Efficient Hop ID Based Routing for Sparse Ad Hoc Networks

Yan Chen

Lab for Internet & Security Technology (LIST)

Northwestern University

Outline

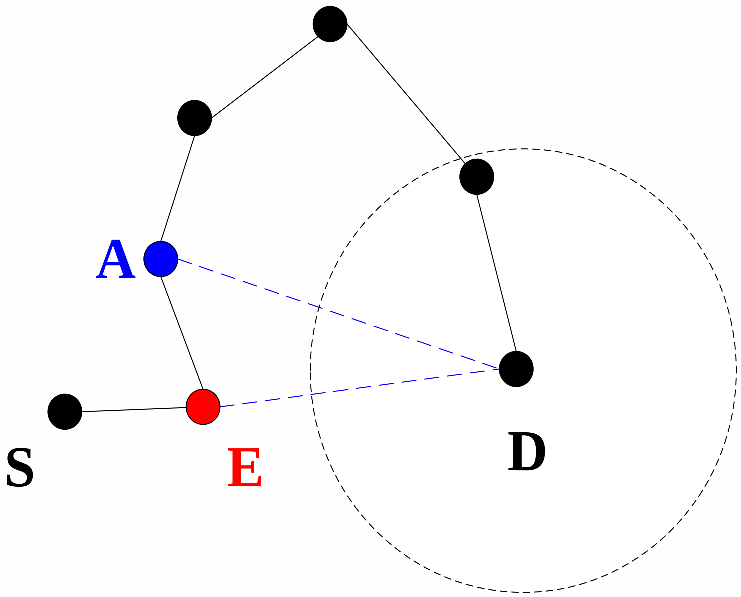
- Motivation
- Hop ID and Distance Function
- Dealing with Dead Ends
- Evaluation
- Conclusion

Motivation: Routing in Ad Hoc Networks

- On-demand routing
  - Flood routing requests
  - No preprocessing needed
  - But poor scalability
- Geographical routing
  - Use node’s location (or virtual coordinates) as address
  - Greedy routing based on geographic distance

Dead End Problem

- Geographic distance d_g fails to reflect hop distance d_h (shortest path length)

