A Statistic-Based Approach towards Routing in Mesh Networks

Alexander Klein
Innovation Works
EADS Deutschland GmbH, Germany
alexander.klein@eads.net

Phuoc Tran-Gia
Department of Distributed Systems
University of Wuerzburg, Germany
trangia@informatik.uni-wuerzburg.de

Abstract

Mesh routing protocols are specifically designed to meet the challenges resulting from frequent topology changes. In addition, they must generate and maintain reliable routes that are optimized with respect to QoS or energy efficiency.

Routing protocols are usually developed for a set of scenarios with a certain traffic pattern and network architecture. Some protocols can be configured to achieve good performance in different kind of scenarios. However, the capability of the protocols to adapt themselves to different network characteristics often comes at the price of increased complexity.

In this paper we introduce a statistic-based approach towards routing in mesh networks which is able to deal with many of the challenges arising in networks suffering from topology changes without the need of complex algorithms or a huge amount of memory.

1. Introduction

Routing protocols operate in dynamic environments due to e.g. mobility, sleep times, link loss or node failures caused by energy exhaustion. Their primary goal is to maintain short and reliable paths without generating a lot of overhead. It has to be kept in mind that sustaining a route from a source to a destination may consume more bandwidth than is required to support the data traffic flow. Thus, it is important for the design of a routing protocol to know the characteristics of the traffic in advance.

Another important issue is the reliability of the used routes. Portable wireless devices are very limited in their transmission range. For that reason, a packet usually travels several hops until the destination or border gateway is reached. In this case, the source must trust in the forwarding capabilities of the intermediate nodes. It can frequently broadcast routing messages to be up to date when topology changes occur. Then the source at least has recent knowledge of the network.

But how reliable is such an existing route? Is it possible to benefit from routing messages received earlier to predict the network behavior? The idea of using previously gathered information to predict the behavior of a path to the destination is not new. The Transmission Control Protocol (TCP) [1] uses previously gathered information to estimate the round trip time in advance. The presented statistic-based routing protocol also uses previously collected information to choose the next hop for packets to be forwarded.

Our work is organized as follows. In Section II we take a look at other routing protocols that have similarities with our approach. Section III describes the idea of the statistic-based routing protocol in more detail. Furthermore, the parameters of the protocol and their impact on the performance are discussed. The simulation results are presented and analyzed in Section IV. Finally, we summarize the results and introduce our future work.

2. Related work

In this section we focus on non-hierarchical protocols that use routing techniques which are similar to the ones used in our approach. After introducing the concept of directed diffusion, we focus on probabilistic and statistic-based solutions.

Directed diffusion represents one of the most popular data aggregation paradigms. This data-centric and application aware paradigm was introduced by C. Intanagonwiwat et. al. [2]. Data that is generated by nodes is labeled with attribute-value pairs. These pairs allow data identification and aggregation.

In general, the transmitted data is part of a specific task. The request for this data is propagated by the message sink via interest broadcast messages. Each intermediate node forwards the interest to the source and sets up a gradient towards the message sink from which it received the interest. Data from the source may then be forwarded along the gradients towards the sink.

The strength of the gradients differs depending on the information and the forwarding capabilities of the node. The variation of the gradient strength allows data dissemination which is very useful to spread the traffic and thus the energy consumption equally over the network.

The Minimum Cost Forwarding Algorithm (MCFA) [3] is based on the idea of directed diffusion. The nodes keep knowledge of the shortest path to the sink or base station. The base station broadcasts a message with the cost field set to zero. In the case that a node receives a broadcast message or a forwarded broadcast message, it adds the cost of the link on which it receives the message to the cost field. If the new value in the cost field is smaller then the currently stored one for this connection, the message is transmitted with the new value. Otherwise the message is silently discarded.

Due to the fact that topology changes near the sink have an impact on routes further away from the sink, a back-off algorithm has to be used to delay the forwarding of broadcast messages. The back-off algorithm is necessary to suppress too frequent updates for nodes far away from the base station.

Another approach based on the paradigm of directed diffusion is Gradient-Based Routing (GBR) that was introduced by Schurgers et al. [4]. The protocol uses the number of hops as cost metric. Thus, each node calculates the distance to the base station in number of hops. The distance to the base station is referred to as the height of the node. A node sets the gradient of a link to the difference of its height and the height of its neighbor. As a result, a packet that is forwarded according to the gradients travels along the shortest path with respect to the number of hops.

A different approach is followed by protocols using swarm intelligence. Ant-based routing represents a well known heuristic using swarm intelligence to find a path between a source and a sink.

