A Parsimonious Model of Mobile Partitioned Networks with Clustering

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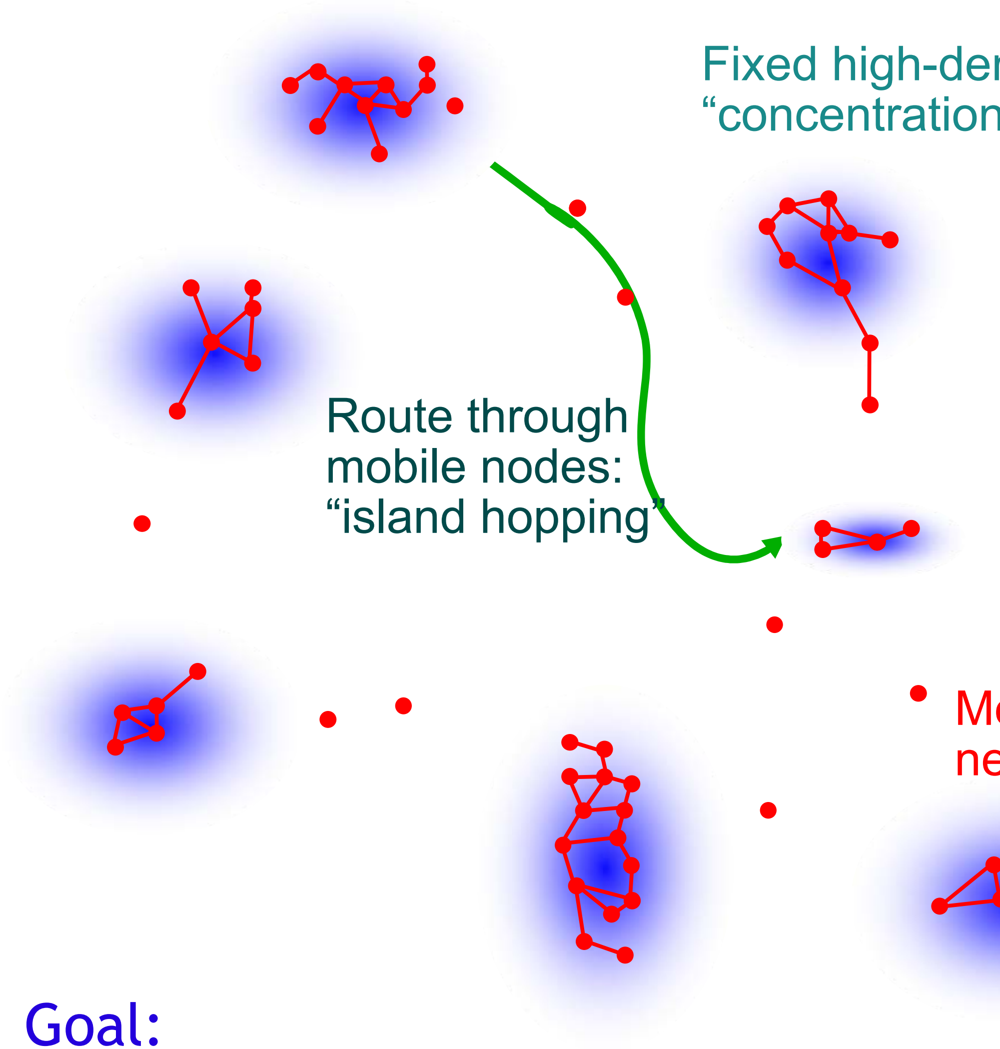
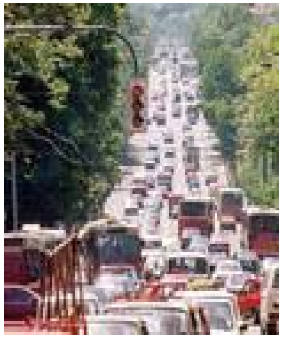
Models and Algorithms for Mobile Networks

Models and Algorithms for Mobile Networks

- Mobile Wireless Networks are different:
  - No wires -> no links
  - Mobility -> uncertainty
  - Heterogeneity -> partition
- Contribution
  - A simple & tractable model capturing heterogeneity in connectivity and in mobility
  - Validation through data
  - Insights into DTN routing design space

