Routing, anycasting, multicasting for sensor-actuator networks

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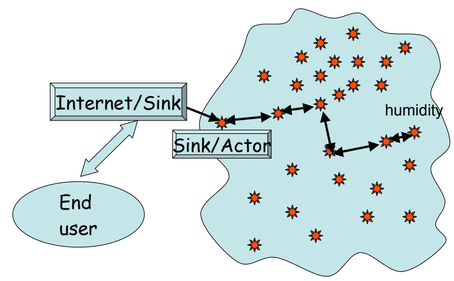
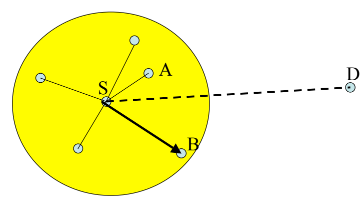
Sensors route reports (measurements) to an actor or a fixed sink



Routing without position information

- Can be applied toward nearest actuator
- **Proactive ?**: Bellman-Ford, Shortest path (OLSR): NO
- **Reactive ?**: Flooding to discover route to an actor, like AODV/DSR: NO,
- Communication overhead at sensors: network flooding for each sensor report
- **Tree creation and maintenance** ?
- Flooding (limited) from each actor to establish routes from each sensor to its nearest actor, then
- modify links near moving actors (or flood again?),
- Sensor maintain hop counts or cost toward actors

Greedy position based localized routing

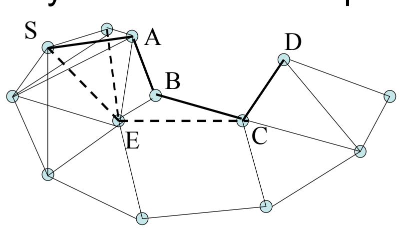


Localized protocol: S knows only position of itself, its neighbors and destination D

S forwards to neighbor B closest to D

Finn 1987

Greedy: SABCD vs shortest path SECD



Localized vs. globalized protocol

SP Overhead: messages to maintain global information at each node following mobility and/or sleep/active periods changes

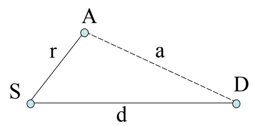
Is hop count the best metric ?

- Power consumption
- Reluctance (avoiding nodes with low energy)
- Power_reluctance
- Delay
- Expected hop count (realistic physical layer)
- COST - selected metric

Cost to progress ratio framework

- Progress: measures advance toward destination
- Progress = |SD|-|AD|=d-a
- Select neighbor A that minimizes cost(SA)/progress(A)
- Hop count: cost=1
- →Maximize advance

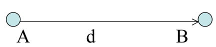
Stojmenovic IEEE Network 2006

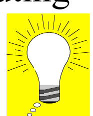


Parameterless behavior

- Cost-to-progress ratio framework has no added parameters such as thresholds
- Threshold based approach: eliminate 'bad' links, drop packet if there is no 'good' neighbor
- What if a solid path has just one weak 'bridge'?
- Experiments so far indicate that threshold based approaches are inferior for all threshold values - either high failure rate or suboptimal since there is no notion of 'best' neighbor

Power saving localized routing





Constant power → minimize hop count

power $=u(d)= d^{\alpha} + c$ → minimize total power

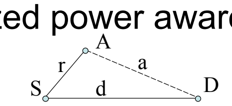
$2 \le \alpha \le 6$ model by Rodoplu, Meng 1999

Many articles assume $c=0$; in practice $c>0$ since power is needed to run hardware at each node, and correct reception requires minimal transmission power (no energy free transmission at zero distance)

reluctance $f(A)$ to forward packets = $=1/g(A)$ $g(A)$ in [0,1] lifetime → minimize total cost

Power_reluctance $= f(A)u(d)$

Localized power aware routing

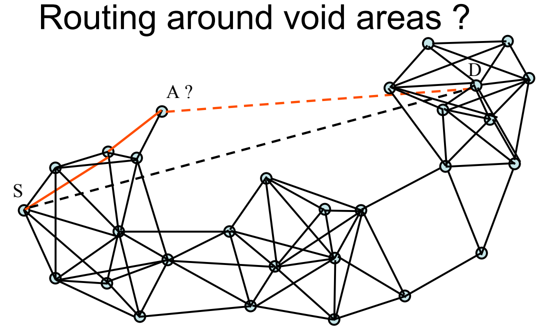


- Kuruvila, Nayak, Stojmenovic 2004
- *Power progress:* minimize $(r^{\alpha}+c)/(d-a)$
- *Iterative power progress:* select *B* if *power(SB)+power(BA) < power(SA)*
- (Iterative) Projection power progress
- Shortest weighted path toward selected neighbor (Ruiz, Sanchez, 2007)

Routing link metric

- Gungot, Sastry, Song, Integlia ICC 2007
- *Routing via both sensors and actors on routes*
- Link Quality Indicator correlates with packet reception probability
- Formula includes:
- Ratio of initial and current node energy for transmitter and receiver
- Energy consumption for transmission and reception
- Cost applied on sensor nodes while actor nodes have zero costs
- Routing otherwise uses so defined link costs

