Geographic Routing in City Scenarios

Christian Lochert[a] *lochert@cs.uni-duesseldorf.de*
Martin Mauve[a] *mauve@cs.uni-duesseldorf.de*
Holger Füßler[b] *fuessler@informatik.uni-mannheim.de*
Hannes Hartenstein[c*] *hartenstein@rz.uni-karlsruhe.de*

[a]Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany
[b]Universität Mannheim, Mannheim, Germany
[c]Universität Karlsruhe (TH), Computing Center and Institute for Telematics, Karlsruhe, Germany

I. Introduction

Position-based routing, as it is used by protocols like Greedy Perimeter Stateless Routing (GPSR) [5], is very well suited for highly dynamic environments such as inter-vehicle communication on highways. However, it has been discussed that radio obstacles [4], as they are found in urban areas, have a significant negative impact on the performance of position-based routing. In prior work [6] we presented a position-based approach which alleviates this problem and is able to find robust routes within city environments. It is related to the idea of position-based source routing as proposed in [1] for terminode routing. The algorithm needs global knowledge of the city topology as it is provided by a static street map. Given this information the sender determines the junctions that have to be traversed by the packet using the Dijkstra shortest path algorithm. Forwarding between junctions is then done in a position-based fashion. In this short paper we show how position-based routing can be aplied to a city scenario without assuming that nodes have access to a static street map and without using source routing.

II. Position-based routing

In existing position-based routing approaches an intermediate node forwards a packet to the direct neighbor which is closest to the geographic position of the destination. This is called greedy forwarding. For this task each node has to be aware of *i)* its own position, *ii)* the position of its direct neighbors and *iii)* the position of the final destination. A node determines its own position by using GPS, the position of the neighbors is received through one hop beacon messages transmitted periodically by all nodes and the position of the final destination is provided by a location service [3] or by a geocast application. Since greedy forwarding uses only local information a packet may reach a local optimum w.r.t. the distance to the destination, i.e. no neighbor exists which is closer to the destination than the intermediate node itself. In order to escape from a local optimum a repair strategy may be used. The general aim of a repair strategy is to forward the packet to a node which is closer to the destination than the node where the packet encountered the local optimum. Once such a node is reached greedy forwarding can be resumed. Several repair strategies have been proposed, including Greedy Perimeter Stateless Routing [5] and face-2 [2]. However, it has been shown [4, 6] that existing repair strategies do not perform well in city environments because they rely on distributed algorithms for planarizing graphs. In the presence of radio obstacles the use of these algorithms frequently partitions an otherwise connected graph, making the delivery of packets impossible. As a result we propose a new routing approach for mobile Ad-Hoc Networks which we call Greedy Perimeter Coordinator Routing (GPCR).

III. Greedy Perimeter Coordinator Routing

Greedy Perimeter Coordinator Routing (GPCR) is a position-based routing protocol. The main idea of GPCR is to take advantage of the fact that streets and junctions form a natural planar graph, without using any global or external information such as a static street map. GPCR consists of two parts: a restricted greedy forwarding procedure and a repair strategy which is based on the topology of real-world streets and junctions and hence does not require a graph planarization algorithm.

III.A. Restricted Greedy Routing

As long as no global optimum is encountered, a special form of greedy forwarding is used to forward

*Hannes Hartenstein would like to thank Brad Karp for helpful and stimulating discussions on GPSR and SPAN.

a data packet towards the destination. Since obstacles (e.g., buildings) block radio signals, data packets should be routed along streets. Junctions are the only places where actual routing decision are taken. Therefore packets should always be forwarded to a node on a junction rather than beeing forwarded accross a junction. This is illustrated in Figure 1 where node u would forward the packet beyond the junction to node $1a$ if regular greedy forwarding is used. By forwarding the packet to node $2a$ an alternative path to the destination node can be found without getting stuck in a local optimum. In the remainder of this work we call nodes that are located in the area of a junction a *coordinator*. A coordinator broadcasts its role along with its position information. In a first step we assume that each node knows whether it is a coordinator (i.e., located in the area of a junction) or not. We will show in section IV how a node can learn about this information.