Forward ants are periodically sent out by the source to find the destination. The next hop is chosen according to a link probability distribution function. After finding the destination a backward ant is created at the sink which traverses the way back to the source. The backward ant grades the path depending on its goodness. The previous set goodness of the path affects the next hop decision of the following ants. Thus, the more ants travel the same path, the higher the probability that other ants follow it.

However, there is always the chance that swarm intelligence based heuristics end up in local minima. Nevertheless, Zhang et. al [5] have shown that standard ant-based routing algorithms can be extended to achieve high performance in mesh and sensor networks.

3. Statistic-Based Approach

In the following we describe the statistic-based approach in detail. The primary goal is to maintain simplicity within the protocol while being able to spread the traffic load equally along optimized paths.

3.1. Hello Messages

Each node periodically transmits hello messages. The format of a hello message is shown in Figure 1. A hello message contains a source field that stores the unique address of the originator of the message. The address of the node which has retransmitted the packet is stored in the intermediate field.
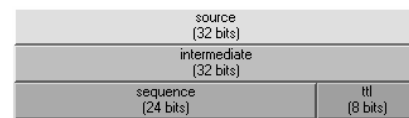

Figure 1. Hello Message Format

Additionally, the message holds a sequence field and a time-to-live field. The sequence number is used to keep track of how up-to-date the information stored in the message is. The time-to-live field is used for two purposes. One is to limit the retransmissions to a certain value. The other is to offer the possibility of using a hop count metric. The sequence number is increased by one every time a node transmits a new hello message.

3.2. Processing of Hello Messages

If a node receives the first hello message from another node it creates a new entry in its routing table. Otherwise the node compares the sequence number in the packet with the last stored sequence number of the source node. A hello message is only considered as new if the received sequence number is higher than the last stored sequence number. The differentiation of packets with equal sequence numbers is done by comparing the time-to-live field. The hello message is stored if the time-to-live field is smaller than the previous stored information with the same sequence number. Furthermore, the entry in the routing table is increased.

3.3. Forwarding of Hello Messages

Packets are forwarded in two cases. New hello messages are forwarded if they are received via the best ranked neighbor and the value stored in the time-

to-live field is higher than zero. The best ranked neighbor is the neighbor from which the most new hello messages are received. In addition, a hello message is forwarded if the originator is a direct neighbor.

3.4. Routing Table

The routing table stores the number of received new hello messages. Figure 2 shows the connectivity graph that is used for demonstration of the routing table usage.
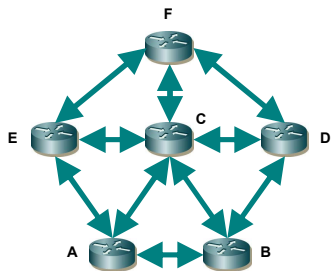

Figure 2. Graph of the Example Net

Table 1 represents the routing table of node F which results from the given network structure. In this example an entry is increased by one each time a new message is received through a neighbor. In this case the first two columns are unused since node F can not communicate directly with nodes A and B. Therefore, the hello messages that are generated by node A and B have to be retransmitted by other nodes to reach node F. Rows C, D, and E only have one single high routing entry since they are all direct neighbors.

Node F	Received Hello Messages				
Originators	A	B	C	D	E
A	-	-	7	2	10
B	-	-	5	11	3
C	-	-	20	-	-
D	-	-	-	19	-
E	-	-	-	-	20

Table 1. Example Routing Table of Node F

The most interesting information is stored in rows A and B. The content of row A shows that node F receives new hello messages first via nodes C, D, and E. The values can be explained as follows. The relatively large and more or less equal values for nodes C and E are resulting from the fact that A-E-F and A-C-F represent the shortest paths. However, sometimes a new hello message transmitted by node A

reaches node F through node D first. Such behavior can be the result of collisions. Another reason may be traffic overload in nodes E and C. Therefore, the three hop path A-B-D-F may be faster than the two hop paths A-E-F and A-C-F.

A closer look on rows A and B reveals that hello messages from node A reach F via node E first and those from B reach F via D first. This behavior is the consequence of the fact that node C is involved in each transmission of the network. For that reason, C is the busiest node in the network. As a result, the retransmission of hello messages received by other nodes takes longer. Nodes like E and D with a lower degree tend to forward new hello messages faster than C in our network example.

3.5. Forwarding of Data Packets

First, a node reads the time-to-live field. If the number stored in the time-to-live field is greater to zero the next hop of a forwarded or generated packet is chosen according to the values stored in the routing table. Otherwise the packet is silently discarded. Additionally, the time-to-live field is decreased by one before the packet is forwarded. The neighbor through which the highest number of new hello messages from the destination is received is chosen as next hop. If the values of several entries are equal the node is selected through which the last hello message was received. In the case that a node receives a packet for which it does not know the next hop it silently discards the packet.