Routing in Partitioned Networks

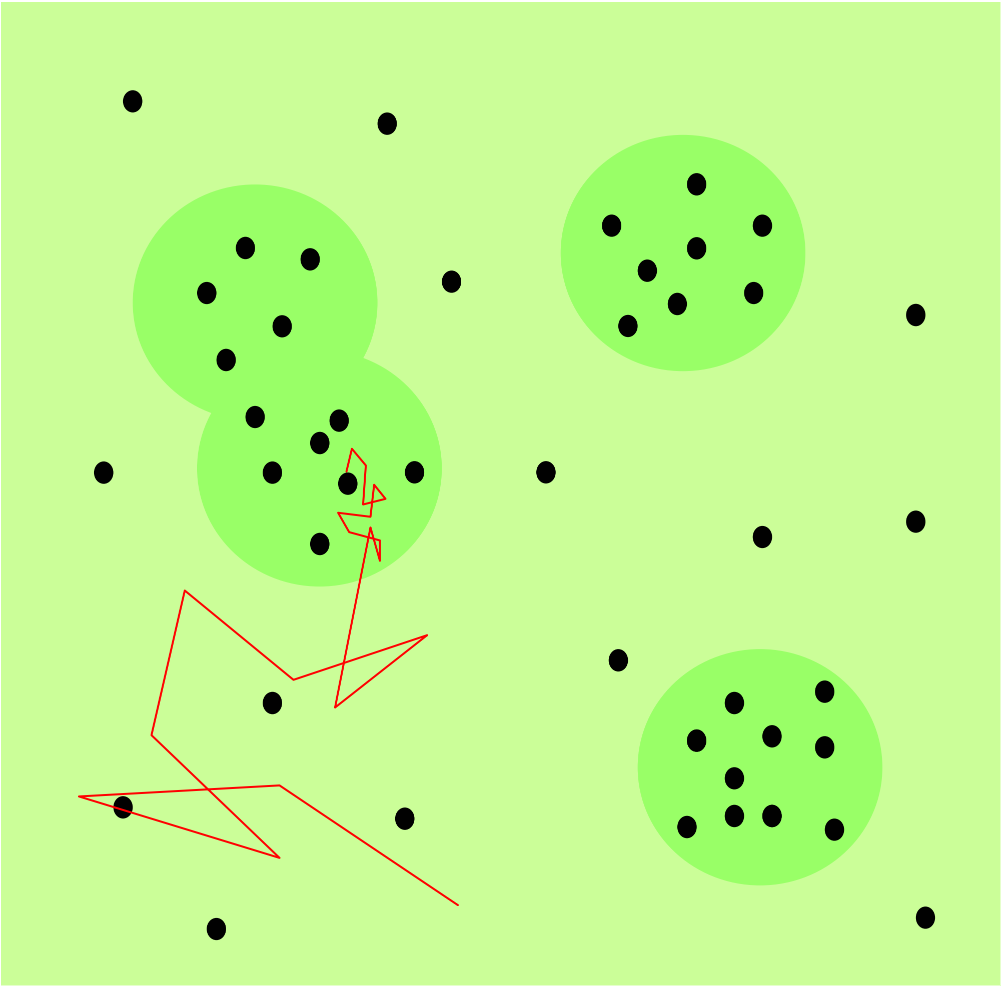




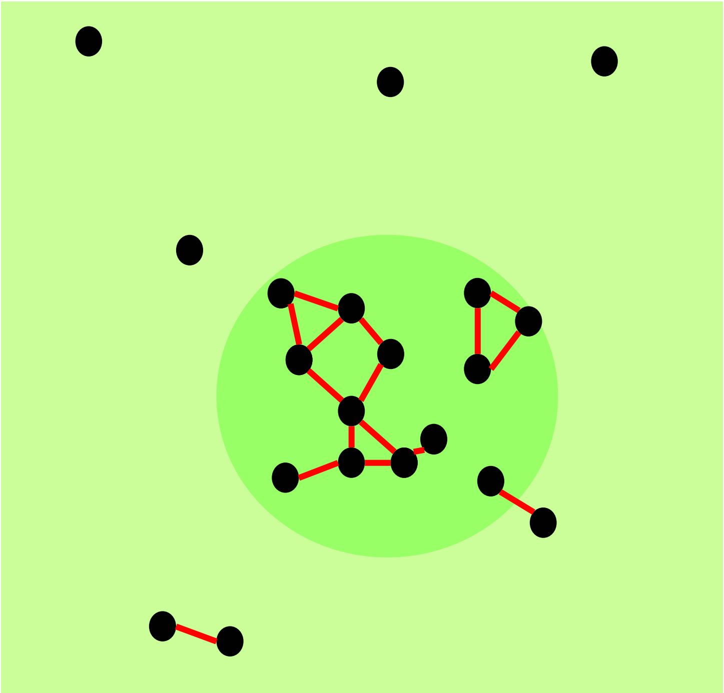
- Goal:
  - Designing robust DTN routing algorithms

Heterogeneous Random Walk Model

- Definition:
  - n nodes on square torus
  - Each node performs independent (scaled) Brownian motion
  - Fixed regions A_l where mobility is slower, and A_h where it is faster
  - For example, A_l = m random disks



HRW Model: Main Properties

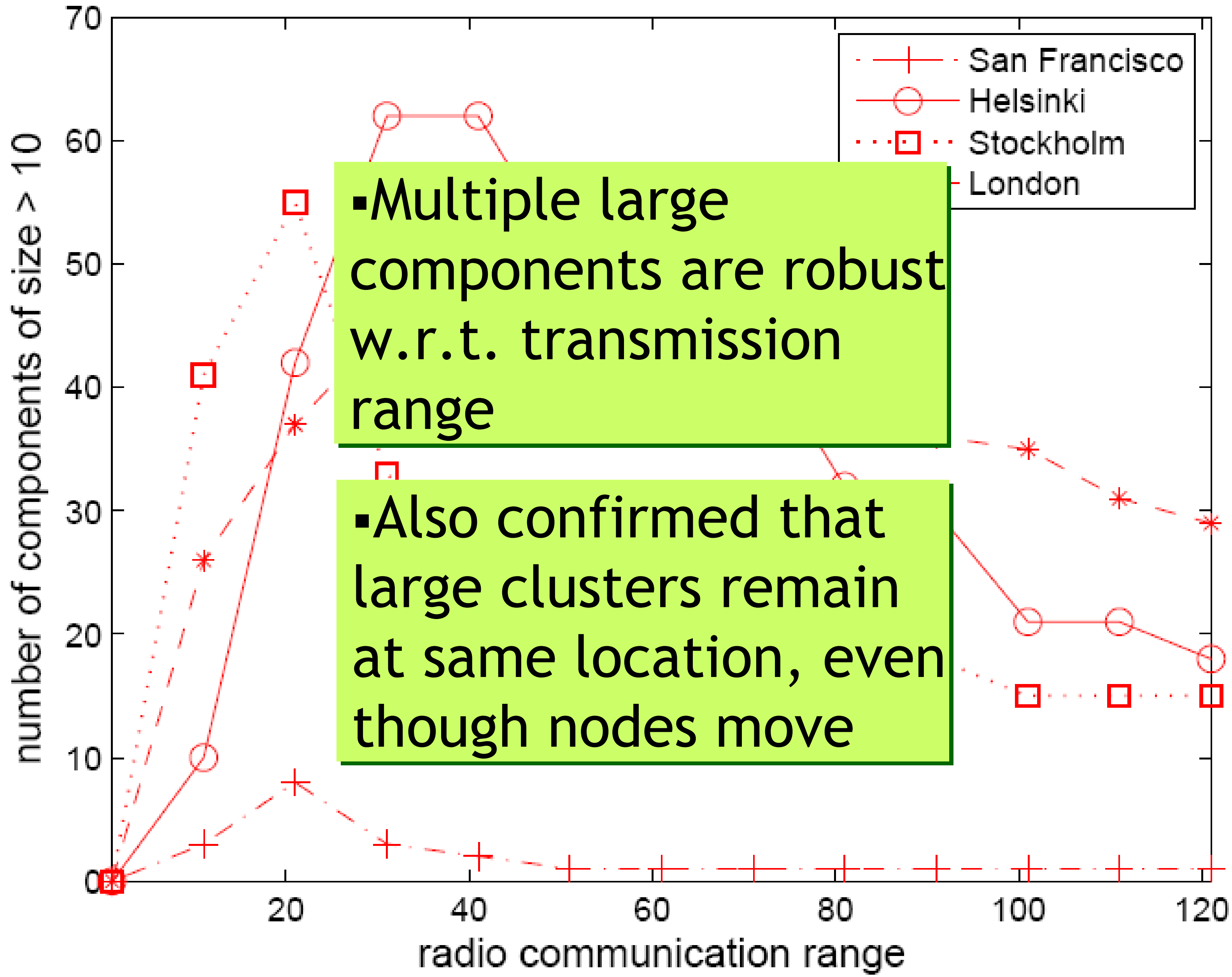


- Stationary distribution
  - $\pi_{l,h} \sim \sigma_{l,h}^{-2}$
  - Density inverse of speed
- Connectivity
  - Rich connectivity inside A_l, scarce connectivity outside
  - Continuous percolation: ensure supercritical density in A_l, subcritical in A_h
  - $\lambda_{l,h} r^2 = n\, \sigma_{l,h}^{-2}\, r^2 <> (\lambda r^2)_{cr} \approx 1.43$
- Discrete-time version and "perfect simulation"
  - Correction when crossing boundary
  - Starting simulation without transient

Validation

- Data set:
  - Fine-grained mobility of taxi cabs in the San Francisco Bay Area
  - 500 cars over one month
  - Position updates approx. every 10 sec
  - Other traces from Nokia Sportstracker dataset
- Verifying features of model:
  - Robustness and stability of clusters (persistent components)
  - Similarity of node mobility patterns
  - Speed-density relationship

