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Networked Embedded Applications

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CS4 : (WSN Localization)

4	➢ WSN Localization ➢ Need for Localization and Issues ➢ Distance Estimation - ToA ➢ Distance Estimation - TDoA ➢ Distance Estimation - RSSI ➢ Classical Localization Techniques ➢ WCL (Weighted Centroid Localization) ➢ APIT (Approximate point in Traingulation) ➢ Bounding Box Algorithm, ➢ Distributed Least Squares, ➢ Sweeps	

Introduction to Localization

- What is Localization?
  - To determine the physical coordinates of a group of sensor nodes in a wireless sensor network (WSN).
  - Due to application context, the use of GPS is unrealistic; therefore, sensors need to self-organize a coordinate system.
  - Localization is a crucial procedure for randomly deployed **wireless sensor networks**. It is generally based on **anchor nodes** with efficient capabilities to acquire their position in global coordinates automatically.

Introduction to Localization

- What is Localization? (continued….)
  - The aim of localization is to supply the physical coordinates for all sensor nodes. In the case of manually deployed WSNs, this localization process is almost straightforward.
  - For random deployments in hostile terrain or dangerous battlefields, often done through aerial scattering procedures from aeroplanes, guided missiles or balloons, the nodes' localization problem becomes complicated, relying on special nodes that can detect their location automatically.
  - These particular nodes are known as **anchor or beacon nodes**, being the cornerstones of every localization technique within global coordinates.

Introduction to Localization

- What is Localization? (continued….)
  - Due to cost and power consumption reasons, every node of a randomly deployed WSN cannot be equipped with localization components, only for a small number of them, named anchors.
  - Anchor node localization is a key prerequisite for every localization technique in wireless sensor networks within global coordinates.

Introduction to Localization

- What is Localization? (continued….)
  - One of the methods to determine the exact position of this special type of nodes is an alternative for using GPS devices in areas where the Earth's magnetic field is not disturbed by structures containing ferrous metals or by electronic interferences.
  - It requires information captured by two sensors that equip the node (video and compass), the exact positions of a few reference objects in the deployment area and some constructive parameters of the mentioned sensors.
  - Parameters, such as a video image, Compass information, a set of reference objects' locations in the field of deployment (towers, lonely trees, electricity transmission towers, furnace chimneys, etc.) and Constructive parameters of the video camera and digital compass (camera angle of view, camera depth of view, compass heading accuracy, etc.)

Introduction to Localization

- Terms Related To Localization
  - **Unknown Nodes/Free Nodes/Dumb Nodes**
    - Nodes, Those Do not know their localization information.
  - **Settled Nodes**
    - Initially unknown nodes but now managed to get their location.
  - **Beacon Nodes/Anchor Nodes/Landmark Nodes**
    - Doesn’t require localization system to get their location.
    - Location obtained by Manual placing or some external means i.e. GPS.

Introduction to Localization

- Why is Localization needed?

The estimation of node position is highly desirable because:

- Sensor measurements without location information are useless
- Knowledge of positions allows energy-efficient geographic routing methods without route discovery
- Basic processes in sensor networks like self-organization or self-healing can be applied very efficiently with position information
- Obstacles can be found and consequently bypassed easily
- Often, position of a sensor itself is the demanded parameter e.g. in applications with target tracking

Introduction to Localization

- Why Localization is necessary?
  - To report data that is geographically meaningful.
  - Services such as routing rely on location information; geographic routing protocols; context-based routing protocols, and location-aware services.

Introduction to Localization

- Why Localization is necessary? (continued ….)
  - Location-aware computing
    - Resource sélection (server, printer, etc)
    - Location aware information services (web-search, advertisement, etc.)
  - Sensor network applications
    - Intruder detection, traffic monitoring, emergency crew coordination, air/water quality monitoring, military/intelligence app

