same scenario. Specifically, we are using the `aodv` and `olsr` submodules of ns-3. For all simulation scenarios we use a fixed transmission power for all nodes. To simulate fading we use the `LogDistancePropagationLossModel` and the `NakagamiPropagationLossModel`. All nodes are fixed to the 1 Mbit/s DSSS data rate. With these settings we realize stable but not perfect link quality conditions between the node pairs which are 150 meters apart. To provide a high network load we create a constant bitrate (CBR) traffic source using UDP sockets. CBR traffic is a typical type of network traffic for applications such as video streaming or voice calls. The CBR traffic is generated with a data rate of 500 kbit/s and each packet contains 500 bytes of payload data. We choose this data rate to ensure that the wireless interface of a forwarding node with 1 Mbit/s data rate will be used up to the full link capacity.

We created two different evaluation scenarios, which are displayed in Figure 1: The first scenario, to which we will refer as the *square scenario* in the following, is a rather simple scenario where four nodes are aligned in a square shape with a distance of 150 meters between the nodes. The CBR traffic will be directed from Node 0 to Node 3. This scenario is used

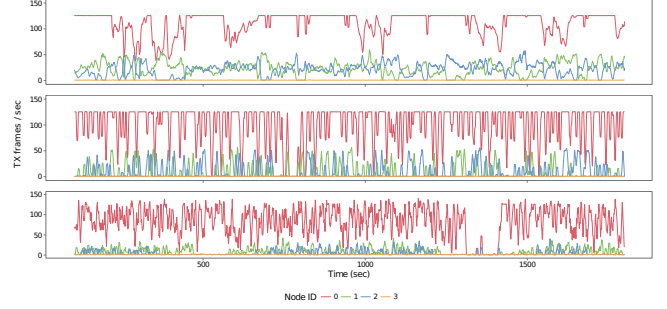


Fig. 2. TX frames per second at each node in the square scenario. From top to bottom: (1) PRIME, (2) OLSR, (3) AODV

to evaluate a situation where only a low number of alternative routes is available to reach a destination node. Given the configuration of the signal propagation model, the horizontal and vertical links between the nodes will be quite stable, but some packet loss may occur. Successful packet reception on the diagonal links might occur infrequently, but the link quality will be very low. The second and more complex scenario is the *grid scenario*. In this case we have built a 4x4 grid of nodes, where again the distance between two nodes is 150 meters. In this case, the CBR traffic will be directed from Node A1 to Node D4. Using this scenario we can evaluate a situation where multiple alternatives for routing traffic towards a destination node are available. Both scenarios intentionally do not include node mobility since we want to monitor the effects of the protocol on route stability in a situation where the topology of the network is stable. In such a situation in the best case no changes to the used routes should be necessary. In the worst case the detected links frequently break down due to the high network load and permanent changes to the used routes are necessary.

V. EVALUATION

In a first step, we compare the route stability of the PRIME, OLSR and AODV protocols by measuring the number of transmitted frames per second (TX frames) at each node. These measurements include forwarded data packets as well as the protocol control messages. If the TX packet count per second of a specific node is higher than the base load generated by the protocol control messages we can deduce that this node is forwarding packets of the CBR traffic stream. Figure 2 shows the TX frames per second during one simulation with a duration of 2000 seconds. The PRIME protocol provides a rather stable development of the TX frame values during the complete simulation time. In contrast the OLSR protocol shows spiky oscillations and we can clearly identify patterns where the sending Node 0 switches back and forth between Node 1 and Node 2 to reach Node 3. Regarding the AODV protocol, we can observe a rapid fluctuation in the TX frame values measured at Node 0 and a highly unstable forwarding activity of Node 1 and Node 2 as well.

In the next step, we are comparing the statistical distribution of the TX values measured in 20 consecutive simulations. The

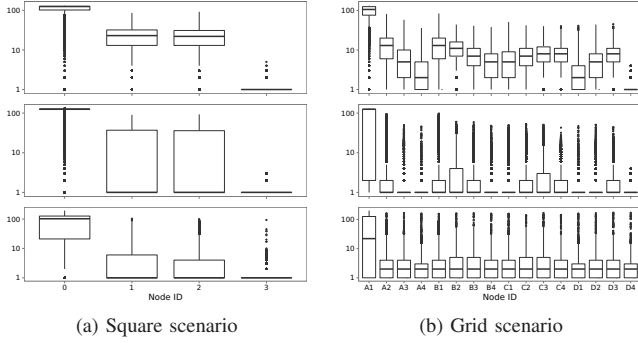


Fig. 3. Statistical analysis of TX frames per second. From top to bottom: (1) PRIME, (2) OLSR, (3) AODV

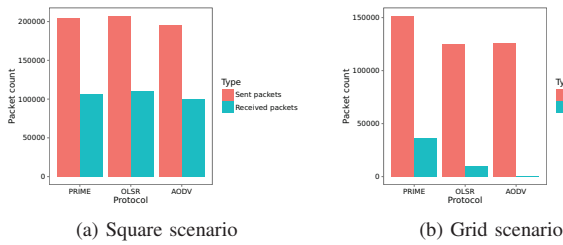


Fig. 4. CBR stream packet delivery statistics

results of this experiment are visualized in Figure 3. Significant differences in the statistical distribution of the measured values for the different protocols exist for both scenarios. For the square scenario we can observe a more widespread distribution for the forwarding nodes (Node 1 and 2) when using OLSR and AODV. The PRIME protocol in contrast provides a more stable load distribution. For the grid scenario, we can notice a considerably more stable forwarding performance when using PRIME. This is especially true regarding the sending Node A1, which provides a mean value of about 106 TX frames per second. For the other protocols the measurement values are more widespread and the number of outliers is much higher, indicating a generally less stable forwarding performance.

