Localization Techniques for Underwater Acoustic Sensor Networks

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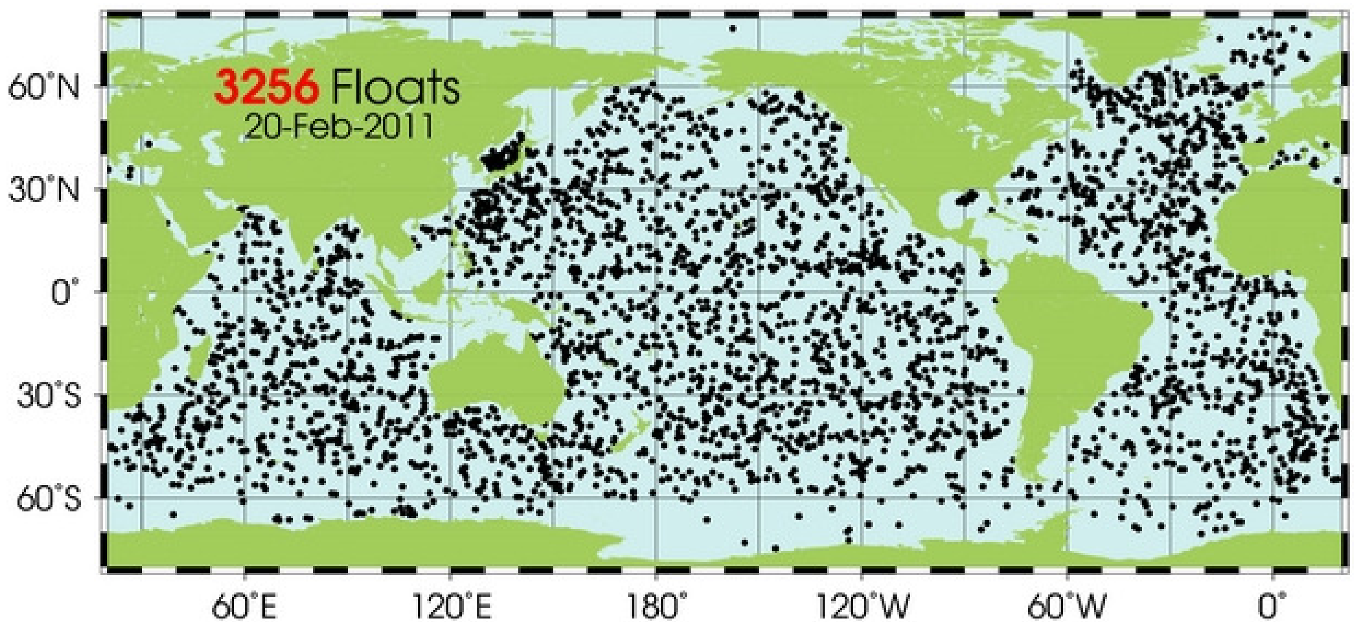
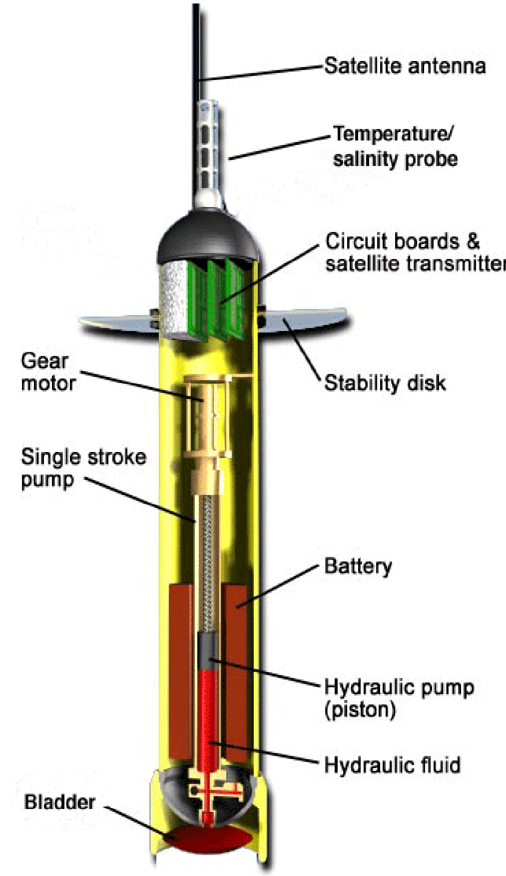
Outline

