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UNIVERSITÄT FREIBURG

Algorithms for Radio Networks

Geometric Routing

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Geometric Routing

► Routing target:

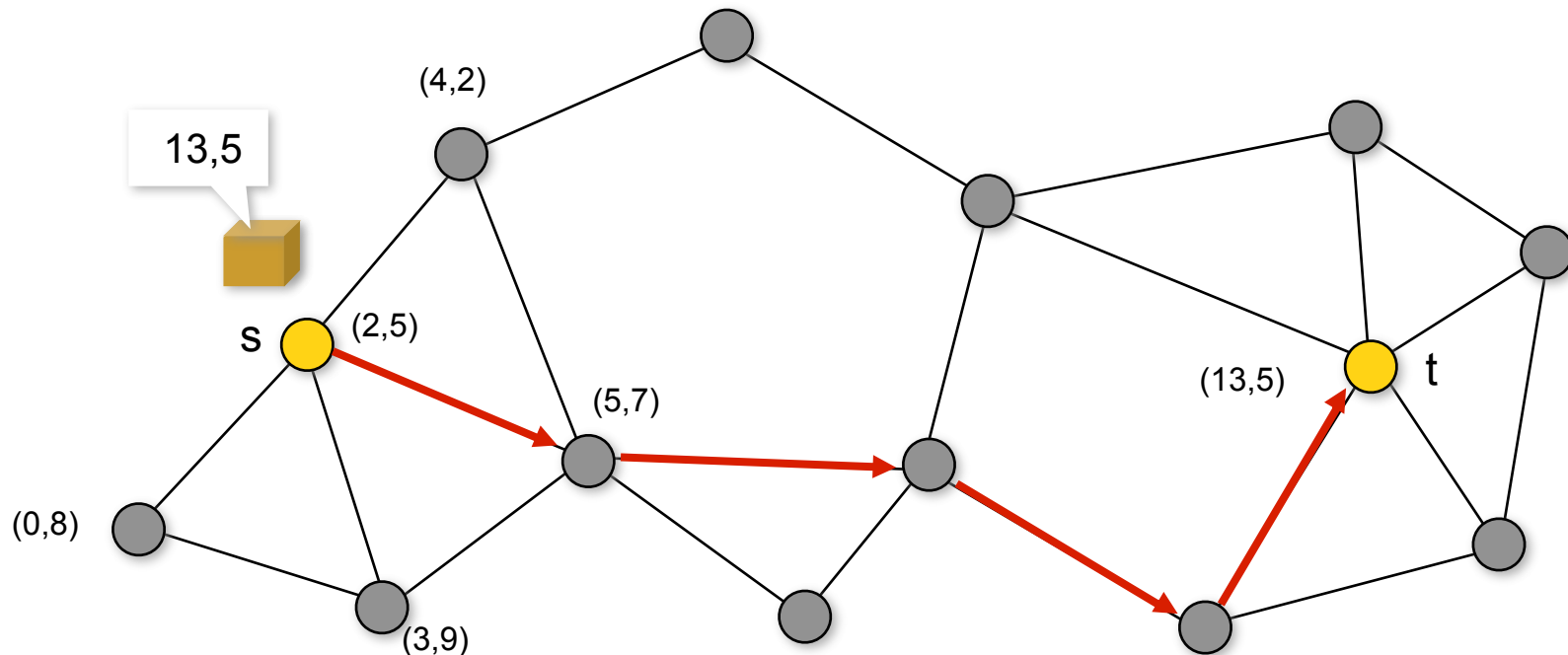
- geometric position

► Idea

- send message to the neighbor closest to the target node (greedy strategy)

► Advantages

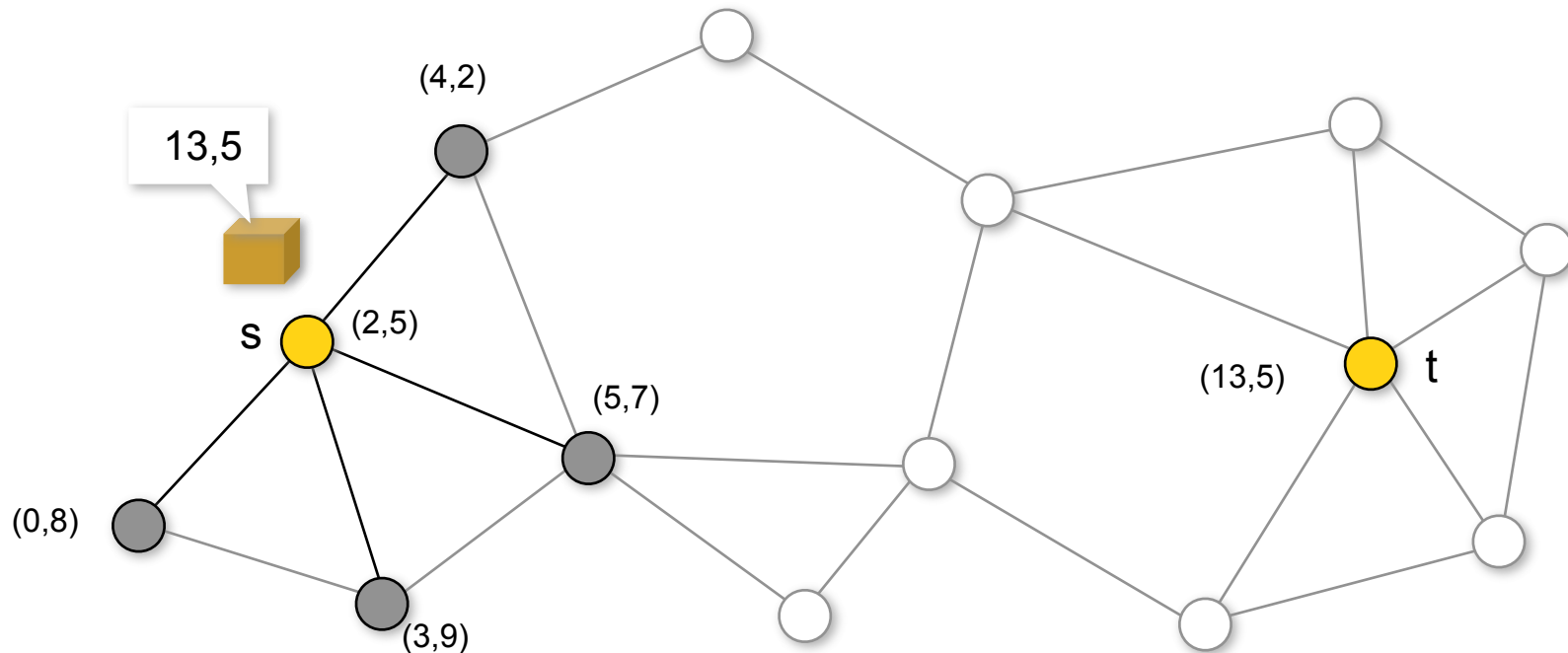
- only local decisions
- no routing tables
- scalable



Position Based Routing

► Prerequisites

- Each node knows its position (e.g. GPS)
- Positions of neighbors are known (beacon messages)
- Target position is known (location service)

