

A Study on Field Based Routing and Extensions

TIK Report 260

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Abstract

Field based routing is an upcoming, promising class of routing algorithms especially for wireless mesh networks. The purpose of this report is to give insides to several issues related to this class of algorithms. Namely the influence of the conductivity parameter κ , the backward path and comparison to AODV. In addition we investigate the impact of gateway placement, the number of gateways and if mobile nodes should be considered for routing. Finally we present an improvement by integrating preferred node groups and our simulation environment.

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1 Introduction

Over the past few years, a new family of routing concepts have been proposed - the family of field-based or potential-based routing schemes [16, 1, 4, 14, 12]. While the concept of field-based routing schemes appears to be fairly simple, it provides a very versatile way of determining routing decisions. For instance, modeling shortest-path routing with a field-based scheme is straightforward. Owing to the fundamental properties of fields, loop freedom of routes can be ensured, and it is guaranteed that packets are forwarded towards the destination.

In [14] we proposed to apply field based routing to wireless mesh networks and in [12] we defined a more general field theory for routing. In this technical report, we address several issues which came up from our previous work. First in section 2, we investigate the field calculation function, especially the influence of different conductivity parameters κ on the field shape. Then we analyse different options of implementing the way back in wireless mesh networks from the gateways to the mobile nodes (section 3). Following, we compare our proposal from [14] with AODV [11] in section 4 and in section 5 we investigate FBR with respect to various scenarios. When thinking of deploying wireless mesh networks several questions come up which we want to address in this report. Should mobile nodes be considered as routers and relay packets (section 6). How important is the placement of gateways (section 7). Which gateway density is required for which node density (section 8). Following we present an integration of the concept of preferred nodes [8] into field based routing (section 9). Finally in section 10 we describe in detail our simulation environment and set-up.

2 Influence of the Conductivity Parameter κ

Field based routing consists of two major units: the field construction and the route selection mechanism. The field construction mechanism enfoldes the exchange mechanism for field information and the field calculation.

In this section, we will have a detailed look at the field calculation and especially on the influence of the conductivity parameter κ . In addition, we investigate the following two features. First, if it is beneficial to penalize nodes with two many neighbors. Second, if it is beneficial to use several neighbors for field calculation or not. Simulations, show that in average conductivity and both features have a negative impact on the performance. Thus using conductivity may be beneficial for specific scenarios, but not for general ones.

Finally we give some more insides to the analogy with temperature fields.

2.1 The Field Calculation Function

The purpose of the field calculation function is to calculate the field value at a certain node. In our proposal, the function takes as input the field values of its neighbors. Based on these values it calculates the new field intensity f_{final} of the node, as follows. First of all, the node sorts its neighbors based on their field intensity values x_i in ascending order (line 1) into a temporary list. Then, it goes through this list, accumulating a temporary field intensity value $f(l)$ until the intensity of the next node in the list is less than the accumulated intensity (line 4).

In each step l , the next value $f(l + 1)$ is calculated as follows (line 5): First of all, the difference between the intensity of the currently considered neighbor, denoted by x_i , and the intensity accumulated so far, $f(l)$, is calculated. Then, this difference is multiplied by the conductivity parameter κ , and the result is added to the intensity accumulated so far, denoted by $f(l)$. A concrete example is given in n Fig. 1.

Algorithm 1 Field Calculation Function

```
1: Sort  $x_i$  in ascending order
2:  $l = 0$ 
3:  $f(0) = 0$ 
4: while  $f(l) < x_i$  do
5:    $f(l + 1) = f(l) + (x_i - f(l)) \cdot \kappa$ 
6:    $l = l + 1$ 
7:   Go to next node in sorted list
8: end while
9:  $f_{\text{final}} = f(l)$ 
```

2.2 Analytical Considerations concerning κ

For getting a petter understanding of the effect of the conductivity parameter κ , lets have a look at a simple scenario (Figure 2). We are interested on the field intensity at node X depending on κ and the amount of intermediate nodes.

The conductivity parameter κ allows to prioritize areas with a certain degree of redundancy. The strength of this effect gets stronger the smaller the parameter is chosen (see Figure 3). Because with a lower κ more intermediate nodes are required to get a higher percentage of the field intensity at node X. The effect of κ can very clear bee seen, when plotting the differences with respect to the number of neighboring gateways (see Fig. 4).

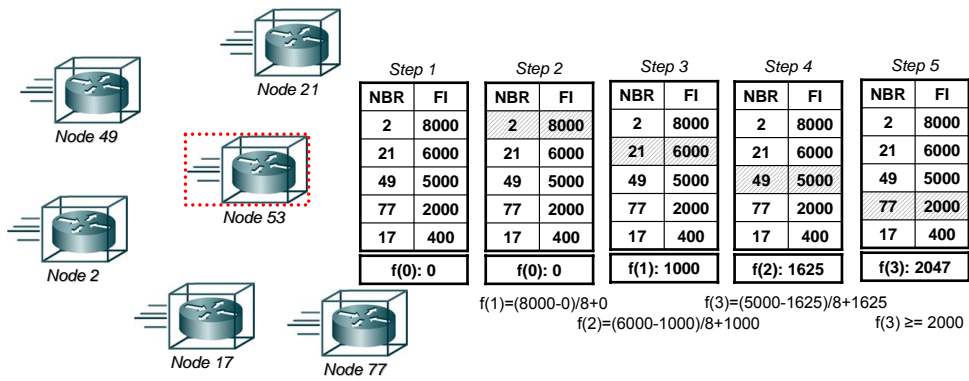


Figure 1: Example of field calculation function with a conductivity value of $\kappa = 1/8$ for node 53: step 1, sort neighbors (nbr) by field intensity; step 2-5 iterate down the table until the given field intensity of the node gets higher or equal to the next neighbor; node 71 and 17 do not contribute to the field intensity of node 53: they will increase their values after the next hello message of node 53 (node 77: 2005 and node 17: 605)

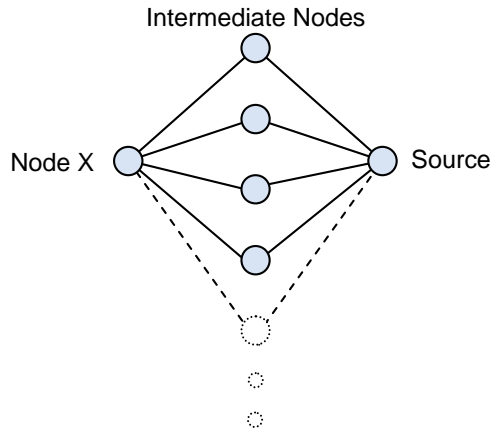


Figure 2: Scenario for Analytical Considerations

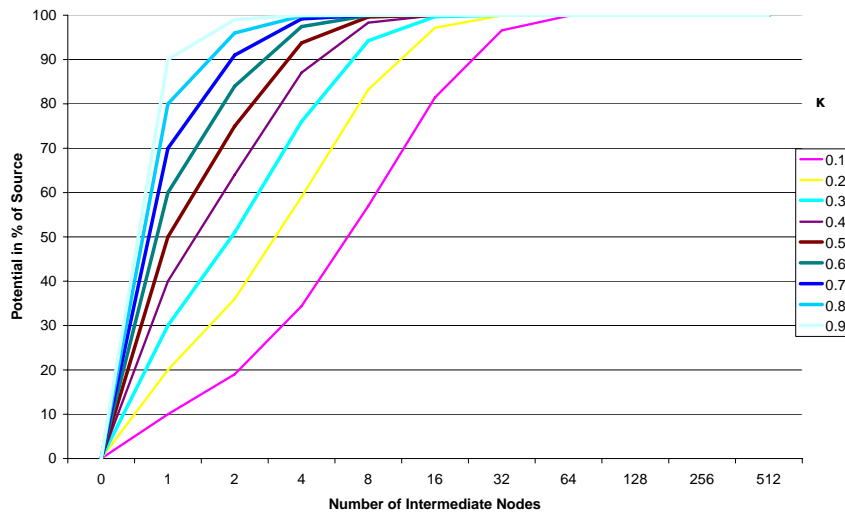


Figure 3: Field intensity at node X based on κ and the amount of intermediate nodes.

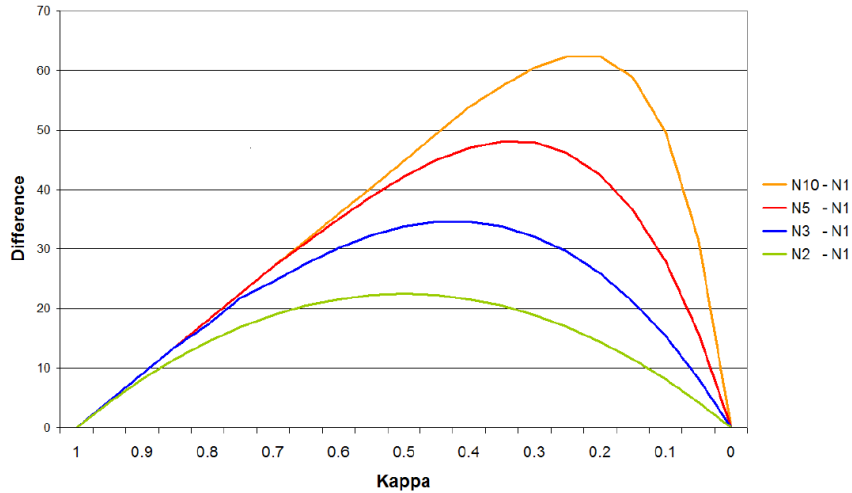


Figure 4: Field intensity at node X based on κ and the amount of gateways.

2.3 Simulations with different κ s

For analyzing the effect of κ in more complex scenarios, we conducted simulations. A description of the simulation set-up can be found in section 10. The results for the packet delivery ratio is plotted in figure 5 and for the number of hellos sent per node and interval in figure 6. They show that the amounts of hellos clearly increases for $0.1 \leq \kappa \leq 0.9$. The packet delivery ratio highly depends on the chosen scenario. Interesting is that turning of the conductivity feature, what is equal to considering only one neighbor, performance almost always the best. Only in scenarios with high mobility and high variance of mobility, a $\kappa \geq 0.9$ is beneficial.