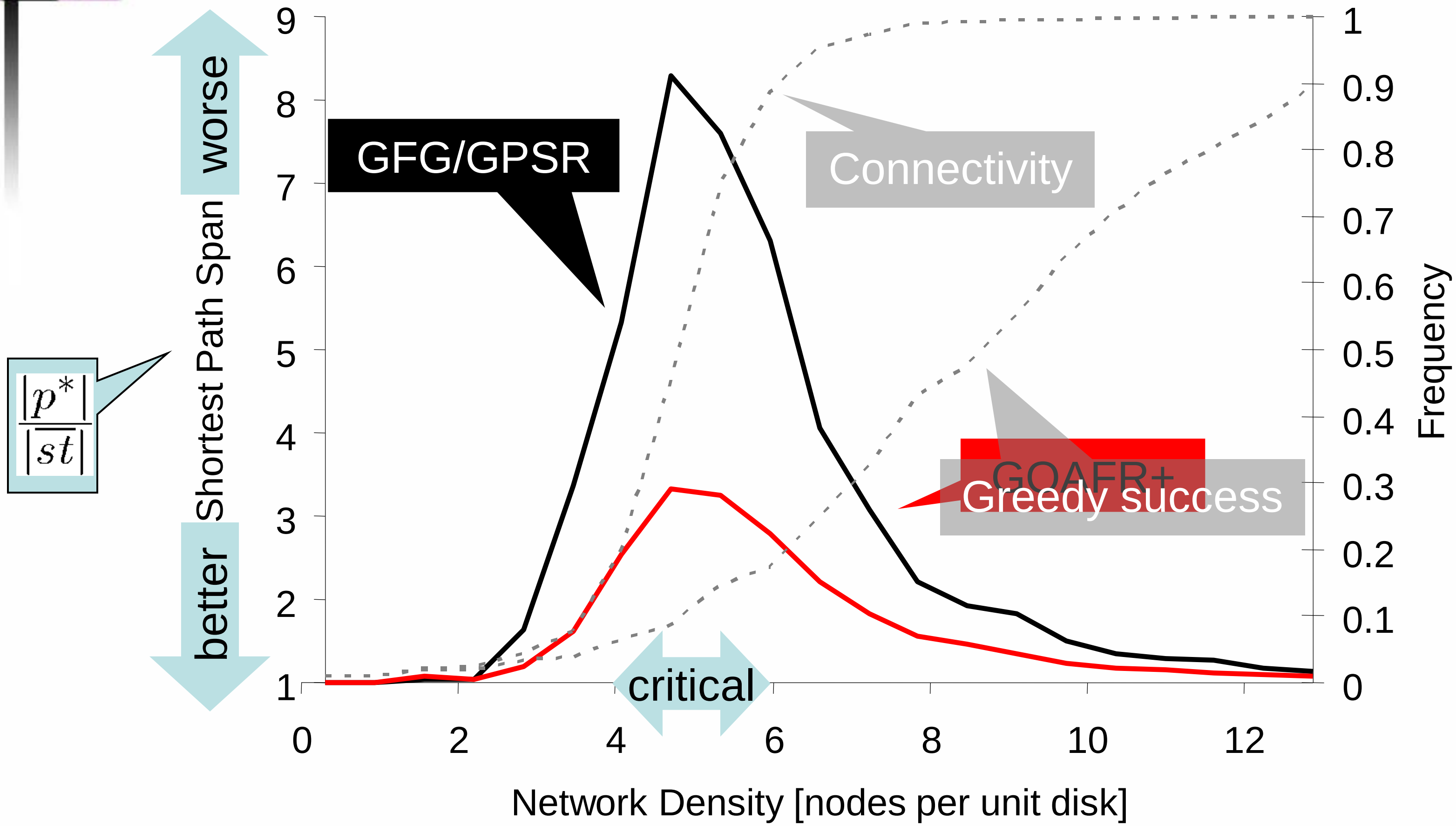


$$d_g(E, D) < d_g(A, D)$$

But

$$d_h(A, D) < d_h(E, D)$$

Existing Work Insufficient for Sparse Ad Hoc Networks



Fabian Kuhn, Roger Wattenhofer and Aaron Zollinger, Mobihoc 2003

Outline

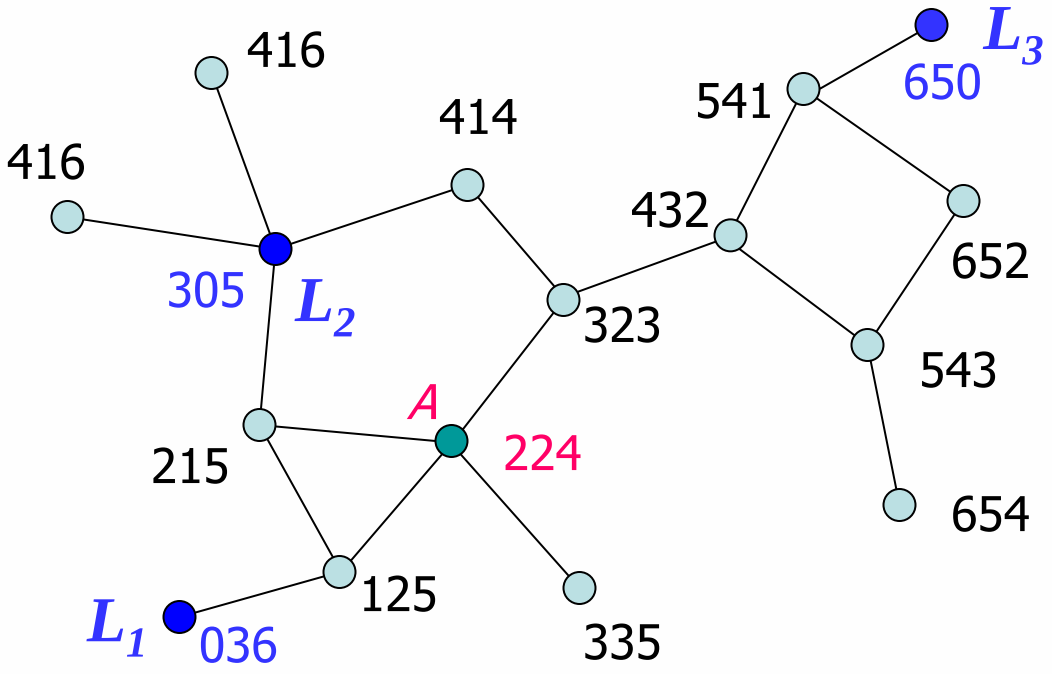
- Motivation
- Hop ID and Distance Function
- Dealing with Dead Ends
- Evaluation
- Conclusion

Virtual Coordinates

- Problem definition
  - Define and build the virtual coordinates, and
  - Define the distance function based on the virtual coordinates
  - Goal: routing based on the virtual coordinates has few or no dead ends even in critical sparse networks
    - virtual distance reflects real distance
    - $d_v \approx c \cdot d_h$, c is a constant

What's Hop ID

- Hop distances of a node to all the landmarks are combined into a vector, *i.e.* the node's Hop ID.

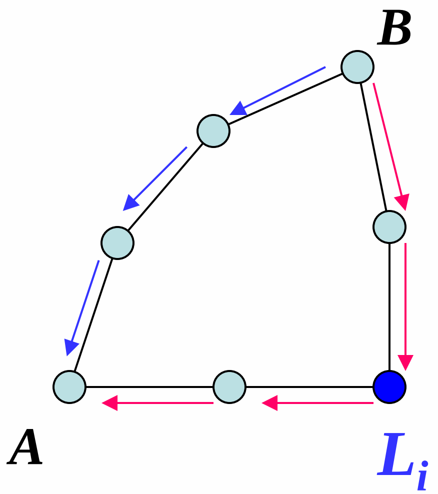


Lower and Upper Bounds

- Triangulation inequality

$$d_h(A, L_i) + d_h(B, L_i) \geq d_h(A, B) \quad (1)$$

$$| d_h(A, L_i) - d_h(B, L_i) | \leq d_h(A, B) \quad (2)$$

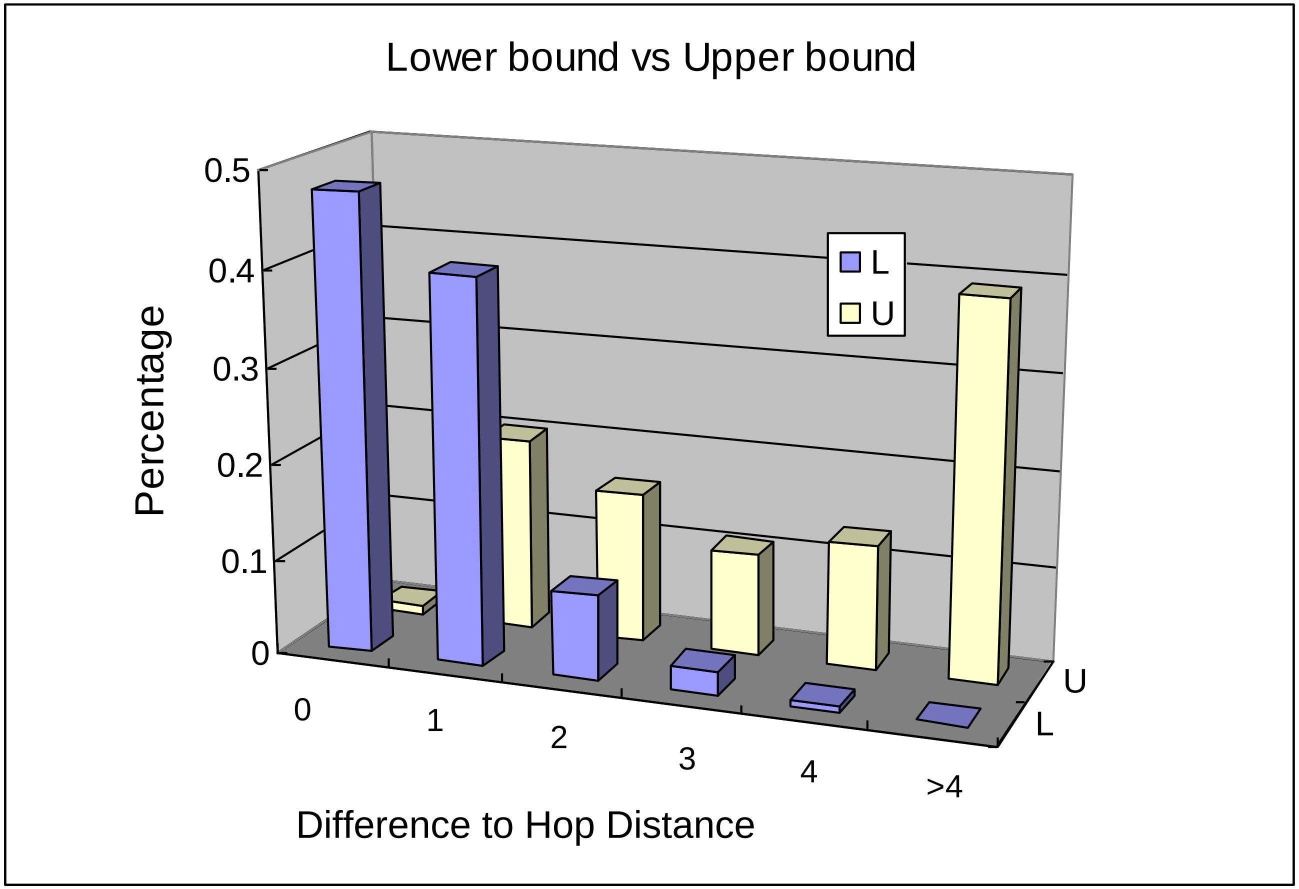


- Hop ID of *A* is $(H_1^{(1)}, H_2^{(1)}, \cdots, H_m^{(1)})$
- Hop ID of *B* is $(H_1^{(2)}, H_2^{(2)}, \cdots, H_m^{(2)})$

$$L = \underset{k}{Max}(| H_k^{(1)} - H_k^{(2)} |) \leq d_h \leq \underset{k}{Min}(H_k^{(1)} + H_k^{(2)}) = U$$

