Robust Geographic Routing and Location-based Services

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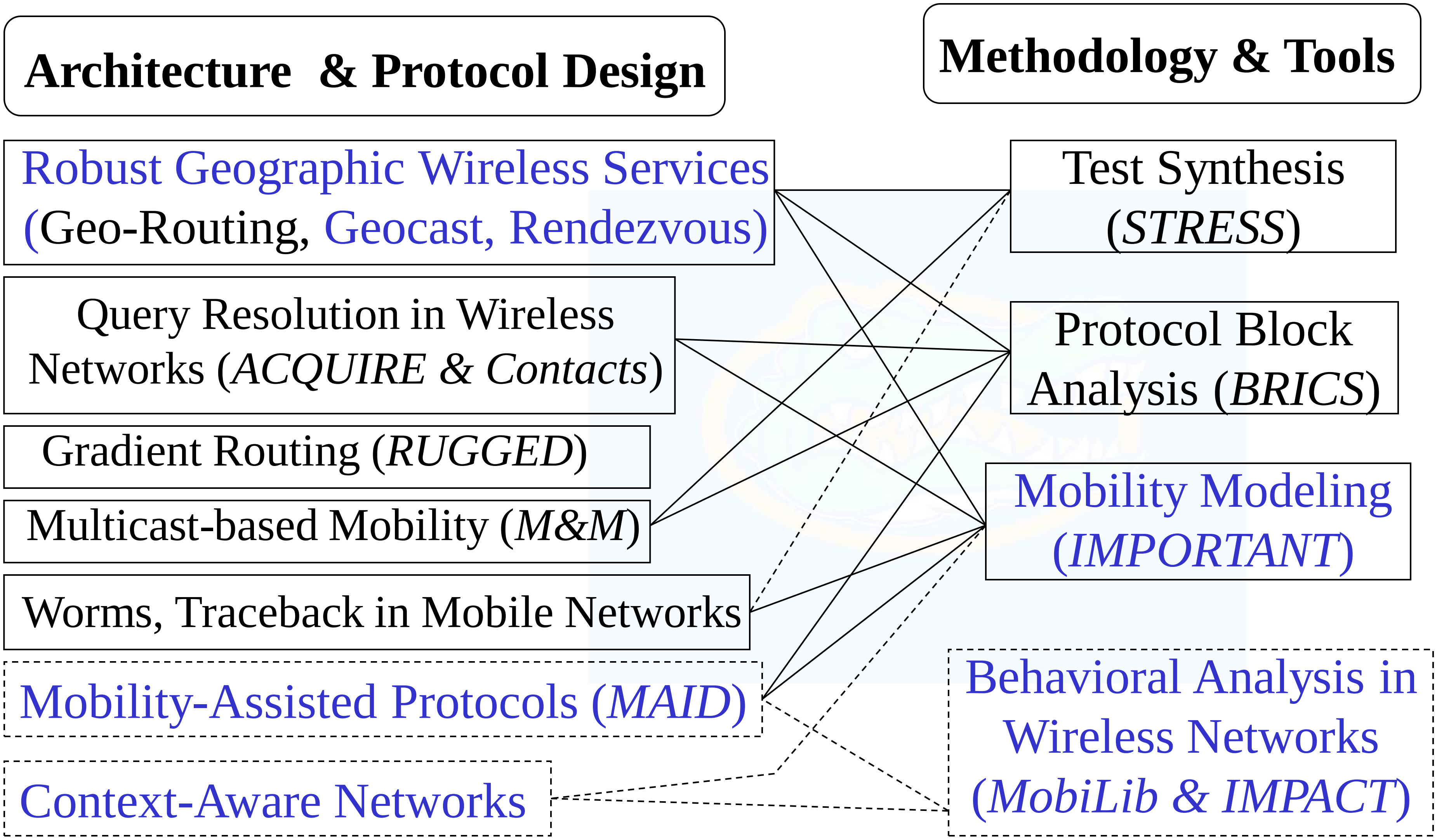
Birds-Eye View: Research in the Wireless Networks Lab at UFL



Outline

- Geographic Services in Wireless Networks
  - Robust Geographic Routing
  - Robut Geocast
  - Geographic Rendezvous for Mobile Peer-to-Peer Networks (***R2D2***)

Robust Geographic Routing

- Geographic routing has been proven correct and efficient under assumptions of:
  - (I) *Accurate* node locations
  - (II) Unit disk graph radio model (Ideal/reliable links)
- In practice
  - Node locations are obtained with a margin of error
  - Wireless links are highly variable and usually unreliable
- So …
  - How would geographic routing perform if these assumptions are relaxed?

On the Effect of Localization Errors on Geographic Face Routing in Sensor Networks

Karim Seada, Ahmed Helmy, Ramesh Govindan

Problem Statement and Approach

Q: How is geographic routing affected by location inaccuracy?

Approach:

- Perform location sensitivity analysis: perturb node locations and analyze protocol behavior
- Conduct:
  - Correctness Analysis (using micro-level stress analysis)
  - Performance Analysis (using systematic simulations, experiments)

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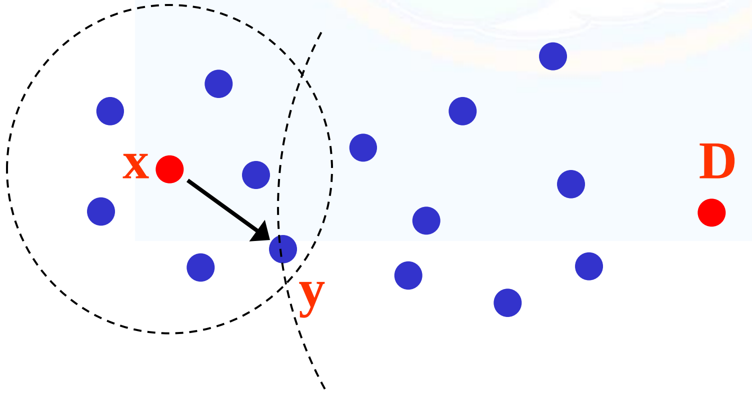
* K. Seada, A. Helmy, R. Govindan, "On the Effect of Localization Errors on Geographic Face Routing in Sensor Networks", *The Third IEEE/ACM International Symposium on Information Processing in Sensor Networks (**IPSN**)*, April 2004.

Basics of Geographic Routing

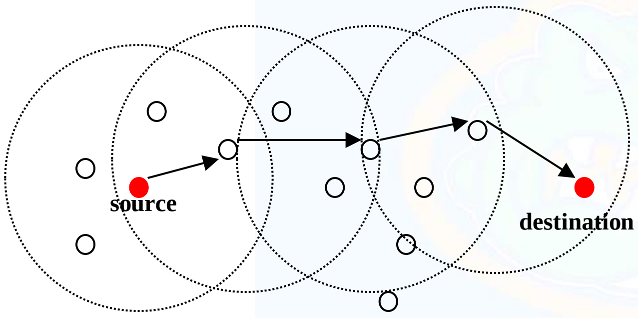
- A node knows its own location, the locations of its neighbors, and the destination's location (*D*)
- The destination's location is included in the packet header
- Forwarding decision is based on local distance information
- *Greedy Forwarding*: achieve max progress towards *D*



Greedy Forwarding

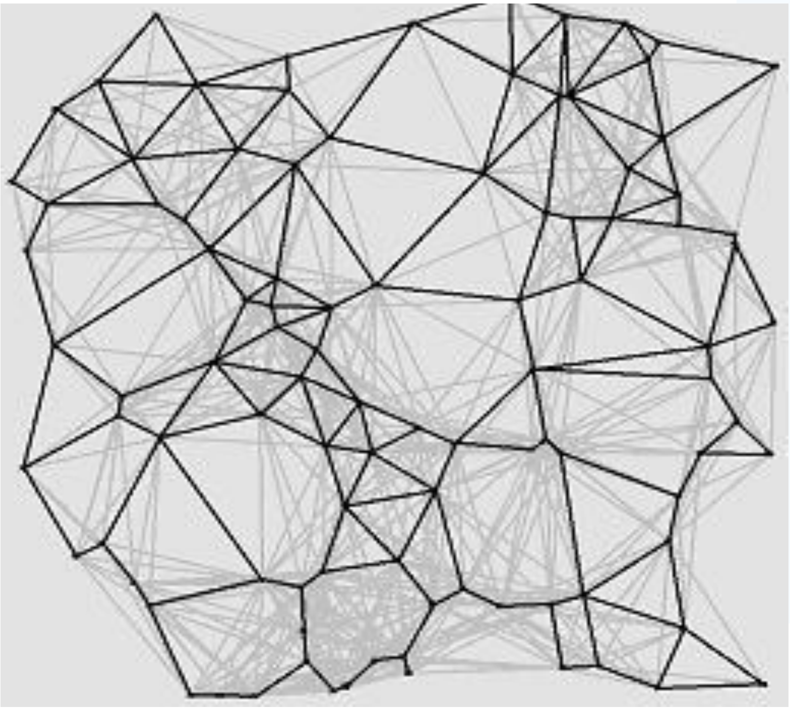
Geographic Routing

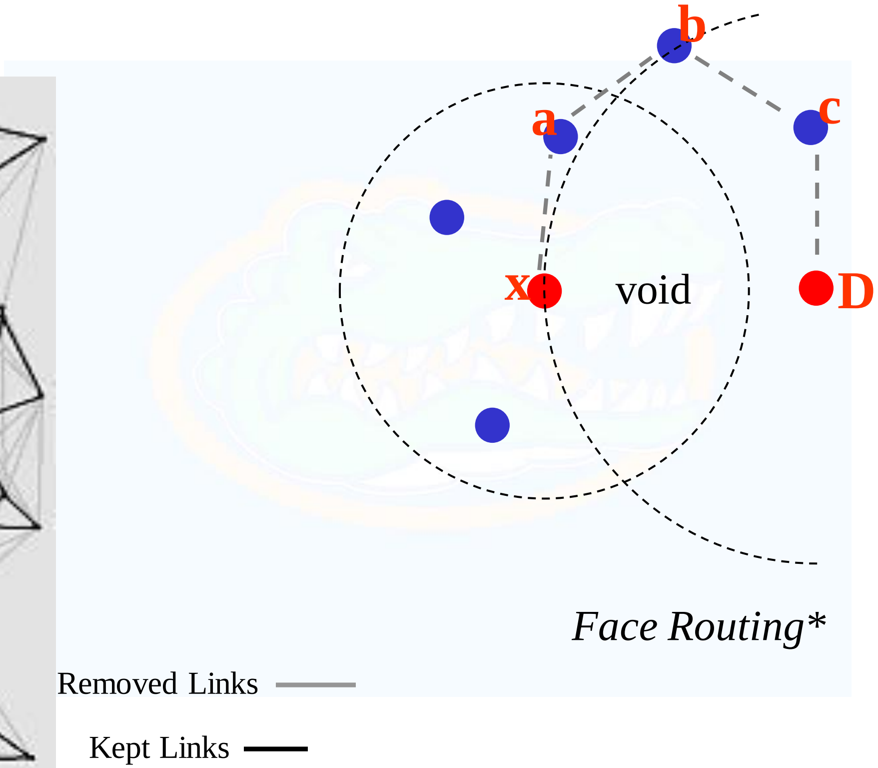
- **(I) Greedy forwarding**
  - **Next hop is the neighbor that gets the packet closest to destination**



  - **Greedy forwarding fails when reaching a 'dead end' (or void, or local minima)**

- **(II) Dead-end Resolution (Local Minima)**
  - **Getting around voids using *face routing* in planar graphs**
  - **Need a *planarization* algorithm**


Planarized Wireless Network



* P. Bose, P. Morin, I. Stojmenovic, and J. Urrutia. “Routing with Guaranteed Delivery in Ad Hoc Wireless Networks”. *DialM Workshop,* 99.

* **GPSR**: Karp, B. and Kung, H.T., Greedy Perimeter Stateless Routing for Wireless Networks, *ACM MobiCom*, , pp. 243-254, August, 2000.

On the Effect of Localization Errors on Geographic Routing in Sensor Networks*

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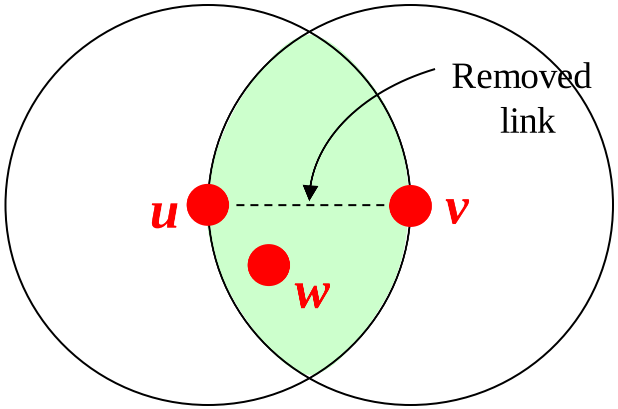
Evaluation Framework

I. Micro-level algorithmic *Stress* analysis
  - Decompose geographic routing into components
    - planarization algorithm, face routing, greedy forwarding
  - Start from algorithm and construct *complete* conditions and bounds for ‘possible’ errors
  - Classify errors and understand cause to aid fix

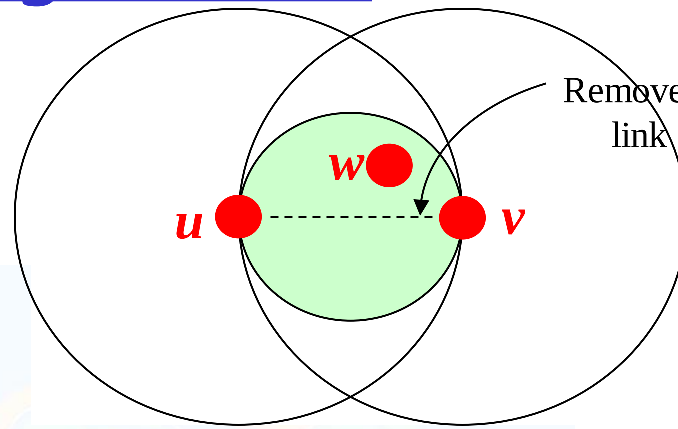
II. Systematic Simulations
  - Analyze performance and map degradation to errors
  - Estimate most ‘probable’ errors and design fixes
  - Re-simulate to evaluate efficacy of fixes

Planarization Algorithms




```
For each node u, where N is a list
of the neighbors of u:
 for all v ∈ N
  for all w ∈ N
   if w == v then continue
   else if d(u,v)>max[d(u,w),d(w,v)]
        remove edge (u,v)
```

*Relative Neighborhood Graph (**RNG**)*

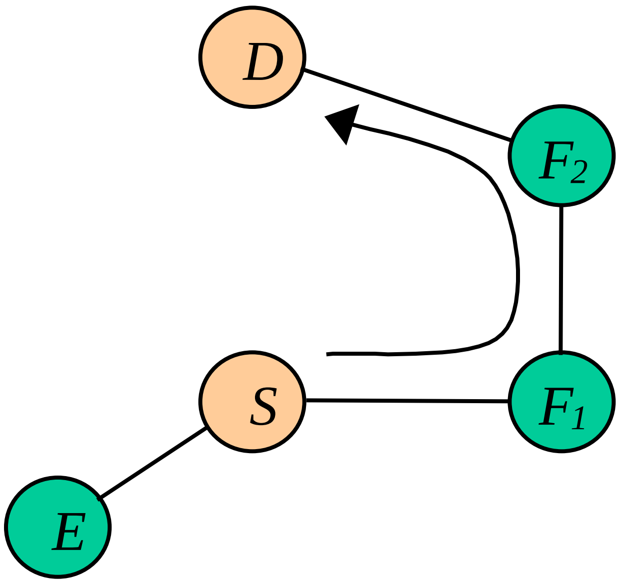



```
For each node u, where N is a list
of the neighbors of u:
 for all v ∈ N
  for all w ∈ N
   if w == v then continue
   else if d(c,w)<d(c,u) {where c
   is the midpoint of edge (u,v)}
        remove edge (u,v)
```

