Locating Nodes with EASE：Last Encounter Routing in Ad Hoc Networks through Mobility Diffusion

Matthias Grossglauser, Martin vetterli

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Outline

- Introduction
- EASE Algorithm
- Performance of EASE
- GREASE
- Simulation Result
- Discussion and Conclusion
- Reference

Introduction

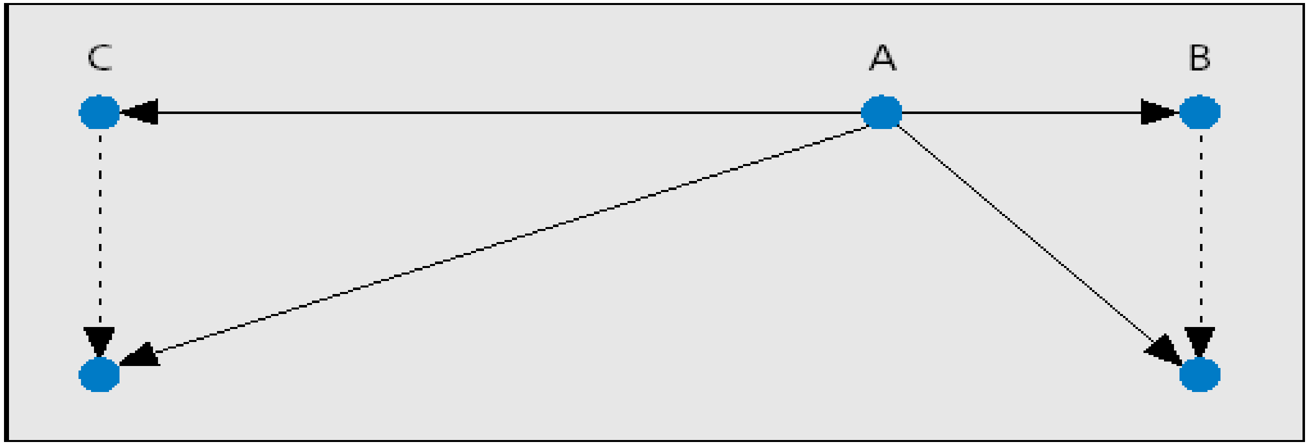
- Routing in mobile Ad Hoc network is a challenging task
  - Mobile ad hoc networks change Topology frequently and without prior notice
- Routing approaches
  - Topology-based
  - Position-based

Introduction

- Topology-based routing protocol
  - Proactive
  - Reactive
  - Hybrid
- Position(Graphic)-based routing protocol
  - Location
  - Routing

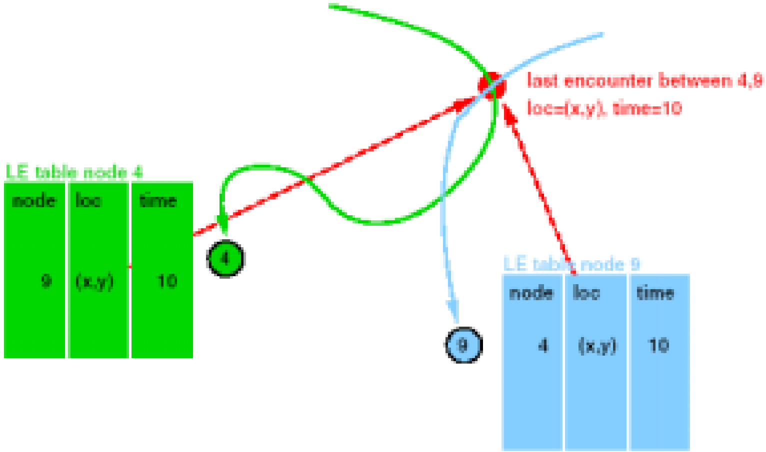
Introduction

- Distance effect
  - allow low spatial resolution in area far away the target node



Introduction

- Last encounter routing (LER)
  - If that every node along a packet's route, the next hop decision depends only on
    - The time and location of the node's last encounter with the destination and
    - Auxiliary information carried by the packet



Introduction

- Three observation explain why LE routing can give rise to efficient routes:
  - The location of the last encounter is still a reasonably good estimate
  - The time(age) of that encounter is a measure for the precision of that estimate
  - Node I's own mobility means that a recent estimate of d's position is available at some distance from d

EASE Algorithm

- Topology
  - Two dimensional square grid of vertices M^2
  - Distance: Manhattan distance $|x_2 - x_1| = |x_2^1 - x_1^1| + |x_2^2 - x_1^2|$
- Routing

$$T_i(t) = t - \max_{\tau \le t} \{ X_i(\tau) - X_1(\tau) \le 1 \} \qquad X_1 = \text{destination}$$

- Time scales
  - Minutes or longer
- Cost metric
  - $C(s,d,t)$ include both transmissions from source to destination and transmission of ”search” packet.