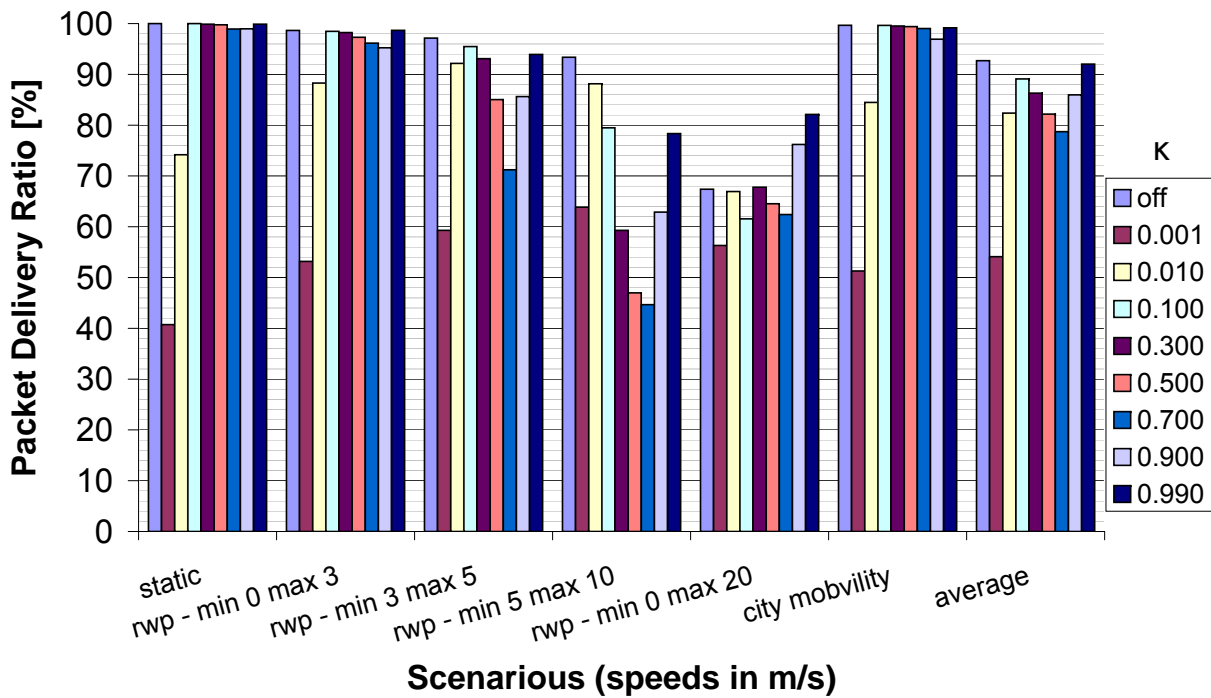


Figure 5: Packet delivery ratio depending on κ

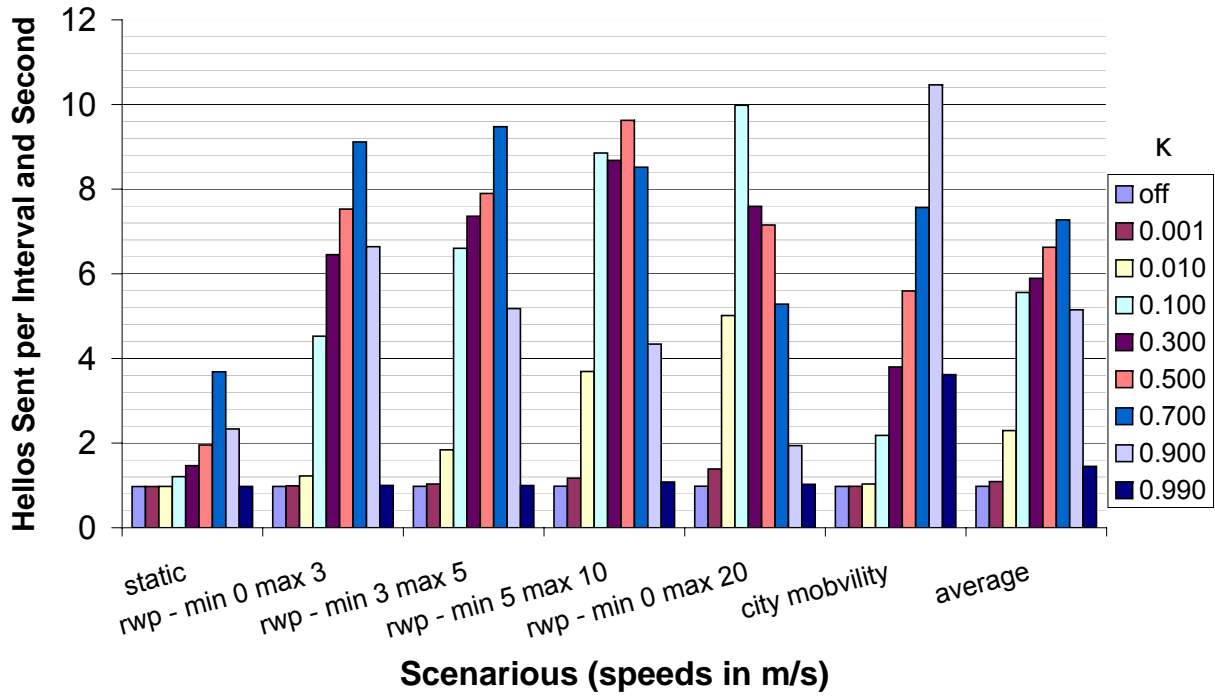


Figure 6: Hellos sent per node and hello interval depending on κ

2.4 Preferring areas with a certain number of nodes

As explained, areas with a high number of nodes are very attractive. But if there are too many nodes in an area, this may be problematic due to interference and high traffic load. To prefer areas with a certain number of nodes, the function can be adapted by decreasing the field intensity after reaching a certain value x_t as for example depicted in Figure 7 and Alg. 2.

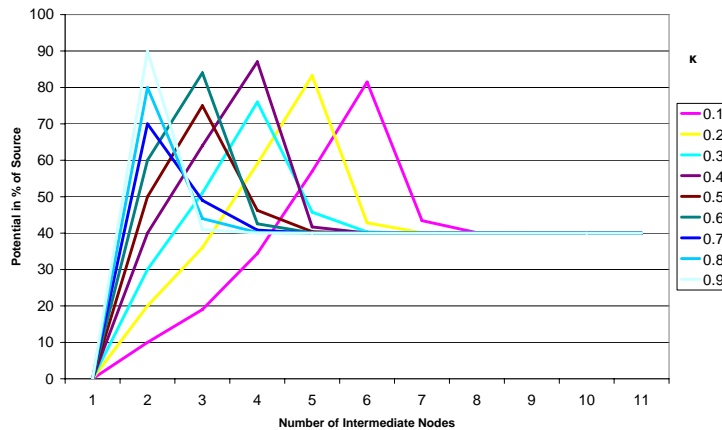


Figure 7: Field intensity at node X based on κ and the amount of intermediate nodes with signum.

For analyzing the effect of this feature in more complex scenarios, we conducted simulations with static, random way-point and city mobility scenarios. A description of the simulation set-up can be found in section 10. The average results for the packet delivery ratio in figure 8 show that considering more than 3 neighbors has a small negative impact. Also the numbers of hellos sent per node and hello interval increases clearly when considering more than 3 neighbors (Figure 9).

Algorithm 2 Field calculation function considering the l_{max} highest neighbors

```
1: Sort  $x_i$  in ascending order
2:  $l = 0$ 
3:  $f(0) = 0$ 
4: while  $f(l) < x_i$  do
5:   if  $x_i < x_t$  then
6:      $f(l+1) = f(l) + (x_i - f(l)) \cdot \kappa$ 
7:   else
8:      $f(l+1) = f(l) - (x_i - f(l)) \cdot \kappa$ 
9:   end if
10:   $l = l + 1$ 
11:  Go to next node in sorted list
12: end while
13:  $f_{final} = f(l)$ 
```

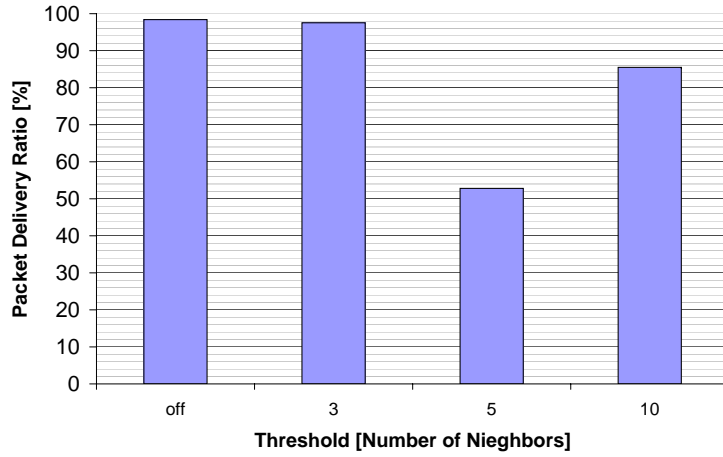


Figure 8: Packet delivery ratio for different thresholds of x_t

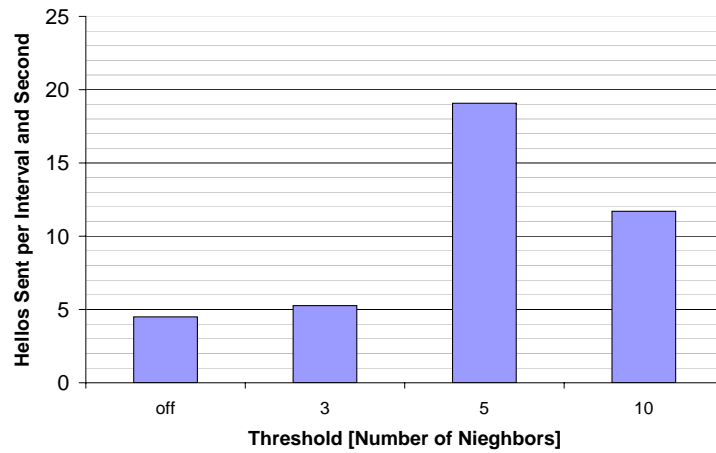


Figure 9: Hellos sent for different thresholds of x_t

2.5 Amount of Neighbors Considered for field calculation

As explained, areas with a high number of nodes are very attractive. But if there are too many nodes in an area, this may be problematic due to interference and high traffic load. Thus it is questionable if it is always the best solution to consider all neighbors for calculating the field. This can be implemented by only considering the l_{max} highest neighbors (see Alg. 3).

Algorithm 3 Field calculation function considering the l_{max} highest neighbors

```

1: Sort  $x_i$  in ascending order
2:  $l = 0$ 
3:  $f(0) = 0$ 
4: while  $f(l) < x_i$  and  $l < l_{max}$  do
5:    $f(l + 1) = f(l) + (x_i - f(l)) \cdot \kappa$ 
6:    $l = l + 1$ 
7:   Go to next node in sorted list
8: end while
9:  $f_{final} = f(l)$ 

```

For analyzing the effect of this feature in more complex scenarios, we conducted simulations with static, random way-point and city mobility scenarios. A description of the simulation set-up can be found in section 10. The average results for the packet delivery ratio in figure 10 show that this feature has a negative impact. Also the numbers of hellos sent per node and hello interval increases (Figure 11). This can be explained by the fact that the field intensities are becoming much more volatile.

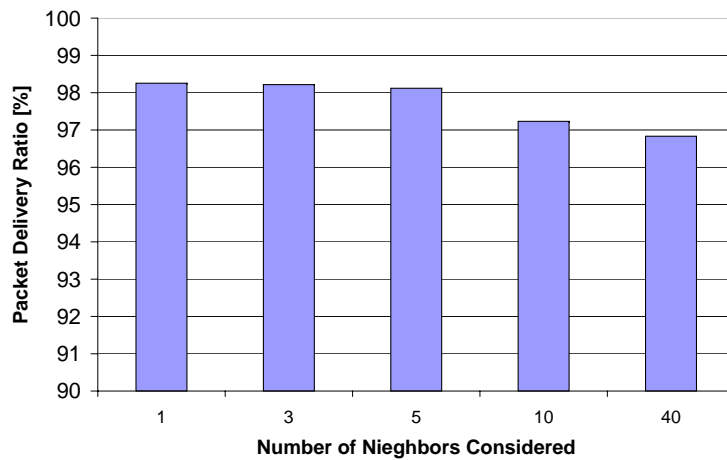


Figure 10: Packet delivery ratio for different considering a certain amount of neighbors.

2.6 Analogy to Heat

In this subsection we want to have a detailed look at the analogy of temperature fields used for our field calculation mechanism.

Our model of field calculation is analog to the temperature or heat field in physics. Heat transfer may occur by conduction, convection and radiation. Conduction is the most common means of heat transfer in a solid. On a microscopic scale, conduction occurs as hot, rapidly moving or vibrating atoms and molecules interact with neighboring atoms and molecules, transferring some of their energy (heat) to these neighboring atoms. Thermal conductivity κ is the intensive property of a material that indicates its ability to conduct heat and depends on the density of matter. The values of the temperature field are

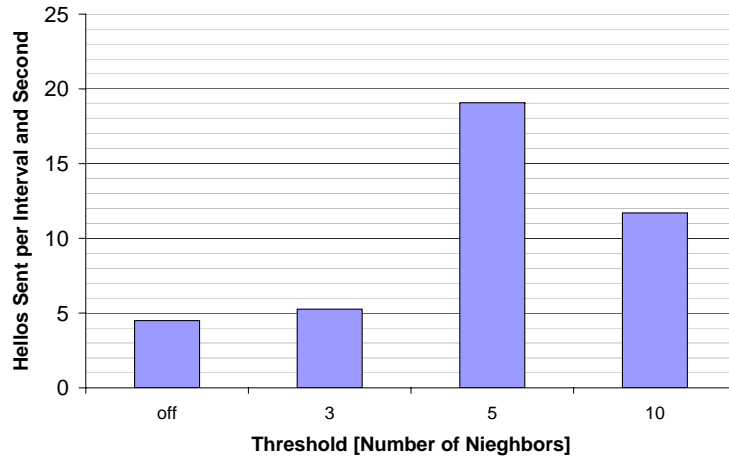


Figure 11: Hellos sent for different considering a certain amount of neighbors.

higher in the vicinity of heat sources, such as heating vents, and lower farther away. A major property of this solution is that the intensity of the field decreases away from a source resulting in a gradient.