Introduction to Localization

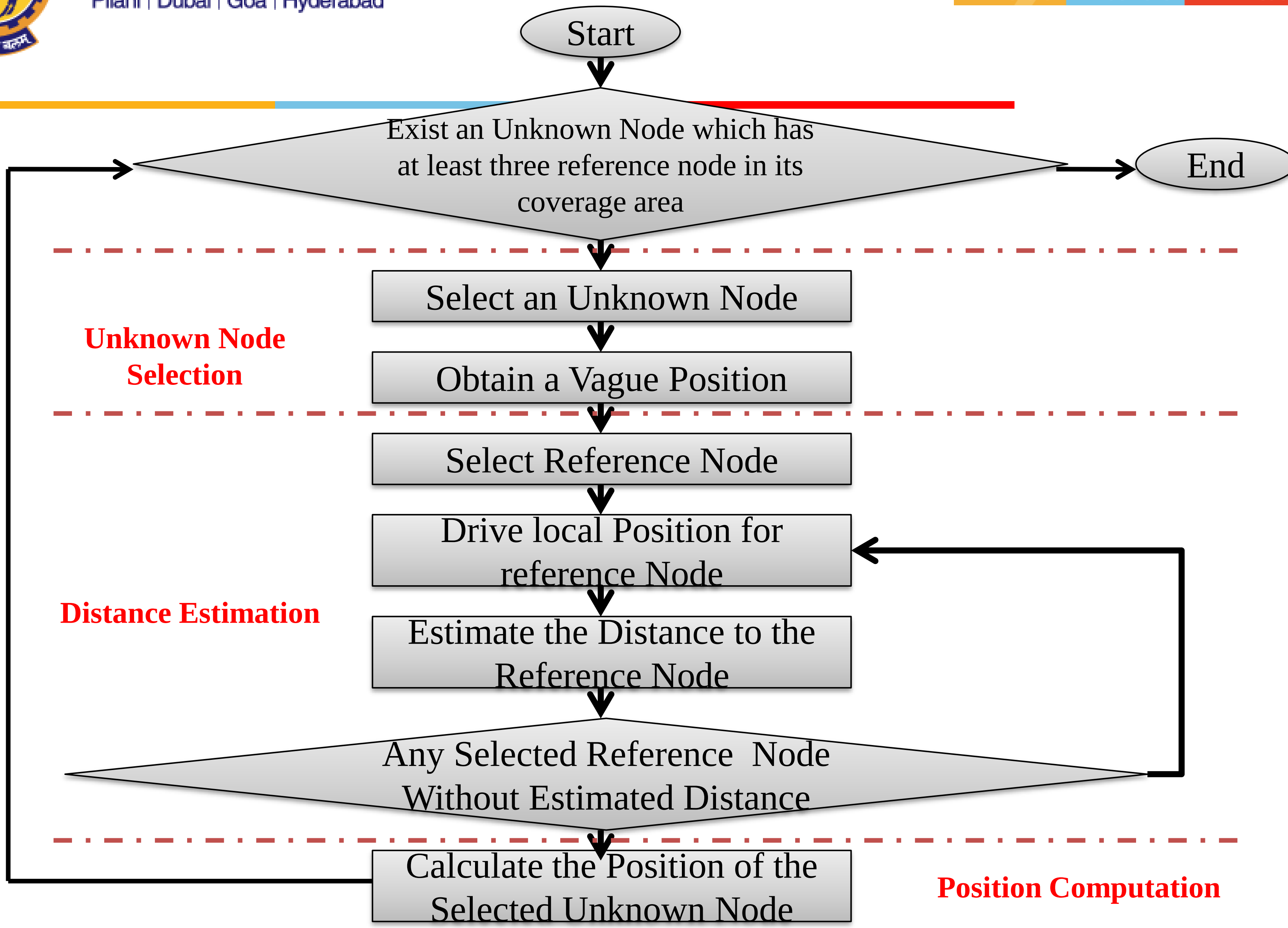
- Why is Localization a Non-Trivial Problem?
  - Manual configuration
    - Unscalable and sometimes impossible
  - Why not use GPS to localize?
    - Hardware requirements vs small sensors
    - Obstructions to GPS satellites common
    - Doesn’t work indoors or underground
    - GPS jammed by sophisticated adversaries
    - GPS accuracy (10-20 feet) poor for short-range sensors

Introduction to Localization

- Representing Location Information
  - Absolute
    - Geographic co-ordinates (Lat: 33.98333, Long: -86.22444)
  - Relative
    - 1 block north of the main building
  - Symbolic
    - High-level description
    - Home, work etc