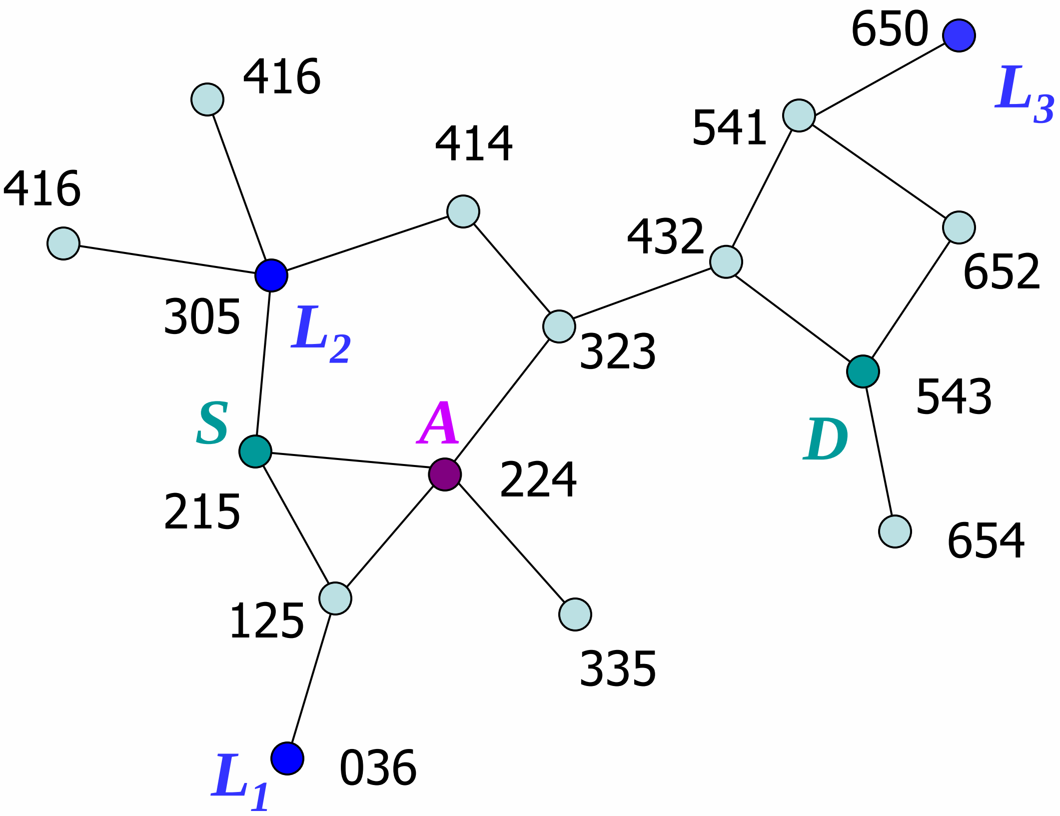
Lower Bound Better Than Upper Bound

- One example: 3200 nodes, density λ=3π
- Lower bound is much closer to hop distance



Lower Bound Still Not The Best

- H(*S*) = *2 1 5*
- H(*A*) = *2 2 4*
- H(*D*) = *5 4 3*
- L(*S*, *D*) = L(*A*, *D*) = 3
- |H(*S*) – H(*D*)|= 3 3 2
- |H(*A*) – H(*D*)|= 3 2 1



Other Distance Functions

- Make use of the whole Hop ID vector

$$D_p = \sqrt[p]{\sum_{k=1}^{m} | H_k^{(1)} - H_k^{(2)} |^p}$$

- If $p = \infty$, $D_p = L$
- If $p = 1$, $D_p = \sum_{k=1}^{m} | H_k^{(1)} - H_k^{(2)} |$
- If $p = 2$, $D_p = \sqrt{\sum_{k=1}^{m} | H_k^{(1)} - H_k^{(2)} |^2}$

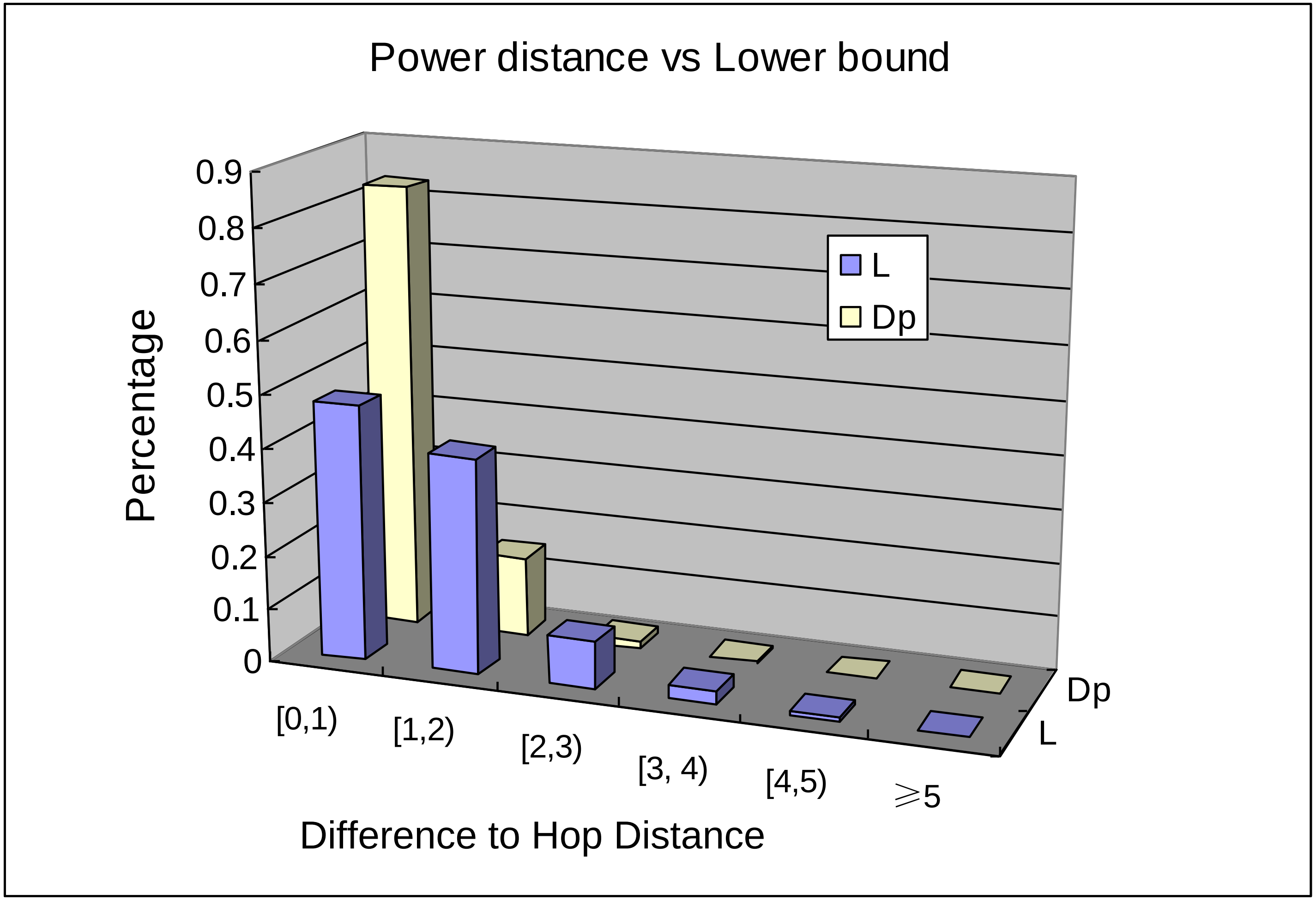
- What values of p should be used?