EASE Algorithm

Algorithm 1: The EASE algorithm

1 Set $T_0 := T_s(0)$, $Y_0 := X_s(0)$, $k := 0$.
2 Repeat
3   Search the nodes around Y_k in order of increasing distance until a node i is found such that $T_i(0) \leq T_k/2$.
4   Let $T_{k+1} = T_i(0)$, and $Y_{k+1} := X_1(-T_{k+1})$ be the new anchor point.
5   While not at Y_{k+1}
6   Route packet: find next hop j towards Y_{k+1} and forward packet to j.
7   End while
8     $k++$.
9 Until $Y_k = X_1(0)$.

Performance of EASE

- Claim : For two arbitrary nodes s and d, the route from s to d calculated by the EASE algorithm satisfies

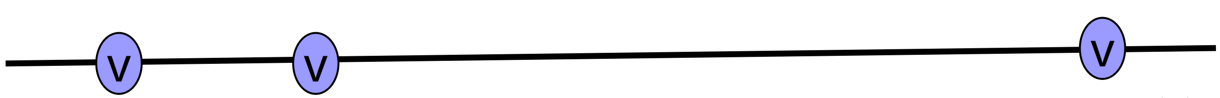
$$E\left|C(s,d,t)\right| = O(\sqrt{N})$$

- The expected distance between a randomly selected node pair is also on the order of $\sqrt{N}$

Performance of EASE

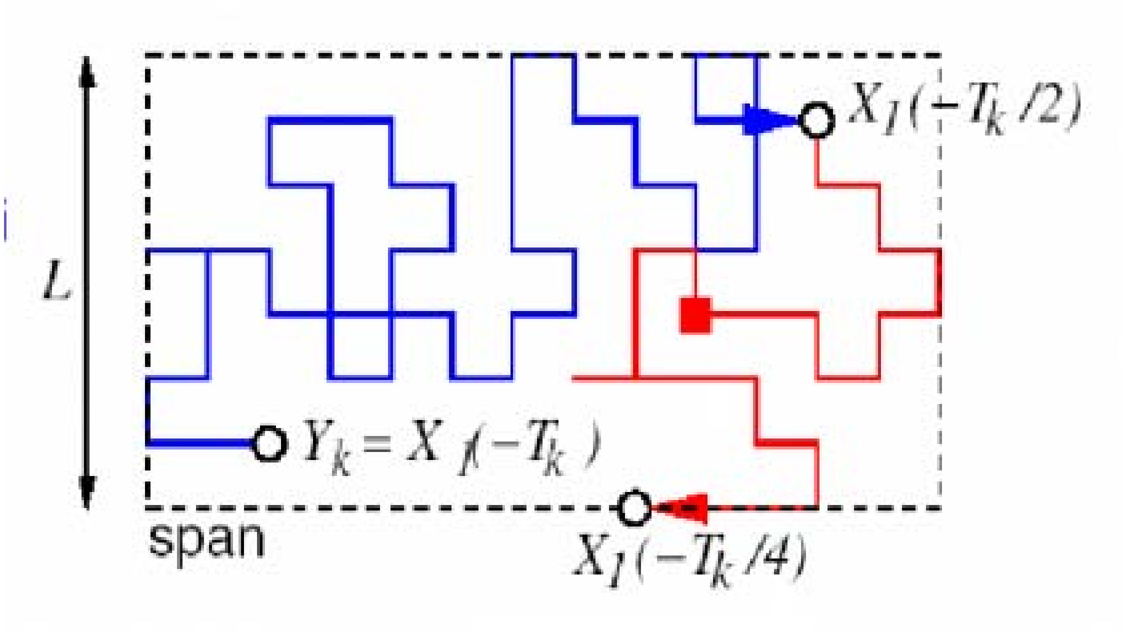
- Definition
  - Search box: a set of S nodes centered an node i (including node i),
    - side length: $\sqrt{\frac{S}{\lambda}}$ $\lambda =$ number of nodes per grid position
  - Span of the random walk:
    - One-dimensional

$$R_s(t) \equiv x_{\max}(t) + x_{\min}(t)$$



Performance of EASE

- Span of Two-dimensional walk



Performance of EASE

- Single search step
- Messenger node
  - At K_{th} iteration , node i that is the neighbor of the destination node at some time $-t$ between $-t_k/2$ and $-t_k/4$.
  - The order of L= $O\sqrt{T_k}$

