GEAR

Geographical Energy Aware Routing: a recursive data dissemination protocol for wireless sensor networks

[Yu, Govindan, Estrin]

Whitepaper summarized by Erik Weathers

GEAR Summary

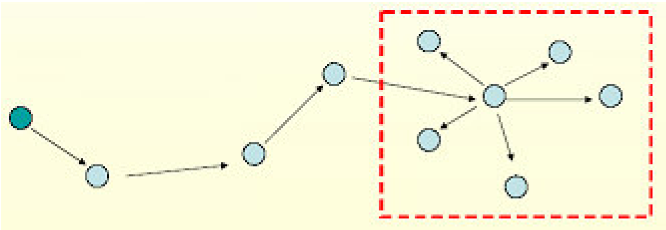
- Energy efficiency is very important for sensor networks. This paper proposes a geographical routing protocol that considers energy levels in nodes to improve network lifetimes.
- Uses energy aware neighbor selection to route a packet towards the target (1st phase of GEAR):
- Within a target region 2 different mechanisms are used to disseminate the packet (2nd phase of GEAR):
  - Recursive Geographic Forwarding or
  - Restricted Flooding

Motivation

- Geographical routing:
  - Other routing techniques have major shortcomings
    - Idealized multicast requires many control packets
    - Full-network flooding is very wasteful
- Energy aware routing:
  - sensor nodes have limited and non-replenishable energy supplies
  - Non-uniform traffic patterns are common, so particular nodes may burn out quickly if energy is not considered

Geographical Routing in GEAR

- Typical network routing
  - packets are routed to a particular node (or set of nodes) based on a destination node id in the packet.
- GEAR's geographical routing
  - Packet's are routed to a "target region" instead of a particular node
    - Data-centric nature of sensor networks makes this appropriate



Related Work

- Geographical Ad-hoc routing
  - Finn's restricted flooding
  - GPSR – planarized graph, but nodes burn out more quickly than GEAR because:
    - Sparser than normal graph, and traffic traverses perimeter nodes often
    - Promiscuous listening mode operation
  - SLURP (Scalable Location Update-based Routing Protocol)
    - Constantly tracks location of nodes on network, and calculates routes on demand → too much overhead for sensors
  - Dataspace
    - Pre-built location indexing structure too difficult for sensors
  - Location Aided Routing
    - Limited flooding, may encompass whole network
  - Location Database
    - Unneeded in GEAR

Related Work (continued)

- Ad-hoc routing
  - DSR (Dynamic Source Routing)
    - Flooding and promiscuous listening
- Energy aware routing
  - Woo et al.
    - Impractical algorithm asking for global optimizations to determine route metrics; e.g., maximize time to network partition
  - etc.

Related Work (continued)

- Sensor network routing mechanism
  - Directed diffusion
    - Data-centric, caches & processes data in-network, but has low-rate flooding
  - Gao & Pottie
    - Pre-built routing table to direct queries from central “USER” to sensors
- Localization (alternatives to GPS)
  - Acoustic and multi-modal sensing
  - Ultrasonic location system based on tri-lateration principle

GEAR Assumptions

- Query packets are destined to a target region
- each node knows:
  - its location (e.g., via GPS)
  - its remaining energy level
  - the location and energy levels of its neighbors (thru a simple hello protocol)
- static sensor locations (immobile)
- Links between nodes are bidirectional

1^{st} Phase of GEAR

- Route packet towards target region
  - Greedy neighbor selection accounting for geography and node energy levels:
    - If there is a neighbor closer to the destination than our current node, use one of these neighbors as next-hop
    - Else there is a hole and we'll try to minimize the energy usage along w/ distance while circumventing the hole

2^{nd} Phase of GEAR

- Dissemination of packet within target region
  - Generally uses Recursive Geographic Forwarding (described later)
  - But some low density networks require restricted flooding to prevent routing loops

Energy-aware neighbor computation

- Minimize learned cost to each neighbor N_i.
  - Learned cost defaults to the estimated cost:

