Ad hoc networks: Localized and position based formation, power management, routing and broadcasting schemes

TUTORIAL

- Ivan Stojmenovic
- www.site.uottawa.ca/~ivan
- ivan@site.uottawa.ca

Contents

- 1. Position based routing in wireless networks
- 2. Broadcasting in ad hoc wireless networks
- 3. Bluetooth scatternet formation

Power management covered in 1-3

Wireless networks have power and bandwidth limitations

Localized: nodes act based on local network information

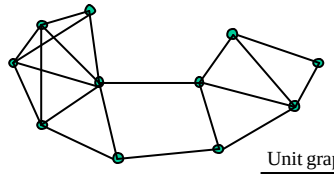
Position based: Nodes are aware of their geographic absolute or relative coordinates

Some solutions in 2. and 3. do not require position information

Position based routing in wireless networks

- *Ivan Stojmenovic*
- ivan@site.uottawa.ca
- www.site.uottawa.ca/~ivan

Multi-hop wireless networks



Unit graphs

radius

Sensor networks
mobile ad hoc networks

•Routing: source → destination

Contributions on routing: 1998-2002

- loop-free: DIR not, GEDIR & MFR yes (Lin)
- Flooding GEDIR & MFR (Lin)
- power aware & loop-free (Lin)
- GFG- guaranteed delivery, no memory (Bose, Morin, Urrutia)
- internal nodes, shortcut (Datta, Wu)
- power aware, guaranteed delivery (Datta)
- QoS DFS based routing (Russell)
- Component routing, multi-paths
- Location updates: quorum, home agent, VD, CH

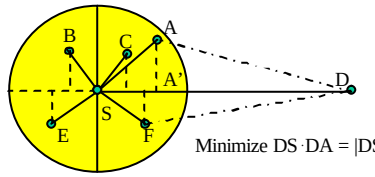
Distributed Routing

localized	Non-localized
• ***Neighboring nodes***	• ***All nodes***
• ***destination***	• ***all edges***
• ***MFR***	• ***shortest path***
• ***DIR***	• ***shortest weighted path:***
• ***GEDIR***	• Singh,Woo… (cost)'98
• ***FACE***	• Rodoplu, Meng '99 (power)
• ***power***	• Basagni, Chlamtac, … '99
• ***cost***	• Camara,Loureiro'00 (agents)
• ***power-cost***	• Joa-Ng, Lu'99 (zones)

Localized routing

- **MFR**= most forward with progress
  Takagi and Kleinrock 1984
- **NFP**= nearest forward progress Hou,Li ‘86
- **DIR**= best direction Basagni-Chlamtac-Syrotiuk ‘98
  Ko-Vaidya 1998 (MOBICOM), Singh, Urrutia 1999
- **Greedy/GEDIR** = closest to destination Finn 1987
- **Flooding GEDIR+MFR** Stojmenovic, Lin 1999
- **FACE, GFG** Bose,Morin,Stojmenovic,Urrutia ‘99
- **Power and cost aware** Stojmenovic, Lin ‘99
- **QoS DFS** Stojmenovic, Russell ’00
- **Dominating sets** (Datta, Stojmenovic, Wu, 2001)
- **Component routing** Stojmenovic + 2001

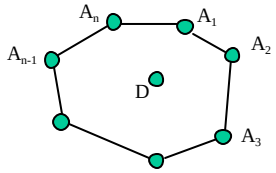
Progress based routing ‘84-86.



Minimize $DS \cdot DA = |DS||DA'|$

Random progress (Nelson, Kleinrock): A, C or F
NFP- nearest forward progress (Hou, Li): C
MFR - most forward within radius
(Takagi, Kleinrock): A

MFR is loop-free



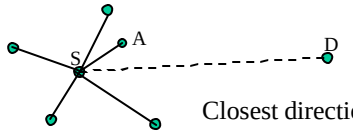
$DA_n \cdot DA_1 > DA_2 \cdot DA_1 \quad A_1 \rightarrow A_2$
$DA_n \cdot DA_1 > DA_1 \cdot DA_2 > DA_2 \cdot DA_3 > \ldots >$
$DA_{n-1} \cdot DA_n > DA_n \cdot DA_1$

DIRectional routing methods

Basagni, Chlamtac, Syrotiuk, Woodward MOBICOM’98

Ko, Vaidya MOBICOM ‘98

Kranakis, Singh, Urrutia CCCG’99 (compass routing)



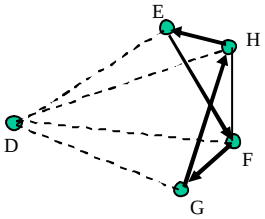
Closest direction

Send to ***several*** neighbors closest to direction [BCSW,KV]

location update schemes [BCSW, KV]

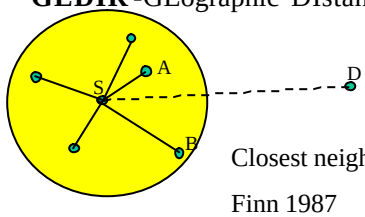
Flooding rate ??