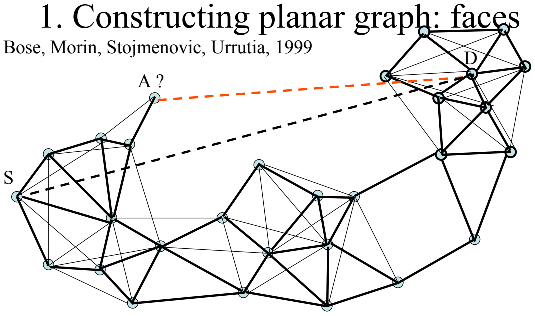
Routing around void areas ?



Recovery, perimeter, face mode

1. Constructing planar graph: faces

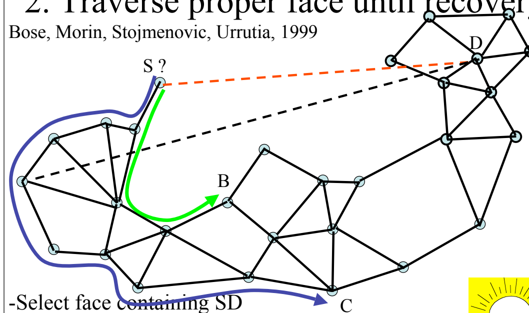
Bose, Morin, Stojmenovic, Urrutia, 1999



Some planar graphs (Gabriel graph) can be constructed without message exchange!

2. Traverse proper face until recovery

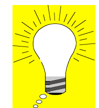
Bose, Morin, Stojmenovic, Urrutia, 1999



-Select face containing SD

- Follow that face by **left** hand or **right** hand rule

until recovery (= closer node reached)

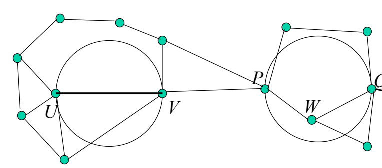


GFG= Greedy-FACE-Greedy

- run Greedy until delivery or a failure node A, |AD|=d,
- run FACE until delivery or B reached, |BD|<d,
- run Greedy …
- paths close to SP for higher degrees,
- <3.5 times longer than SP for low degrees,
- No traffic memorization, localized, close to SP → ***scalable*** !! Bose, Morin, Stojmenovic, Urrutia, 1999
- Karp and Kung MOBICOM 2000 duplicated (with citation) GPSR= GFG (added MAC, mobile nodes)

Gabriel graph

Gabriel, Sokal 1984



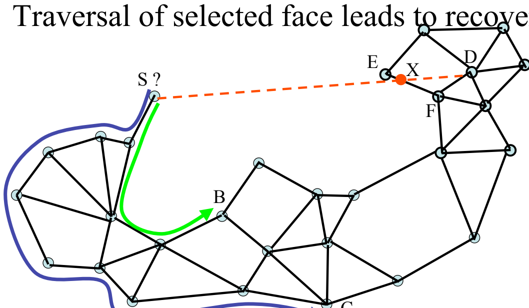
Gabriel graph GG(S) contains an edge (U,V) iff the disk with diameter (U,V) contains no other point from S

= distance from other points to center of UV is > |UV|/2

= Acute angles for all joint neighbors → in GG

GG(S) is planar and connected (contains MST)

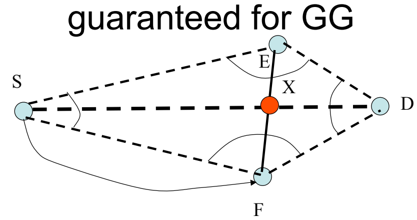
Traversal of selected face leads to recovery



-Line SD intersects the face in X on an edge EF

- E or F is closer to D than A (if nothing else found before)

Getting closer on the face is guaranteed for GG

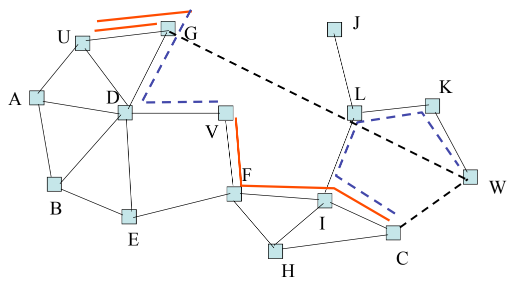


$\angle S < \pi/2$, $\angle D < \pi/2$ since EF is in GG → $\angle E > \pi/2$ or $\angle F > \pi/2$

$\angle F > \pi/2$ → |SD| > |FD| → F is closer to D than S

Frey, Stojmenovic MOBICOM 2006

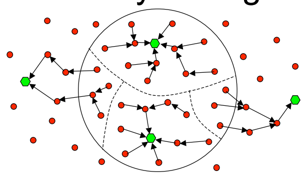
Greedy, GFG (greedy-face-greedy)



