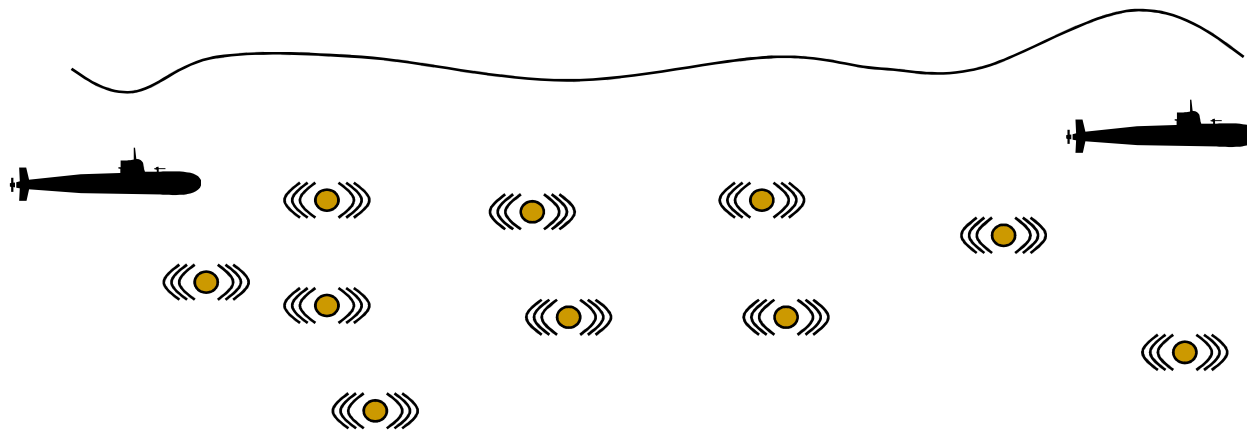

Phero-Trail: A Bio-inspired Location Service for Mobile Underwater Sensor Networks

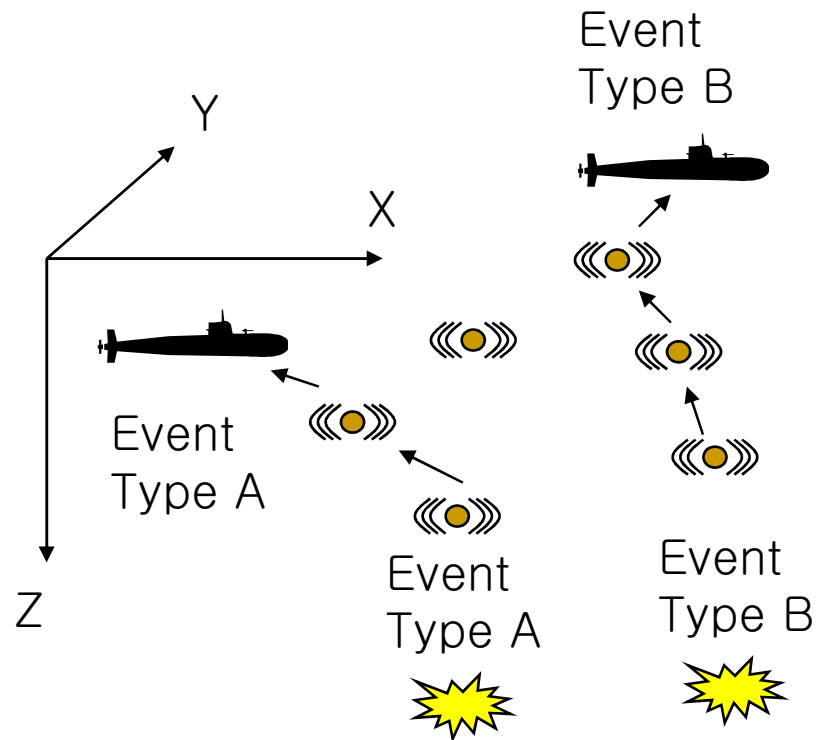
Luiz F. Vieira, Uichin Lee, Mario Gerla
UCLA