The Practical Distance Function

- The distance function d should be able to reflect the hop distance d_h
  - $d \approx c \cdot d_h$, c is a constant
  - L is quite close to d_h ($c = 1$)
- If $p = 1$ or 2, Dp deviates from L severely and arbitrarily
- When p is large, $Dp \approx L \approx d_h$
  - $p = 10$, as we choose in simulations

Power Distance Better Than Lower Bound

- 3200 nodes, density λ=3π



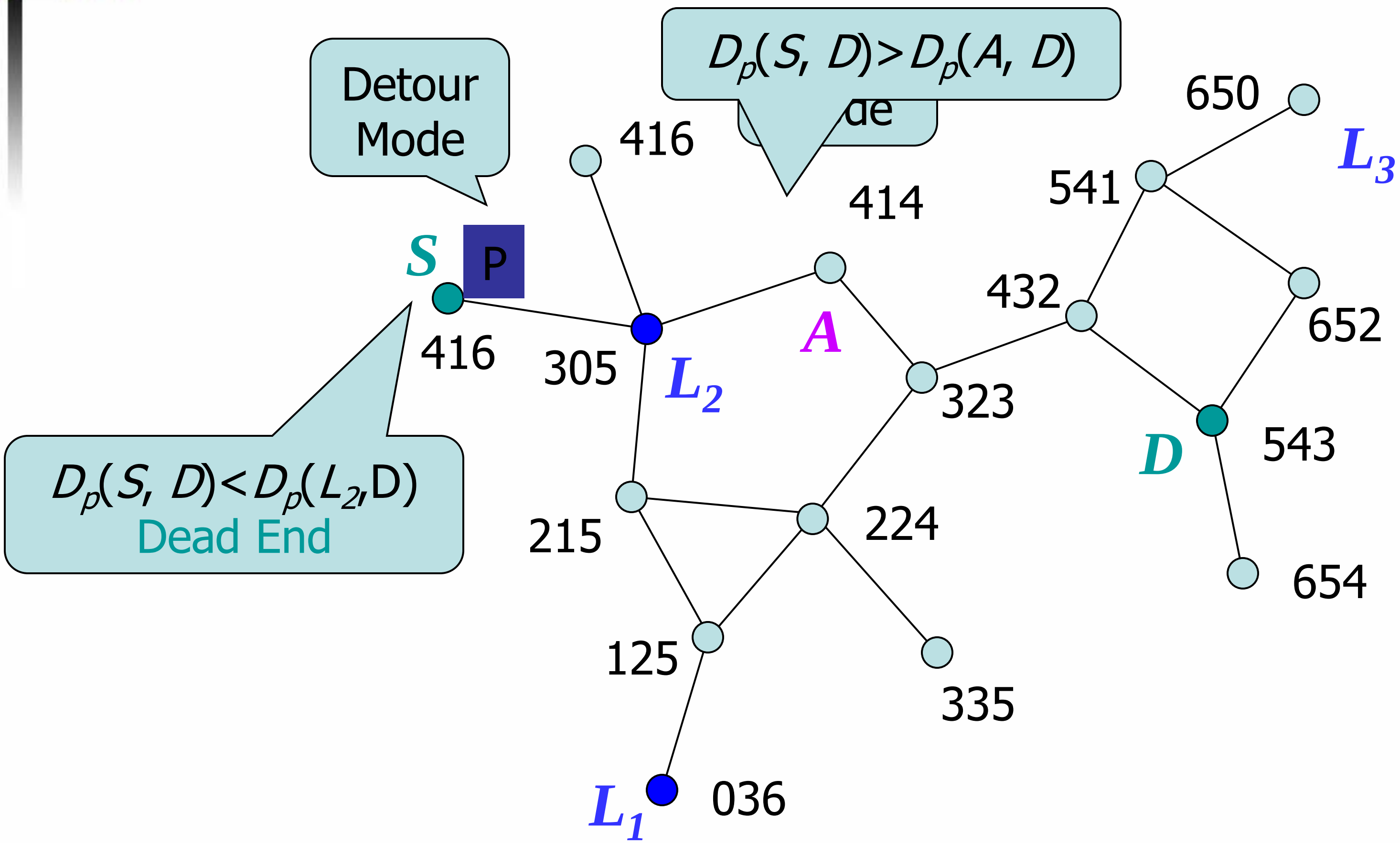
Outline

- Motivation
- Hop ID and Distance Function
- Dealing with Dead Ends
- Evaluation
- Conclusion

Dealing with Dead End Problem

- With accurate distance function based on Hop ID, dead ends are less, but still exist
- Landmark-guided algorithm to mitigate dead end problem
  - Send packet to the closest landmark to the destination
  - Limit the hops in this detour mode
- Expending ring as the last solution

Example of Landmark Guided Algorithm



Practical Issues

- Landmark selection and maintenance
  - $O(m \cdot N)$ where m is the number of landmarks and N is the number of nodes
- Hop ID adjustment
  - Mobile scenarios
  - Integrate Hop ID adjustment process into HELLO message (no extra overhead)
- Location server
  - Can work with existing LSes such as CARD, or
  - Landmarks act as location servers

Outline

- Motivation
- Hop ID and Distance Function
- Dealing with Dead Ends
- Evaluation
- Conclusion