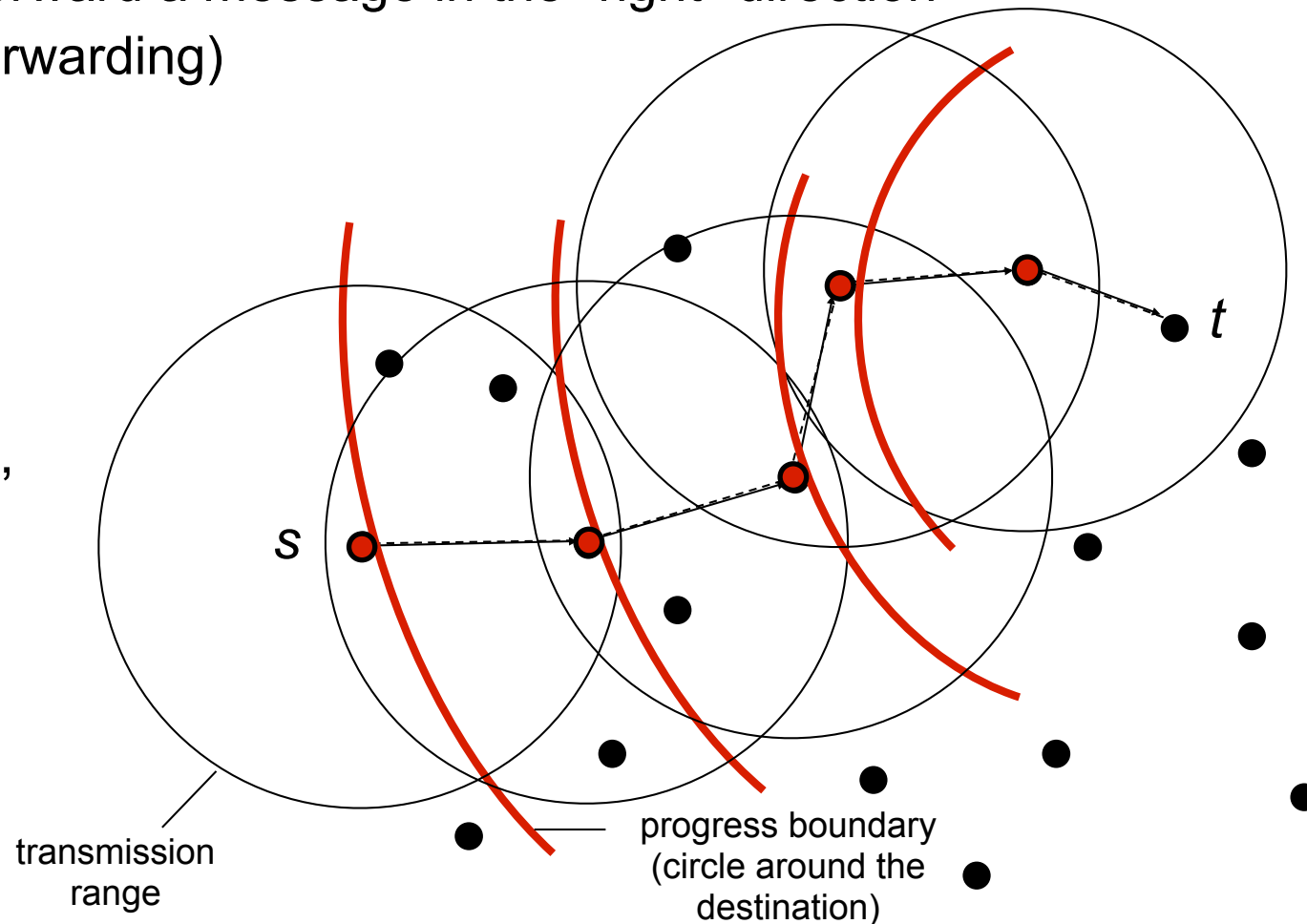


Greedy forwarding and recovery

► With position information

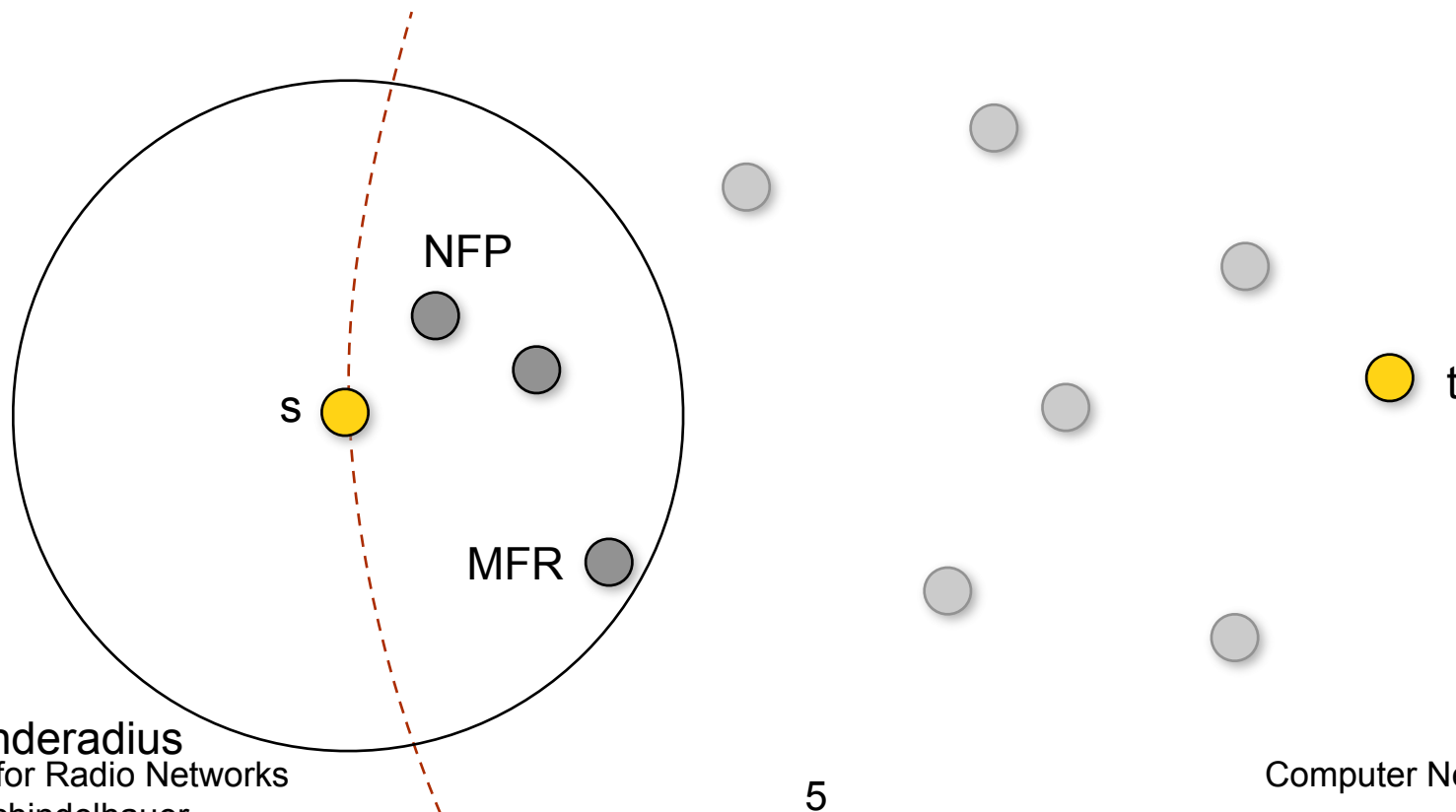
- one can forward a message in the "right" direction (greedy forwarding)

no routing tables,
no flooding!