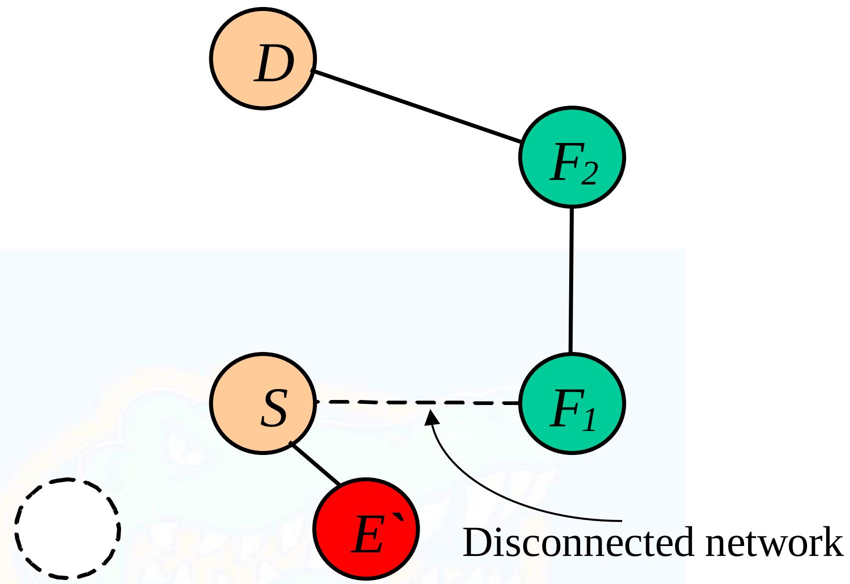
*Gabriel Graph (**GG**)*

A node *u* removes the link *u-v* from the planar graph, if node *w* (called a witness) exists in the shaded region

Mirco-level Algorithmic Errors



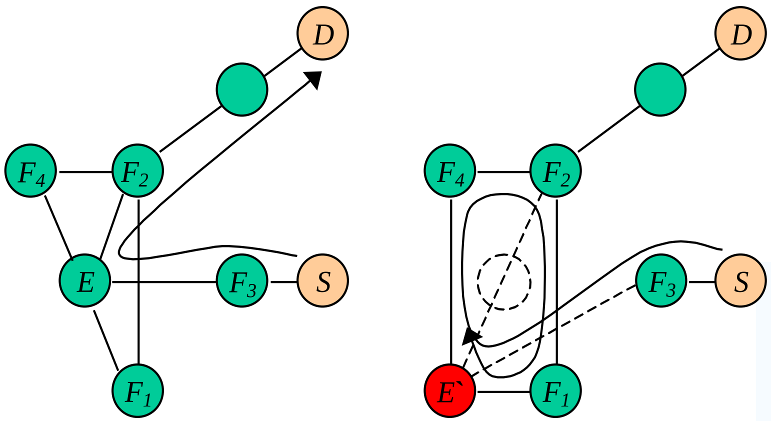
(a) Accurate Locations



(b) Inaccurate Location for ***E***

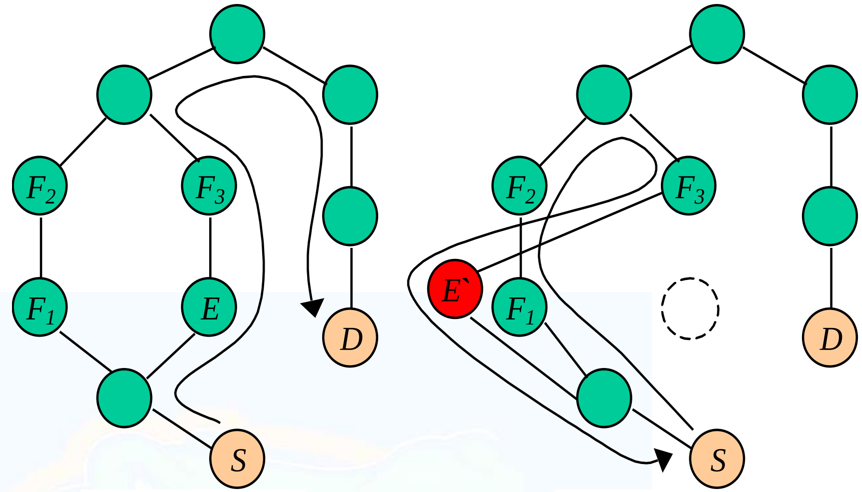
Excessive edge removal leading to network disconnection

- **In *RNG* an error will happen when**
  - decision{*d*(*u*,*v*)>*max*[*d*(*u*,*w*),*d*(*w*,*v*)]}≠ decision{*d*(*u*`,*v*`)>*max*[*d*(*u*`,*w*`),*d*(*w*`,*v*`)]}
- **While in *GG* error will happen when**
  - decision{*d*(*c*,*w*) < *d*(*c*,*u*)} ≠ decision{*d*(*c*`,*w*`) < *d*(*c*`,*u*`)}



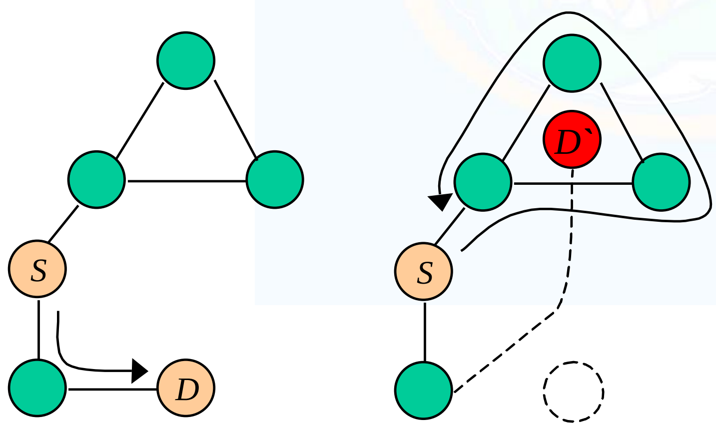
(a) Accurate (b) Estimated

Permanent loop due to insufficient edge removal



(a) Accurate (b) Estimated

Cross links causing face routing failure



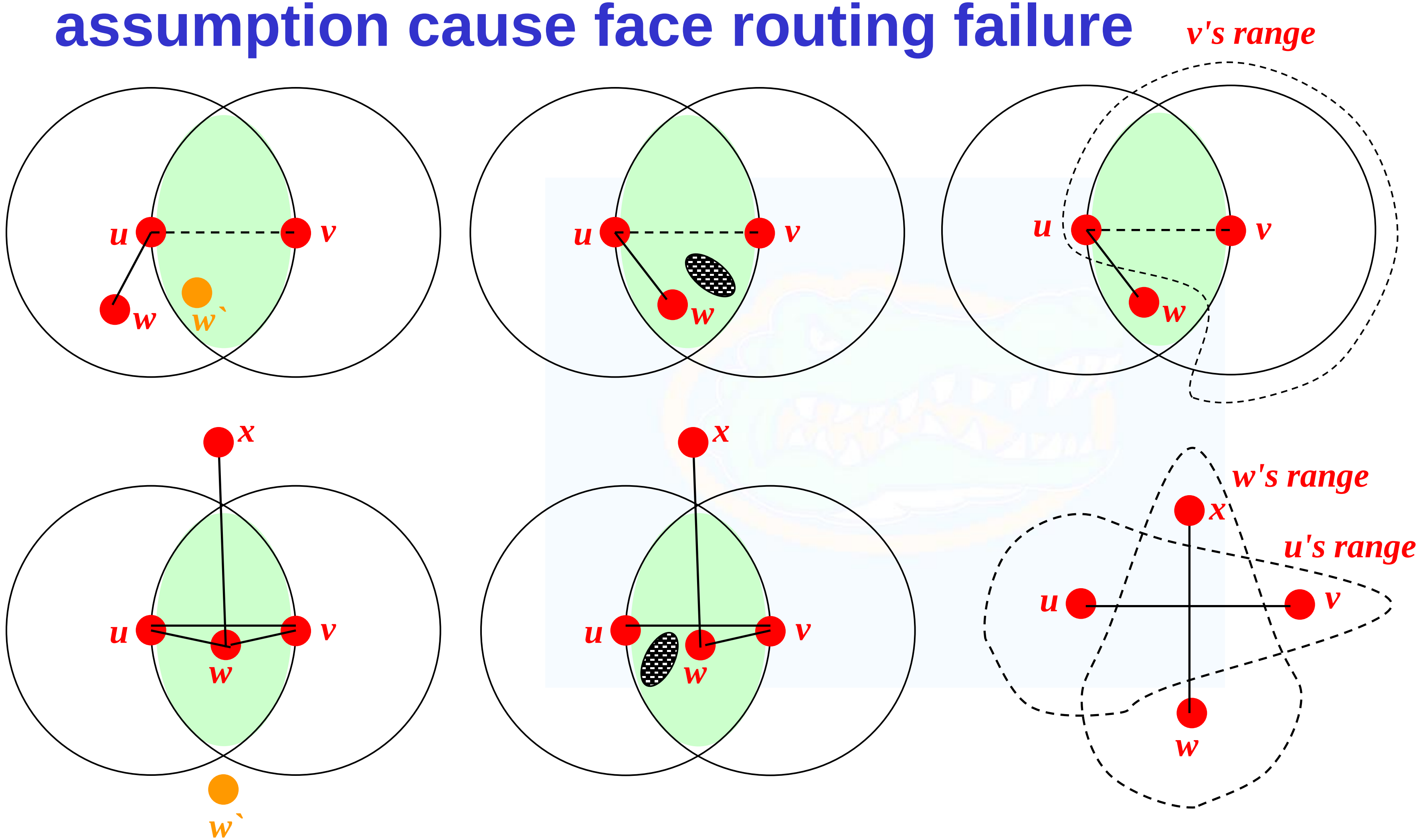
(a) Accurate (b) Estimated

Inaccuracy in destination location leading to looping and delivery failure

- **Conditions that violate the unit-graph assumption cause face routing failure**

Disconnections

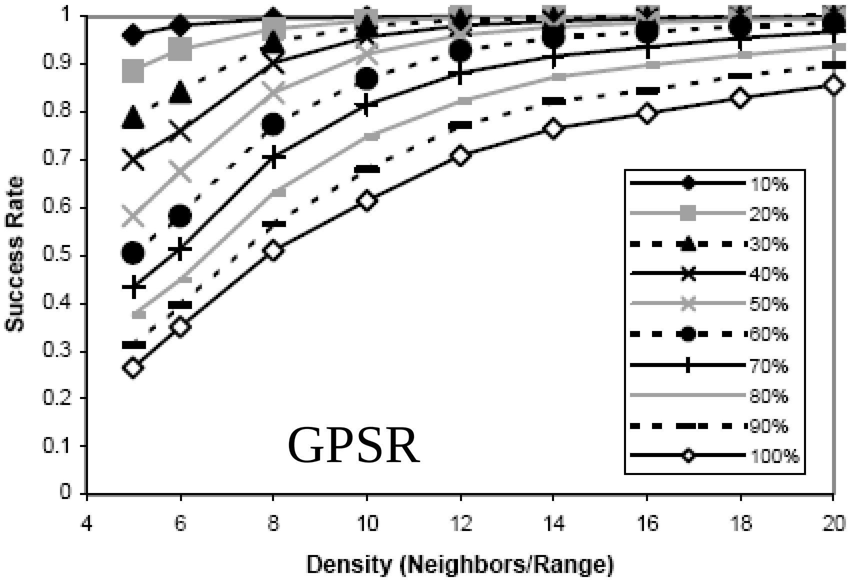
Cross-Links



Inaccurate Location Estimation **Obstacles** **Irregular Radio Range**

Systematic Simulations

- **Location error model: uniformly distributed error**
  - Initially set to 1-10% of the radio range (*R*)
  - For validation set to 10-100% of *R*
- **Simulation setup**
  - 1000 nodes distributed uniformly, clustered & with obstacles
  - Connected networks of various densities
- **Evaluation Metric**
  - Success rate: fraction of number of reachable routes between all pairs of nodes
- **Protocols : GPSR and GHT**



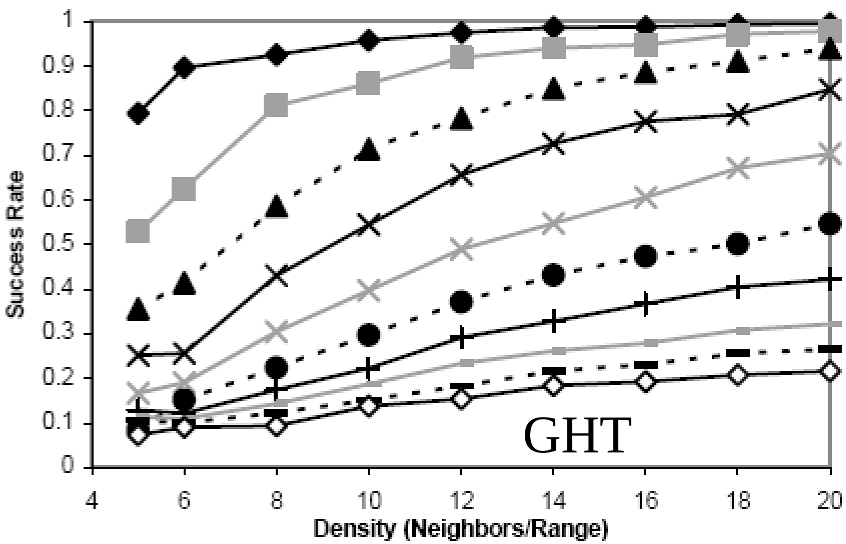
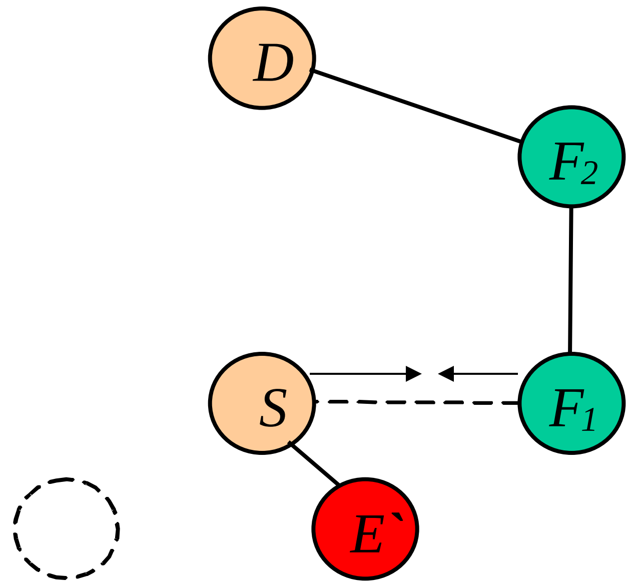


Figure 16: The success rate of GHT at high inaccuracy ranges (% of radio range) *without* the fix