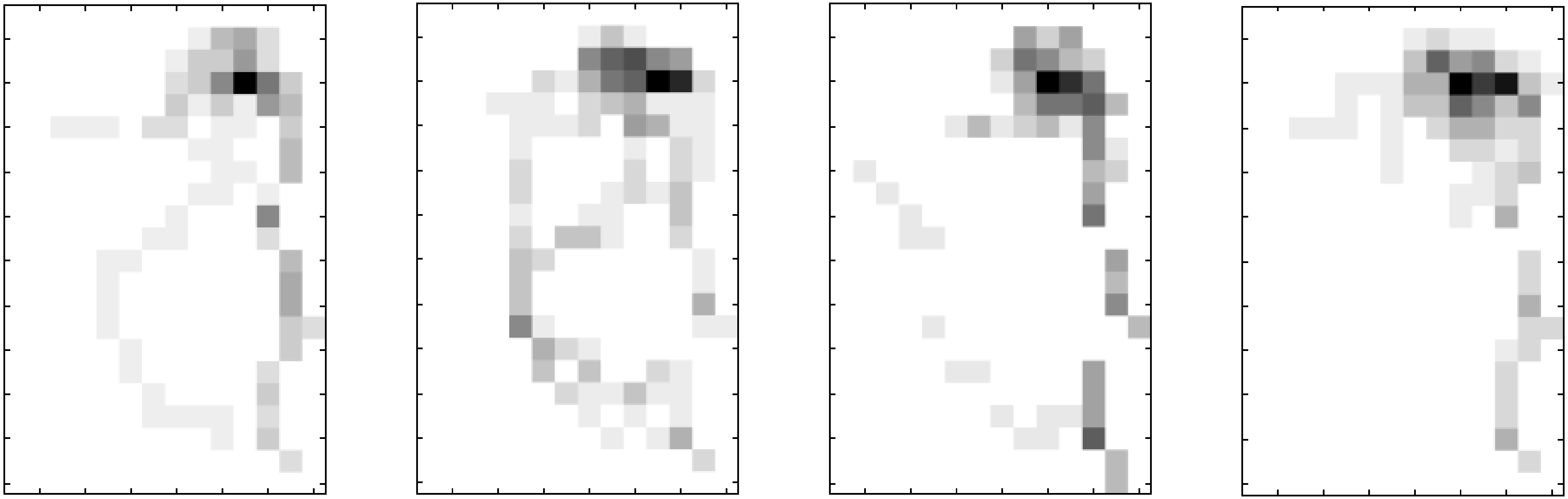
Number of Components vs Radio Range



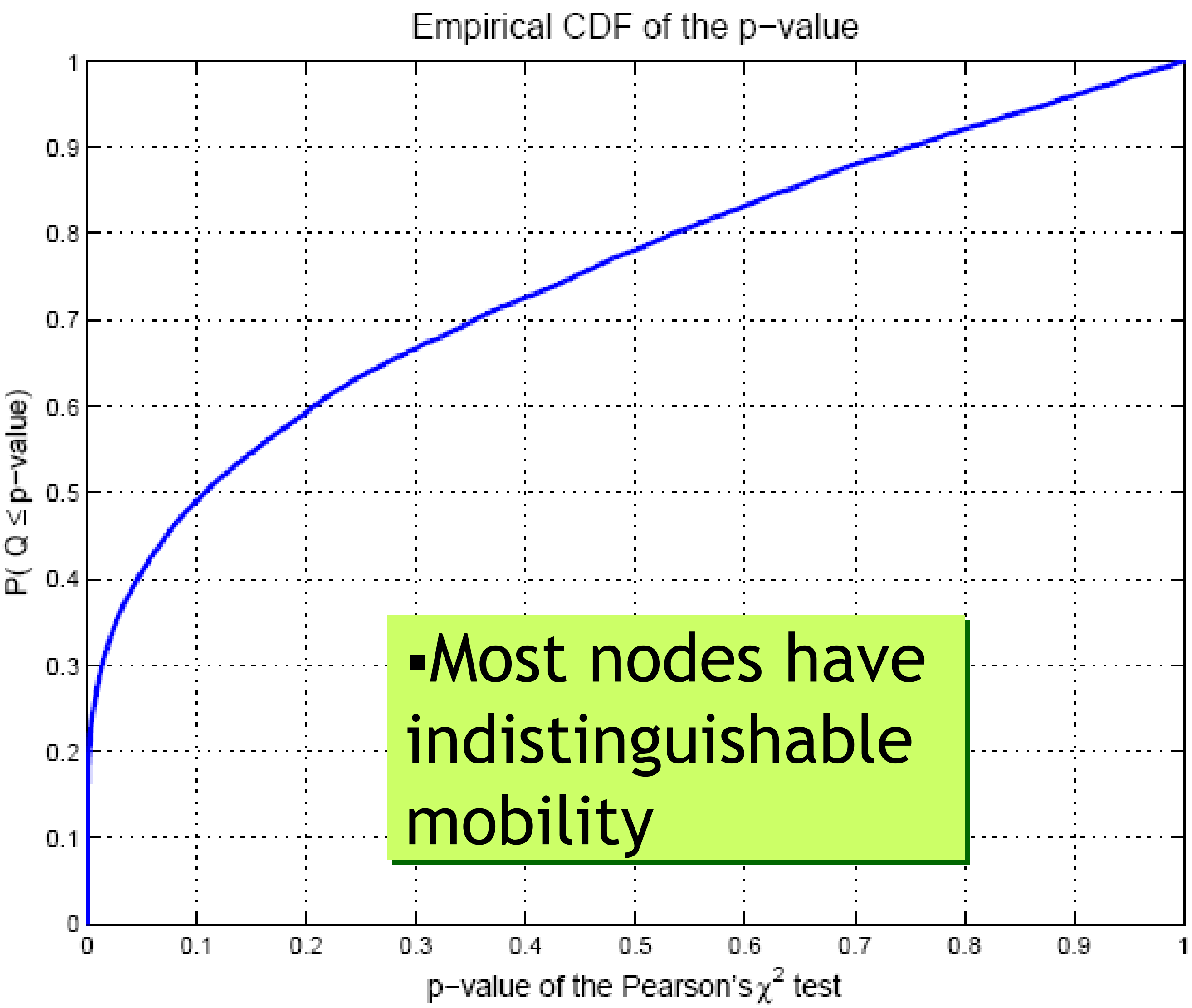
- Multiple large components are robust w.r.t. transmission range
- Also confirmed that large clusters remain at same location, even though nodes move