    $c(N_i, R) = \alpha d(N_i, R) + (1 - \alpha)e(N_i)$
    - α : a tunable weight
    - $d(N_i, R)$: normalized distance from N_i to center of region R
    - $e(N_i)$: normalized consumed energy at N_i
  - NOTE: Estimated cost degenerates to greedy geographic forwarding when energy levels are equal

Learned Cost Calculation

- The learned costs change when next hop decisions are made
  - When a next hop N_{min} is chosen, set current node's learned cost:
    - $h(N, R) = h(N_{min}, R) + C(N, N_{min})$
      - $C(N, N_{min})$ is the cost of sending a packet from N to N_{min}

Closer Neighbor Exists

- A neighbor closer to the destination than ourselves exists.
- Simple, just pick neighbor that minimizes the learned cost.

No Closer Neighbor Exists

- Illustrate thru example (assume α is 1)
- S trying to send packet to T, but G, H, & I are depleted of energy.
- Initially, h(B, T) = h(D, T) = sqrt(5), h(C, T) = 2
- S sends packet to C, but C is in a hole so it sends packet to B (or D), then updates its cost:

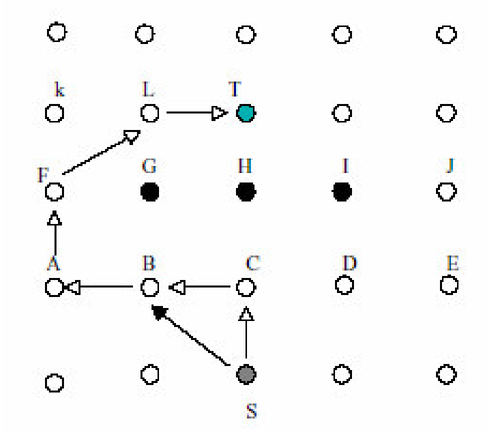
  h(C, T) = h(B, T) + C(C, B)

- Then S learns the new values thru hellos:

  h(C, T) = sqrt(5) + 1

  h(B, T) = h(D, T) = sqrt(5)

- So S will forward packets directly to B now

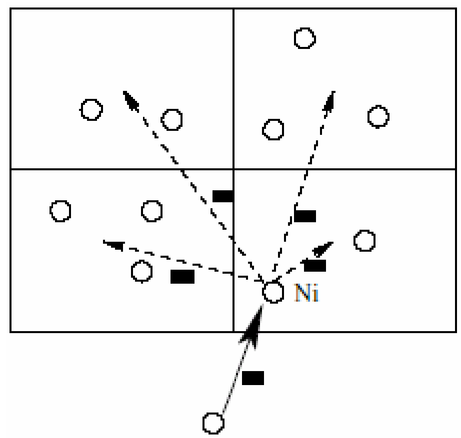


No Closer Neighbor Exists (cont.)

- So best routes are propagated back one hop at a time as packets are routed.
- Allows avoidance of holes and the nodes surrounding them.
- Learned cost algorithm inspired by LRTA* (covered in 4/13 lecture), which has a proof of correctness. It is felt by the GEAR authors that the strong similarity of GEAR's algorithm means it too is provably correct.

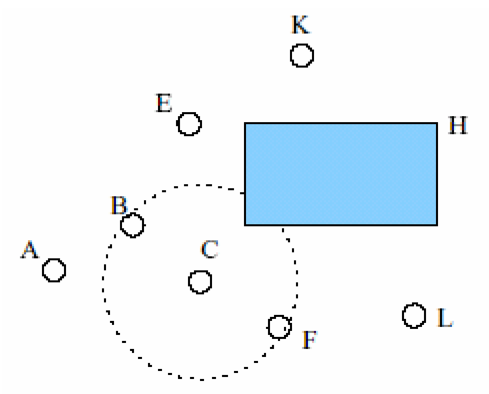
Recursive Geographic Forwarding

- Once packet reaches target region, need to disseminate it to all nodes. Flooding in target region too energy expensive, since each node needs to broadcast and all of its neighbors need to listen.
- Instead packets are sent to recursively smaller sub-regions.
- e.g., packet destined for region R (whole rectangle below) is received by node N_i. N_i creates 4 copies of the packet and sends them into 4 sub-regions of R. This happens recursively until:
  - the farthest point of the region is within a node's transmission range, but none of its neighbors are inside the region.



