Chapter 11: A Survey of Architectures and Localization Techniques for Underwater Acoustic Sensor Networks

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Outline

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- Introduction
- Background
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Abstract

- The widespread adoption of the Wireless Sensor Networks (WSNs) in various applications in the terrestrial environment and the rapid advancement of the WSN technology have motivated the development of Underwater Acoustic Sensor Networks (UASNs).
- Localization is one of the fundamental tasks for UASNs which is required for data tagging, node tracking, target detection, and it can be used for improving the performance of medium access and network protocols.
- In this paper, we present a comprehensive survey of these architectures and localization methods.

Introduction

- Applications
- Features and Benefits
- Challenges

Applications

- UASN technology provides many applications:
  - The climate change.
  - The life of ocean animals and the variations in the population of coral reefs.
  - UASNs can enhance the underwater warfare capabilities of the naval forces since they can be used for surveillance, submarine detection, mine countermeasure missions and unmanned operations in the enemy fields.
  - monitoring the oil rigs with UASNs can help taking preventive actions for the disasters such as the rig explosion that took place in the Gulf of Mexico in 2010.
  - Last but not least, earthquake and tsunami forewarning systems can also benefit from the UASN technology.

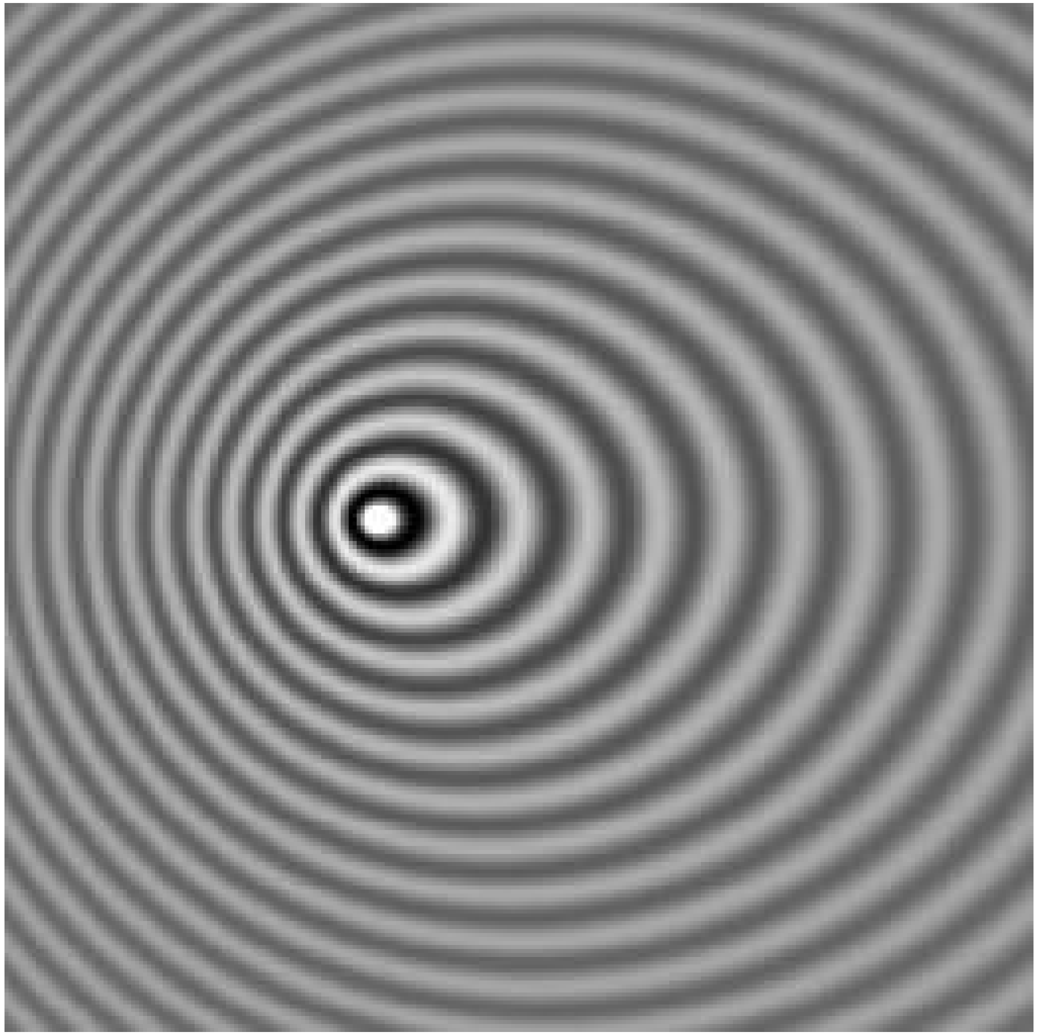
Features and Benefits

- In UASNs, these equipments are replaced by relatively small and less expensive underwater sensor nodes that house various sensors on board, e.g. salinity, temperature, pressure, current speed sensors.
- The underwater sensor nodes are networked unlike the traditional equipments, and they communicate underwater via acoustics.
- In underwater, radio signals attenuate rapidly, hence they can only travel to short distances while optical signals scatter and cannot travel far in adverse conditions.
- On the other hand, acoustic signals attenuate less, and they are able to travel further distances than radio signals and optical signals.
- Consequently, acoustic communication emerges as a convenient choice for underwater communications.

Challenges

- The bandwidth of the acoustic channel is low, hence the data rates are lower than they are in terrestrial WSNs.
- Data rates can be increased by using short range communications which means more sensor nodes will be required to attain a certain level of connectivity and coverage.
- Moreover, the acoustic channel has low link quality which is mostly due to the multi-path propagation and the time-variability of the medium.
- Furthermore, the speed of sound is slow (approximately 1500 m/s) yielding large propagation delay.
- In addition to those, in mobile UASNs, the relative motion of the transmitter or the receiver may create the Doppler effect.
- Besides these communication channel related challenges, UASNs are also energy limited similar to other WSNs.

Doppler Effect



Background

- In this section, we aim to familiarize the reader with the fundamental concepts of localization and UASNs.
    - *Localization Basics*
    - *State-of-the-art Oceanographic Systems and Localization Techniques in Oceanography*
    - *Challenges of UASNs and Underwater Communications*

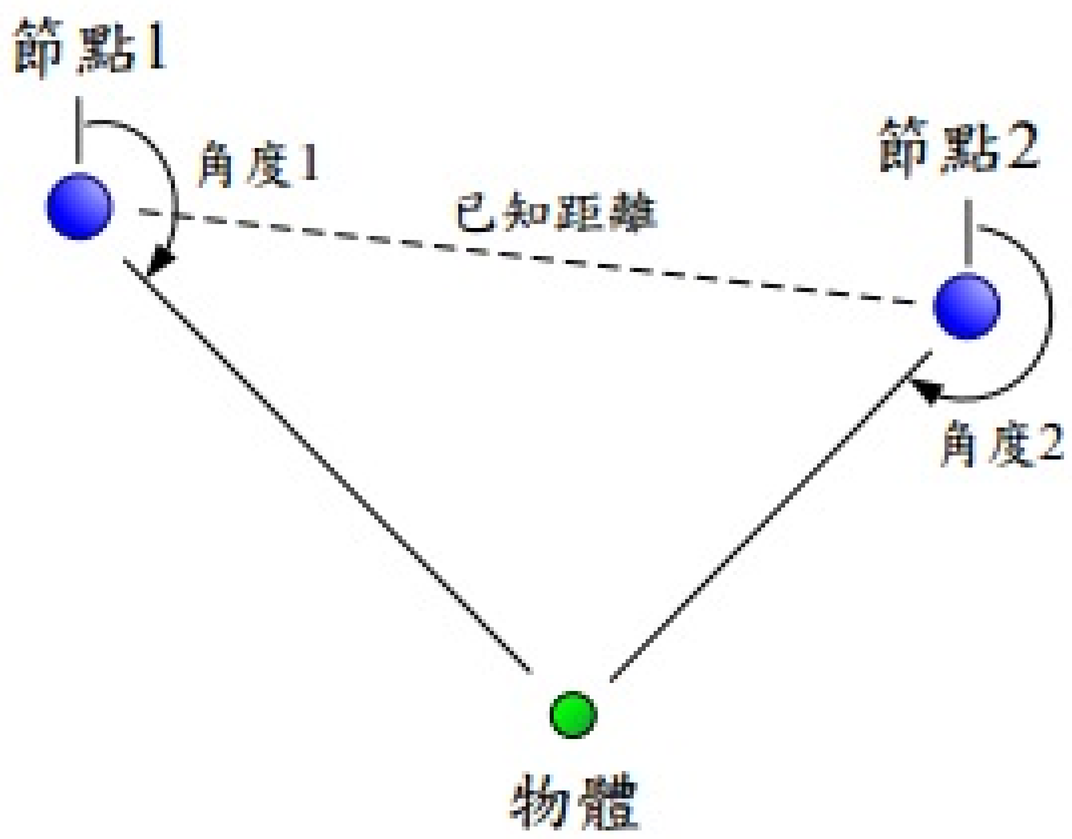
Localization Basics

- Localization generally requires several objects with known locations (anchors) and distance or angle measurements between these anchors and the object to be localized (unknown node).

- Anchors may be placed at fixed locations and their coordinates may have been pre-configured, or they may have special hardware to learn their locations from a location server, such as the Global Positioning System (GPS).

- For estimating the location of an unknown node, traditional localization methods generally use distance or angle measurements between the anchor and the unknown node or a combination of the two measurements.

