Mesh-based Sensor Relocation for Coverage Maintenance in Mobile Sensor Networks

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Sensor Relocation

- Objective
  - To replace failed sensors with redundant mobile ones through autonomous node movement.
- Evaluation criteria
  - # of message, storage load, total moving distance and # of moves.

Two tasks

Replacement discovery
- Finding a redundant sensor for node replacement

Node relocation
- Moving the discovered redundant sensor to the position of a failed one

Discovering replacement

Flooding-based [example] $M = O(n'n)$
- WCP [Wang, Cao, and Porta; 2004]

Quorum-based [example] $M = O(n'\sqrt{n})$
- WCPZ [Wang, Cao, Porta, and Zhang; 2005]
- ZONER [Li and Santoro; 2006]

Quorum formation requires cross network communication and generates inconstant per node storage load

Relocating replacement

– Direct relocation (move directly on straight line)
- WCP [Wang, Cao, and Porta; 2004]

– Shifted relocation [example]
- WCPZ [Wang, Cao, Porta, and Zhang; 2005]
- ZONER [Li and Santoro; 2006]

WCPZ relies on flooding for relocation path discovery, and ZONER uses inefficient relocation path

A Mesh-based Sensor Relocation Protocol

- A localized position based algorithm generating constant per node storage load.
- Requires no pre-knowledge of the sensor field.
- Uses near optimal relocation delay and balanced energy consumption.
- Guarantees nearby node replacement with very high probability, larger than 96%.

MSRP: Replacement Discovery

- The information of redundant nodes is distributed in a localized planar structure, ***information mesh***.
- Replacement search is done by a ***cross lookup***, restricted within a mesh cell or the aggregation of several mesh cells.

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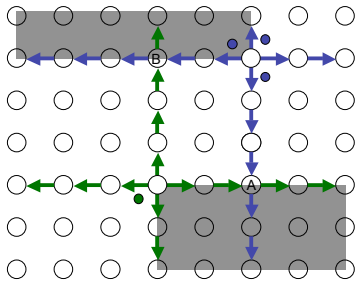
Information Mesh Construction



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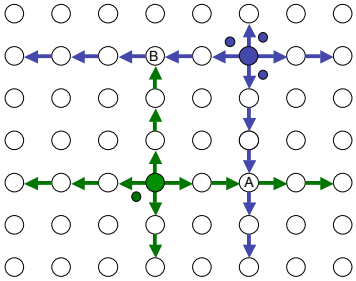
Adding blocking rule



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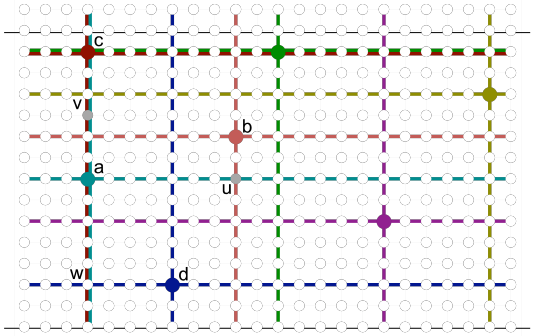
A Complete Mesh



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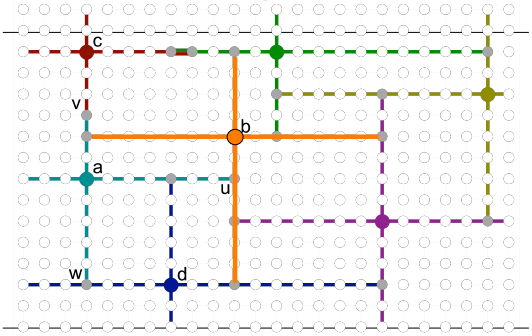
The Corresponding Information Mesh



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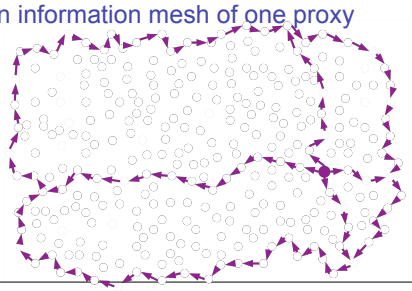
Information Mesh in Arbitrary Networks