- Ocean Monitoring Systems
- Underwater Acoustic Sensor Networks (UASN)
- Localization Techniques for UASNs
- Open Issues and Future Directions

Ocean Monitoring Systems- ARGO Project

- Argo floats measure the temperature and salinity of the upper 2000 m of the oceans
- Over 3000 profiling floats

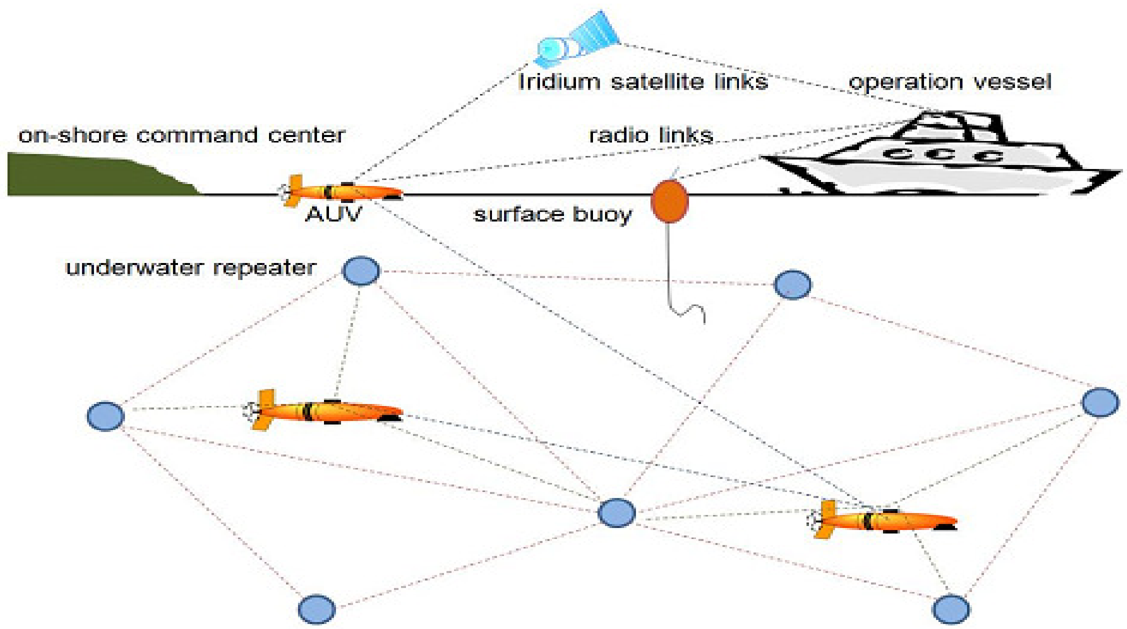




Ocean Monitoring System - Seaweb

US Navy Project (since 1980s)

- Seaweb includes AUVs, gliders, buoys, repeaters and ships
- Devices communicate via telesonar, radio and satellite links



Traditional Ocean Monitoring Systems and UASNs

Traditional equipments

- Disconnected, individual and large
- Transmit data only when they are close to surface or by underwater cables
- No node-to-node communications

UASNs:

- Relatively small and less expensive underwater sensor nodes
- Sensor nodes communicate underwater via acoustics

Underwater Acoustic Communications - I

- Why acoustics?
  - Radio signals attenuate rapidly
  - Optical signals scatter
- Acoustic signals attenuate less and they are able to travel further distances
  - Bandwidth of the acoustic channel is low
    - For 10-100km (long-range), the bandwidth is a few kHz
    - For 1-10km (medium range),the bandwidth is in the order of 10kHz
    - For <100m (short range), the bandwidth is only over a few hundred kHz

Underwater Acoustic Communications - II

- Acoustic Channel Cont'd
  - Data rates are low
    - The maximum attainable range-rate product is 40 km.kbps
    - Data rate can be increased by using short range communications

Span	Range (km)	Data rate
Short range	<1	~20 kbps
Medium range	1–10	~10 kbps
Long range	10–100	~1 kbps
Basin scale	3000	~10 bps