DIR is not loop-free



Transmission radius

GEDIR -GEographic DIstance Routing



Closest neighbor to D

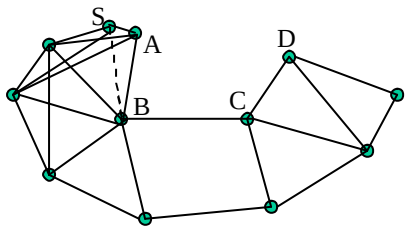
Finn 1987

Ko, Vaidya MOBICOM’98: LAR2

send to ***all*** neighbors closer to destination

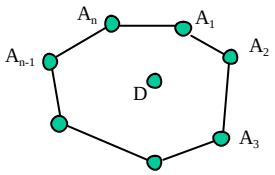
Flooding rate XL ??

GEDIR vs SP



GEDIR: SABCD SP: SBCD

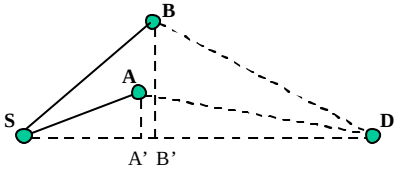
GEDIR is loop-free



Assume A_1 closest to D

A_2 sends to A_3 - contradiction

GEDIR vs. MFR



may choose different node

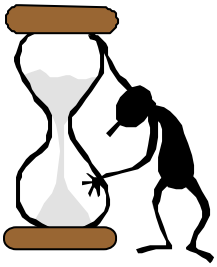
choice is same most of time!

GEDIR wins in power efficiency AD<BD

Stoppage criteria

- If message is to be returned to the neighbor it came from
  = concave node
- MFR, DIR, GEDIR
- Flooding GEDIR, Flooding MFR:
- Concave nodes flood message to all neighbors and then reject further copies of the same message:
- Loop-free methods that guarantee delivery, but
- Nodes memorize past traffic

Performance evaluation



- GEDIR-D1R-MFR
- flooding GEDIR-DIR-MFR
- c-GEDIR, c-DIR, c-MFR

Hop count

success rate

flooding rate

Static nodes

Generating random unit graphs

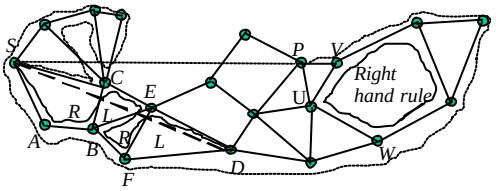
- Choose **n** points at random in [0,m]x[0,m]
  n=20,50,100,200 m=100
- select average node degree **d** = 2,3,4,5,…
- sort all (n-1)n/2 edges in increasing order
- Radius R= nd/2-th edge in sorted order!
- Reject graph if disconnected

Success rate = high for high degree, low for low degree

hop count = successful GEDIR/MFR close to SP, DIR >

flooding rate = close to SP

Face routing – guaranteed delivery



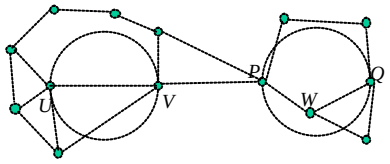
Bose, Morin, Stojmenovic, Urrutia, 1999

1. Construct planar subgraph
2. Route in planar subgraph:

SABCEBFED

SC…ABFD…W…VP

Gabriel graph



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

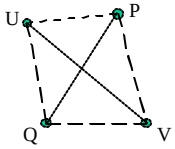
= distance from other points to center of UV is > |UV|/2

= angle UWV < π /2 for any other point W

GG(S) is planar and connected

Gabriel graph is planar

Planar graph = no two edges intersect



Proof by contradiction: Assume

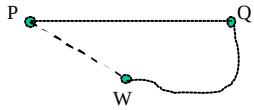
UV, PQ ∈ GG(S), UV ∩ PQ

→∠ PUQ < π /2, ∠ PVQ < π /2,

∠ UPV < π /2, ∠ UQV < π /2,

→ Sum of angles in UPVQ < 2π

Gabriel graph contains MST



By contradiction: Assume

PQ ∈ MST, PQ ∉ GG;

