Routing using Local Information: Introduction to Geographic Routing

Réseaux & Communication

Alain Cournier Stéphane Devismes

Université de Picardie Jules Verne

January 13, 2026

Roadmap

Roadmap

Preamble

This lesson is mainly based on the chapter

"Theory and Practice of Geographic Routing [10],"

by Stefan Ruhrup,

from the book "*Ad Hoc and Sensor Wireless Networks: Architectures, Algorithms and Protocols*" [9].

Definition

Geographic routing is a technique to deliver a message to a node in a network over multiple hops by means of position information.

Geographic routing is also known as position-based routing or geometric routing in the literature.

Hypotheses

Geographic routing algorithms work nearly stateless and apply under the following assumptions:

1. A node can determine its own position, *e.g.*, using a GPS
2. A node is aware of its neighbors' positions, *e.g.*, acquired using local broadcast
3. The position of the destination is known

   Require a *location service* (out of the scope of this course)

Network Model

Geographic routing is based on geometric criteria and is often used in the context of wireless networks

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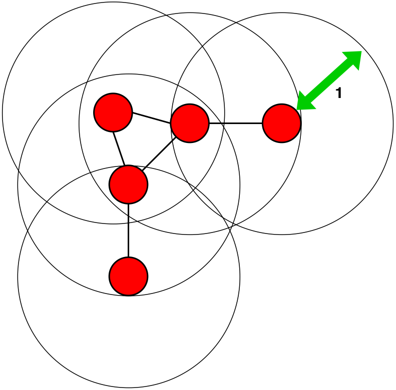
Geographic routing is based on geometric criteria and is often used in the context of wireless networks $\Rightarrow$ **Unit Disk Graphs (UDG)**

Nodes u and v are neighbors $\equiv \|u, v\| \leq 1$[1]



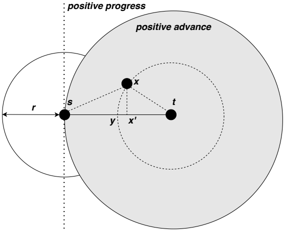
[1] The transmission range is normalized to 1

Roadmap

If the node is not the destination, it selects a neighbor for the next hop based on local information.

Routing decisions are **locally optimal**, based on a given criteria.

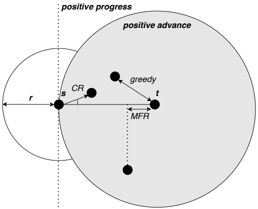
Criteria for the Next Hop Selection



- Progress: the projection of the location of neighbor x on the s-t-line, *i.e.*, $|x', t|$
- Distance to the destination: $|x, t|$
- Advance: $|s, y|$
- Angular distance / angular separation: Absolute angular deviation $\angle_{xst}$[2]

[2] The absolute angular deviation is the smallest angle between two directions, taken as a non-negative value, regardless of clockwise or counterclockwise orientation.

Instances



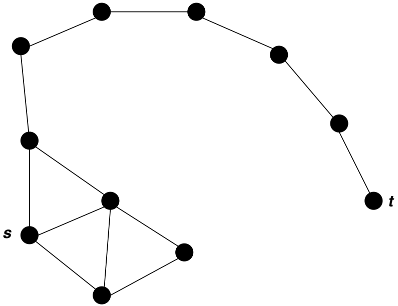
- MFR [12]: choosing the neighbor with **most forwarding progress** among neighbors with positive progress
- Greedy [5]: choosing the neighbor that **minimizes the distance to the destination**, or equivalently that **maximizes the advance** among neighbors with positive advance
- Compass Routing (CR) [7]: choosing the neighbor that **minimizes the angle separation *w.r.t.* the destination**[3] among all neighbors

[3] CR does not require GPS, a compass is sufficient!