Performance of EASE

- Hitting probability of a single messenger node
  - Worst case: the messenger node starts in one corner of the span at the latest possible time.

$$\begin{aligned} p &= \Pr\left\{ X_i^d(0) - X_i^d(-T_k/4) \in \left[L - \sqrt{\frac{S_k}{\lambda}}, L \right] \right\} \\ &= \Pr\left\{ \frac{X_i^d(0) - X_i^d(-T_k/4)}{\sigma\sqrt{T_k/4}} \in \right. \\ &\qquad \left. \left[\frac{L - \sqrt{S_k/\lambda}}{\sigma\sqrt{T_k/4}}, \frac{L}{\sigma\sqrt{T_k/4}} \right] \right\} \\ &= Q\left(\frac{L - \sqrt{S_k/\lambda}}{\sigma\sqrt{T_k/4}} \right) - Q\left(\frac{L}{\sigma\sqrt{T_k/4}} \right) \\ &\approx \frac{16}{\sigma}\sqrt{\frac{S_k}{\lambda T_k}}\phi\left(\frac{2}{\sigma}\right) = c\sqrt{\frac{S_k}{T_k}}, \end{aligned}$$

$$p_{hit} = p^2 = c^2 \frac{S_k}{T_k}.$$

Performance of EASE

- Number of messenger nodes
  - We need to compute the size of the set of (distinct) nodes W encountered by the destination
  - The probability that node i and 1 don't encounter each other again within T_k steps after a first encounter

    =the difference random walk $X_1(T_k)$ –Xi(Tk) doesn't return to the origin within Tk steps

    $$= O(\frac{1}{\log T_k})$$

    $$\Rightarrow \|W\| = \Theta(\frac{T_k}{\log T_k})$$

Performance of EASE

- Hitting probability for any messenger node

$$p_{any} = 1-(1-p_{hit})^{\|W\|} \approx\sim 1-(1-\frac{S_k}{T_k})^{\frac{T_k}{\log T_k}}$$

$$\lim_{N\to\infty}\frac{S_k}{C(Y_k, Y_{k+1}, 0)} = 0$$

S_k is on the order of $\log T_k$,

$C(Y_k, Y_{k+1}, 0)$ is on the order of $\sqrt{T_k}$

Performance of EASE

- Total cost

$$C(s,d,0)=\sum_{k=0}^{K-2} C(Y_k,Y_{k+1},0)+S_k+C(Y_{K-1},X_d(0),0)$$

k is the number of steps required to reach the destination

  - Because typical age $T_s(0)$ is O(N) and the first EASE step is therefore of typical length $|Y_0-Y_1|=O(\sqrt{N})$
  - Its sum converges and is therefore $O\sqrt{N}$

Performance of EASE

- Problem :
  - if L happens to be atypically large, then the search box is atypically large
- Solution:
  - Find a node i such that either

$$\text{(a)} \quad T_i(0) < \frac{T_k}{2}$$

$$\text{(b)} \quad T_i(0) < T_k \text{ and } \left| X_1(-T_i(0) - Y_k \right| > c\sigma\sqrt{T_k}$$

Performance of EASE

- Some qualitative properties of the node mobility processes that make LER succeed
  - The distance traveled by the messenger nodes
  - The density of messenger nodes within the span