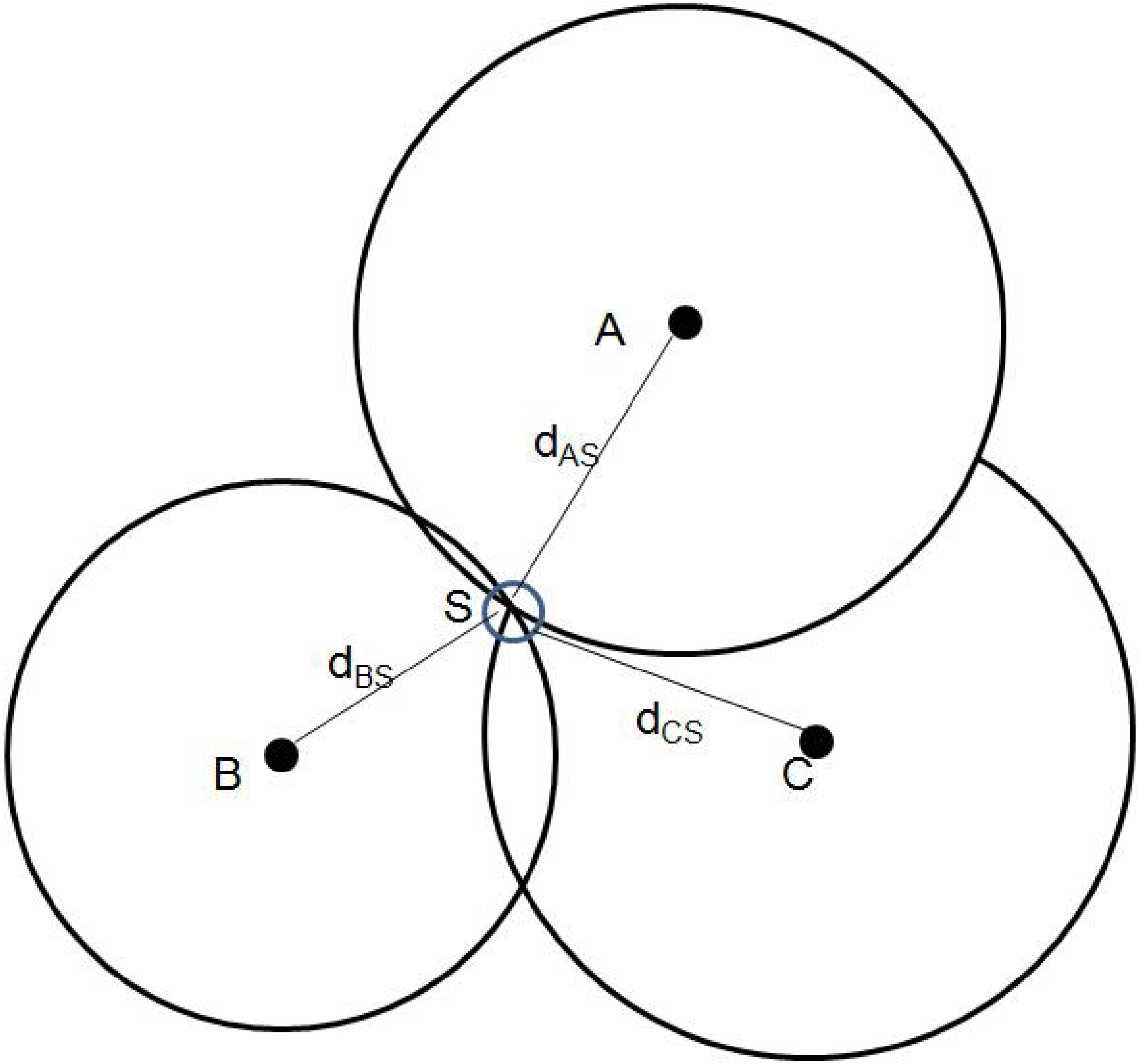
Angulation



Lateration

- Two well-known localization techniques are angulation and lateration.
- Angulation utilizes the bearing information and the geometric principles of triangles, whereas lateration uses the distance between two nodes, i.e. the range, and intersecting circles.
- Lateration is a widely used technique which is also employed by the GPS system.
- For simplicity, we show the principles of trilateration (three anchors) in Figure 1.

Localization in Two Dimensional Space using Lateration



Trilateration

- For instance, to estimate the coordinates of a node, denoted by (x, y, z), one can use the set of equations:

$$(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2 = d_i^2$$

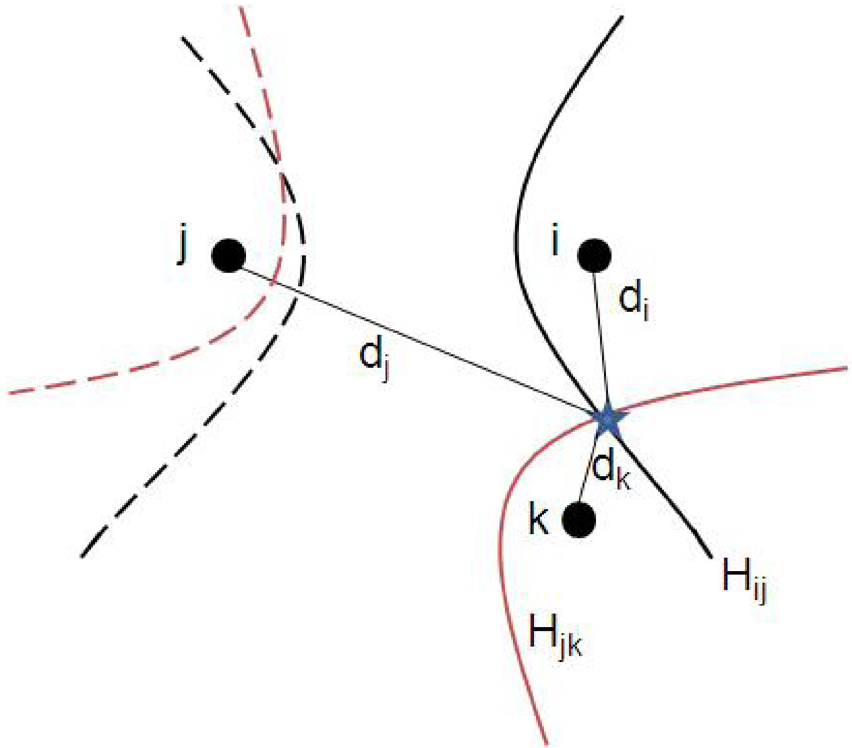
- where(x_i,y_i,z_i) are the coordinates of the anchor and d_i is the measured distance between the anchor i and the node.

- Note that, underwater nodes are usually able to attain their depth by their pressure sensors, hence in UASN research generally the localization problem is simplified to estimating the (x, y) coordinates.

Two Dimensional Hyperbola-Based Localization

- The difference between the arrival times of the acoustic signal at different nodes can be also used to form intersecting hyperbolas.

- The two dimensional hyperbola-based localization is shown in Figure 2.



Two Dimensional Hyperbola-Based Localization Equation

- H_{ij} and H_{jk} are the hyperbolas whose foci are at the locations of the anchors i, j and j, k, respectively.
- Assuming that the anchor locations are given as (x_i, y_i), (x_j, y_j), (x_k, y_k), and the sensor (or event) is at (x, y).
- di denotes the distance of the i^{th} anchor from the unknown node and $t_{ij} = t_i - t_j$ where t_i and t_j are the arrival times of the signal at anchor i and anchor j, respectively.
- The speed of sound is denoted by c.
- The set of points satisfying (x, y) are given by the hyperbola equation:

$$\begin{aligned} d_i - d_j &= c.t_{ij} \\ &= \sqrt{(x - x_i)^2 + (y - y_i)^2} \\ &\quad - \sqrt{(x - x_k)^2 + (y - y_k)^2}. \end{aligned}$$

Received Signal Strength Indicator, RSSI

- In a WSN, angle and distance measurements can be collected by one of the following methods:
  - Received Signal Strength Indicator, RSSI
  - Angle-of-Arrival, AOA
  - Time Difference of Arrival, TDoA
  - Time of Arrival, ToA
- RSSI is based on converting the propagation loss, which is the difference between the transmitted and the received signal power, into a distance estimate.

Angle-of-Arrival, AoA and Time Difference of Arrival, TDoA and Time of Arrival, ToA

- AoA is the angle between the propagation path of the signal and a reference direction.

- TDoA uses the time difference between the arrival of two signals, usually Radio Frequency (RF) signals and acoustic signals.

- ToA method generally calculates the distance by using one-way ranging and the speed of the signal assuming the nodes are synchronized.

One-Way Range and Two-Way Range

- One-way range is calculated by the difference between the arrival time of the signal and the sending time of the signal which is included as a timestamp field in the packet.
- When synchronization cannot be achieved, average of the two-way (round trip) ranging is also used as an estimate of the range.
- Two-way range is calculated by the time difference between sending a short packet and receiving a response.
- Two-way ranging does not require synchronization among nodes however, for asymmetric channels this method may give inaccurate range information.

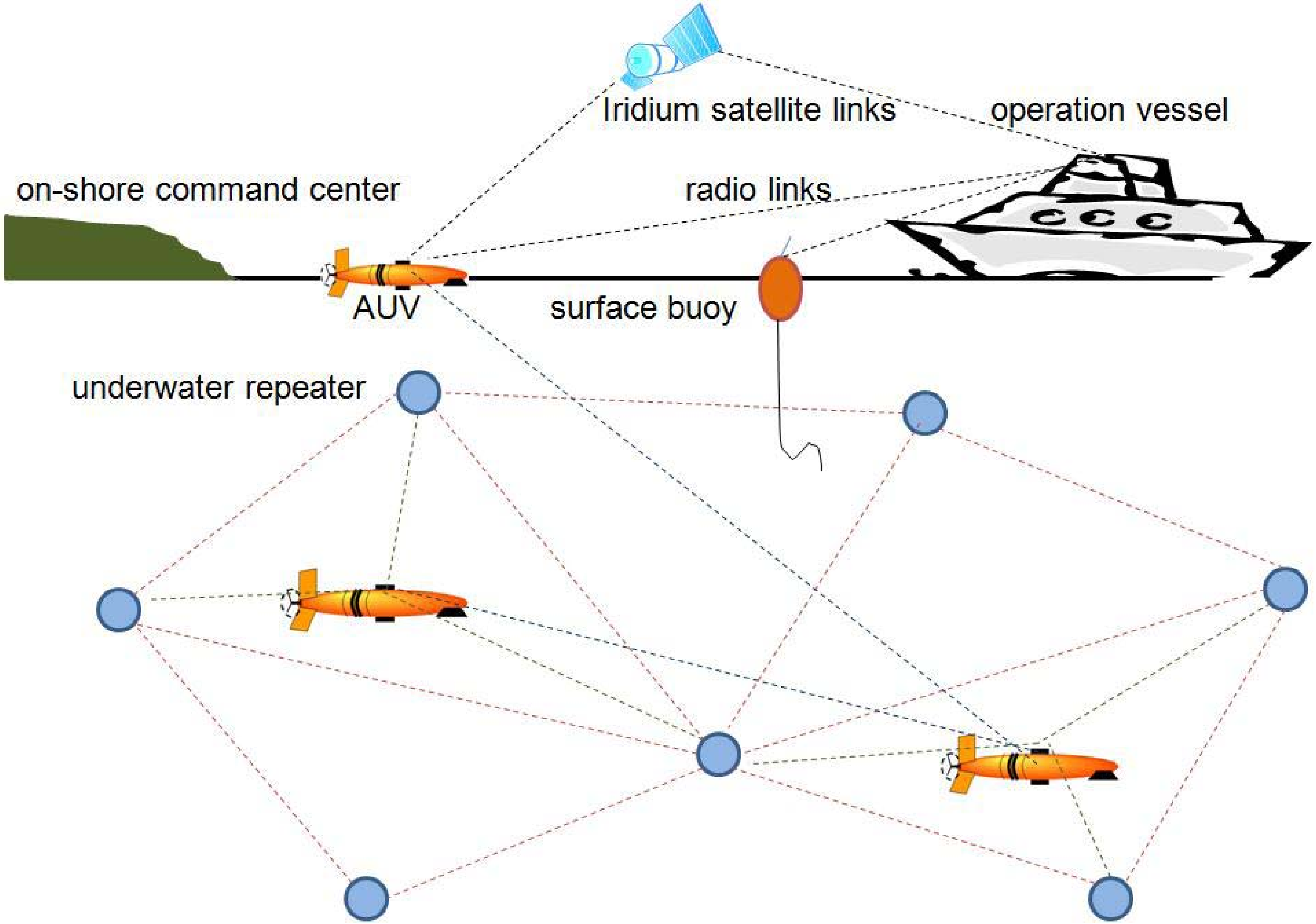
Localization Basics (cont.)

