Efficient Hop ID Based Routing for Sparse Ad Hoc Networks

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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

Geographic routing suffers from dead end problem in sparse networks.

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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 \((H_1^{(1)}, H_2^{(1)}, \ldots, H_m^{(1)})\)
- Hop ID of B is \((H_1^{(2)}, H_2^{(2)}, \ldots, H_m^{(2)})\)

\[
L = \text{Max}(| H_k^{(1)} - H_k^{(2)} |) \leq d_h \leq \text{Min}(H_k^{(1)} + H_k^{(2)}) = U
\]
Lower Bound Better Than Upper Bound

- One example: 3200 nodes, density $\lambda = 3\pi$
- Lower bound is much closer to hop distance

![Bar chart showing comparison between lower and upper bounds vs difference to hop distance. The lower bound is consistently closer to the hop distance across different difference categories.]
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

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

• 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 $\lambda=3\pi$
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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

- **Detour Mode**

- **Dead End**

- \( D_p(S, D) < D_p(L_2, D) \)

- \( D_p(S, D) > D_p(A, D) \)
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
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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
• 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
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 \(U \leq 1.1L\)
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
Motivation

- Geographic routing suffers from dead end problem in sparse networks

Fabian Kun, 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