- An information mesh of one proxy



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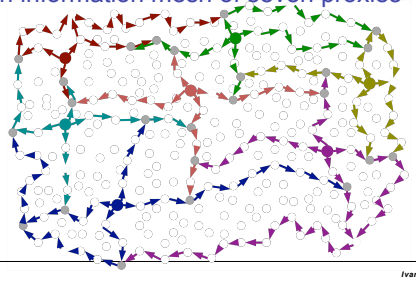
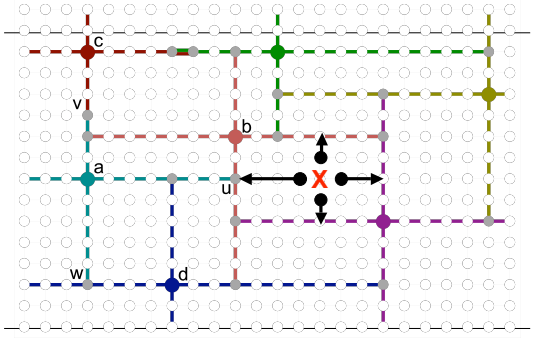
Information Mesh in Arbitrary Networks

- An information mesh of seven proxies

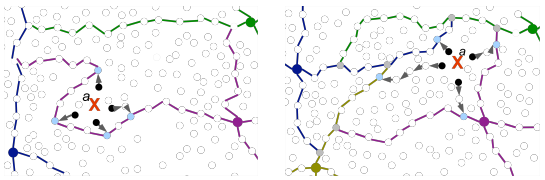


Cross Lookup



Cross Lookup in Arbitrary Network

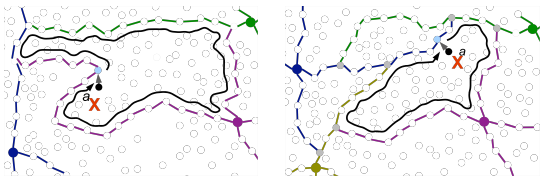
- Cross lookup failures



Curly-edge Irregular-shape

An Alternate Lookup method

- Perimeter lookup

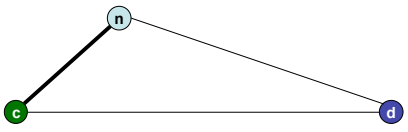


Curly-edge Irregular-shape

MSRP: Replacement Relocation

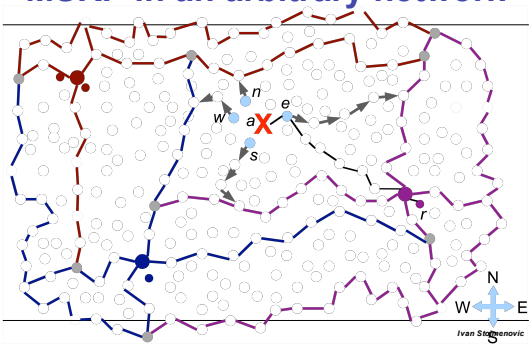
- Shifted relocation
  - A novel relocation path discovery method
    - A combination of the Greedy-Face-Greedy routing [Bose, Morin, Stojmenovic, and Urrutia; 1999] and the concept of COST over PROGRESS ratio [Stojmenovic; 2006]
    - Cost of a relocation path is proportional to its length

COST over Progress Ratio



$$f(n) = \frac{|cn|}{|cd| - |nd|}$$

MSRP in an arbitrary network



Future Work

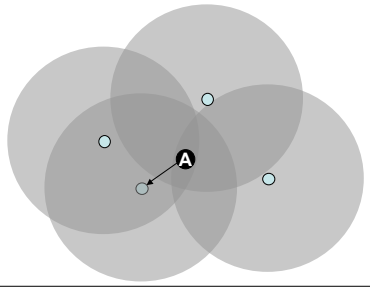
- Finding closer replacement node in the worst and average case
- by allowing backward information propagation at blocking points (submitted)
- Voronoi diagram type of meshes ?
- Triangular or hexagonal meshes ?

References

1. G. Wang, G. Cao, and T. L. Porta. “Proxy-Based Sensor Deployment for Mobile Sensor Networks”. In *Proc. of IEEE MASS*, pp. 493-502, 2004.
2. G. Wang, G. Cao, T. L. Porta, and W. Zhang. “Sensor Relocation in Mobile Sensor Networks”. In *Proc. of IEEE INFOCOM*, pp. 2302-2312, 2005.
3. X. Li and N. Santoro. “ZONER: A ZONE-based Sensor Relocation Protocol for Mobile Sensor Networks”. In *Proc. of IEEE LCN/WLN*, pp. 923-930, 2006.