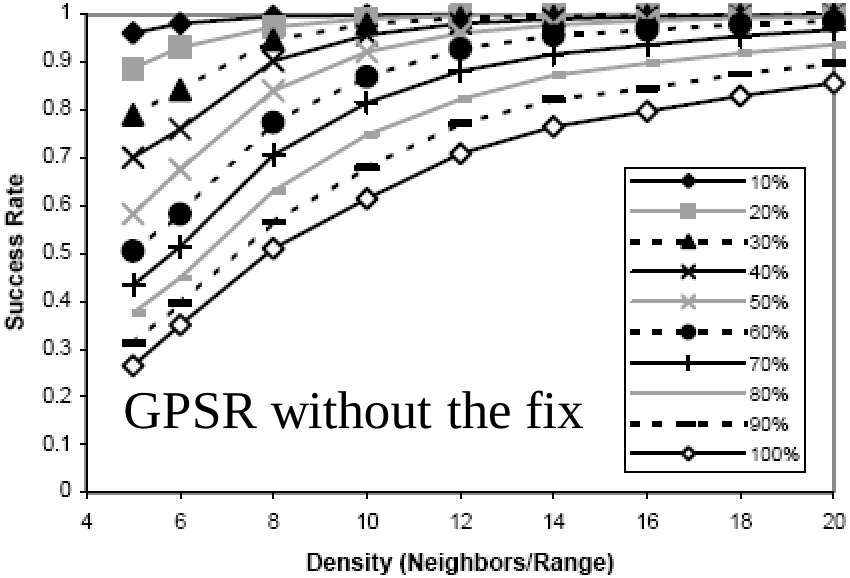


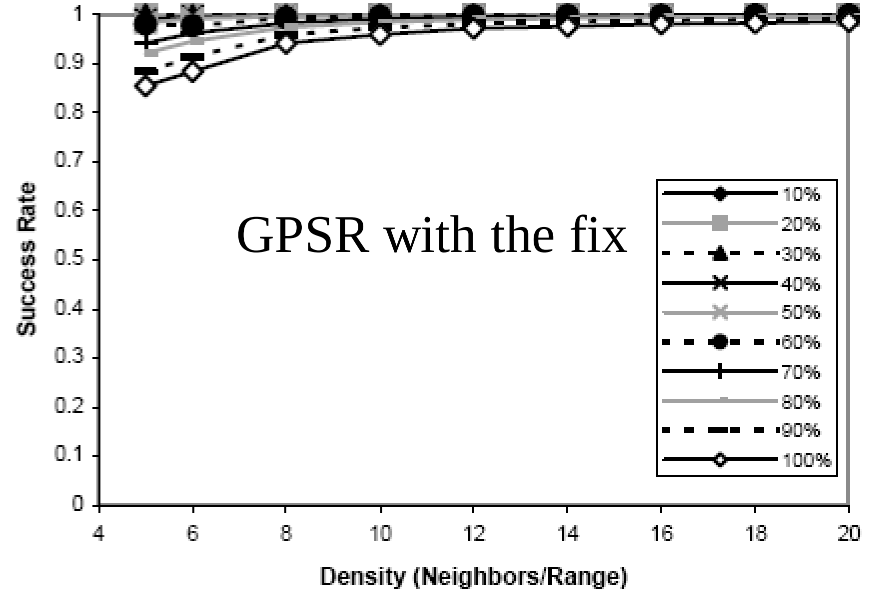
Most Probable Error
(Network Disconnection)

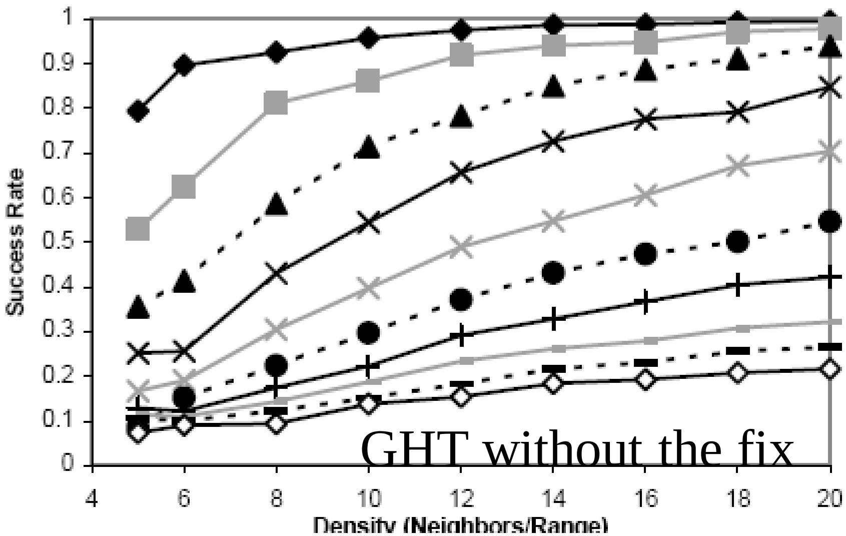
Mutual Witness Mechanism

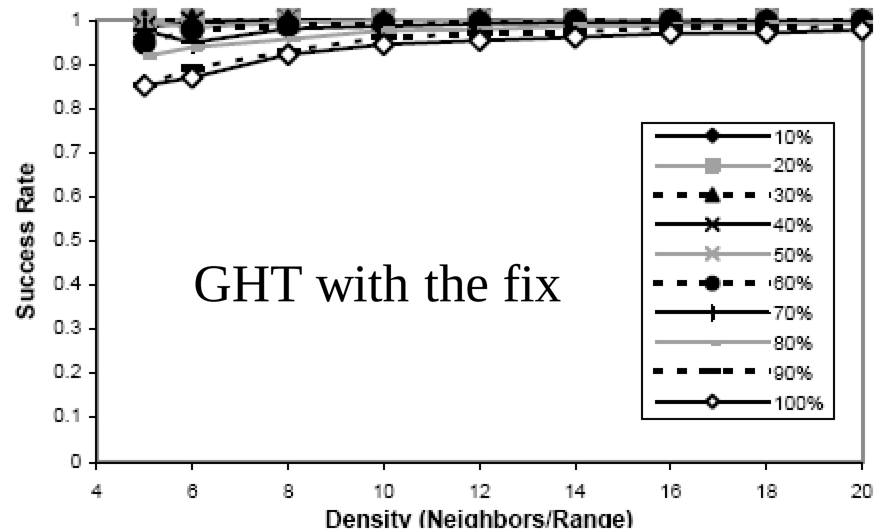
–These are *correctness* errors leading to *persistent* routing failures. Even small percentage of these errors are Unacceptable in *static stable* networks

Before **_After_**









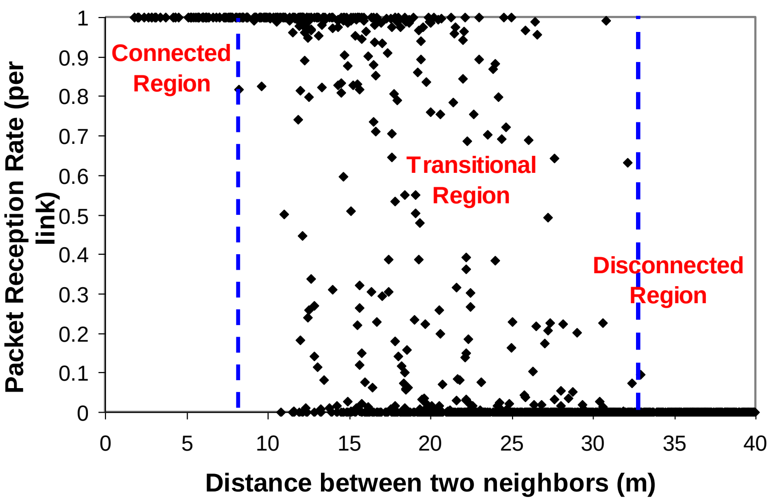
The *mutual witness* fix achieves near-perfect delivery even in the face of large location inaccuracies.

Geographic Routing with Lossy Links*

Karim Seada, Marco Zuniga, Ahmed Helmy, Bhaskar Krishnamachari

- Geographic routing employs max-distance greedy forwarding
- Unit graph model unrealistic
- Greedy routing chooses ***weak links*** to forward packets

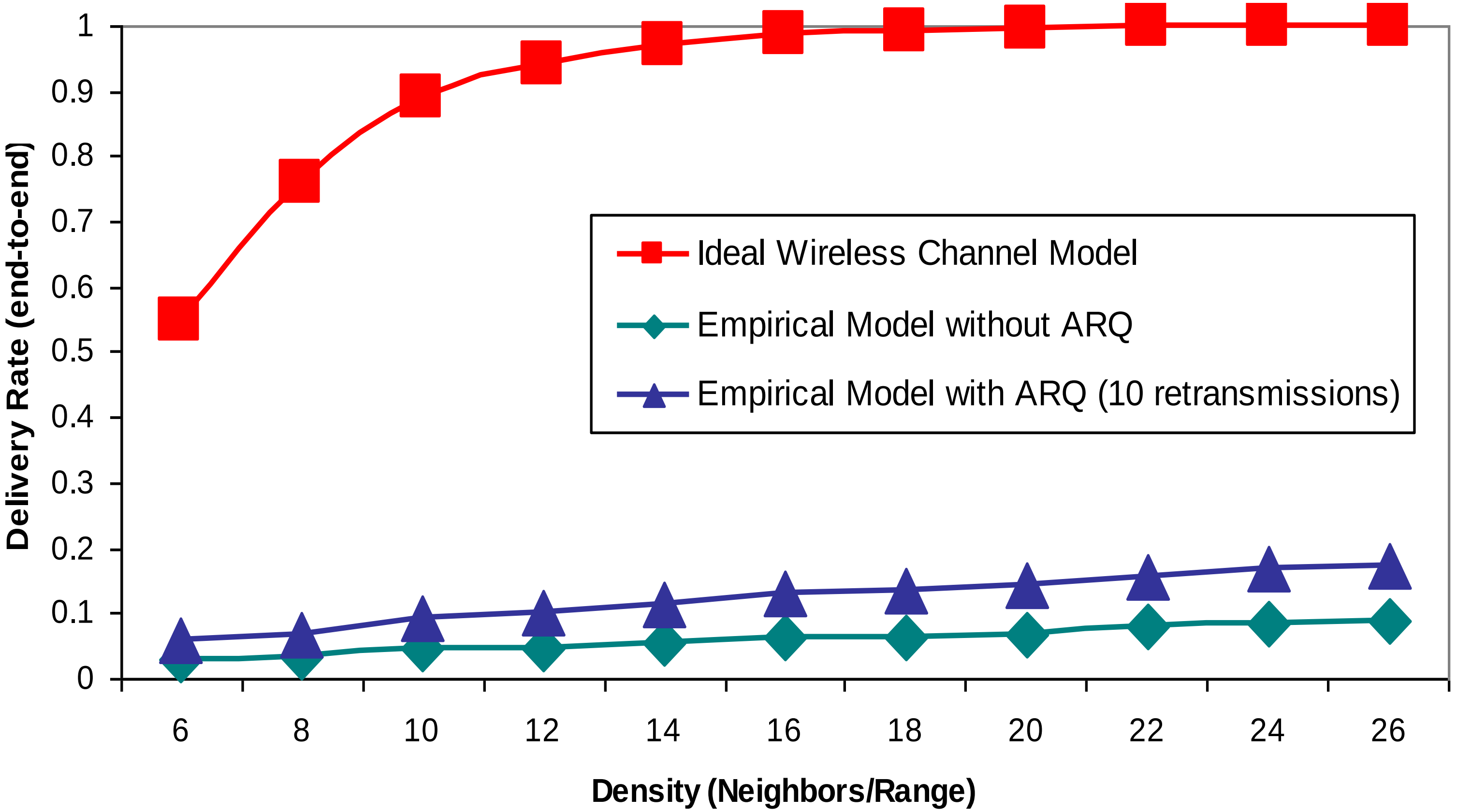
Wireless Loss Model



$$PRR(d) = \left(1 - \frac{1}{2}\exp^{\frac{-\gamma(d)}{2}\frac{1}{0.64}}\right)^{\rho 8 f}$$

* K. Seada, M. Zuniga, A. Helmy, B. Krishnamachari, "Energy-Efficient Forwarding Strategies for Geographic Routing in Lossy Wireless Sensor Networks", *The Second ACM Conference on Embedded Networked Sensor Systems (**SenSys**)*, pp. 108-121, November 2004.

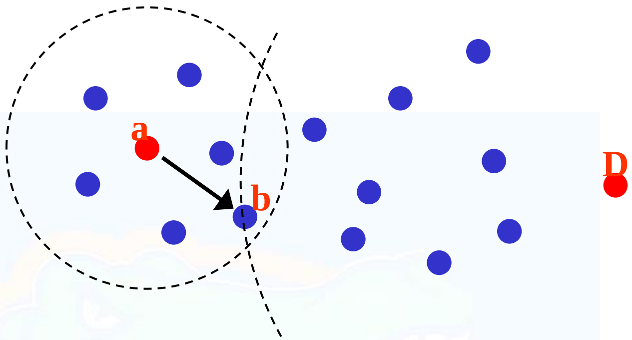
Greedy Forwarding Performance

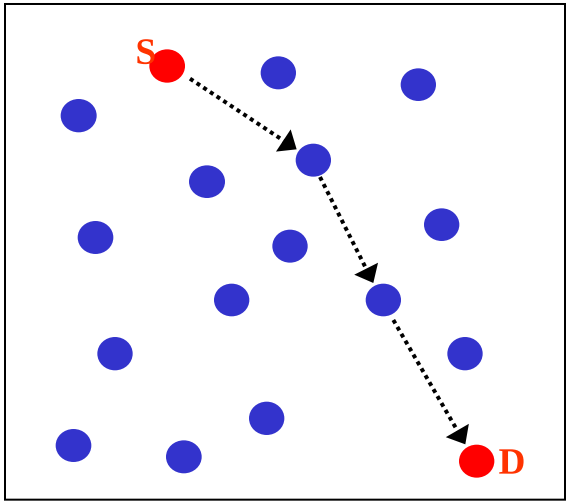


Greedy forwarding with ideal links vs. empirical link loss model

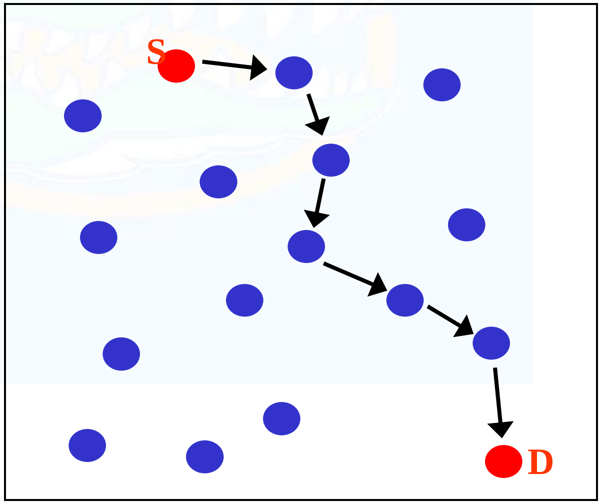
Distance-Hop Energy Tradeoff

- **Geographic routing protocols commonly employ maximum-distance greedy forwarding**
- **Weakest link problem**





Few long links with low quality



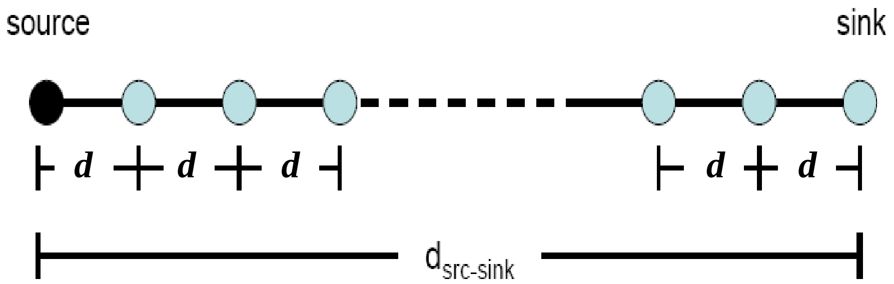
Many short links with high quality

Analysis of Energy Efficiency

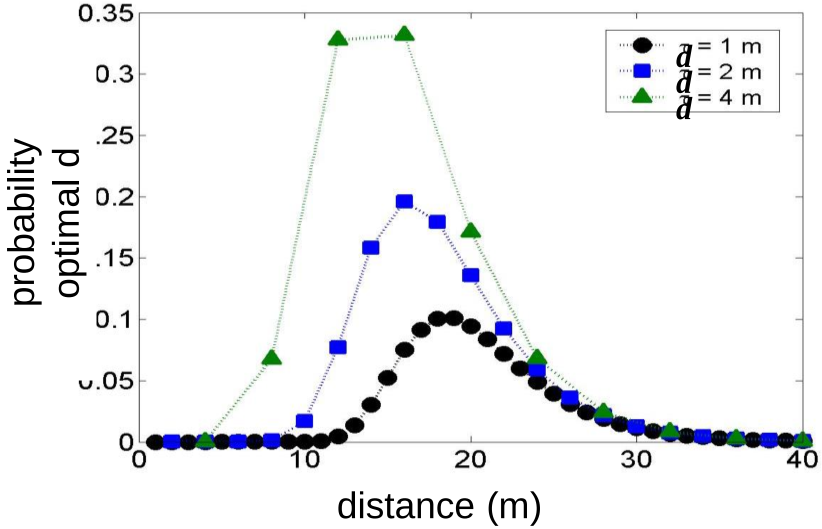
No. Tx = No. hops * Tx per hop

$$= d_{src\text{-}snk}/d * 1/PRR(d)$$

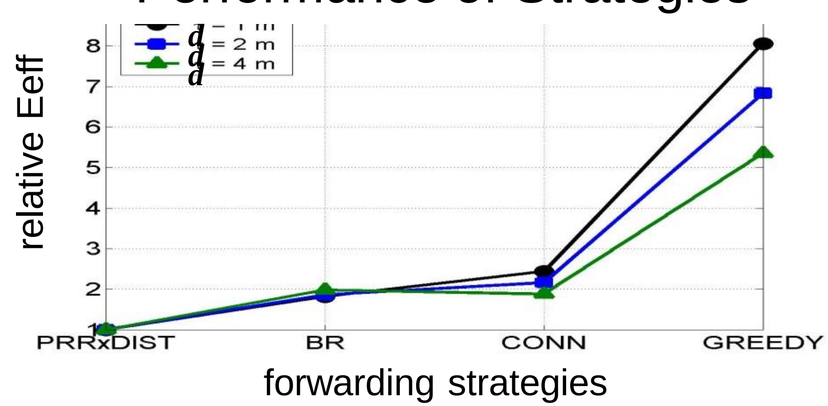
$$Eeff = \frac{PRR(d)\,d}{k\,d_{src-snk}}$$