3.6. Extended Functionality

Now that we have introduced the basic features of the statistic-based routing protocol we focus on the extended functionality. The routing entries increase steadily if the basic functionality is used. Consider a scenario where no changes in topology and traffic pattern occur for a long time. The best routes will have very high values in the routing table compared to alternative routes. Thus, if a node with a very high routing value becomes unreachable due to battery exhaustion, temporarily high traffic load or interference it will still be regarded for a long time as best next hop.

Different functionalities can be implemented to improve the reaction time of the routing protocol. A possibility is to use a maximum routing value which means that the routing value is not increased beyond a certain value.

In addition, we must add some functionality that decreases the routing value, otherwise all entries will reach the maximum value sooner or later. We use a

timer that triggers the decrease of all routing entries at the same time. The minimum value is set to zero indicating that no path is known to the destination.

The forwarding of packets can be manipulated by deferring the forwarding of hello messages. Additional delay of hello messages reduces the chance that packets will be routed through the node. The higher the additional delay of the hello message, the lower the chance that a node receives a forwarded hello message via this node first. As a result, the node falls behind in the routing tables of the other nodes.

3.7. Tuning Capabilities

The introduced protocol offers several possibilities to optimize the performance by setting the following parameters: Hello Message Interval (HMI), Hello Message Time-To-Live, Hello Message Forwarding Delay, Decrease Routing Value Interval (DRVI), Increase Routing Value Function (IRVF), Decrease Routing Value Function (DRVF), and the Maximum Routing Value (MRV).

A simple way to reduce overhead is to increase the HMI. The HMI can be increased if the number of topology changes is very small. Remember that a long Hello Message Interval and a high Maximum Routing Value lead to long response times to recognize topology changes. Furthermore, a short HMI and a low MRV do not represent a good choice, either. A too short HMI results in many entries increasing to the maximum.

The increase and decrease of the values stored in the routing table offers a way to manipulate the time that is needed by the protocol to adapt itself to topology changes. To give a better impression of the impact of the routing value functions we assume a constant increase and decrease value of one. Consider the case that the DRVI is twice as long as the HMI. The change of the routing entry values as consequence of topology changes is shown in Figure 3.
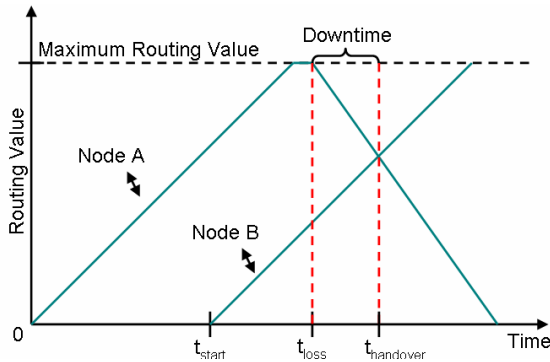
The Figure shows the entry for a node X that travels through the transmission range of nodes A and B. Node X is recognized by node A at time t_0. Thus, hello messages from node X are received by node A. From time t_{start} node A and B receive the messages from node X. Therefore, both entries in node A and B increase. At time t_{loss} node X leaves the coverage area of node A. From this point the routing entry in node A decreases whereas the entry in node B still increases.

Nevertheless, the protocol tries to forward packets dedicated for node X via node A as long as the entry value in node A is higher. The time between t_{loss} and $t_{handover}$ is referred to as downtime. Packets that are forwarded to node X during the downtime are lost because node X has left the coverage area of node A.

Figure 3 points out that a higher increase value can only shorten the downtime if a MRV is used to limit the values. As a result of a high increase value nodes quickly reach the MRV. Therefore, many paths are considered as shortest paths.