  - The acoustic channel has low link quality due to the multi-path propagation and the time-variability of the medium
  - Long propagation delay
    - 1.5×10^3 m/s vs. 3×10^8 m/s

Challenges of Localization in UASNs

- Underwater Communications
- Mobility
- Limited battery life
- GPS cannot be used underwater
  - High-frequency GPS signal does not propagate well
- GPS-free WSN techniques cannot be directly applied to UASNs
  - Extensive messaging
  - Infrastructure

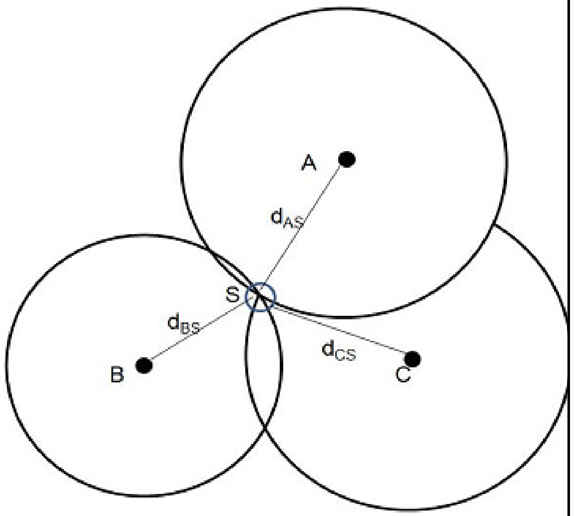
Localization Basics

Localization has two steps

- Collecting information about the neighbor nodes
  - Range, angle, connectivity

    Ranging Techniques:

    - Received Signal Strength Indicator (RSSI)
    - Angle-of-Arrival (AoA)
    - Time Difference of Arrival (TDoA)
    - Time of Arrival (ToA)
- Using this information in lateration



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Localization Techniques for UASNs

- Distributed Protocols
  - Estimation-based Protocols
    - DNRL, MSL, AAL, LDB, LSL, UPS, LSLS, USP
  - Prediction-based Protocols
    - SLMP
- Centralized Protocols
  - Estimation-based Protocols
    - MASL, ALS
  - Prediction-based Protocols
    - CL

•M. Erol-Kantarci, H. T. Mouftah, S. Oktug, "Localization Techniques for Underwater Acoustic Sensor Networks," IEEE Communications Magazine, vol. 48, no.12, 2010.

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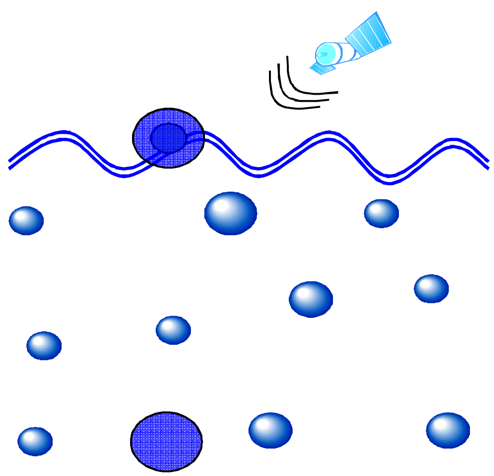
Distributed and Estimation-based Localization Techniques

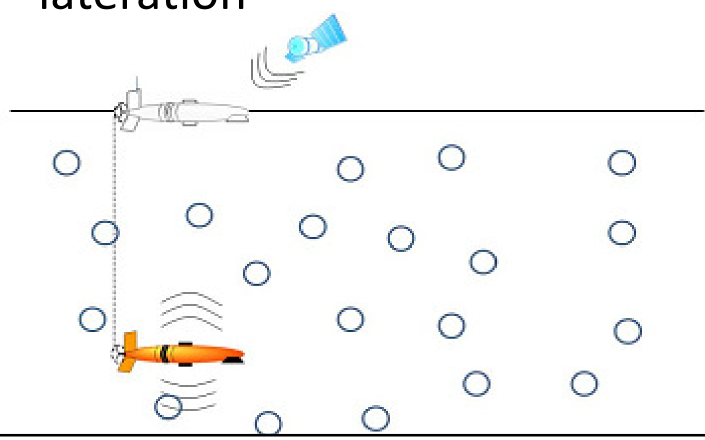
- DNRL (Dive and Rise Localization)
  - DNR beacons learn coordinates via GPS
  - Descend and ascend periodically
  - Broadcast localization messages at several intervals
  - Sensor nodes do lateration after receiving localization messages from at least three DNR beacons