Issues with Greedy Forwarding

Loops

CR may **loop**



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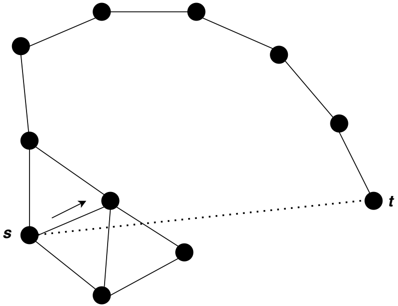

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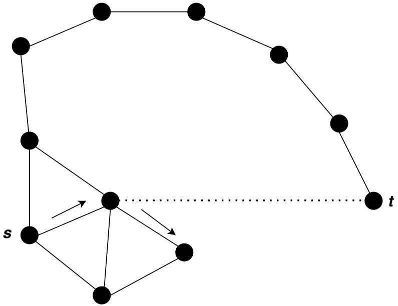

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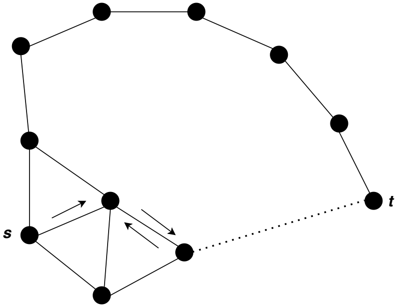

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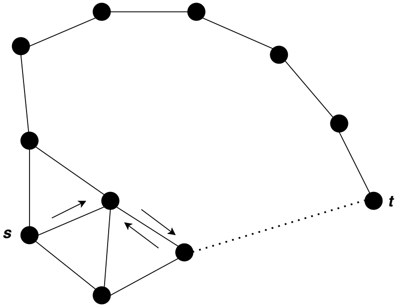
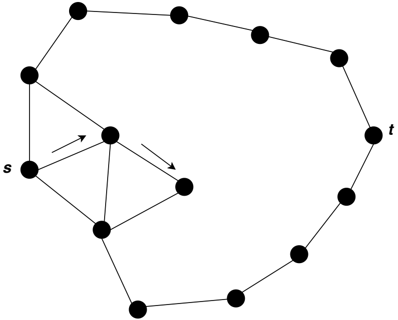


MFR and Greedy are loop-free

Issues with Greedy Forwarding

Loops

MFR and Greedy may lead to **dead ends**



Example with the Greedy Forwarding

Advanced Strategies

- 2-hop knowledge (virtual edge $(a, b) = b$ is 2-hop away from a)

  This does not work: the previous counter-example still works

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  This works! But, the taboo list is stored in the message: the overhead in messages is huge and routes may be very long!

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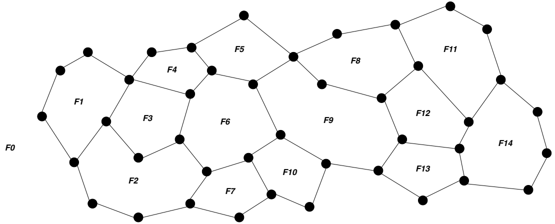
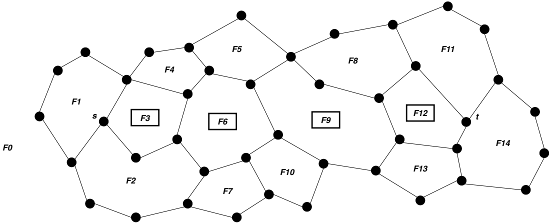
- **Using faces in planarized UDG**

Roadmap

Faces in (UDG) Planar Graphs

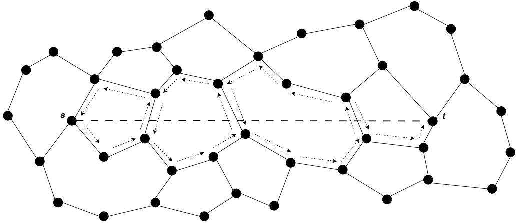


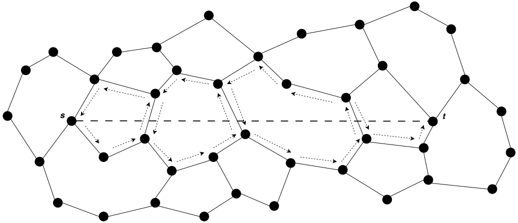
Faces in (UDG) Planar Graphs



Idea: traverse faces toward the destination using the left-hand or right-hand rule

