CS649
Sensor Networks
Lectures 12-13: Routing II

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Outline

• Geography-based routing
  • GPSR
• Diffusion + Geographical Routing + Energy Aware = GEAR
• Scalable routing
  • TTDD
• What metric should we be using?
  • “Taming the Underlying...” [ATC03]
Motivation

- Two dominant factors in the scaling of a routing algorithm are:
  - The rate of change of the topology.
  - The number of routers in the routing domain.
- Both factors affect the message complexity of DV and LS routing algorithms.
- On-demand ad-hoc routing algorithms require state at least proportional to the number of destinations a node forwards packets toward.
- GPSR uses geographical routing to achieve scalability, allowing routers to be nearly stateless.

Assumptions

- All wireless routers know their own positions (GPS device).
- Bidirectional radio reachability - a set of nodes with radios, where all radios have identical, circular radio range.
- Topologies where wireless nodes are roughly in a plane.
- Packet sources can determine the locations of packet destinations, to mark packets they originate, with their destination’s location.
  - local registration, lookup service
**Greedy Forwarding**

- Packets are marked by the originator with the destination’s location.
- A forwarding node can make a locally optimal, greedy choice in choosing a packet’s next hop.
- Specifically, if a node knows its radio neighbor’s positions, the locally optimal choice of next hop is the neighbor geographically closest to the packet’s destination.
- On a dense network, greedy forwarding approximates to shortest-path routing.
Greedy Forwarding
Greedy Forwarding

- Advantages:
  - Reliance on knowledge of the forwarding node’s immediate neighbors only.
  - State required is negligible, and dependent on the density of nodes in the wireless network, not the total number of destinations in the network.
  - Consumes considerably less bandwidth than
    - protocols which distribute state globally throughout the routing domain (DV and LS).
    - Protocols which accumulate state along an entire source route (DSR).

Greedy Forwarding Failure

- Drawbacks:
  - There are topologies where the only route to a destination requires a packet move temporarily farther in geometric distance from the destination.
The Right-Hand Rule

Sequence of edges traversed by the right-hand rule is called a perimeter – hence the name perimeter forwarding

Problems with the Right-Hand Rule

- $x$ originates a packet to $D$
- Right-hand rule results in the tour $x\rightarrow w\rightarrow z\rightarrow u\rightarrow w\rightarrow x \ldots$
- Packet never arrives at $v$ where it can be forwarded to $t$ and finally $D$
Solution

- Remove \((u, z)\) from the graph
- Right-hand rule results in the tour \(x - w - z - v - x\)

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Solutions

- Methods for eliminating crossing links from a network:
  - Relative Neighborhood Graph.
  - Gabriel Graph.
- Remove edges from the graph that are not part of the RNG or GG - yields a network with no crossing links.
- The resulting graph is still connected.
Relative Neighborhood Graph

- An edge \((u,v)\) exists between vertices \(u\) and \(v\) if the distance between them, \(d(u,v)\), is less than or equal to the distance between every other vertex \(w\), and whichever of \(u\) and \(v\) is farther from \(w\).

\[ \forall w \neq u, v: d(u,v) \leq \max[d(u,w),d(v,w)] \]

Gabriel Graph

- An edge \((u,v)\) exists between vertices \(u\) and \(v\) if no other vertex \(w\) is present within the circle whose diameter is \(uv\).

\[ \forall w \neq u, v: d2(u,v) < [d2(u,w) + d2(v,w)] \]
**Full graph**  
- 200 nodes  
- randomly placed on a 2000 x 2000 meter region  
- radio range of 250 m

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**GPSR Algorithm**

- All nodes maintain a neighbor table, which stores the address and the locations of their single hop radio neighbors.  
- Upon receiving a greedy-mode packet for forwarding, a node searches its neighbor table for a node geographically closest to the destination.  
- If this neighbor is closer to the destination, the node forwards the packet to that neighbor.  
- When no neighbor is closer, the node marks the packet into perimeter mode.
GPSR Algorithm

- Perimeter forwarding is only intended to recover from a local maximum.