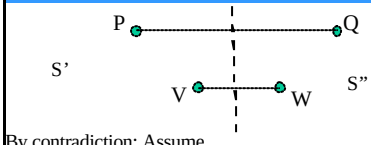
→ ∃W, PW<PQ, QW<PQ, PW ∉ MST

Replace PQ by PW in MST

→ new MST has smaller sum of edge lengths. contradiction

→ Gabriel graph connected

Unit (connected) graph contains MST



By contradiction: Assume

PQ ∈ MST, PQ ∉ U(S) (unit graph on point set S);

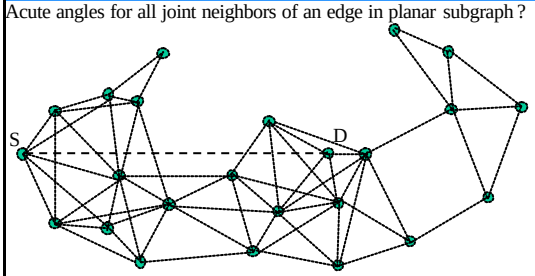
delete PQ → S divided into two components S', S" → ∃VW ∈ U(S), V ∈ S, W ∈ S" Replace PQ by VW in MST

→ new MST has smaller sum of edge lengths. contradiction

→ GG(S) ∩ U(S) planar and connected!

Constructing planar subgraph

Acute angles for all joint neighbors of an edge in planar subgraph ?

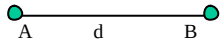


Computing planar subgraph requires no message exchange!

GFG= GEDIR-FACE-GEDIR

- run GEDIR until delivery or a failure node A, |AD|=d,
- run FACE until delivery or B reached, |BD|<d,
- run GEDIR …
- paths close to SP for higher degrees,
- <3.5 times longer than SP for low degrees

Power saving localized routing

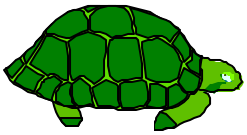


Constant power → minimize hop count
power =u(d)= $ad^{\alpha} + bd + c$ → minimize total power
cost f(A)= reluctance to forward packets =
=1/g(A) g(A) in [0,1] lifetime → minimize total cost
power-cost = f(A)u(d)

-close to corresponding SP algorithm if delivered;

- guaranteed delivery → PFP, CFC, PcFPc

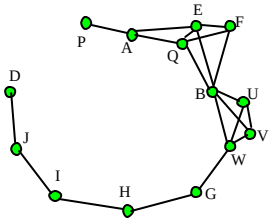
QoS DFS routing



Work in progress

- Depth First Search with GEDIR to sort neighbors, and O(1) memory in each node, guaranty delivery
- bandwidth criterion = edge elimination
- delay criterion = hop count + more bandwidth
- new connection time criterion !!

Component routing

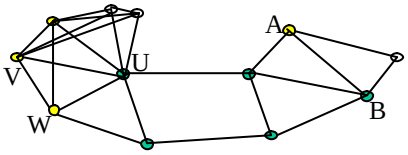


Concave nodes send packet to one neighbor in each connected component of subgraph of neighbors:

Parallel path search

Components in routing from *A* to *D:*
***AP**, PA**Q**, Q**A**E, E**A**, E**BWGHIJ**D.*

Internal nodes based routing and broadcasting



Wu, Li '99

Intermediate node = two neighbors not connected
(inter)gateway = + not covered by 1 or 2 neighbors

Routing: Apply GFG on internal nodes

Broadcasting: only internal nodes retransmit

Location updates - moving nodes

- Updates proportional to mobility ?
  Moving in small circle?
  Moving together e.g. army ?
- Update only when links change
- send update only to designated region
- Destination search
- Route from destination to source !!
- Message speed >> node speed → apply routing for static networks

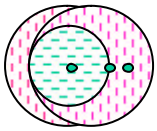
Doubling circles update

Circle sizes *R, 2R, 4R, 8R, …* Amouris, Papavassiliou, Li, 1999

For each circle size $t=2^kR$, $k=0,1,2,\ldots$ **do** {

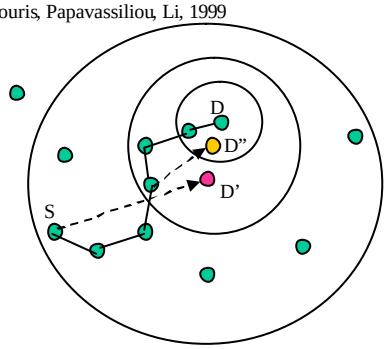
whenever node exits circle of size *t* centered at previous update of same size do

send location update to all nodes inside circle of size 2t centered at current position }