- In UASNs, ToA is preferred more than it is preferred in terrestrial systems since the ToA method using the radio signal in air acquires high resolution timers.
- However, the speed of sound in water is slow, hence ToA can be used in ranging for UASNs.
- On the other hand, RSSI is not convenient since predicting the propagation loss accurately is difficult due to time-varying properties of the underwater environment.
- Using AoA for UASNs has been considered in but it has not been widely employed due to the size and cost of the directional antennas.
- There are several schemes employing TDoA for UASNs, as well.

State-Of-The-Art Oceanographic Systems and Localization Techniques in Oceanography

- Stationary surface buoys, ocean floor units and floats are among the most common ocean monitoring devices.
- Surface buoys and ocean floor units collect data from the ocean surface and the ocean floor, respectively.
- They have fixed locations and they communicate with a central station using either satellite communications or cables.
- On the other hand, floats do not have fixed locations, they are dropped from vessels and they drift with the force of the ocean currents.
- Profiling floats which are special types of floats having the ability of moving vertically in the water column, i.e. descend and ascend, are able to collect data from a certain depth up to approximately 2km.

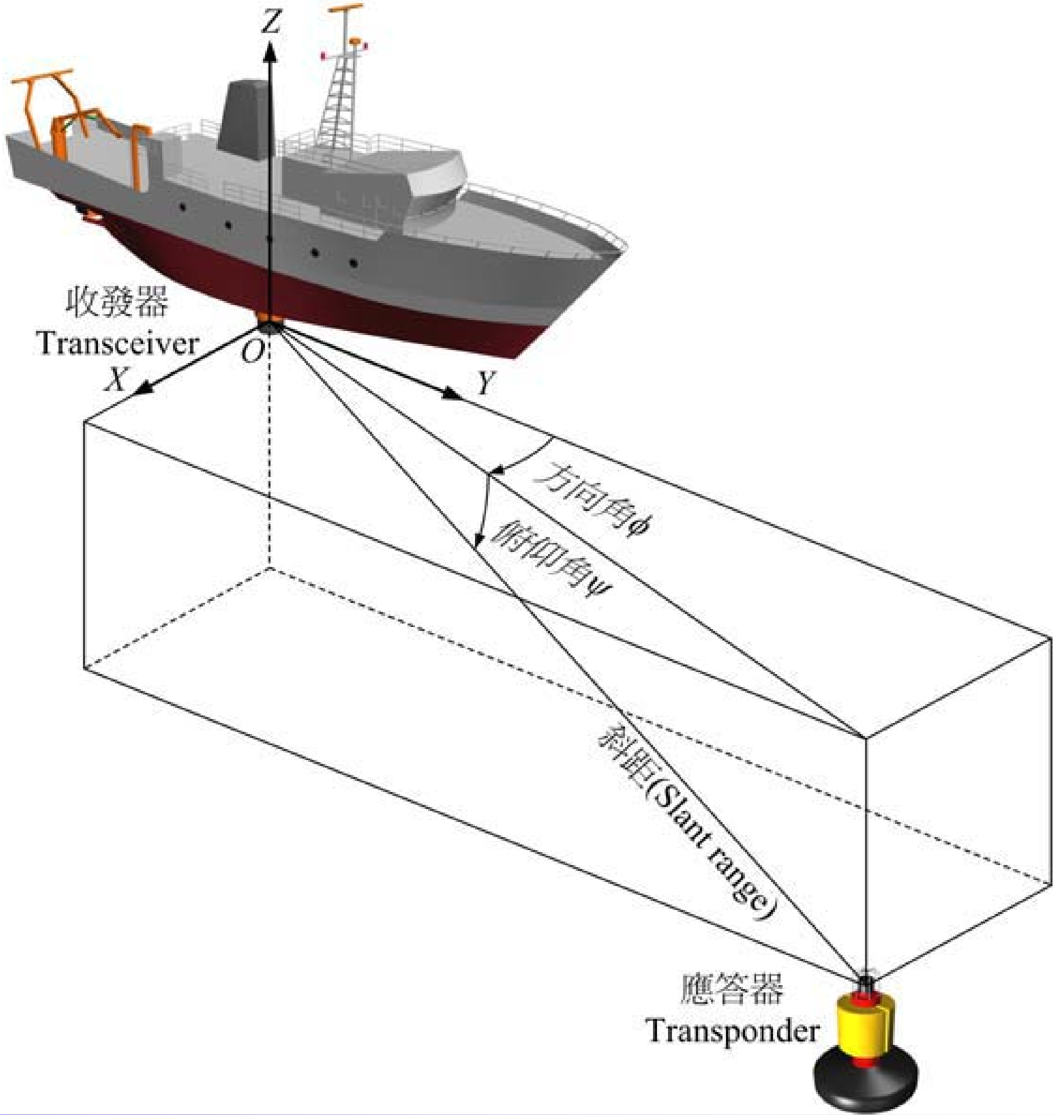
Seaweb network in the Eastern Gulf of Mexico on February 2003



Short Base-Line, SBL and Long Base-Line, LBL

- Localization in the traditional oceanographic systems generally utilize one of the two acoustics-based approaches, namely Short Base-Line (SBL) or Long Base-Line (LBL).
- In the SBL system, a ship follows the underwater devices and uses a short-range acoustic emitter to enable localization.
- In the LBL system, acoustic transponders are deployed either on the seafloor or on moorings around the area of operation.
- Devices that are in the transmission ranges of several sound sources estimate their location by triangulation.
- LBL or SBL cannot be used for UASNs because LBL uses long range signals which create interference and disable the communication among the sensor nodes while SBL involves a ship in the operation area which is not feasible for the large-scale and mobile UASNs.

Short Base-Line, SBL



GPS Intelligent Buoy, GIB

- For instance, GPS Intelligent Buoy (GIB), which is a commercial system, is designed to track individual units, such as AUVs, divers and other underwater equipments.
- In the GIB system, GIB buoys, which have GPS receivers and hydrophones, listen to the signals that are emitted by an underwater equipment and estimate its distance via ToA.
- GIB buoys periodically send these distance measurements and self coordinates to a central station where the location of the underwater equipment is determined.
- First, the underwater equipments emit signals to be tracked which means they consume high amount of energy especially when longrange communications are required to reach the GIB buoys.
- On the other hand, if short range communications are used, a large number of GIB buoys may be needed.
- Moreover, GIB is a centralized technique and it does not provide location information for the sensors, it provides tracking ability for the central station.

Challenges of UASNs and Underwater Communications

- Acoustic communications, despite having several drawbacks, are preferred to radio communications and optical communications because the acoustic signals attenuate less than the RF and the optical signals.
- Attenuation in an underwater acoustic channel for a signal with frequency f over a distance l is given as:

$$A(l,f) = A_{norm} l^k a(f)^l$$

- where A_{norm} is a normalization constant, a(f) is the absorption coefficient, k is the spreading factor that is used to describe the geometry of propagation, and k = 1.5 is assumed to be the practical spreading value.

Challenges of UASNs and Underwater Communications (cont.)

- The absorption coefficient is expressed empirically for frequency values above a few hundred Hz as:

$$10 \log a(f) = 0.003 + 0.11 \frac{f^2}{1+f^2} + 44 \frac{f^2}{4100 + f^2} + 2.75.10^{-4} f^2$$

- where f is given in kHz and a(f) is given in dB/km.
- Eq. 4 is simplified into the following expression for lower frequencies

$$10 \log a(f) = 0.002 + 0.11 \frac{f^2}{1 + f^2} + 0.011 f^2$$

Bit Error Rate, BER

- Acoustic channel also suffers from the multi-path propagation and the time-variability of the underwater medium.
- The major reason for multi-path propagation is the reflections from the ocean surface and the ocean floor.
- Additionally, temperature and conductivity (salinity) differences form virtual layers which have varying reflection and refraction properties and they contribute to the multi-path propagation.
- Time-variability is mainly due to the surface waves where the place of the reflection point changes with the waves.
- Consequently, low link quality causes high Bit Error Rate (BER).

Link Quality

- Additionally, link quality of the acoustic channel depends on the direction of the communication (vertical or horizontal) and the deployment environment of the system (deep water or shallow water).

- For the former, the vertical channel has less multi-path spread than the horizontal channel, and for the latter, in shallow waters multi-path is more pronounced due to ocean floor and surface bounces.

- The propagation speed of the acoustic signal is slow, introducing a large propagation delay which is almost five orders of magnitude higher than radio communications.

- In addition, temperature and salinity variations in different parts of the ocean affect the speed of sound and cause high delay variance.

Mobile UASN May Create the Doppler Effect

- In a mobile UASN, motion of the sensor nodes may create the Doppler effect which is due to the relative motion of the transmitter or the receiver.
- In underwater applications, mobile platforms such as AUVs can move with a speed of several knots, while untethered, free-floating equipments can drift with the ocean currents which are generally slower than 1 knot (0.514444444 m/s).
- Doppler effect is related with the ratio of the relative transmitter-receiver velocity and the speed of the signal.
- Since the speed of sound in water is slower than speed of the electromagnetic waves in the air, Doppler effect can be more significant in UASNs than in WSNs.
- Mobility also mandates that the localization process is repeated at certain intervals so that the node locations do not become obsolete.

Communications Overhead and Energy-Efficiency

- Therefore, mobility introduces another challenge from the view point of communications overhead and energy-efficiency.
- Energy-efficiency is required since underwater equipments are expected to be left in the ocean for several weeks or months before they are collected and recharged for their next mission.
- Each mission cycle will possibly involve vessels to collect the sensors and due to the high cost of vessel operation, longer mission cycles are desired.
- Underwater sensor nodes may benefit from the force of currents or solar radiation or wind power to generate their own energy, however those energy sources are intermittent and energy-efficiency is again essential for UASNs.
- Currently, energy harvesting underwater sensor nodes are not available because of size and cost limitations.

UASN Architectures

- UASN architectures can be classified based on two criteria, one is the motion capability of the sensor nodes, such as stationary, mobile or hybrid UASNs, and the other is the spatial coverage of the UASN such as two-dimensional or three-dimensional UASNs.
- In the stationary UASNs, sensor nodes are attached to surface buoys or ocean floor units which have fixed locations.
- Stationary UASNs are utilized for monitoring a certain region, e.g. the harbor entrances.
- In the mobile UASNs, mobility of the nodes may have different characteristics.

Motion Capability of the Sensor Nodes

- In a UASN with unpropelled and untethered sensor nodes, the nodes float freely underwater and drift with the currents.
- In a UASN with propelled sensor nodes, the motion of the nodes can be controlled by inertial navigation devices.
- Examples of such propelled equipments are AUVs and Unmanned Underwater Vehicles (UUVs) while examples of unpropelled mobile equipments are drifters, floats, profiling floats and gliders.
- Drifters operate on the surface and drift with the winds and the surface waves while floats move with the subsurface currents and they are able to operate at several hundreds of meters below the surface.
- Profiling floats also drift with the subsurface currents however they have the capability of moving up and down by using buoyancy properties.