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



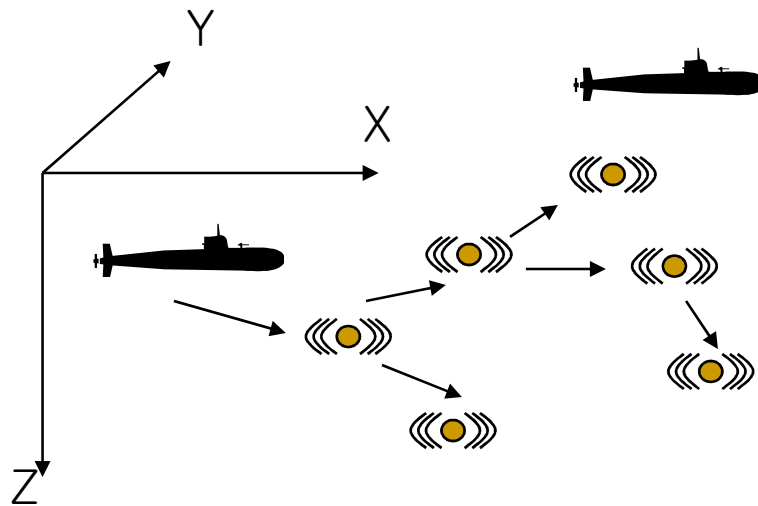
- Sensor Equipped Aquatic (SEA) swarm of mobile sensors:
 - Enable 4D (space and time) monitoring
 - Dynamic monitoring coverage
- Sensor nodes notify events to corresponding submarines

Problem Statements

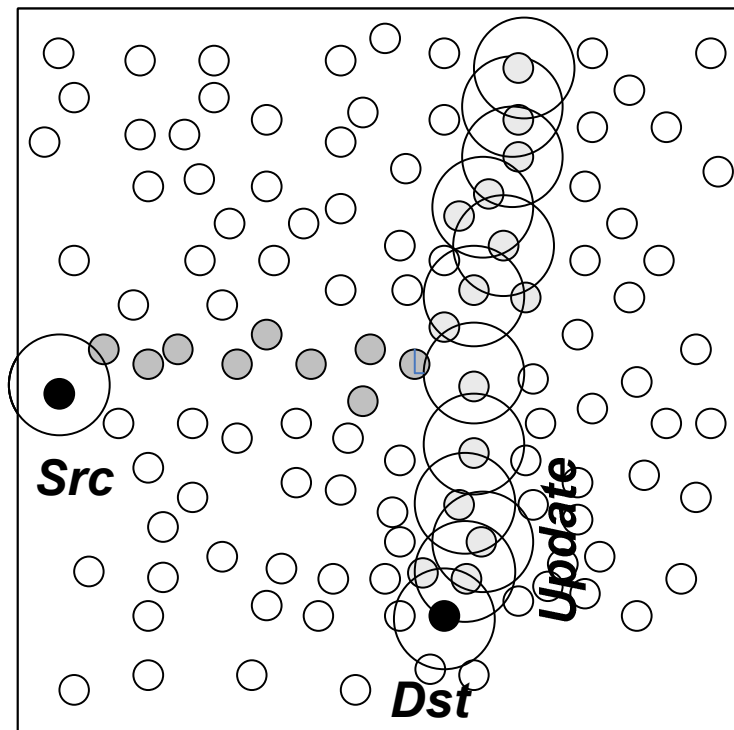
- Mobile sensors report events to submarines
- Proactive (OLSR), Reactive Routing (AODV), or Sensor data collection (Directed Diffusion)
 - All require route discovery (**flooding**) and/or maintenance
 - Not suitable for bandwidth constrained underwater mobile sensor networks (collision + energy consumption)
- 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



