Proactive Route Maintenance for Vehicular Mobility

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Rainer Baumann*
*Computer Engineering and Networks Laboratory
ETH Zurich, Switzerland

I. INTRODUCTION

Inexpensive wireless network connectivity for mobile users as pedestrian or car drivers becomes more and more demanded. But using common 802.11 WLAN hardware for building citywide wireless mesh networks for mobile users or inter-vehicular networks is very challenging, because of the fast changing topology and the limited communication range.

In networks with very fast changing topologies, flooding is the only possibility to deliver data. This is because routing protocols can no longer forward packets towards the destinations, because their information about the topology are outdated even before they can be applied. If the topological changes are a bit more moderate, the main concern is to avoid route breakages because they generate a lot of additional overhead and delay as well as packet losses resulting in connection losses. In these scenarios, most route breaks can be attributed to link failures due to node mobility. Thus the distance between two neighboring nodes of a route should be much shorter then the maximal communication range. On the other hand, neighboring nodes of a route should not be to close together. Otherwise, the hop count of the route would increase dramatically, resulting in much higher delays, more interference, and bandwidth usage. Following, the distance between neighboring nodes of a route should be somewhere in between at a preferred value. The signal strength offers the most direct estimate of this preferred distance because it is a direct indicator of the reachability between two neighboring nodes.

In recent years, a new flexible group of routing protocols emerged, the field-based routing protocols. The idea of these routing protocols is to construct a strict monotonically increasing scalar field where the destination represents the maximum value of this field. Packets are then routed along the steepest gradient towards the destination. This notion of a field offers many perspective of integrating various routing metrics as the signal strength.

Our primary contribution is a fine grained neighbor selection mechanism to determine and maintain routes consisting of nodes with preferred distances between each other. For this, we use the signal strength as propagation metric in a proactive field-based routing algorithm. In more detail, we use an exponential weighted moving average of the received signal strength to smooth out short term fading. This average is used to calculate the field propagation between neighbors. The reduction of the field intensity between neighbors at the preferred distance is very low while it is rapidly increasing for nodes further away from this distance.

For evaluation, we have implemented our proposal into an exemplary field-based routing protocol using Glomosim. Our simulations are based on a detailed mobility pattern extracted from geographical data of large Swiss cities. The results show that the probability of route breakages decreases dramatically and that the packet loss ratio in scenarios with car mobility decreases by a factor of 15. Further more, we show that form a performance perspective, it is important to use routes with a high number of preferred neighbors instead of just locally preferring single links.

The rest of this paper is organized as follows. In the following Section, we highlight related work. Then, we present our approach of preferring certain neighbors over others using field-based routing. In Section IV, we specify our simulation environment while in Section V, we present our evaluation results. Finally, we discuss the results and conclude the paper.

II. RELATED WORK

Routing in wireless networks has undergone extensive study. In this Section, we discuss related work that has influenced our work and we point out what we have done differently.

A. Ad Hoc and Mesh Routing Protocols

In the recent years, many different ad hoc and mesh routing protocols have been proposed. Since, we do not want to give an other overview over the most popular of these protocols, we just briefly list three primarily characteristics of these protocols related to our work.

1) *Initiation of route determination*: reactive (on-demand) or proactive (table-driven).
2) *Scope of topology information exchange*: locally with neighbors (distance-vector) or globally with all nodes (link-state).
3) *Data packet forwarding technique*: hop-by-hop routing or source routing.

B. Field-based Routing

Field-based or gradient-based routing has been proposed in the past for various type of applications including routing in MANETs [1], [2], load balancing in the Internet [3], data collection in sensor networks [4], [5], sensor node placement [6], guided navigation [7], or service discovery in MANETs [8].

These schemes all share the same design idea: the construction of a scalar field on the network which assigns a scalar value to every node in the network. The destinations are represented as maximum scalar values and packets are always forwarded along the steepest gradient towards the destination. While being fairly simple, the concept of field-based routing provides a very versatile way of determining routing decisions. For instance, modeling shortest-path routing with a field-based scheme is straightforward and has been demonstrated in [9]. Owing to the fundamental properties of fields, loop freedom of routes is ensured, and it is guaranteed that packets are forwarded towards the destination.

