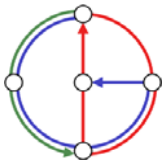
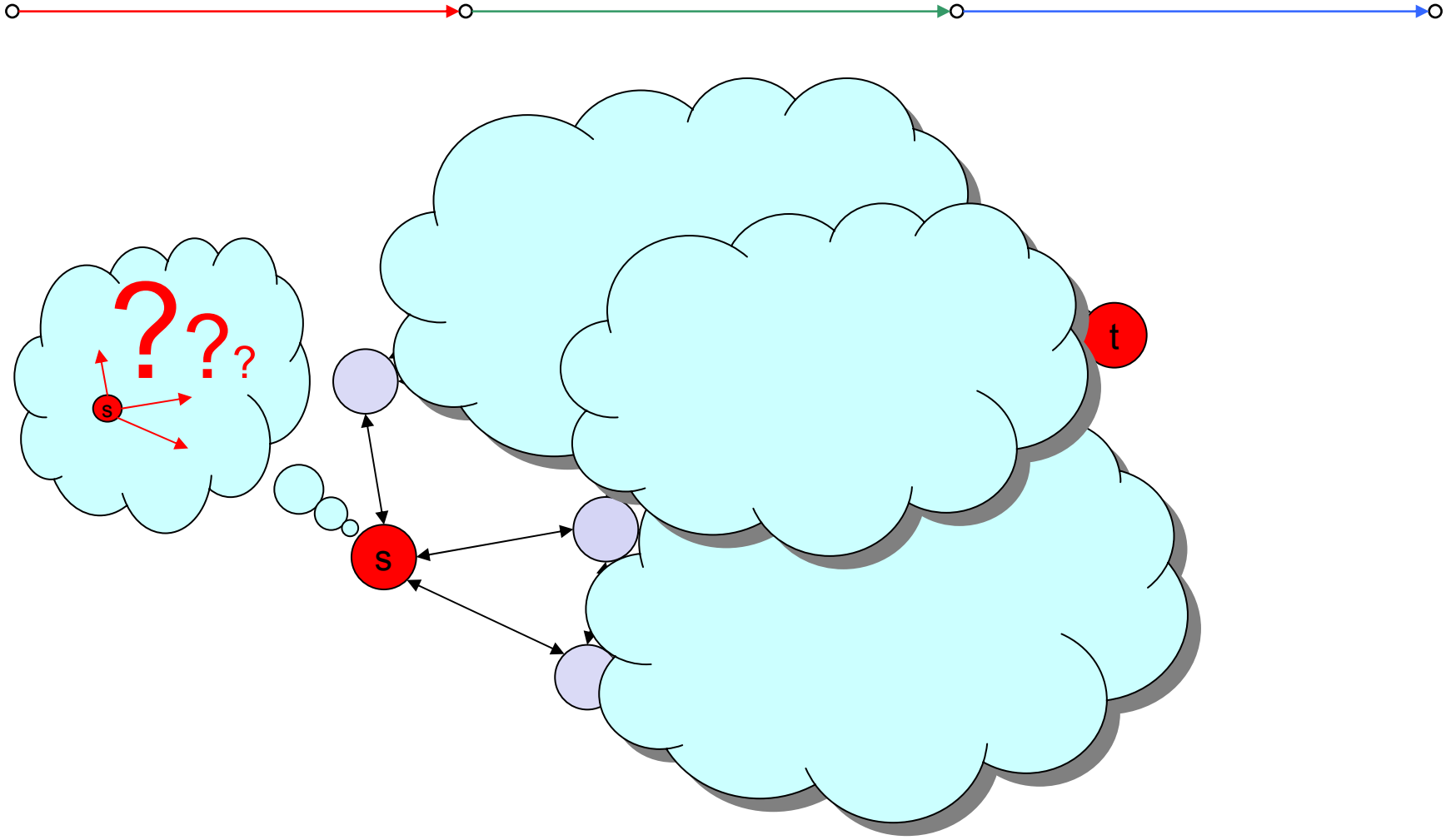
Geometric Ad-Hoc Routing: Of Theory and Practice

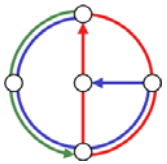
Fabian Kuhn
Roger Wattenhofer
Yan Zhang
Aaron Zollinger



ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

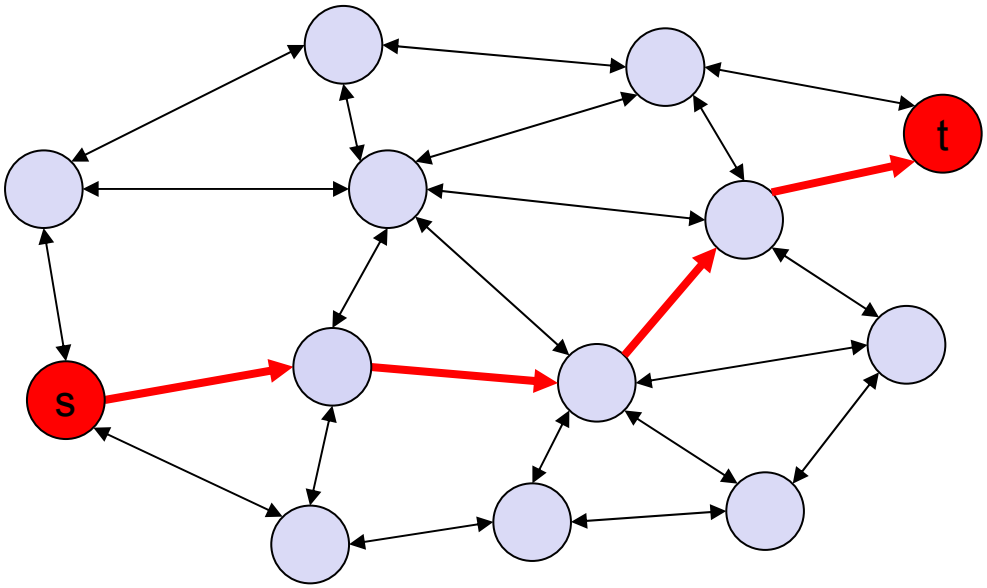
Geometric Routing

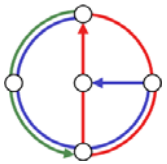




Greedy Routing

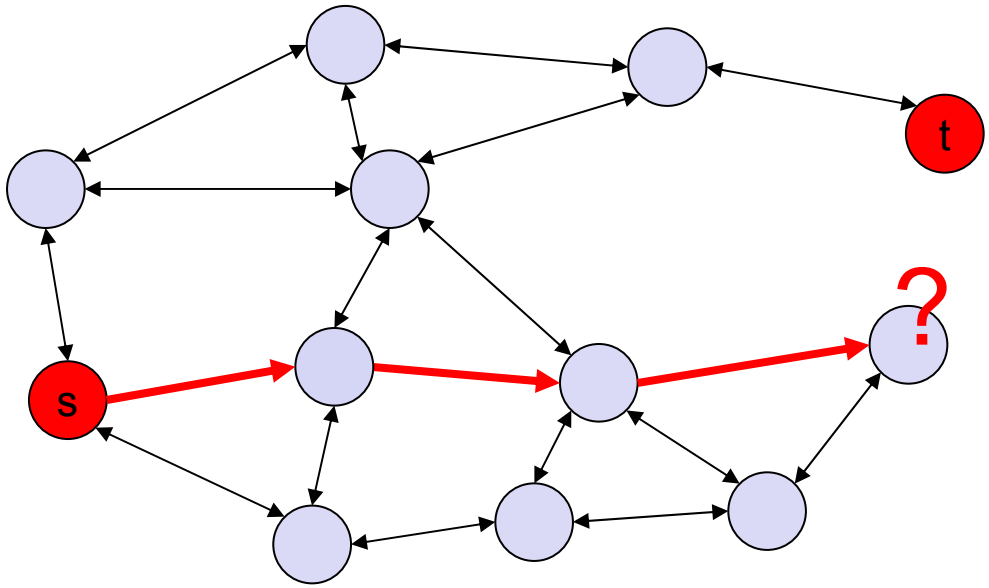
- Each node forwards message to “best” neighbor



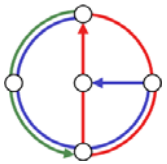


Greedy Routing

- Each node forwards message to “best” neighbor



- But greedy routing may fail: message may get stuck in a “dead end”
- Needed: Correct geometric routing algorithm

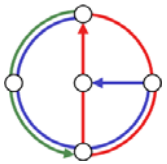


What is Geometric Routing?

- A.k.a. location-based, position-based, geographic, etc.

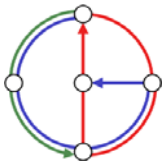
- Each node knows its own position and position of neighbors
- Source knows the position of the destination
- No routing tables stored in nodes!

- Geometric routing is important:
  - GPS/Galileo, local positioning algorithm, overlay P2P network, Geocasting
  - Most importantly: Learn about general ad-hoc routing



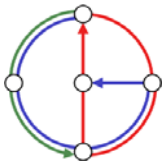
Related Work in Geometric Routing

Kleinrock et al.	Various 1975ff	MFR et al.	Geometric Routing proposed
Kranakis, Singh, Urrutia	CCCG 1999	Face Routing	First correct algorithm
Bose, Morin, Stojmenovic, Urrutia	DialM 1999	GFG	First average-case efficient algorithm (simulation but no proof)
Karp, Kung	MobiCom 2000	GPSR	A new name for GFG
Kuhn, Wattenhofer, Zollinger	DialM 2002	AFR	First worst-case analysis. Tight $\Omega(c^2)$ bound.
Kuhn, Wattenhofer, Zollinger	MobiHoc 2003	GOAFR	Worst-case optimal and average-case efficient, percolation theory
Kuhn, Wattenhofer, Zhang, Zollinger	PODC 2003	GOAFR+	Improved GOAFR for average case, analysis of cost metrics



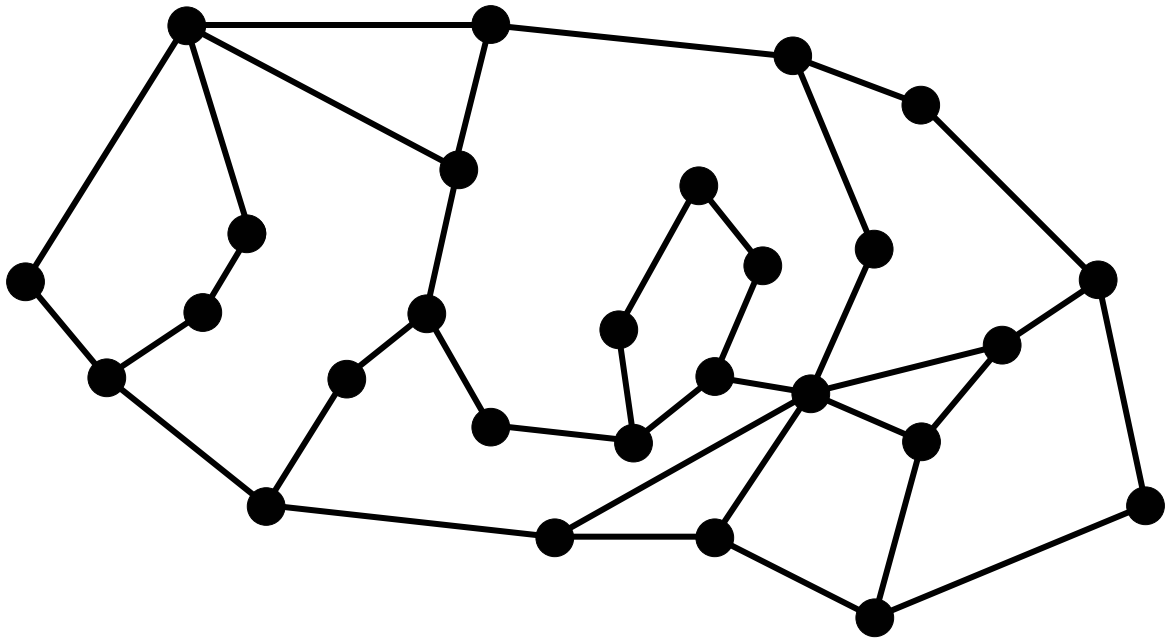
Overview

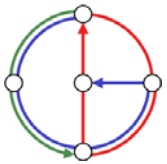
- Introduction
  - What is Geometric Routing?
  - Greedy Routing
- Correct Geometric Routing: Face Routing
- Efficient Geometric Routing
  - Worst-Case Optimality: Adaptively Bound Searchable Area
  - Average-Case Efficiency: GOAFR+
- Analysis of Cost Metrics
  - Linearly Bounded vs. Super-Linear Cost Metrics
- Conclusions



Face Routing

- Based on ideas by [Kranakis, Singh, Urrutia CCCG 1999]
- Here simplified (and actually improved)

