An Ant-Based Routing Algorithm to Achieve the Lifetime Bound for Target Tracking Sensor Networks

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Target Tracking Sensor Networks

- Delay Sensitive
  - Information gathered by sensor nodes needs to be transmitted to a central controller reliably within a certain deadline.
- Energy Constrained
  - Sensor nodes having limited and unreplenishable power resources.

It's a challenge to design a real-time routing protocol while increasing the network lifetime.

Energy-Latency Aware Protocols

- Geographic and Energy Aware Routing (GEAR)
  - Builds routes depending on both geographic and energy factor.
- QoS and Energy Aware Routing (QEAR)
  - Based on GEAR and further balances node energy utilization by adaptively changes the transmission range.
- More…

Maximum Lifetime & Real Time Routing

- Lifetime is an important design metric for sensor networks, however
  - Both GEAR and QEAR are designed without knowledge of what factors determine the lifetime of such network that aims to handle deadline-driven transmission tasks .
- Our approach
  - Develop a mathematical model to formally define the lifetime that explicitly considers the end-to-end delay constraint.
  - With the reference of this model, design an ant based routing algorithm to achieve the Maximum lifetime.

Assumptions on the Sensor Network

- A static homogeneous network has a uniform density.
- The network works with an event-driven model, each node generates one data packet per round.
- The target behavior is modeled by a spatial probability distribution function.
- The delay per hop is the same along a path, the end-to-end delay constraints can be mapped to the bounds on path length.
- All nodes have the same radio transmission range, the same energy consumption for receiving & transmitting one packet.

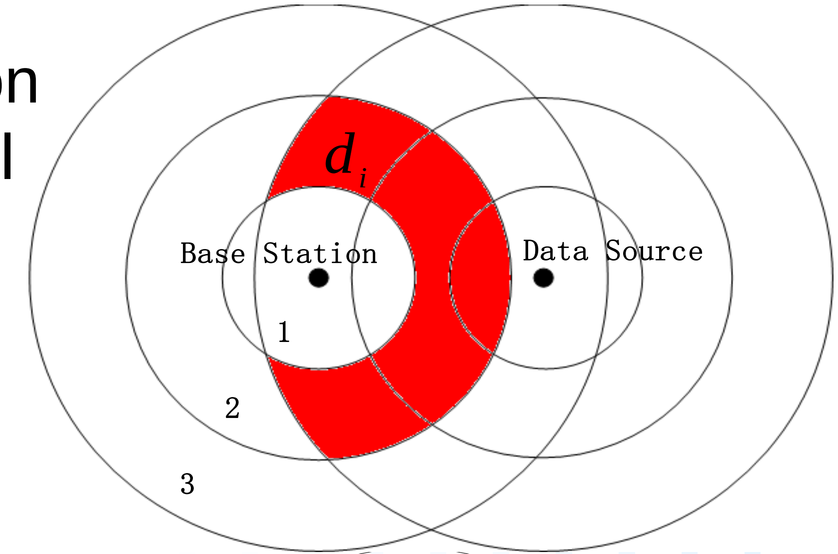
Modeling Energy Consumption of Routings during One Round

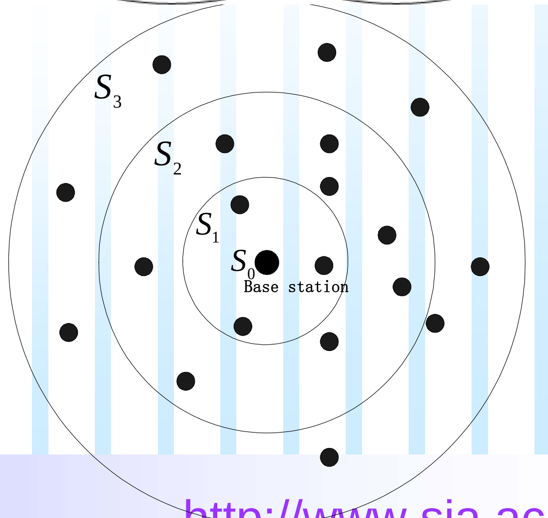
- The only restriction we place on routings is that they should satisfy the end-to-end delay constraints, so
  - Not all of the intermediate nodes between data sources and the base station are eligible to participate in routing.
  - We call the nodes that can construct a routing shorter than path length Bounds the "***eligible nodes***" .

Spheres and Eligible Nodes

- Based on the radio transmission range, we partition the set of all sensor nodes into spheres.

- the nodes in the same sphere can transmit data to the base station node with the same delay, so they may have the same energy consumption model in routing.





Three Cases

- For each node in Sphere i
- *Case one – target is in the outsider of sphere i*
  - Energy is cost by eligible nodes to relay packets.
- *Case two – target is in sphere i*
  - Energy is cost by data sources to send packets.
- *Case three – target is in the insider of sphere i*
  - No energy cost.
- Total Energy Consumption
  - Mi = Case one + Case two + Case three.

Defining Lifetime

- lifetime is defined as cumulative time of network working while satisfying the quality of tracking requirement (end-to-end delay constraint).
- Bottleneck sphere
  - Has Max {M1,M2,…,Mi}, consumes more energy than other spheres.
- Lifetime Bound

$$LB = \frac{E}{\max\{m_1, m_2, \ldots, m_n\}}$$

Discussion

- Bound the network lifetime by the longevity of eligible nodes in bottleneck sphere, When
  - All eligible nodes in the bottleneck sphere run out of energy during the same round.

- Best routing algorithm should balance the traffic evenly between the eligible nodes in the bottleneck sphere, But
  - None exist energy-latency aware routing algorithm has considered this factor and make the traffic planning from the global view.