C. Received Signal Power

Several signal strength based routing protocols have been proposed such as ABR [10], SSR [11], RABR [12]. The common idea behind these approaches is to prefer stable links or strongly connected links rather than transient links.

The routing protocol, however, is concerned more with the route lifetime than individual link lifetimes. Therefore, choosing a long lifetime route rather than individual long life time links should be considered as proposed in LLR [13]. But choosing routes with longer life time does not prevent route breakages and the resulting packet losses, additional delays, additional overheads and connection losses. Another disadvantage of LLR is that it requires the source node to determine long lifetime route. Thus, the source node requires full knowledge about the topology.

Preemptive Routing in Ad Hoc Networks [14] and Proactive Route Maintenance [15] are reactive routing protocols, which attempt to determine an alternative route when they detect a possible link breakage from weak received signal strength. They do this by informing the source that it should determine a better route. This information process as well as the determination of a new route takes a while and generates a lot of overhead. Especially in highly mobile networks as in vehicular networks, the repair time might bee too long so that the route breaks before a better one is determined or the overhead of permanently finding new routes overloads the network.

In this paper, we propose to combine these two concepts to proactive maintain long lifetime routes for combining the advantages of both concepts. In addition, we show how to implement a local route maintenance mechanism by preferring certain neighbors over other. This eliminates the need of informing the source, of rediscovering a complete new route, and of determining the long lifetime route at the source.

III. PREFERRED NEIGHBOR ROUTES FOR FIELD-BASED ROUTING

In this section, we present the concept of preferring neighbors based on their received signal strengths for field-based routing. For this purpose, we first briefly describe HEAT [2], a field-based routing protocol, we use exemplarily to demonstrate our idea. Then we explain the fundamental concept of preferring neighbors on a hop-by-hop bases. Following, we describe how to combine this concept with field-based roting in a way to get routes with a high number of preferred neighbors. Finally, we show that field-based routing allows to construct routes with very fine grained neighbor selection.

A. HEAT, A Field-Based Routing Protocol

HEAT constructs a scalar field per destination by periodically exchanging the field intensities of the nodes between neighbors using beacons. The destination of a field is represented by the maximum scalar value. A node keeps a list of the field intensities for all destinations at all neighbors. It calculates its field intensity for every destination by looking up the neighbor with the highest field intensity and subtracts a constant κ. Thus, the field intensity decreases per hop by κ. A data packet is then forwarded towards the destination by following at each hop the steepest gradient.

B. Preferred Neighbor

The aim of preferring certain neighbors over others for routing packets is to avoid link breakages due to mobility and thus route breakages. The signal strength offers the most direct estimate of the ability of the nodes to reach each other. But the received signal power is vulnerable to fluctuations due to fading and similar temporary disturbances. For mitigating the effects of random signal fades, we use an averaging technique widely used in telecommunication: Exponential Weighted Moving Average (EWMA, see Alg. 1). pn_i denotes the received signal strength of the i-th packet received from node *n* in dB, an_{i-1} the last average for node *n* and an_i the new average for node *n*. The smoothing factor α determines the weight of each measured value pn_i and reduces the weight of a single measure, if there are many actual measures available.

Algorithm 1 Exponential Weighted Moving Average of Signal Strength.

```
for packets received do
    $an_i = \alpha \; an_{i-1} + (1-\alpha) \; pn_i$
    $\alpha = \frac{nn}{nn-1}$; nn: number of packets received in the last second from node n
end for
```

Using the actual signal strength an_i, we classify the neighboring node *n* according to two threshold IT and OT into one of three groups (Fig. 1):

- Preferred Neighbor (PN).
- Out neighbor - node with a signal weaker than the Outer Threshold (OT) - link is likely to break.
- In neighbor - node with a signal stronger than in Inner Threshold (IT) - node is very close.

For simplicity, we depict the communication range (rxThresh) of a node and the power levels for the in and out groups as circles in Fig. 1, but our algorithm by no means assumes that the range is indeed circular.