Simulation Results and Evaluation

- Simulates nodes moving in an unobstructed plane. Motion follows random waypoint model.
- A node
  - chooses a destination at random in the simulated region,
  - chooses a velocity at random from a configurable range,
  - and then moves to that destination at the chosen velocity.
- Upon arriving at the chosen waypoint, the node pauses for a configurable period before repeating the same process.
Packet Delivery Success Rate

Routing Protocol Overhead
Geographical and Energy Aware Routing: A recursive data dissemination protocol for wireless sensor networks

Yan Yu, Ramesh Govindan, Deborah Estrin

Background

- Directed diffusion paradigm argues for data centric routing
  - E.g. "Give me the sensor readings of sensors in [(x1,y1),(x2,y2)]
  - Directed diffusion uses flooding to locate sensors within the specified area
  - Geographic routing would increase efficiency
Assumptions

- Each query packet has a target region
- Each node knows its location and remaining energy level and its neighbors locations and remaining energy levels
- Links are bidirectional

Energy-Aware Neighbor Computation

- Each node maintains state $h(N,R)$: learned cost to region $R$
  - Infrequently update neighbors
- If $h(N,R)$ is unknown, estimated cost $c(N,R)$
  - $c(N,R) = ad(N,R)+(1-\alpha)c(N)$
  - Use estimated cost as initial estimate of learned cost
- After node picks $N_{min}$ updates its own $h(N,R)$
  - $h(N,R) = h(N_{min},R)+C(N,N_{min})$
  - Intuition for estimated cost?
GEAR Routing

- Two cases:
  - At least one neighbor of N is closer to D than N
    - Among the nodes that are closer to destination, pick the one
      with the minimum $h(N,R)$
  - All neighbors are further away from D than N
    - Node knows it is in a "hole"
    - In this case $h(N,R) > c(N,R)$
    - Eventually high learned costs propagate around the hole

Example

- Nodes G,H,I are depleted
- S wants to send packet to T
- Initially
  - $h(B,T) = c(B,T) = \sqrt{5}$
  - $h(C,T) = c(C,T) = 2$
  - $h(D,T) = c(D,T) = \sqrt{5}$
- S forwards packet to C
- C forwards packet to B, updates $h(C,T)$
  - $h(C,T) = h(B,T) + c(C,B) = \sqrt{5} + 1$
- Next packet from S is sent to B
Recursive Geographic Forwarding

- Once the packet reaches R it has to be sent to all nodes inside the region
- Alternatives
  - Flooding (expensive in high-density networks)
  - Recursive Geographic Forwarding
    - Send multiple unicast copies of the packet to the four quadrants

Pathologies

- Non-termination
  - If node-density is low
  - Region R is large compared to radio range r
  - Possible to have loops
- Solution
  - Restricted flooding in low density scenarios
  - For large paths geographically direct path is more efficient
    - Path length threshold
    - Heavily depleted node neighborhood
Simulation Results

GEAR delivers 25%-35% more packets

More paths
Stay active after partition

Effect more pronounced with non-uniform traffic

Spring 2005  Uniform Traffic  CS 649  Non-uniform Traffic

Discussion

- GPSR assumes obstacle-free area
  - Effect of obstacles
  - Irregular transmission range
- GEAR
  - In certain cases routing will not find path
TTDD: A Two-tier Data Dissemination Model for Large-scale Wireless Sensor Networks

Haiyun Luo
Fan Ye, Jerry Cheng
Songwu Lu, Lixia Zhang
UCLA CS Dept.

Outline

- Data dissemination to mobile sinks
- Two-tier query and data forwarding
- Performance evaluation
- Related work
- Conclusion
Sensor Network Model

Mobile Sink

Excessive Power Consumption
Increased Wireless Transmission Collisions
State Maintenance Overhead
Challenges

- Battery powered sensor nodes
- Communication via wireless links
  - Bandwidth constraint
  - Load balancing
- Ad-hoc deployment in large scale
  - Fully distributed w/o global knowledge
  - Large numbers of sources and sinks
- Unexpected sensor node failures
- Sink mobility
  - No a-priori knowledge of sink movement

Goal, Idea

- Efficient and scalable data dissemination from multiple sources to multiple, mobile sinks
- Two-tier forwarding model
  - Source proactively builds a grid structure
  - Localize impact of sink mobility on data forwarding
  - A small set of sensor node maintains forwarding state
**TTDD Multiple Mobile Sinks**