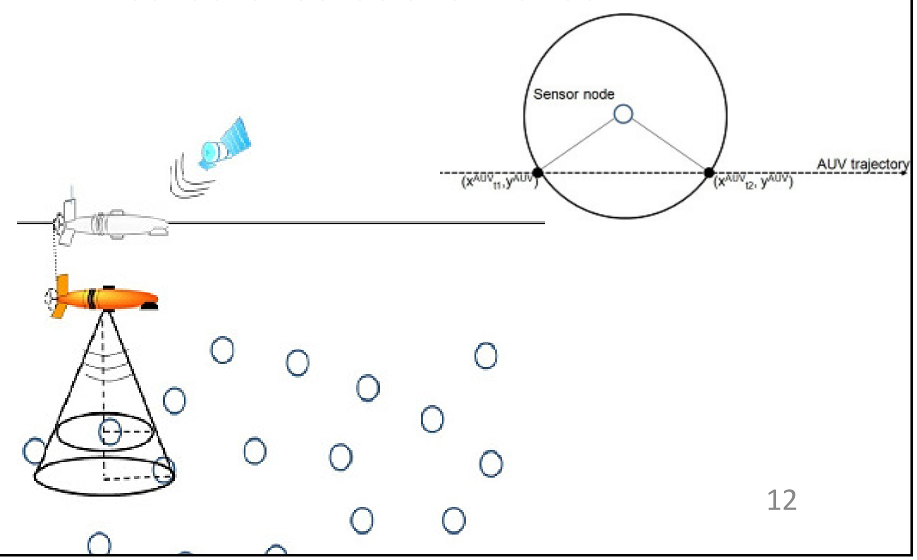
- MSL (Multi-Stage Localization)
  - Localized nodes become reference nodes for the non-localized nodes
  - Sensor nodes do lateration after receiving localization messages from DNR beacons or localized nodes
  - DNRL and MSL uses ToA for ranging
    - Require synchronization
  - Coverage of MSL is larger whereas the error of DNRL is lower

Distributed and Estimation-based Localization Techniques

- AAL (AUV-Aided Localization)
  - AUV broadcasts “wake-up messages” from different places on its route
  - An underwater sensor node sends a request packet and AUV replies with a response packet
  - This request/reply packet pair enables two-way ranging
  - The underwater node does lateration

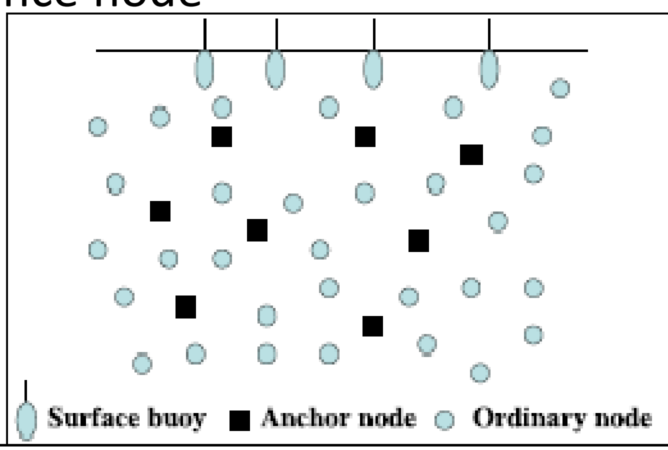


- LDB (Localization with Directional Beacons)
  - AUV roams above the area of operation and uses a directional acoustic transceiver to broadcast its coordinates
  - Sensor node maps AUV coordinates on its plane and calculates coordinates