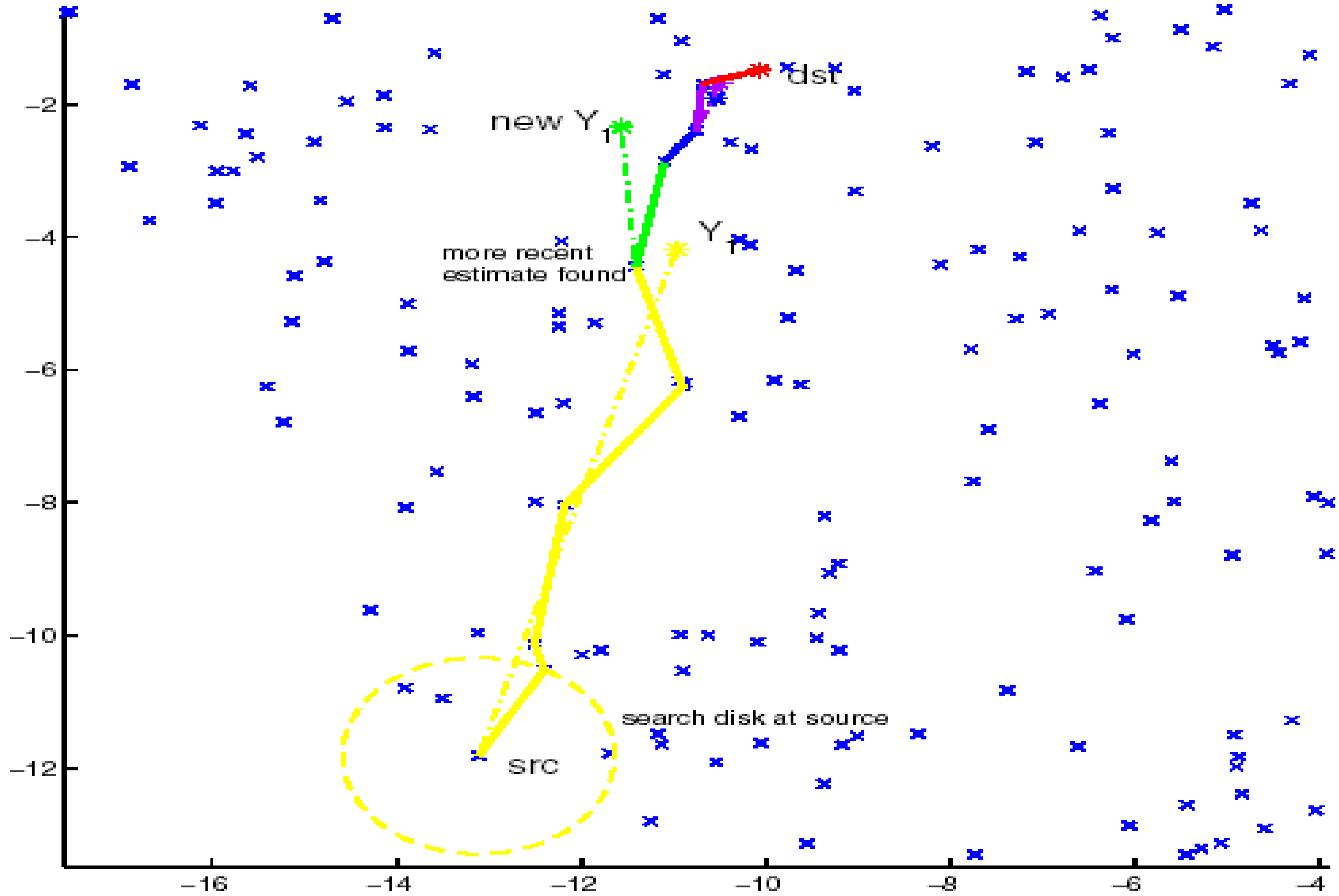
GREASE Algorithm

- Two phase
  - Search
  - Route

Algorithm 2: The GREASE algorithm

1 Set $T_0 := T_s(0)$, $Y_0 := X_s(0)$, $k := 0$.
2 Repeat
3   Search the nodes around Y_k in order of increasing distance until a node i is found such that $T_i(0) \leq T_k/2$.
4   Let $T_{k+1} = T_i(0)$, and $Y_{k+1} := X_1(-T_{k+1})$ be the new anchor point.
5   While not at Y_{k+1}
6   Route packet: find next hop j towards Y_{k+1} and forward packet to j.
7   If $T_j(0) \leq T_{k+1}$, then $T_{k+1} := T_j(0)$, $Y_{k+1} := X_1(-T_{k+1})$.
8   End while
9     $k++$.
10 Until $Y_k = X_1(0)$.