Optimal Distance (*pmf*)



Performance of Strategies

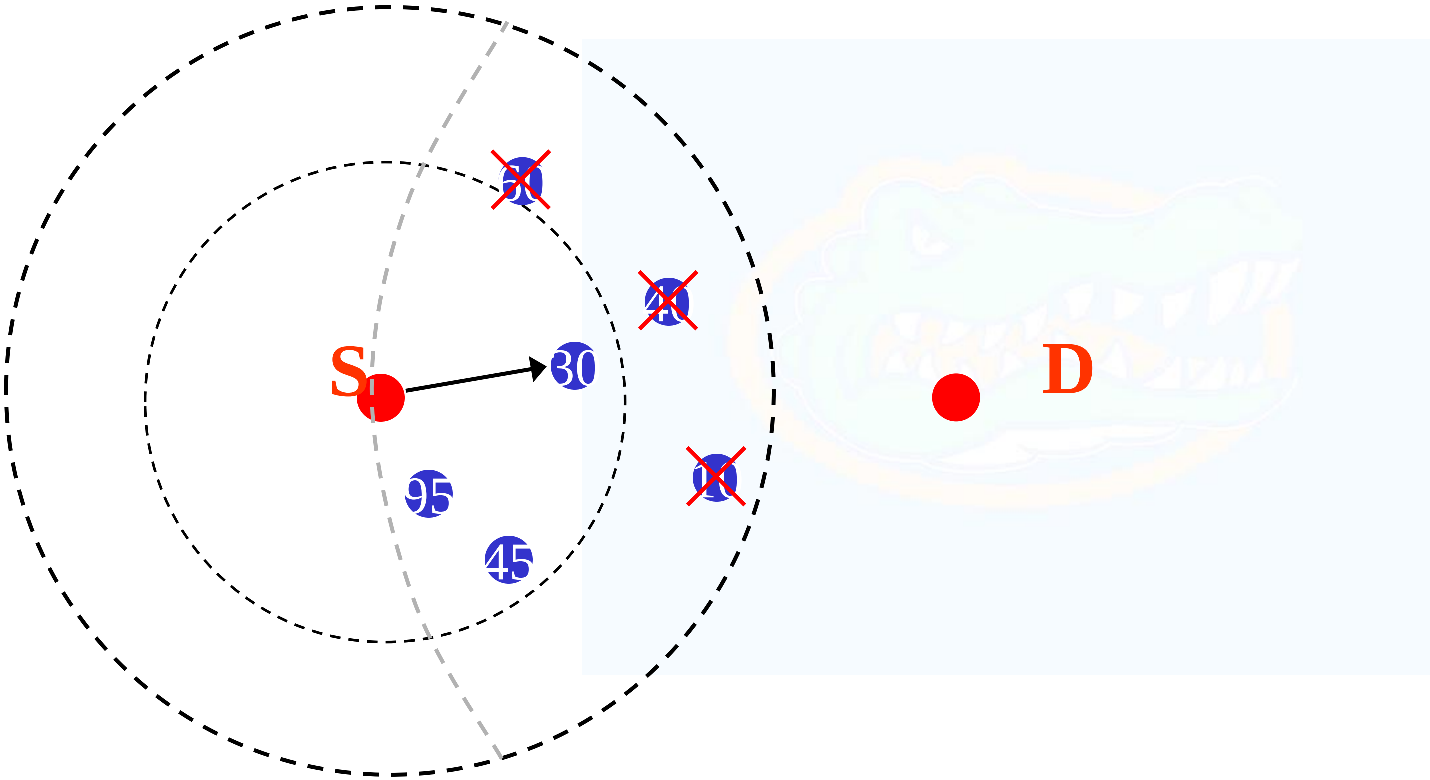


- Optimal forwarding distance lies in the transitional region
- *PRR* x *d* performs at least 100% better than other strategies

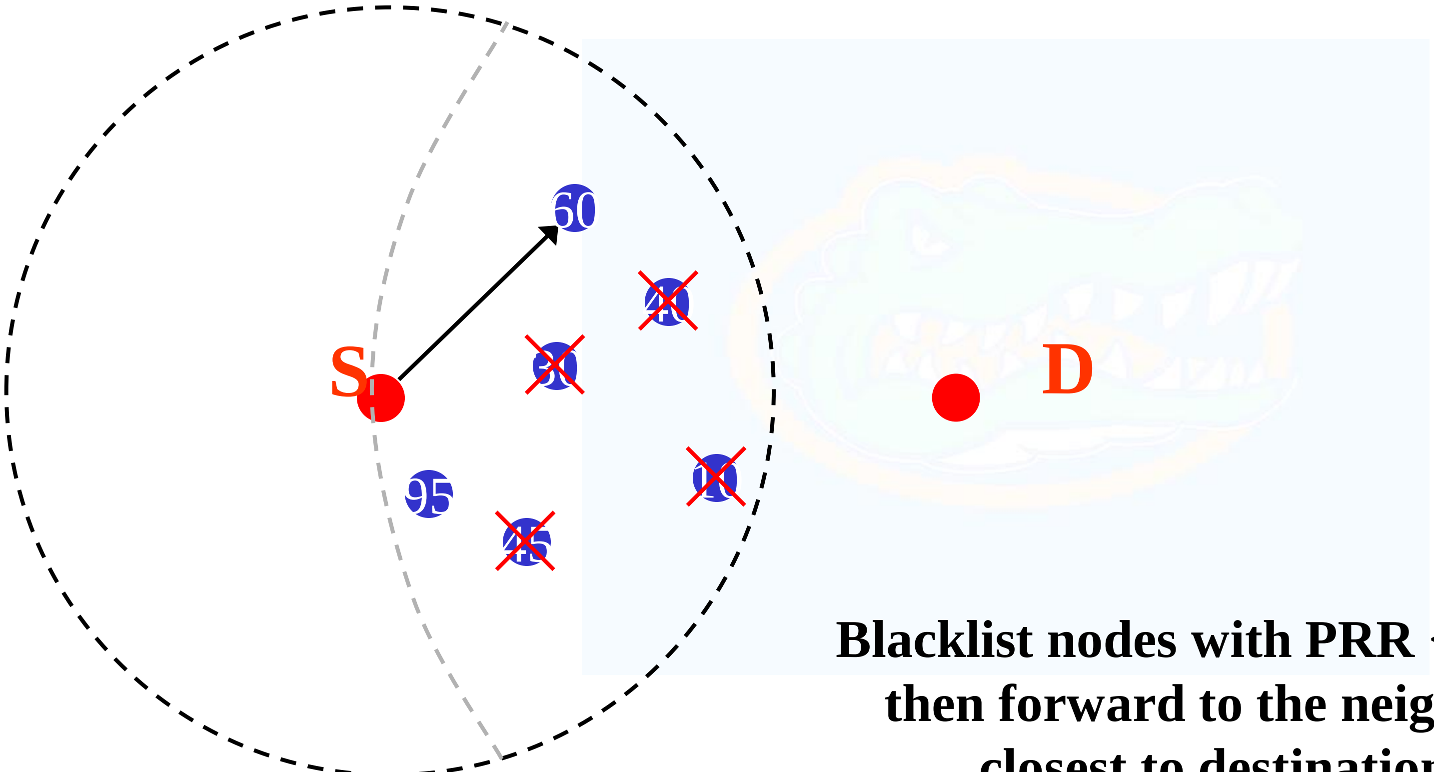
Geographic Forwarding Strategies

- **Distance-based**
  - **Original Greedy**
  - **Distance-based Blacklisting**
- **Reception-based**
  - **Absolute Reception-based Blacklisting**
  - **Relative Reception-based Blacklisting**
  - **Best Reception**
- **Hybrid**
  - **PRR*Distance**

Distance-based Blacklisting

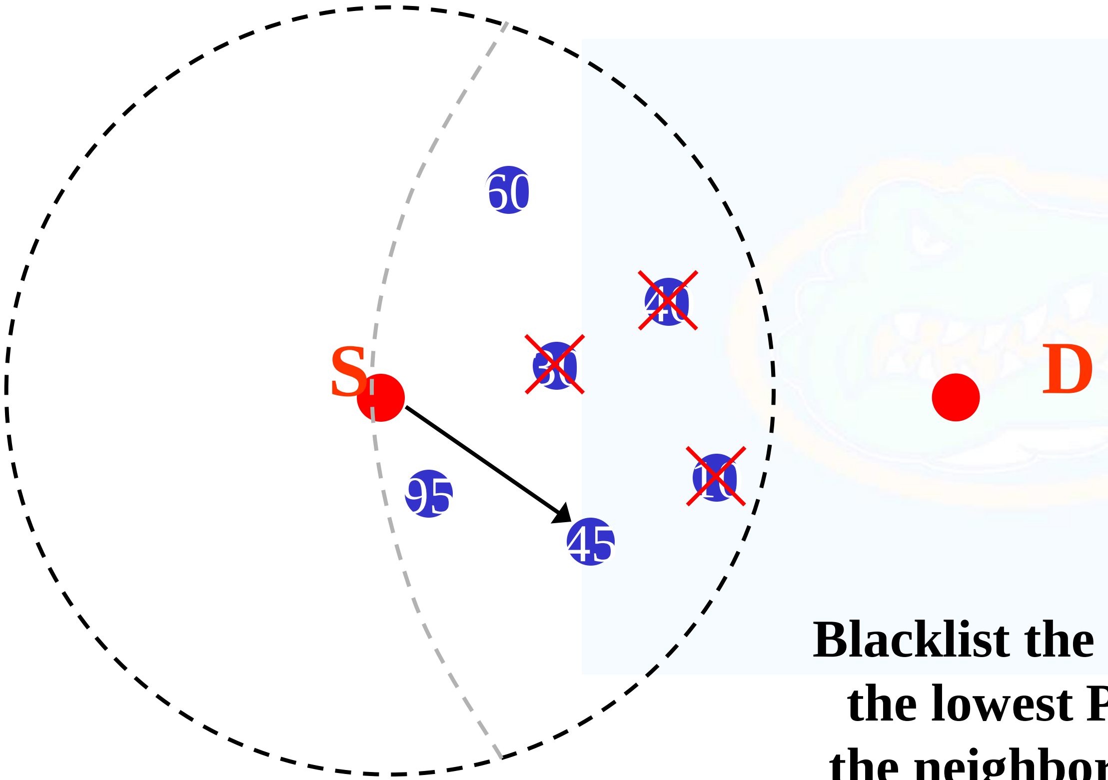


Absolute Reception-based Blacklisting



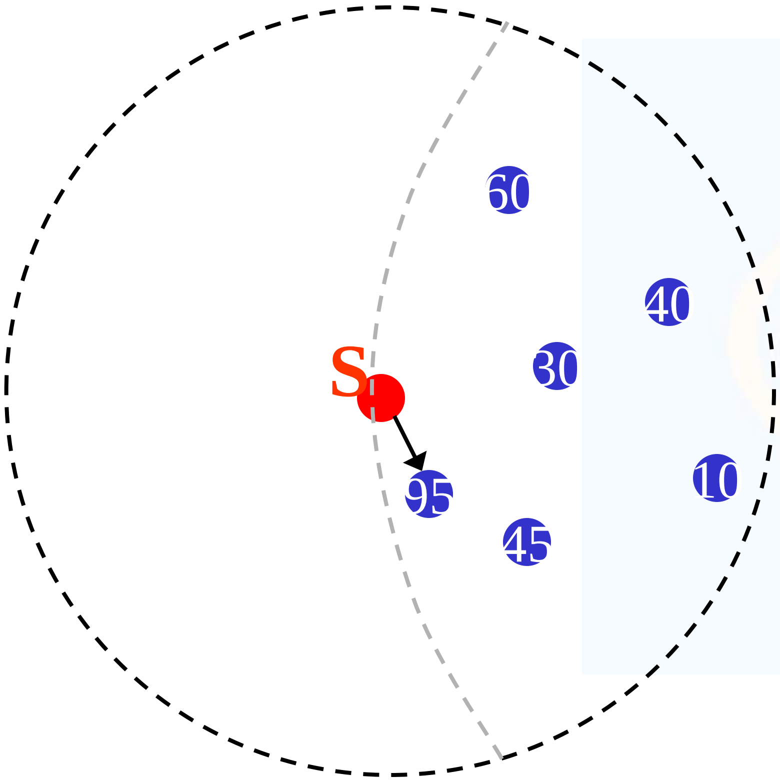
Blacklist nodes with PRR < 50%, then forward to the neighbor closest to destination

Relative Reception-based Blacklisting



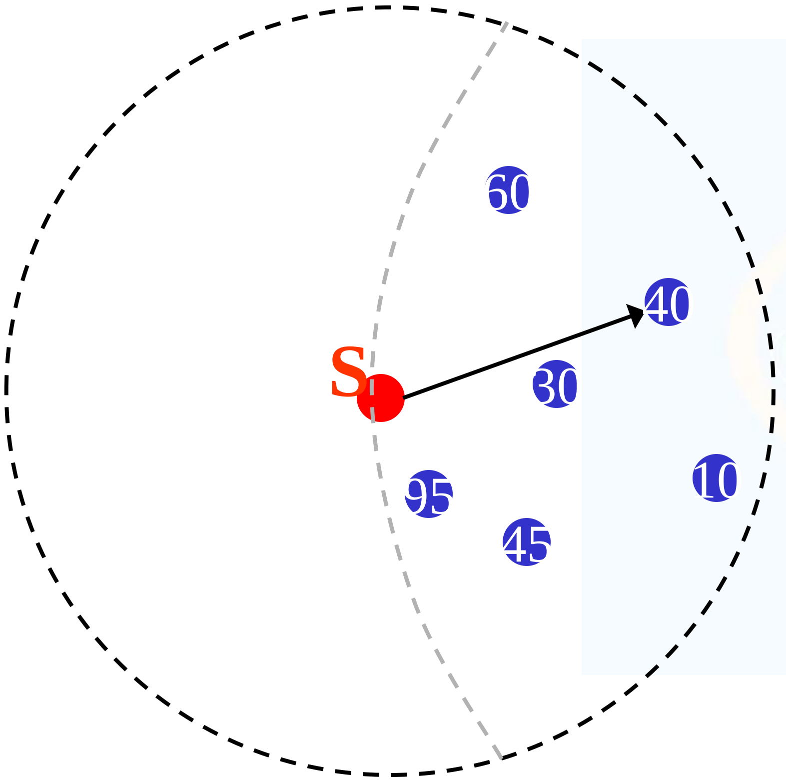
Blacklist the 50% of the nodes with the lowest PRR, then forward to the neighbor closest to destination