Statistical Similarity of Node Mobility

- One-day snapshots of individual visits to cells

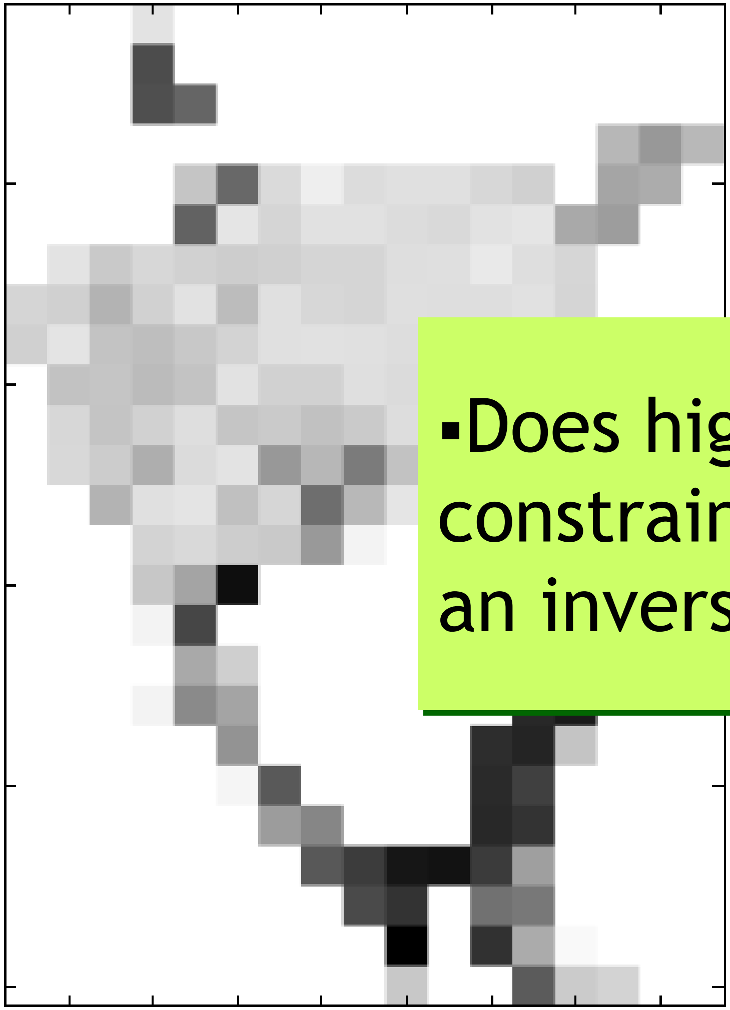


X^2-Test: Similarity of Marginal Distributions



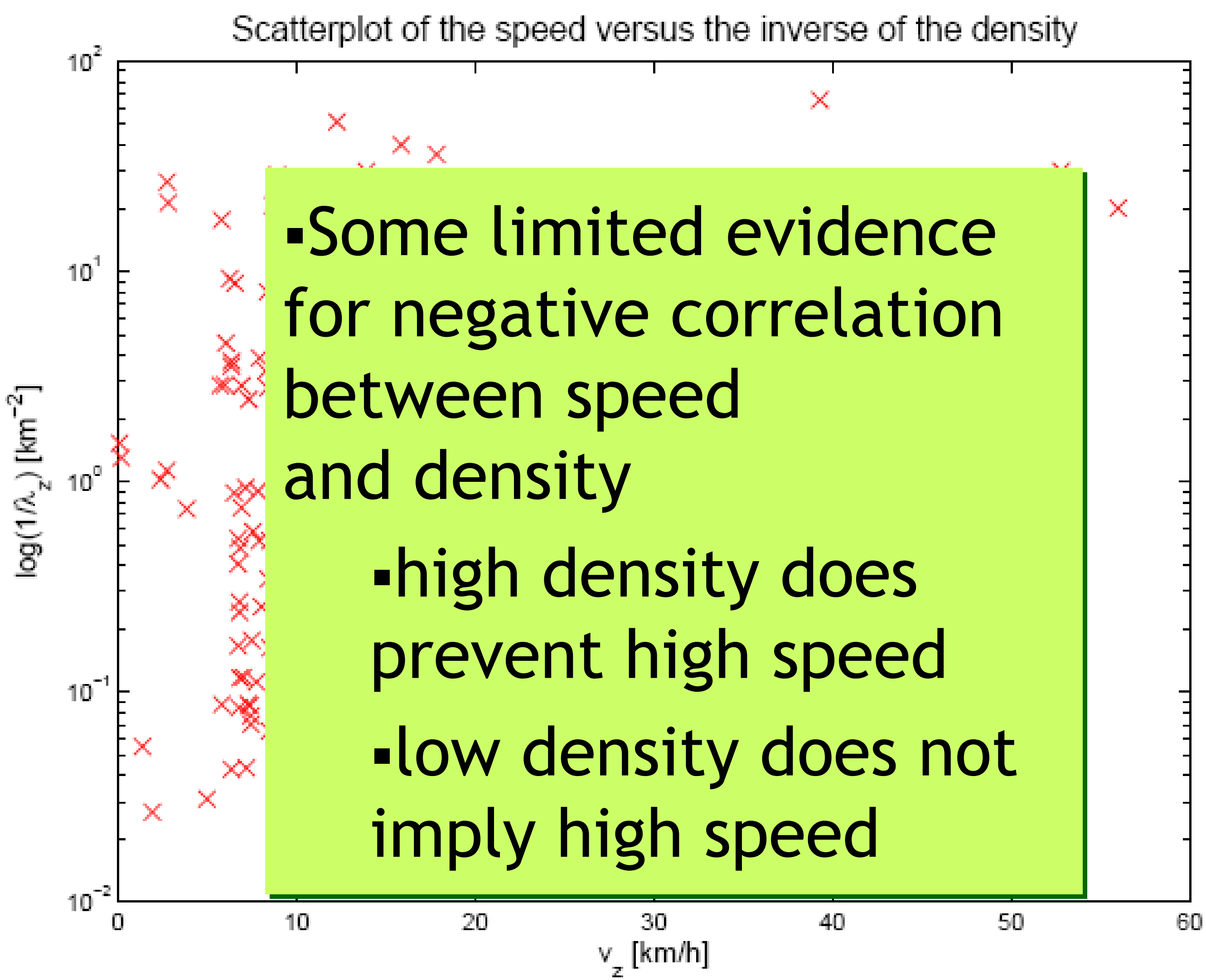
- Most nodes have indistinguishable mobility

Speed and Density Maps



- Does high density constrain speed? Is there an inverse relationship?

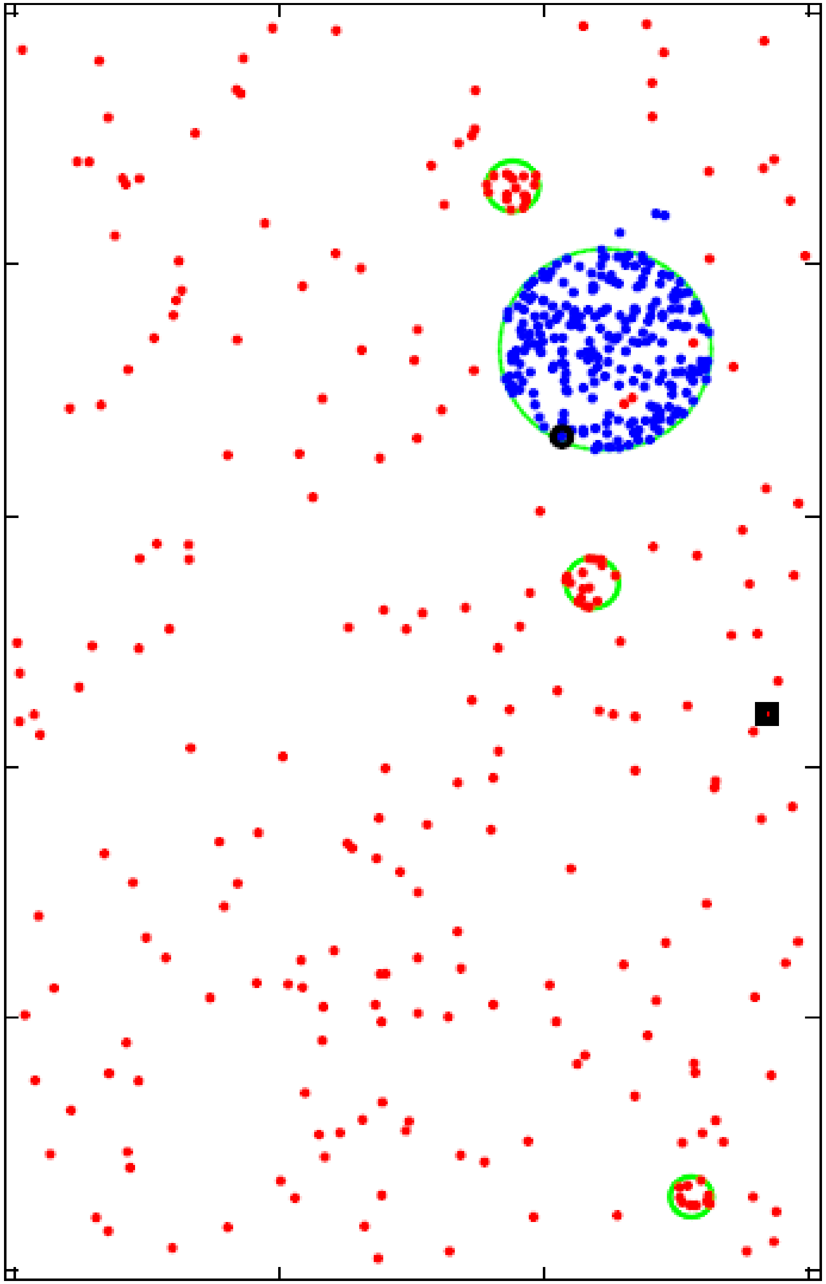
Speed and Density Scatter Plot



- Some limited evidence for negative correlation between speed and density
  - high density does prevent high speed
  - low density does not imply high speed