Evaluation Methodology

- Simulation model
  - Ns2, not scalable
  - A scalable packet level simulator
    - No MAC details
    - Scale to 51,200 nodes
- Baseline experiment design
  - *N* nodes distribute randomly in a 2D square
  - Unit disk model: identical transmission range
- Evaluation metrics
  - Routing success ratio
  - Shortest path stretch
  - Flooding range

Evaluation Scenarios

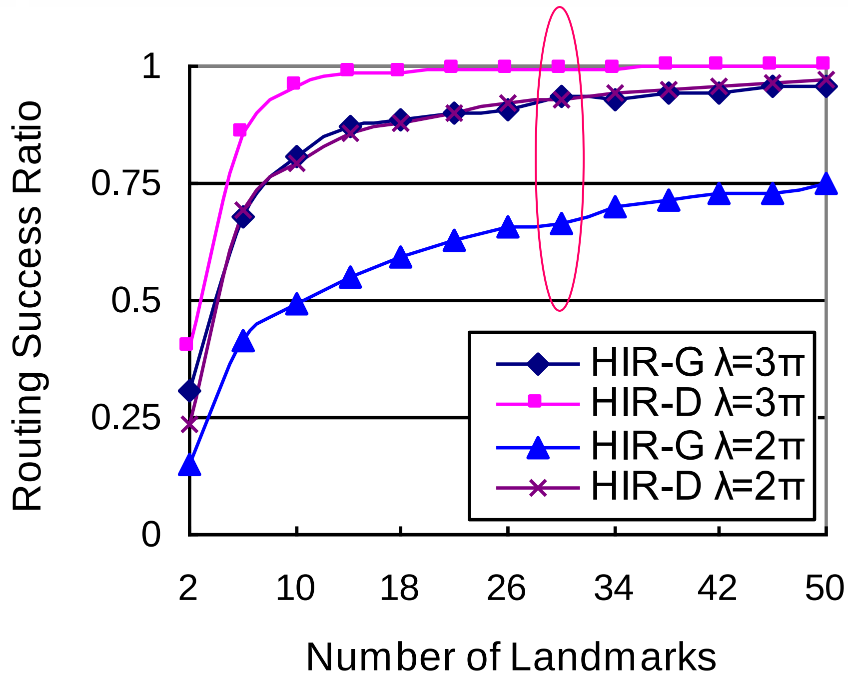
- Landmark sensitivity
- Density
- Scalability
- Mobility
- Losses
- Obstacles
- 3-D space
- Irregular shape and voids

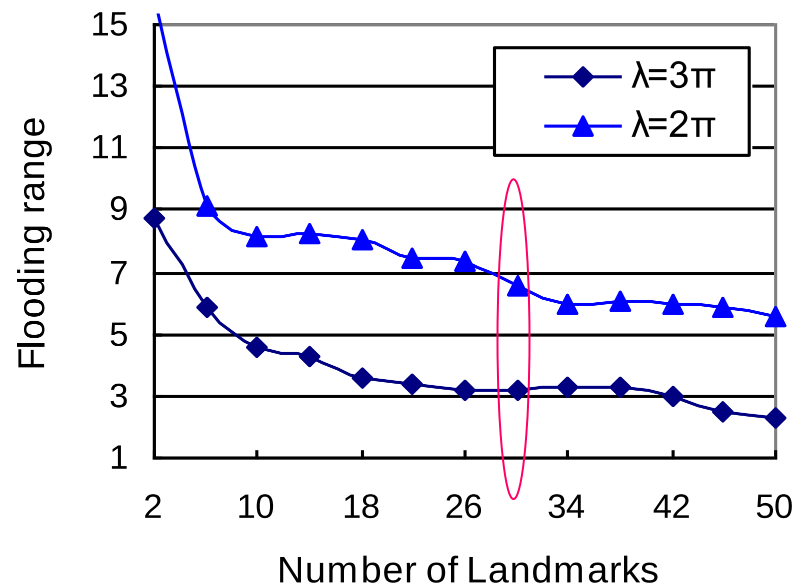
Simulated Protocols

- HIR-G: Greedy only
- HIR-D: Greedy + Detour
- HIR-E: Greedy + Detour + Expending ring
- GFR: Greedy geographic routing
- GWL: Geographic routing without location information [Mobicom03]
- GOAFR+: Greedy Other Adaptive Face Routing [Mobihoc03]

Number of Landmarks

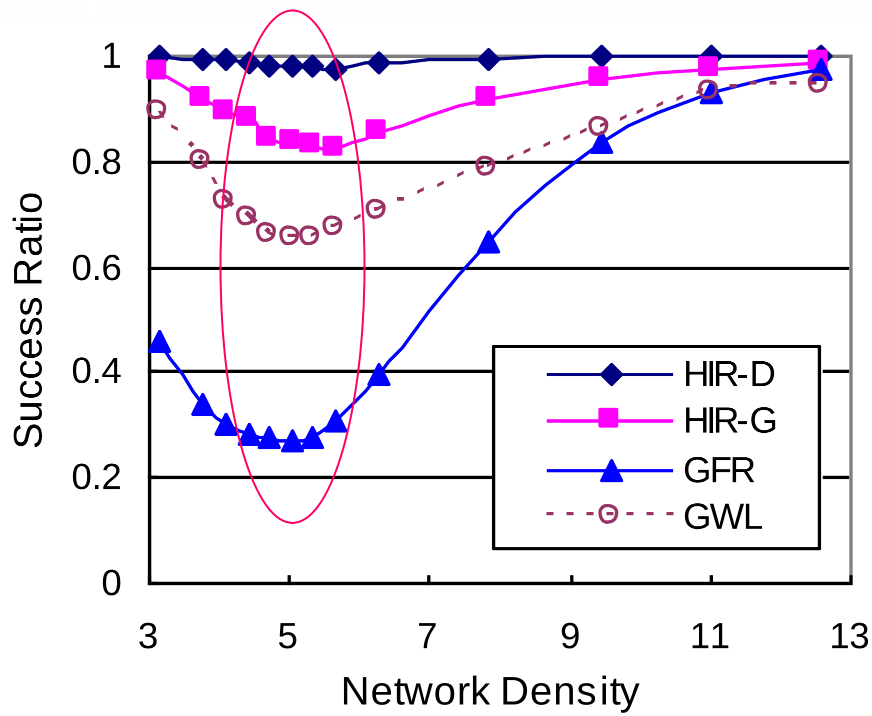
- 3200 nodes, density shows average number of neighbors
- Performance improves slowly after certain value (20)
- Select 30 landmarks in simulations