Localization in Wireless Sensor Networks

- In general, almost all the sensor network localization algorithms share three main phases
  - Distance Estimation
  - Position Computation
  - Localization Algorithm


Start
Exist an Unknown Node which has at least three reference node in its coverage area
End
Select an Unknown Node
Obtain a Vague Position
Unknown Node Selection
Select Reference Node
Drive local Position for reference Node
Estimate the Distance to the Reference Node
Distance Estimation
Any Selected Reference Node Without Estimated Distance
Calculate the Position of the Selected Unknown Node
Position Computation

Localization in Wireless Sensor Networks

- The **Distance Estimation** phase involves measurement techniques to estimate the relative distance between the nodes.
- The **Position Computation** consists of algorithms to calculate the coordinates of the unknown node with respect to the known anchor nodes or other neighbouring nodes.

Localization in Wireless Sensor Networks

- The **Localization Algorithm**, in general, determines how the information concerning distances and positions, is manipulated in order to allow most or all of the nodes of a WSN to estimate their position. Optimally the localization algorithm may involve algorithms to reduce the errors and refine the node positions.

Distance Estimation

- There are following common methods for measuring in distance estimation technique:
    1. Angle Of Arrival (AOA)
    2. Time Of Arrival (TOA)
    3. Time Difference Of Arrival (TDOA)
    4. Received Signal Strength Indicator (RSSI)
    5. Propagation time measurement techniques

Distance Estimation

- **Angle Of Arrival (AOA)** method allows each sensor to evaluate the relative angles between received radio signals.
- **Time Of Arrival (TOA)** method tries to estimate distances between two nodes using time-based measures.
- **Time Difference Of Arrival (TDOA)** is a method for determining the distance between a mobile station and a nearby synchronized base station
  - In this method, we measure the time-difference-of-arrival for each pair of receivers.