Best Reception Neighbor



Forward to the neighbor with the highest reception rate

Best PRR*Distance

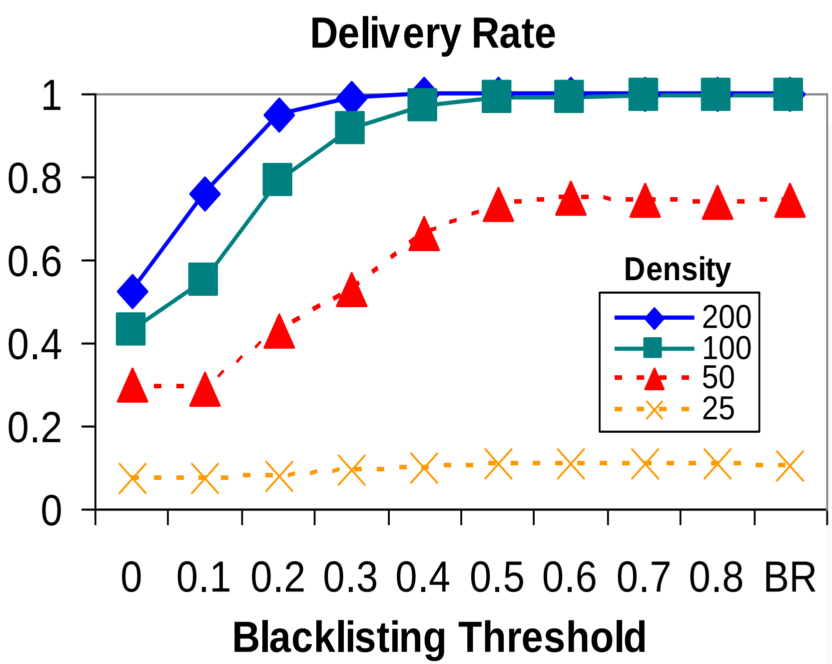


Forward to the neighbor with the highest PRR*Distance

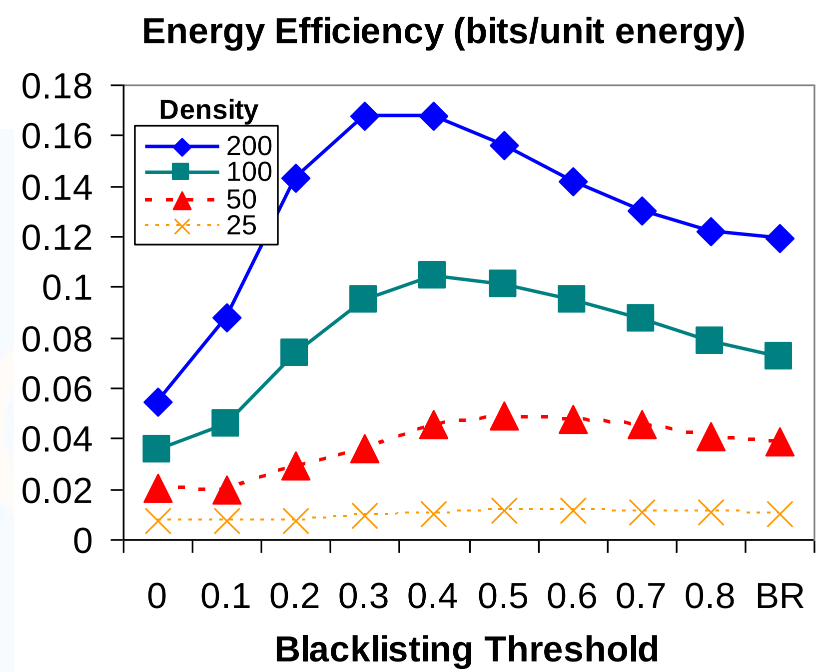
Simulation Setup

- **Random topologies up to 1000 nodes**
  - Different densities
  - Each run: 100 packet transmission from a random source to a random destination
  - Average of 100 runs
  - No ARQ, 10 retransmissions ARQ, infinity ARQ
  - Performance metrics: delivery rate, energy efficiency
- **Assumptions**
  - A node must have at least 1% PRR to be a neighbor
  - Nodes estimate the PRR of their neighbors
  - No power or topology control, MAC collisions not considered, accurate location

Relative Reception-based Blacklisting



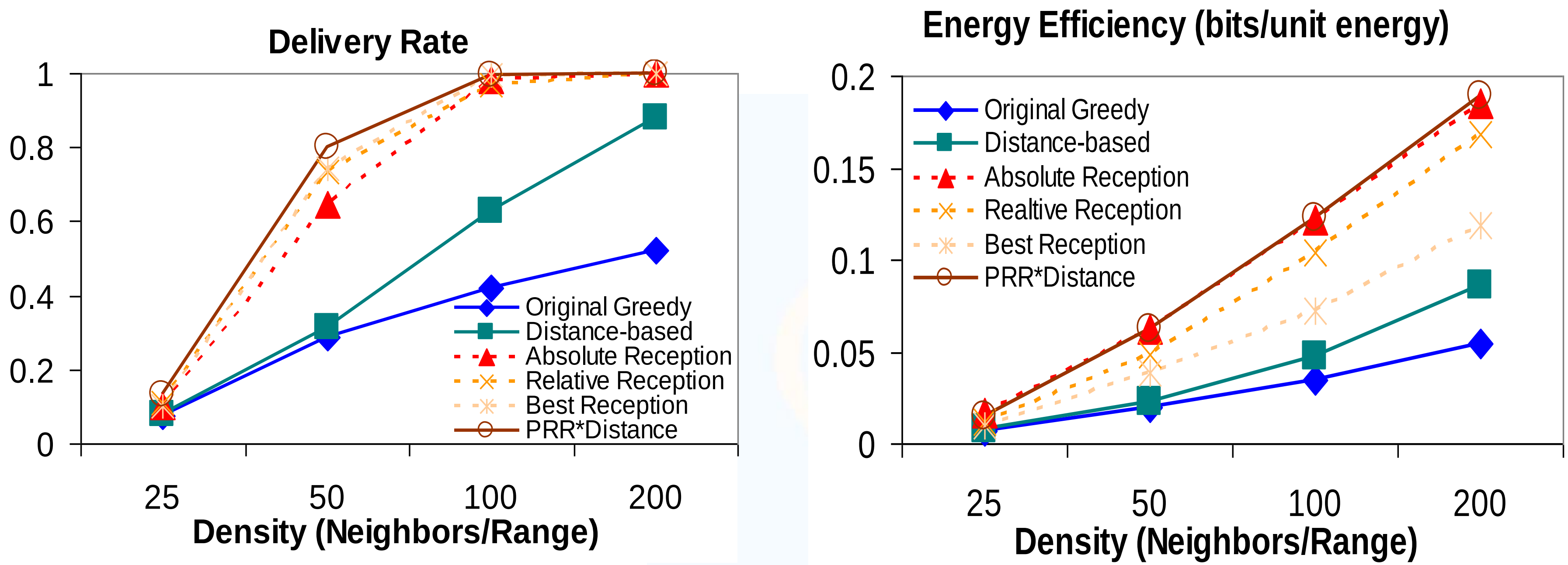
Stricter blacklisting



Stricter blacklisting

The effect of the blacklisting threshold

Comparison between Strategies



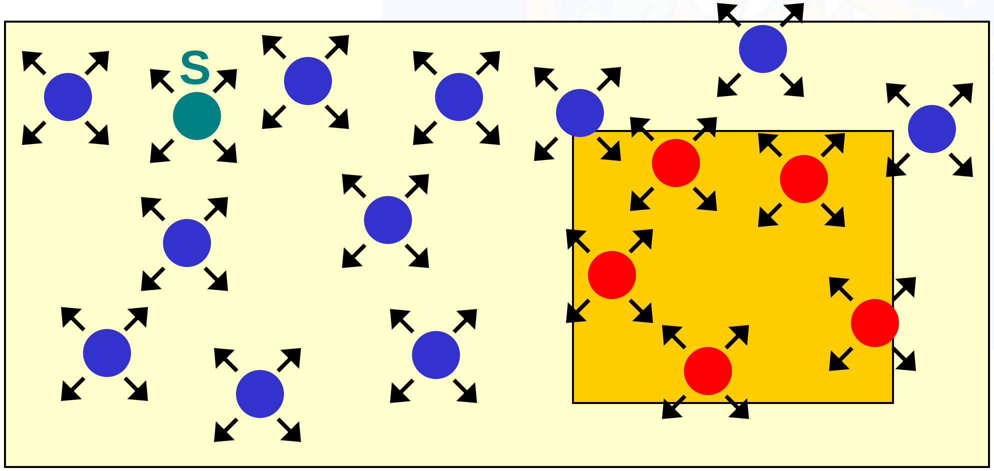
- ‘*PRR**Distance’ has the highest delivery and energy efficiency
- Best Reception has high delivery, but lower energy efficiency
- Absolute Blacklisting has high energy efficiency but lower delivery rate

Geocast

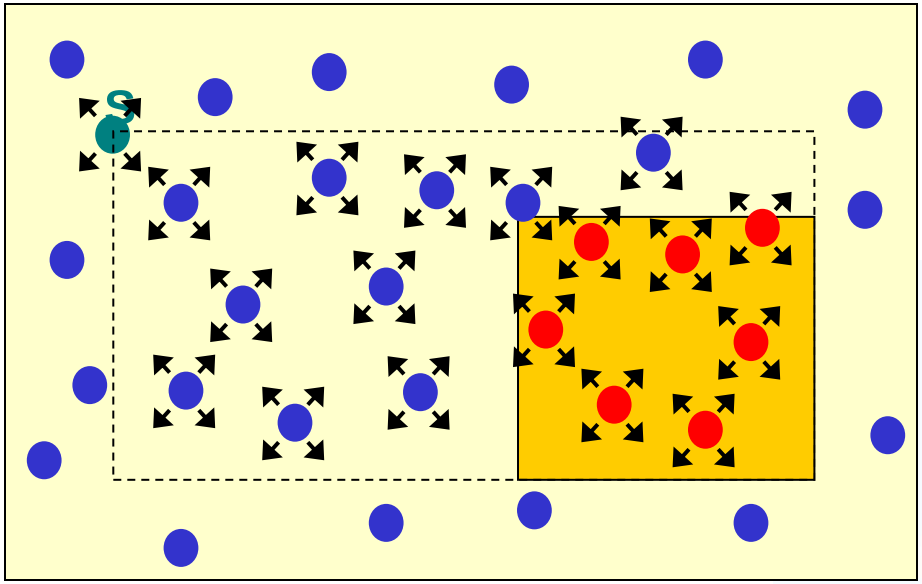
- Definition:
  - **Broadcasting to a specific geographic region**
- Example Applications:
  - **Location-based announcements (local information dissemination, alerts, …)**
  - **Region-specific resource discovery and queries (e.g., in vehicular networks)**
- Approaches and Problems
  1. **Reduce flooding by restricting to a fixed region**
  2. **Adapt the region based on progress to reduce overhead**
  3. **Dealing with gaps. Can we guarantee delivery?**

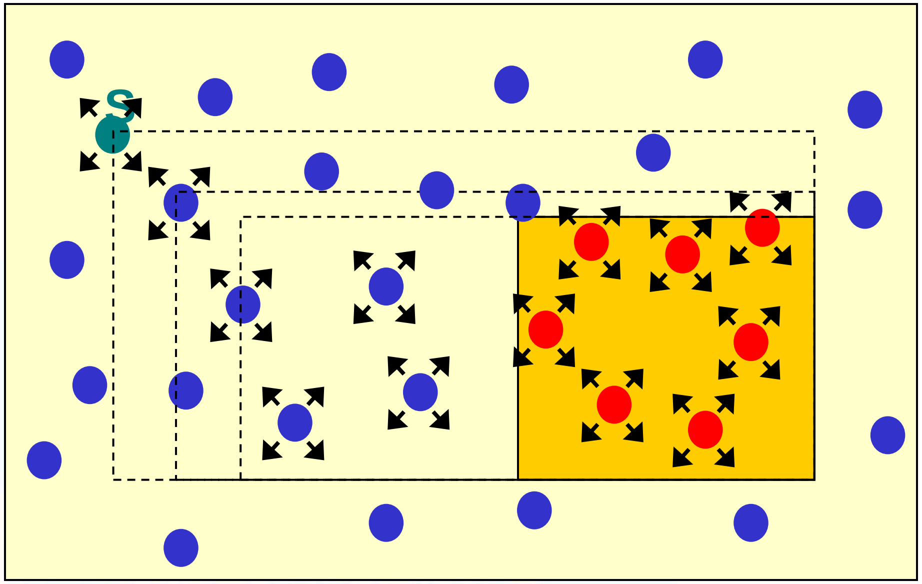
Previous Approaches

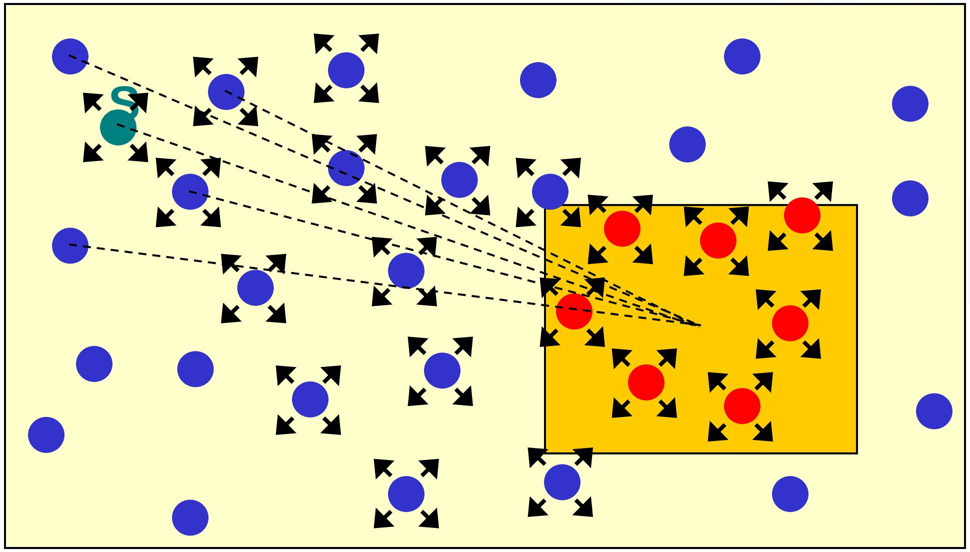
- Simple global flooding
- Guaranteed routing delivery, but high waste of bandwidth and energy



Previous Geocast Approaches …

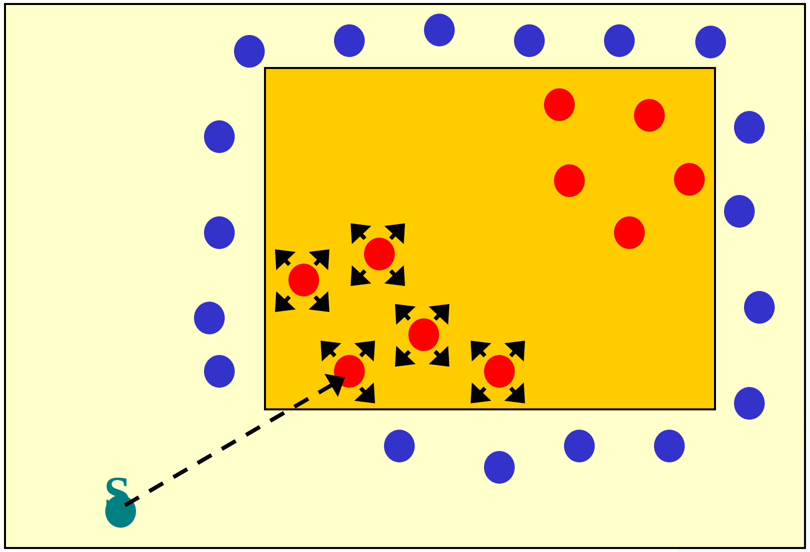




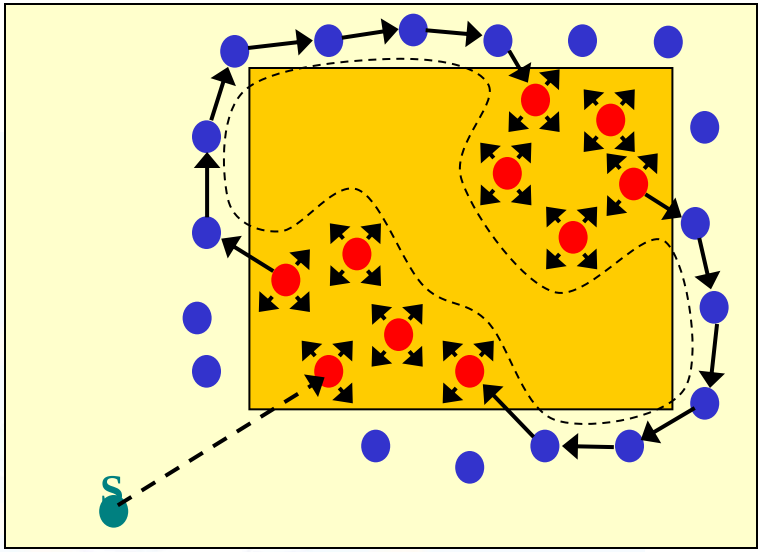


Progressively Closer Nodes (PCN)
Only nodes closer to the geocast region forward the packets