Let's have a look at a concrete example. For simplicity reasons we will only focus on a single one-dimensional field with two heating sources and two different particle densities and thus κ s (Figure 12). We assume that the system cools down as fast as it gets heated, otherwise the system would end up in a steady state with all particles having the same temperature as the heat sources.

$$\frac{dQ}{dt} = -\lambda * A * \frac{dT}{dx} T = T_0 - dx * \frac{C}{\lambda} T_0 = 1000; C = 500; \lambda_1 = 1.43; \lambda_2 = 2.5 \quad (1)$$

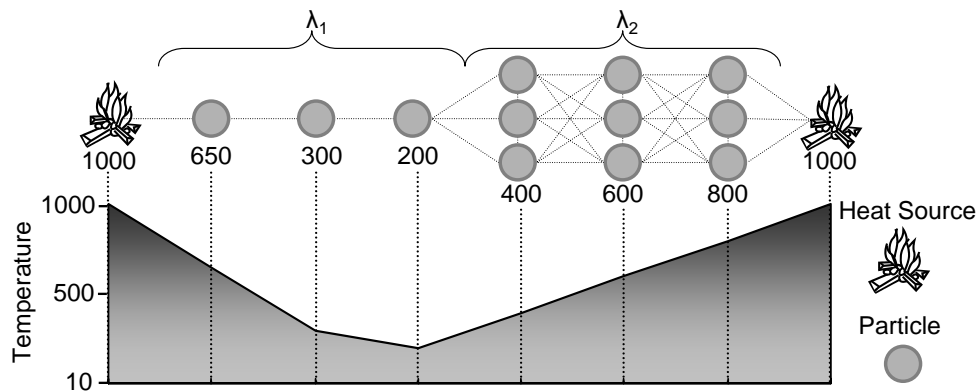


Figure 12: Temperature field with different κ s

3 Routing Packets from Gateways to Mesh Nodes (Backward Path)

The main idea of FBR is to route packets along an increasing field to a destination. For making this solution scalable for wireless mesh networks, only a single field is constructed for indicating the direction to gateways and thus to the Internet. The way back from the gateways to the wireless nodes can not be implemented the same way by only using a single field.

In this section we investigate three possible solutions for the backward path. First, constructing a field for every node. Second, recording the route of the forward paths and using them for source routing packets back. Third, using a reactive hop-by-hop routing approach based on AODV [11].

Our evaluation shows that the recorded routes are quiet up to date and of high quality resulting in a good packet delivery ratio. The packet delivery ratio for backward paths based on fields for every node is not as good due to fast changes of the field due to node mobility. Also in comparison with a reactive hop-by-hop routing approach the source routing approach wins due to its proactive maintenance.

3.1 Constructing a Field for Every Mesh Node

The most obvious approach is to use the same concept based on fields as for the forward path. The gateways have to propagate the information about the fields to the border router. Thus, field based routing can be deployed in the whole access network behind the border router. But this approach does not scale with respect to the number of nodes.

There are two improvements to this approach. First, the nodes which participate in the mesh without generating any traffic do not announce their fields. This reduces the amount of fields to be propagated over the network and stored in the border router.

Second, the field of a node are only propagated towards the gateways. This allows for much better scalability. This approach can be implemented by letting nodes ignore fields announced by neighboring nodes which are further away from the gateways. This can be determined based on the field strength of the field indicating the direction to the gateways. This improvement limits the fields of the mesh nodes to their local area making the solution more scalable. But in case of fast route changes it may have a negative impact on the reachability of a node.

3.2 Source Routing Using Recorded Routes on the Forward Path

The approaches of using a field per client impose scalability and performance problems in larger networks, because a route has to be maintained for every single mesh node. A more scalable alternative would be to take advantage of the paths of packets being forwarded toward the gateways. If these paths are stored in a central routing server connected to the gateways, they can be used to source route packets from gateways to mesh nodes. The advantages of this approach are manifold. Most importantly, this approach is very scalable as it imposes no overhead for the mesh nodes. Only the central routing server has to maintain up-to-date routes to individual mesh nodes. Another advantage is that it causes no additional communication.

Our source routing-based solution poses two minor issues to be discussed next:

(i) a path to a mesh node is only available after this node has sent a packet to a gateway. However, this is not a limitation. The vast majority of communication is initiated by mesh nodes. And, if a mesh node acts as a server, a dedicated addressing mechanism (e.g. [7], [10]) is necessary to enable reachability from the Internet. Any mechanism providing this reachability requires periodic registration messages from the mesh node. This periodic registration allows for updating the path.

(ii) the path to a mesh nodes are only updated when packets are sent to gateways. Again this property is not a limitation; all applications based on TCP and most other applications, generate bidirectional traffic. Even streaming requires some sort of keep-alive messages from the receiver. The uncommon

case where a node only receives traffic for a long period of time could be solved by having the node send ping packets to a gateway periodically.

3.3 Reactive Hop by Hop Routing

An alternative is to use a reactive hop-by-hop routing mechanism like AODV [11]. Like this the routing for the forward and backward path are completely different. This would be no problem, but the common scalability issue come up again. Mainly as a comparison baseline, we include this alternative in our evaluation.

3.4 Comparison

For comparing the backward paths, we conducted simulations with the following implementations. (1) a field per mesh node (2) a field per mesh node only propagated towards the gateway (3) source routing (4) reactive hop-by-hop routing. The simulations have been done with Glomosim [17] using static, random way-point (rwp) and city mobility scenarios. The parameter setting are according to 10. The results for the packet delivery ratio is plotted in figure 13, for the number of hellos sent per node and interval in figure 14 and for the routing overhead per packet or node and second in Fig. 16 and Fig. 15.

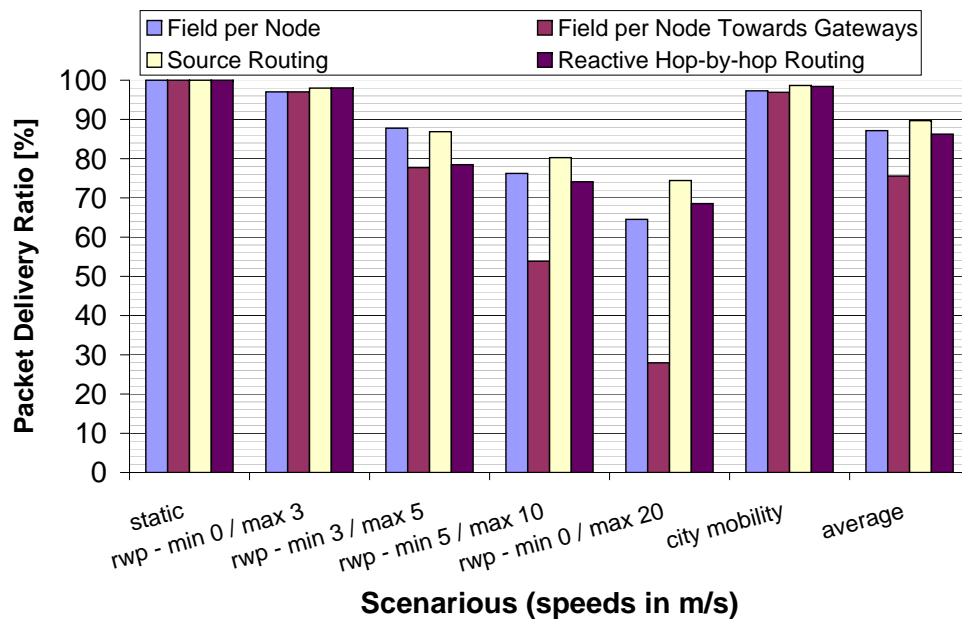


Figure 13: Packet delivery ratio

In the static scenario, the delivery ratio is 100% for all implementations. Also the amount of hellos is similar. For the random way-point and city mobility scenario, a significant increase of the amount of hellos sent is measured. In average, using a field at each client doubles the amount of hellos sent. This effect can clearly be reduced by only propagating the hellos only towards gateways. In addition this reduces the size of the hello messages dramatically, since the hello messages do not have to include a field value for all nodes. When comparing the packet delivery ratios of the scenarios with mobility, it can be seen, that the delivery ratio is the highest for source routing. This can be explained by the following effect. When a field with stationary sources is constructed, the overall field remains the similar, even if mobile nodes move around. Some of the nodes move towards the gateways and some away. These movements already compensates them self and the field gets only locally changed. On the other hand, if a field is constructed for a mobile node. This field moves with the node resulting in large changes of

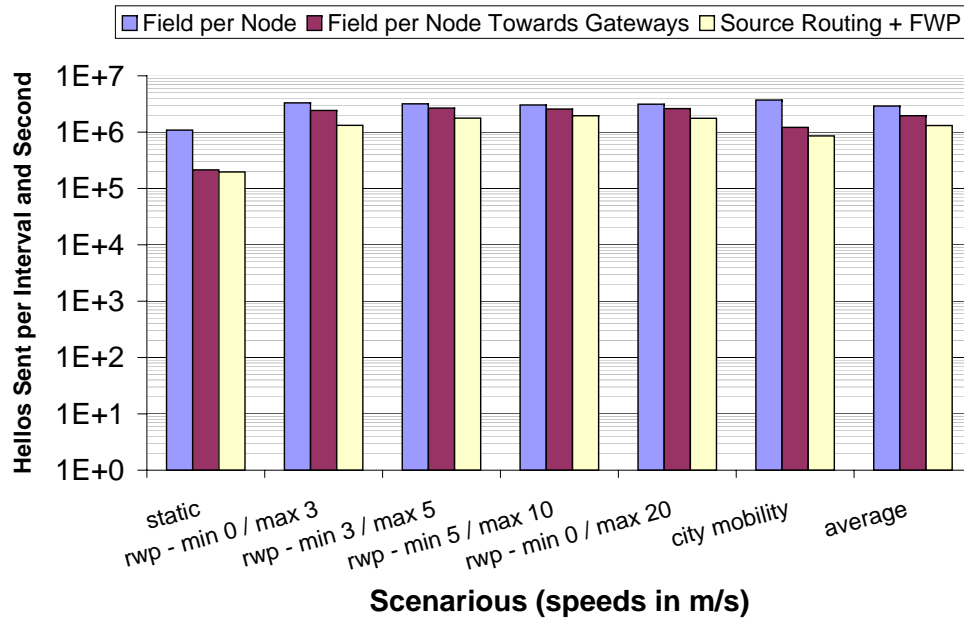


Figure 14: Hellos sent per interval and node (FWP: Forward Path)