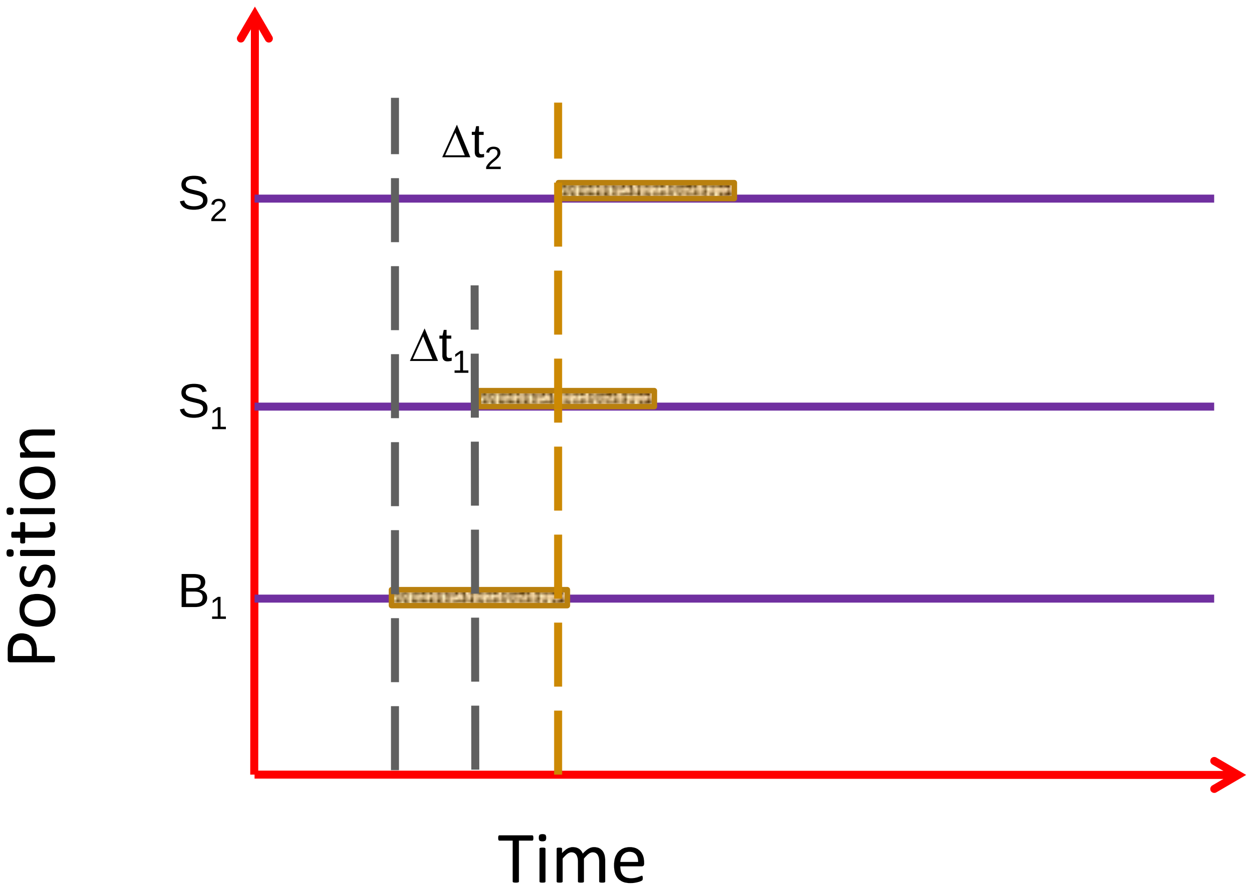
Distance Estimation

- **Received Signal Strength Indicator (RSSI)** techniques are used to translate signal strength into distance.
- **Propagation time measurement techniques**
  - One-way propagation time measurements
    - Measure the difference between the sending time of a signal at the transmitter and the receiving time of the signal at the receiver.
    - Requires synchronized local times at the transmitter and receiver.
    - Interesting approach: two signals (RF and ultrasonic) sent simultaneously.
    - Since vsound << c, the time difference between the receipt of signals can be used to calculate the distance.

Distance Estimation

- **Propagation time measurement techniques (continued ….)**
  - Roundtrip propagation time measurements
    - Measure the difference between the time when a signal is sent by a sensor and the time when the returned signal is received.
    - No synchronization problem.
    - The major error source: is the delay required for handling the signal in the second sensor.
      - A priori known internal delay.
      - Delay measured by the second sensor and sent to the first sensor to be subtracted.

Time of Arrival (ToA)



$$d = c_{AIR}\,\Delta t$$

Issues with ToA??

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- C_{AIR} - 297,702 km/s $\approx 3 \times 10^6$ m/s
- d = 30cm btwn B1 & S1
- Δt = 1ns

Time of Arrival (ToA)