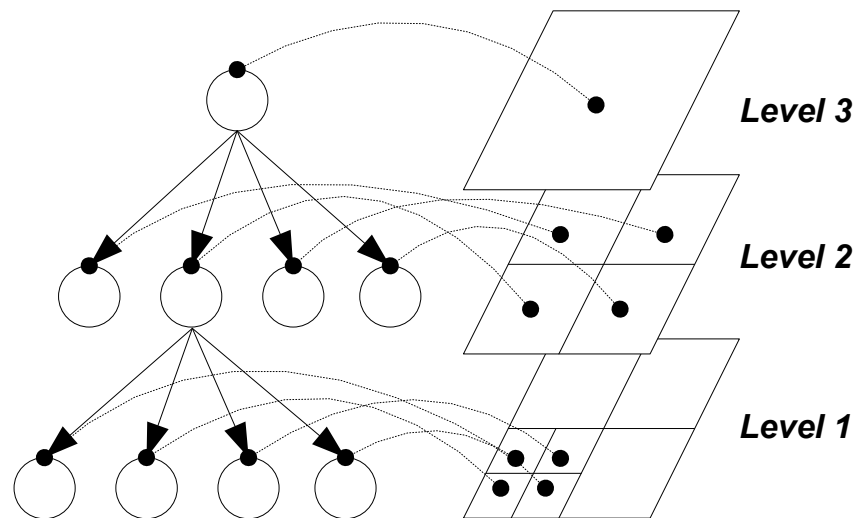
Related Work – Quorum Based



XYLS

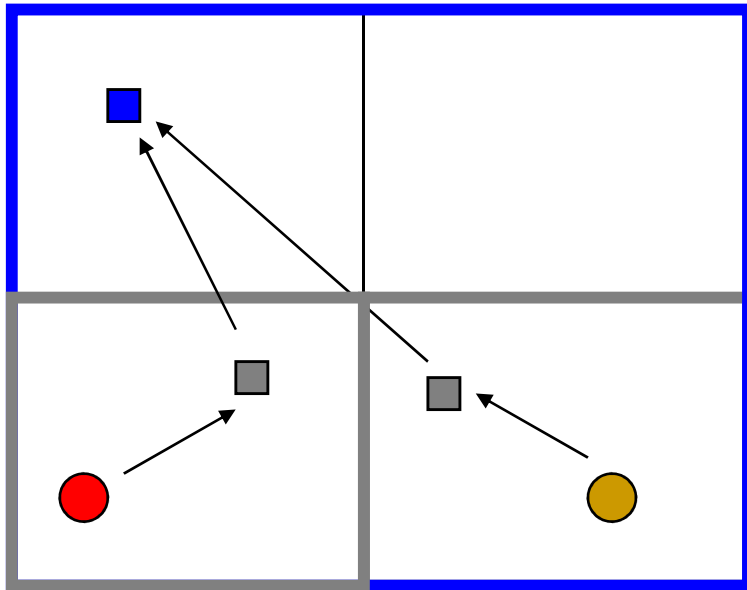
- Each location update is sent to a subset of nodes (update quorum)
- Location query is sent to a subset of nodes (or query quorum)
- The query will be resolved when their intersection is non-empty

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

	Update	Query
Naïve flooding	$O(M^3)$	$O(1)$
Quorum-based	$O(M^2)$	$O(M^2)$

- 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., $O(M^2)$

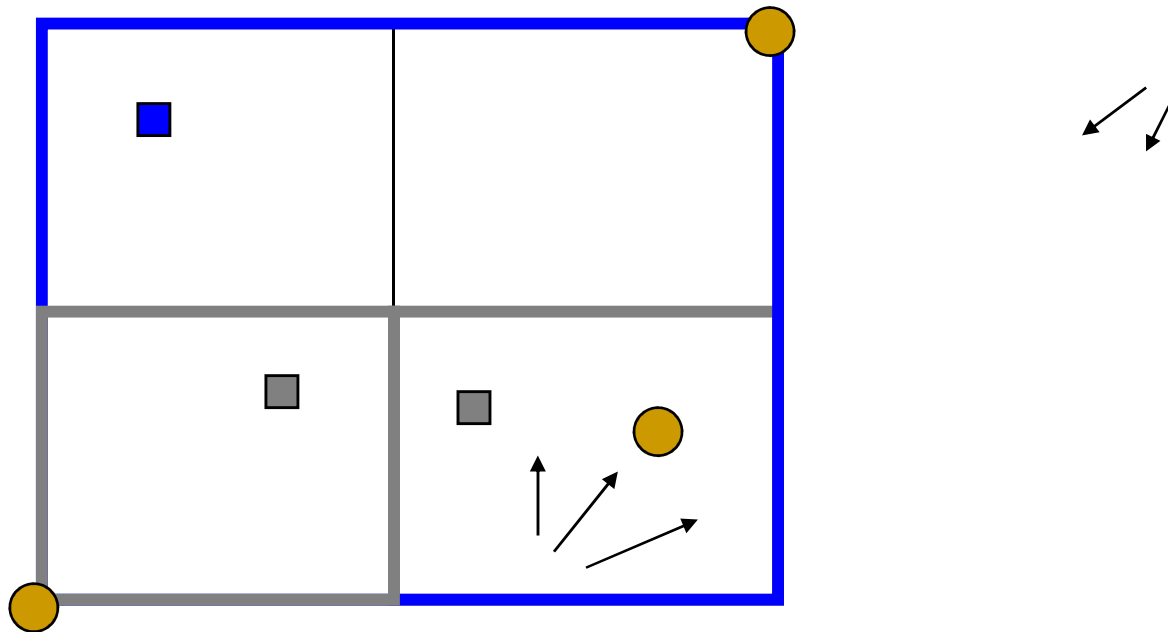
Protocol Analysis

- 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.