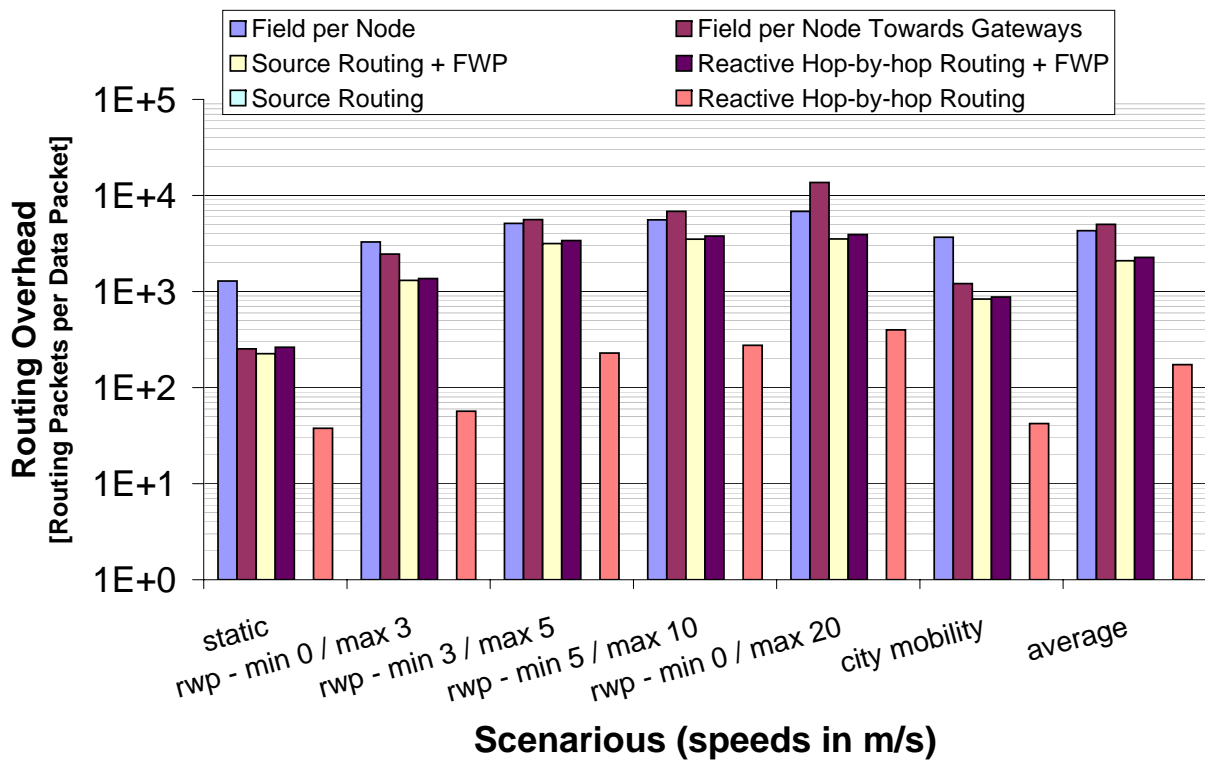


Figure 15: Comparison of per packet routing overhead (FWP: Forward Path)

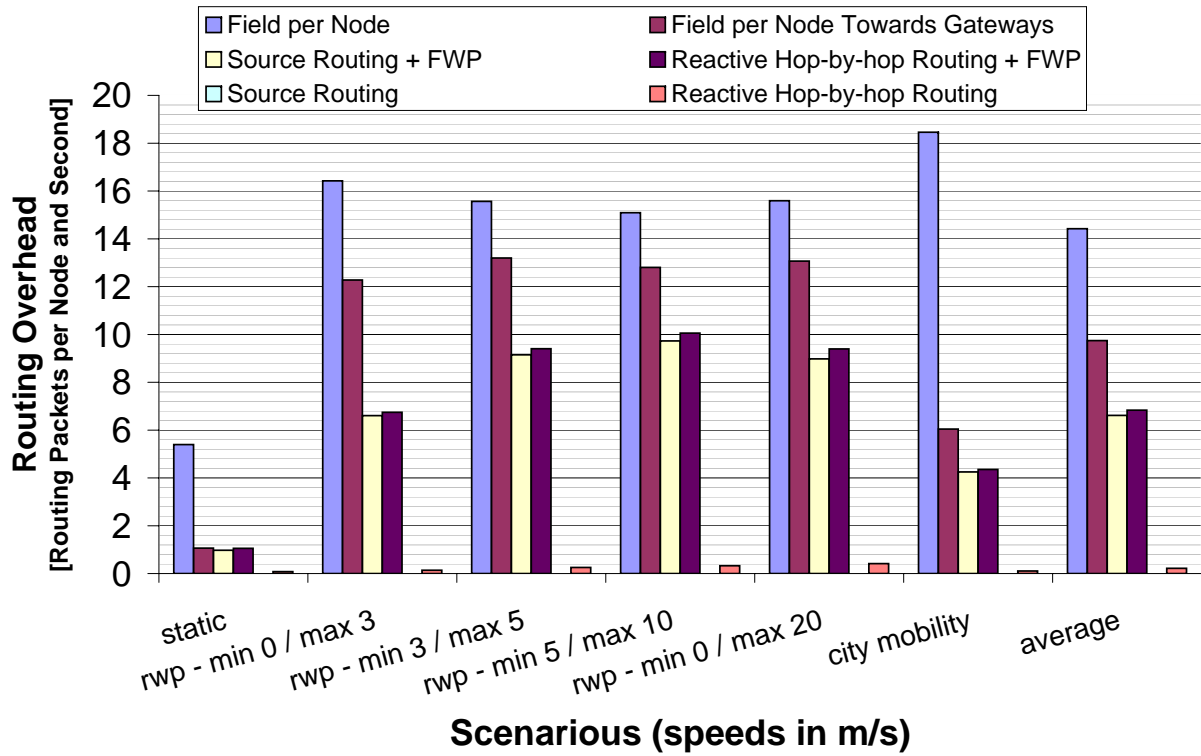


Figure 16: Comparison of per node and second routing overhead (FWP: Forward Path)

the field strength. Since constructing and updating a field over the whole network is a time consuming process, the field is smudged out resulting in route breaks and packet losses. Figure 13 shows that this effect gets stronger with increasing mobility. The delivery ratio even further decreases if we limit the propagation of the fields towards the gateways. In addition an increase of packet drops at intermediate nodes can be detected. This effect can also be explained by the mobility of nodes. If a node moves away from gateways, it first has to establish a field for itself in this region. This takes a certain time, while it is not reachable. Also comparing source routing to reactive hop-by-hop routing, the packet delivery ratio for source routing performs better. This can be ascribed to the permanent maintenance of the field which proactively tries to get the best route and does not wait until a route breaks.

4 Comparative Study

In this section we present the results of a comparative study between AODV [11] and FBR. We found that FBR outperforms AODV especially in moderate mobile scenarios. Also the routing overhead per packet for networks with an average traffic load is smaller for FBR.

Comparisons of different routing algorithms is especially hard. Due to cost reasons this has to be done by simulation. These simulation only give a limited picture of the reality. Never the less we tried to develop a realistic simulation environment for large-scale wireless mesh network based on metropolitan scenarios. In order to achieve a model that is as close to reality as possible, we extract vectorized street and building maps including speed information of several major cities of Switzerland from the Swiss Geographic Information System (GIS) [2]. Detailed parameter settings are according to [13].

A second problem is that it is hard to get implementations of other routing protocols. So for AODV, we had to implement the extension for Internet connectivity according to [9] based on the actual Glosim implementation.

We conducted comparative simulations with various scenarios as described in section 10. The packet delivery ratio in Fig.17 shows that FBR performs better than AODV. Especially in moderate mobile scenarios FBR outperforms AODV. When analyzing traffic traces, it can be seen, that this is especially due to the nodes far a way from a gateway. This also explains that the difference decreases for scenarios with high mobility because enabling connectivity for nodes farther away becomes more and more difficult. Also the routing overhead per packet (Fig. 18) or per node and second Fig. 19) looks promising for FBR. Even though it is a proactive approach in contrast to AODV, the routing overhead is smaller. This can be ascribed to the fact that in FBR only one single route has to be maintained, the route from the nodes to the Internet while in AODV for every communicating node a route to the Internet and a route from the Internet back has to be maintained.