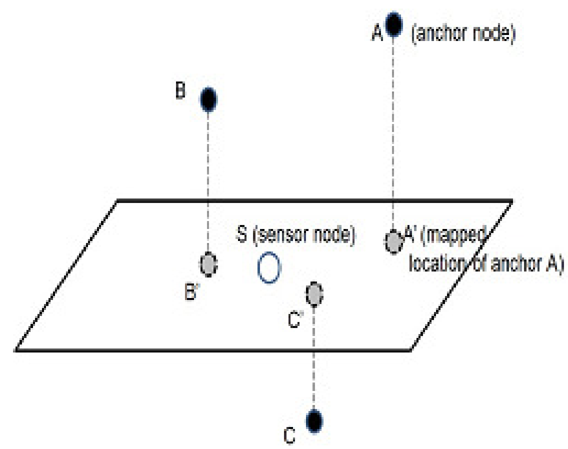


Distributed and Estimation-based Localization Techniques

- LSL (Large-Scale Hierarchical Localization)
  - Anchor nodes broadcast localization messages
  - Underwater nodes exchange beacons periodically to measure the distances to their neighbors
  - If an ordinary node gathers adequate localization messages it does lateration
  - A localized node may become a reference node

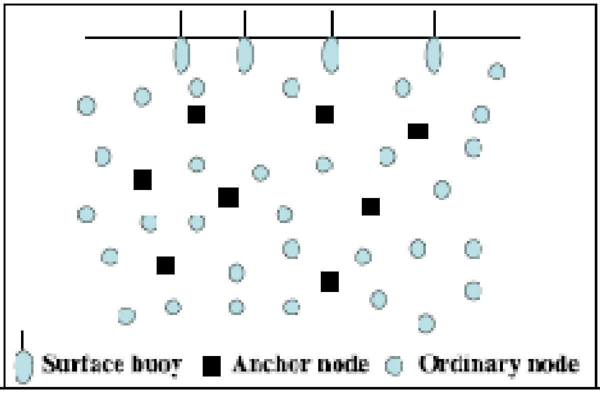


- USP (Underwater Sensor Positioning)
  - Anchor coordinates are mapped onto the 2D plane that the sensor resides on
  - Bilateration and trilateration are used to estimate sensor coordinates



Distributed and Prediction-based Localization Technique

- SLMP (Scalable Localization with Mobility Prediction)
- Anchor nodes and ordinary nodes predict their locations by using their previous coordinates and their mobility patterns
- Anchor nodes periodically check the validity of their mobility pattern:
  - An anchor node, after predicting its location, uses surface buoy coordinates and distance measurements to buoys to estimate its location
  - If the Euclidean difference between the predicted and estimated locations is less than a threshold, the anchor node assumes its mobility model is accurate
  - Otherwise, the anchor node runs its mobility prediction algorithm, determines the new mobility pattern
- New model parameters are broadcasted to the ordinary nodes



Localization Techniques for UASNs

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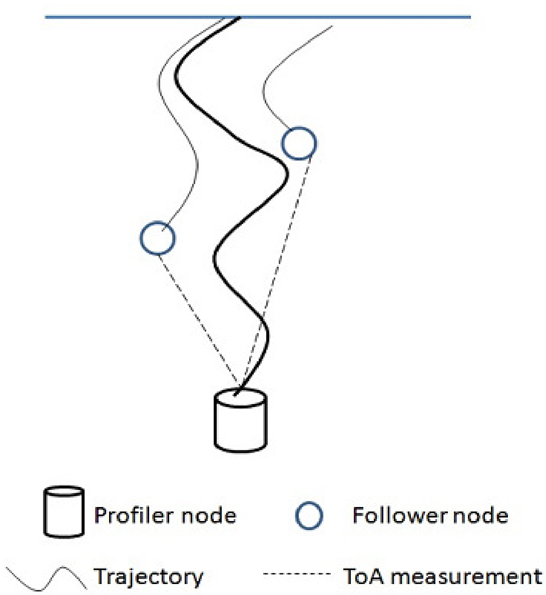
Centralized and Estimation-based Localization Techniques

- MASL (Motion-Aware Self Localization)
  - Underwater nodes collect distance estimates to their neighbours
  - Distance estimates are fed into an iterative estimation algorithm at the end of the mission
  - At each iteration, the algorithm refines position distributions by dividing the area of operation into smaller grids and
  - Selecting the area in which the node resides with the highest probability
- ALS (Area-Based Localization Scheme)
  - Anchors partition the region into non-overlapping areas by sending messages at varying power levels
  - An underwater sensor listens to anchor messages, keeps a list of anchors and their power levels, and sends this information to a sink node
  - The sink knows the coordinates of the anchors and determines the location of the sensor node