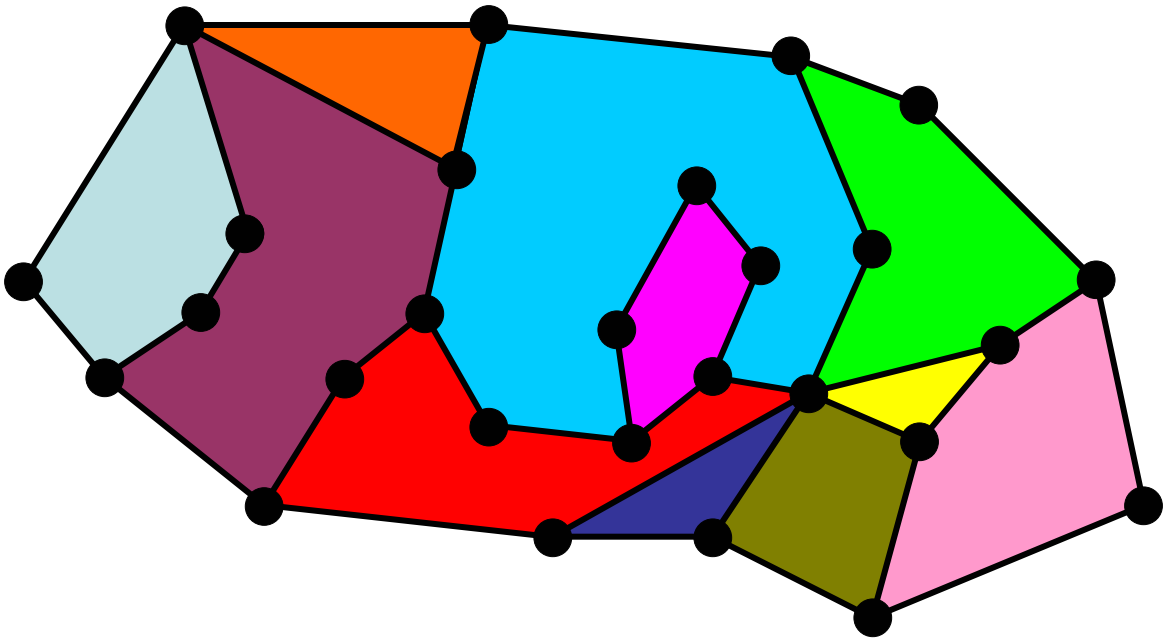


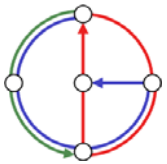


Face Routing

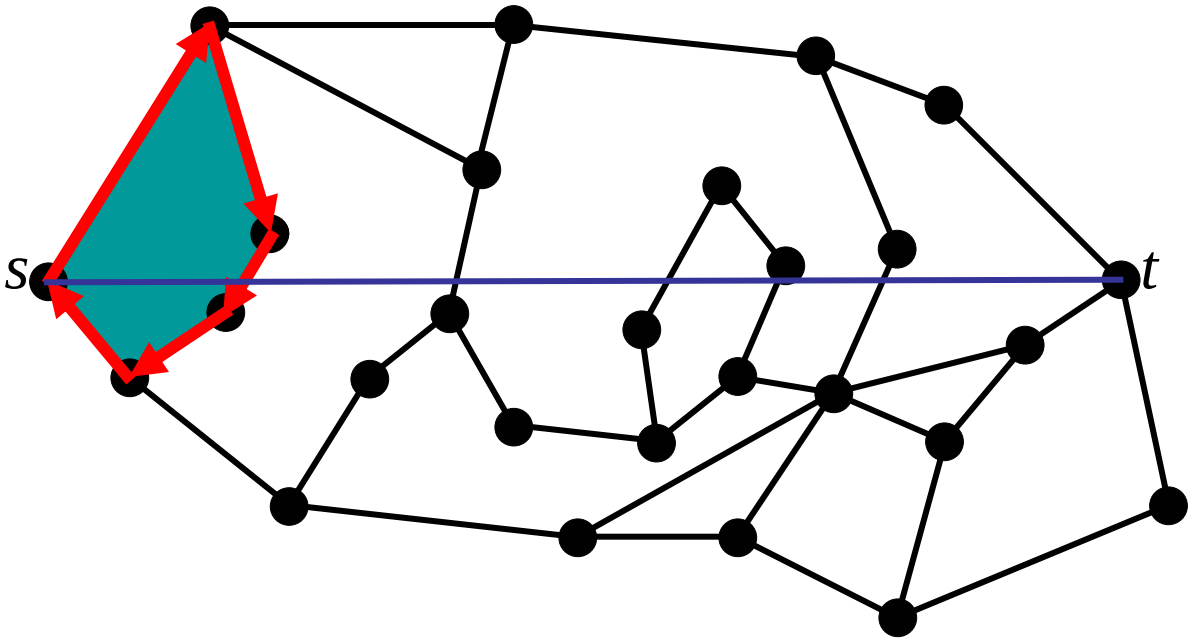
- Remark: Planar graph can easily (and locally!) be computed with the Gabriel Graph, for example