Robustness of GFG

- GFG requires unit graph = equal transmission radius, no obstacles, nodes in plane
- Extension for fuzzy unit graphs = connected if distance < r, nor connected if distance >R, may or may not be connected otherwise, R/r < 1.41
  Barriere, Fraigniaud, Narajanan, and Opatrny 2001
- Loop-free for static nodes; loops can be created by mobile nodes but exit can be found by adding timestamp of the last intersection with imaginary line SD and ignoring links created afterwards

Anycasting



Routing from a sensor to one of sinks/actuators

Position of sinks/actuators known

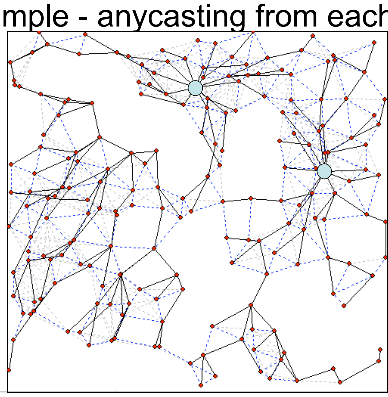
Anycasting may advance toward one sink but could eventually reach a different one

Kalosha, Stojmenovic 2007 (in progress)

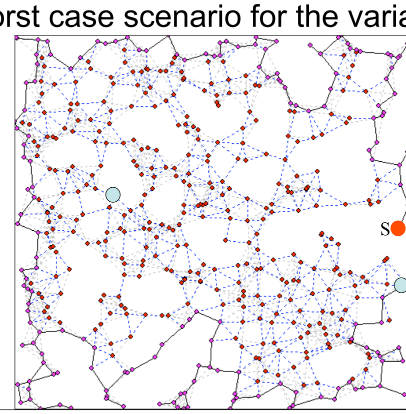
Algorithm - one variant

- Modified GFG approach
- In greedy mode, select neighbor providing best cost/progress ratio toward any actuator
- to preserve a single path, select only the closest sink node D for face routing toward it.
- The distance to D is recorded and forwarded with the message. Recovery mode stops when a node has a neighbor that is at shorter distance to one of sinks (not necessarily D) than recorded distance.

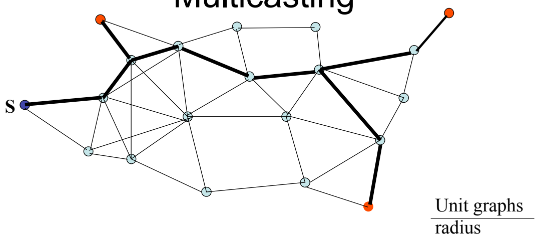
Example - anycasting from each sensor



A worst case scenario for the variant



Multicasting



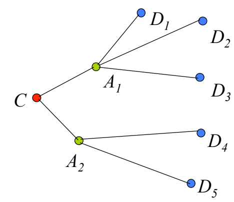
•source → several destinations

Position information

•Sanchez, Ruiz, Liu, Stojmenovic 2006

•Stojmenovic IEEE Network Jan. 2006

Evaluating the candidate forwarding from *C* to *A1* and *A 2*



The current total distance is $T1=|CD_1|+|CD_2|+|CD_3|+|CD_4|+|CD_5|$.
new total distance is $T_2=|A_1D_1|+|A_1D_2|+|A_1D_3|+|A_2D_4|+|A_2D_5|$.

Progress made is T1-T2, cost is 2 transmissions

forwarding set {*A1, A2*} is evaluated as $2/(T_1-T_2)$.

GMR: Multicasting algorithm

- Greedy advance toward each group of destinations, with or without splitting
- If no greedy advance toward any destination, follow face routing toward it
- Several destinations could be followed by same faces for a while
- Continue greedy advance after recovery
- Power instead of hop count as a metric ?

Multicasting to many destinations

- Das, Pucha, Hu 2006
- Destinations are locally grouped
- Group leaders report to source
- Source constructs Minimal Spanning Tree of group leaders, and
- Initiates greedy routing between edges in MST (face routing added to recover)
- MST can be replaced by cost-to-progress ratio framework

HGMR: Hierarchical multicasting

- Hierarchical Geographic Multicast Routing for Wireless Sensor Networks
- Dimitrios Koutsonikolas, Saumitra Das, Y. Charlie Hu, and Ivan Stojmenovic SENSORCOMM 2007
- starts with a hierarchical decomposition of a multicast group into subgroups of manageable size using HRPM's key concept *mobile geographic hashing*.
- Within each subgroup, HGMR uses GMR's *local multicast scheme* to forward a data packet along multiple branches of the multicast tree in one transmission.

MSTEAM

- Frey, Ingelrest, Simplot-Ryl 2008
- Message replication occurs when MST of current node and multiple destinations has multiple edges originating at current node
- Group, best neighbor, cost/progress ratio..
- Progress= difference in MSTs to the group
- Multicast generalization of face recovery:
- Face (over GG) stops when MST of current node and 'face' destinations is shorter than MST of starting node and destinations
- Matches centralized algorithm for high densities