Instead of using a constant increase and decrease value it is also possible to use functions to estimate the goodness of a path. The following characteristics are required to shorten the downtime. The gradient of the IRVF has to be high for low values and low for high values. The gradient of the DRVF has to be high for high values and low for low values. Equations 1 and 2 are used to increase and decrease the routing entries.

$$ I_{n+1} = 2I_n + \frac{4}{I_n^2 + 1} \qquad D_{n+1} = \frac{D_n}{2} $$

Equation 1+2. Increase and Decrease Function

Figure 4 shows a typical development for a routing entry. We have used an equal HMI and DRVI. In addition, we set a hello message loss according to a normal distribution with a mean value of three percent.
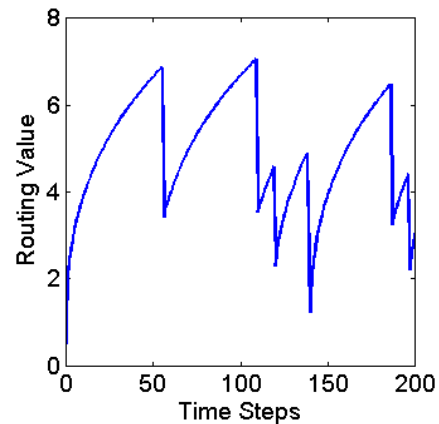

Figure 3. Routing Values during Handover

Figure 4. Snapshot of Routing Value Function

4. Simulation Studies

In this section we compare the statistic-based approach with the Open Link State Routing (OLSR) [6] protocol with respect to reliability, path length, number of hops, and overhearing. We have chosen the OLSR protocol because it presents one of the most popular routing protocols in wireless mesh networks.

To compare the performance, we decided to build a simulation within the OPNET Modeler 12.0 [7]. The simulated scenario consists of 50 mobile nodes in a square of 1000 x 1000 meters. Carrier Sense Multiple Access (CSMA) is used as media access protocol. The transmission speed of the nodes is 256 Kbits per second. The start position of the nodes is set by using a poisson field. The movement of the nodes is generated by a random waypoint model. The configuration of the mobility model is shown in Table 2.

Start time	10.0 s
End time	End of Simulation
Minimum speed	$1.0\ \mathrm{ms^{-1}}$
Maximum speed	$1.0 - 13.0\ \mathrm{ms^{-1}}$
Pause time	10.0 s

Table 2. Mobility Configuration

At the beginning of the simulation a random node is chosen as the sink. All other nodes transmit data to the sink. The packet inter arrival time is generated by an exponential distribution with a mean value of 100 seconds. The packets have a constant size of 1024 bits.

The routing protocols are set such that they generate the same amount of overhead and are able to deal with frequent topology changes. In the case of OLSR, we use a Topology Control Interval of 4 seconds which is even shorter than the duration proposed in RFC3626. We must keep in mind that the hello messages of both protocols are used for different purposes. The protocols begin uniformly distributed within 5 seconds after the simulation start to minimize side effects caused by synchronous message transmission. The configurations of both protocols are shown in Table 3 and 4.

Hello Message Interval	2.0 s
Hello Message Time-To-Live	10
Increase Routing Value Function	Equation 1
Decrease Routing Value Function	Equation 2
Decrease Routing Interval	2.5 s
Maximum Routing Value	10

Table 3. Statistic-Based Configuration

Hello Interval	2.0 s
Refresh Interval	2.0 s
Duplication Hold Time	20.0 s
Topology Control Interval	4.0 s
Max Jitter	0.1 s
Time-To-Live	10

Table 4. OLSR Configuration

We use the maximum speed of our mobility model as a parameter to simulate the capability of the protocols to deal with an increasing number of topology changes. Therefore, the maximum node speed is increased from 1.0 to $13.0\ \mathrm{ms^{-1}}$ in steps of $2\ \mathrm{ms^{-1}}$.

One of the most important performance parameter in mesh networks is represented by the End-To-End reliability. The protocols in our simulation do not buffer any packets. Thus, the End-To-End reliability in the simulation corresponds to the availability of the sink. The 99 percent confidence intervals of the End-To-End reliability depending on the maximum node speed are shown in Figure 5.
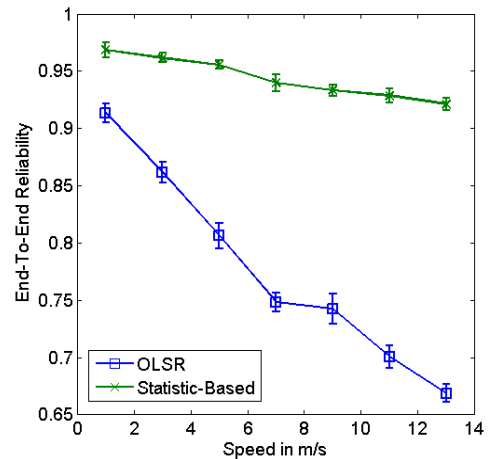

Figure 5. End-To-End Reliability

The results point out that the statistic-based approach is capable to achieve a high End-To-End reliability even in scenarios with frequent topology changes. Its performance is much less affected by mobility than the performance of a mesh network using OLSR. Thus, the statistic-based approach is able to operate in different environments without the need for reconfiguration.