Region Dissemination Pathologies

- Can be inefficient to recursively split the region instead of just flooding it, when the density of sensors is low
- Non-termination
  - Low density can also lead to routing loops
    - e.g., none of nodes can tell that blue region is empty, since the corners are outside of their transmission range, so packet will continually circle the region until hop count is exhausted.



Adaptive Energy Aware Behavior

- Pure geographical distance metric used for efficiency when:
  - Hop count exceeds some threshold
  - Current node's neighbors are all energy depleted
  - Packet is "near" the target region

Simulation and Comparison

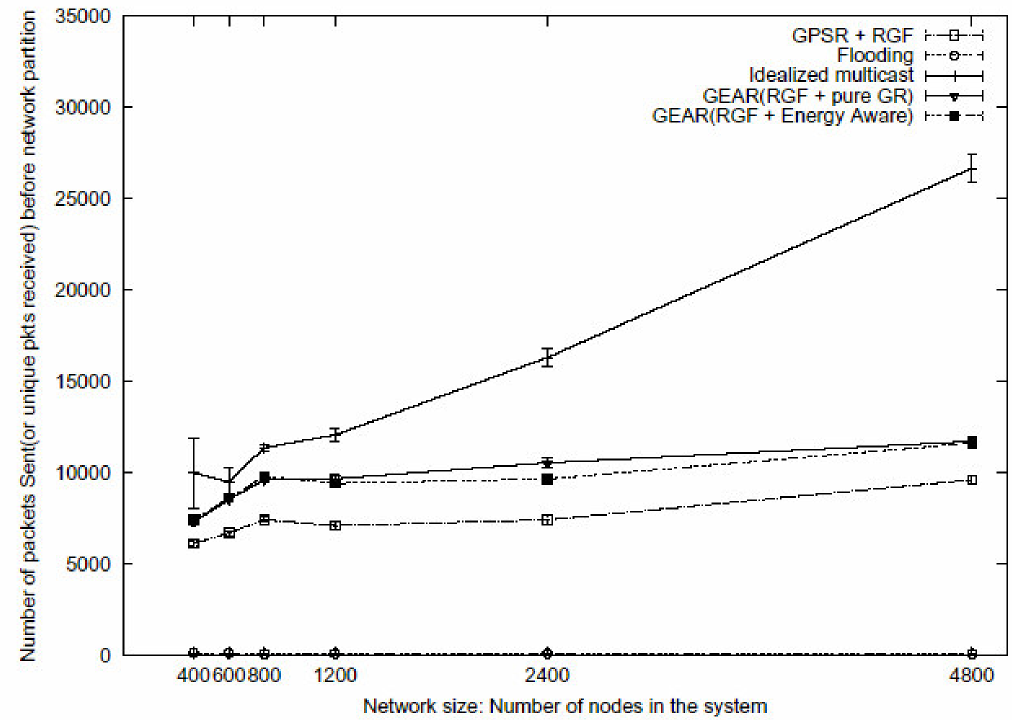
- GEAR (with and without energy aware component) is compared against:
  - GPSR
  - Idealized Multicast (without accounting for energy usage of control packets)
  - Flooding
- Uniform vs. Non-Uniform traffic
  - Uniform: all nodes are equally likely to be source and destination
  - Non-uniform: source and destination are not equally distributed, a more clustered distribution is used. More realistic scenario.