Doubling circles routing

Amouris, Papavassiliou, Li, 1999



LU when edge makes or breaks

- *Karumanchi, Muralidharan and Prakash 1999*
- Use last known position of neighbors
- When an edge is about to break, send LU (loc.upd.)
- If a new edge is created, respond with LU
- If 2-hop neighbor info → send LU when edge made
- Dead-reckoning for mobile phones, *Wolfson, Sistla '99:*
- Report position, speed and direction of movement
- Use last known position, updated by reported movement, for edge make or break estimates

Routing strategies

- **Multi-path full message** strategies: send full message to several neighbors which are best choices for all possible destination positions

  Ko, Vaidya, MOBICOM '98
  Basagni, Chlamtac, Syrotiuk, Woodward '98

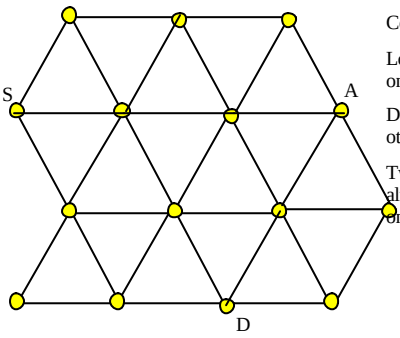
- **Single-non-optimal-path full message strategy**:

  Amouris, Papavassiliou, Li, 1999

- **Short message destination search, full message optimal path**:

  - *destination search* by short messages
  - routing from destination to source by short msg: *path creation*
  - (QoS) routing from source to destination by full msg: *data traffic*

Quorum based location management



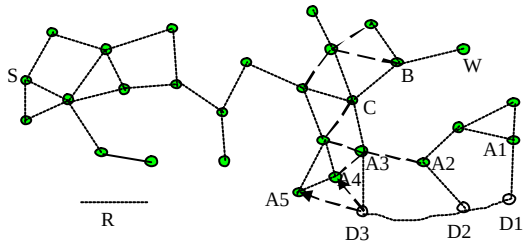
Cellular network:

Location update in one direction

Destination search in other direction

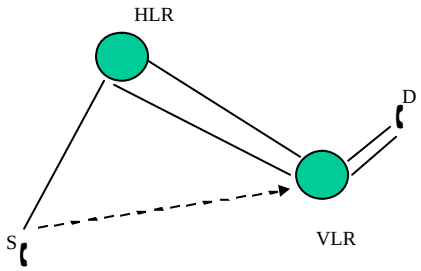
Two directions always intersect in one base station

Quorum based LU and DS

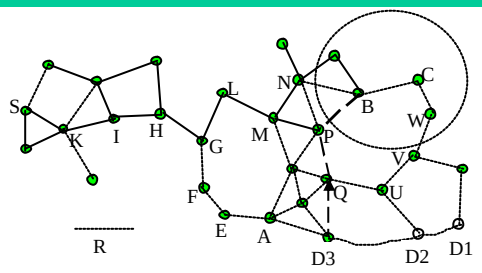


Location update from D3 and Destination search from S
Destination D moves from D1 to D2 to D3 – other nodes static

Home agent based cellular networks



Home agent based LU and DS



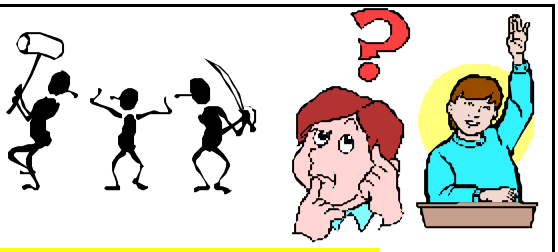
Location update from D2 and destination search from S
Destination D moves from D1 to D2 to D3 – other nodes static

Home agent based scheme - history

- ***Stojmenovic, TR September 1999***
- Woo and Singh, TR March 2000, Oregon State University; **Wireless Networks**, 7, 5, September 2001, 513-529.
- Blazevic, Buttyan, Capkun, Giordano, Hubaux and Le Boudec, TR, Swiss, Lausanne, December 2000;
  IEEE Communication Magazine, June 2001.
- Morris, Jannotti, Kaashoek, Li, Decouto (**MIT**), 9th ACM SIGOPS European Work., Kolding, Denmark, Sept. 2000.
- G. Pei and M. Gerla, **Mobile Networks and Applications**, 6, 4, August 2001, 331-337.

Open problems

- Zone routing
  = half-localized
- better location update
- better formulas for power/cost routing
- guaranty delivery for graphs which are not strictly unit graphs
- QoS routing



- *Ivan Stojmenovic*
- ivan@site.uottawa.ca
- www.site.uottawa.ca/~ivan