When a packet has to be forwarded to the destination *d*, a node selects the next hop as following. It first looks up

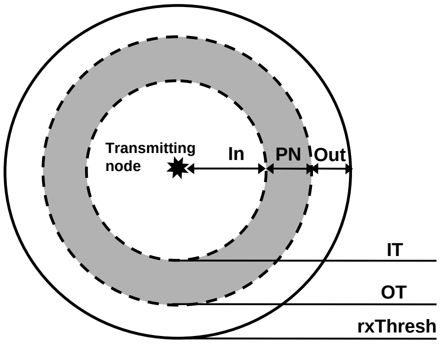

Fig. 1. Preferred Neighbor.

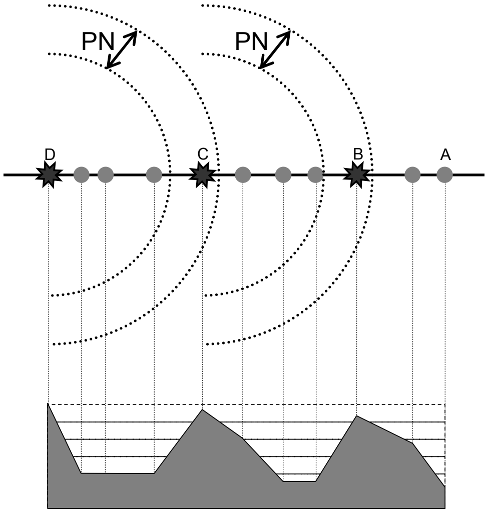

Fig. 2. A Preferred Neighbor Route form A to D on a Straight Route.

its preferred neighbors field intensities for the neighbor with the highest intensity for the destination *d*. If the intensity of this neighbor is higher then its own, it selects it. Otherwise it repeats the selection process using the *out neighbors* and if this fails again, it uses the *in neighbors*. According to the fundamental properties of field-based routing, there must always be a neighbor with a higher field intensity. Thus, we will always find a neighbor with a higher field intensity.

C. Preferred Neighbor Routes

Up to now, we preferred neighbors as next hops based on local decisions. But, since a routing protocol is more concerned with the route lifetime than individual link lifetimes, we extend this concept to prefer routes with a high number of preferred neighbors.

The necessary information can very well be incorporated into a field. Up to now, the field intensity declines constantly per hop by κ. To reflect the preference of the nodes in the three different groups, we adjust κ accordingly, so that the field declines faster for non preferred neighbors: $0 < \kappa_{pn} << \kappa_{out} << \kappa_{in}$. An example of a preferred neighbor route and the according field is given in Fig. 2.

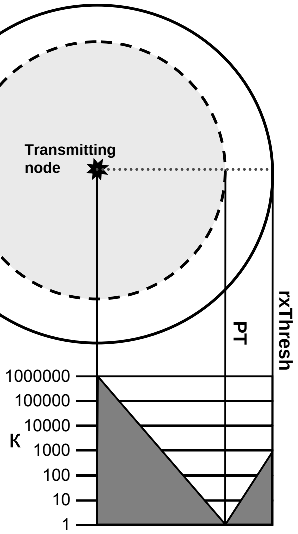

Fig. 3. Preferred Neighbor.

D. Fine Grained Preferred Neighbor Routes

Up to now, the presented concept does a discrete classification into three groups. Based on these groups, different κ gets applied. But field-based routing allows for a much fine grained, continuous classification by a wide range of κs. Neighbors close to the preferred threshold (PT) get high κ's, while nodes further away get smaller ones (see Fig.3). The detailed algorithm is given in Alg. 2.

Algorithm 2 Calculation of κ.

```
if $an_i > PT$ then
    $kappa_x = \frac{an_i - rxThresh}{PT - rxThresh} \kappa_{out} + \kappa_{pn}$
else
    $kappa_x = \frac{an_i - PT}{rxMax - PT} \kappa_{in} + \kappa_{out} + \kappa_{pn}$
end if
```

IV. SIMULATION SETUP

To evaluate and compare the performance of our approach, we performed simulations with Glomosim [16], a network simulator for wireless networks. We implemented preferred neighboring routes using the implementation of HEAT [2] for Glomosim. As a reference for the performance of our implementation we use the shortest path routes from HEAT. The settings and assumptions we used for our simulations are described next.