Performance Metrics

- Packets delivered before network partition
- Connectivity after network partition
  - fraction of node pairs still connected after partition
- Resource expended per packet delivered:
  - $(N_b - N_e)$ / (total number of delivered packets)
    - N_b: total number of connected pairs in beginning
    - N_e: total number of connected pairs after partition

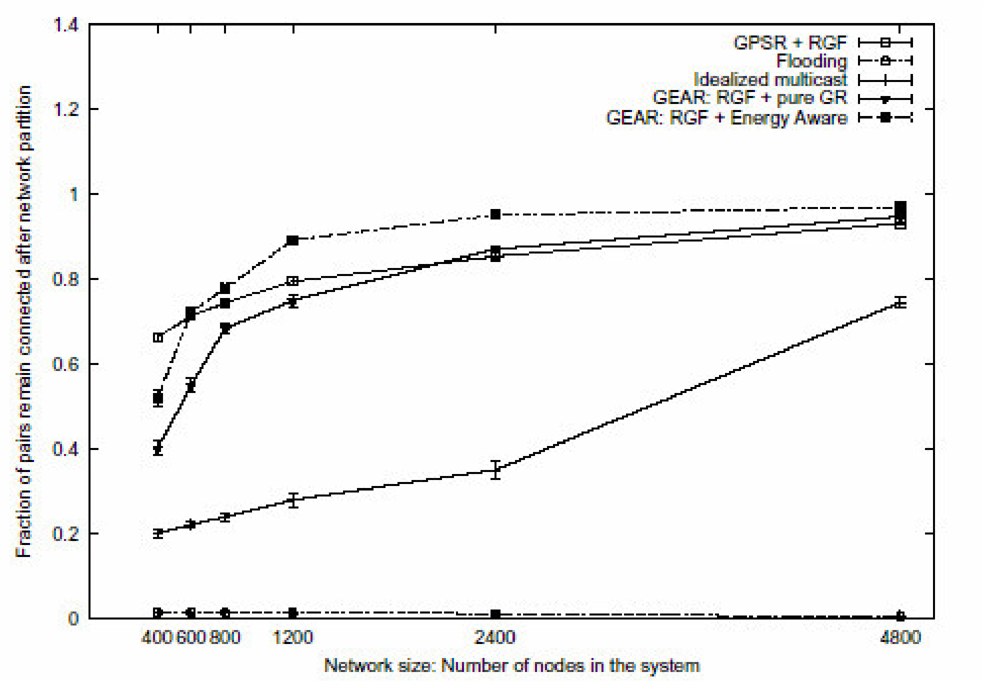
Packets sent - Uniform

- Multicast dominates, but GEAR delivers 25-35% more packets than GPSR



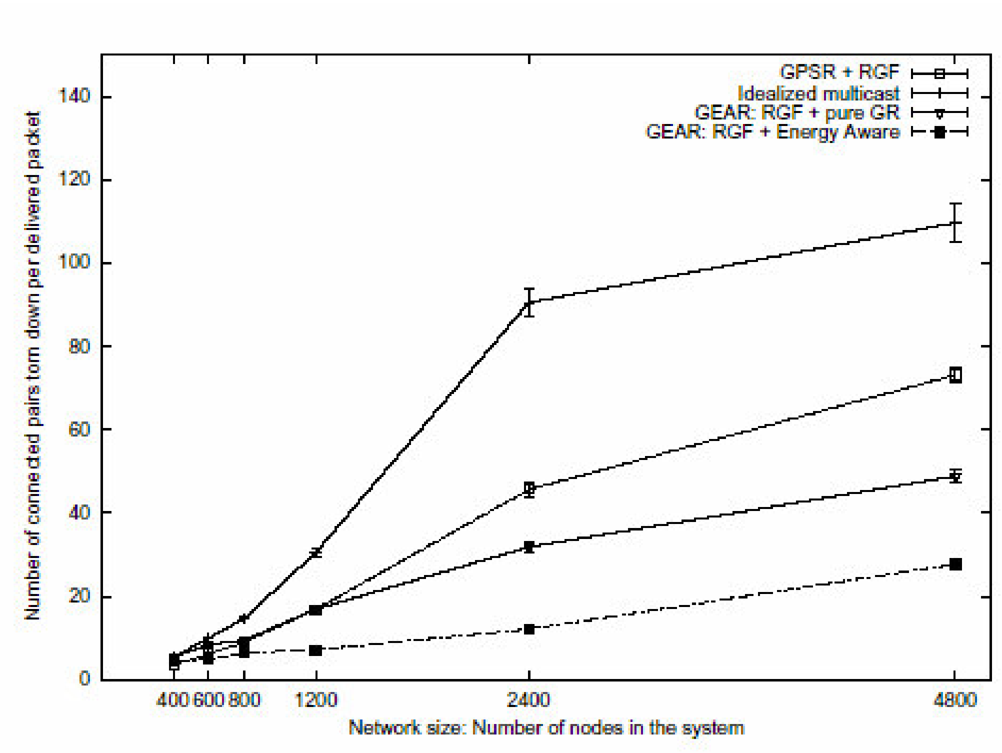
Pairs Connected After Partition