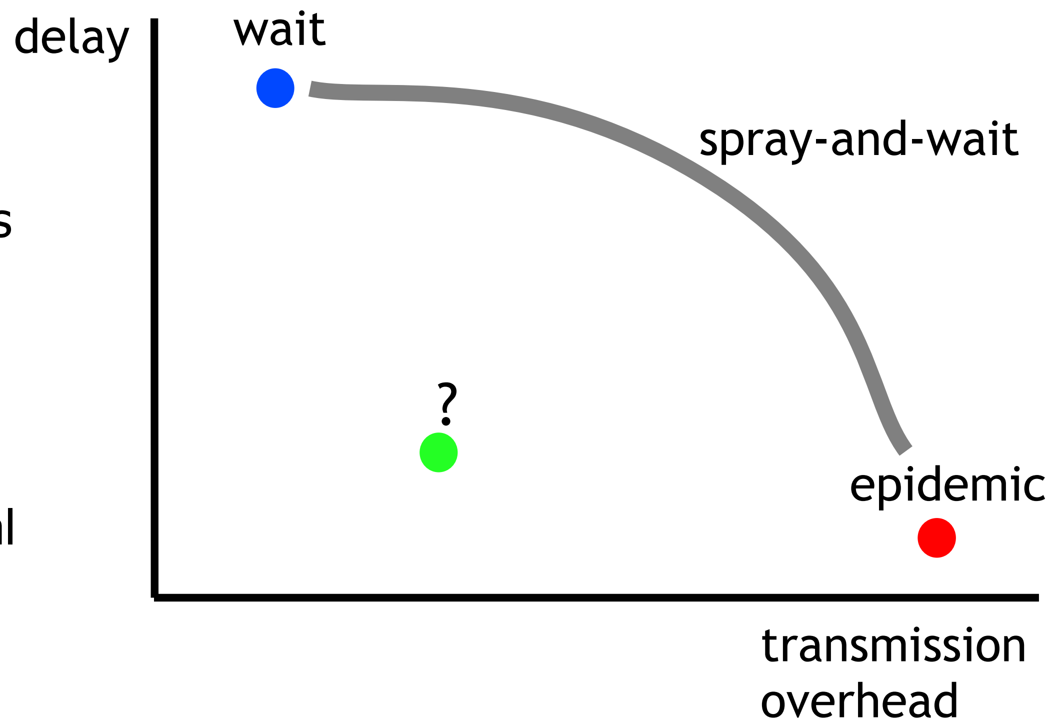
Example: Epidemic Dissemination

- Experiment: fit model to trace
  - A_l = highly connected areas
  - match average speed separately in A_l and A_h
- Metrics:
  - delay, overhead (# copies), min-delay-path length
- Comparison:
  - Random walk
  - Random waypoint
- Result:
  - HRW best overall predictor



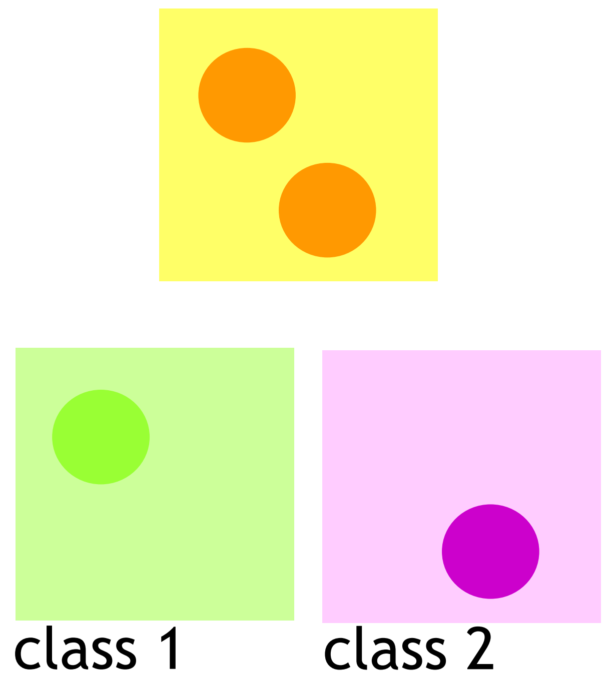
DTN Routing under Random Walk Mobility

- Design space of DTN routing algorithms:
  - Single or multiple copy
  - Forward and/or copy decisions
  - Control information (e.g., encounter frequency)
- HRW: Markov chain, state = location
  - No "predictability" of individual node's future movements
  - Given current location, every node is equivalent
- Question:
  - Can we actually route in such a model, i.e., do better than random dissemination?
  - If we can, what information should nodes collect and exchange?