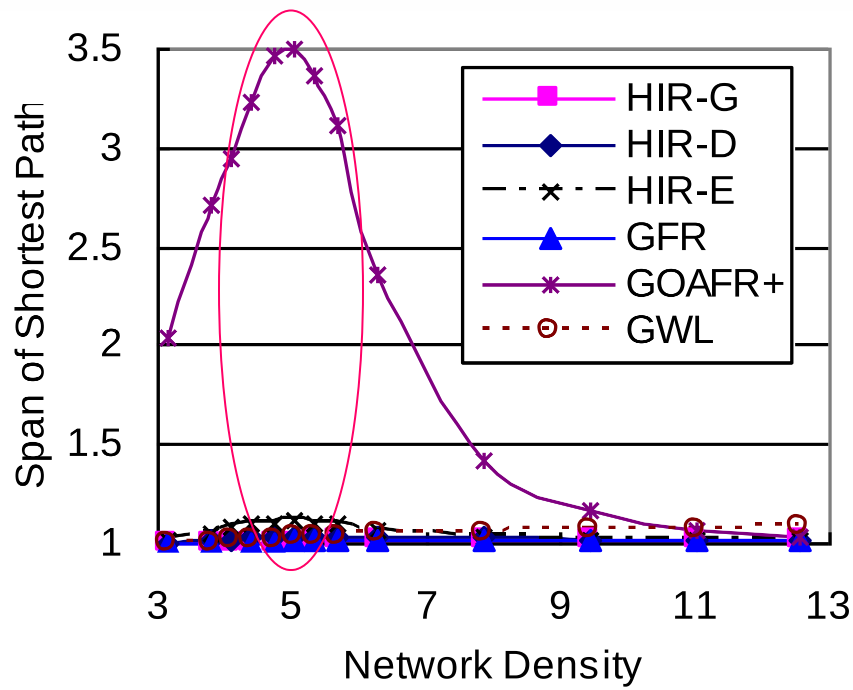




Density

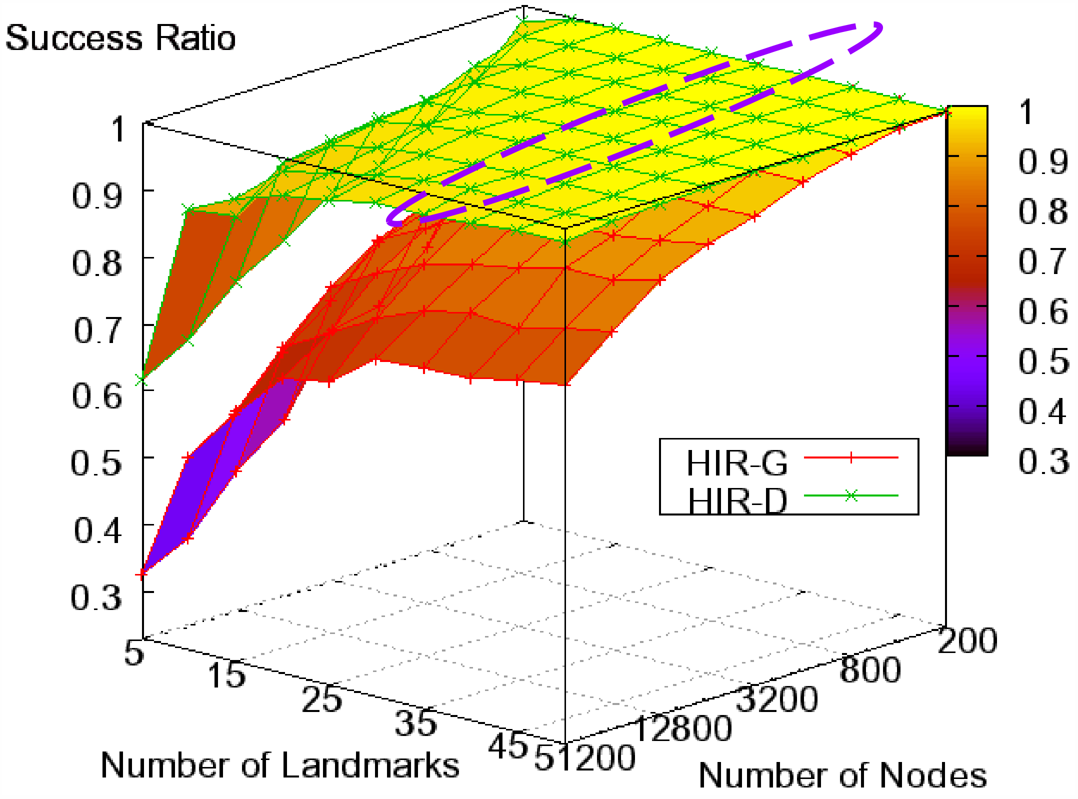
- HIR-D keeps high routing success ratio even in the scenarios with critical sparse density.
- Shortest path stretch of HIR-G & HIR-D is close to 1.





Scalability

- HIR-D degrades slowly as network becomes larger
- HIR-D is not sensitive to number of landmarks



Conclusions

- Hop ID distance accurately reflects the hop distance and
- Hop ID base routing performs very well in sparse networks and solves the dead end problem
- Overhead of building and maintaining Hop ID coordinates is low

Secure Wireless Communication

- Secure communication in high-speed WiMAX networks
  - Design secure communication protocols through formal methods and vulnerability analysis
  - Wireless network anomaly/intrusion detection
    - Separating noises, interference, hidden terminal problems, etc.

Future Work: Sensor Networks (1)

- Topology Control in Sensor Networks
  - Motivation
    - Optimize sensing coverage and communication coverage
  - Sensing coverage
    - Active nodes cover all the required area without holes
      - Let as many as possible nodes to sleep to save energy
  - Communication coverage
    - Select active nodes to form a well-connected network
      - Enable simple routing
      - Routing paths are good in terms of bandwidth, delay and energy cost

Future Work: Sensor Networks (2)

- Routing in Sensor Networks
  - Motivation
    - Optimize lifetime of sensors
    - Avoid hotspots
  - Proposed routing: Position-based routing
    - Distance metric takes energy cost into account, e.g., HopID

Future Work: Delay Tolerant Networks

- Applications
  - Interplanetary Internet
  - Spacecraft communications
  - Mobile ad hoc networks w/ disconnections (Zebranet)
  - Military/tactical networks
  - Disaster response
- Challenges
  - Stochastic Mobility
  - Sparse connectivity
    - May not have contemporaneous end-to-end path
  - Delay tolerability
    - With an upper bound of the delay (e.g., Mars: 40 min RTT)
  - Limited buffer size
- Focus: Routing and Message Delivery

Research methodology

Combination of theory, synthetic/real trace driven simulation, and real-world implementation and deployment

Microsoft Research

AT&T

Fermilab

SANS

Internet Storm Center

China Education and Research Network

中国教育和科研计算机网

Related Work to Dead End Problem

- Fix dead end problem
  – Improves face routing: GPSR, GOAFR+, GPVFR
  – Much longer routing path than shortest path
- Reduce dead ends