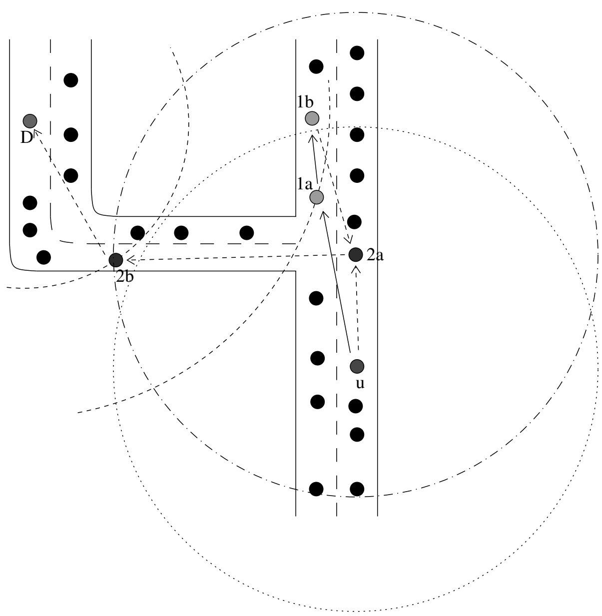

Figure 1: Greedy Routing vs. Restricted Greedy Routing in the area of a junction.

If the forwarding node is located on a street and not on a junction the packet is forwarded along the street towards the next junction. To achieve this, the forwarding node selects those neighbors whose positions approximate an extension of the line between the forwarding node's predecessor and the forwarding node itself. Out of these qualified neighbors one has to be selected as the next hop of the packet. As long as there are no qualified neighbors which are coordinators the node with the largest distance to the forwarding node is chosen. If coordinators are qualified then one coordinator is randomly chosen as the next hop. With this approach packets will not be forwarded across junctions. Figure 2 shows an example of how the next hop is selected on a street. Node a receives a packet from node b. Because a is located on a street and not on a junction it should forward the packet along this street. First the qualified neighbors of a are determined. Then it is checked whether at least one of them is a coordinator. As in this example there are three coordinator nodes that qualify as a next hop one of these coordinator nodes is chosen randomly and the packet will be forwarded to this coordinator.

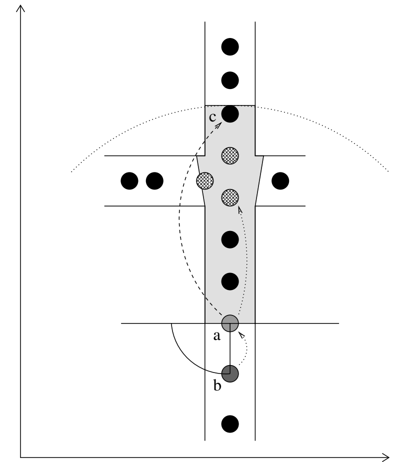

Figure 2: Coordinator nodes are preferred to non-coordinator nodes.

Once a packet reaches a coordinator a decision has to be made about the street that the packet should follow. This is done in a greedy fashion: the neighboring node with the largest progress towards the destination is chosen. This implies a decision on the street that the packet should follow.

III.B. Repair Strategy

Despite of the improved greedy routing strategy the risk remains that a packet gets stuck in a local optimum. Hence a repair strategy is required. The repair strategy of GPCR avoids using graph planarization by making routing decision on the basis of streets and junctions instead of individual nodes and their connectivity (which do not form a natural planar graph). As a consequence the repair strategy of GPCR consists of two parts: (1) On each junction it has to be decided which street the packet should follow next. (2) In between junctions greedy routing to the next junction, as described above, can be used.

If the forwarding node for a packet in repair mode is located on a junction (i.e., it is a coordinator) then the node needs to determine which street the packet should follow next. To this end the topology of the city is regarded as a planar graph and the well known right-hand rule [2, 5] is applied.

We illustrate the use of the right hand rule in figure 3. A packet with destination D reaches a local optimum at node S. The forwarding of the packet is then switched to the repair strategy and it is routed along the the street until it hits the first coordinator node. Node C_1 receives the packet and has to decide on the street the packet should follow. Using the right-hand rule it chooses the street that is the next one counterclock wise from the street the packet has arrived on. Therefore node I will be chosen to forward the packet. The packet will then be forwarded along the street until the next junction is reached. When the packet arrives at the coordinator C_2 this node has to decide again on the next street that is to be taken and decides to forward the packet to node L. At this point the distance to the destination is less than at the beginning of the repair strategy at node S. Hence the mode is switched back to the greedy strategy described above.