Spatial Coverage of the UASN

- The latter classification of UASN architectures is based on spatial coverage property.
- In the two-dimensional UASNs, all of the sensor nodes are assumed to be at the same depth, e.g. they may be deployed on the ocean surface or the ocean floor, or they may be floating at a certain depth.
- In the three dimensional UASNs, each sensor node may be floating at an arbitrary depth.
- In general, stationary sensor networks are considered to be two-dimensional since the sensor nodes are placed on the surface buoys or ocean floor anchors.

■ The authors have used stationary surface buoys with tethered sensor nodes where the length of the tether is modified to increase the coverage of the network, forming a threedimensional UASN.

UASN Architectures (cont.)

- Here, we briefly summarized the architectures as there are several localization techniques that are tailored for specific architectures, and there are architectures where localization might be simpler than the others.
- For example, for a twodimensional stationary UASN with nodes deployed on the sea surface, GPS can be used for localization, or for a similar UASN with ocean floor units, the nodes may be deployed in predefined locations so that localization is trivial.
- Moreover, stationary UASNs do not require periodic localization as the mobile UASNs do, which means localization protocols with relatively high communication overhead may still be used since they will only run at the setup time.
- As obvious from these examples, the choice of the localization protocol may depend on the architecture.

Localization Techniques for UASNs

- Centralized Localization Techniques
  - Estimation-Based Schemes
    - Motion-Aware Self Localization, MASL
    - Hyperbola-Based Localization, HL
    - Three Dimensional Multi-Power Area Localization Scheme, 3D-MALS
    - Silent Localization using Magnetometers, SLM
  - Prediction-Based Scheme
    - Collaborative Localization, CL

Motion-Aware Self Localization, MASL

- In the underwater environment, due to long propagation delays, collecting the number of distance estimates required for localization may take relatively long time which increases the possibility of obsolete information.
- MASL aims to address the inaccuracies in the distance estimates and provide accurate localization.
- It targets applications where the relation between data and location is raesolved at the post processing stage by a central station.
- In MASL, an underwater node collects distance estimates between itself and its neighbors.
- The advantages of MASL are reducing the computational burden of the underwater nodes and being anchor-free.

Hyperbola-Based Localization, HL

- In HL, the sensor node (event in the traditional oceanographic systems) sends long-range signals (around 1km) to the anchor nodes (sensors or hydrophones in the traditional systems), and its location is estimated by a centralized node.
- HL has several architectural constraints, i.e. the anchor nodes need to be placed at the corners of the UASN and hence it is not extendable to three-dimensional mobile UASNs.
- Moreover, underwater sensor nodes consume excessive energy for sending long-range signals.

Three Dimensional Multi-Power Area Localization Scheme, 3D-MALS

- 3D-MALS combines the idea of anchors with variable transmission power levels and the idea of anchors with vertical mobility.
- Surface buoys of house a mechanical unit that works like an elevator for the underwater transceivers, which are called Detachable Elevator Transceivers (DETs).
- In 3D-MALS, DETs broadcast their set of GPS-driven coordinates at varying power levels as they descend underwater.
- Unlocalized nodes collect mobile anchor positions and their respective lowest power levels and send these to the sink node.
- Sink node uses the power level values and anchor locations to determine the area at which the node resides in.
- 3D-MALS may introduce additional overhead by sending anchor locations and power levels to the sink node where sensor nodes can already estimate self location using the anchor messages.

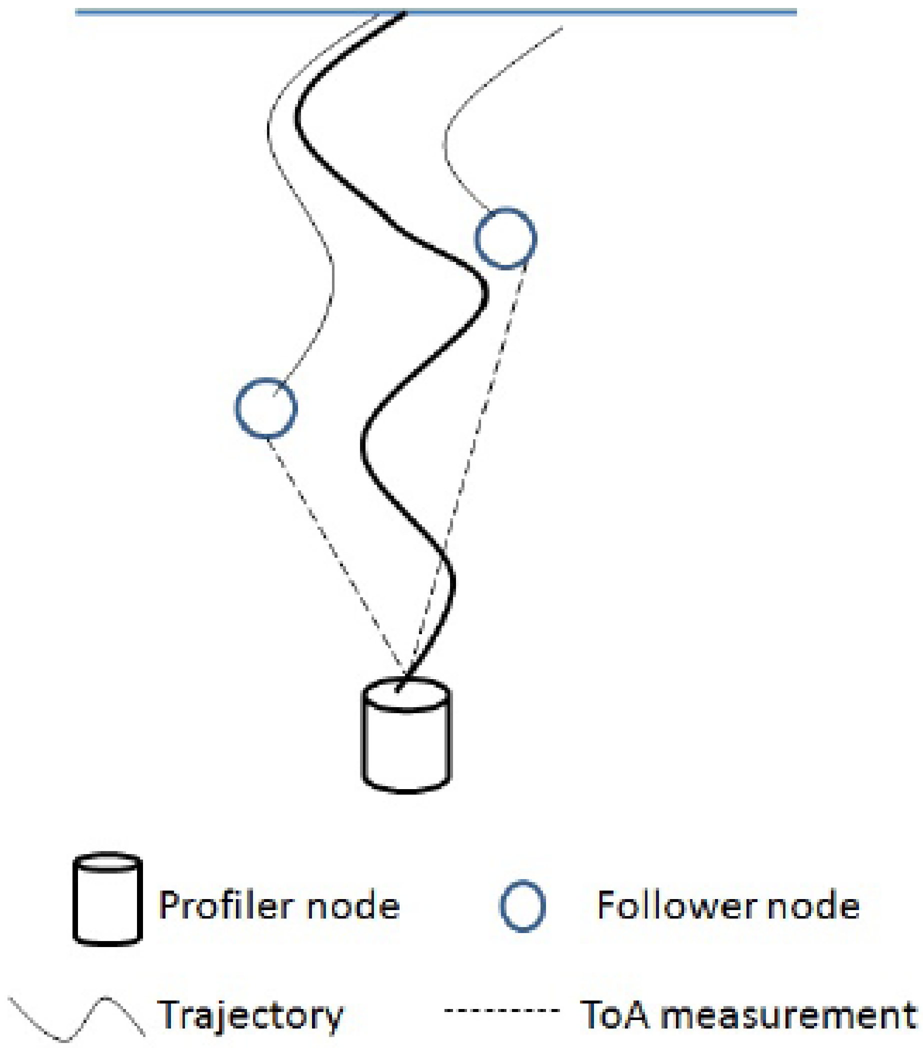
Silent Localization using Magnetometers, SLM

- In SLM, the sensor nodes are not allowed to use acoustic communications to be completely hidden.
- They are assumed to send data via wired communications.
- The term “silent” is generally used in the literature to refer to the localization techniques that do not require sensor nodes to send packets for localization, and the sensors are localized by listening to the messages of the anchor nodes.
- In SLM, sensors are assumed to be observing the vessel from the landmark positions.
- SLM assumes that the sensors estimate their depth via pressure sensors and the accelerometer gives the orientation of the sensor nodes which is used to estimate the trajectory of the vessel.

Silent Localization using Magnetometers, SLM (cont.)

- For civilian applications, SLM can be favored for its energy-efficiency since underwater sensors do not spend energy for localization.
- Although SLM has been initially proposed for wired underwater networks it can be extended to UASNs.
- However, the cost of operating a ship and the cost of the additional hardware is the drawback of SLM.