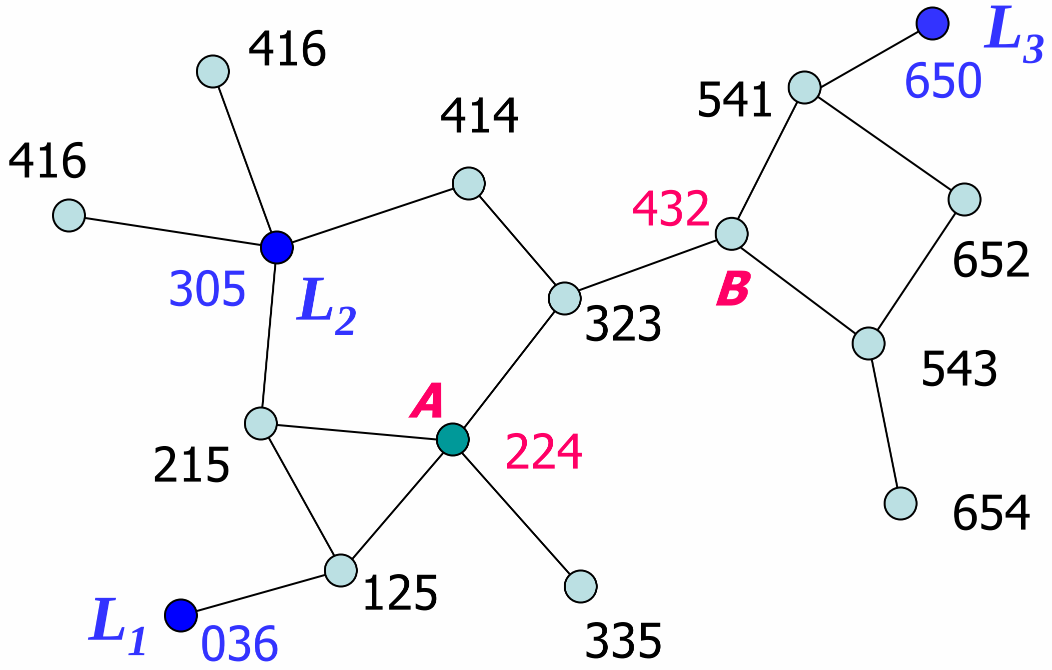
  "Geographic routing without location information" [Rao et al, mobicom03]
  – Works well in dense networks
  – Outperforms geographic coordinates if obstacles or voids exist
  – Virtual coordinates are promising in reducing dead ends
  – However, degrades fast as network becomes sparser

How Tight Are The Bounds?

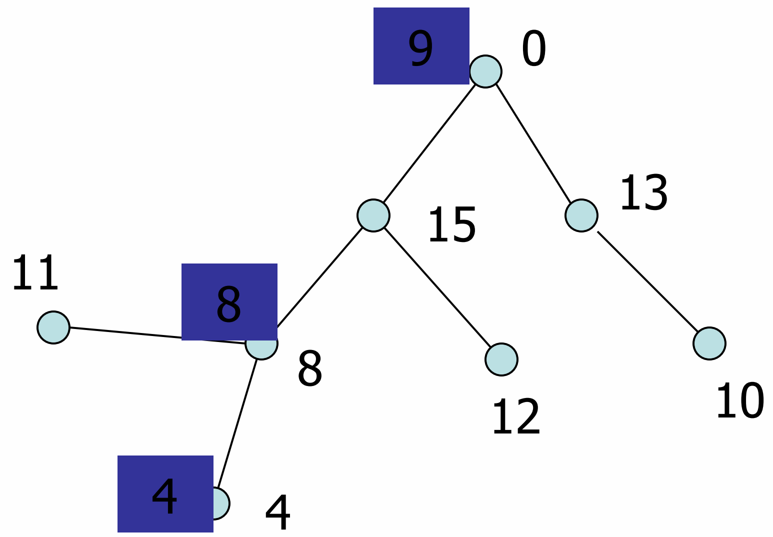
- Theorem [FOCS'04)]
  - Given a certain number (*m*) of landmarks, with high probability, for most nodes pairs, *L* and *U* can give a tight bound of hop distance
    - *m* doesn’t depend on *N*, number of nodes
  - Example: If there are *m* landmarks, with high probability, for 90% of node pairs, we have $U \leq 1.1L$

U Is Not Suitable for Routing

- If two nodes are very close and no landmarks are close to these two nodes or the shortest path between the two nodes, *U* is prone to be an inaccurate estimation
- $U(A, B) = 5$, *while* $d_h(A, B)=2$