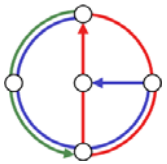
Planarity is NOT an assumption



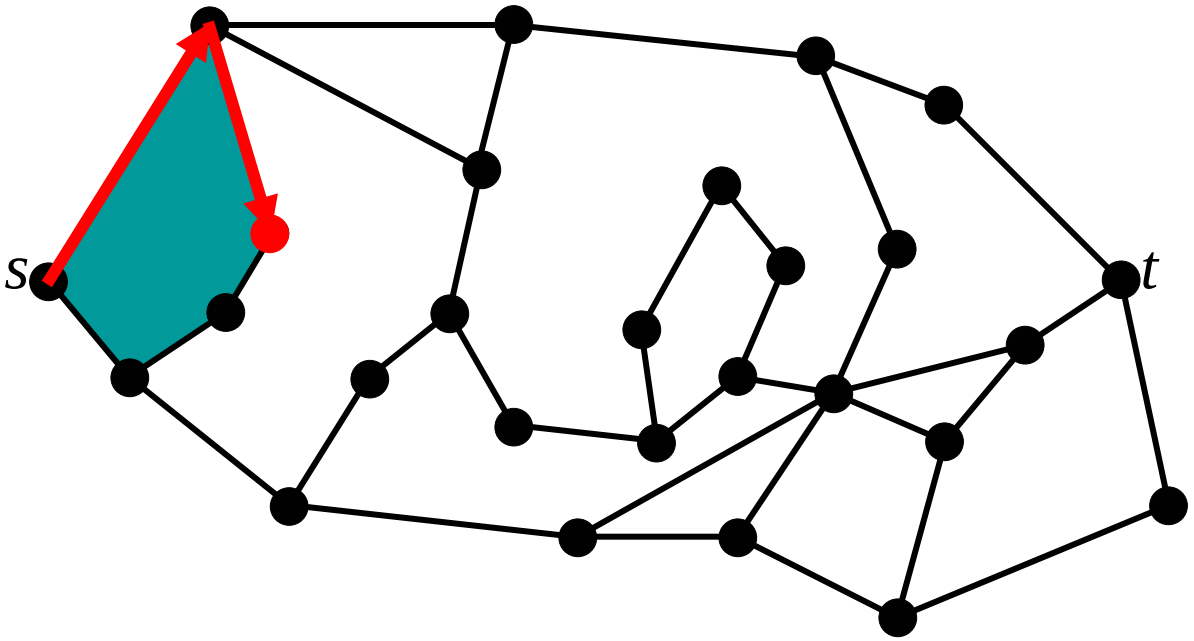


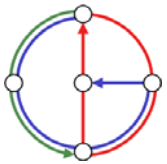
Face Routing



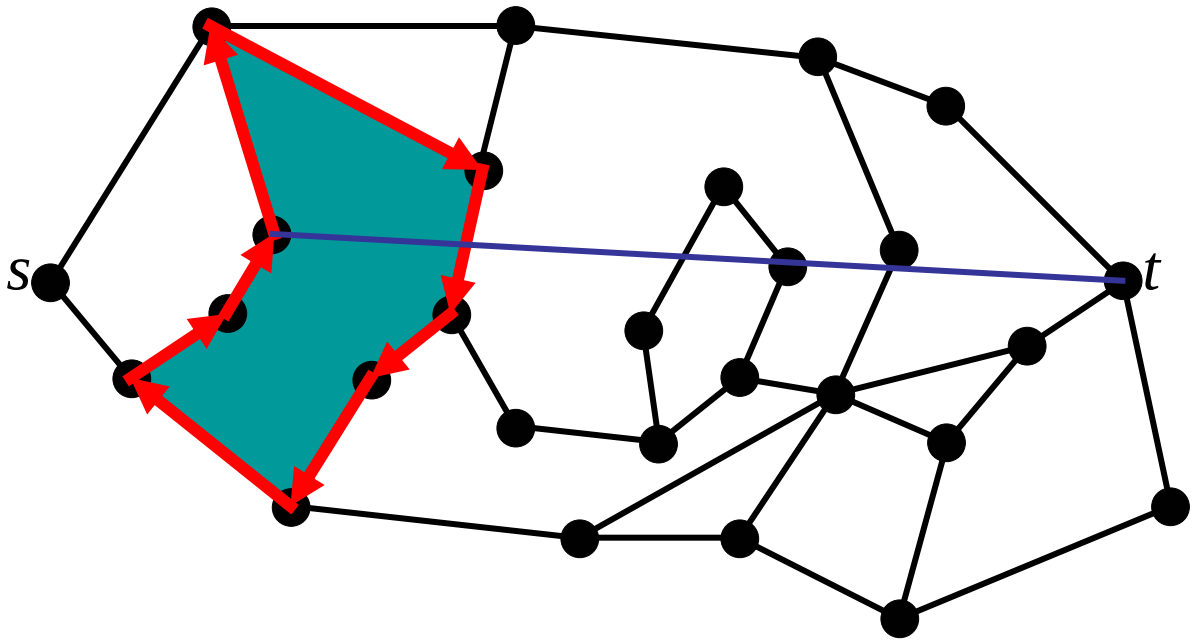


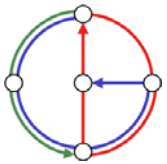
Face Routing



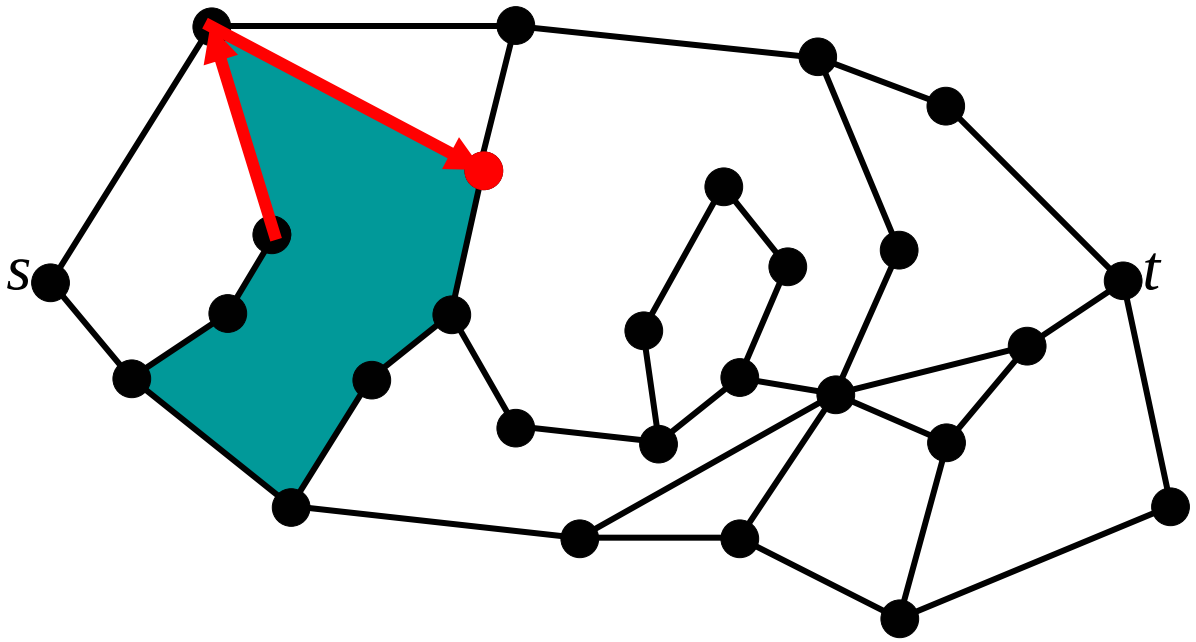


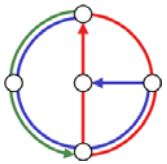
Face Routing



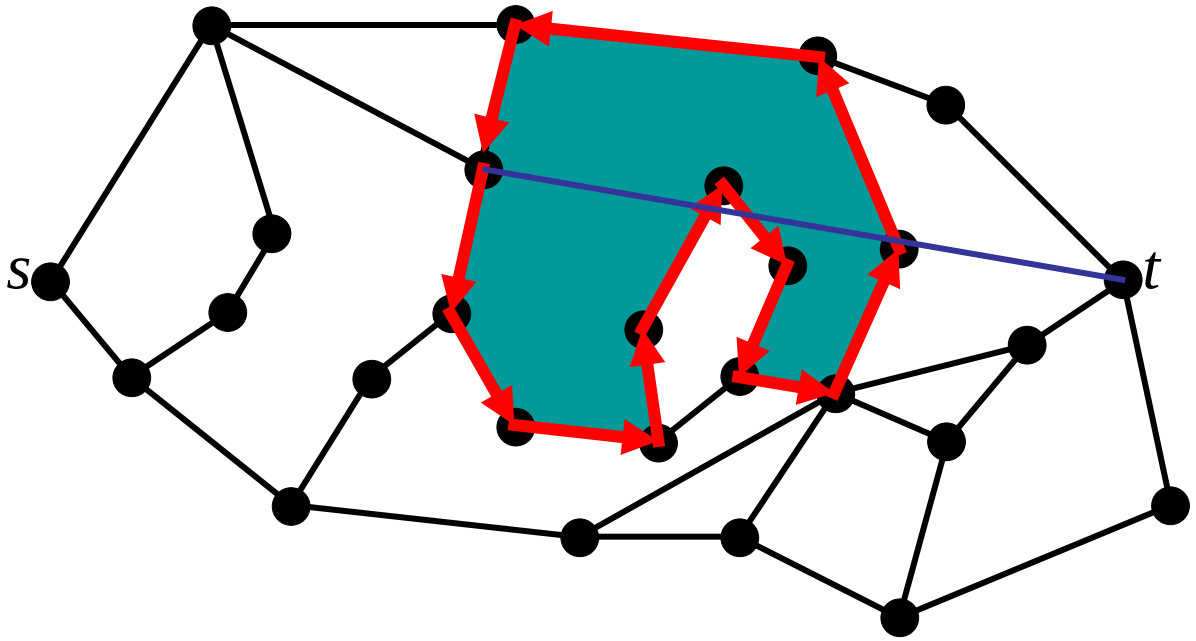


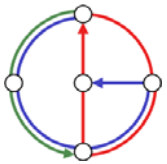
Face Routing



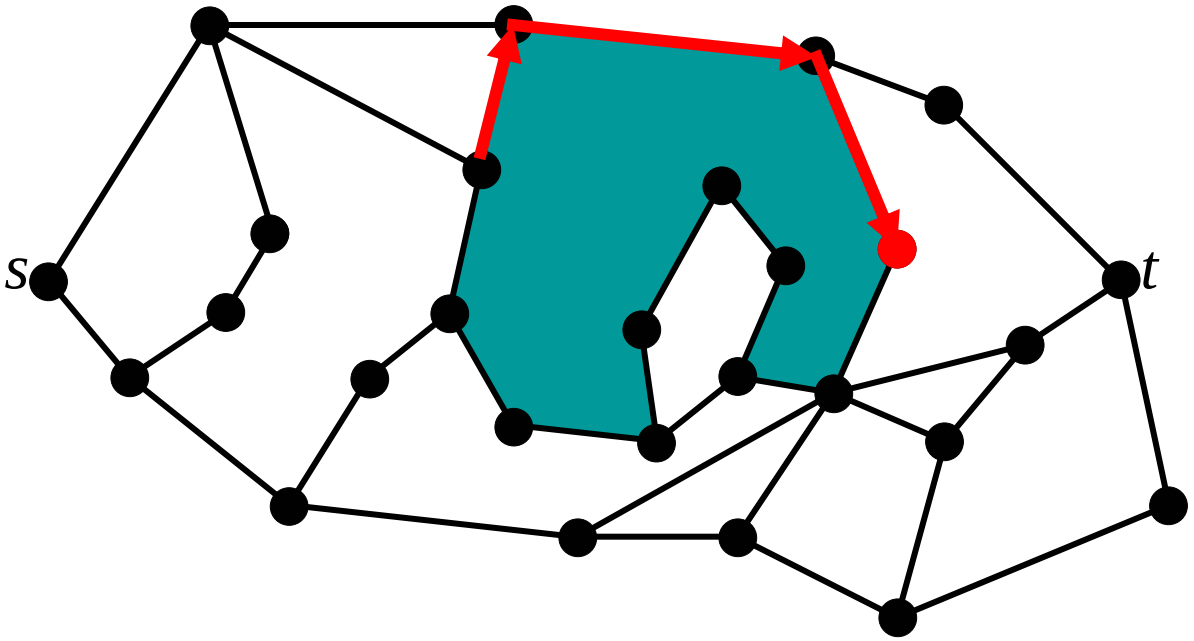


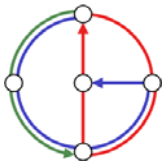
Face Routing



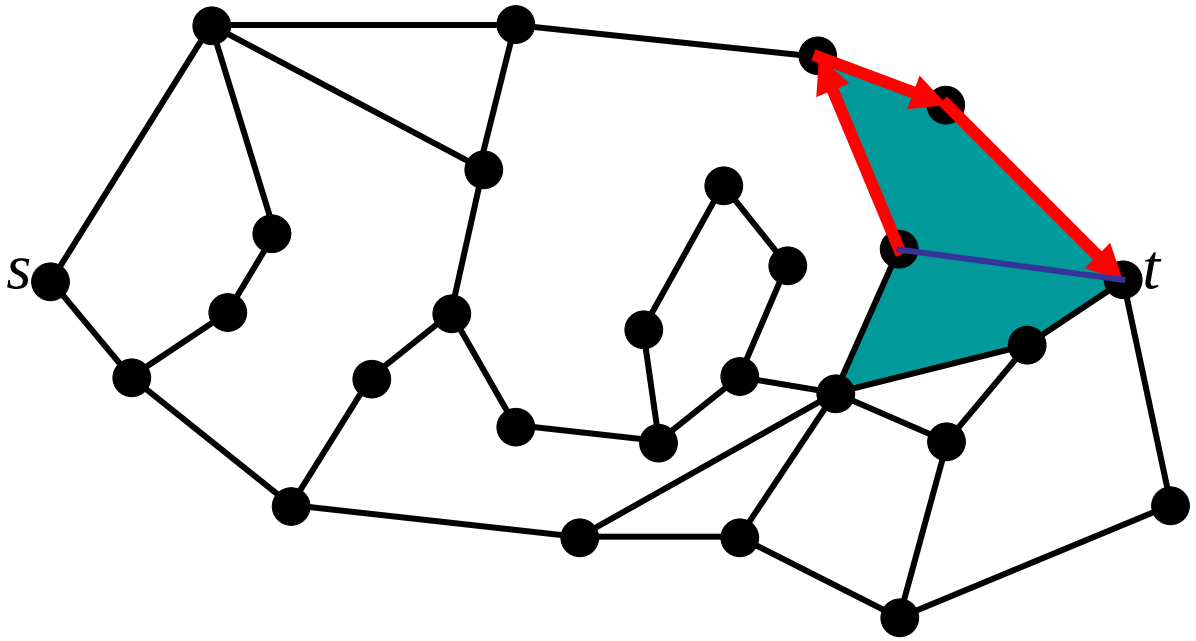


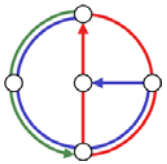
Face Routing





Face Routing

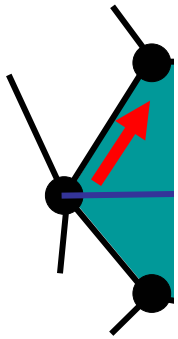


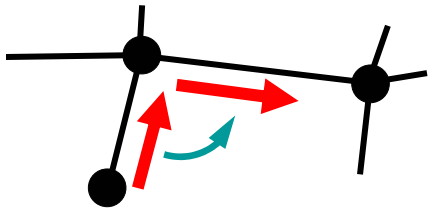


Face Routing Properties

- All necessary information is stored in the message
  - Source and destination positions
  - Point of transition to next face

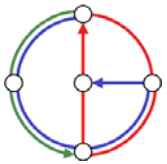
- Completely local:
  - Knowledge about direct neighbors‘ positions sufficient
  - Faces are implicit





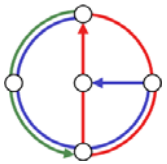
“Right Hand Rule”

- Planarity of graph is computed locally (not an assumption)
  - Computation for instance with Gabriel Graph