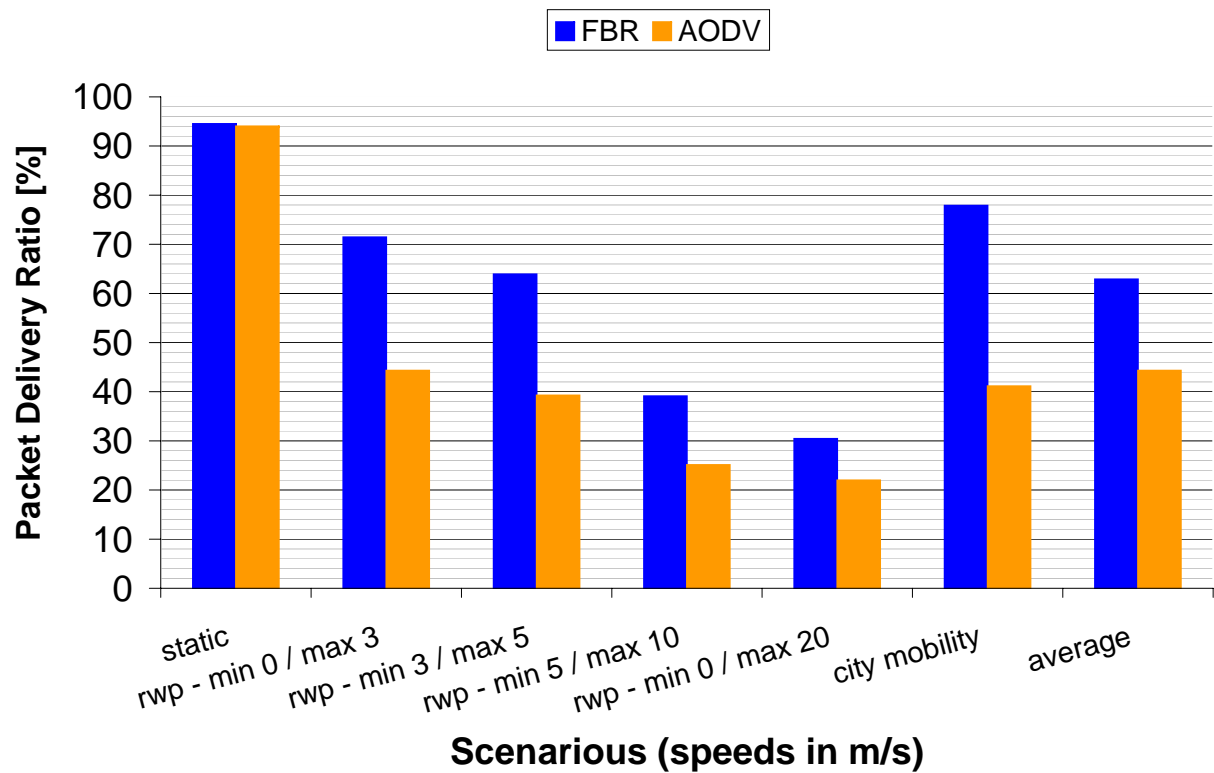


Figure 17: Comparison of packet delivery ratio between AODV and FBR

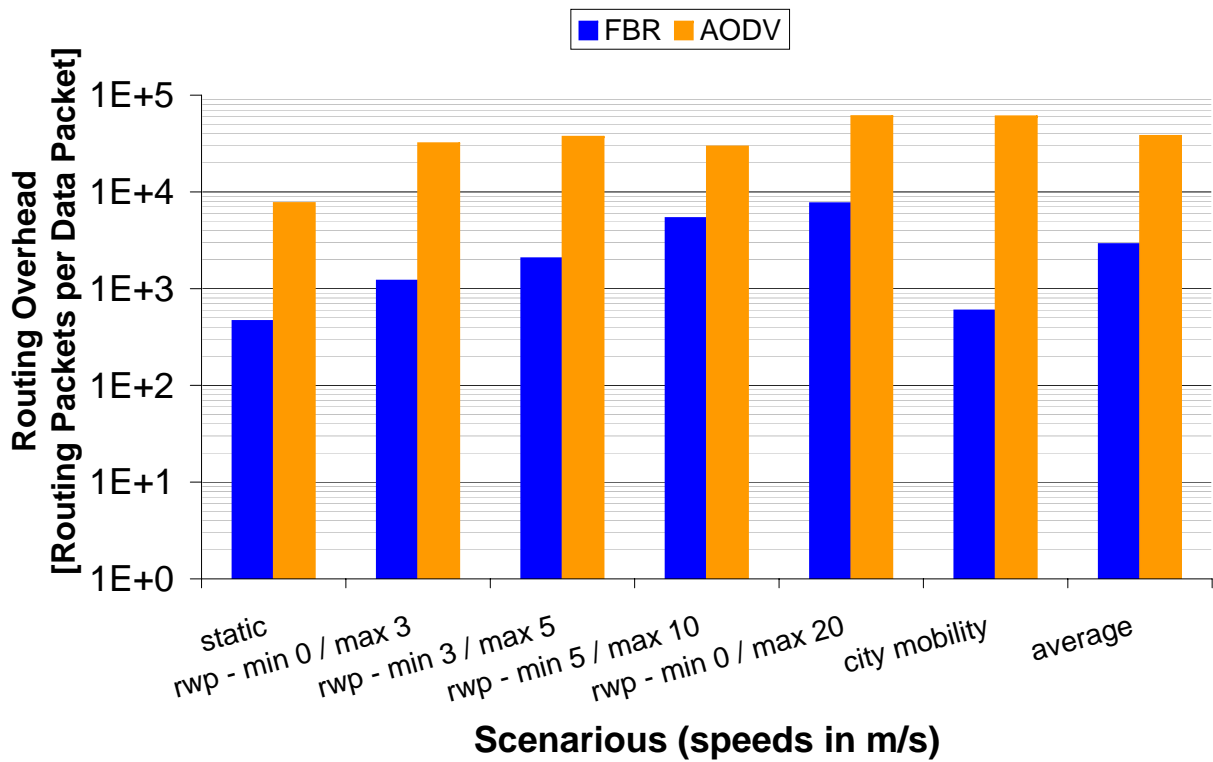


Figure 18: Comparison of per packet routing overhead between AODV and FBR

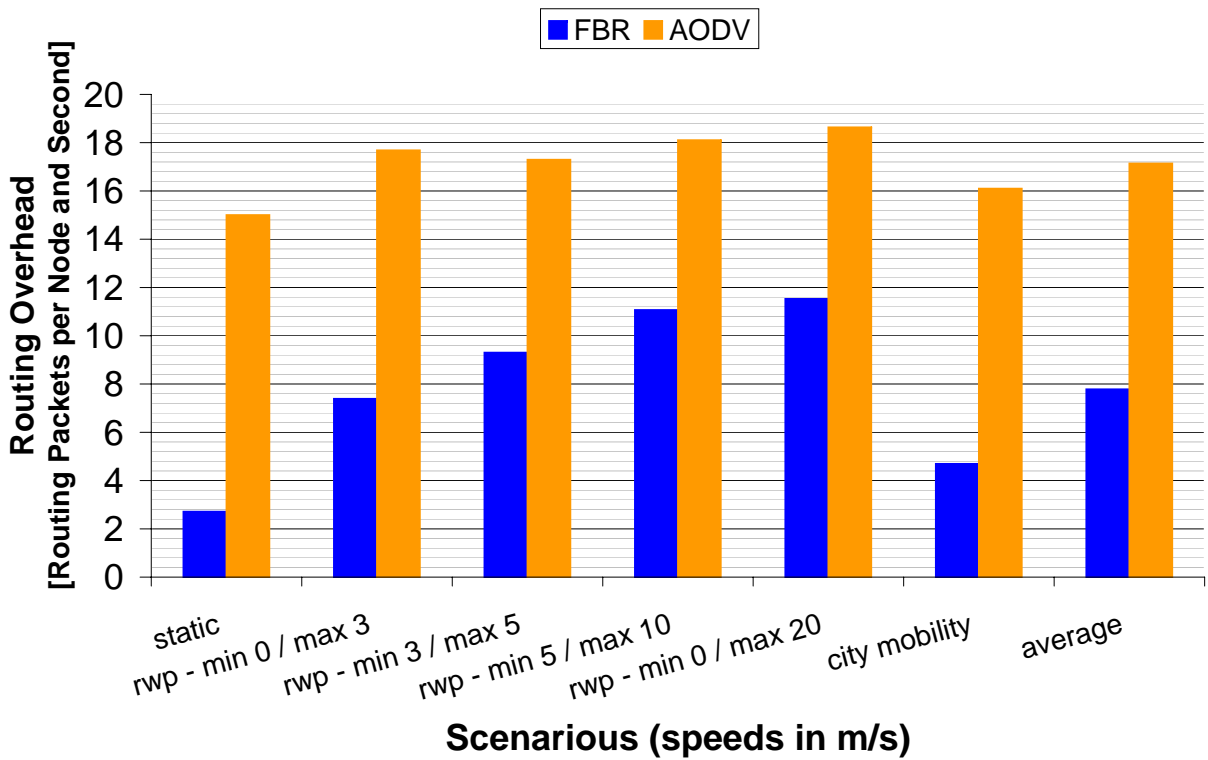


Figure 19: Comparison of per node and second routing overhead between AODV and FBR

5 Investigation of FBR in various Scenarios

In this section we investigate with simulations the question in which scenarios field based routing performs the best and in which it is not that strong.

For our simulations, we extended the simulation set-up described in section 10 to the following scenarios.

Node mobility and placement:

1. static, random placement
2. Random way-point: min 0 m/s | max 3 m/s
3. Random way-point: min 3 m/s | max 5 m/s
4. Random way-point: min 5 m/s | max 10 m/s
5. Random way-point: min 0 m/s | max 20 m/s
6. Random way-point: min 10 m/s | max 30 m/s
7. City mobility

Number of nodes:

1. 800
2. 1000
3. 1500
4. 2000

Figure 20: *Packet delivery ratio with respect to the different scenarios.*

Figure 21: *Average of hellos sent per node and second with respect to the different scenarios.*

6 Impact of Considering Mobile Routers

In a mesh network with fixed and mobile nodes it is of interest if mobile nodes should be used as relaying nodes or not. In this section we investigate this question by simulation using field based routing and several different mobility models. The simulations show that for networks with a high density of routers (fixed nodes), it is the best not to consider client nodes (mobile nodes) for relaying. For networks with a low density it is advisable to consider all wireless nodes for relaying. In networks with a moderate density it is the best to consider all nodes but to prioritize routers.

In wireless mesh networks, there are three kind of nodes: routers, gateways and clients. Routers are fixed nodes with unlimited power. Gateways are routers which in addition have a connection to the Internet over a second Interface. And finally clients are mobile, unreliable nodes in the mesh. When deploying routing to a wireless mesh network, it is of interest if the clients should also be used for packet forwarding as routers or if they should be given lower priority or even ignored. The lower priority can be given when constructing the field or when selecting the route.

For investigating this question we implemented and evaluated the following five extensions for field based routing (see Tab. 1).

	Field Calculation	Route Selection	Abbreviation
(1)	-	-	glomosim
(2)	$\kappa_{client} = \kappa \bullet 0.01$	-	glomosim_k01
(3)	-	if possible take a router as next hop	glomosim_nh
(4)	$\kappa_{client} = \kappa \bullet 0.01$	if possible take a router as next hop	glomosim_k01_nh
(5)	ignore clients	-	glomosim_no

Table 1: *Extensions to FBR*

The packet delivery ratio plotted in Fig. 22 shows that for wireless mesh networks with a high density of routers one should not consider clients for relaying. With a low density of routers, it is the best to treat all wireless nodes the same. For moderate densities of routers ignoring of clients or equal consideration is not optimal. All three proposed solutions perform similar for such networks. If the density of routers may change frequently or is not known, the best choice is (4).

Fig.23 shows the amount of hellos sent per node and second. The amount of hellos can be impressively decreased, when only considering the static routers (5). Extension (3) and (4) cut in half the amount of hellos.

6.1 Detailed Results

In this subsection we present detailed results for several scenarios (Fig. 24 25 26 27).

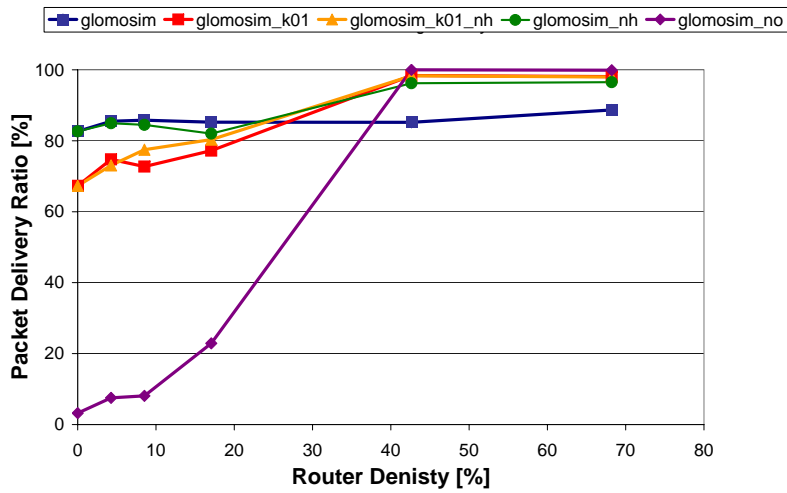


Figure 22: Packet delivery ratio averaged over all scenarios with respect to the percentage of fixed routers.

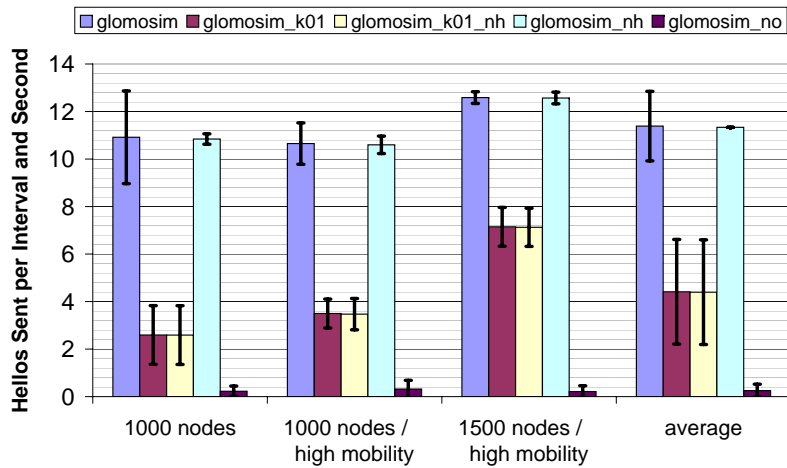


Figure 23: Average of hellos sent per node and second in the different scenarios.

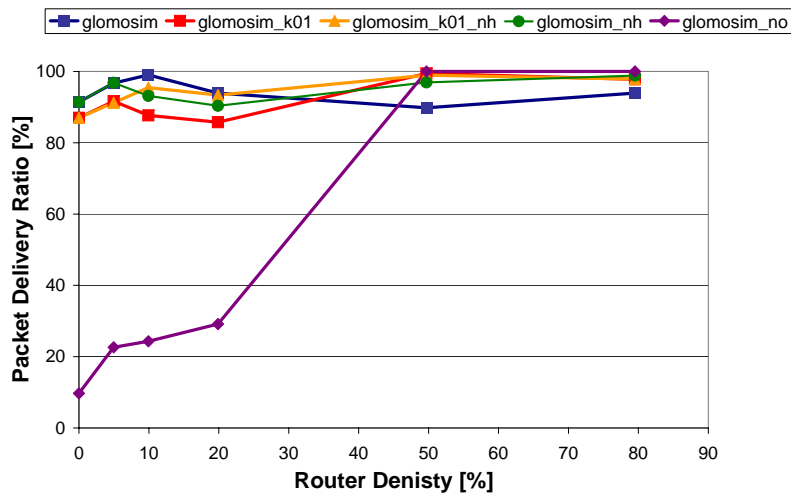


Figure 24: Packet delivery ratio for a scenario with 1000 nodes with respect to the percentage of fixed routers.

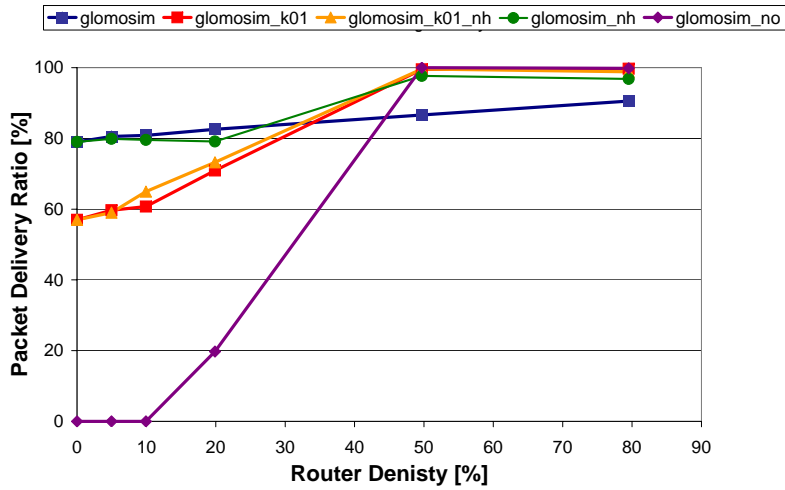


Figure 25: Packet delivery ratio for a scenario with 1000 nodes and high mobility with respect to the percentage of fixed routers.