- GEAR wins, but not by much over GPSR, since GPSR may deliver far fewer packets than GEAR prior to partition, leaving lots of energy in the nodes after partition, and thus leaving more connected pairs



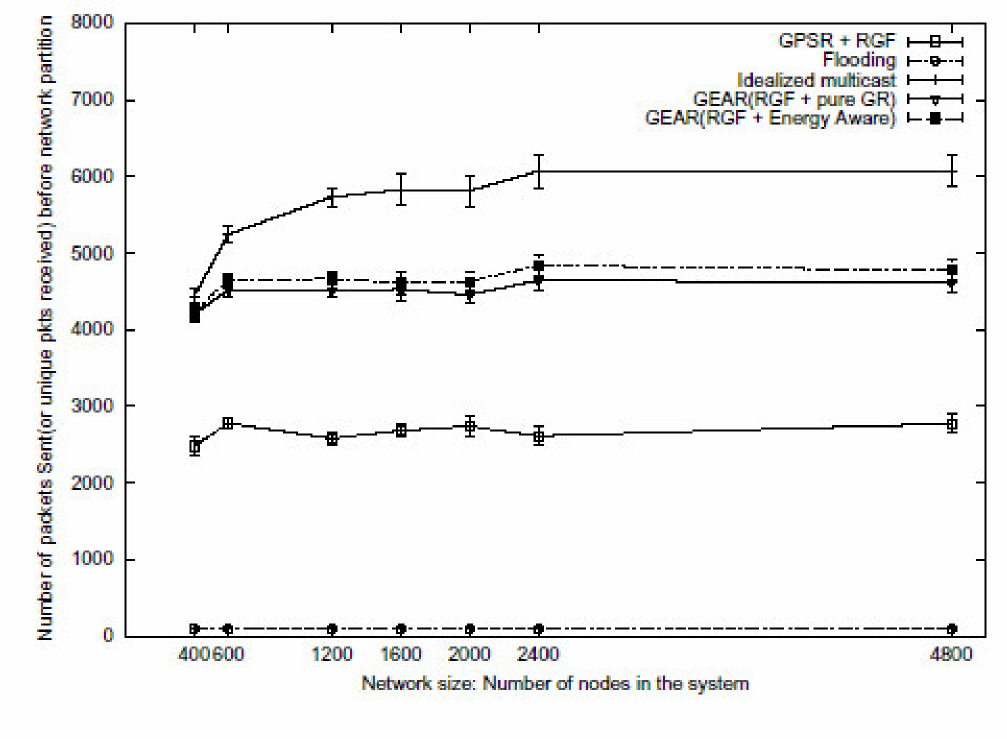
Pairs disconnected per delivered packet

- Now the energy efficiency of GEAR over GPSR is evident, since far fewer pairs are disconnected per delivered packet



Number of packets sent for non-uniform traffic

- GEAR delivers 70-80% more packets than GPSR



Conclusion

- GEAR's consideration of energy levels increases network lifetime dramatically over GPSR
  - Non-uniform: 70-80% more packets delivered
  - Uniform: 25-35% more packets delivered
- Also has much better connectivity after partition.