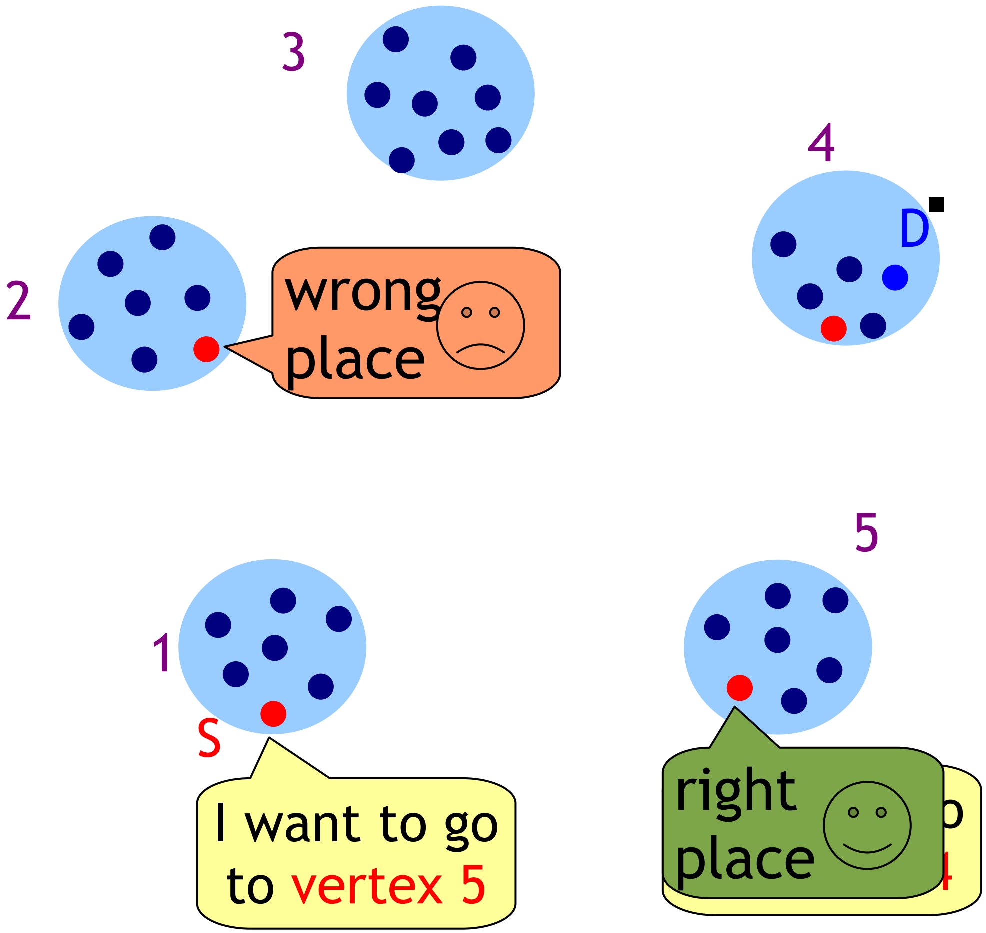


Single Copy and Spray-and-Wait in HRW Mobility

- HRW model:
  - Single copy: no benefit in relaying copy -> no control information needed
  - Spray-and-wait: set of relays is irrelevant -> min of i.i.d. delays
- Beating spray-and-wait boundary
  - Requires "continuous multi-copy" scheme, i.e., decisions after realization
- Contrast with node-heterogeneous model:
  - Assume each node has its own preferred (set of) location(s)
  - All indep. random walks, same aggregate node density
  - But: single copy and spray-and-wait benefits from control information

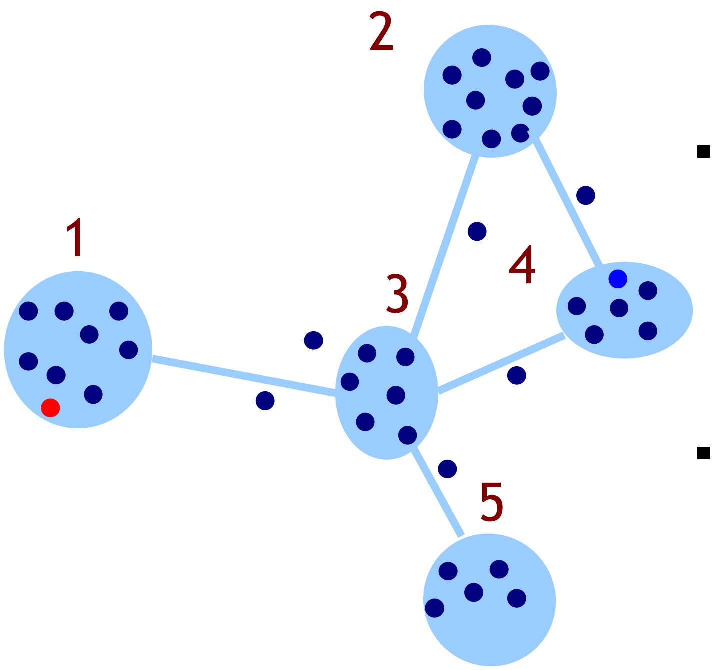


Beating Spray-and-Wait with HRW Mobility



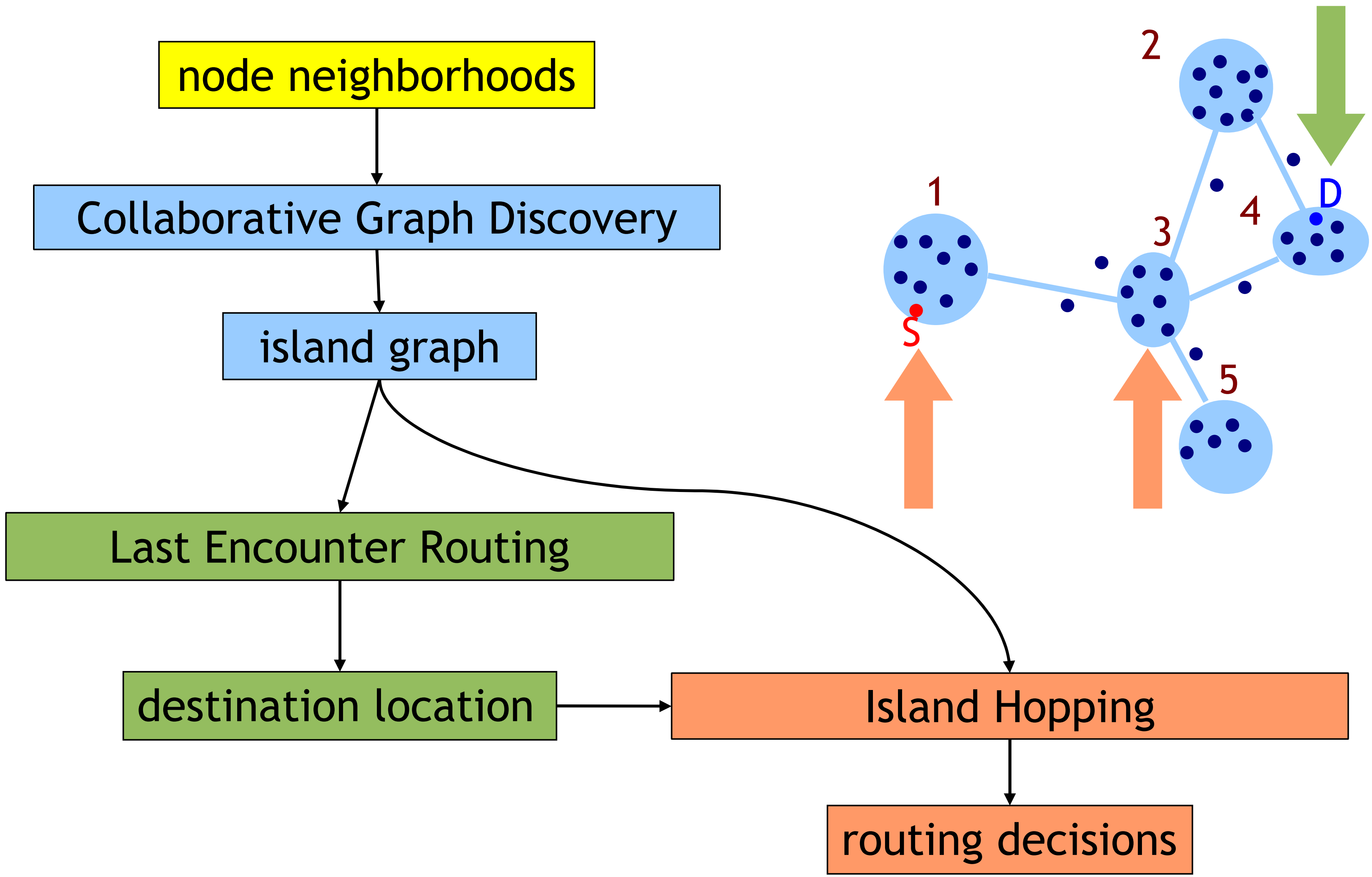
- Problem:
  - How to make predictable progress under unpredictable mobility?
- Key idea:
  - Cannot control mobility of individual message
  - But can control mobility of set of copies of a message
  - Deferred copy and kill decisions at islands

Collaborative Graph Discovery



- Assume no external signal
  - No GPS or fixed beacon
  - No information about movement of self and others
- Collaborative graph discovery:
  - Stable islands with high connectivity: natural "beacons"!
  - Derive island graph only from observation of neighbors
- Key idea:
  - Vertex labeling:
    - Assign unique labels to islands
    - Maintain the labels stable as long as possible -> "voting for labels"
  - Edge Discovery:
    - Discover the labeled edges of the CP graph
    - Gossiping, aging, handling error conditions