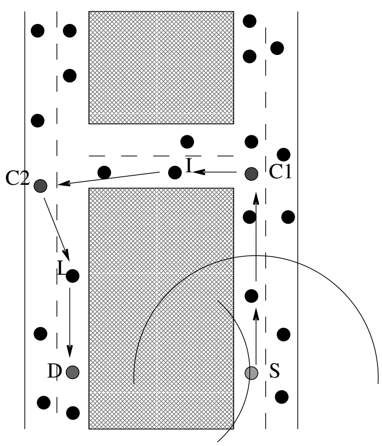

Figure 3: The right hand rule is used on the level of streets as a repair strategy in GPCR.

IV. Detecting junctions

One key challenge of GPCR is to detect whether a node is located on a junction without using external information. In the following we present two alternative approaches.

In the first approach each node regularly transmits beacon messages including the position of the node that is sending the beacon as well as the position of all of its neighbors. By observing the beacon messages a node has the following information for each neighbor: its position and the position and presence of the neighbor's neighbors. A node x is then considered to be located in a junction if it has two neighbors y and z that are within transmission range to each other but do not list each other as neighbors. This indicates that those neighbors are separated by an obstacle and that x is able to forward messages around this obstacle.

The second approach does not require special beacon messages. Each node calculates the correlation coefficient with respect to the position of its neighbors. We define x_i and y_i as the x-coordinate and y-coordinate of a node i. The variables x and y subsume the population of all these positions x_i and y_i, respectively. The mean of a population x is marked by $\bar{x}$. σ_{xy} indicates the covariance of two populations x and y and σ_x indicates the standard deviation of a population x. The correlation coefficient ρ_{xy} is then defined as:

$$\rho_{xy} = \left| \frac{\sigma_{xy}}{\sigma_x \sigma_y} \right| = \left| \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\left(\sum_{i=1}^{n} (x_i - \bar{x})^2 \right) \left(\sum_{i=1}^{n} (y_i - \bar{y})^2 \right)}} \right|$$

with $\rho_{xy} \in [0, 1]$. A correlation coefficient close to 1 indicates a linear coherence as it is found when the node is located in the middle of a street. A correlation coefficient close to 0 shows that there is no linear relationship between the positions of the neighbors. Consequentially we conclude that the node is located on a junction. By adjusting a threshold ϵ a node can evaluate the correlation coefficient and assume with $\rho_{xy} \geq \epsilon$ that it is located on a street and with $\rho_{xy} < \epsilon$ that it is located within the area of a junction. We use a very large value $\epsilon = 0.9$ for our implementation to account for the highly linear relationship between node positions on streets.

V. Simulation Results

We simulated the performance of GPCR with the `ns-2` simulator version ns-2.1b9a. For the simulations we used a real city topology which is a part of Berlin, Germany. The scenario consists of 955 cars (nodes) on 33 streets in an area of 6.25 km × 3.45 km. The movement of the nodes was generated with a dedicated vehicular traffic simulator and represents a real world movement pattern for this given scenario [6]. IEEE 802.11 was used as MAC with a transmission rate of 2 Mbps. The transmission range was set to 500 m. Real world tests with cars have shown this to be a reasonable value when using external antennas. For each simulation run we randomly selected ten sender-receiver pairs. Each pair exchanges 20 packets over 5 seconds. We measured the achieved packet delivery rate (Fig. 4) versus the distance between the two communication partners and the number of hops (Fig. 5). The communication distance between two nodes is calculated as the minimal distance based on the street topology at the beginning of the communication. Each point in the graphs is based on 10 independent simulation runs.