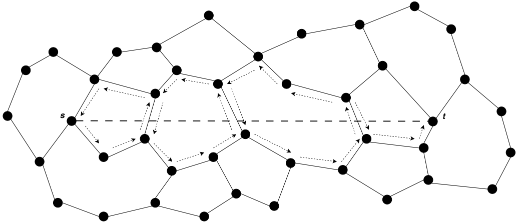
Face Routing, Kranakis *et al.* [7]





1. Select next hop v in cw (or ccw) direction from (s, t)

cw = clockwise   ccw = counterclockwise



1. Select next hop v in cw (or ccw) direction from (s, t)
2. Select next hop v as the successor node in cw (or ccw) after the predecessor until coming back to s

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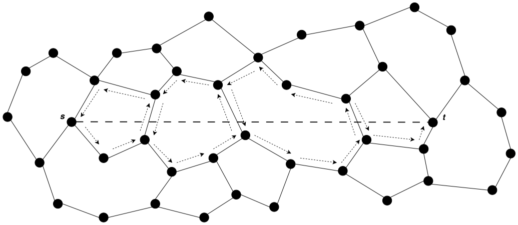

1. Select next hop v in cw (or ccw) direction from (s, t)
2. Select next hop v as the successor node in cw (or ccw) after the predecessor until coming back to s
3. Select a node u of the face incident to a segment intersecting (s, t) that is closest from t

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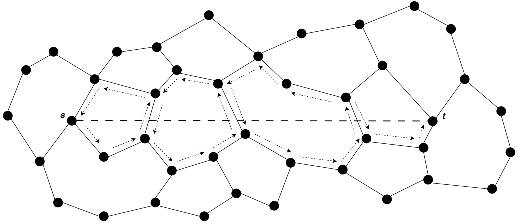

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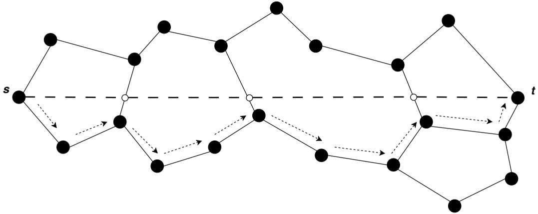
3. Select a node u of the face incident to a segment intersecting (s, t) that is closest from t
4. Route the packet to u and restart with $s = u$ until finding t

cw = clockwise   ccw = counterclockwise

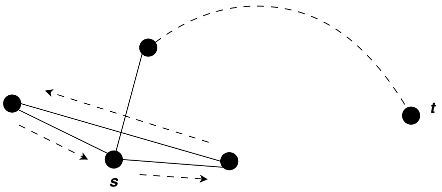
Improved Strategy: Face-2 Routing, Bose *et al.* [2]



Face change **right before crossing the s-t-line**

Planarity Assumption

Planarity is mandatory to ensure the delivery guarantee



Mixed Strategy

- Greedy is efficient but delivery is not guaranteed
- Face Routing guarantees delivery but is inefficient

Mix both: **Greedy-Face-Greedy** (GFG), Datta *et al.* [3]

Principle of GFG

Two modes: Greedy and Face

- Start in greedy mode
- In case of dead end, store the distance d to the destination t and switch to face mode
- Switch back to greedy mode when finding a node u such that $|u, t| < d$