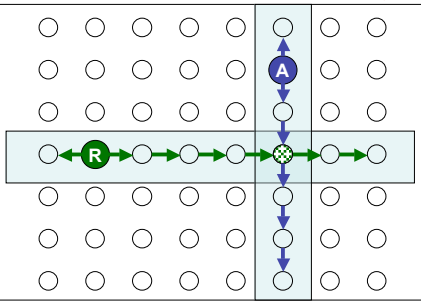
Flooding-based node discovery

[WCP]



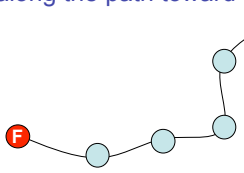
Quorum concept

[Stojmenovic;1999]



Shifted node relocation

- Find a path from replacement to the failed node and shift the position of the nodes along the path toward the failed node.



Location service for sensor and actuator networks

Ivan Stojmenovic

Problem statements

- Single actor/actuator/mobile sink moves in sensor networks
- Sensors are static
- Tradeoff between frequent reporting position and overhead for routing toward latest known position of actor (this problem elaborated here)
- Variant: several actors, each may report to neighboring sensors only, coordination among actors (ongoing research, see also **relocation** for some ideas)

Location service - how and when ?

- Updates proportional to mobility ? Moving in a small circle?

Update only when links change

- Send update only to designated region or periodic flooding ?
- Message speed >> node speed → apply routing for static networks toward last known sink location
- Otherwise flooding to route

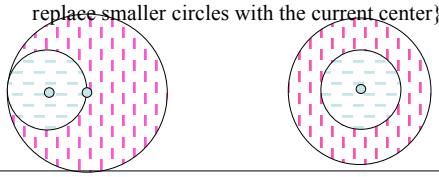
Doubling circles update

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

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

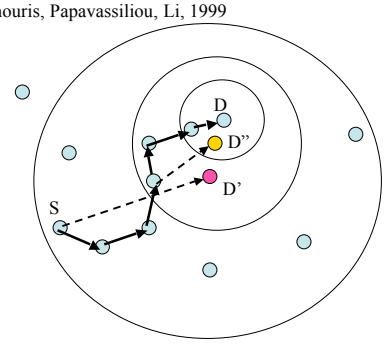
whenever node exits circle of size *t* centered at previous update of same size **do**

send location update to all nodes inside circle of size 2t centered at current position and replace smaller circles with the current center}



Doubling circles routing

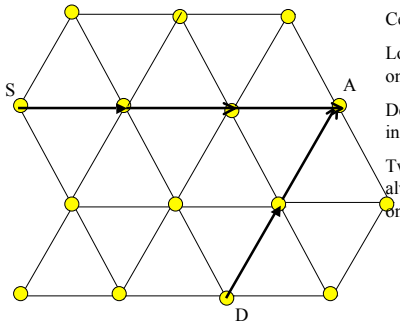
Amouris, Papavassiliou, Li, 1999



Dynamic update

- **Dead-reckoning** for mobile phones, *Wolfson, Sistla '99:*
- Report position, speed and direction of movement
- Use last known position, updated by reported movement, for sink position estimates
- Stojmenovic, Russell, Vukojevic 2000 for ad hoc networks

Quorum based location management

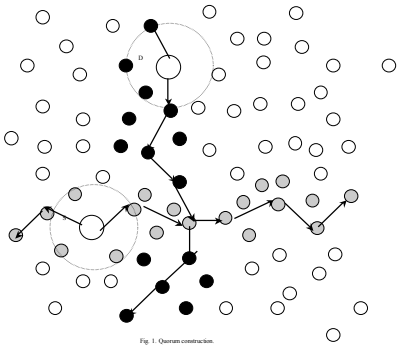


Cellular network:

Location update in one direction

Destination search in other direction

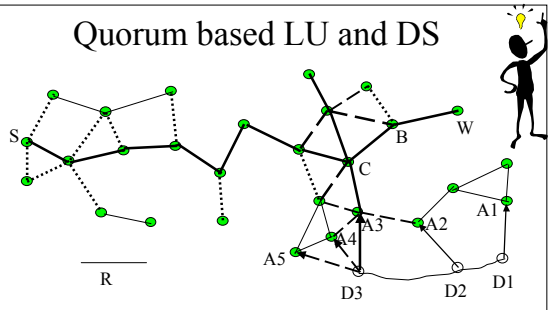
Two directions always intersect in one base station