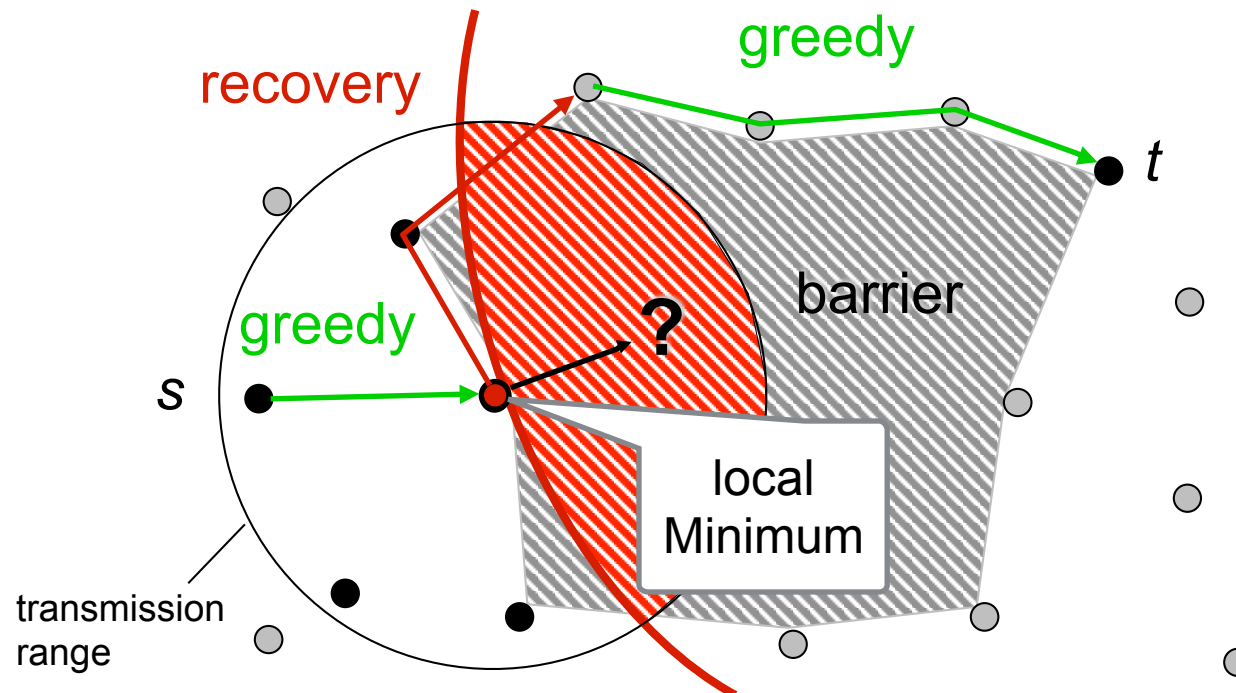
First Approaches

- ▶ **Routing in packet radio networks**
- ▶ **Greedy strategies:**
 - MFR: Most Forwarding within Radius [Takagi, Kleinrock 1984]
 - NFP: Nearest with Forwarding Progress [Hou, Li 1986]



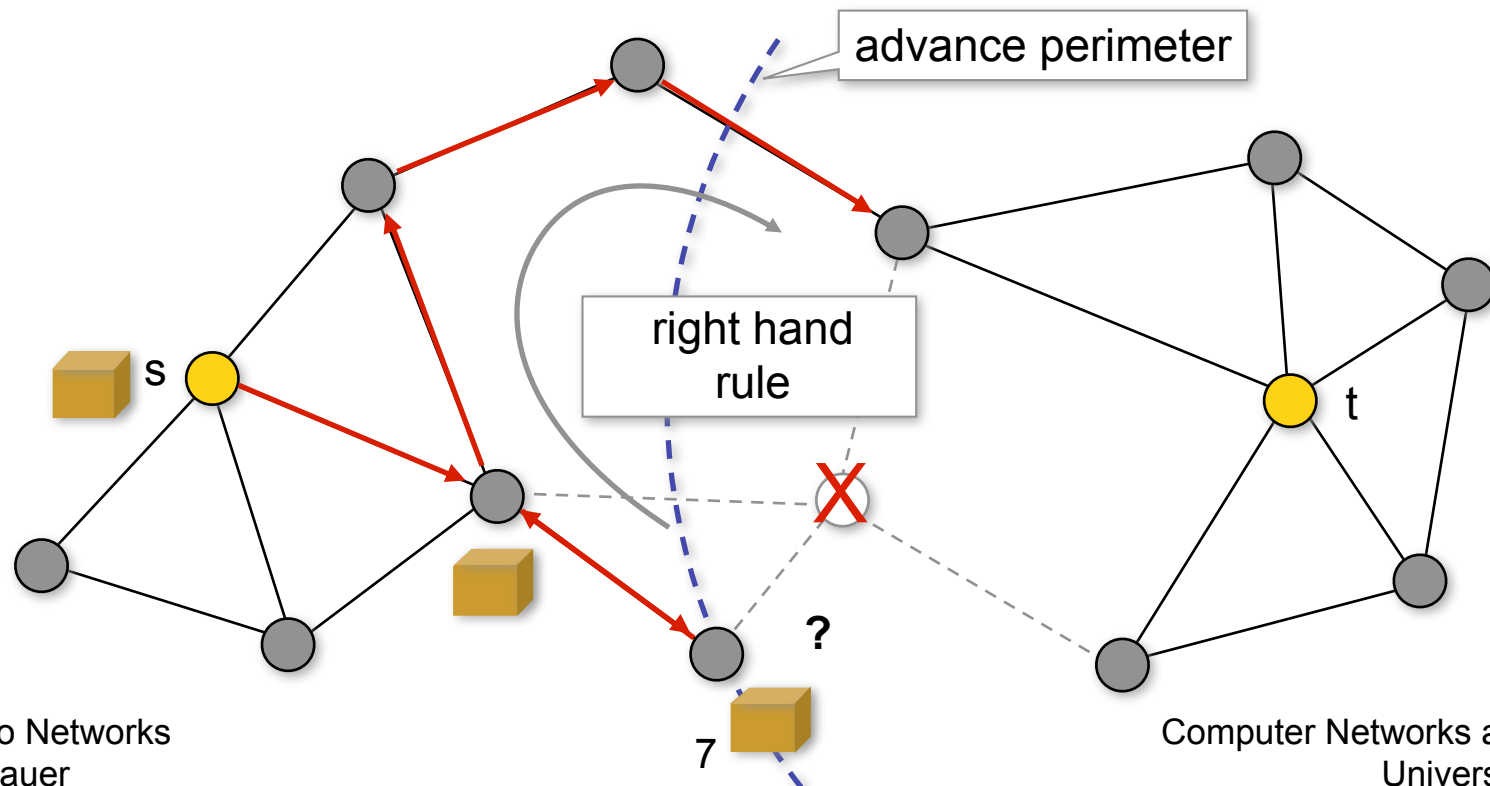
Greedy forwarding and recovery

- ▶ **Greedy forwarding is stopped by barriers**
 - (local minima)
- ▶ **Recovery strategy:**
 - Traverse the border of a barrier until a forwarding progress is possible (right-hand rule)
 - routing time depends on the size of barriers