Dealing with Gaps: Efficient Geocasting with Perfect Delivery



Problem with gaps, obstacles, sparse networks, irregular distributions



Using region face routing around the gap to guarantee delivery

GFPG* (Geographic-Forwarding-Perimeter-Geocast)

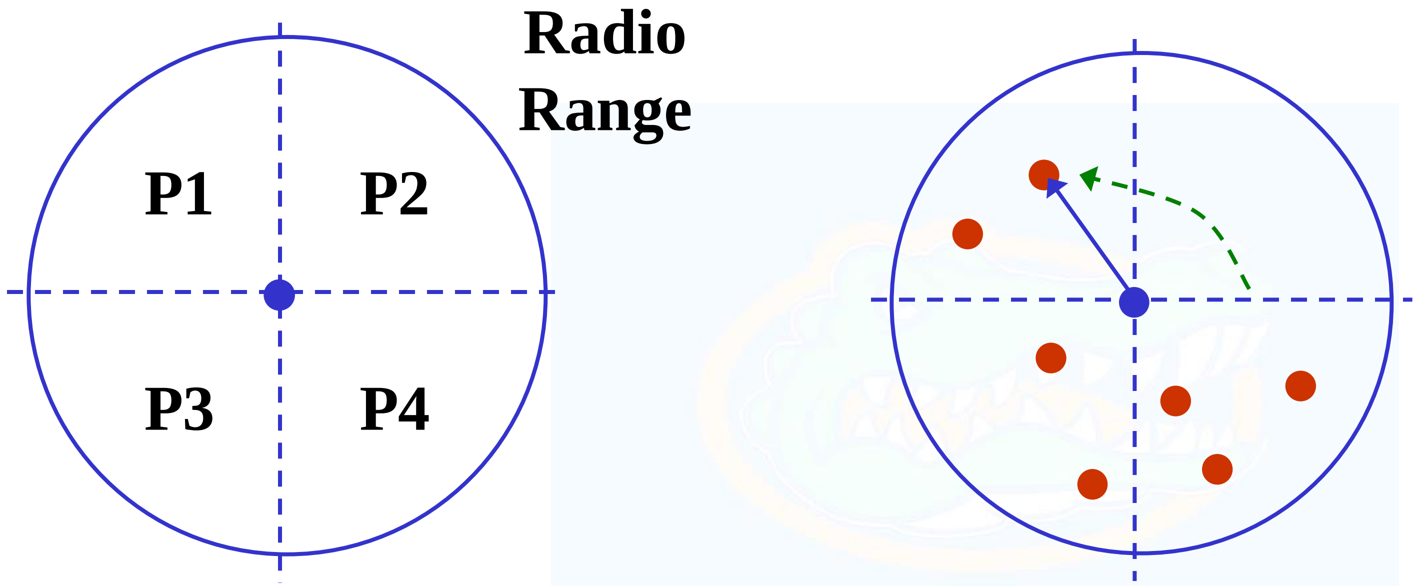
- K. Seada, A. Helmy, "Efficient Geocasting with Perfect Delivery in Wireless Networks", *IEEE WCNC*, Mar 2004.

- K. Seada, A. Helmy, "Efficient and Robust Geocasting Protocols for Sensor Networks", *Computer Communications Journal – Elsevier*, Vol. 29, Issue 2, pp. 151-161, January 2006.

Geographic-Forwarding-Perimeter-Geocast (*GFPG**)

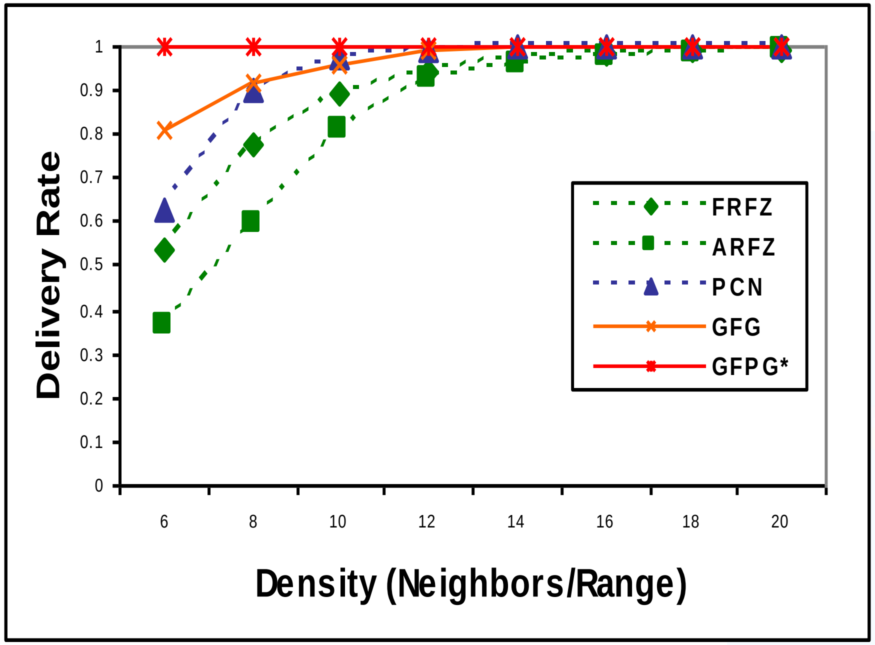
- **Combines perimeter routing and region flooding**
- **Traversal of planar faces intersecting a region, guarantees reaching all nodes**
- **Perimeter routing connects separated clusters of same region**
- **Perimeter packets are sent only by *border nodes* to neighbors outside the region**
- **For efficiency send perimeter packets only when there is *suspicion of a gap* (using heuristics)**

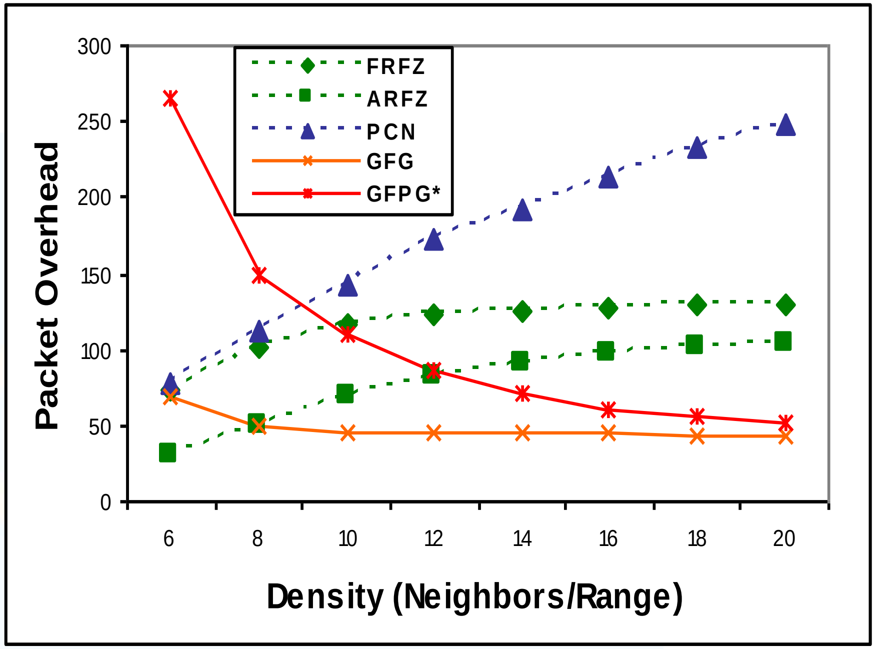
GFPG*: Gap Detection Heuristic



- If a node has no neighbors in a portion, it sends a perimeter packet using the right-hand rule
- The face around suspected void is traversed and nodes on other side of the void receive the packet

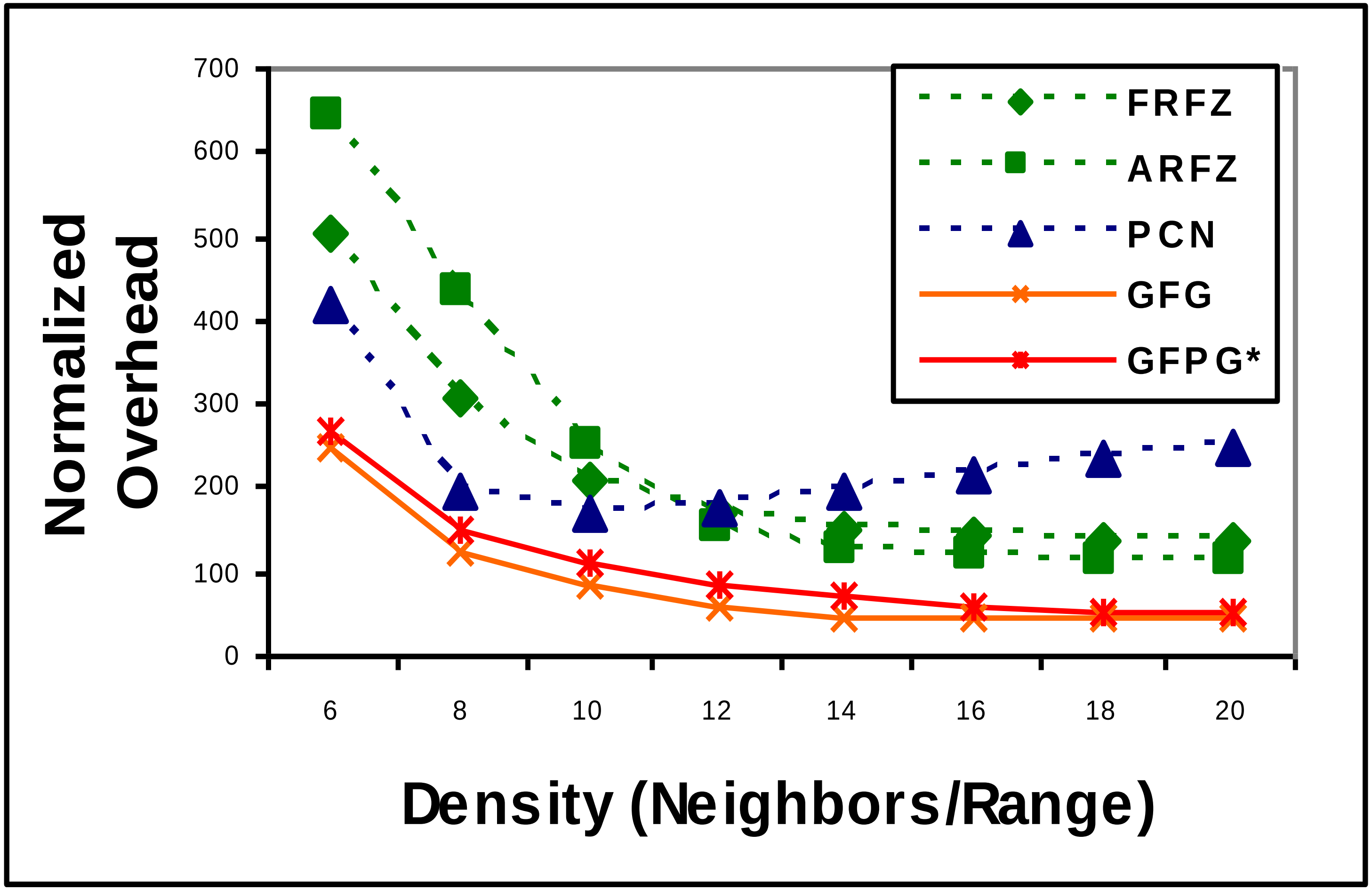
Evaluation and Comparisons





- In all scenarios GFPG* achieves 100% delivery rate.
- It has low overhead at high densities.
- Overhead increases slightly at lower densities to preserve the prefect delivery.
- [Delivery-overhead trade-off]

Comparisons…



To achieve perfect delivery protocols fallback to flooding when delivery fails using geocast

R2D2: Rendezvous Regions for Data Discovery

A Geographic Peer-to-Peer Service for Wireless Networks

Karim Seada, Ahmed Helmy

- A. Helmy, "Architectural Framework for Large-Scale Multicast in Mobile Ad Hoc Networks", *IEEE International Conference on Communications (**ICC**)*, Vol. 4, pp. 2036-2042, April 2002.

- K. Seada and A. Helmy, "*Rendezvous Regions*: A Scalable Architecture for Service Location and Data-Centric Storage in Large-Scale Wireless Networks", *IEEE/ACM* ***IPDPS***, April 2004.

(*ACM SIGCOMM 2003 and ACM Mobicom 2003* posters)

Motivation

- **Target Environment**
  - ***Infrastructure-less* mobile ad hoc networks (MANets)**
  - **MANets are self-organizing, *cooperative* networks**
  - **Expect common interests & sharing among nodes**
  - **Need scalable information sharing scheme**
- **Example applications:**
  - **Emergency, Disaster relief (search & rescue, public safety)**
  - **Location-based services (tourist/visitor info, navigation)**
  - **Rapidly deployable remote reconnaissance and exploration missions (peace keeping, oceanography,…)**
  - **Sensor networks (data dissemination and access)**

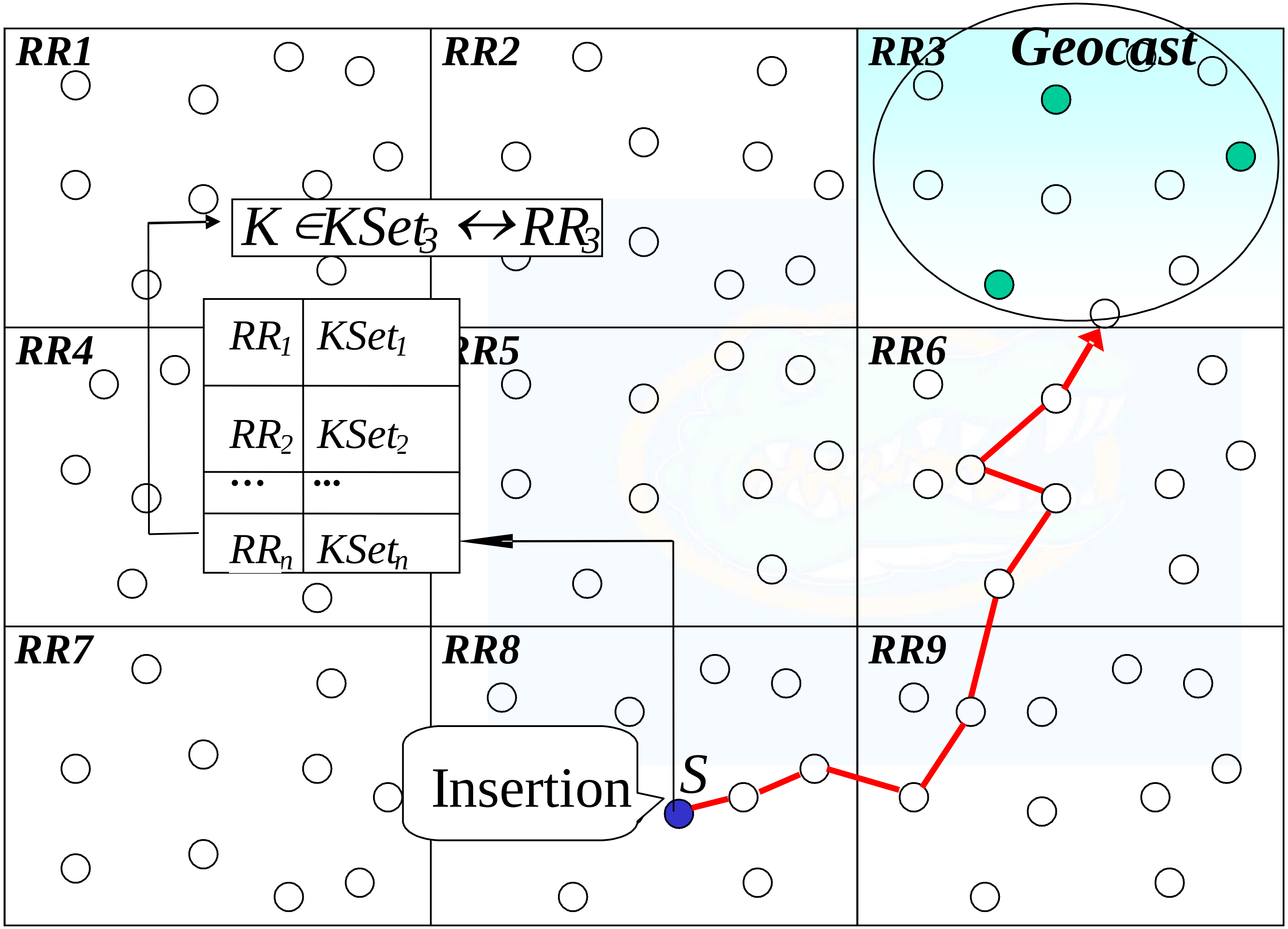
Architectural Design Requirements & Approach