Swarm Intelligence

- Swarms
  - Containing thousands or tens of thousands of elements, routinely perform extraordinarily complex tasks of global optimization and resource allocation using only local information.

- Ant System
  - Positive feedback, distributed computation, and constructive greediness.

Ant-Based Routing Algorithm

- Routing is determined through complex interactions of network exploration agents, called ants, which are divided into two classes
  - the forward ants and the backward ants.
- Forward ants find paths from source to destination according to the link probability distribution.
  - Initially all the links have equal probability.
- Backward ants travel back along the paths and report network energy distribution conditions.
  - The information is to change the link probability distribution.

Path Finding at Initial State

- All the links have equal probability
- It is a shortest path routing
  - Selecting the next hop node according to its distance to the base station.

Pheromone Maintenance

- The pheromone is used as a way to record the traffic load in each path on global behavior.

- During each backward travel, the backward ant refresh pheromone according the gathered information, include
  - Path length *Hop*.
  - Residual energy level of the path *Eall*.

- The pheromone of each intermediate node in the path is updated as:

$$\tau_i = \tau_i + \frac{E_{all}}{Hop}$$

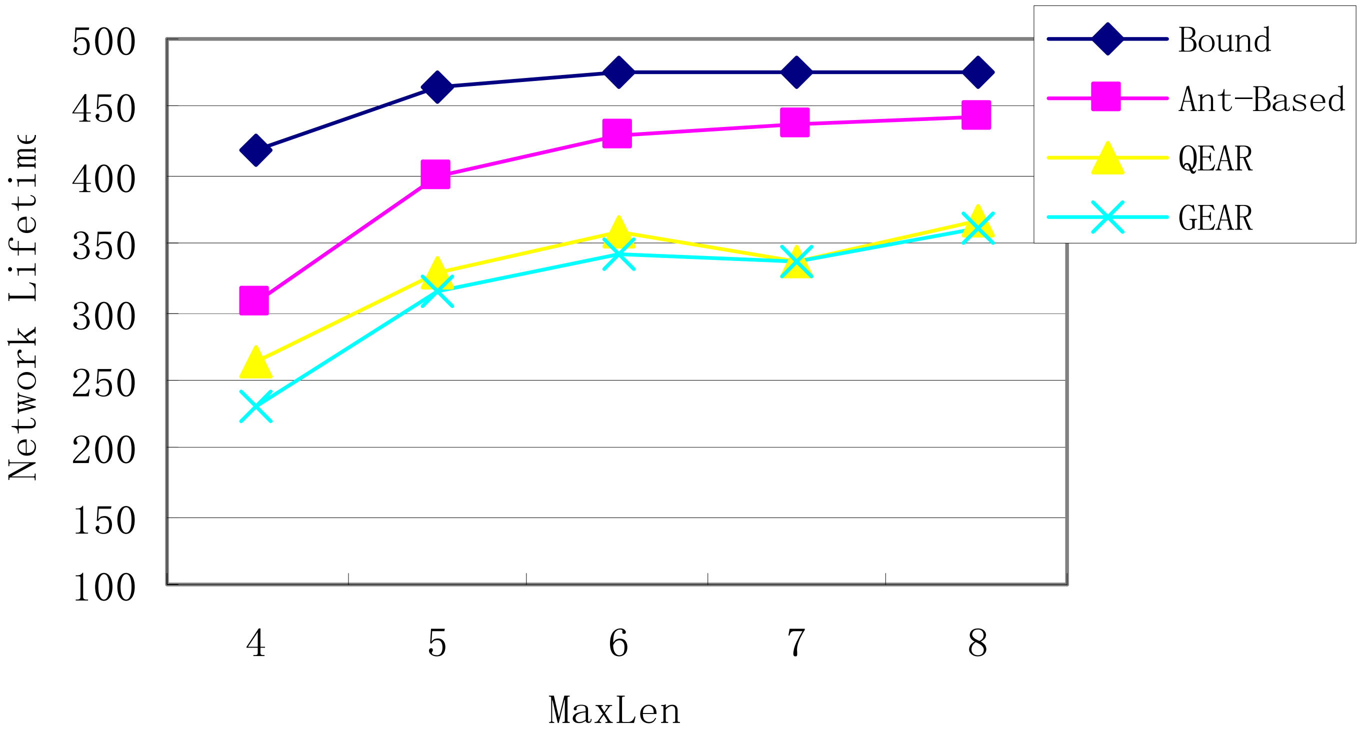
Link Probability Distribution Management

- Constructs a table to store the neighbor information for each node.
- According to the neighbor table, each node establishes its link probability distribution ***P*** as follow:
  - *n* : number of neighbor nodes；
  - *D**i*** : distance from the neighbor node i to the final destination;
  - τ_i : pheromone at the neighbor node ;
  - α, β: static coefficients;

$$P_i = \frac{(\tau_i)^\alpha / (D_i)^\beta}{\sum_{j=1}^{n} (\tau_i)^\alpha / (D_i)^\beta}$$

Preliminary Results

- Simulation results for a sensor network with 900 nodes uniformly distributed across a 300m*300m plane.



Summary and Future Work

- An alternate formulation for maximum lifetime and real-time routing problem of wireless sensor networks.
  - Define the lifetime by establishing the relationship between individual sensors and the whole sensor network.
  - To achieve global optimization using swarm intelligence-based method.

- Future work
  - Parameter Selection in Optimization
  - Performance evaluation in different conditions, such as: network density, radio transmission range, target spatial probability distribution function.
  - Extensions.