Phero-Trail: A Bio-inspired Location Service for Mobile Underwater Sensor Networks

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Application Scenario

- Protecting critical installation such as harbor, underwater mining facility, and oil rigs.
  - Mobile floating sensor nodes
  - Autonomous Underwater Vehicles (AUV) or Submarines
SEA Swarm Architecture

- **Sensor Equipped Aquatic (SEA) swarm of mobile sensors:**
  - Enable 4D (space and time) monitoring
  - Dynamic monitoring coverage

- Sensor nodes notify events to corresponding submarines
Problem Statements

- Mobile sensors report events to submarines
- Proactive (OLSR), Reactive Routing (AODV), or Sensor data collection (Directed Diffusion)
  - All require route discovery (flooding) and/or maintenance
  - Not suitable for bandwidth constrained underwater mobile sensor networks (collision + energy consumption)
- Geographical routing is preferable, but requires geo-location service to know the destination’s location
- Goal: design an efficient location service protocol for a SEA swarm
Related Work – Naïve Flooding

- Node periodically floods its current position to the entire network
Related Work – Quorum Based

- Each location update is sent to a subset of nodes (update quorum)
- Location query is sent to a subset of nodes (or query quorum)
- The query will be resolved when their intersection is non-empty
Related Work – Hierarchical

- Location servers are chosen via a set of hash functions.
- Area recursively divided into a hierarchy of smaller grids.
- For each node, one or more nodes in each grid at each level of the hierarchy are chosen as its location servers.
Hierarchical - Example

- Node updating location
- Node requesting location
- Server at level 2
- Server at level 3
## Protocol Analysis

<table>
<thead>
<tr>
<th></th>
<th>Update</th>
<th>Query</th>
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</thead>
<tbody>
<tr>
<td>Naïve flooding</td>
<td>$O(M^3)$</td>
<td>$O(1)$</td>
</tr>
<tr>
<td>Quorum-based</td>
<td>$O(M^2)$</td>
<td>$O(M^2)$</td>
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</tbody>
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- $M$: number of hops to travel a width of a network ($L$); i.e., $L / R$ (com. range)
- Quorum-based must store information in a 2D plane; i.e., $O(M^2)$
Protocol Analysis

- Hierarchical
  - Must first find a reference point for geographic hashing and propagate this information to every node.
  - Overhead of “periodical” reference point updates dominates the update/query overhead.
Reference Point Updates in Hierarchical Schemes

- Periodic reference update $O/H: O(M^3)$
Location Service in 2D?

- Store location information in 2D; search and update in 2D
- But at the cost of vertical routing $O(M)$ to given a location service plane
- Where to put a 2D plane?
  - Ex: Upper hull (easy to detect)
    - Simply check local max
Location Service in 2D: Analysis

- Naïve flooding
  - Update and query costs are $O(M^2)$

- Quorum-based
  - Store information in a 1D line
  - Update and query costs scale as $O(M)$

- Hierarchical
  - Reference update, location update, and query operations take $O(M^2)$, $O(H)$, and $O(M)$ respectively.
  - Reference point update is still expensive!!!
AUV stores the location updates (pheromone) along its projected trajectory on the upper hull
- Periodic updates create a pheromone trail
A mobile node first routes a query packet vertically upwards to the node on the projected position of the convex hull plane.

Node performs an expanding spiral curve search to find a pheromone trail.
Location Service Cost Analysis

- **Update**
  - Length of a pheromone trail is fixed $2^{(H-1)}$
  - We mimic the behavior of a hierarchical scheme by setting the probability that the update propagation distance is $2^k R$ is to be given by $1=2^k$
  - Vertical routing $O(M)$

- **Search: expanding spiral curve search**
  - Worst case: in $k$-th step, a curve search of $2^k$ sizes.
    \[
    \sum_{k=1}^{H} 2^k R = \frac{2^{H+1} - 1}{2} R = \Theta(2^H) = \Theta(M)
    \]
Simulation Results

- 1 Km x 1 Km x 1 Km
- Submarine 5 m/s
- Vary the network size
- Compared with flooding (based for comparison)
- Number of transmitted messages during update.
Simulation Results

- Figure shows the number of transmitted messages with the number of submarines.
Conclusion

- Presented a novel bio-inspired location service (PTLS)
  - efficient location service protocol for a SEA swarm
  - comparable with the hierarchical schemes
    - Search O(M)
    - Update O(M)
  - maintaining location information in a 2D plane is optimal
Future Work

Future work

- Compare performance PTLS with High-Grade, XYLS
- Evaluate the performance of Phero-Trail with various system configurations such as the number of sensors/sinks, the speed of sensors/sinks, the deployment area size (including various depths), and the search pattern of mobile sinks.