- Robustness
  - Adaptive to link/node failure, and to mobility
  - (use multiple dynamically elected servers in regions)
- Scalability & Energy Efficiency
  - Avoids global flooding (use geocast in limited regions)
  - Provides simple hierarchy (use grid formation)
- Infrastructure-less Frame of Reference
  - Geographic locations provide natural frame of reference (or rendezvous) for seekers and resources

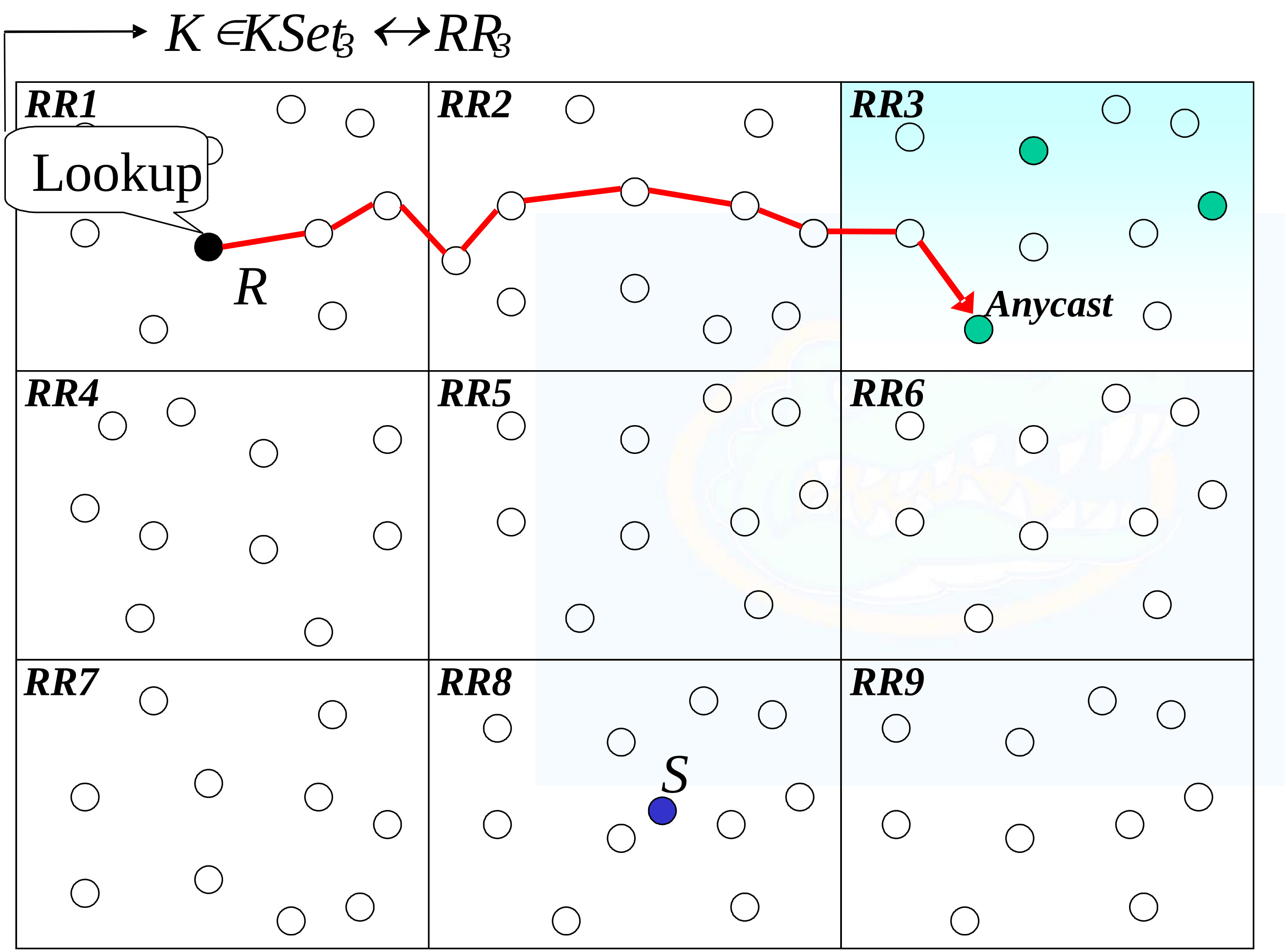
Rendezvous-based Approach

- **Network topology is divided into *rendezvous regions (RRs)***
- **The information space is mapped into *key space* using prefixes *(KSet)***
- **Each region is responsible for a set of keys representing the services or data of interest**
- **Hash-table-like mapping between keys and regions (*KSet* ↔ *RR)* is provided to all nodes**

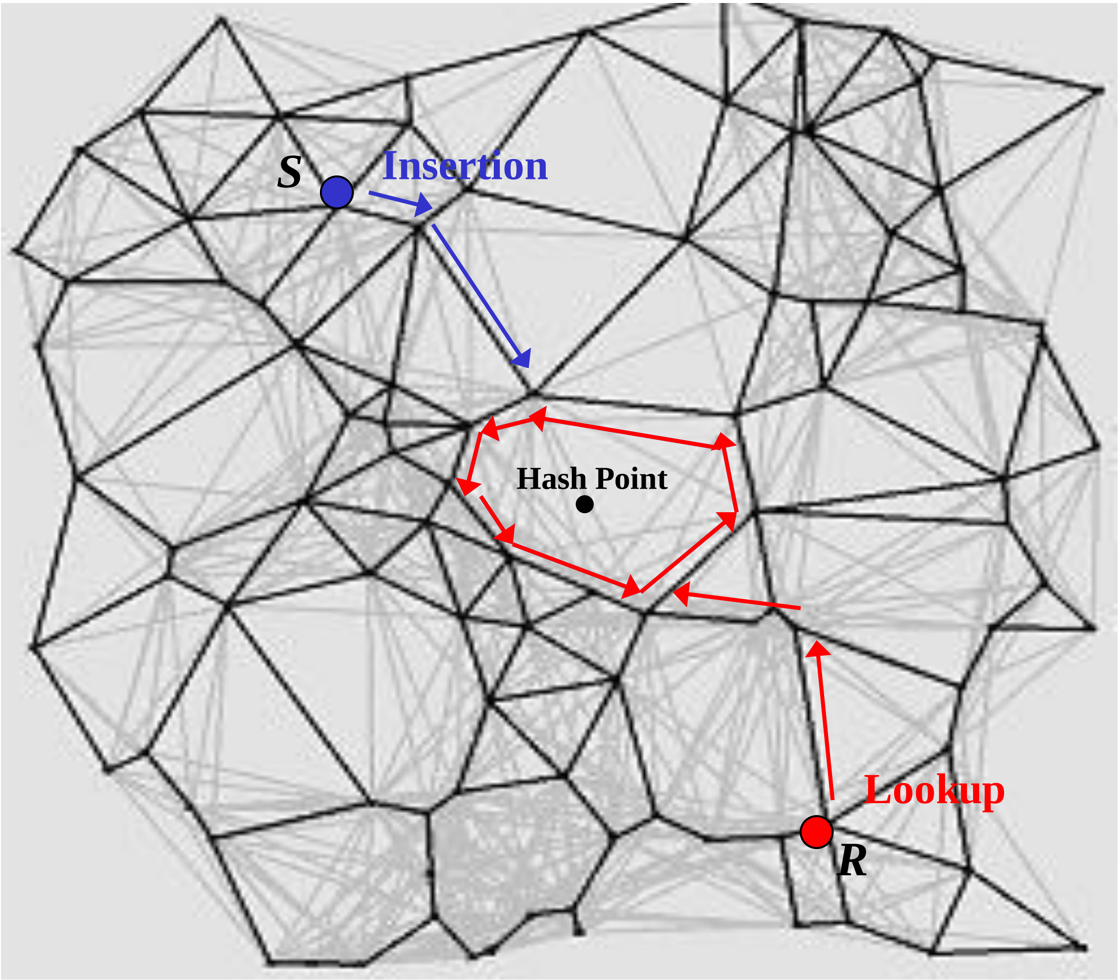
Inserting Information from Sources in *R2D2*



Lookup by Information Retrievers in *R2D2*

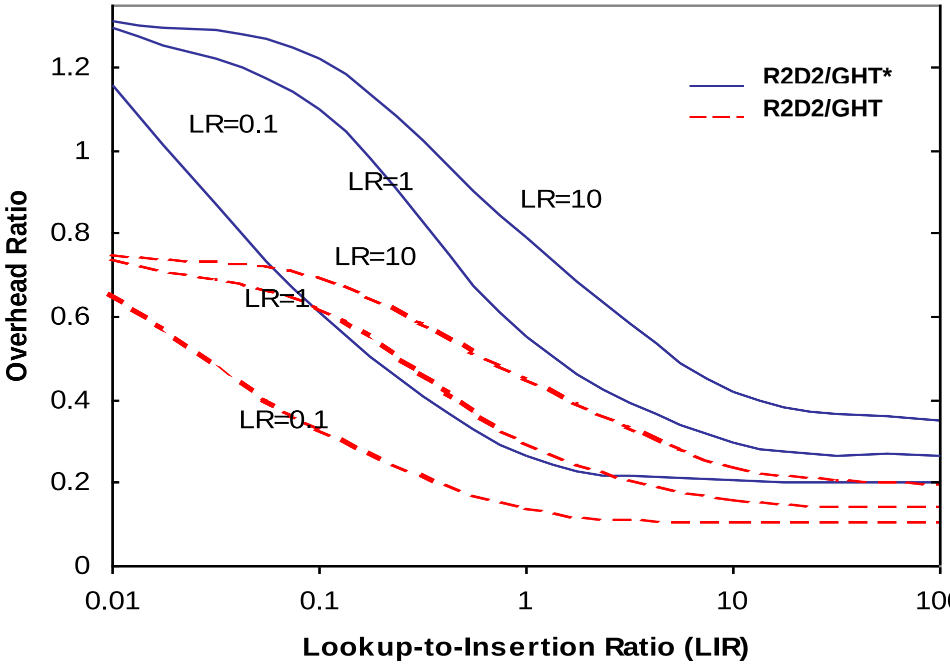


Another Approach: GHT (Geographic Hash Table)*

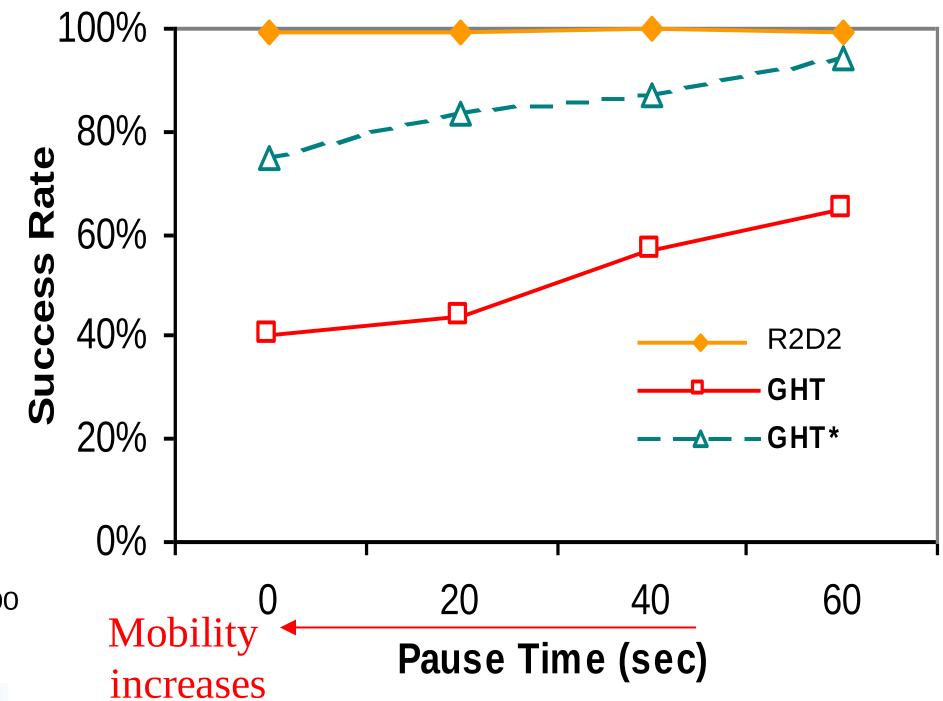


* S. Ratnasamy, B. Karp, S. Shenker, D. Estrin, R. Govindan, L. Yin, F. Yu, Data-Centric Storage in Sensornets with GHT, A Geographic Hash Table, *ACM MONET,* Vol. **8**, No. 4, 2003.

Results and Comparisons with GHT



(LR: Lookup Rate)

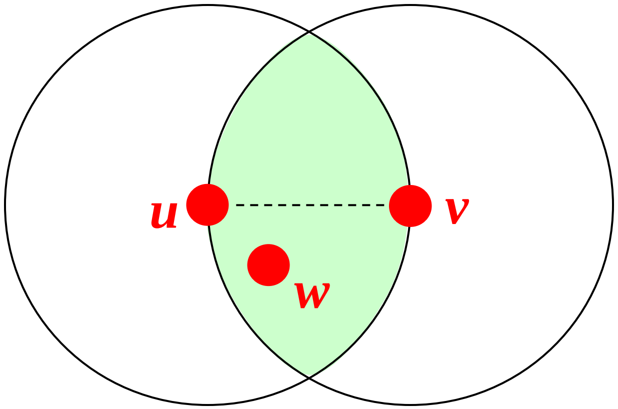


- Geocast insertion enhances reliability and works well for high lookup-to-insertion ratio (*LIR*)
- Data update and access patterns matter significantly
- Using *Region* (vs. point) dampens mobility effects

Evaluation Framework

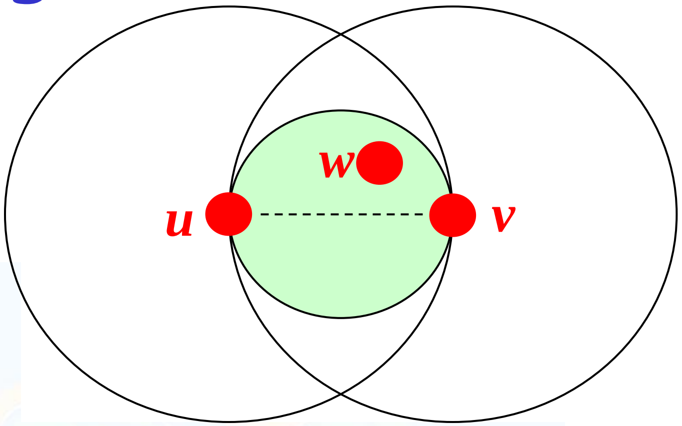
- **Micro-level algorithmic Stress analysis**
  - Decompose geographic routing into its major components
    - greedy forwarding, planarization algorithm, face routing
  - Start from the algorithm(s) and construct *complete* conditions and bounds of 'possible' errors
  - Classify the errors and understand their cause to aid fix
- **Systematic Simulations**
  - Analyze results and map performance degradation into micro-level errors
  - Estimate most 'probable' errors and design their fixes
  - Re-simulate to evaluate efficacy of the fixes