Position Based Routing

- **Combination of greedy routing and recovery strategy**
- **Recovery from local minima (right hand rule)**
 - Example: GPSR [Karp, Kung 2000]

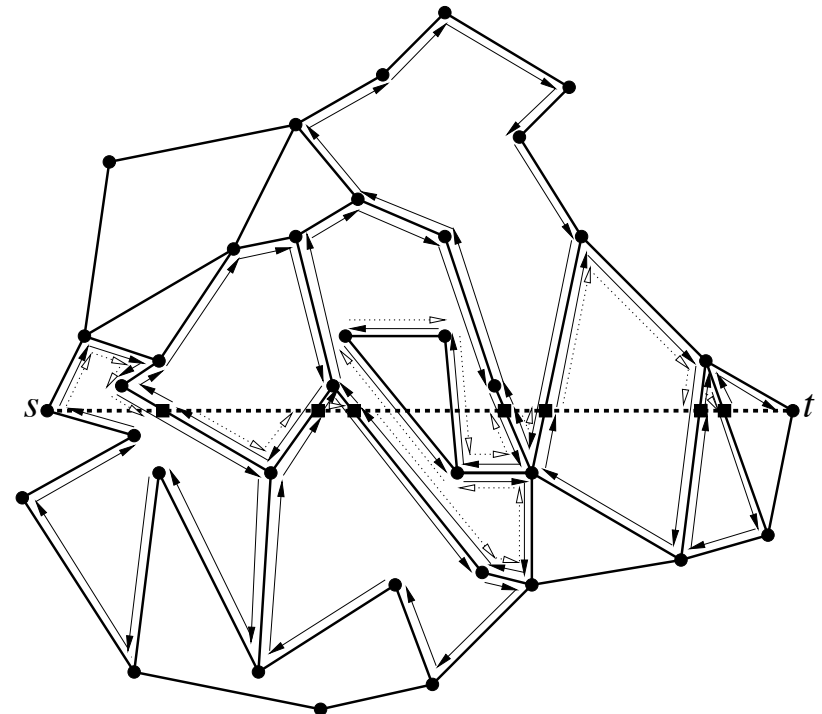
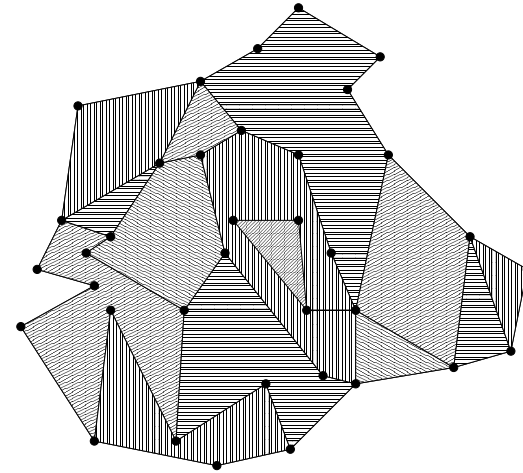


Problems of Recovery

- ▶ **Recovery strategy can produce large detours**

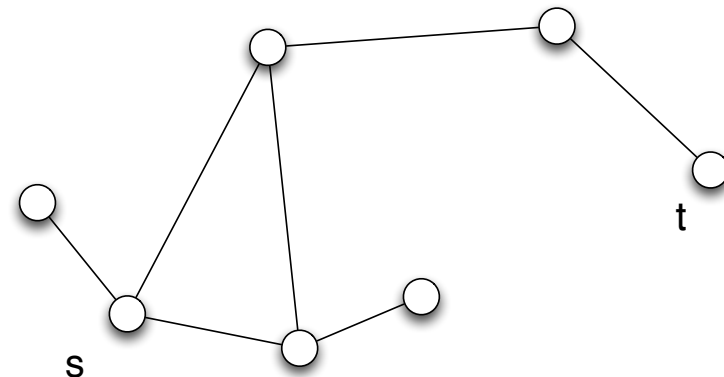
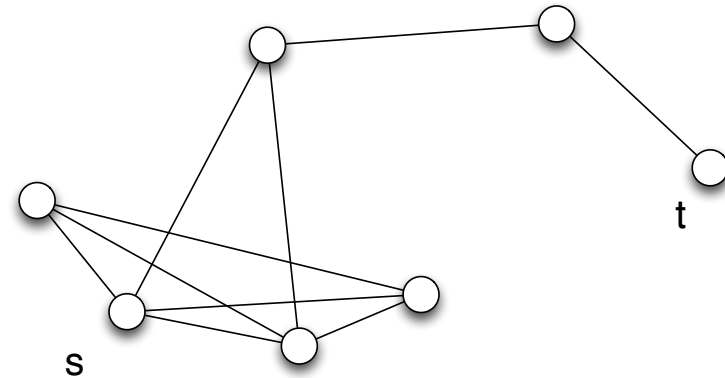
- ▶ **Solutions**

- Follow recovery strategy until the situation has absolutely improved
 - e.g. until the target is closer
- Follow a thread
 - e.g. Face Routing strategy
 - by Kuhn, Wattenhofer, Zollinger, Asymptotically Optimal Geometric Mobile Ad-Hoc Routing, DIAL-M 2002



Greedy forwarding and recovery

- **Right-hand rule needs planar topology**
 - otherwise endless recovery cycles can occur
- **Therefore the graph needs to be made planar**
 - erase crossing edges
- **Problem**
 - needs communication between nodes
 - must be done careful in order to prevent graph from becoming disconnected