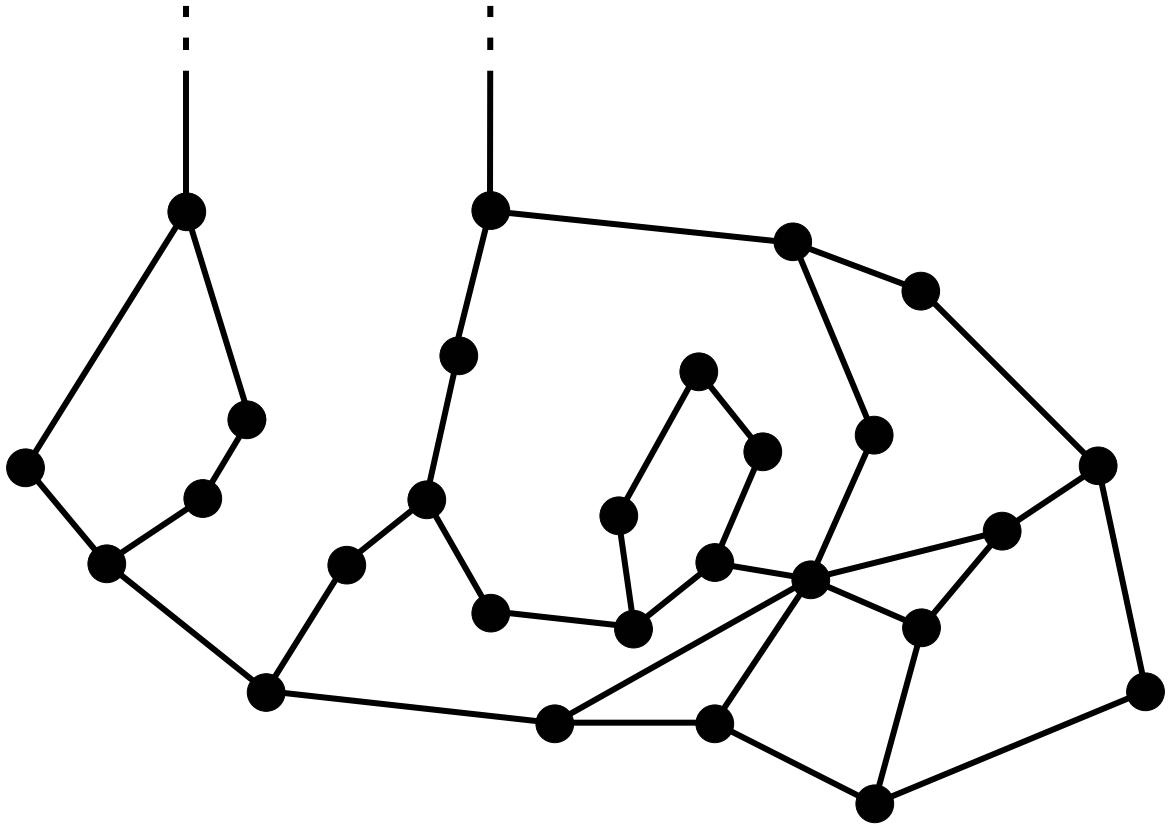
Overview

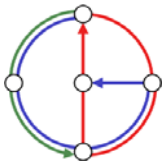
- Introduction
  - What is Geometric Routing?
  - Greedy Routing
- Correct Geometric Routing: Face Routing
- Efficient Geometric Routing
  - Worst-Case Optimality: Adaptively Bound Searchable Area
  - Average-Case Efficiency: GOAFR+
- Analysis of Cost Metrics
  - Linearly Bounded vs. Super-Linear Cost Metrics
- Conclusions



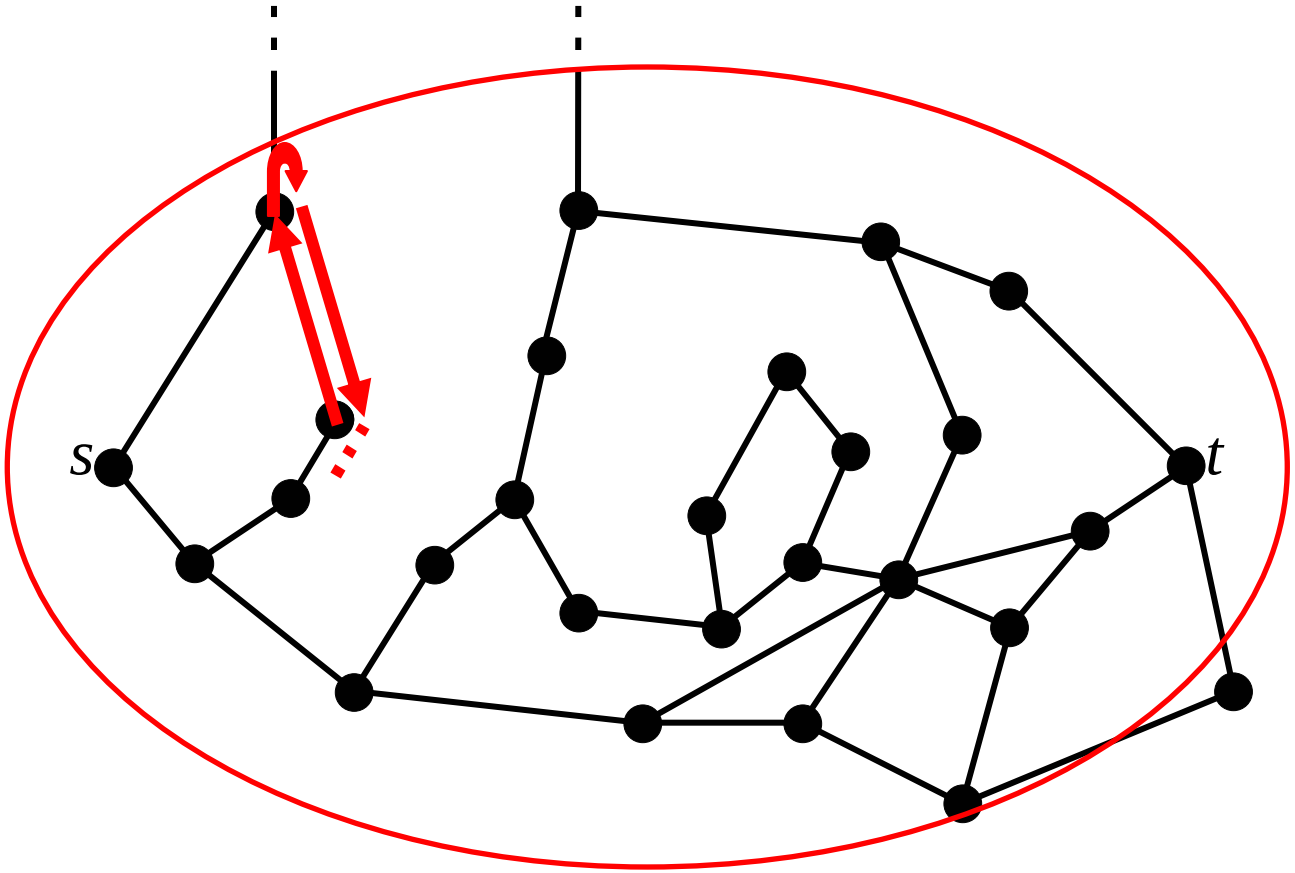
Face Routing

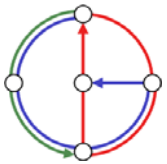
- Theorem: Face Routing reaches destination in O(n) steps
- But: Can be very bad compared to the optimal route





Bounding Searchable Area





Adaptively Bound Searchable Area

What is the correct size of the bounding area?