GFG Algorithm

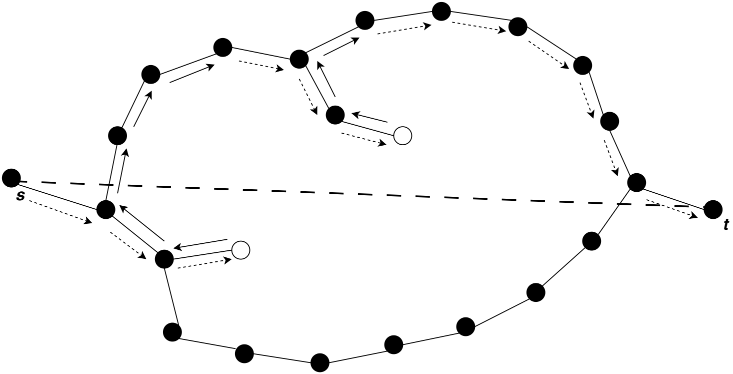
Values stored in the packet:

t: the target position; $mode \in \{Greedy, Face\}$, initialized to $Greedy$; p: the previous hop
e_f: first edge of the current face; d_f: distance to target (in the face mode)

Code:

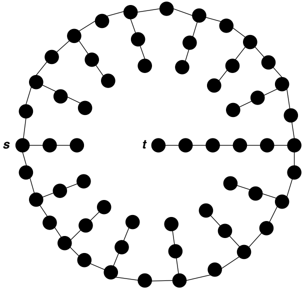
Let u be the current position
if $u = t$ **then**
    deliver the packet
else
    if $mode = Greedy$ **then** ▷ Greedy Mode
        if u is a dead end **then** ▷ Switch to the Face Mode
            Select next hop v in ccw direction from (u, t)
            $d_f \leftarrow |u, t|$; $e_f \leftarrow (u, v)$; $p \leftarrow u$ ▷ To prepare the next hop
            $mode \leftarrow Face$
        else
            Select next hop v according to the greedy rule
        end if
    else ▷ Face Mode
        if there is a neighbor w with $|w, t| < d_f$ **then** ▷ Switch to the Greedy Mode
            Select next hop v according to the greedy rule; $mode \leftarrow Greedy$
        else
            Select next hop v in ccw direction from (u, p)
            If $(u, v) = e_f$ **then** return ▷ The packet is dropped: the destination is unreachable
            $p \leftarrow u$ ▷ To prepare the next hop
        end if
    end if
    Send the packet to v
end if

GFG: Example



Lower bound [8]

$\Omega(k^2)$ for a shortest path of length $O(k)$



- External ring of length $2k$
- $O(k)$ "branches" of length $\Theta(k)$

From s, at least k nodes of the external ring and $O(k)$ "branches" are visited before reaching t

Roadmap

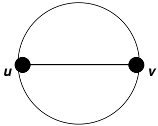
Planarization Techniques

1. Gabriel Graphs [6]
2. Relative Neighborhood Graphs [13]
3. Delaunay Triangularization [4]

Gabriel Graphs [6]

A **Gabriel graph** of a given point set S is defined as follows: $\forall u, v \in S$, it contains the edge $\{u, v\}$ if the Thales' circle on $\{u, v\}$ is empty.

Thales' circle (also called the Gabriel circle) on $\{u, v\}$ = the circle having $\{u, v\}$ as diameter.



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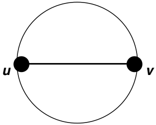

Gabriel graphs are planar and connected.

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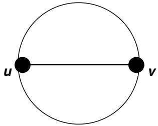
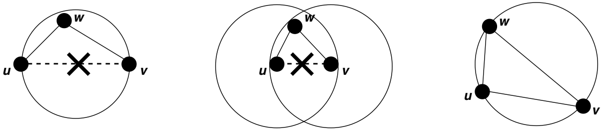


Gabriel graphs are planar and connected.

This construction rule can be applied locally to a node's 1-hop neighborhood in order to extract a planar subgraph.

Planarization Techniques



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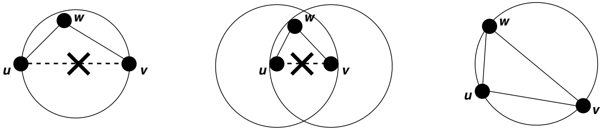

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   Applying the Gabriel Graphs criterion to a unit disk graph yields a planar and connected graph, if the unit disk graph is connected.