As the final part of the protocol performance evaluation, we measure both the number of packets sent by the UDP source socket and the number of packets received at the UDP destination socket. Using both values we can calculate the end-to-end packet delivery probability for each evaluated protocol. The measured end-to-end packet delivery statistics of the UDP CBR data stream are visualized in Figure 4. Comparing the results of the evaluated protocols in the square scenario, only small differences are observable. Significant differences are present in the grid scenario: For the PRIME routing protocol there are about 150.000 sent packets and a measured delivery ratio of 24%, while OLSR is at 7% and AODV performs even worse with a delivery ratio of only 0.6%. This shows the clear advantage of the probabilistic multipath routing approach over conventional singlepath routing protocols in situations with a dense network topology and high traffic load.

VI. CONCLUSION

Our evaluation shows that compared to other well-known MANET routing protocol the PRIME routing protocol provides a significantly higher route stability. This means that the traffic is more evenly shared between the MANET nodes and rapid fluctuations of the network load are avoided, which is a substantial benefit in respect of the limited energy and processing power of the MANET nodes. Furthermore, our evaluation results indicate that PRIME does not compromise the reliability of the protocol. In fact, our evaluation shows that in a dense network topology the end-to-end packet delivery ratio can even be increased compared to other MANET protocols. Hence the PRIME routing protocol may provide a clear advantage over other well-known protocols in scenarios with high network load. However, the work we have done so far covers only a limited amount of scenarios. For the future, it is desirable to evaluate the performance of the PRIME routing protocol in additional scenarios. One interesting aspect that has not yet been evaluated is the influence of node mobility on the protocol performance.

REFERENCES

- [1] T. Clausen and P. Jacquet, "Optimized Link State Routing Protocol (OLSR)," RFC 3626 (Experimental), Internet Engineering Task Force, Oct. 2003. [Online]. Available: <http://www.ietf.org/rfc/rfc3626.txt>
- [2] D. S. J. De Couto, D. Aguayo, J. Bicket, and R. Morris, "A high-throughput path metric for multi-hop wireless routing," *Wirel. Netw.*, vol. 11, no. 4, pp. 419–434, Jul. 2005. [Online]. Available: <http://dx.doi.org/10.1007/s11276-005-1766-z>
- [3] R. Draves, J. Padhye, and B. Zill, "Comparison of routing metrics for static multi-hop wireless networks," in *Proceedings of the 2004 Conference on Applications, Technologies, Architectures, and Protocols for Computer Communications*, ser. SIGCOMM '04. New York, NY, USA: ACM, 2004, pp. 133–144. [Online]. Available: <http://doi.acm.org/10.1145/1015467.1015483>
- [4] T. R. Henderson, M. Lacage, G. F. Riley, C. Dowell, and J. Kopena, "Network simulations with the ns-3 simulator," *SIGCOMM demonstration*, vol. 14, 2008.
- [5] S. J. Lee and M. Gerla, "Split multipath routing with maximally disjoint paths in ad hoc networks," in *Communications, 2001. ICC 2001. IEEE International Conference on*, vol. 10, 2001, pp. 3201–3205 vol.10.
- [6] R. Leung, J. Liu, E. Poon, A. L. C. Chan, and B. Li, "Mp-dsr: a qos-aware multi-path dynamic source routing protocol for wireless ad-hoc networks," in *Local Computer Networks, 2001. Proceedings. LCN 2001. 26th Annual IEEE Conference on*, 2001, pp. 132–141.
- [7] C. Mbarushimana and A. Shahabi, "Comparative study of reactive and proactive routing protocols performance in mobile ad hoc networks," in *Advanced Information Networking and Applications Workshops, 2007. AINAW '07. 21st International Conference on*, vol. 2, May 2007, pp. 679–684.
- [8] C. Perkins, E. Belding-Royer, and S. Das, "Ad hoc On-Demand Distance Vector (AODV) Routing," RFC 3561 (Experimental), Internet Engineering Task Force, Jul. 2003. [Online]. Available: <http://www.ietf.org/rfc/rfc3561.txt>
- [9] K. Ramachandran, I. Sheriff, E. Belding, and K. Almeroth, *Passive and Active Network Measurement: 8th International Conference, PAM 2007, Louvain-la-neuve, Belgium, April 5-6, 2007. Proceedings*. Berlin, Heidelberg: Springer Berlin Heidelberg, 2007, ch. Routing Stability in Static Wireless Mesh Networks, pp. 73–82.
- [10] N. Sarma and S. Nandi, "A multipath qos routing with route stability for mobile ad hoc networks," *IETE Technical Review*, vol. 27, no. 5, pp. 380–397, 2010.
- [11] A. T. Tran and M. K. Kim, "Characteristics of etx link quality estimator under high traffic load in wireless networks," in *High Performance Computing and Communications 2013 IEEE International Conference on Embedded and Ubiquitous Computing (HPCC EUC), 2013 IEEE 10th International Conference on*, Nov 2013, pp. 611–618.