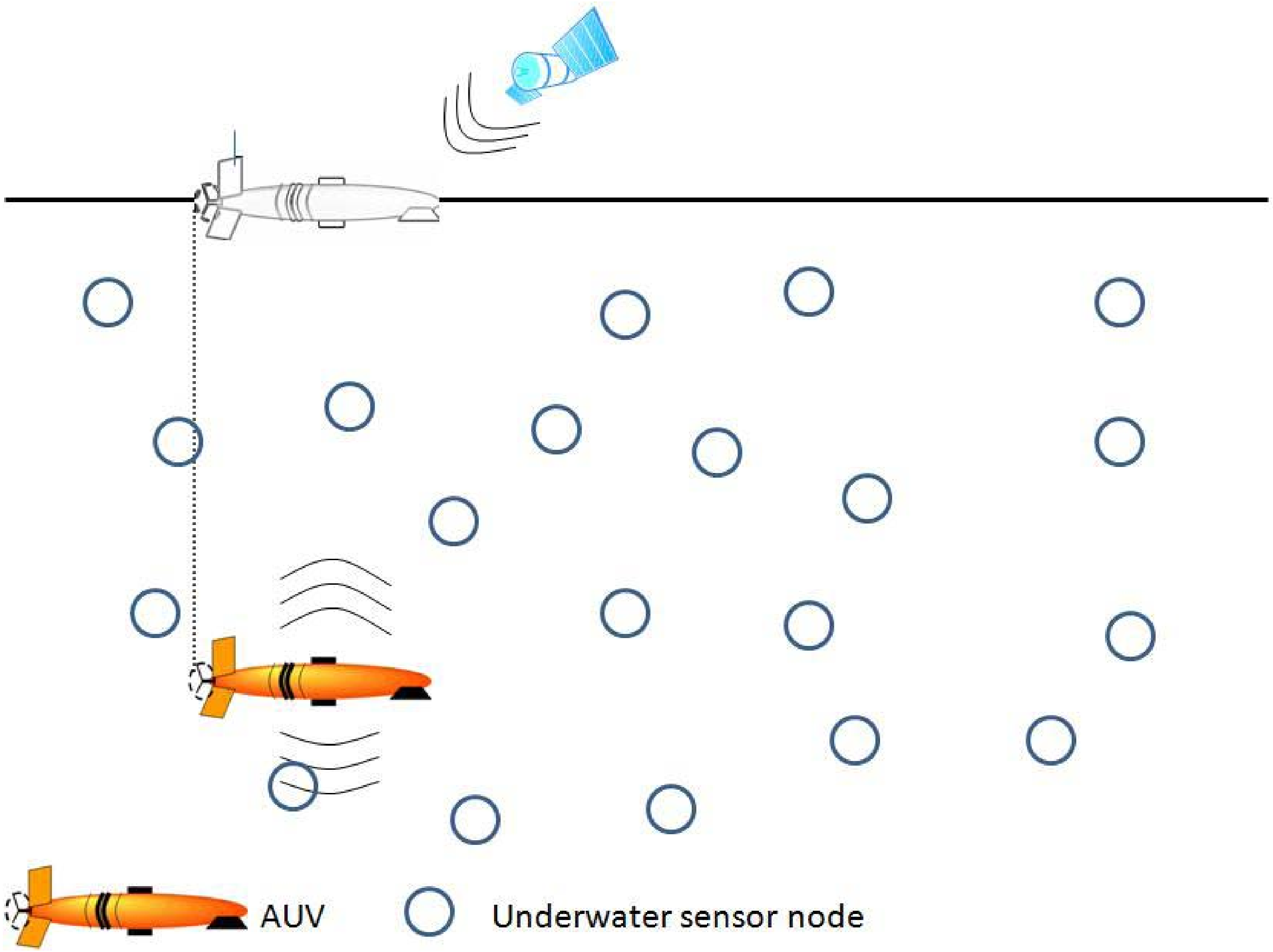
Collaborative Localization, CL



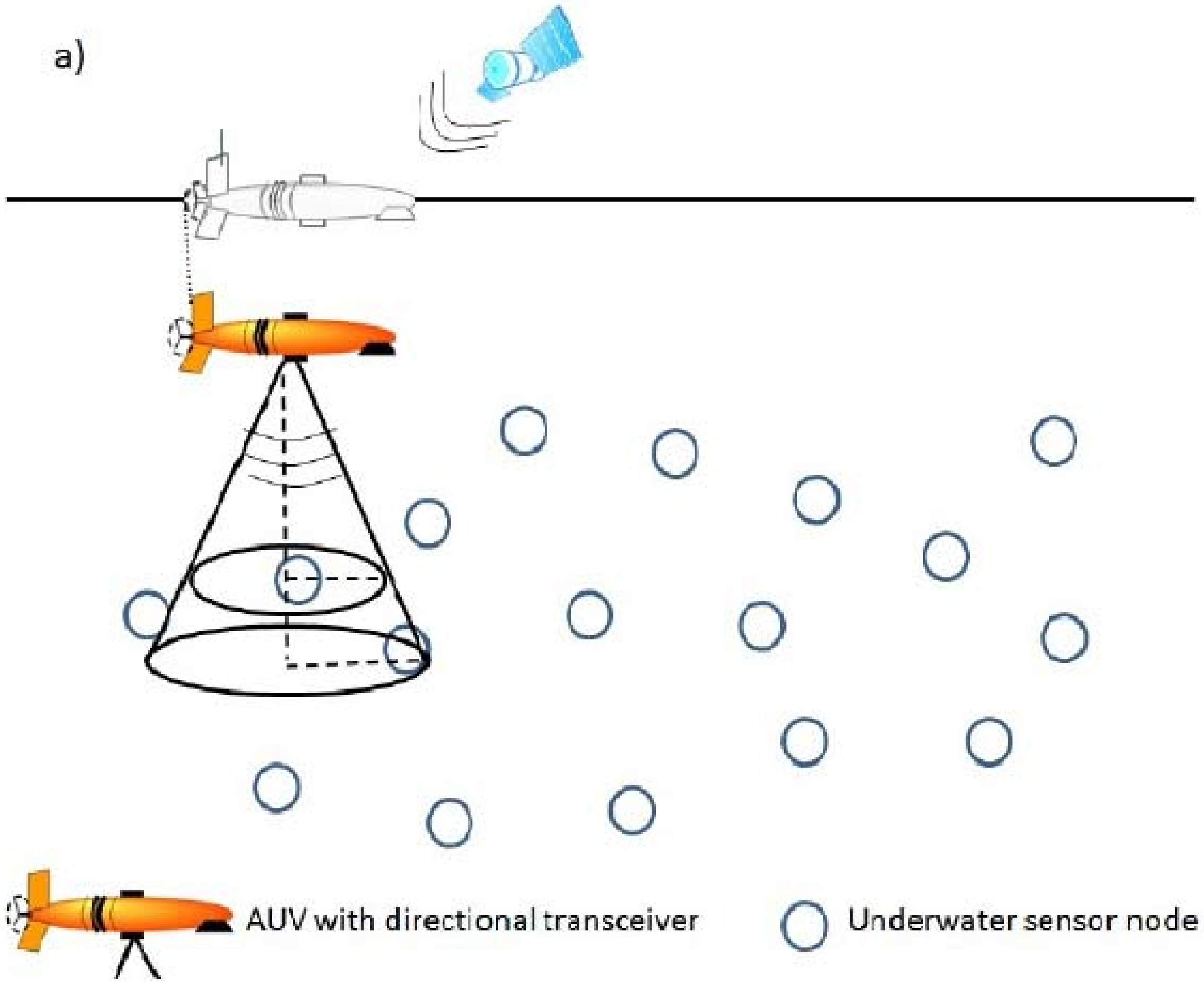
Localization Techniques for UASNs (cont.)

- Distributed Localization Techniques
  - Estimation-Based Schemes
    - AUV-Aided Localization, AAL
    - Localization with Directional Beacons, LDB
    - Dive and Rise Localization Protocol, DNRL
    - Multi-Stage Localization, MSL
    - Large-Scale Hierarchical Localization, LSHL
    - Detachable Elevator Transceiver Localization, DETL
    - Three-Dimensional Underwater Localization, 3DUL
    - Anchor-Free Localization, AFL
    - Underwater Positioning Scheme, UPS
    - Wide Coverage Positioning, WPS
    - Large-Scale Localization Scheme, LSLS
    - Underwater Sensor Positioning, USP
  - Prediction-Based Scheme
    - Scalable Localization with Mobility Prediction, SLMP

AUV-Aided Localization, AAL



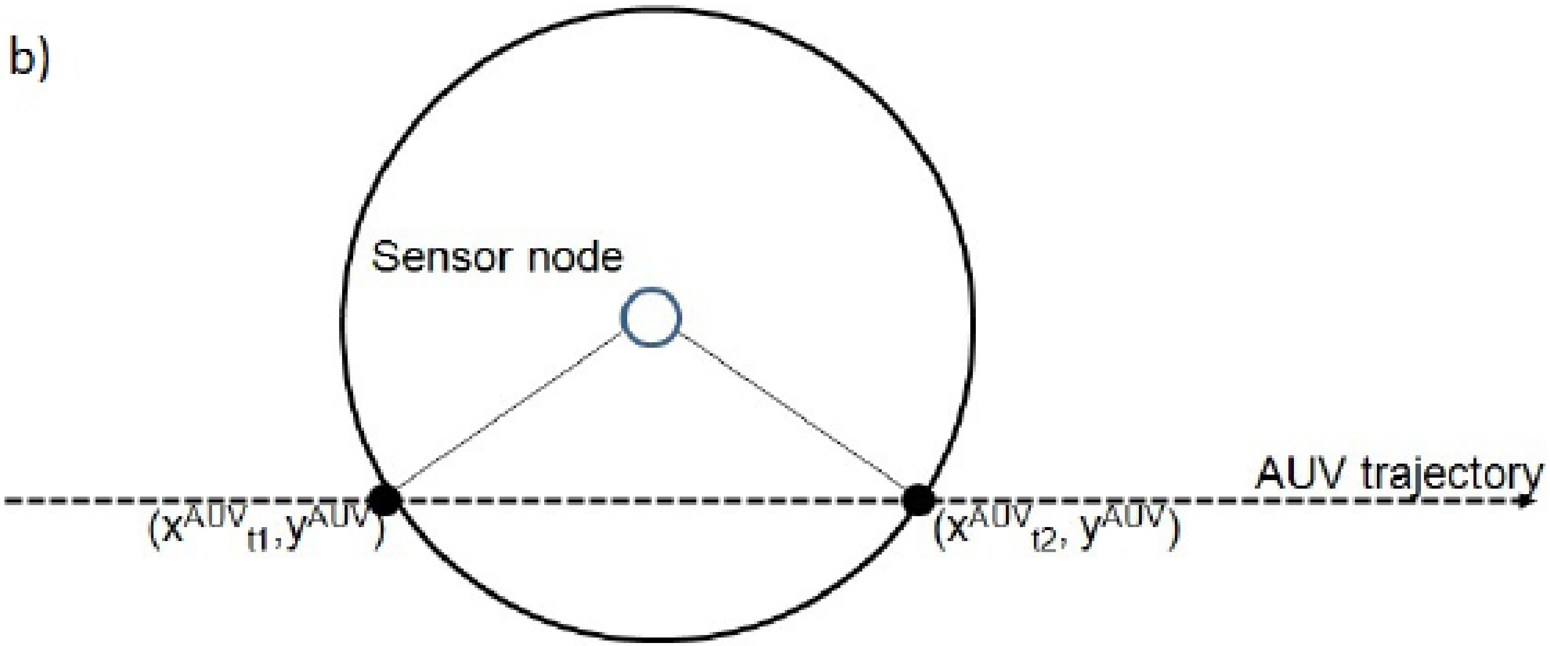
Localization with Directional Beacons, LDB



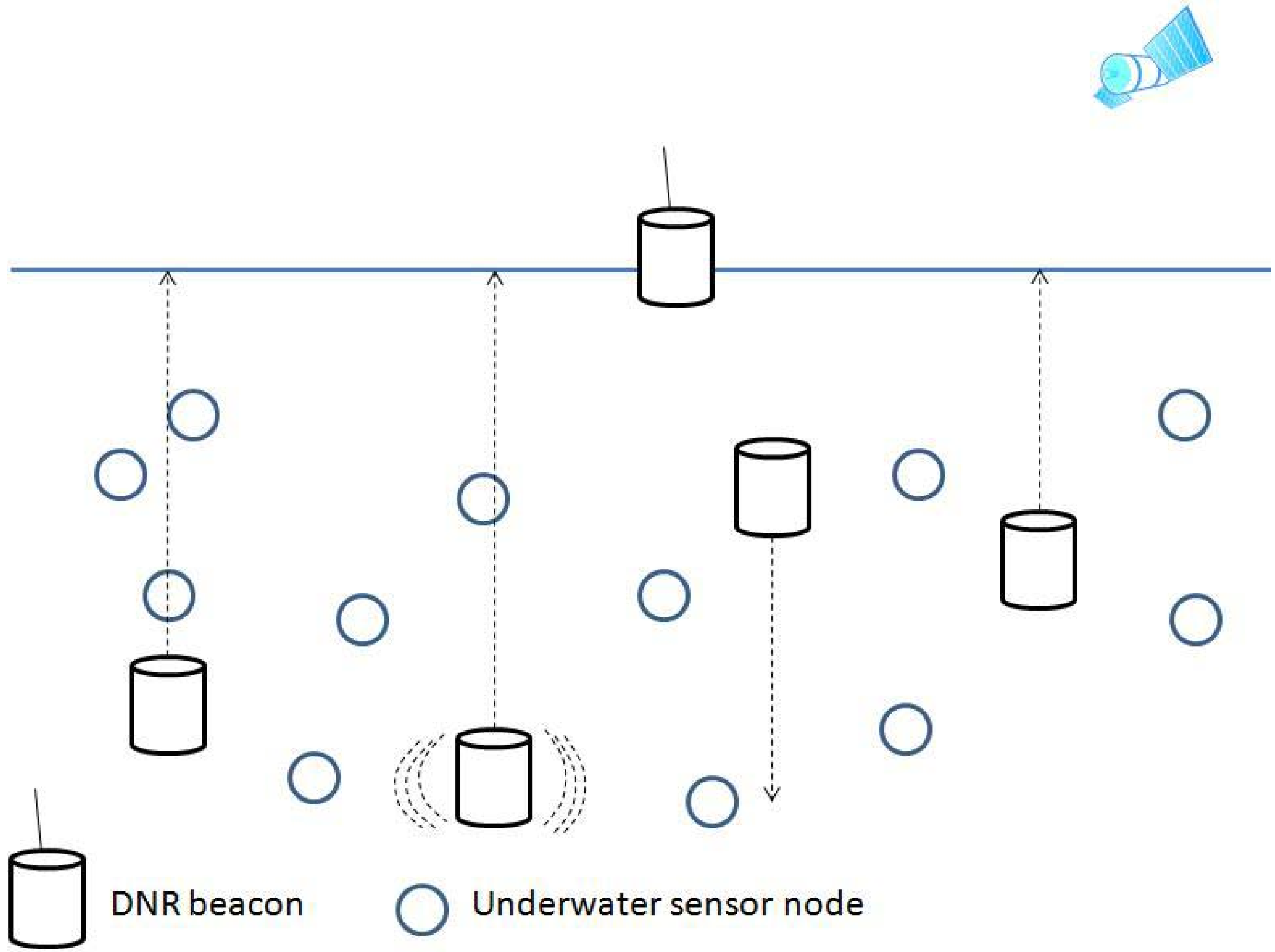
Localization with Directional Beacons, LDB (cont.)