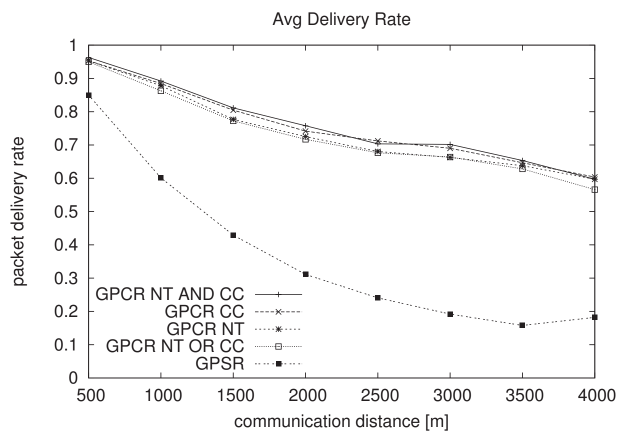

Figure 4: GPCR vs. GPSR. – Delivery rate

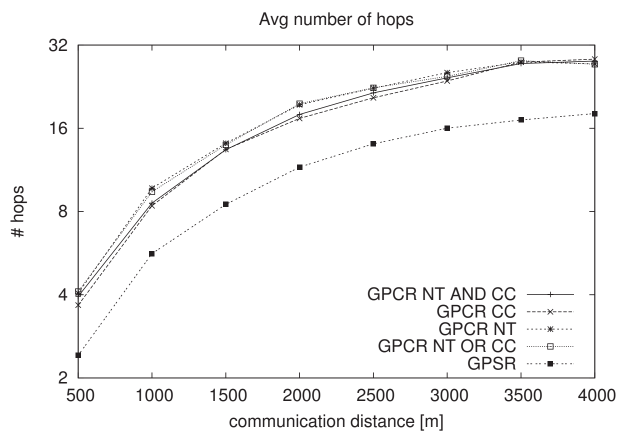

Figure 5: GPCR vs. GPSR. – Avg. no. of hops

Fig. 4 also depicts how the delivery rate is influenced by the algorithms used for junction detection. It shows that calculating the correlation (CC) coefficient performs slightly better than relying on the comparison of the neighbortables of the neighbors (NT). We also analyzed a compound decision consisting of the neighbortable comparison and correlation coefficient, concatenated by logical OR as well as by logical AND. The latter one outperforms the other approaches slightly but it does not come for free: the size of the beacon packets increases for each of the two approaches. Therefore, GPCR simply uses the correlation coefficient. In general the study on achievable packet delivery rate (Fig. 4) shows good results for our approach compared to GPSR. This improvement in performance comes at the expense of a higher average number of hops and a slight increase in latency. This increase in hop counts and latency is mainly caused by those packets that could not be delivered at all by GPSR and thus did not impact the hop-count and latency for GPSR.

VI. Conclusions and Future work

We presented a new position-based routing approach, GPCR, which is able to deal with the challenges of city scenarios where obstacles often block radio signals. Our approach does not require external information such as a static street map to avoid the problems that existing position-based approaches face in this type of environment.

GPCR still has some potential for future improvement: currently the next street to be taken is determined without considering whether there is a sufficient number of nodes on the street to allow packet forwarding to the next junction. We plan to augment GPCR with a very low overhead proactive probing scheme to predict whether the next junction in a given direction can be reached or not.

References

[1] L. Blažević, S. Giordano, and J.-Y. LeBoudec. Self Organized Terminode Routing. *Cluster Computing Journal*, 5(2), April 2002.

[2] P. Bose, P. Morin, I. Stojmenovic, and J. Urrutia. Routing with guaranteed delivery in ad hoc wireless networks. *Wireless Networks*, 7(6):609–616, 2001.

[3] T. Camp, J. Boleng, and L. Wilcox. Location Information Services in Mobile Ad Hoc Networks. In *Proc. of IEEE ICC '02*, pages 3318–3324, New York City, New York, April 2002.

[4] B. N. Karp. Challenges in Geographic Routing: Sparse Networks, Obstacles, and Traffic Provisioning. Talk at DIMACS Workshop on Pervasive Networking, May 2001.

[5] B. N. Karp and H. T. Kung. GPSR: Greedy Perimeter Stateless Routing for Wireless Networks. In *Proc. of ACM MobiCom '00*, pages 243–254, Boston, Massachusetts, August 2000.

[6] C. Lochert, H. Hartenstein, J. Tian, H. Füßler, D. Hermann, and M. Mauve. A Routing Strategy for Vehicular Ad-Hoc Networks in City Environments. In *Proc. of IEEE IV'03*, pages 156–161, Columbus, OH, 2003.