GREASE Algorithm

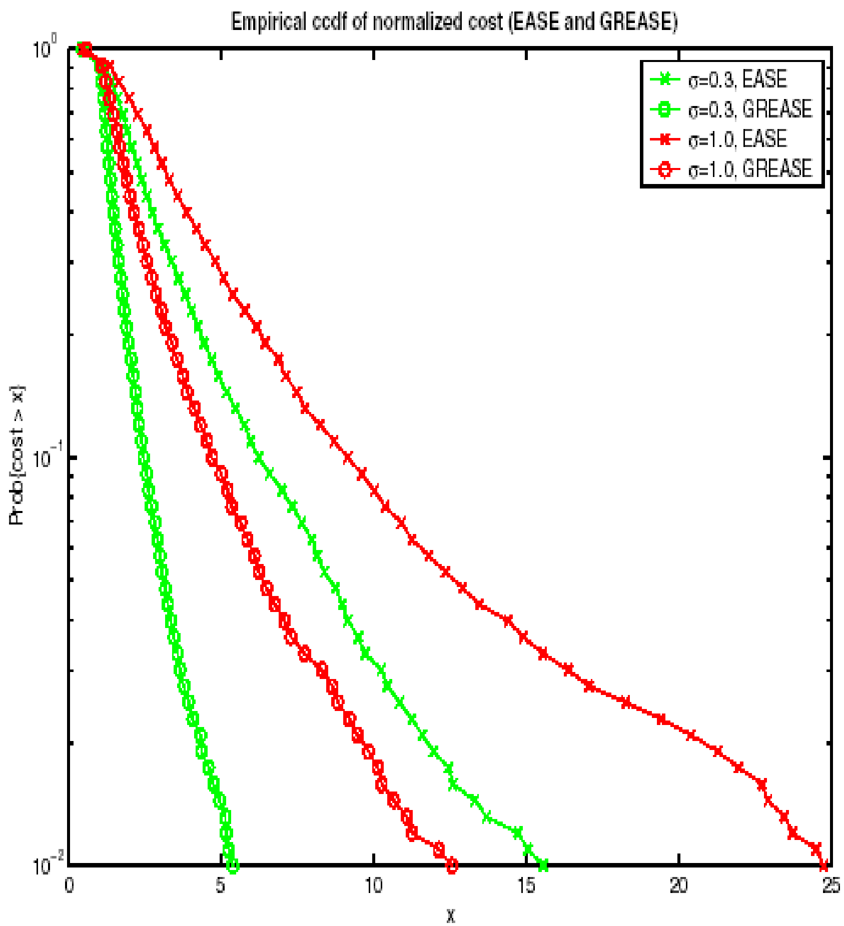


Simulation Results

- EASE and GREASE are compared to the shortest path between the source and destination
- Difference mobility processes
  - Small versus large variances
  - Homogeneous versus heterogeneous
  - Various single step distributions including heavy tailed ones
  - Random waypoint mobility

Simulation Results

Gaussian increments, homogeneous mobility



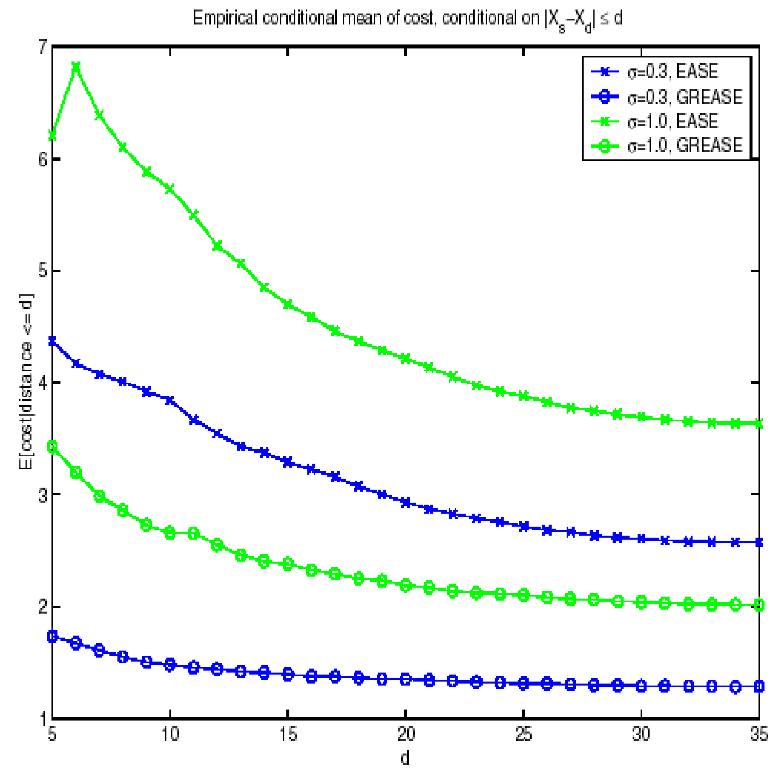


Fig. 7. The empirical conditional mean of the normalized cost, conditional on the initial source-destination distance $|X_s(0) - X_d(0)| \leq d$, plotted as a function of d.