$$y = y^{AUV} + \sqrt{r^2 - \left(\frac{x_{t_1}^{AUV} - x_{t_2}^{AUV}}{2}\right)^2}$$

b)



Dive and Rise Localization Protocol, DNRL



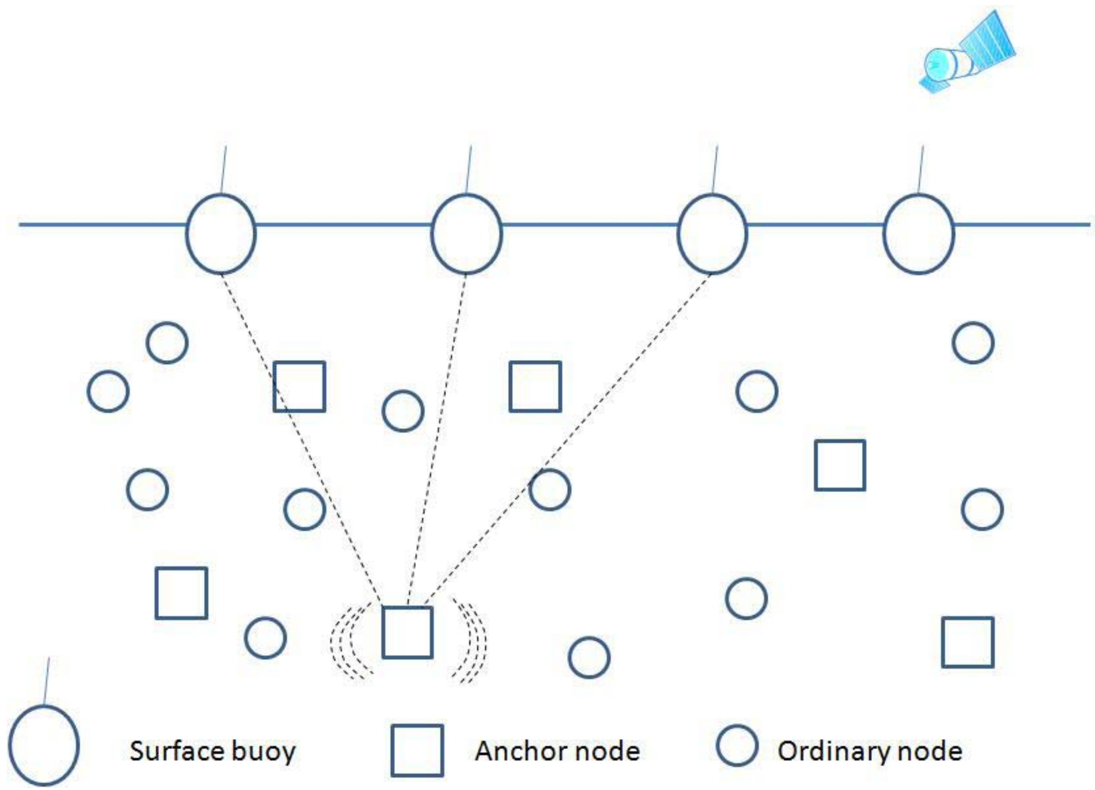
Dive and Rise Localization Protocol, DNRL (cont.)

- One of the advantages of DNRL is being silent which yields low communication overhead and high energy efficiency.
- Furthermore, DNRL has high coverage and provides accurate estimates because the mobile anchors descend to the vicinity of the underwater nodes, and they update their locations by surfacing periodically.
- On the other hand, DNRL requires a large number of DNR beacons for high localization success while the DNR beacons are expected to be more expensive than the other underwater nodes due to their motion capability.
- Moreover, DNR beacons are not able to descend fast because they are not propelled.
- This leads to nonhomogenous diffusion of the location information where the nodes that float deeper receive DNR messages later than the nodes closer to the surface and it also increases the localization delay.

- The authors propose the MSL scheme which addresses the coverage and delay concerns of DNRL by adding an iterative localization phase and using successfully localized underwater nodes as anchors.
- An unlocalized node uses the coordinates and distance measurements from three non-coplanar nodes which may be DNR beacons or a localized underwater node.
- One of the major drawbacks of MSL is its high communication overhead due to iterative localization.
- Moreover, in MSL, localized underwater nodes provide their estimated locations, which already include estimation errors.
- Error accumulates at the nodes that use the coordinates of the localized underwater nodes instead of the coordinates of the anchor nodes.

Large-Scale Hierarchical Localization, LSHL

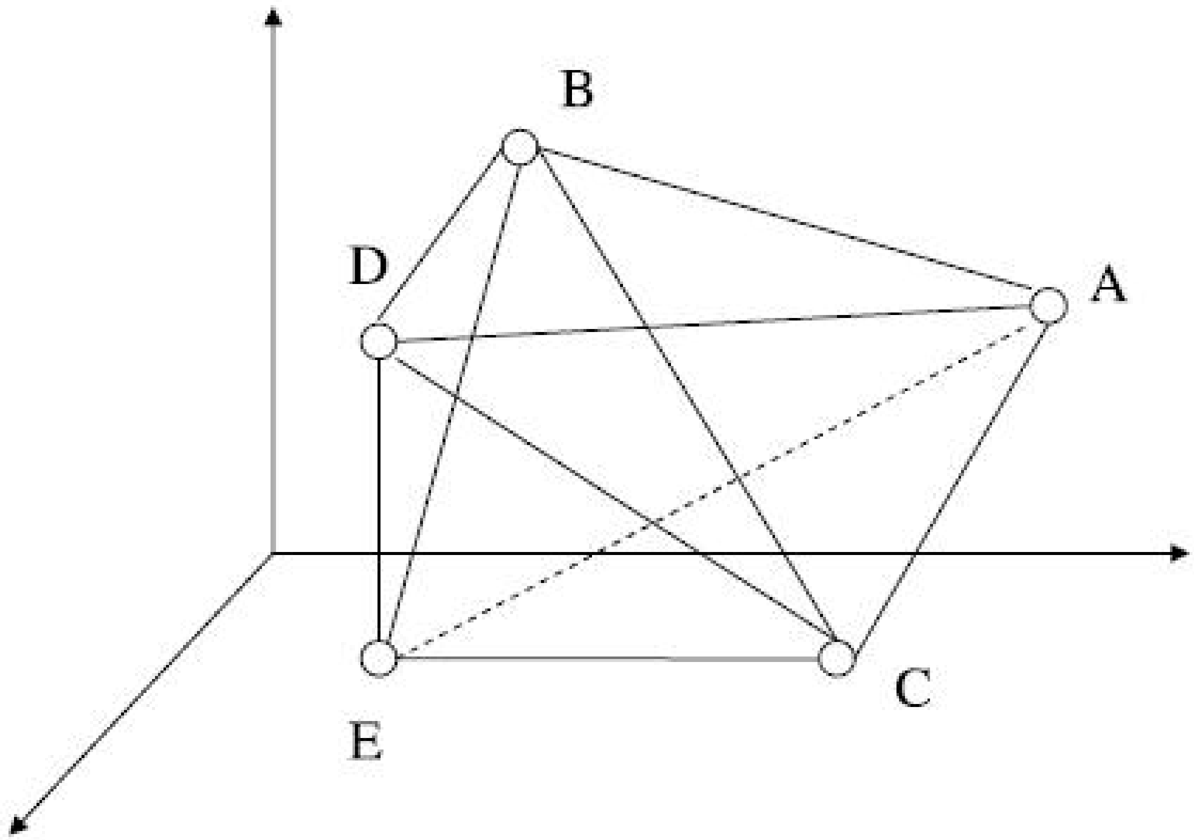
- The authors propose a hierarchical localization scheme for a stationary UASN.
- LSHL employs three types of nodes: "surface buoys", "anchor nodes" and "ordinary sensor nodes".



Large-Scale Hierarchical Localization, LSHL (cont.)

- LSHL considers only the localization of the ordinary sensor nodes.
- In the “ordinary sensor localization process”, anchor nodes periodically broadcast their coordinates.
- Ordinary nodes exchange beacons with their peers.
- Beacons are short messages sent periodically to measure distance to the neighbors.
- The distance is measured with one-way ranging ToA method.
- If an ordinary node gathers the coordinates of three noncoplanar anchors, and the distance in between, it performs lateration to estimate its location.