A. Radio Settings

Our simulations are based on a WiFi network. All nodes are equipped with a 802.11b radio with a bandwidth of 11 $Mbps$ and a nominal range of 250 $meters$. As MAC layer protocol we use the 802.11 DFWMAC-DCF w/RTS/CTS and as propagation model two-ray ground. Due to the large network sizes we use, we were unable to simulate the effect of intermediate buildings in our city scenarios. However, we

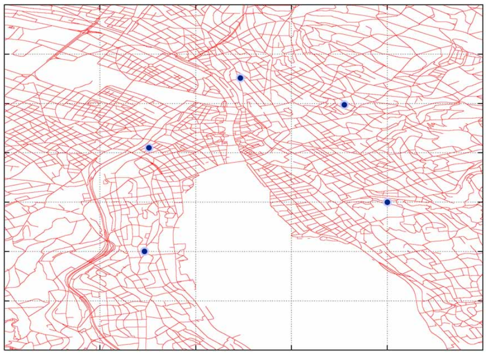

Fig. 4. Vectorized street map of the city (5km by 7km) of Zurich.

expect that the trends of our results also hold when such obstacles are present.

B. City Mobility Model

The literature shows that the results of performance studies of ad hoc networks depend heavily on the chosen mobility model [17], [18] and that simple mobility models like random way point [19] are no option. But for hundreds of pedestrians or vehicles moving around in cities, there are now real traces available expect from public transport. Saha and Johnson proposed in [20] to use street maps form the TIGER database to generate quiet realistic mobility patterns. They do neither have speed information or use detailed geometry of the streets. We use detailed vectorized street maps of real Swiss cities as well as speed information.

The road maps of these cities are extracted from the Swiss geographic information system (GIS) [21] which includes vectorized building and street maps together with speed information. The vectorized map of the city center of Zurich for which we present our results in this paper, is shown in Fig. 4.

The actual node movement is modeled according to the steady-state random trip mobility model [22] on the vectorized maps. That is, a node chooses a random destination in the city and moves to this position with a constant speed along the shortest way. We do not introduce any pausing of the nodes, and a node therefore begins to move to a new destination as soon as it arrives at the target position. Our model is applied for pedestrians as well as cars since the movements of both are constrained by the streets in the city.

C. Traffic Pattern

We expect wireless mesh networks to be used for Internet-type of applications like web browsing, messaging, chatting, etc. Therefore, we rely on an Internet traffic model as used in [23], [24] consisting of a half-half mix of streaming and web-like traffic. Streaming traffic has a bidirectional constant bit rate of 64 kb/s and the duration of streams are exponentially distributed with an average of 480 seconds. Web-like traffic consists of sporadic 1 kB requests according to an exponentially distributed inter-request time with an average of 10 seconds, followed by response messages with a message size that is Pareto II [25] distributed (average 12 kB, minimal 0.1 kB, maximum 1000 kB).

All simulations have a duration of at least 10000 seconds and are always an average over at least 20 runs with different random seeds.

Parameter	Value
Maximum Field Intensity	4294967295
κ	1
κ_{pn}	1
κ_{out}	1000
κ_{in}	1000000
IT	rxThresh + 12dB
PT	rxThresh + 10dB
OT	rxThresh + 6dB

TABLE I

PARAMETERS.

D. Parameters

For our simulation we use the standard parameter setting of HEAT. The parameters for the calculations of preferred neighbor routes are set according to Tab. I.

V. SIMULATION RESULTS

We present the following metrics to compare the performance and overhead of the three techniques of preferring neighbors:

- *Packet delivery ratio* - The total number of packets that are successfully received at a destination to the total number of packets sent from a source.
- *Path length* - The average average path length of a route measured in hops.
- *Route break probability* - The average probability that a routes breaks in the next second. In other words, the probability that a packet is forwarded to a neighbor which is no longer in the communication range of a node.

A. Packet delivery ratio

When looking at the packet delivery ratio plotted in Fig. 5, it can bee seen that in the static scenario with no link breakages, there is no significant difference. But for the scenario with car mobility, locally preferring neighbors already doubles the packet delivery ratio. Selecting routes with a high number of preferred neighbors again increases the packet delivery ratio. The usage of the fine grained function for neighbor selection cuts in half the remaining packet loss ratio.