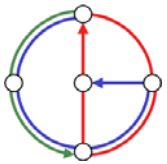
- Start with a small searchable area
- Grow area each time you cannot reach the destination
- In other words, adapt area size whenever it is too small

→ Adaptive Face Routing AFR

Theorem: AFR algorithm finds destination after $O(c^2)$ steps, where c is the cost of an optimal path from source to destination.

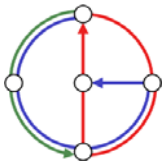
Theorem: AFR algorithm is asymptotically worst-case optimal.

[Kuhn, Wattenhofer, Zollinger DIALM 2002]



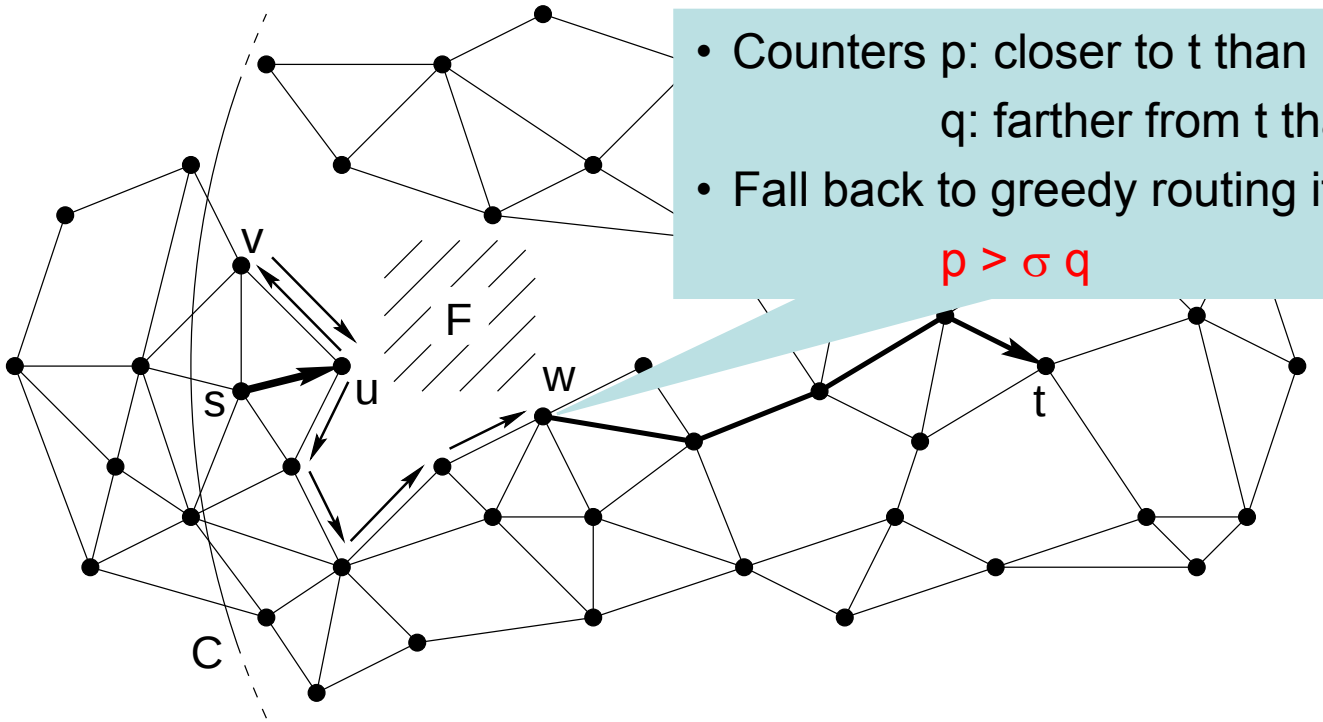
Overview

- Introduction
  - What is Geometric Routing?
  - Greedy Routing
- Correct Geometric Routing: Face Routing
- Efficient Geometric Routing
  - Worst-Case Optimality: Adaptively Bound Searchable Area
  - Average-Case Efficiency: GOAFR+
- Analysis of Cost Metrics
  - Linearly Bounded vs. Super-Linear Cost Metrics
- Conclusions

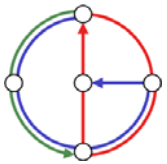


GOAFR+ – Greedy Other Adaptive Face Routing

- AFR Algorithm is not very efficient (especially in dense graphs)
- Combine Greedy and (Other Adaptive) Face Routing
  - Route greedily as long as possible
  - Overcome “dead ends” by use of face routing
  - Then route greedily again
- Similar as GFG/GPSR, but adaptive



- Counters p: closer to t than u
  q: farther from t than u
- Fall back to greedy routing if
  $p > \sigma q$



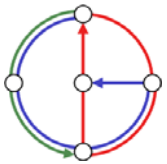
GOAFR+ Is Worst-Case Optimal

- GOAFR+
  - Early fallback technique with counters
  - Bounding searchable area with circle centered at t