![Diagram of TTDD Multiple Mobile Sinks](image)

**Grid Maintenance**

- **Issues:**
  - Handle unexpected dissemination node failures
  - Efficiency
- **Solutions:**
  - Source sets the Grid Lifetime in Data Announcement
  - DN replication: each DN recruits several sensor nodes from its one-hop neighbor, replicates the location of the upstream DN
  - DN failure detected and replaced on-demand by on-going query and data flows
Grid Maintenance

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Grid Maintenance (cont’d)

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Performance Evaluation

- Compare with sink-oriented data dissemination approaches
  - Communication overhead
    \[
    \frac{CO_{TTDD}}{CO_{SODD}} \rightarrow \frac{1}{mk} \left(1 + \frac{4}{\sqrt{n}}\right)
    \]
  - State maintenance complexity
    \[
    \frac{S_{TTDD}}{S_{SODD}} \rightarrow \frac{sb}{n(D - 1)}
    \]

Ns-2 Simulation

- Metrics
  - Energy consumption, delay, success rate
- Impacts of
  - Cell size
  - Number of sources and sinks
  - Sink mobility
  - Node failure rates

When number of sinks is small, TTDD consumes much less power.
Conclusion

- TTDD: two-tier data dissemination Model
  - Exploit sensor nodes being stationary and location-aware
  - Construct & maintain a grid structure with low overhead
- Proactive sources
  - Localize sink mobility impact
- Infrastructure-approach in stationary sensor networks
  - Efficiency & effectiveness in supporting mobile sinks

Taming the Underlying Challenges of Reliable Multihop Routing in Sensor Networks

Alec Woo, Terence Tong, David Culler
UC Berkeley
Presented at Sensys 2003
Outline

- Goal: Tree Routing
  - Many-to-one routing from all sensors to sink
- Question: What metric should be used?
  - Hop Count
  - Link Quality
    - How to estimate link quality?
- Metric: Create *high quality* trees
  - Percentage of packets delivered at the sink

Hop Count is a bad metric

- Reception rate deteriorates quickly as transmission range grows
- Hop count tends to pick *long* links -> lossy links
- Pick instead *high quality* links
  - How do we estimate link quality?

(a) Reception probability of all links in a network with a line topology.
Link Quality Estimation

- Estimate rate of successful reception from neighboring nodes
  - RSSI may not work well
  - Neighbors exchange estimations to derive bi-directional link quality
- 2 Techniques: Passive vs. Active
  - Key decision factor: broadcast medium
    - Passive: snoop on neighbor packets
- Packet sequence number for inferring packet loss
  - Issue: cannot infer loss until hearing the next packet
    - E.g. dead node or mobility
- Can infer losses based on time
  - Assume minimum data rate is known
  - Likely to be true in periodic data collection

WMEWMA Estimator

- Compute an average success rate over time, T, and smooths with an exponentially weighted moving average (EWMA)
- Average calculation
  - Packet Received over T divided by
  - Max of
    - Number of packets expected over T
    - Number of packets sent over T suggested by sequence number
- Tuning parameters:
  - T and history size of EWMA
- Performance
  - Yields agile and stable estimations
  - Uses constant memory, and is very simple
Routing Algorithms

- Shortest Path (SP)
- Shortest Path with threshold (SP(t))
  - Use a link only if link quality estimate > threshold
- Minimum Transmission (MT)
  - Link cost = 1/linkquality_fw * 1/linkquality_bk

Evaluation (I)

- Evaluation Metrics
  - Hop Distribution
  - Path reliability
- Network Graph analysis
  - 400 nodes, 20x20 grid
  - Sink placed at corner
- Results
  - SP produces more shallow trees
    - Most nodes < 3 hops away - >links 40-50 feet
  - Path reliability < 5% after 50 feet
  - SP(50%) performs worse than SP(70%)
  - MT performs comparably without need to set threshold
Evaluation (II)

- Empirical Evaluation
  - 50-node network, 5x10 grid, 8 foot spacing, indoors
- Results
  - SP(70%) failed to create a tree!
  - MT has comparable performance to SP(40%)