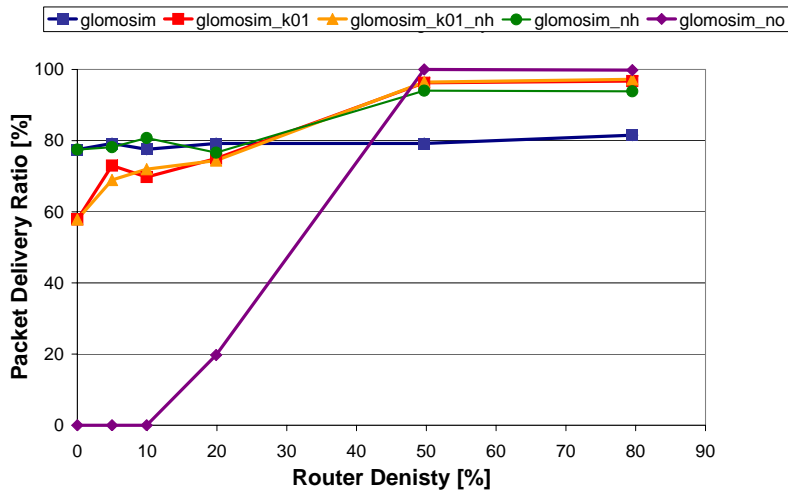


Figure 26: Packet delivery ratio for a scenario with 1500 nodes and high mobility with respect to the percentage of fixed routers.

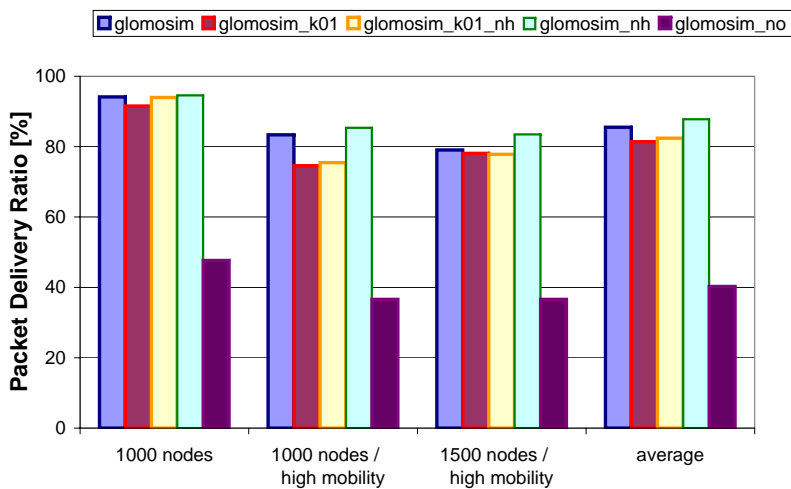


Figure 27: Average of packet delivery ratio in the different scenarios.

7 Impact of Gateway Placement

When constructing a wireless mesh network, a widely discussed question is where to place the gateways. In this section we address the question how important these placement really is. We conducted comparative simulations with optimal, random and bad gateway placement. We found that random placement of gateway performs quiet as good as strategic placement of gateways with respect to packet delivery. But the management overhead increases.

For analyzing the impact of gateway placement, we conducted simulations with the following gateway placements.

- Strategic placement of gateways
- Random placement of gateways (average over 50 seeds)
- Placement of gateways at the border of the simulation
- All gateways are placed at one place at the border of the simulation

A detailed description of the simulation parameters and set-up can be found in section 10.

The results show that the packet delivery ratio for random placement is nearly as good as for strategic placement of gateways (see Fig. 28). But for inappropriate gateway placements, the ratio clearly decreases. In contrast to the packet delivery ration, the management overhead measured in therms of hellos sent per node and seconds gets worse for random node placement (see Fig. 29). With inappropriate placements the management overhead increases even more.

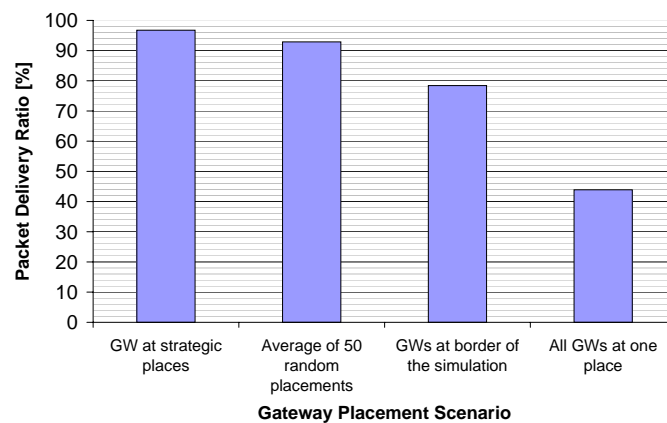


Figure 28: Packet delivery ratio based on the gateway placement

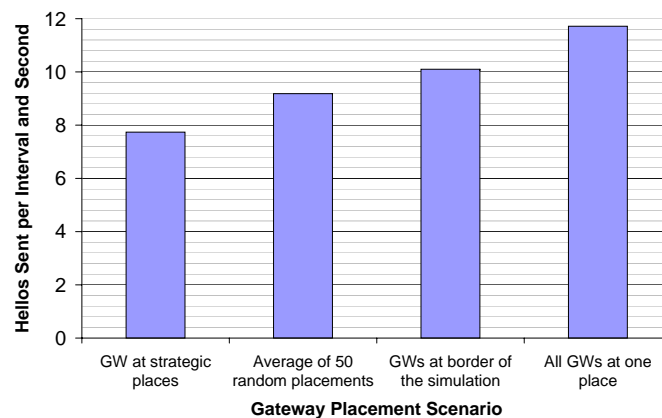


Figure 29: Hellos sent per node and interval based on the gateway placement

8 Impact of the Number of Gateways

When constructing a wireless mesh network, a widely discussed question is how many gateways are needed to cover a certain area. But this question highly depends on the communication range and the number of nodes participating in the mesh. Another important factor is the environmental influence of the radio propagation as buildings or power lines. In this section we address the question how many gateways are required for a good coverage with respect to the number nodes and the communication range. Due to the complexity, we do not consider environmental effects.

We conducted comparative simulations with the parameters listed in Table 2. Due to limitations in the simulation software we can only simulate up to 30 gateways.

Number of nodes	1000 / 1500 / 2000
Communication range	150 / 200 / 250 / 300 [m]
Number of gateways	1 / 5 / 10 / 20 / 30
Area	$6000 \times 6000 m^2$

Table 2: Simulation Parameters

As expected the achieved packet delivery ratio increases with the number of gateways (see Figure 30) as well as the number of sent hellos per node and second increases with the increasing density. Increasing the number of gateways from 1 to 5, significantly improves the packet delivery ratio. Interesting is that almost no packets are getting lost with a node density per communication range of about 8 nodes. The amount of hellos sent per node and second increases clearly with the node density up to around 8 nodes per communication range (see Figure 31). Afterwards the increase becomes fairly moderate.

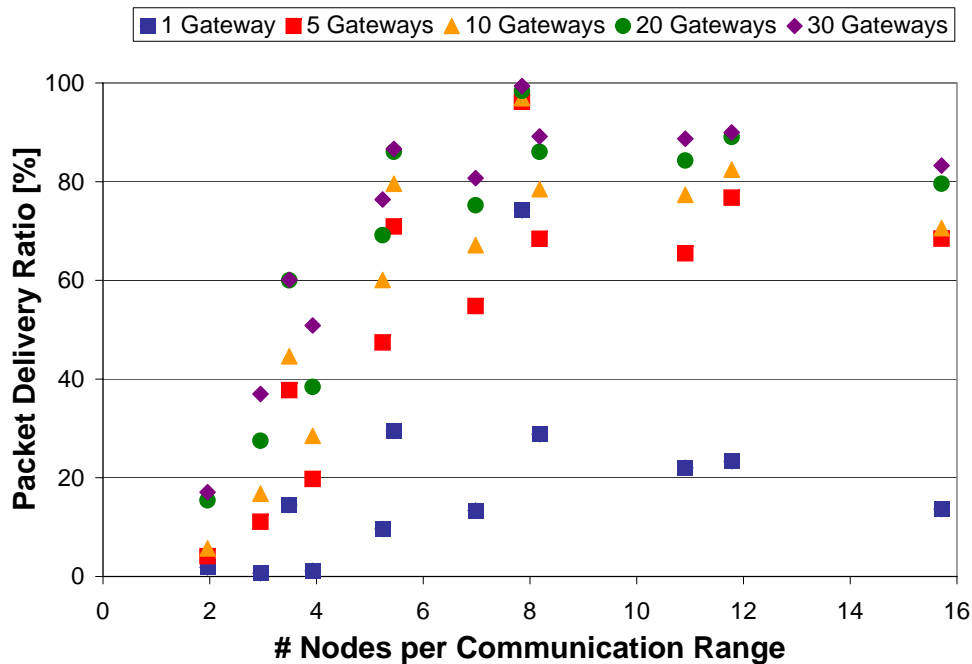


Figure 30: Packet delivery ratio with respect to the number of gateways and nodes per communication range

8.1 Detailed Results

In this subsection, we present more detailed results split up to the different node densities.

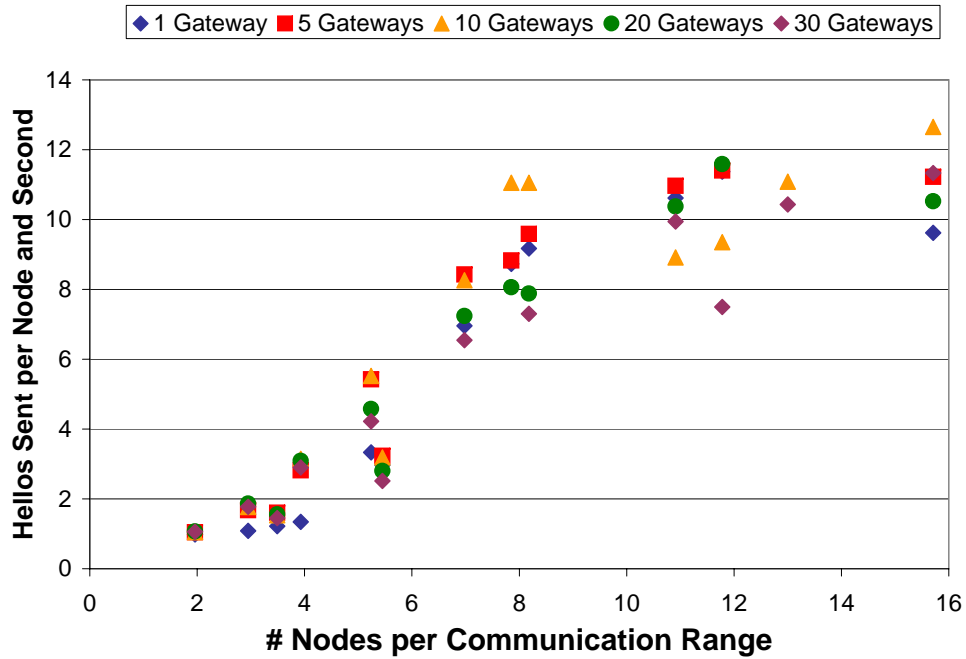


Figure 31: Hellos sent per node and second with respect to the number of gateways and nodes per communication range