In the following we take a closer look on the chosen routes with respect to path length and overhearing. Figure 6 shows the average number of nodes that are within the coverage area of a transmitting node.
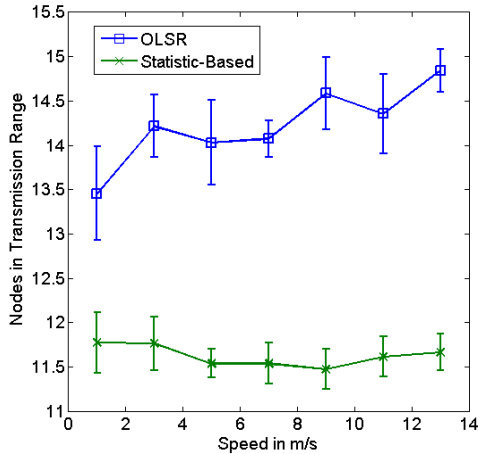
Figure 6. Overhearing

The results presented in Figure 6 indicate that OLSR routes traffic through more dense areas than the statistic-based approach. Furthermore, the number of nodes which are in the range of a transmitting node increase with the node speed if OLSR is used as routing protocol. In contrast to OLSR, the statistic-based approach shows a slight decrease with increased maximum node speed. The lower overhearing value of the statistic-based approach is a result of its next hop selection. Nodes in less dense areas tend to forward hello messages faster than other nodes. Thus, they are chosen with a higher probability as forwarding nodes. Another result of the next hop selection is data dissemination. Due to the fact that busy nodes forward hello messages slower, their routing entries increase less than those of other nodes. Therefore, the probability that such a node is selected as next hop decreases. However, longer paths are necessary to reduce overhearing which is shown in Figure 7.
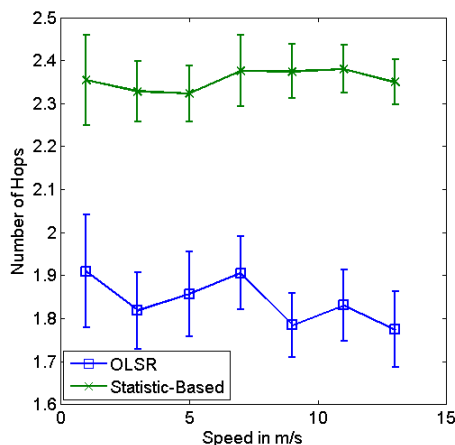

Figure 7. Average Number of Hops

A slight decrease of the path length can be recognized for OLSR. The decrease is the consequence of the reduced End-To-End reliability in scenarios with higher node speeds.

5. Conclusion and Outlook

The main goal of this paper is the introduction of a new approach towards statistic-based routing. In addition, we want to show that routing protocols which are based on statistics present an underestimated alternative to existing routing protocols like OLSR. Furthermore, the results pointed out that no complex routing algorithms are needed to achieve high End-To-End reliability in mesh networks.

In future studies we will take a closer look at the capability of the protocol to adapt to different traffic characteristics. A performance analysis of the Increase and Decrease Routing Value Functions with respect to reliability, path length, and energy efficiency will also be part of our future work.

6. References

[1] V. Cerf and R. Kahn, "A Protocol for Packet Network Intercommunication", IEEE Transactions on Communication, vol. 22 pp. 637-648, May, 1974.

[2] C. Intanagonwiwat, R. Govindan, and D. Estrin, "Directed Diffusion: a Scalable and Robust Communication Paradigm for Sensor Networks", Proceeding of ACM MobiCom `00, pp. 56-67, Boston, MA, 2000.

[3] F. Ye, A. Chen, S. Liu, and L. Zhang, "A Scalable Solution to Minimum Cost Forwarding in Large Sensor Networks", Proceeding of the tenth International Conference on Computer Communications and Networks (ICCCN), pp. 304-309, 2001.

[4] C. Schurgers and M.B. Srivastava, "Energy Efficient Routing in Wireless Sensor Networks", MILCOM Proceedings on Communications for Network-Centric Operations: Creating the Information Force, McLean, VA, 2001.

[5] Y. Zhang, L.D. Kuhn, and M.P.J. Fromherz, "Improvements on Ant Routing for Sensor Networks", Proceeding of the fourth International Workshop ANTS 2004, pp. 154-165, Brussels, Belgium, September, 2004.

[6] T. Clausen and P. Jacquet, "Optimized Link State Routing Protocol (OLSR) RFC 3626", IETF Network Working Group, October 2003.

[7] OPNET Modeler, OPNET University Program: http://www.opnet.com/services/university/