Centralized and Prediction-based Localization Technique

- Collaborative Localization (CL)
  - A follower node predicts its location by using its previous location and the displacement of the profiler
  - The displacement of the profiler is attained by periodically measuring distances in between via ToA



Localization Protocols

	Distributed/ Centralized	Estimation/ Prediction	Anchor type	Ranging method	Communication	Synchronization
DNRL [3]	Distributed	Estimation	Non-propelled mobile anchors	ToA (one-way ranging)	Silent	Yes
MSL [4]	Distributed	Estimation	Non-propelled mobile anchors and reference nodes	ToA (one-way ranging)	Iterative	Yes
AAL [5]	Distributed	Estimation	Propelled mobile anchor (AUV)	ToA (two-way ranging)	Silent	No
LDB [6]	Distributed	Estimation	Propelled mobile anchor (AUV)	Range-free	Silent	No
LSL [7]	Distributed	Estimation	Surface buoys, underwater anchors, and reference nodes	ToA (one-way ranging)	Iterative	Yes
UPS [9]	Distributed	Estimation	Stationary anchors	TDoA	Silent	No
LSLS [10]	Distributed	Estimation	Stationary anchors and reference nodes	TDoA	Iterative	No
USP [11]	Distributed	Estimation	Stationary anchors	Not specified	Silent	No
SLMP [12]	Distributed	Prediction	Surface buoys, underwater anchors, and reference nodes	ToA (one-way ranging)	Iterative	Yes
MASL [13]	Centralized	Estimation	No anchors	ToA (one-way ranging)	Active	Yes
ALS [14]	Centralized	Estimation	Anchors with variable power levels	Range-free	Active	No
CL [15]	Centralized	Prediction	No anchors	ToA (one-way ranging)	Active	Yes

Distributed VS Centralized Localization

- Distributed techniques:
  - Suitable for a large number of applications
    - online monitoring, target tracking, coordinated motion
  - Computational burden is on the sensors

- Centralized techniques:
  - Computational burden is shifted from the sensors
  - Work offline (MASL) and coarse-grained (ALS)
  - Unsuitable for data tagging, online monitoring and tracking applications

Estimation VS Prediction Based Localization

- Estimation can be used for stationary and mobile UASNs
- Prediction-based schemes inherently address localization of mobile UASNs
- Their performance is closely coupled with the mobility of the sensors

Open Issues

- Analyzing the performance of prediction-based localization schemes on accurate mobility models
- The impact of various localization techniques on the performance of networking in UASNs and other UASN applications
  - Geographic routing algorithms and geographic clustering schemes
- Cross layer design
  - Using link quality information in selecting anchor nodes or reference nodes

Publications on UASNs

Journals

- **Melike Erol-Kantarci, H. T. Mouftah, S. Oktug, "A Survey of Architectures and Localization Techniques for Underwater Acoustic Sensor Networks," accepted for publication, IEEE Communications Surveys and Tutorials, 2011.**
- Melike Erol-Kantarci, S. Oktug, L. Vieira, M. Gerla, "Performance Evaluation of Distributed Localization Techniques for Mobile Underwater Acoustic Sensor Networks", Elsevier Ad Hoc Networks Journal, vol.9 no.1, 2011, pp. 61-72.
- **Melike Erol-Kantarci, H. T. Mouftah, S. Oktug, "Localization Techniques for Underwater Acoustic Sensor Networks," IEEE Communications Magazine, vol. 48, no.12, 2010.**

Conferences

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- A. Caruso, F. Paparella, L. Vieira, Melike Erol, M. Gerla, "The Meandering Current Mobility Model and its Impact on Underwater Mobile Sensor Networks," IEEE INFOCOM, 13-19 April 2008, Phoenix, AZ.
- Melike Erol, L. Vieira, M. Gerla, "Localization with Dive'N'Rise (DNR) Beacons for Underwater Acoustic Sensor Networks," The Second ACM International Workshop on UnderWater Networks WUWNet (in conjunction with ACM MobiCom 2007), September 14 2007, Montreal, Quebec, Canada.
- Melike Erol, L. Vieira, M. Gerla, "AUV-Aided Localization for Underwater Sensor Networks", WASA special track on Underwater Sensor Networks, August 1-3, 2007, Chicago, IL.

Thank you

Questions?

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