Euclidean Distance Estimation Algorithm



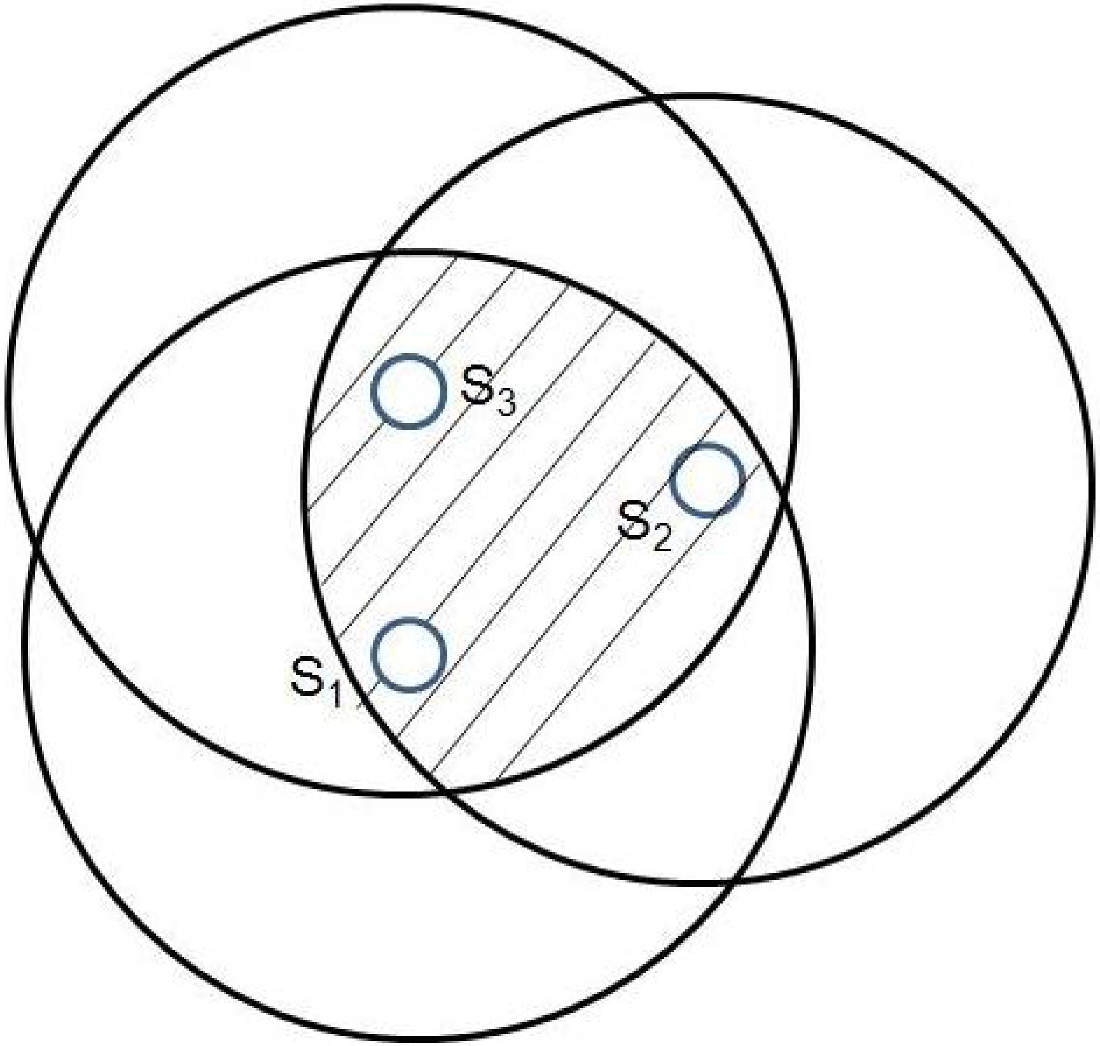
Detachable Elevator Transceiver Localization, DETL

- DET eliminates the need for long-range communication between surface buoys and anchors and solves the anchor localization problem of LSHL.
- Surface buoys learn their coordinates from GPS, DET units descend and ascend, and broadcast surface buoy coordinates at several depths, similar to DNRL beacons but this time they are attached to cables.
- Anchor nodes are localized using the coordinates of the DETs and the distance estimates to those units.
- Ordinary sensor nodes are localized similar to LSHL.
- DETL may be a practical solution for anchor localization for deep and narrow UASNs where DETs can descend until a certain depth and broadcast coordinates with short-range acoustic links.
- However, for a horizontally wide UASN, either the number of DETs needs to be increased or DETs would use long-range communication

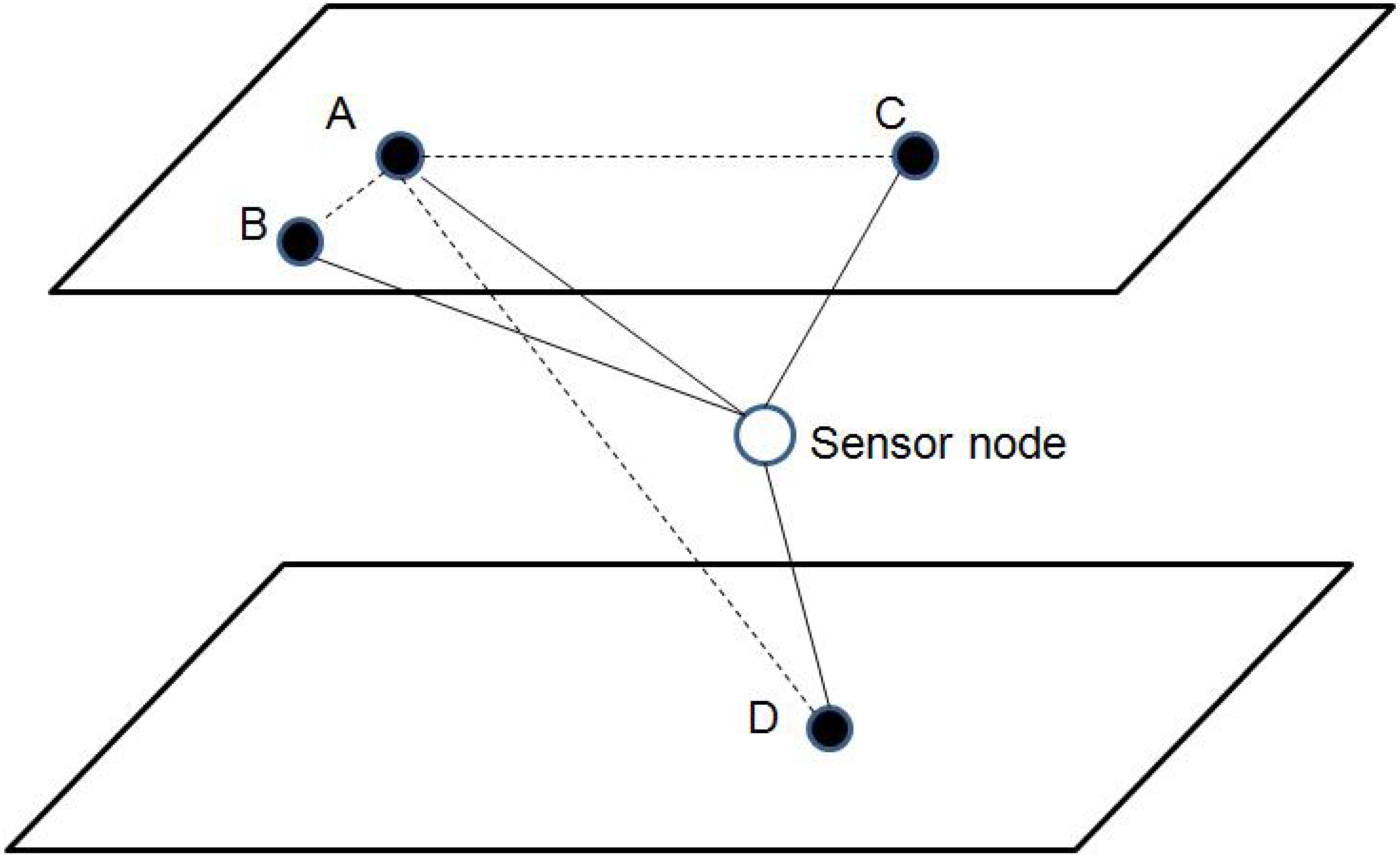
Three-Dimensional Underwater Localization, 3DUL

- Localization starts with a ranging phase where the surface anchors broadcast their GPS-driven coordinates.
- Underwater sensor nodes, that are in one hop distance, receive the anchor packets and send a response back to the anchors to measure the distance using two-way ranging ToA technique.
- When distance measurements to three anchors are completed, the sensor node projects the location of the anchors on its plane and estimates self location via lateration.
- Following localization phase, the underwater node becomes an anchor, and the above process continues iteratively similar to MSL and LSHL.
- The drawback of 3DUL is the long localization delay.
- In underwater acoustic propagation is already slow, using two-way ranging and a limited number of initial anchors at the surface may increase the localization delay.

Anchor-Free Localization, AFL



Underwater Positioning Scheme, UPS



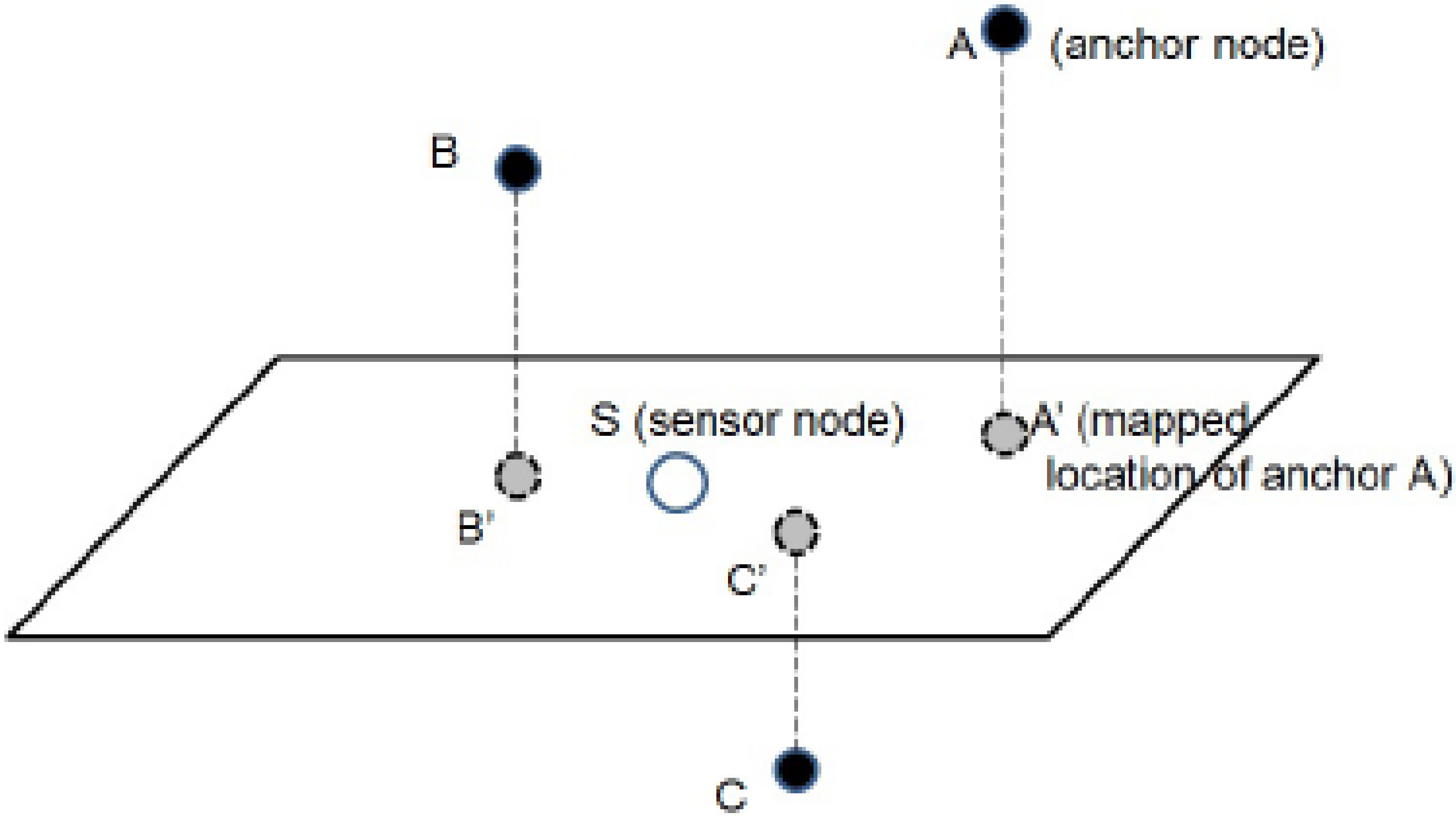
Wide Coverage Positioning, WPS

- WPS uses four anchors whenever unique localization is attainable by using four anchors (called as UPS(4)), otherwise WPS uses five anchors (UPS(5)).
- UPS(4) and UPS(5) are used together to reduce the communication overhead for the nodes that are already localizable with four anchors.
- In WPS, if a message is lost due to adverse acoustic channel conditions, the sensor node waits for a timeout period and then, re-initiates the localization procedure.
- WPS is claimed to provide higher unique localization success than UPS however its localization delay and communication cost is higher than UPS.