Island Hopping for DTN Routing



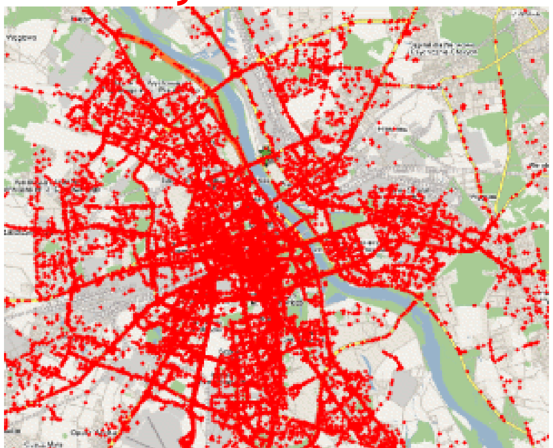
Key Points

- Real DTN scenarios are heterogeneous
  - Node mobility, connectivity
- HRW model:
  - Corner case: homogeneous nodes, heterogeneous space
  - Stable islands of connectivity, but "maximally unpredictable" nodes
  - Parsimonious, tractable
- Validation
  - San Francisco taxi trace + Nokia Sportstracker traces
  - Statistical similarity of nodes, clustering vs range, speed-density
  - Capturing "high connectivity" and "high mobility" regions
- Routing:
  - Random Walk: no predictability for individual nodes
  - But "deferred multi-copy" schemes can perform well
  - Optimal scheme and control information are open questions

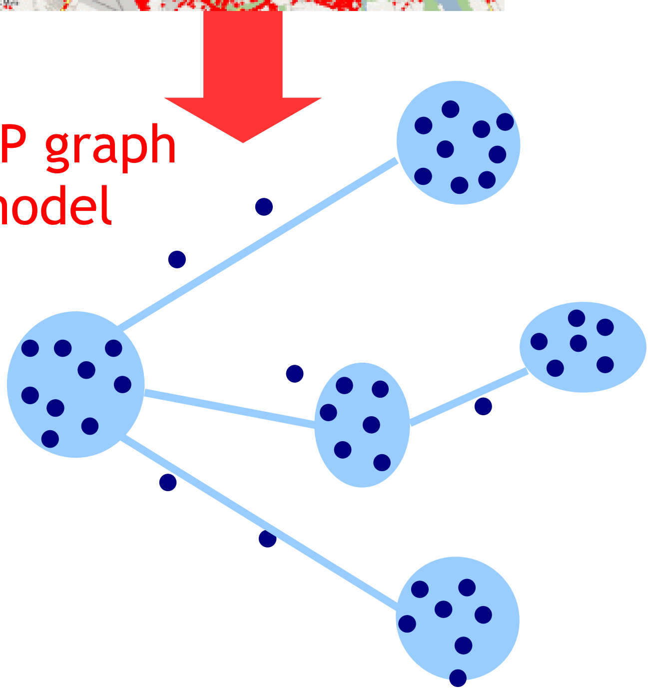
Backup

Stable Concentration Points

Mobility traces



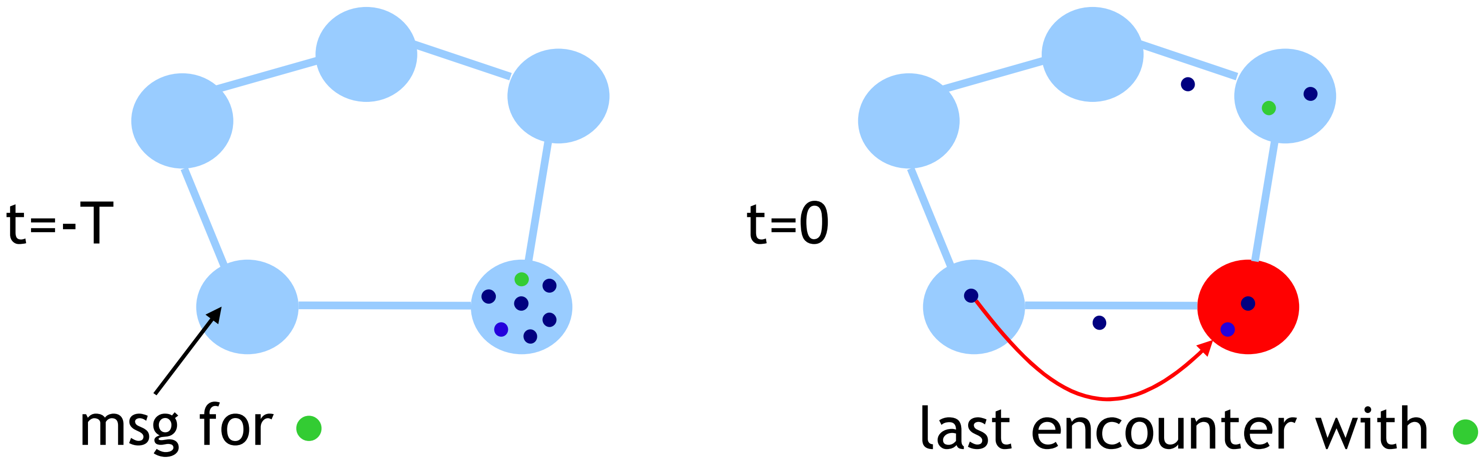
CP graph model



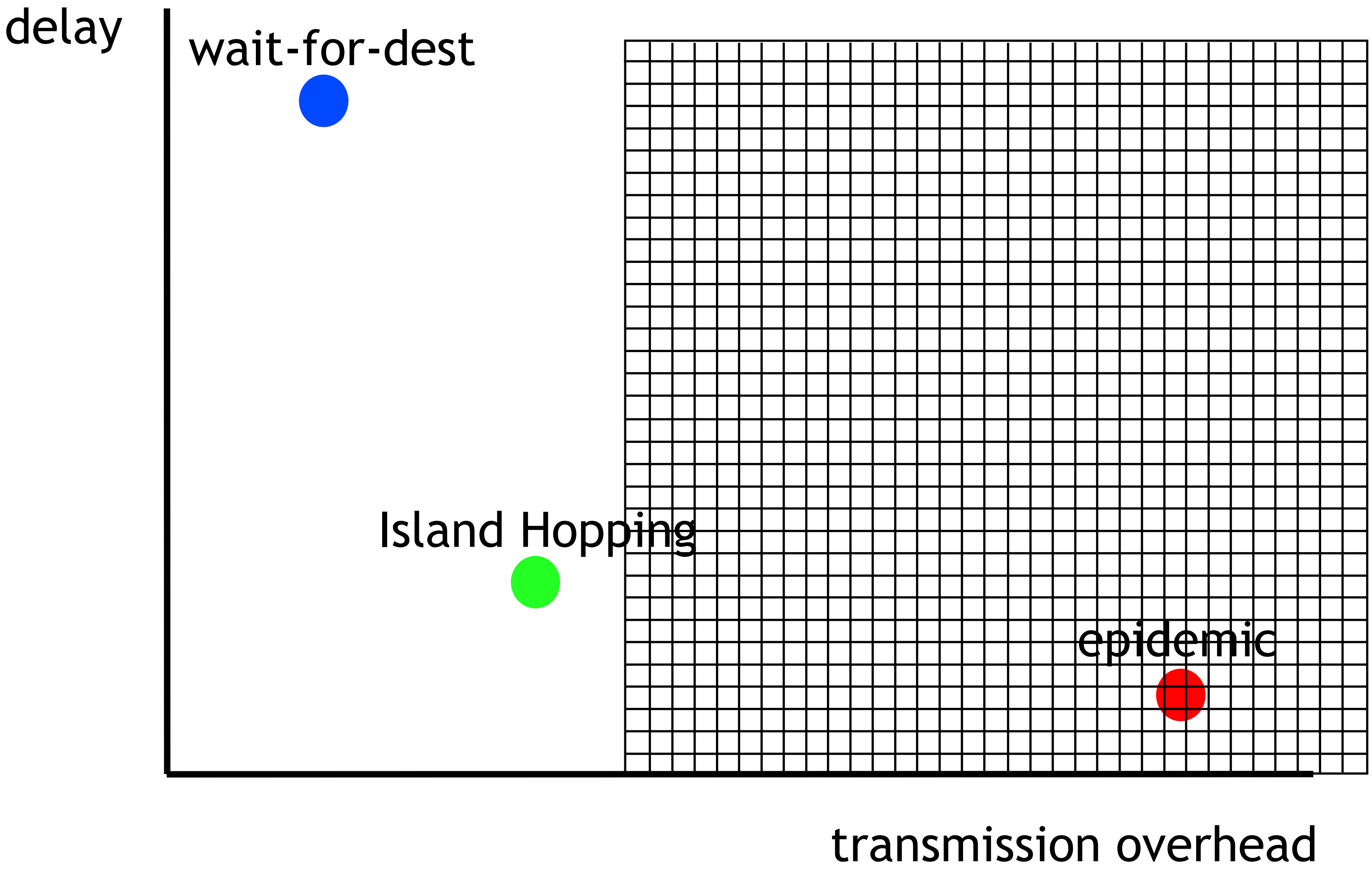
- CP graph:
  - Vertices = CPs
  - Edges = flows of nodes between CPs
- Worst-case connectivity & mobility model:
  - Only nodes at the same vertex can communicate
  - A node in transit can not communicate with anyone
  - Nodes perform independent random walks on CP graph