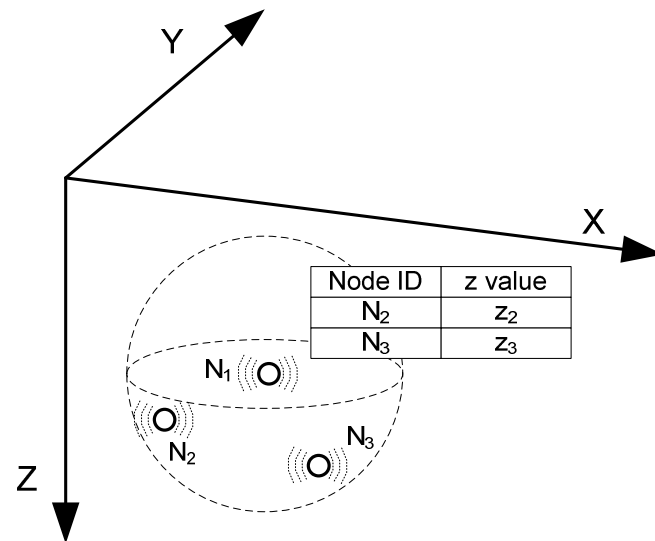
Reference Point Updates in Hierarchical Schemes

- 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

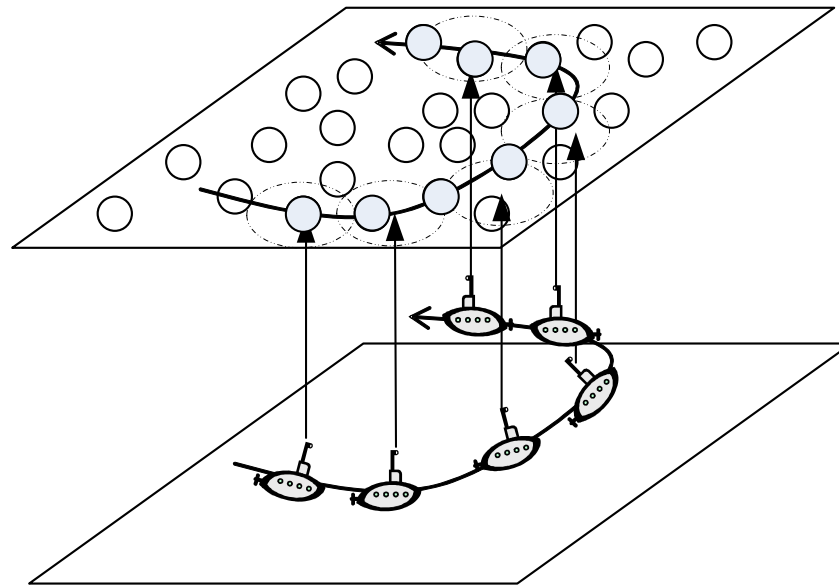


Location Service in 2D: Analysis

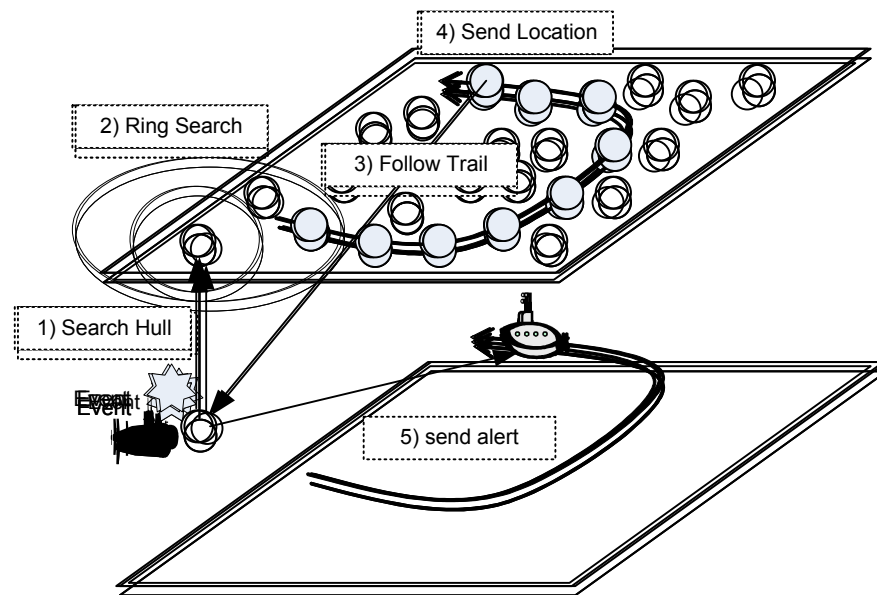
- Naïve flooding
 - ❑ update and query costs are $O(M^2)$
- Quorum-based
 - ❑ store information in a 1D line
 - ❑ Update and query costs scale as $O(M)$
- Hierarchical
 - ❑ Reference update, location update and query operations take $O(M^2)$, $O(H)$, and $O(M)$ respectively.
 - ❑ Reference point update is still expensive!!!