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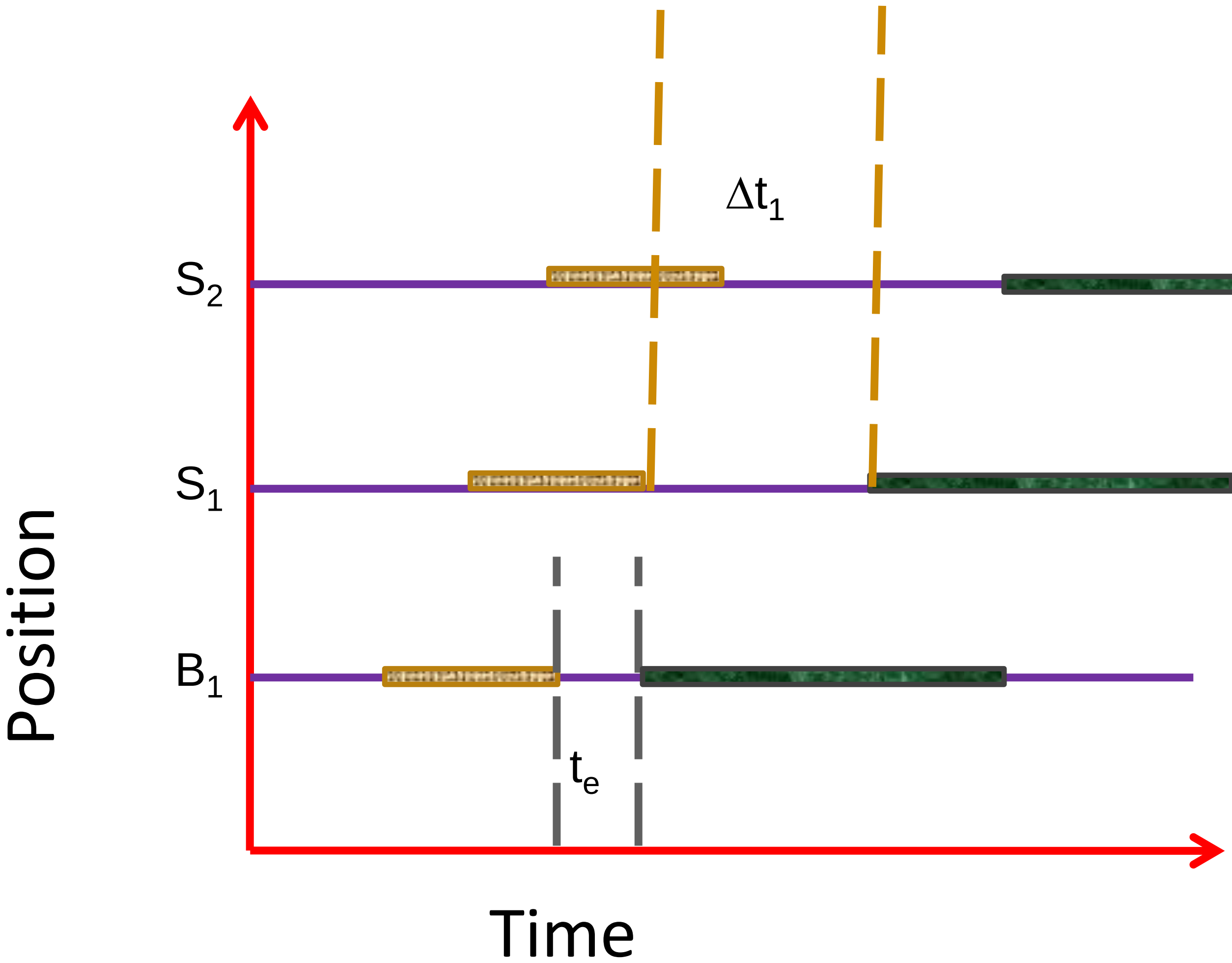

$$d = c_S * (\Delta t_1 - t_e)$$

Improvement??

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- C_S - 340 m/s
- All time measurements will not be affected by lack of time sync
- Sound unpredictable medium
- Additional hardware

Time of Arrival (ToA)

- Sender sends a short pulse to the receiver
- Receiver receives the pulse after a time, say Δt.
- Say, the speed of the pulse is c (For radio wave, c = 297,702 km/s)
- Assuming that receivers knows when the pulse is sent, it finds out the distance

$$d = c \cdot \Delta t$$

Disadvantage of this approach:
It requires highly synchronized senders and receivers.

For example, for a radio wave pulse and distance d = 30cm,

$\Delta t = d/c = 0.0003$ km / 297702 km/s = 1 ns.

So the synchronization error should be less than 1 ns.

If the clock rate of the nodes is 1 GHz, it will be impossible to calculate distance using radio waves, since clock resolution is 1 / 1GHz = 1 ns.

Time Difference of Arrival (TDoA)