Simulation Results

Gaussian increments, heterogeneous mobility

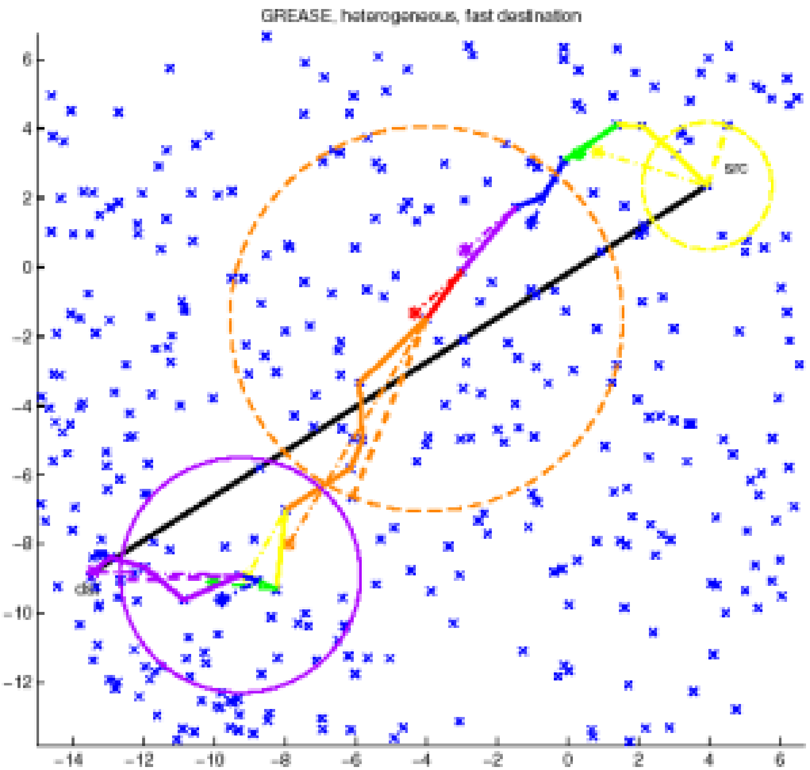


Fig. 8. A sample route for a fast destination with $\sigma_{fast} = 0.5$. Note that GREASE invokes searches around its current anchor point several times, and that the route is relatively long.