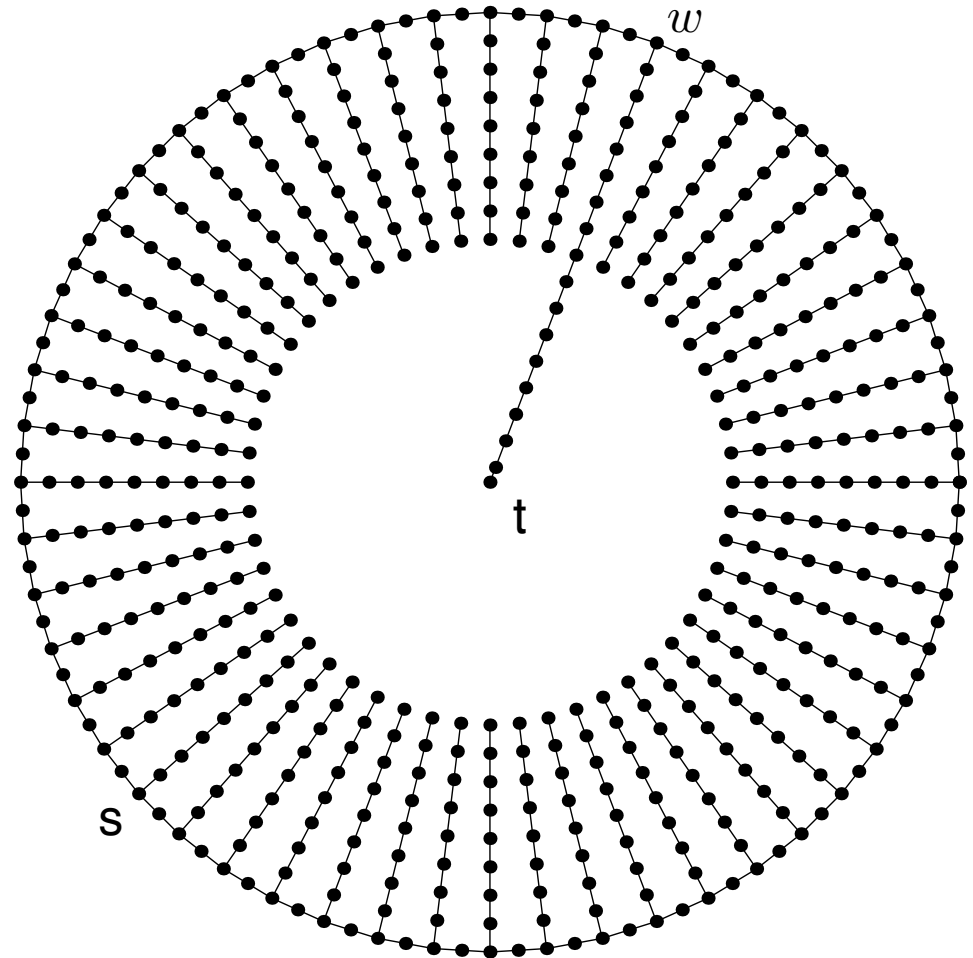
Lower Bound

- Kuhn, Wattenhover, Zollinger,
Asymptotically Optimal Geometric
Mobile Ad-Hoc Routing, DIAL-M
2002

d = length of shortest path

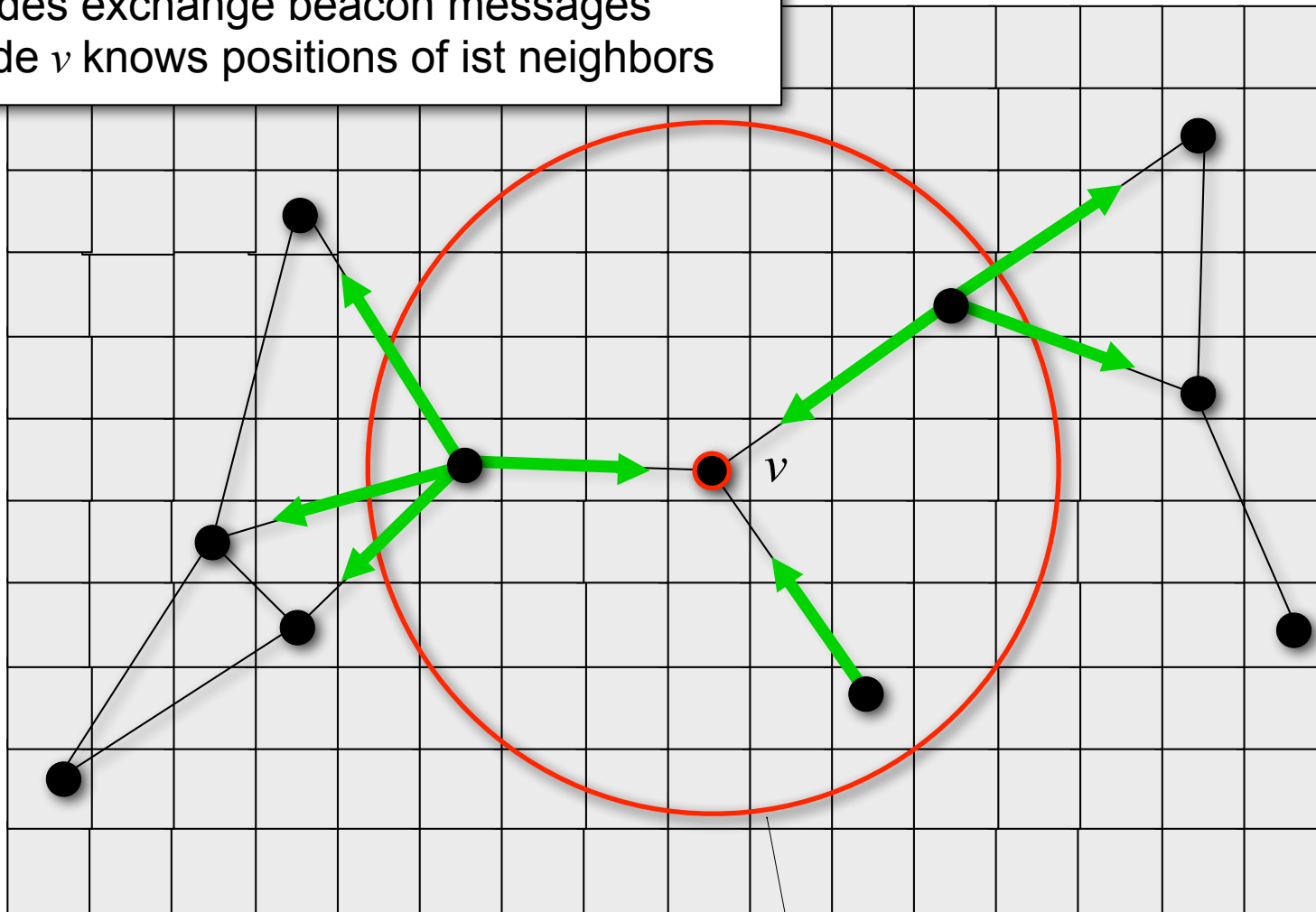
time = #hops, traffic = #messages

Time: $\Omega(d^2)$



A Virtual Cell Structure

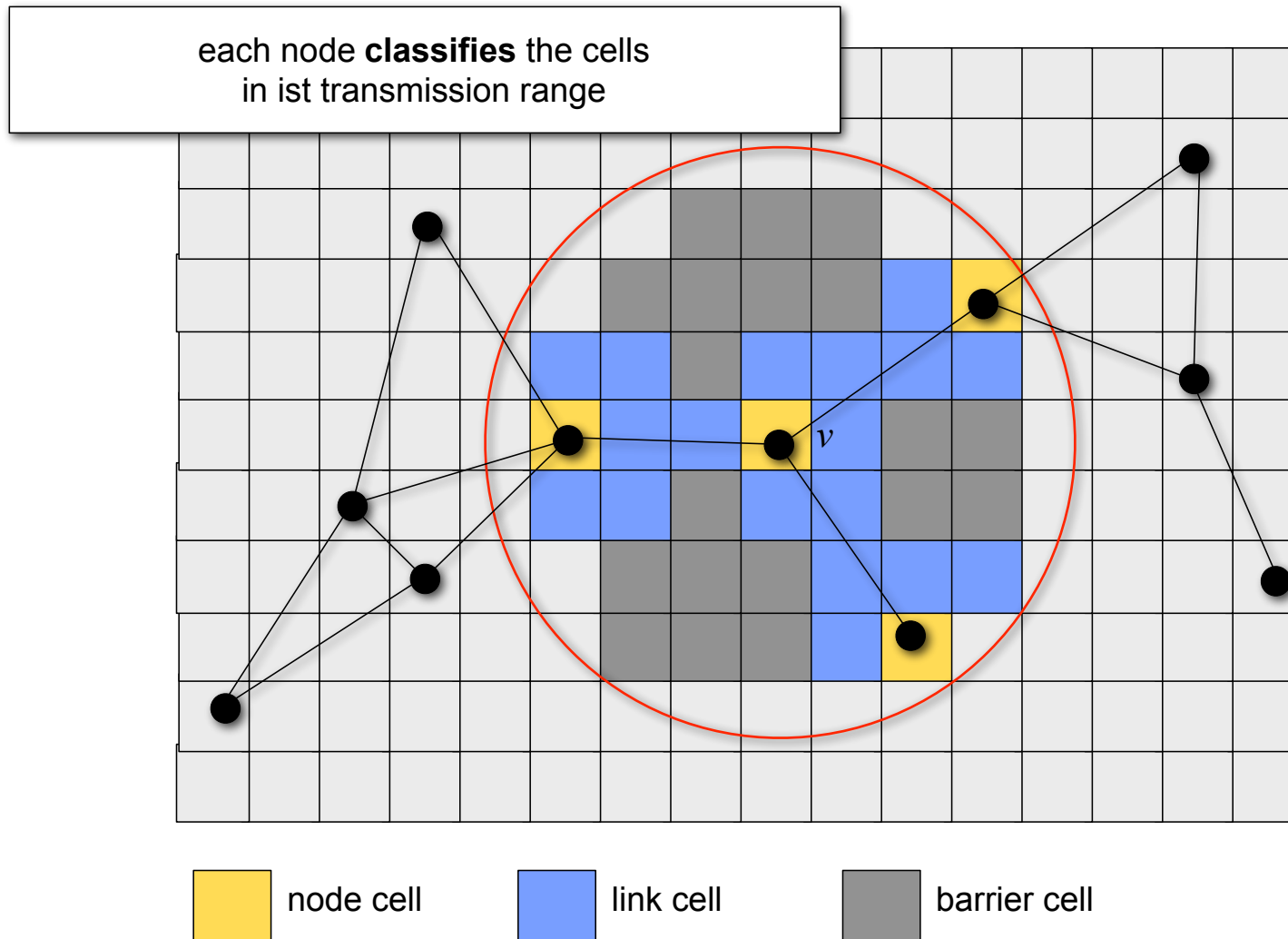
nodes exchange beacon messages
⇒ node v knows positions of its neighbors