Phero-Trail – Location Update

- AUV stores the location updates (pheromone) along its projected trajectory on the upper hull
 - Periodic updates create a pheromone trail



Phero-Trail – Location Query



- 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

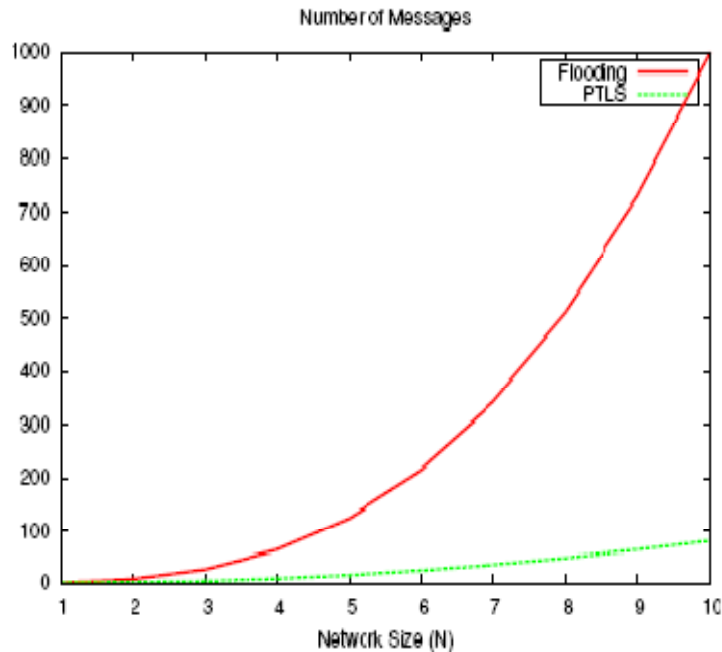
- Length of a pheromone trail is fixed $2^{(H-1)}$
- We mimic the behavior of a hierarchical scheme by setting the probability that the update propagation distance is $2^k R$ is to be given by $1/2^k$
- Vertical routing $O(M)$

■ Search: expanding spiral curve search

- Worst case: in k -th step, a curve search of 2^k sizes.

$$\sum_{k=1}^H 2^k R = \frac{2^{H+1}-1}{2} R = \Theta(2^H) = \Theta(M)$$

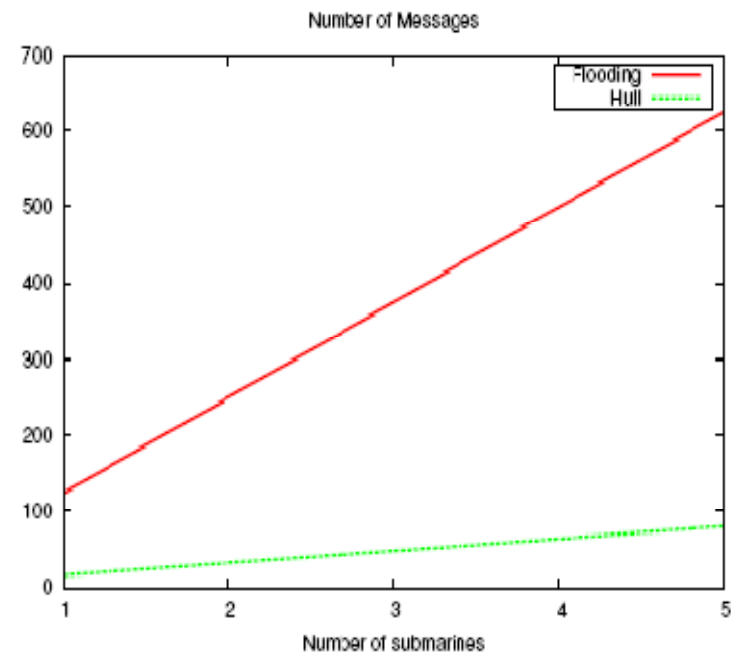
Simulation Results



- 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.