Island Hopping through Mobility

- Only way from island to island is through movement of nodes
  - But how? Obvious approaches:
    - Epidemic: Flood entire network -> fast but costly
    - Wait-for-dest: slow but cheap
  - Make smart "hitchhiking decisions"
    - How to find the destination in a disconnected network?
    - Last Encounter routing on the CP graph
      -> try to move in "the right direction"

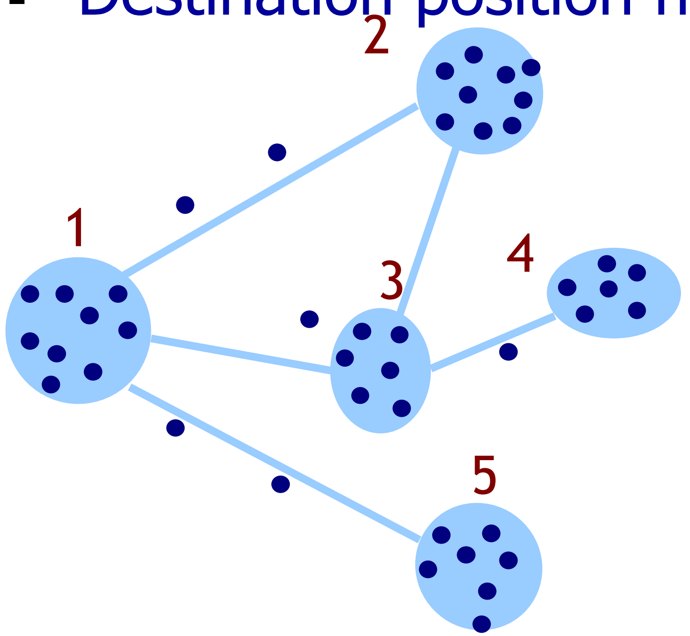


Island-Hopping: Delay-Overhead Sweetspot



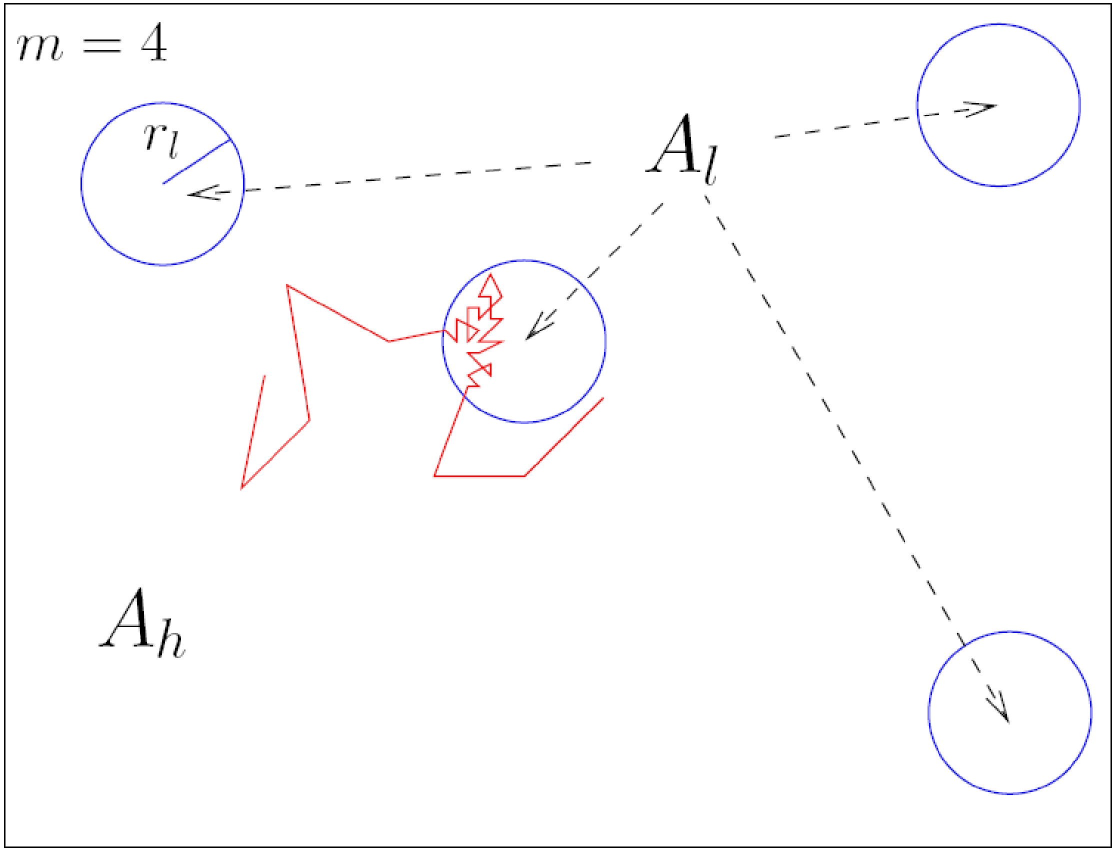
Execution Example COGRAD + IH

- 500 nodes on a 5x5 grid of concentration points
- No positioning information available to nodes
- Grid topology not known to nodes
- Destination position not known to nodes



Summary: Partitioned Mobile Networks

- References:
  - Last Encounter Routing
    EASE: Learning Efficient
    IEEE/ACM Trans. on Ne
  - [Sarafijanovic-Djukic, Pi
    Mobility-Assisted Forwa
    2006]



Conclusion

- Models for main aspects of mobile wireless networks
  - Model 1: Optimal Opportunistic Routing
  - Model 2: Routing under Mobility
  - Model 3: Partitions
- The right abstraction is half the solution
  - Depends on the problem
  - Should inform the solution
- Future research:
  - Heterogeneity and asymmetry: energy, communication, computation
  - Hybrid scenarios
  - Addressing information vs network entities: overlays, pub-sub,…