transmission radius
(Unit Disk Graph)

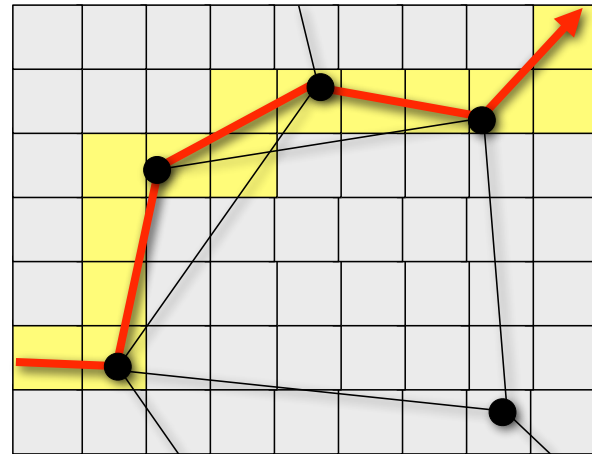
Rührup et al. Online Multi-Path Routing in a Maze, ISAAC 2006

A Virtual Cell Structure

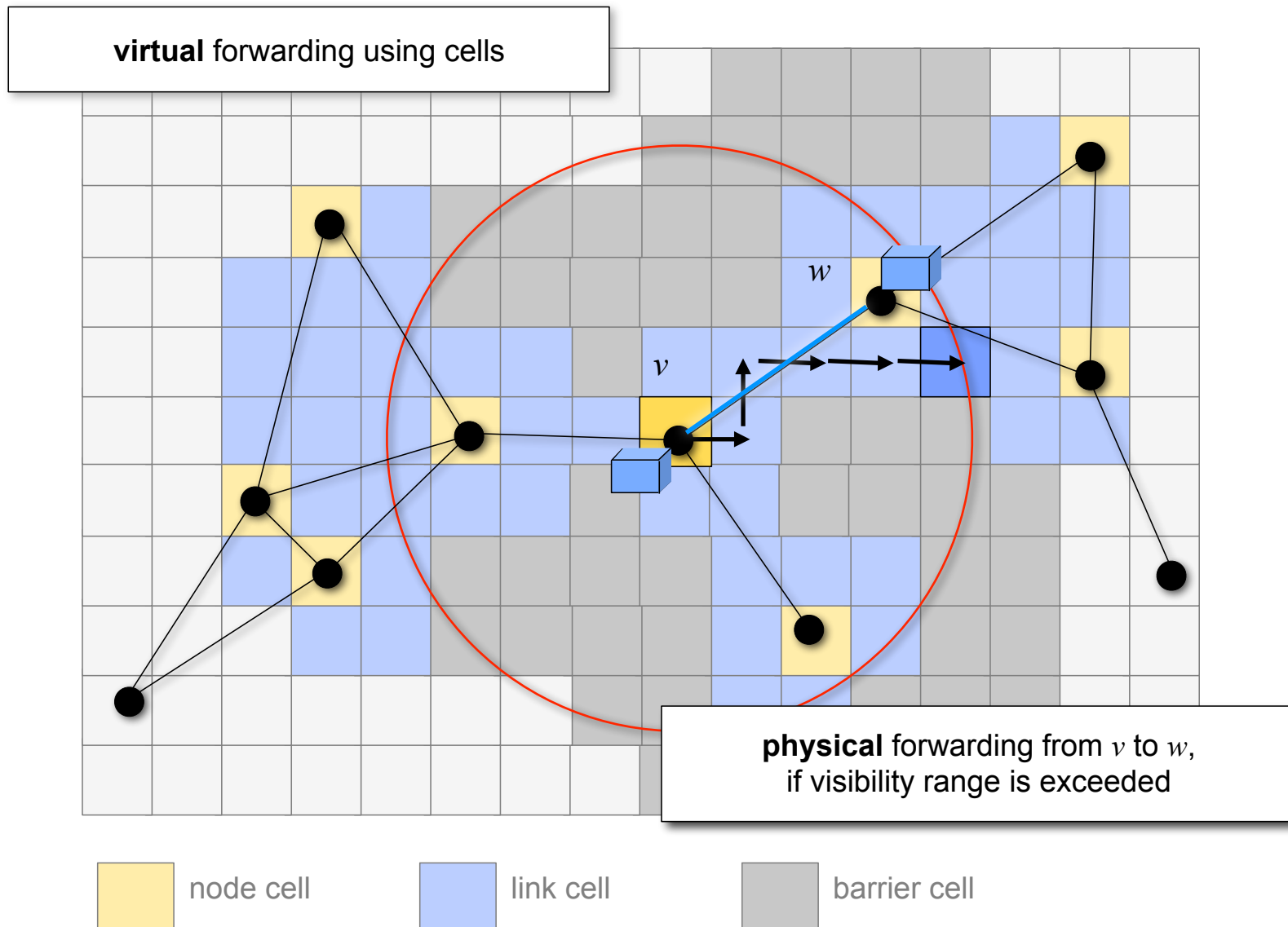


Routing based on the Cell Structure

- ▶ **Routing based on the cell structure uses cell paths**
 - cell path**
 - = sequence of orthogonally neighboring cells
- ▶ **Paths**
 - in the unit disk graph and cell paths are equivalent up to a constant factor
- ▶ **no planarization strategy needed**
 - required for recovery using the right-hand rule