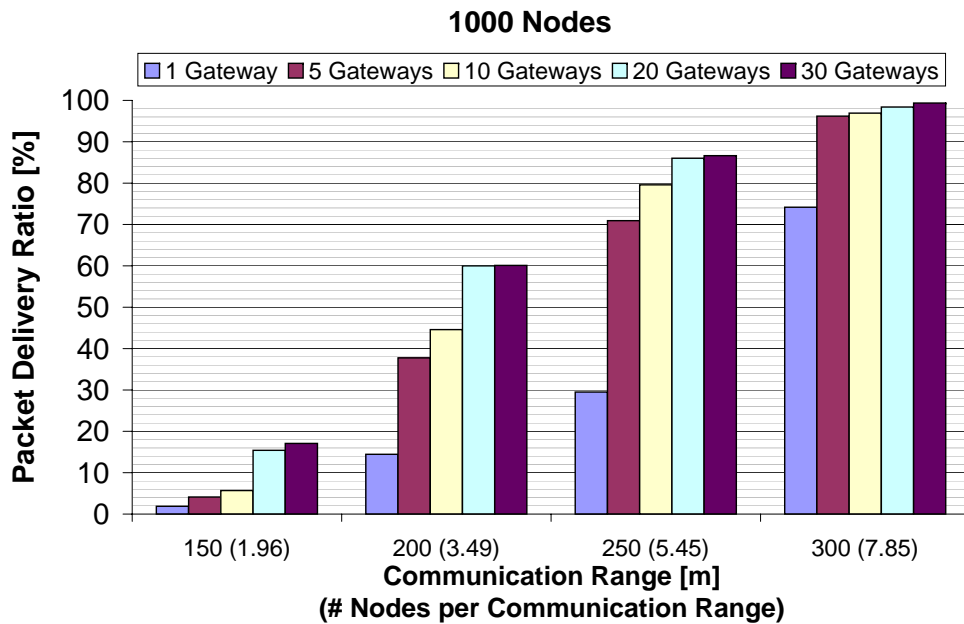


Figure 32: Packet delivery ratio with respect to the number of gateways and communication range for 1000 nodes on an area of $6000 \times 6000 \text{m}^2$

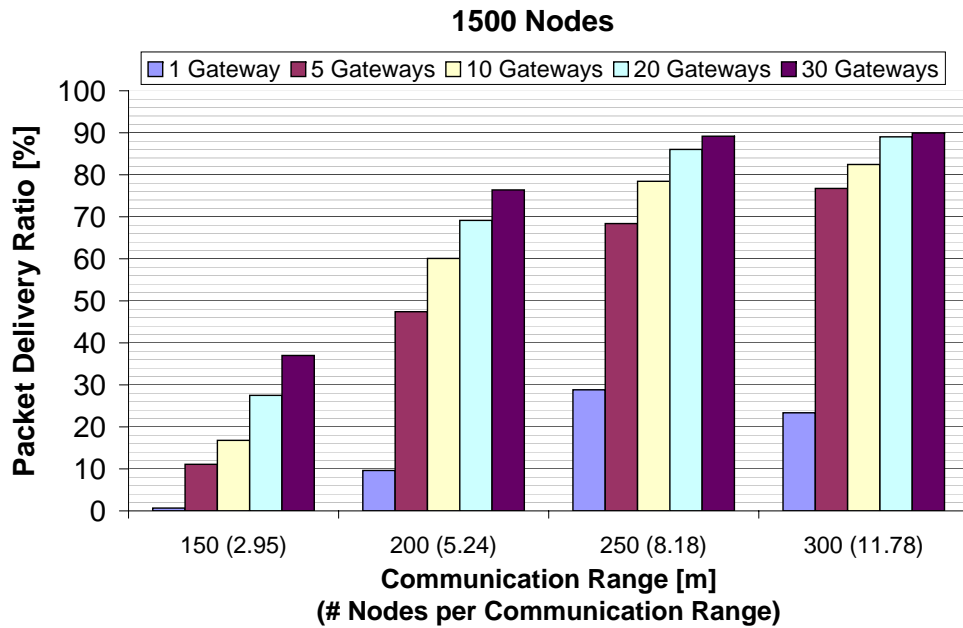


Figure 33: Packet delivery ratio with respect to the number of gateways and communication range for 1500 nodes on an area of $6000 \times 6000 m^2$

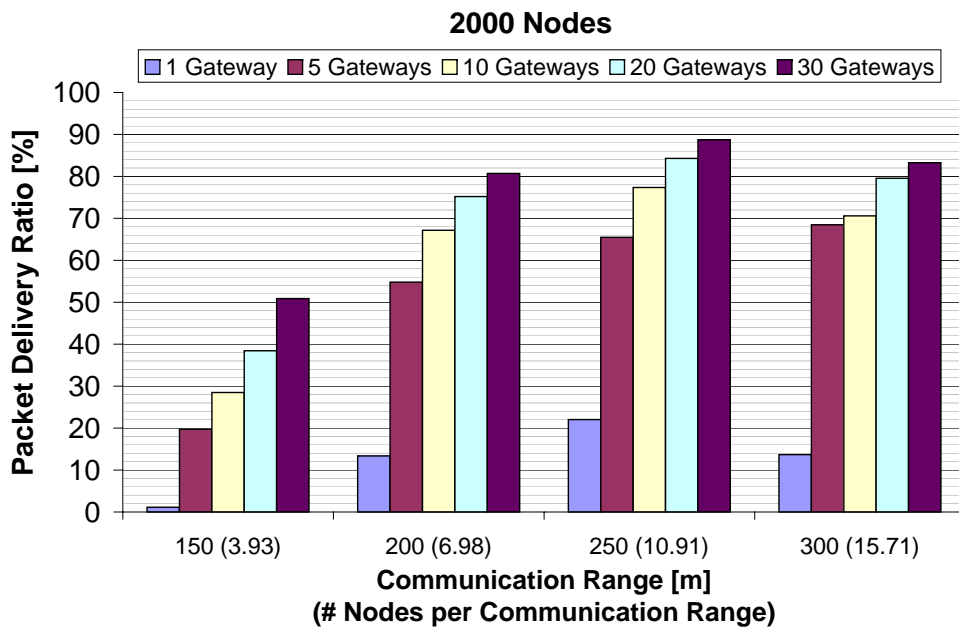


Figure 34: Packet delivery ratio with respect to the number of gateways and communication range for 2000 nodes on an area of $6000 \times 6000 m^2$

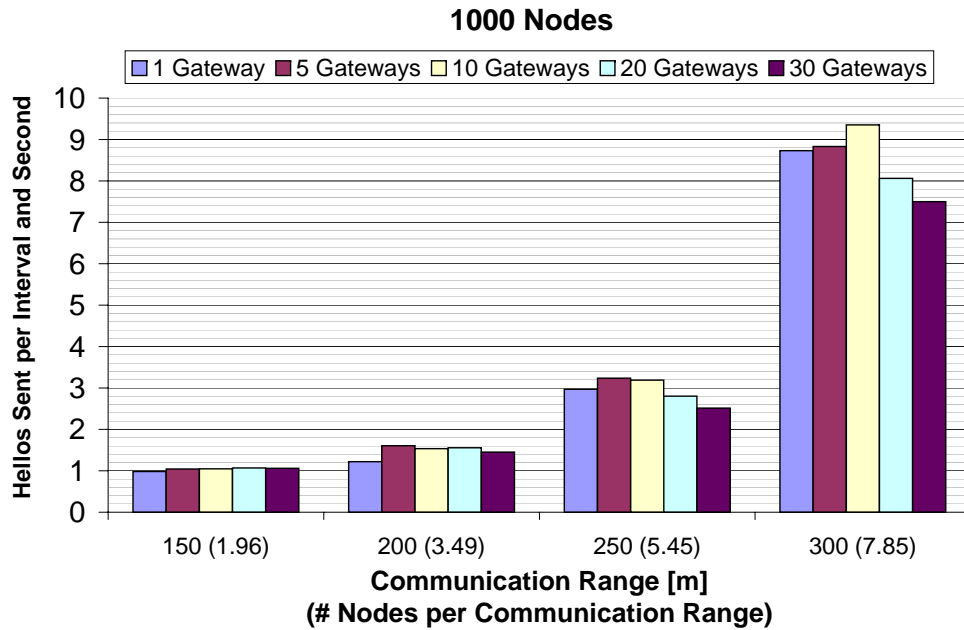


Figure 35: Hellos sent per node and second with respect to the number of gateways and communication range for 1000 nodes on an area of $6000 \times 6000 m^2$

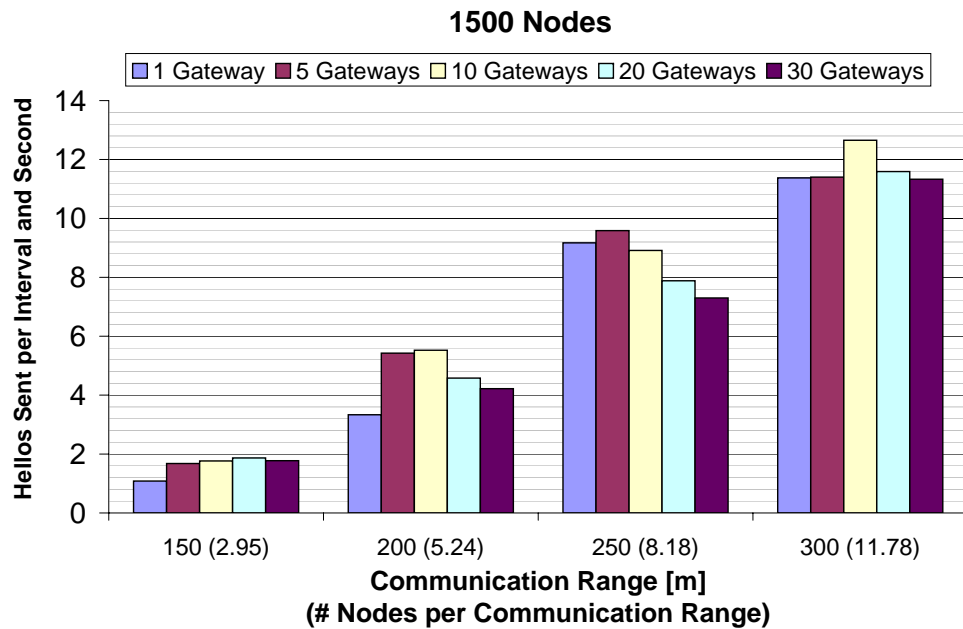


Figure 36: Hellos sent per node and second with respect to the number of gateways and communication range for 1500 nodes on an area of $6000 \times 6000 m^2$

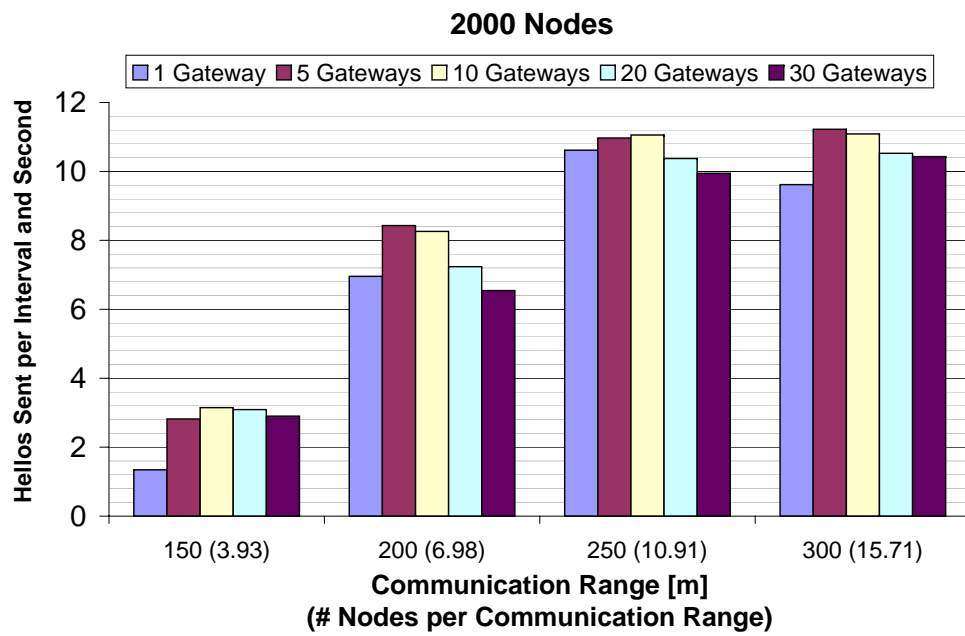


Figure 37: Hellos sent per node and second with respect to the number of gateways and communication range for 2000 nodes on an area of $6000 \times 6000 m^2$

9 Preferred Node Group

When building a wireless mesh network, it can be beneficial to prefer certain nodes over other based on their distance to the other nodes. A prioritization mechanism based on the signal strength has been presented in [8]. In this section we apply this scheme to field based routing and investigate it by simulation.