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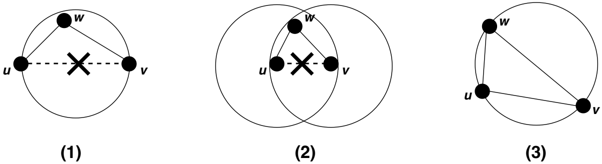

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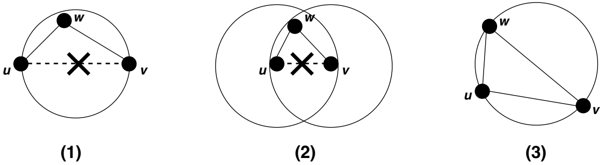
2. Relative Neighborhood Graphs [13]: remove an edge $\{u, v\}$ if if the intersection of the two circles with radius $|u, v|$ centered at u and v contains another node w

   Applying the RNG criterion to a unit disk graph yields a planar and connected graph, if the unit disk graph is connected.

Planarization Techniques



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3. Delaunay Triangularization [4]: the Delaunay triangulation of a given point set contains all triangles whose circumcircle is empty.

Stretch Factor

Planarization removes (omit) crossing edges $\Rightarrow$ **Detours**

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Stretch Factor allows to evaluate the quality of the planarization

Stretch Factor: $\max \frac{\text{shortest path length between } u \text{ and } v \text{ in the subgraph}}{\text{shortest path length between } u \text{ and } v \text{ in the original graph}}$

Comparison

Technique	Local[4]	Stretch Factor[5][6]
Gabriel Graph	Yes	$\Theta(\sqrt{n})$
RNG	Yes	$\Theta(n)$
Delaunay Triangularization	No	$\Theta(1)$

[4] By Local, we mean using only 1-hop information

[5] n is the number of nodes

[6] Stretch factors come from Bose *et al.* [1]

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State-of-the-art: Local variants of the Delaunay Triangularization

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Roadmap

Pros and Cons of GFG + planarization

Pros:

- Correctness
  (if the links are reliable)
- Local Information only: small messages and low memory requirements
- Robust
- FIFO
- Fair

Cons:

- Not adaptive
- Load-balancing: many links are not used, in particular due to planarization
- Not efficient
- Unrealistic Model: UDG topology and reliable link

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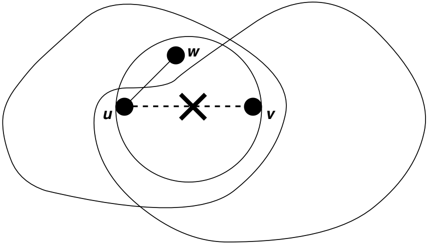
Toward more realistic topologies

GFG works in any planar graph

However, previously introduced planarization techniques may disconnect a non-UDG graph such as a Quasi-UDG.



Other planarization techniques exist
but they are more complex (in particular, not local) and so more costly.

Unreliable links

Greedy (and greedy mode in GFG): designed with respect to distance and does not take lossy links into account.

Idea: adapting greedy (mode) forwarding by considering the reception probability into the criteria that is locally optimized.

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Idea: adapting greedy (mode) forwarding by considering the reception probability into the criteria that is locally optimized.

Motivation: If a node on the edge of the range with low link quality is selected as a next hop, it might take a few transmission attempts to successfully forward a packet, whereas another node with a smaller advance could be reached on the first try.

Hence, **the criteria for forwarding decisions should include the cost for re-transmissions.**

Estimating the cost for re-transmissions

Packet Retransmission Rate (PRR):

$$\frac{\text{successfully received packets}}{\text{the total number of transmitted packets}} \text{ over a specific time period}$$

$\approx$ a reception probability p for future transmissions
$\approx$ cost for re-transmissions

$\frac{1}{p} \approx$ the expected number of transmissions needed for a successful reception

(if acknowledgments are not taken into account).

A new criteria to deal with a realistic physical layer model

In [11], Seada *et al.* propose to (locally) maximize

$$\text{PRR} \times \text{advance}$$

Essentially, it is a ratio of the advance over the expected number of transmissions

Roadmap

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