B. Path length

The common HEAT protocol constructs shortest routes, thus the draw back of preferring certain neighbors over others is that routes might get longer (see Fig. 6). It is striking that paths get much longer if routes with a high number of preferred neighbors are selected instead of locally preferring neighbors. This effect gets relaxed by applying the continuous classification of neighbors with fine grained preferred neighbor routes.

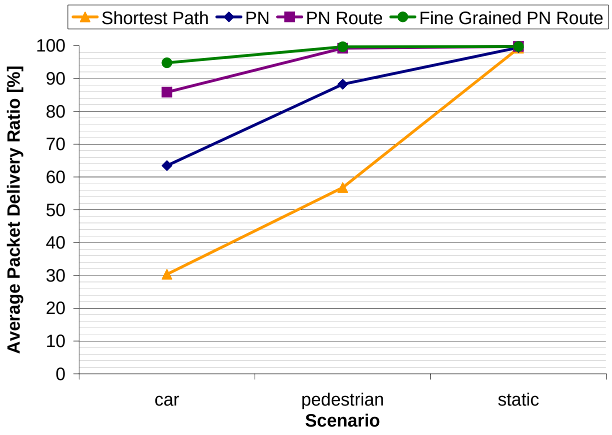

Fig. 5. Packet delivery ratio.

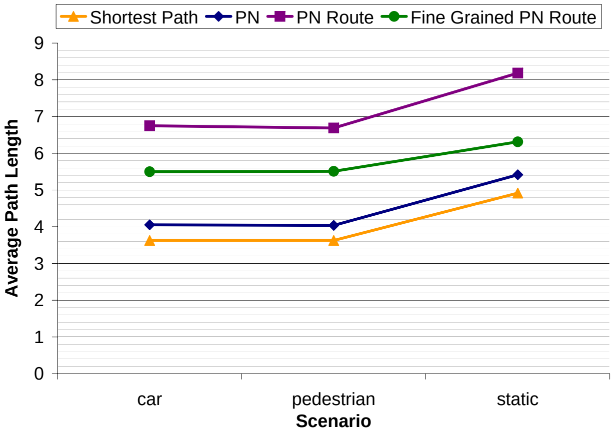

Fig. 6. Path length.

C. Route break ratio

Fig. 7, shows the improvement of the presented concept for the average probably of a route breakage in the next second. The average route life time in scenarios with car mobility is more then seven times longer using routes with the fine grained preferred neighbor routes (see Tab. II).

VI. CONCLUSION

The success of wireless mesh networks or inter-vehicular networks depends on the reliability of packet delivery. Often route disruptions, high packet loss ratios, and long varying delays are common problems in such networks with highly mobile users. In this paper, we present a concept to permanently locally optimize routes to counter these problems. We propose a fine grained mechanism to prefer routes with nodes at preferred distances. Our evaluation shows, that for scenarios with nodes moving at car speed, the packet loss ratio can be reduced roughly by a factor of 15 by using the proposed concept.

Shortest Path	6.8s
Per Hop PN	10.5s
Over Route PN	16.7s
Over Route PN Function	50.5s

TABLE II
AVERAGE ROUTE LIFE TIME WITH CAR MOBILITY

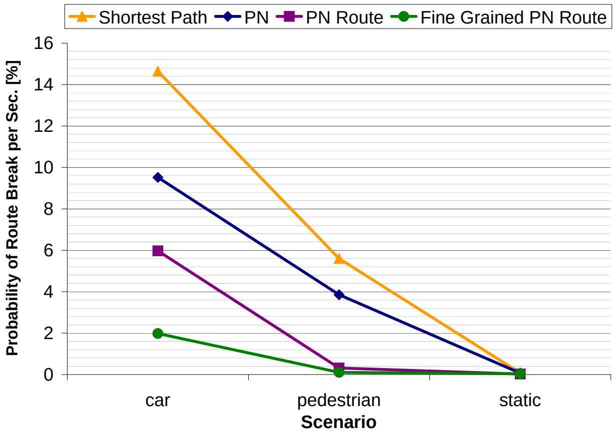

Fig. 7. Route break ratio.

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