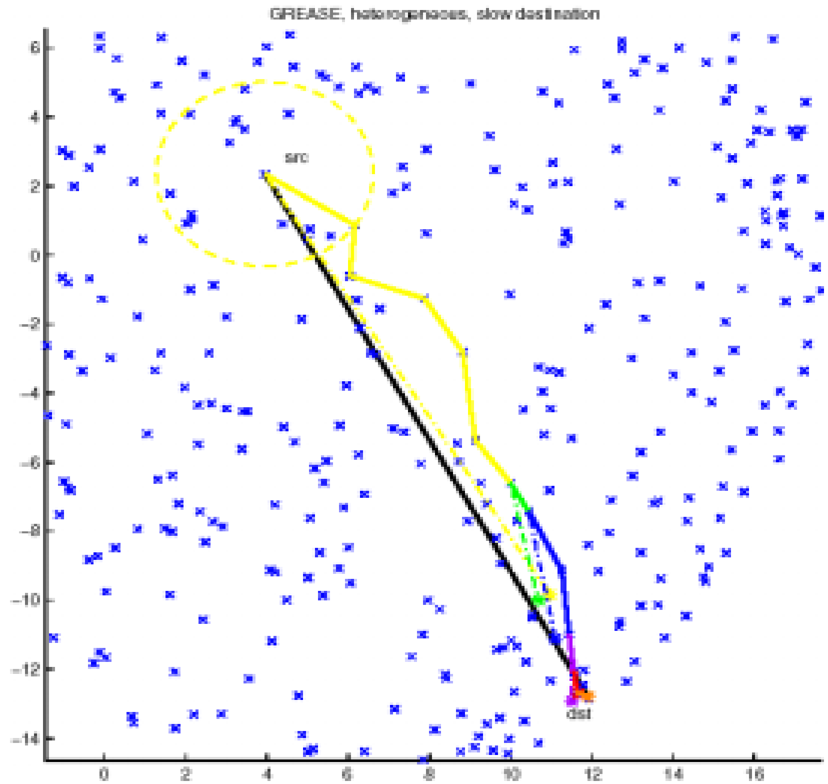
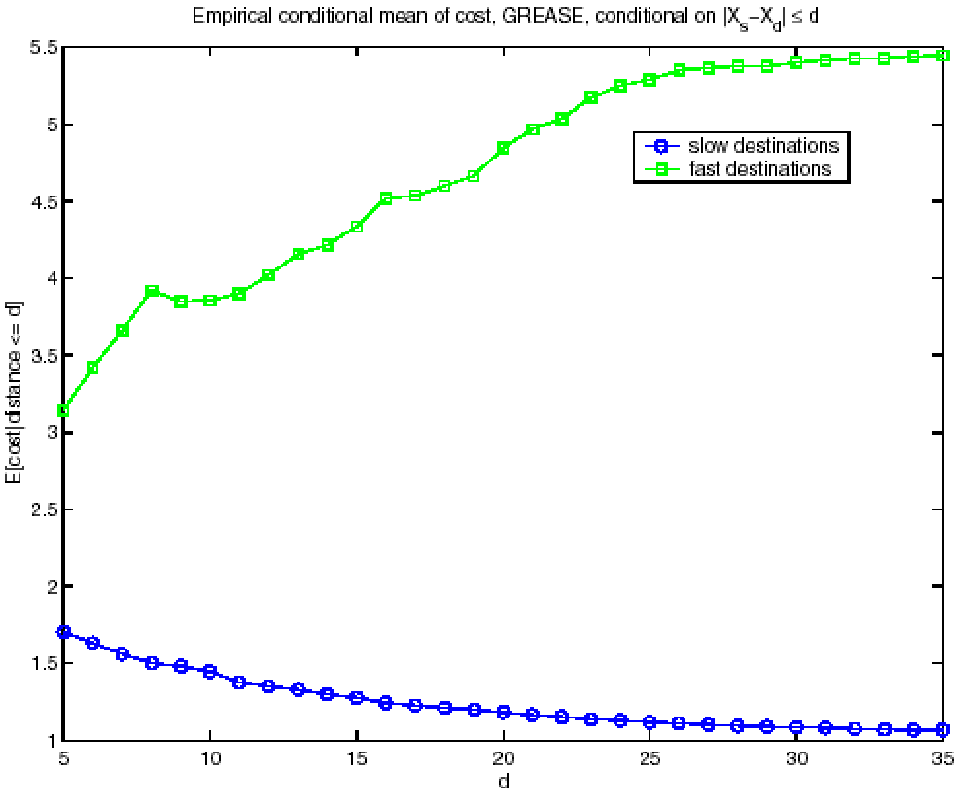


Fig. 9. A sample route for a slow destination with $\sigma_{slow} = 0.05$. Note that GREASE invokes no local searches beyond the initial search around the source, and the route is very efficient.