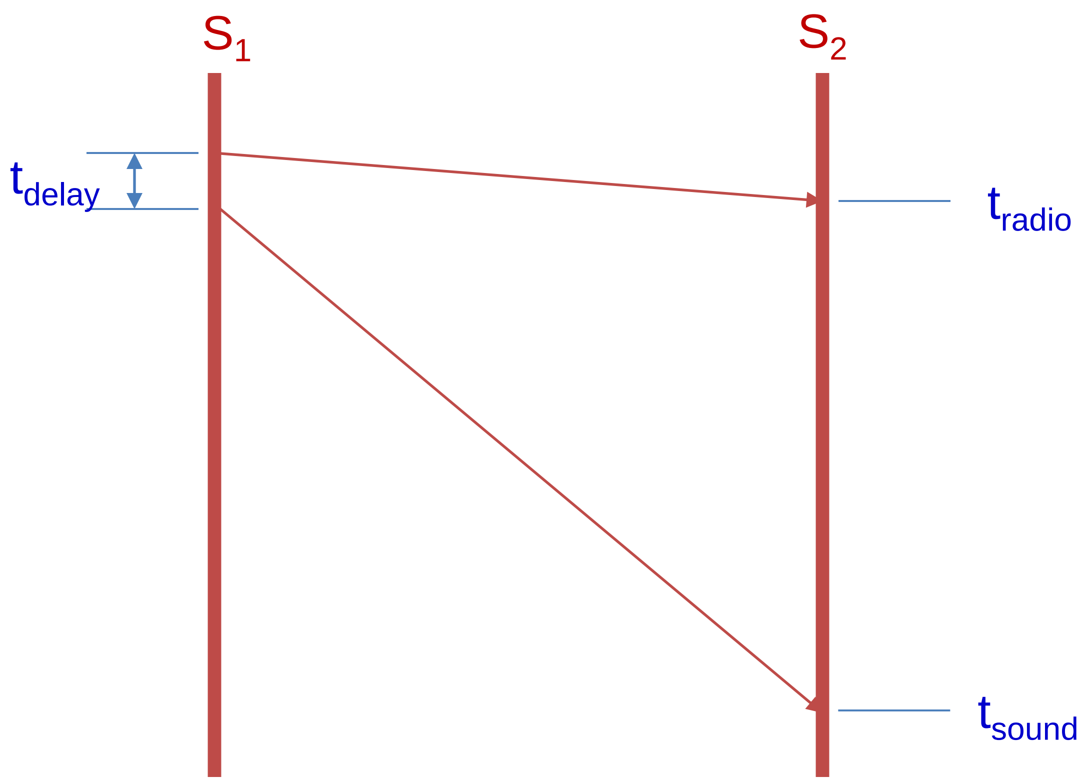
- Tries to overcome the explicit synchronization required
- Sender sends two pulses of different transmission media of very different speeds.

  Example: Sender sends a radio wave pulse (Speed = 297,702 km/s) and after a delay (delay may be zero) an ultrasound pulse (speed = 340 m/s)

- The receiver can use the arrival of the radio transmission to start measuring the time until arrival of the ultrasound transmission (safely ignoring the propagation time of the radio communication)

  t_{radio} = Time when radio signal is received by the receiver node.
  t_{sound} = Time when ultrasound signal is received by the receiver node
  t_{delay} = Time delay between the sender sent the radio and the ultrasound pulses (may be equal to zero)
  c_{radio} = Speed of radio wave
  c_{sound} = Speed of ultrasound signal
  d = Distance between the sender and receiver

Time Difference of Arrival (TDoA)



Time Difference of Arrival (TDoA)

Then distance between sender and receiver,

$$(d / c_{sound}) - (d/ c_{radio}) = (t_{sound} - t_{radio} - t_{delay})$$

Since (d/ c_{radio}) is very small, we can safely ignore it.

In that case, $d = c_{sound}\ X\ (t_{sound} - t_{radio} - t_{delay})$

- Disadvantage: The need for two types of senders and receivers on each node.
- Advantage: Considerably better accuracy

Received Signal Strength Indicator (RSSI)