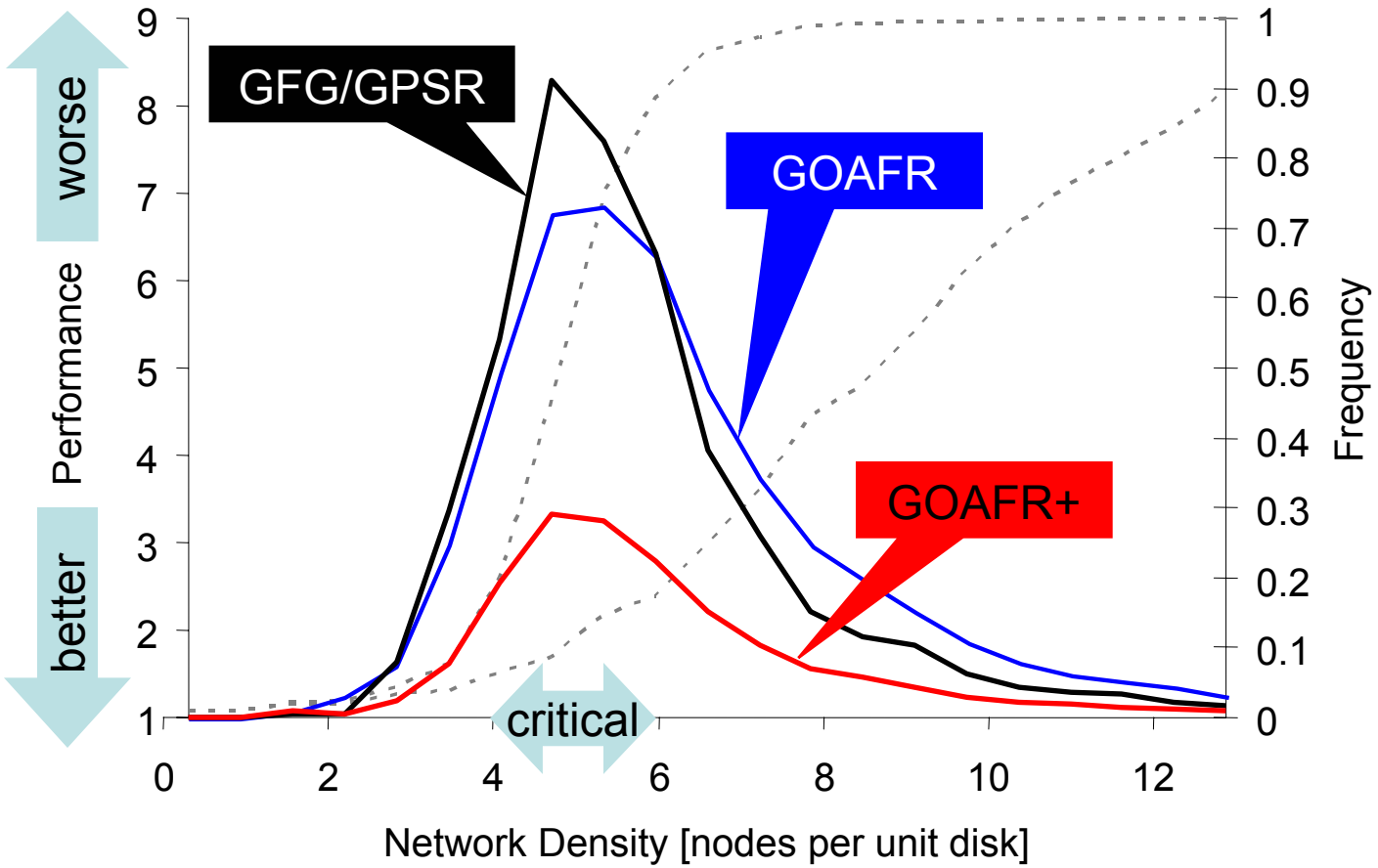
Theorem: GOAFR+ is asymptotically worst-case optimal.

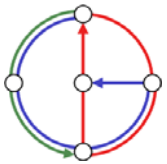
- Remark: GFG/GPSR is not
  - Searchable area not bounded
  - Immediate fallback to greedy routing

- GOAFR+'s average-case efficiency?



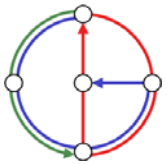
Simulation on Randomly Generated Graphs





Overview

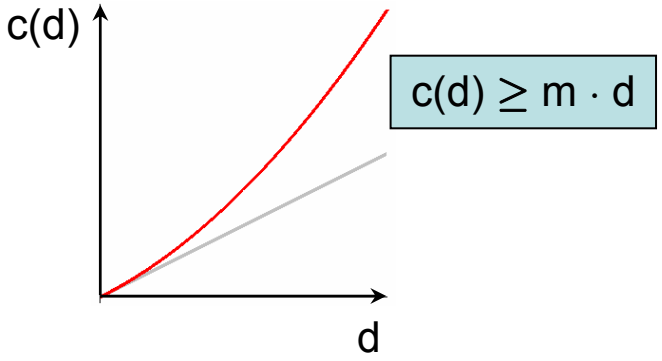
- Introduction
  - What is Geometric Routing?
  - Greedy Routing
- Correct Geometric Routing: Face Routing
- Efficient Geometric Routing
  - Worst-Case Optimality: Adaptively Bound Searchable Area
  - Average-Case Efficiency: GOAFR+
- Analysis of Cost Metrics
  - Linearly Bounded vs. Super-Linear Cost Metrics
- Conclusions



Analysis of Cost Metrics

- Dropping $\Omega(1)$-model / civilized graphs
- Cost metric: nondecreasing function $c:]0,1] \mapsto \mathbb{R}^+$

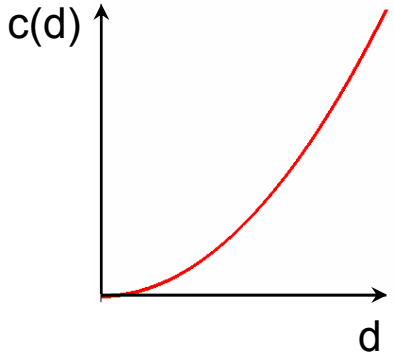
Linearly Bounded Cost Metrics



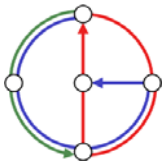
Link/hop metric $c(d) \equiv 1$

Euclidean metric $c(d) = d$

Super-Linear Cost Metrics



Energy metric $c(d) = d^2$



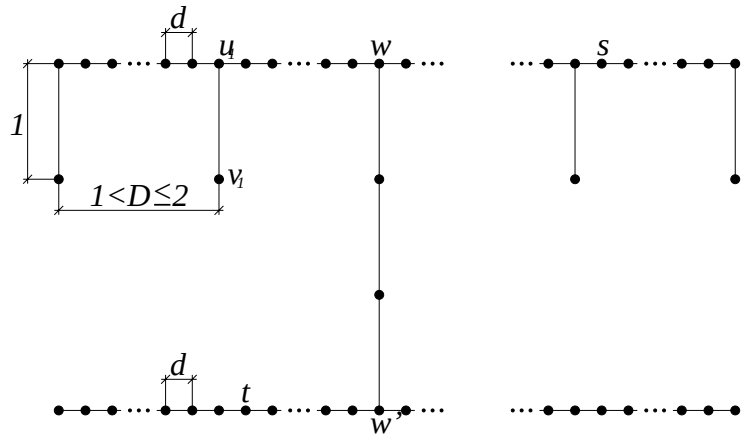
Linearly Bounded vs. Super-Linear Cost Metrics

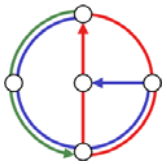
Linearly bounded cost metrics

- Backbone graph constructible for general Unit Disk Graphs
- All linearly bounded cost metrics asymptotically equivalent
- Asymptotically optimal geometric routing

Super-linear cost metrics

- No geometric routing algorithm can perform competitively





Conclusion

- “Geometric Ad-Hoc Routing: Of Theory and Practice“

Asymptotic worst-case optimality

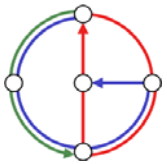
GOAFR+

Average-case efficiency

~~O(1)-model~~

Analysis of cost metrics

Drop assumption on distance between nodes



Questions?
Comments?
Demo?