Large-Scale Localization Scheme, LSLS

- The authors propose the LSLS scheme which increases the coverage of UPS by adding an iterative localization phase and a complementary phase.
- LSLS inherits the advantages of UPS, and it can additionally localize a large-scale UASN with short-range acoustic communications.
- Iterative phase increases coverage while the complimentary phase can address the unique localization concerns raised.
- On the other hand, LSLS has higher communication overhead and energy consumption than UPS since in the iterative and complementary phases underwater nodes send messages.

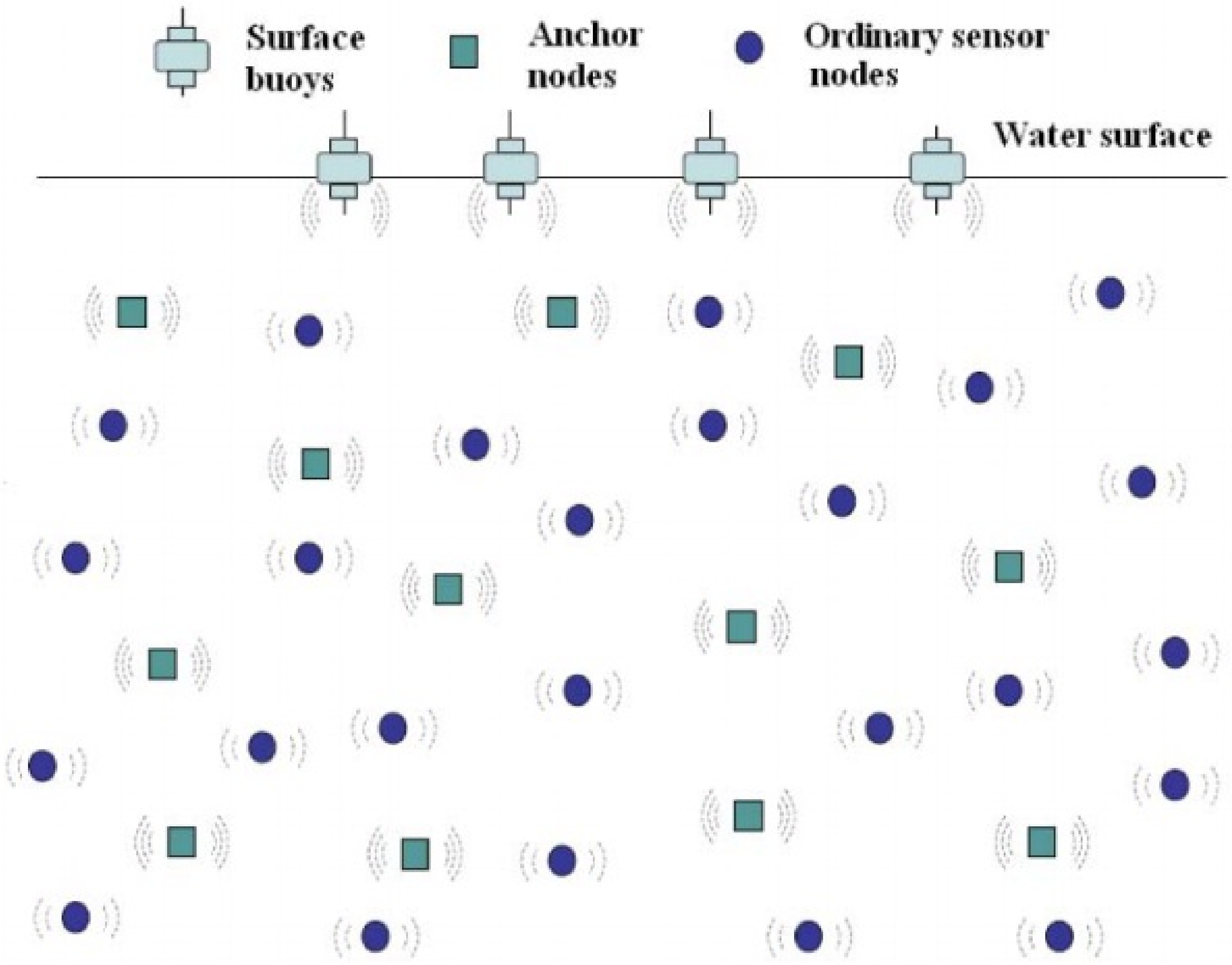
Underwater Sensor Positioning, USP



Scalable Localization with Mobility Prediction, SLMP

- Following surface buoys, anchor nodes and ordinary sensor nodes are used.
- Anchor nodes estimate their locations by using their **previous coordinates** and their **mobility patterns**.
- Since mobility patterns may become obsolete in time, anchor nodes periodically check the validity of the pattern.
- When the model is no longer valid, anchors trigger updates.
- The validity of the model is checked as follows.
- Surface buoys receive their coordinates from GPS and send these to anchor nodes.

Scalable Localization with Mobility Prediction, SLMP (cont.)



Scalable Localization with Mobility Prediction, SLMP (cont.)

- An anchor node, after predicting its location, uses surface buoy coordinates and distance measurements to buoys in lateration, and estimates its location.
- If the Euclidean difference between the predicted and the estimated locations is less than a threshold, then the anchor node assumes its mobility model is valid.
- Otherwise, the anchor node runs its mobility prediction algorithm, determines the new mobility pattern and broadcasts its coordinates along with the updated pattern.
- When ordinary nodes hear messages from anchors, they run their mobility prediction algorithm and update their mobility patterns, as well as their locations.
- The ordinary nodes use the mobility pattern to predict their locations, and the pattern is assumed to be valid until an update from an anchor node is received.

Scalable Localization with Mobility Prediction, SLMP (cont.)

- In SLMP, communication overhead and energy consumption depend on the mobility pattern.
- SLMP uses a temporally and spatially correlated mobility model which represents the tidal currents in shallow waters.
- Due to this correlated motion, SLMP requires low number of updates and consequently its communication overhead and energy consumption are low.

Discussion and Open Research Issues

		Technique	Architecture	Anchor Properties	Ranging Properties	Messaging Properties
Centralized	Estimation	MASL	3D Mobile	No anchors	ToA (one-way ranging)	Active
		HL	2D Stationary	Stationary anchors	TDoA	Active
		ALS	2D Stationary	Anchors with variable power levels	Range-free	Active
		3D-MALS	3D Mobile	Mobile anchors (Electro-mechanical motion)	ToA (one-way ranging)	Active
	Prediction	CL	3D Mobile	No anchors	ToA (one-way ranging)	Active

Discussion and Open Research Issues (cont.)

Distributed	Estimation	**AAL**	3D Hybrid	Propelled mobile anchor (AUV)	ToA (two-way ranging)	Silent
		LDB	3D Hybrid	Propelled mobile anchor (AUV)	Range-free	Silent
		DNRL	3D Mobile	Non-propelled mobile anchors	ToA (one-way ranging)	Silent
		MSL	3D Mobile	Non-propelled mobile anchors and reference nodes	ToA (one-way ranging)	Active
		LSHL	3D Stationary	Surface buoys, underwater anchors and reference nodes	ToA (one-way ranging)	Active
		DETL	3D Mobile	Surface buoys with DETs, underwater anchors and reference nodes	ToA (one-way ranging)	Active
		3DUL	3D Hybrid	Three initial anchors and reference nodes	ToA (two-way ranging)	Active
		AFL	3D Stationary	Anchor-free (one initial seed)	Not specified	Active

Discussion and Open Research Issues (cont.)

		UPS	3D Stationary	Four stationary anchors	TDoA	Silent
		WPS	3D Stationary	Four or five stationary anchors	TDoA	Silent
		LSLS	3D Stationary	Stationary anchors	TDoA	Active
		USP	3D Stationary	Stationary anchors	Not specified	Active
	Prediction	**SLMP**	3D Mobile	Surface buoys, underwater anchors and reference nodes	ToA (one-way ranging)	Active

Conclusion

- In this paper, we give a comprehensive survey of the UASN architectures and the localization techniques for UASNs.
- We group the UASN architectures based on their motion ability and spatial coverage, such as stationary/mobile/hybrid or two/three dimensional UASNs, respectively.
- Furthermore, we group the localization techniques under two categories, i.e. centralized and distributed techniques.
- Most of the underwater applications in literature demand distributed localization since they are more convenient for online monitoring systems than centralized protocols.
- However, distributed schemes require processing on the sensor nodes.

Conclusion (cont.)

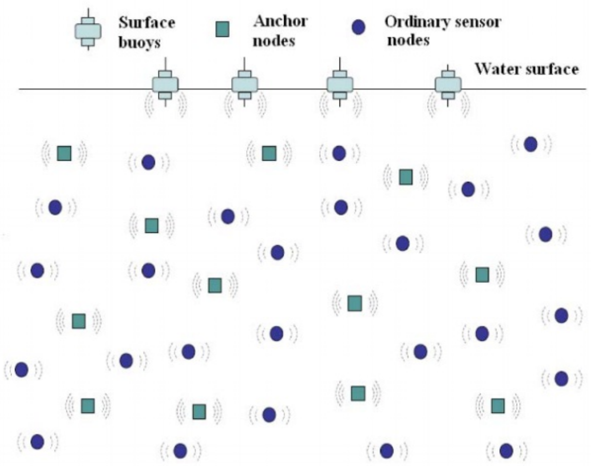
- Centralized and distributed localization schemes can be further divided into two categories as estimation-based or prediction-based techniques.
- Prediction is applicable to mobile UASNs and its accuracy depends on the underlying mobility model.
- The performance of the localization techniques under various mobility models are still unexplored.
- Moreover, future research needs to address the impact of the localization protocols on location-based routing and clustering protocols.
- In addition, cross layer approaches such as the ones considering the link quality in the underwater medium or the energy indicators of the underwater nodes are among the open issues.

Homework #11:

- Which are several ways to collect the measurement of angle and distance ?
- What is the SLMP architecture and methods to solve the obsolete information problem?

Solution #11:

- Q1
  - Received Signal Strength Indicator, RSSI
  - Angle-of-Arrival, AOA
  - Time Difference of Arrival, TDoA
  - Time of Arrival, ToA
- Q2



Architectures

Methods:

Previous Coordinates
Mobility Patterns