9.1 Preferred Nodes

Preferred Node (PN) is a mechanism that aims (1) to reduce control messages overhead, by eliminating redundant transmissions and (2) to obtain stable routes with the ability to auto-correct. While a minimization of a routing load is very desirable in any of the possible ad hoc scenarios, the stability of a chosen route becomes especially important in an environment where fast moving nodes are used as wireless hosts.

Usually in field based routing, no special criteria are used when considering neighbors for field calculation or forwarding. Thus it can easily be the case that two neighbors in a path are very close to each other, or vice versa are separated by a distance close to the maximum communication range. Neither of the cases is desirable. Short distances between hops imply a high number of hops in the path. On the other hand, when a hop length is close to a maximum coverage range, the connection can be easily lost if one of the nodes moves out of the range, or slightly changed interference jams the weak signal. Moreover, poor connection quality leads to throughput degradation, due to an increased number of errors. If an adaptive data-rate is used, then a high bit error rate forces the data-rate to decrease, and this step may lead to a bottleneck problem in the current node.

PN address these and other problems by preferring certain node over other. With PN, a node which relives a hello packet classifies a node into one of the three groups, based on the sensed signal level (Fig. 38):

- Preferred node group (PNG) - the preferred set of nodes;
- IN group - nodes with a signal stronger than in PG;
- OUT group - nodes with a signal weaker than in PG.

For simplicity we depict the communication range of a node and the power levels for the IN and OUT groups as circles in Fig. 38, but our algorithm by no means assumes that the range is indeed circular. To classify a node, the power of a received signal is compared to two values: Inner Threshold (IT) and Outer Threshold (OT). More details can be found in [8].

Based on this classification we implemented several extensions to FBR and compared them by simulation. First we present three extensions to the field calculation function and then two extensions to the route selection.

Ignore Non Preferred Neighbors

Ignore non preferred neighbors is a very simple extension. Nodes simply ignore hellos from all neighbors not being in the preferred node group. Like this, the non preferred neighbors are not considered when calculating the field intensity. But traffic will still be handled.

Preferred Node

Preferred node does not take such an extreme approach as ignoring non preferred neighbors but giving them higher conductivity. When summing up the field intensity of a node, the conductivity parameter κ is used to reduce the field intensity over a link. With the preferred node extension, we substitute it as following: *if*(neighbor \in PN) $\kappa_{new} = \kappa_{old}$ *else* $\kappa_{new} = \kappa_{old} * \kappa_{pn}$. For our evaluation we set $\kappa_{pn} = \kappa_{old}$ resulting in $\kappa_{new} = \kappa_{old}^2$.

Preferred Node Function

The preferred node function tries to integrate the preferred nodes more granular into the field calculation function. When summing up the field intensity of a node, the conductivity parameter κ is used to reduce

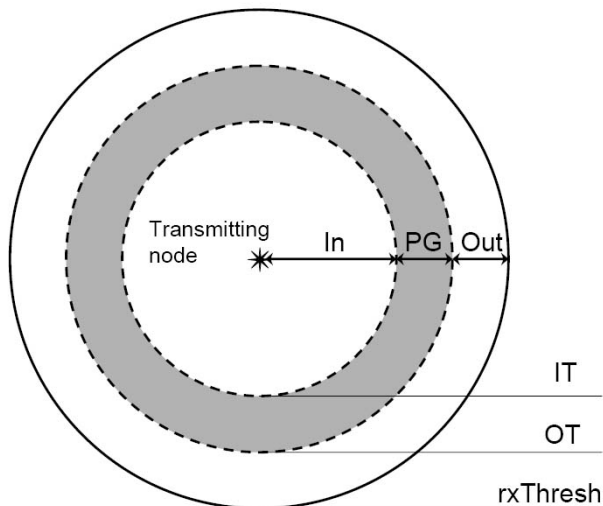


Figure 38: *Proffered Nodes*

the field intensity over a link. With the preferred node function extension, we substitute it as following: $\kappa_{new} = \kappa_{old} * (1 - \kappa_{pn} * \sigma)$. With $\sigma \in [0, 1]$ where $\sigma = 0$ if the neighbor is in the preferred group and linearly increasing up to 1 for neighbors very close or very far away. For our evaluation we set $\kappa_{pn} = \kappa_{old}$.

Preferred Next Hop

An option is to use the idea of preferred nodes in the route selection process. Commonly we look at all neighbors and take the one with the highest field value as the next hop (steepest gradient). With preferred next hop, we first consider only nodes in the preferred node group. If there are nodes with a higher potential than the sending node, accordingly, we take the one with the highest field value out of the preferred node group. If there is none, we also consider the remaining neighbors as next hops and choose the one with the highest field values out of them.

Preferred Next Hop Gradient

Preferred next hop gradient is an extension to preferred next hop. Instead of taking the node with the highest field value, we choose the node with the best *weighted gradient* (wg). The weighted gradient is calculated as follows.

$$wg = \frac{\phi_{neighbor} - \phi_{thisnode}}{\kappa_{neighbortothisnode}} \quad (2)$$

Preferred Node Function	PGF	field calculation
Ignore Non Preferred Neighbors	INPN	field calculation
Preferred Next Hop	PNH	route selection
Preferred Next Hop with Gradient	PNHG	route selection
Preferred Node	PN	field calculation

Table 3: *Abbreviations of different preferred neighbor extensions.*

9.2 Results and Discussion

For comparing the different preferred node extensions, we conducted simulations with static, random way-point and city mobility scenarios. The detailed simulations setting are described in 10. According to [8], we set the inner threshold to 5dB and the outer threshold to 3 dB. The abbreviations for the

different extensions are listed in Table 3. The results for the packet delivery ratio is plotted in figure 39 and for the number of hellos sent per node and interval in figure 40.

Preferred Node Function	PGF
Ignore Non Preferred Neighbors	INPN
Preferred Next Hop	PNH
Preferred Next Hop with Gradient	PNHG
Preferred Node	PN

Table 4: Abbreviations of different preferred neighbor extensions.

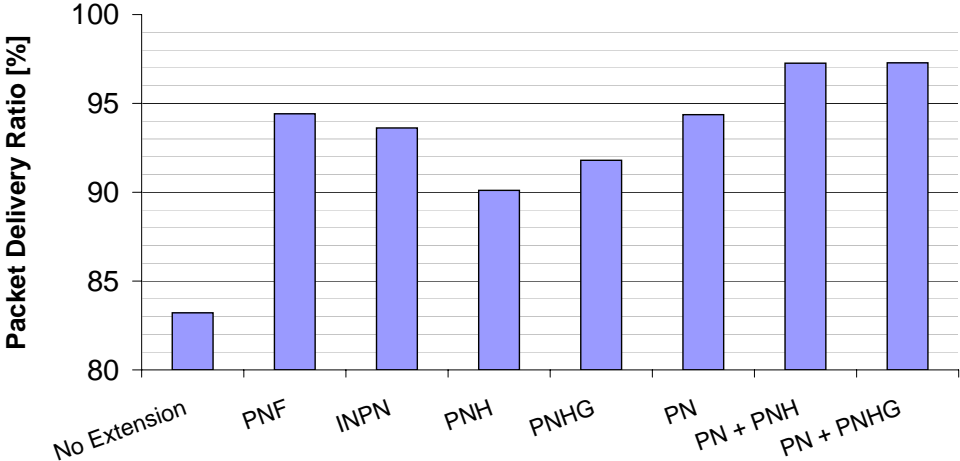


Figure 39: Packet delivery ratio depending on the extension

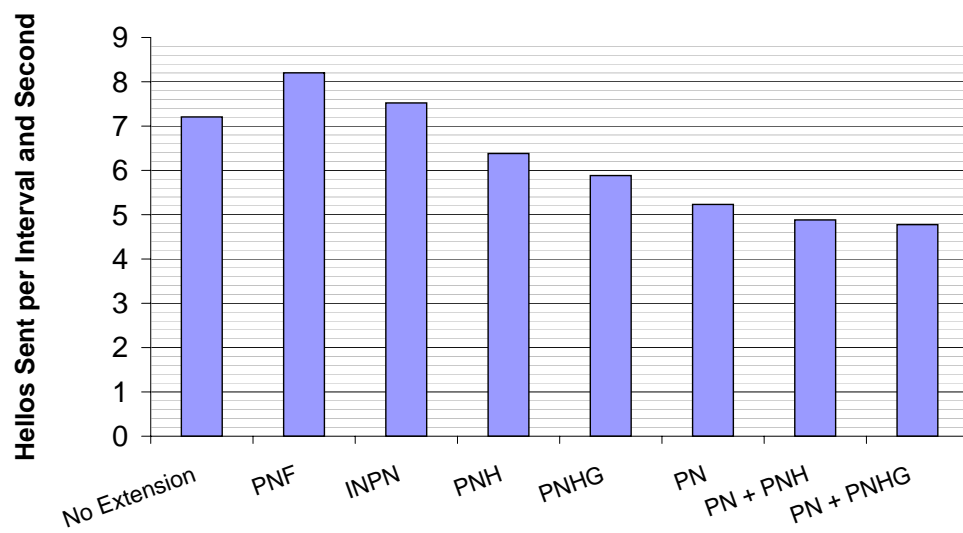


Figure 40: Hellos sent per node and second depending on the extension

10 Simulation Environment

In this section, we specify the parameters we use in the experiments for the simulation environment as well as for FBR. Then, we present the static, random way-point and city mobility scenarios that we use for our simulations.

10.1 Simulation Parameters

We use Glomosim [17] for all simulations. All nodes are equipped with 802.11b radios with a bandwidth of 11 *Mbps*. All other parameters are left at their default value. Since our study focuses on the wireless network, we assume that the wired network between the gateways and the servers in the Internet does not represent a bandwidth bottleneck.

10.2 Field Based Routing Parameters

If not stated differently we used the following parameterization of FBR for our simulations.

- Hello interval: 1 second
- Hello timeout interval: 5 seconds
- Delay for early hellos: 20 milliseconds
- Broadcast jitter: 10 milliseconds
- Kappa: 0.3
- Backward path: source routing

10.3 Scenarios

Unless stated otherwise, we use a scenario of 1000 mesh nodes and 5 gateways.

Static

All nodes (including the gateways) are randomly distributed over an area of $5000 \times 5000 m^2$.

Random way-point

Initially, all nodes (including the gateways) are randomly distributed over an area of $5000 \times 5000 m^2$. Node movement is based on the random way point model. Pause time is always set to 0 seconds. The minimum and maximum movement speed are set the following.

- min 0 m/s | max 3 m/s
- min 3 m/s | max 5 m/s
- min 5 m/s | max 10 m/s
- min 0 m/s | max 20 m/s

City mobility

In order to achieve a model that is as close to reality as possible, we extract vectorized street and building maps including speed information of several major cities of Switzerland from the Swiss Geographic Information System (GIS) [2]. We place 5 gateways at strategic places of the cities. Additionally, 1000 mesh nodes are distributed randomly over the roads of each city. The mesh nodes move along the roads according to the steady-state random trip mobility model [5] using the speed information from the GIS.

The GIS tells us about the maximum allowed speed on a certain street (in Switzerland for streets in cities, usually 50 km/h). This maximum speed is used as a maximum for the mobility model. As the minimum the half of the maximum is taken. The average pause time is set to 100 seconds.

10.3.1 Traffic Pattern

In accordance to [15, 3, 13] we employ a mix of streaming and web-like traffic between mesh nodes and servers in the Internet.

Web-like traffic consists of requests from mesh nodes and responses from servers in the Internet. The inter-request times follow an exponential distribution. The response message size is Pareto II [6] distributed. The detailed configurations are as following.

- Constant request size 2kB
- Average answer size 12kB
- Minimal answer size 100Bytes
- Maximum answer size 1MB
- Minimal inter request time 0.1 seconds
- Maximal inter request time 180 seconds
- Sleep probability 0.1
- Average sleep time 480 seconds

The **streaming traffic** uses constant bit rates between servers in the Internet and mesh nodes. The streaming and pause times are again exponentially distributed. The detailed configurations are as following.

- Constant bidirectional data rate 64kBits
- Minimal streaming duration 1 seconds
- Maximal streaming duration 180 seconds
- 20% of streamings have an average duaration of 180 seconds
- 80% of streamings have an average duaration of 480 seconds

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