Routing based on the Cell Structure

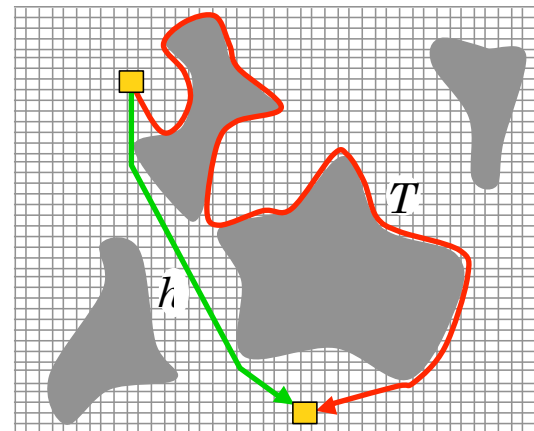


Performance Measures

- ▶ **competitive ratio:** $\frac{\text{solution of the algorithm}}{\text{optimal offline solution}}$
- ▶ **competitive time ratio of a routing algorithm**
 - h = length of shortest barrier-free path
 - algorithm needs T rounds to deliver a message

$$\mathcal{R}_t := \frac{T}{h}$$

single-path



Comparative Ratios

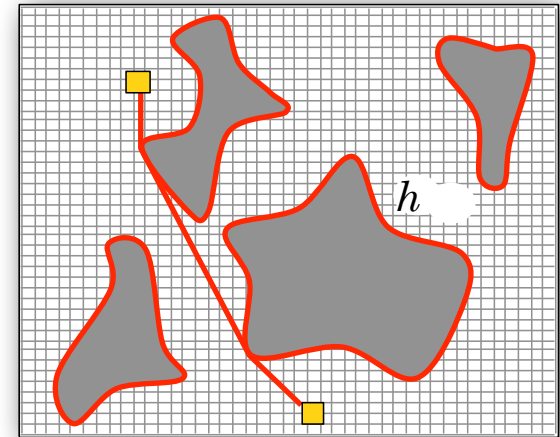
- ▶ **optimal (offline) solution for traffic:**
 - h messages (length of shortest path)
- ▶ **Unfair, because**
 - offline algorithm knows the barriers
 - but every online algorithm has to pay exploration costs
- ▶ **exploration costs**
 - sum of perimeters of all barriers (p)
- ▶ **comparative traffic ratio**

$$\mathcal{R}_{Tr} := \frac{M}{h + p}$$

M = # messages used

h = length of shortest path

p = sum of perimeters

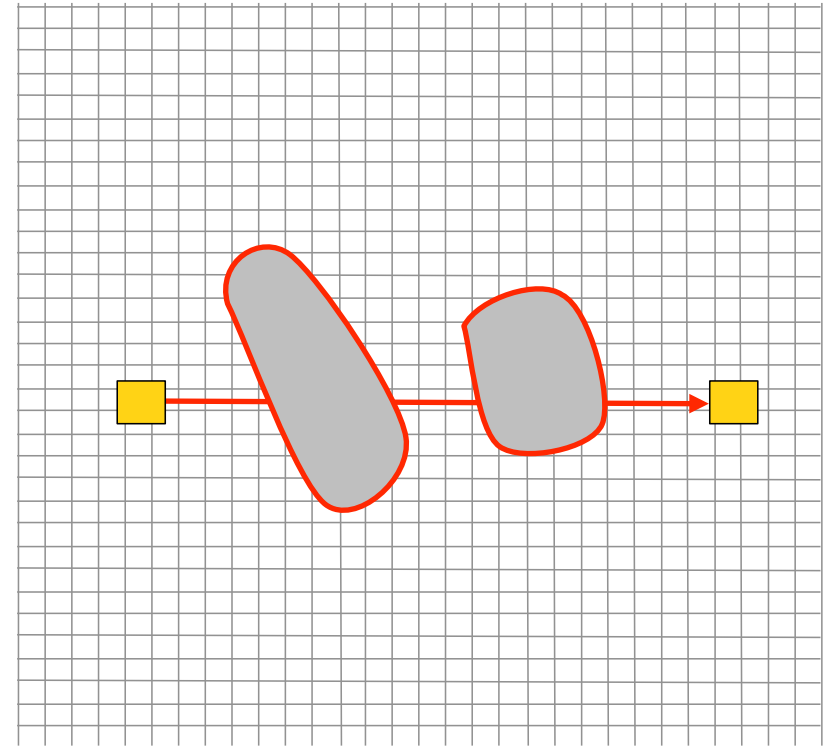


Comparative Ratios

- ▶ **measure for time efficiency:**
 - competitive time ratio
$$\mathcal{R}_t := \frac{T}{h}$$
- ▶ **measure for traffic efficiency:**
 - comparative traffic ratio
$$\mathcal{R}_{Tr} := \frac{M}{h + p}$$
- ▶ **Combined comparative ratio** $\mathcal{R}_c := \max\{\mathcal{R}_t, \mathcal{R}_{Tr}\}$
 - time efficiency and traffic efficiency

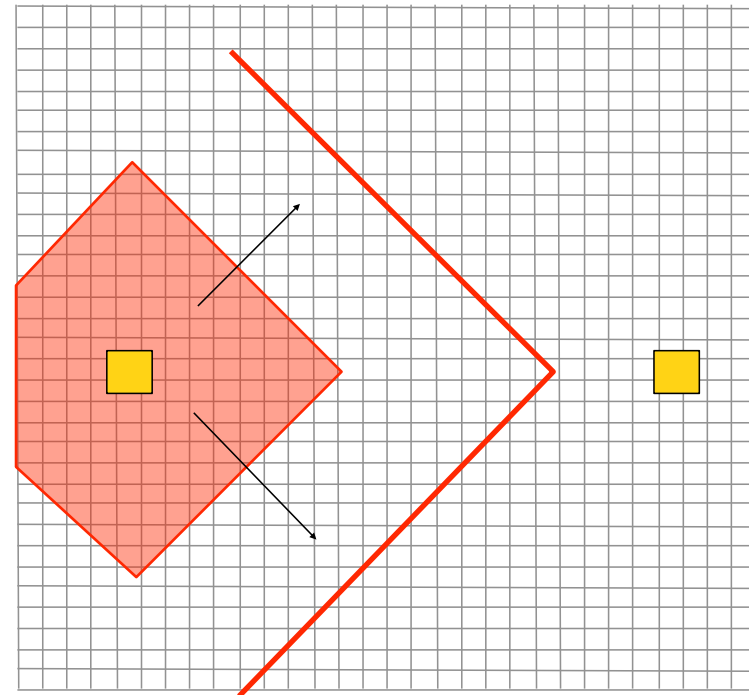
Single Path Strategy

- **no parallelism**
 - traffic-efficient (time = traffic)
 - example: GuideLine/Recovery
- **follow a guide line connecting source and target**
- **traverse all barriers intersecting the guide line**
- **Time and Traffic:** $\mathcal{O}(h + p)$



Multi-path Strategy

- **speed-up by parallel exploration**
 - increasing traffic
 - example: Expanding Ring Search
- **start flooding with restricted search depth**
- **if target is not in reach then**
 - repeat with double search depth
- **Time** $\mathcal{O}(h)$
- **Traffic** $\mathcal{O}(h^2)$



Algorithms under Comparative Measures

	time	traffic
<i>GuideLine/Recovery</i> (single-path)	$\mathcal{O}(h + p)$	
<i>Expanding Ring Search</i> (multi-path)	$\mathcal{O}(h)$	$\mathcal{O}(h^2)$

$$\mathcal{R}_t := \frac{T}{h} M$$

$$\mathcal{R}_{Tr} := \frac{M}{h + p}$$

Is that good?