Planarization Algorithms




```
For each node u, where N is a list
of the neighbors of u:
 for all v ∈ N
  for all w ∈ N
   if w == v then continue
   else if d(u,v)>max[d(u,w),d(w,v)]
        remove edge (u,v)
```

*Relative Neighborhood Graph (**RNG**)*

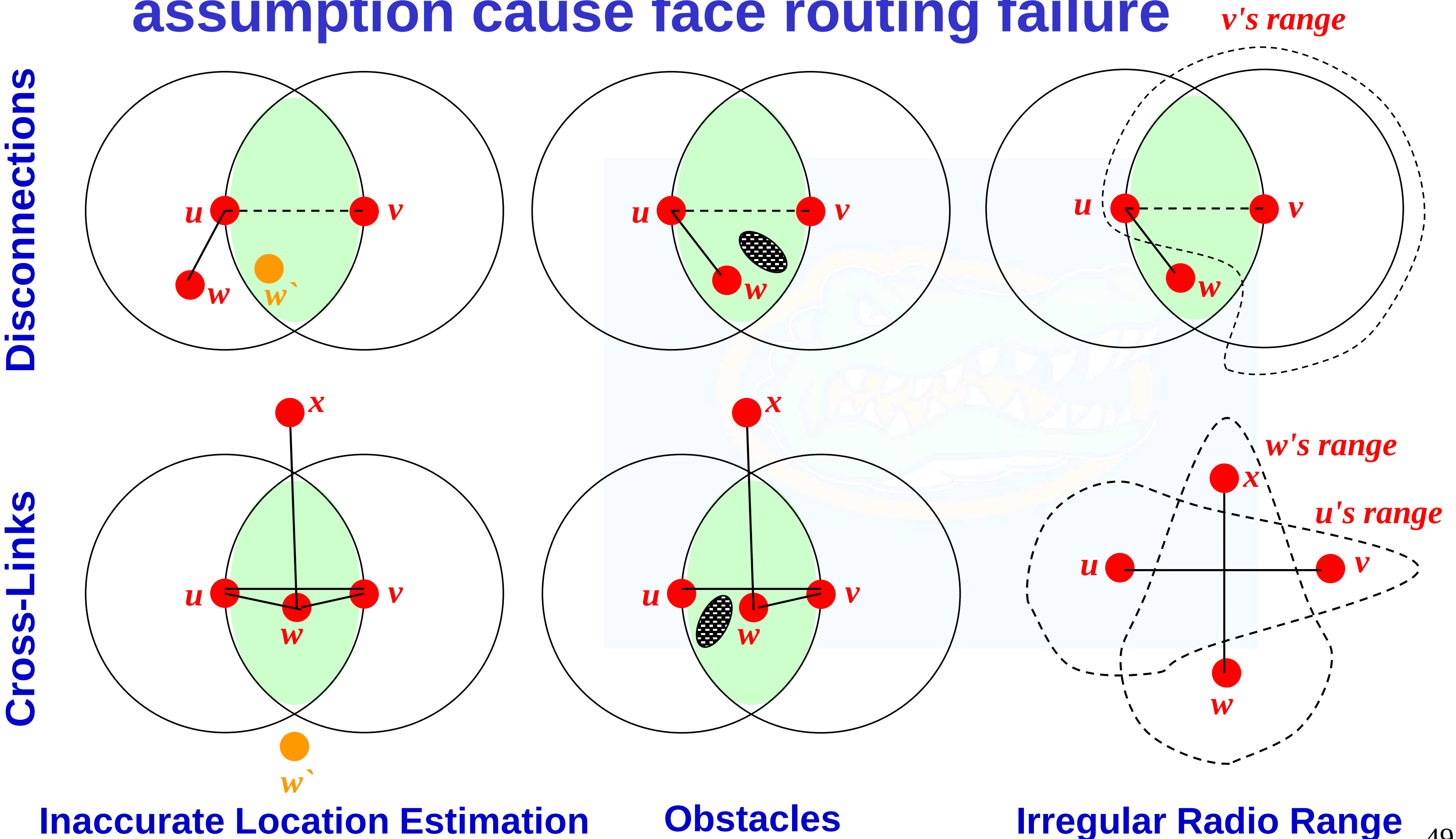



```
For each node u, where N is a list
of the neighbors of u:
 for all v ∈ N
  for all w ∈ N
   if w == v then continue
   else if d(c,w)<d(c,u) {where c
   is the midpoint of edge (u,v)}
        remove edge (u,v)
```

*Gabriel Graph (**GG**)*

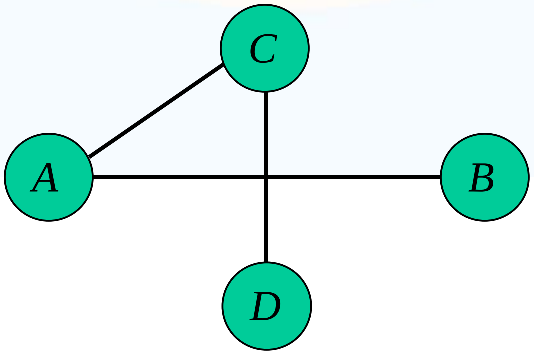
A node *u* removes the edge *u-v* from the planar graph, if node *w* (called a witness) exists in the shaded region

- **Conditions that violate the unit-graph assumption cause face routing failure**



Error Fixing

- **Is it possible to fix all face routing problems (disconnections & cross links) and guarantee delivery, preferably using a local algorithm?**
  - **Is it possible for any planarization algorithm to obtain a planar and connected sub-graph from an arbitrary connected graph? No**



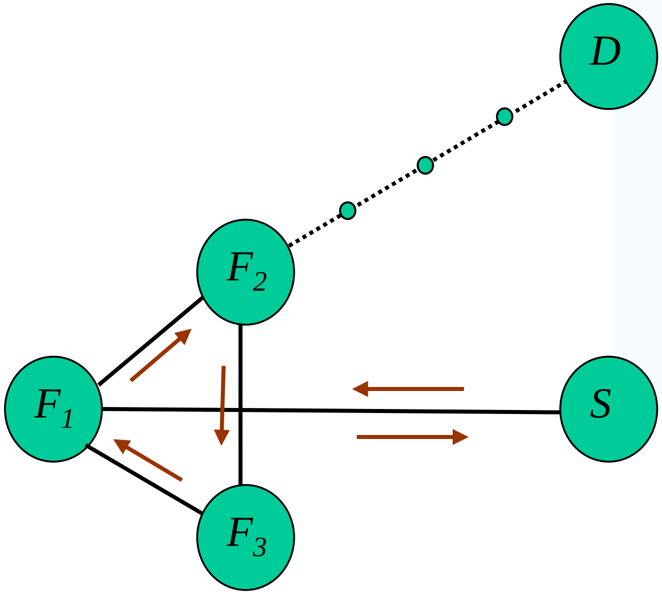
Error Fixing

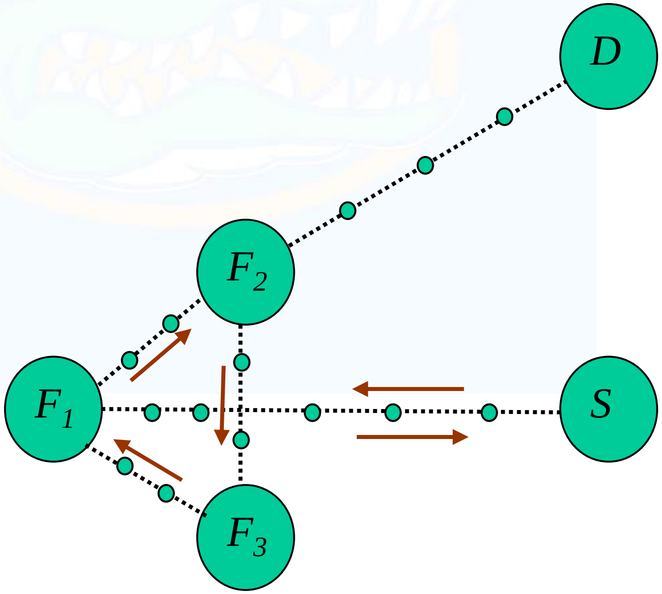
- **Is it possible to fix all face routing problems (disconnections & cross links) and guarantee delivery, preferably using a local algorithm?**
  - **Could face routing still work correctly in graphs that are non-planar?**

    In a certain type of sub-graphs, yes.
    CLDP [Kim05]: Each node probes the faces of all of its links to detect cross-links. Remove cross-links only if that would not disconnect the graph. Face routing work correctly in the resulting sub-graph.

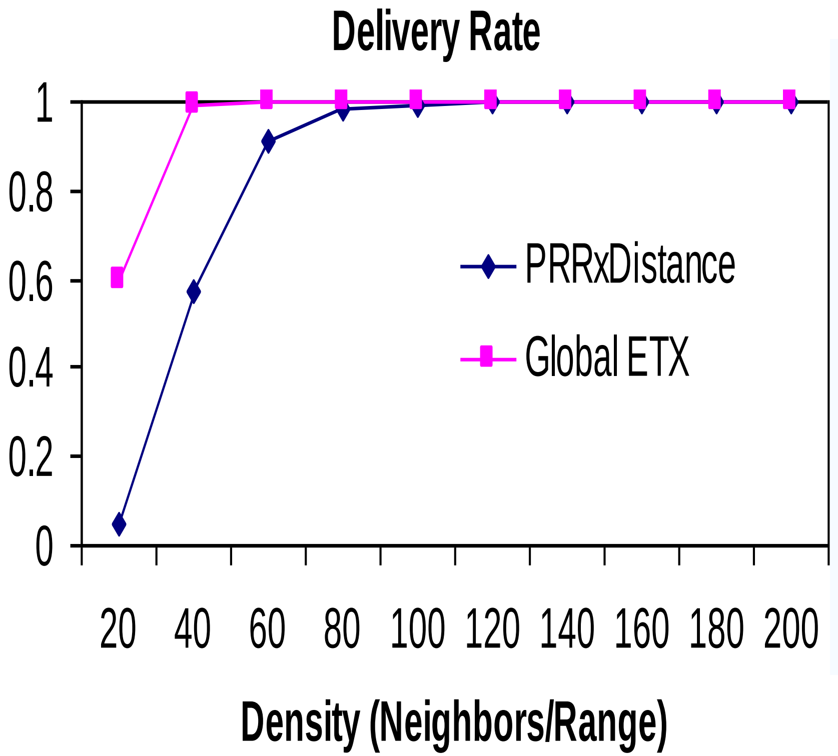
Error Fixing

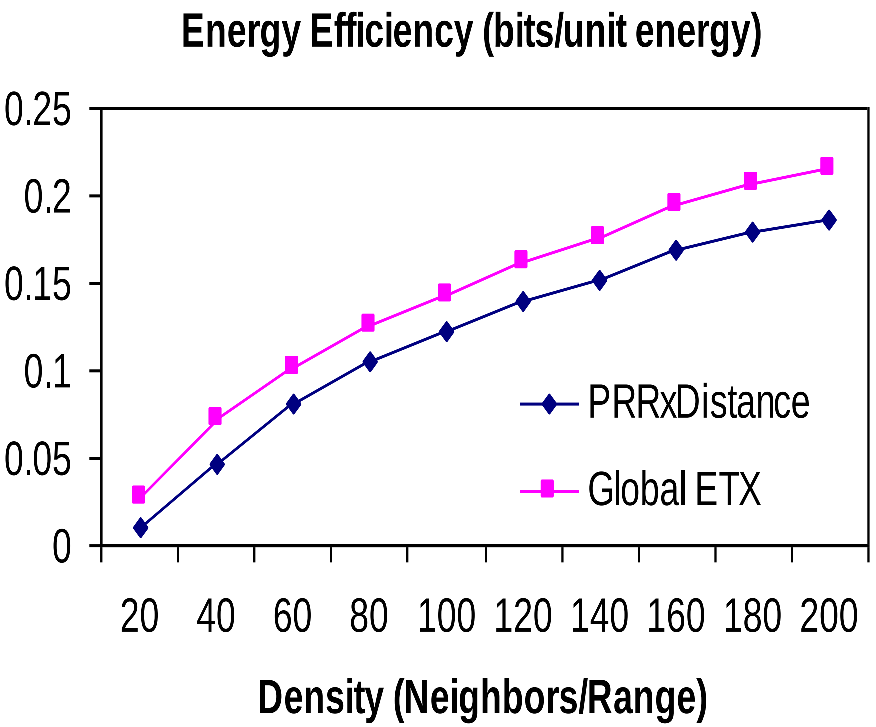
- Is it possible to fix all face routing problems (disconnections & cross links) and **guarantee delivery** using a **local algorithm** (single-hop or a fixed number of hops)? **No**





Local PRRxDistance vs. Global ETX





Previous Approaches …

- Restricted forwarding zones
- "Flooding-based Geocasting Protocols for Mobile Ad Hoc Networks". Ko and Vaidya,
- Reduces overhead but does not guarantee that all nodes in the region receive the packet

R2D2 vs. GHT (overhead with mobility)

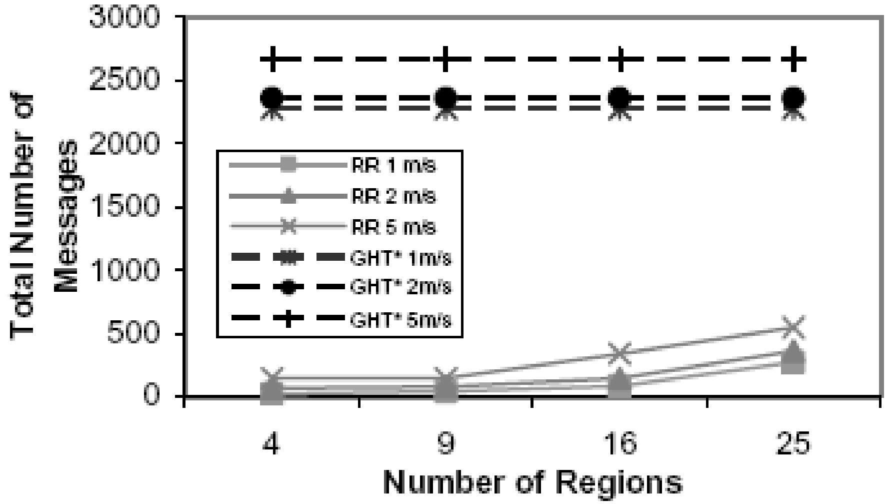


Figure 2: Mobility update (refresh) overhead in RR and GHT

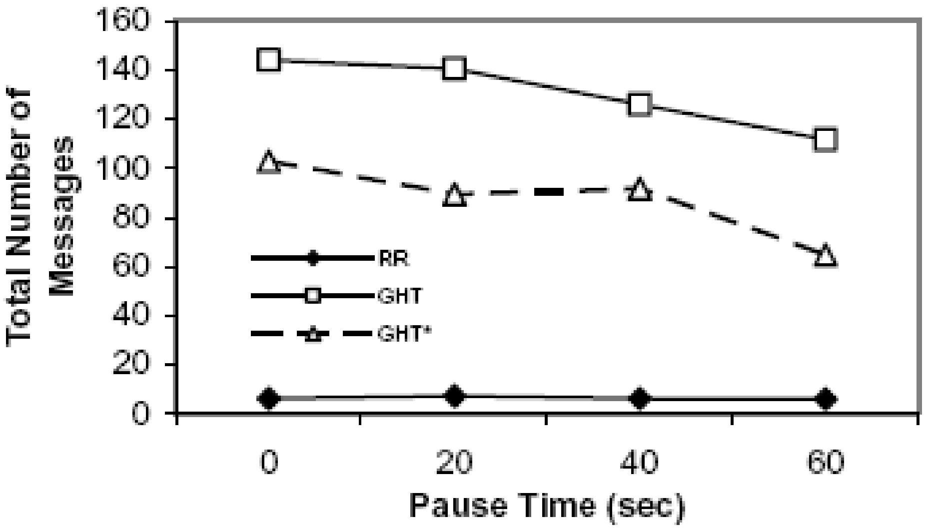


Figure 4: Lookup overhead for different node pause times