Simulation Results

Gaussian increments, heterogeneous mobility



Simulation Results

Infinite-variance increments and random waypoints

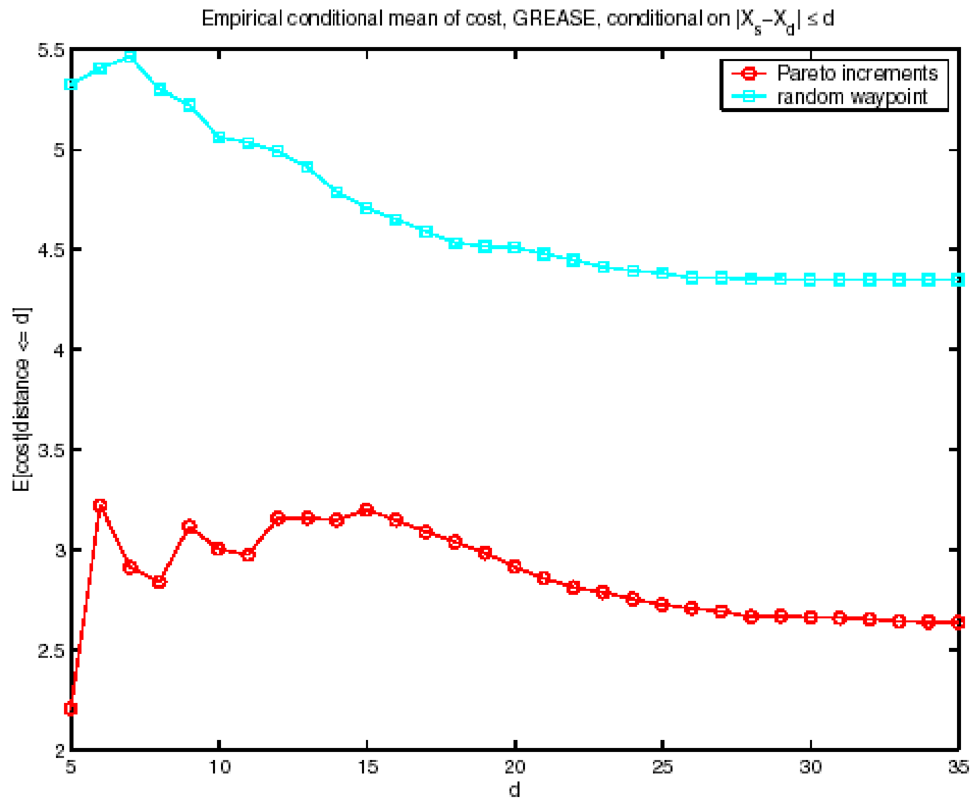


Fig. 11. The empirical conditional mean of the normalized cost, conditional on the initial source-destination distance $|X_s(0) - X_d(0)| \le d$, plotted as a function of d, for (1) heavy tailed single step distributions; (2) random waypoints.

Discussion and Conclusion

- This paper defines last-encounter routing, a scheme that solely relies on information carried by a packet
  - LER uses no network capacity to explicit update location information
- Mobility diffusion exploit three salient features of the node mobility processes
  - Locality
  - Mixing
  - homogeneity

Discussion and Conclusion

- Several way to further improve the performance of LE routing
  - Use packet-based diffusion
  - Mobility has more temporal structure than a random walk,
    - Estimation based on the whole path of the packet from the source to the current position.

Reference

[1] F. Baccelli, K. Tchoumatchenko, and S.Zuyev. Markov Paths on the Poisson-Delaunay Graph with applications to routing in mobile networks. *Advances in Applied Probability*, 32(1), 2000.

[2] S. Basagni, I. Chlamtac, and V. R. Syrotiuk. A Distance Routing Effect Algorithm for Mobility (DREAM). In *ACM MOBICOM 98*, Dallas, Texas, October 1998.

[3] P. Bose, P. Morin, I. Stojmenovic, and J. Urrutia. Routing with guaranteed delivery in ad hoc wireless networks. In *3rd Int'l Workshop on Discrete Algorithms and Methods for Mobile Computing and Communications*, Seattle, August 1999.

[4] S. Giordano and M. Hamdi. Mobility Management: The Virtual Home Region. Technical Report No. SSC/1999/037, EPFL, Lausanne, Switzerland, October 1999.

[5] P. Gupta and P. R. Kumar. The Capacity of Wireless Networks. *IEEE Transactions on Information Theory*, 46(2):388–404, March 2000.

[6] P. H. Hsiao. Geographical Region Summary Service for Geographical Routing. *Mobile Computing and Communications Review*, 5(4):25–39, January 2002.

[7] R. Jain, A. Puri, and R. Sengupta. Geographical Routing Using Partial Information for Wireless Ad Hoc Networks. *IEEE Personal Communications*, 8(1):48–57, February 2001.

Reference

[8] B. Karp and H. T. Kung. Greedy Perimeter Stateless Routing for Wireless Networks. In *ACM MOBICOM 2000*, Boston, Mass., August 2000.

[9] J. Li, J. Jannotti, D. S. J. De Couto, D. R. Karger, and R. Morris. A Scalable Location Service for Geographic Ad Hoc Routing. In *ACM MOBICOM 00*, Boston, Mass., August 2000.

[10] M. Mauve, J. Widmer, and H. Hartenstein. A Survey on Position-Based Routing in Mobile Ad Hoc Networks. *IEEE Network Magazine*, 15, November 2001.

[11] Charles E. Perkins. *Ad Hoc Networking*. Addison-Wesley, Boston, 2001.

[12] Frank Spitzer. *Principles of Random Walk (2nd ed)*. Springer Verlag, 1976.

[13] G. H. Weiss. *Aspects and Applications of the Random Walk*. (H. E. Stanley and E. Guyon, ed.). North-Holland, 1994.

[14] V. W. S. Wong and V. C. M. Leung. An adaptive distance-based location update algorithm for next-generation PCS networks. *IEEE Journal on Selected Areas of Communications*, 19(10), October 2001.