Stojmenovic TR 1999

Liu, Stojmenovic, Jia MASS 2006

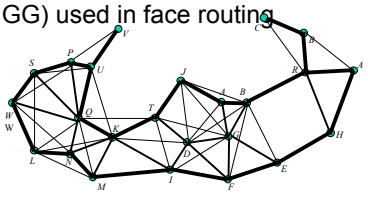
Quorum based LU and DS



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

Quorum based LU continued

- Rows and columns can have guaranteed intersection by applying face routing
- Location updates and destination search can 'meet' at the perimeter of planar graph (e.g. GG) used in face routing



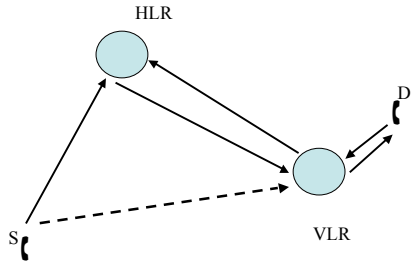
Quorum - history

- Ivan Stojmenovic, A routing strategy and quorum based location update scheme for ad hoc wireless networks, SITE, University of Ottawa, TR-99-09, September 1999.
- Duplications (no citation):
- J. B. Tchakarov and N.H. Vaidya, Efficient **content location** in mobile ad hoc networks, IEEE Int. Conf. on Mobile Data Management MDM, 2004.
- I. Aydin and C.C. Shen, Facilitating **match making service** in ad hoc and sensor networks using pseudo quorum, 11th IEEE Int. Conf. Comp. Comm. Networks ICCCN, October 2002.
- Application and generalization (with citation):
- D. Niculescu and B. Nath, **Trajectory based forwarding** and its applications, Proc. ACM MOBICOM, San Diego, CA, Sept. 2003, 260-272.

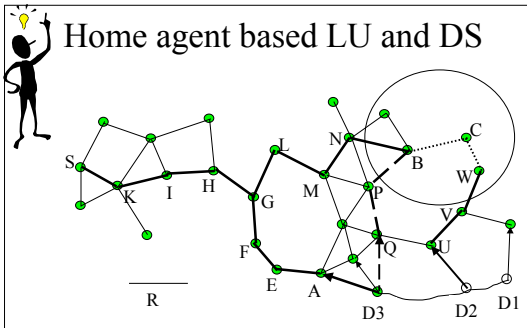
Trajectory based forwarding

- Niculescu, Nath Mobicom 2003
- Generalizing line update/search in quorum LU
- possible destinations (servers S) advertise their position along arbitrary lines
- = routing with destination at infinity in given direction
- clients C will replace their flooding phase with a query along another arbitrary line which will eventually intersect the desired destination's line
- The intersection node then notifies the client about the angle correction needed to contact the server directly.

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

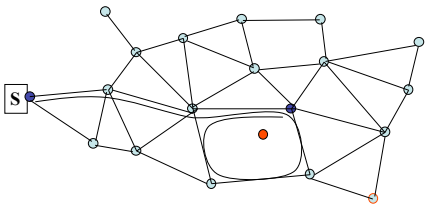
- ***Stojmenovic, TR September 1999***
- Woo and Singh, TR March 2000, Oregon State University; **Wireless Networks**, 7, 5, September 2001, 513-529.
- Blazevic, Buttyan, Capkun, Giordano, Hubaux and Le Boudec, TR, Swiss, Lausanne, December 2000;
  IEEE Communication Magazine, June 2001.
- Morris, Jannotti, 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.

Quorum vs Home Agent

- If sensors also mobile then what if they all
- Move together ? Quorum OK but Home Agent fails
- Sensors can be static but several mobile sinks may keep routes between them
- Sink may be nearby but both methods may involve long searches, resolution?
- Hierachical Home agent is like 'doubling circle' with area flooding replaced by hashing to a location
- Hierarchical quorum (Stojmenovic et all, in progress)

Data centric storage

- Ratnasamy, Estrin, Govindan, Karp, Shenker, Yin Yu 2002
- Geographic hash table
- Route data toward 'home' decided by hash table and store there;
- 'home'= nearest sensor on the face containing hashed location
- Find data by hashing and GFG routing toward storage location



Storing or retrieving