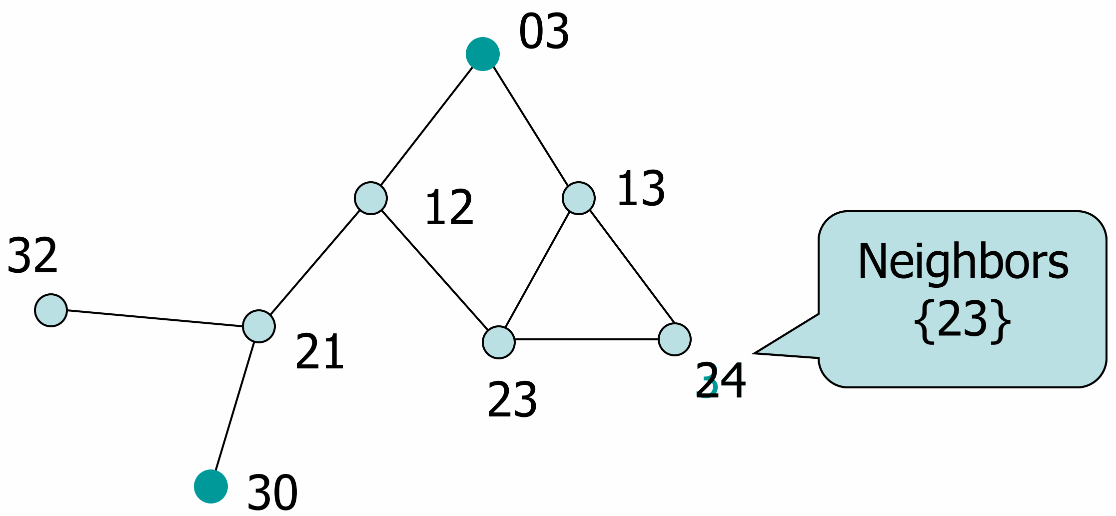


Landmark Selection



Hop ID Adjustment

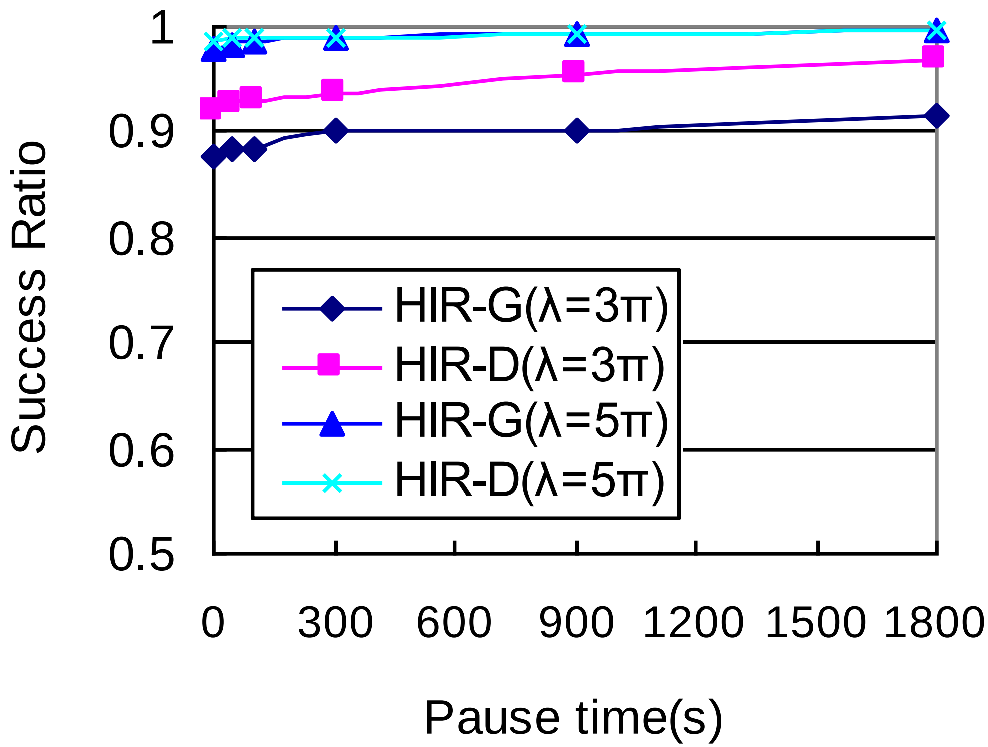
- Mobility changes topology
- Reflooding costs too much overhead
- Adopt the idea of distance vector



Build Hop ID System

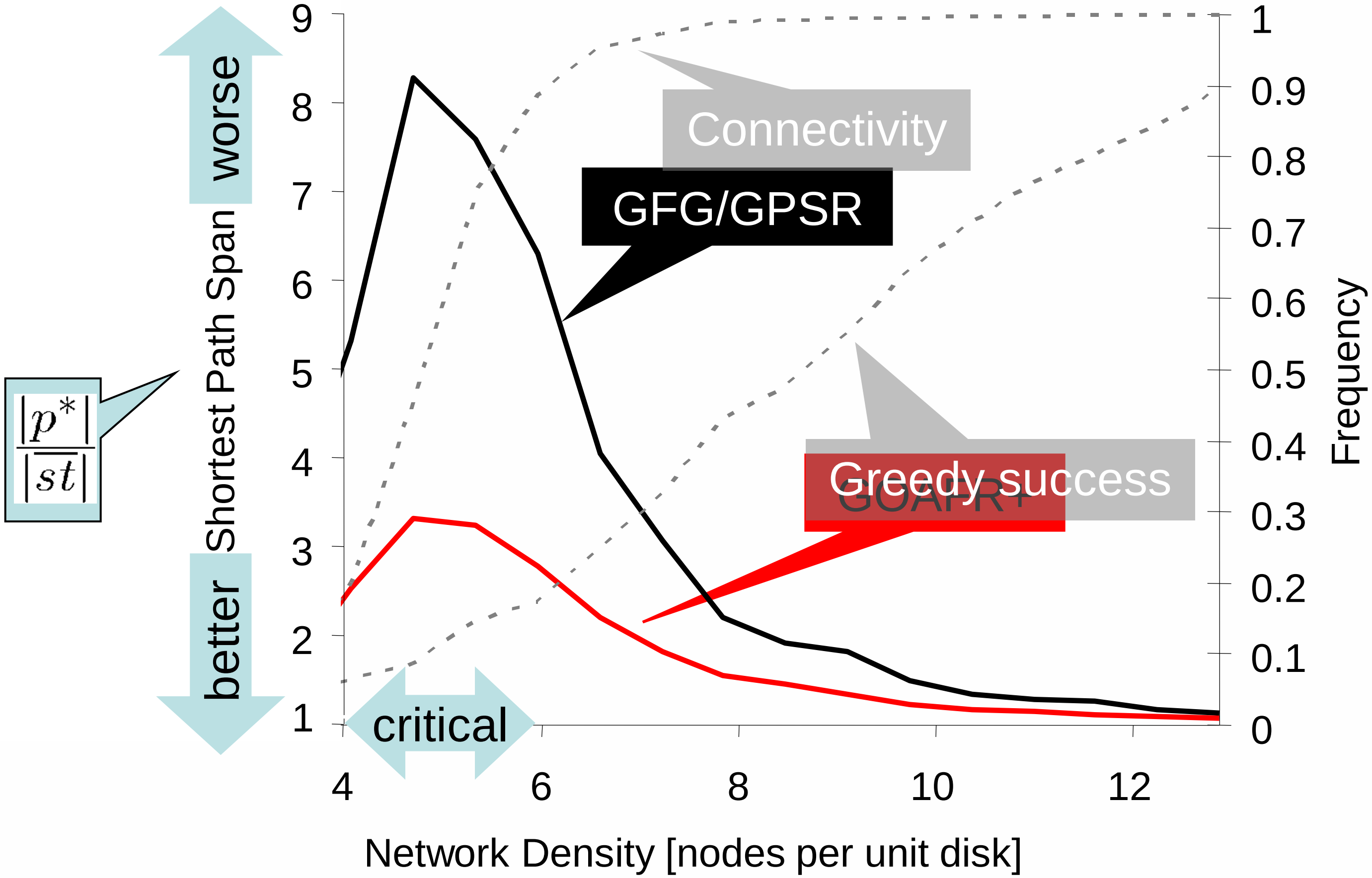
- Build a shortest path tree
- Aggregate landmark candidates
- Inform landmarks
- Build Hop ID
  - Landmarks flood to the whole network.
- Overall cost
  - O($m*n$), m = number of LMs, n=number of nodes

Mobility



Success Ratio
1
0.9
0.8
0.7
0.6
0.5
0
300
600
900
1200
1500
1800
Pause time(s)
HIR-G(λ=3π)
HIR-D(λ=3π)
HIR-G(λ=5π)
HIR-D(λ=5π)

Motivation



- Geographic routing suffers from dead end problem in sparse networks

Fabian Kuhn, Roger Wattenhofer and Aaron Zollinger, Mobihoc 2003

Virtual Coordinates

- Problem definition
  - Define the virtual coordinates
    - Select landmarks
    - Nodes measure the distance to landmarks
    - Nodes obtain virtual coordinates
  - Define the distance function
  - Goal: virtual distance reflects real distance
  - $d_v \approx c \cdot d_h$, c is a constant