It depends ...	on the	scenario	time ratio	traffic ratio	combined ratio
<i>GuideLine/Recovery</i> (single-path)	maze $p = h^2$		<u>$\mathcal{O}(h)$</u>	$\mathcal{O}(1)$	$\mathcal{O}(h)$
<i>Expanding Ring Search</i> (multi-path)	open space $p < h$		$\mathcal{O}(1)$	<u>$\mathcal{O}(h)$</u>	$\mathcal{O}(h)$

The Alternating Algorithm

► **uses a combination of both strategies:**

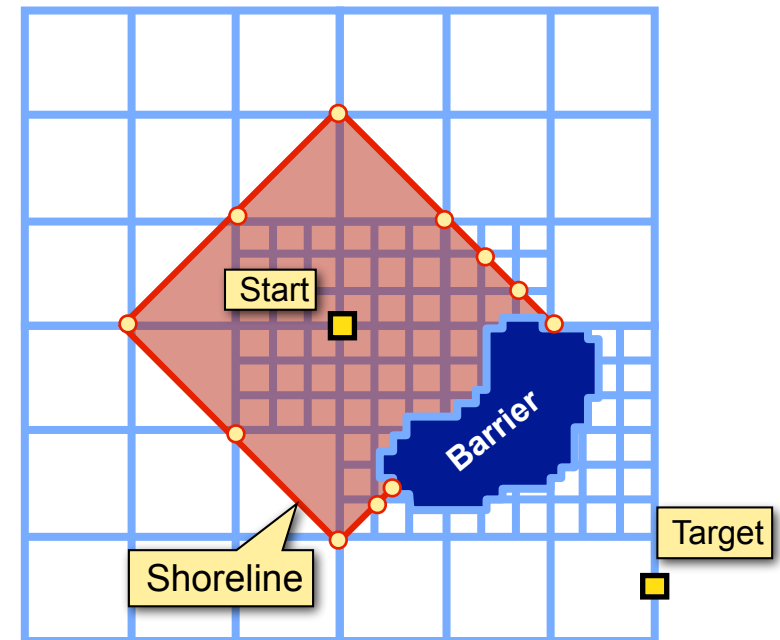
1. $i = 1$
2. $d = 2^i$
3. start GuideLine/Recovery with time-to-live = $d^{3/2}$
4. if the target is not reached then
 start Flooding with time-to-live = d
5. if the target is not reached then
 $i = i+1$
 goto line 2

► **Combined comparative ratio:** $\mathcal{R}_c = \mathcal{O}(\sqrt{h})$

The JITE Algorithmus

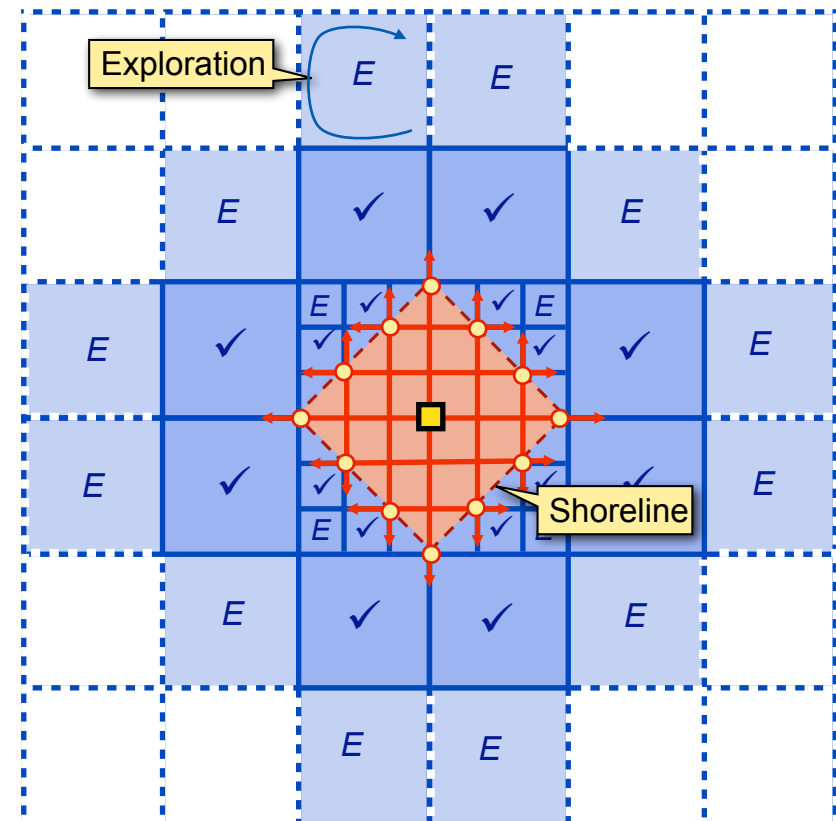
Rührup et al. Online Multi-Path Routing in a Maze, ISAAC 2006

- **Complex algorithm**
- **Message efficient parallel BFS (breadth first search)**
 - using Continuous Ring Search
- **Just-In-Time Exploration (JITE)**
 - construction of search path instead of flooding
- **Search paths surround barriers**
- **Slow Search**
 - slow BFS on a sparse grid
- **Fast Exploration**
 - Construction of the sparse grid near to the shoreline



Slow Search & Fast Exploration

- ▶ **Slow Search** visits only explored paths
- ▶ **Fast Exploration** is started in the vicinity of the BFS-shoreline
- ▶ **Exploration** must be terminated before a frame is reached by the BFS-shoreline



Performance of Geometric Routing Algorithms

Strategy	Time	Traffic	Comb. Comp. Ratio
Exp. Ring Search [9, 18]	$\mathcal{O}(d)$	$\mathcal{O}(d^2)$	$\mathcal{O}(d)$
Lucas' Algorithm [13]	$\mathcal{O}(d + p)$	$\mathcal{O}(d + p)$	$\mathcal{O}(d)$
Alternating Strategy [20]	$\mathcal{O}(d^{3/2})$	$\mathcal{O}(\min\{d^2, d^{3/2} + p\})$	$\mathcal{O}(\sqrt{d})$
Selective Flooding [21]	$d \cdot 2^{\mathcal{O}\left(\sqrt{\frac{\log d}{\log \log d}}\right)}$	$\mathcal{O}(d) + p d^{\mathcal{O}\left(\sqrt{\frac{\log \log d}{\log d}}\right)}$	$d^{\mathcal{O}\left(\sqrt{\frac{\log \log d}{\log d}}\right)}$
JITE (this paper)	$\mathcal{O}(d)$	$\mathcal{O}((d + p) \log^2 d)$	$\mathcal{O}(\log^2 d)$
Online Lower Bound (cf. [3])	$\Omega(d)$	$\Omega(d + p)$	$\Omega(1)$

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Summary

‣ Geometric Routing

- is a scalable alternative with only local information

‣ Recovery strategies

- are necessary since barriers might occur

‣ Planarization

- underlying communication graph should be planar
- erase edges or use cell structure

‣ Performance

- should be measured by the competitive or comparative ratio

‣ JITE

- best solution, but only of theoretical interest

‣ Face Routing

- only of theoretical interest, because only a small fractions of the edges are used

‣ Real-world Solutions

- Flooding
- Alternating algorithm
- Greedy with right-hand recovery
- Greedy with flooding recovery



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