Transmission power = P_{tx},

System loss = L

Transmitter antenna gain = G_{tx}

Receiver antenna gain = G_{rx}

Wavelength of the signal = λ_0

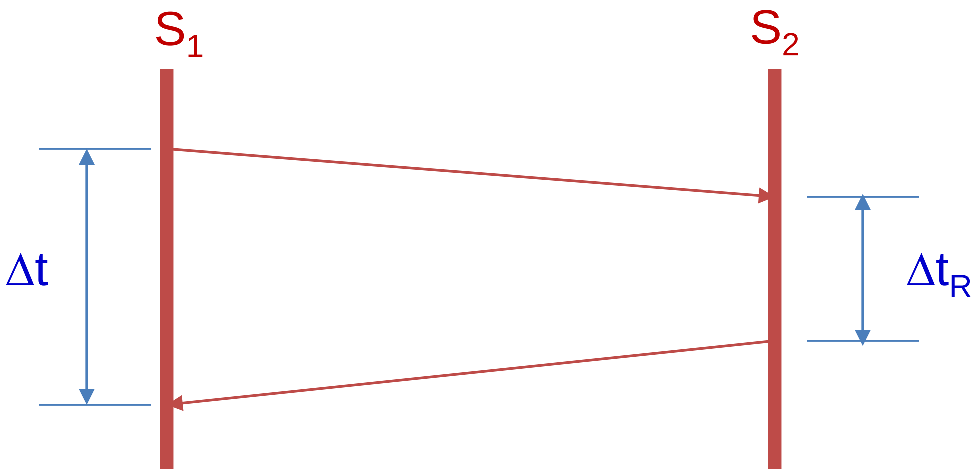
Received signal strength at receiver side = P_{rx}

Distance between sender and receiver = d

Then,

$$\frac{P_{tx}}{P_{rx}} = \frac{G_{rx}G_{tx}}{L}\left(\frac{\lambda_0}{4\pi d}\right)^2$$

Round Trip Time



- S_1 transmits a message to S_2
- After receiving the message, S_2 sends back an ACK back to S_1.
- Total round trip time = Δt
- Time spent by S_2 from receiving the packet and sending the ACK $= \Delta t_R$
- Distance, $d = c \, . \, \dfrac{\Delta t - \Delta t_R}{2}$

Methods to estimate distances

Method to estimate distances based on

- Time Period
  - ToA
  - TDoA
- Signal Attenuation
  - RSS
  - MTP
- Neighborhood Information
  - Connectivity
  - Hop Count

Position Computation

- The common methods for position computation techniques are:

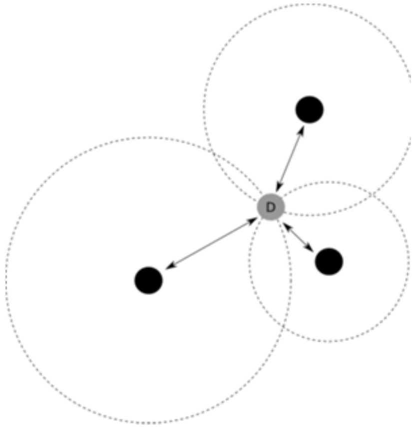
  1. Proximity
  2. Lateration
  3. Angulation

Position Computation

- **Proximity** is simplest positioning technique
  - Closeness to a reference point
    - It can be used to decide whether a node is in the proximity of an anchor
    - Based on loudness, physical contact, etc.

Position Computation

- **Lateration** techniques based on the precise measurements to three non collinear anchors. Lateration with more than three anchors called multilateration.
  - Measure distance between device and reference points
  - 3 reference points needed for 2D and 4 for 3D

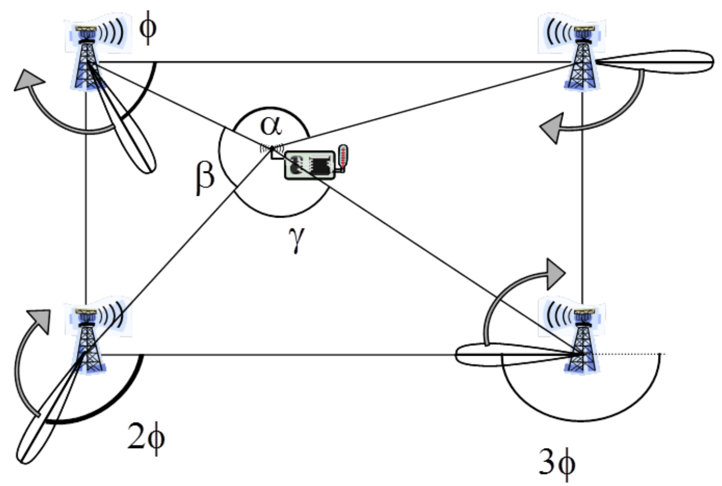


Position Computation

- **Angulation or triangulation** is based on information about angles instead of distance.
  - When distances between entities are used, the approach is called **lateration**
  - when angles between nodes are used, the approach is called **angulation**

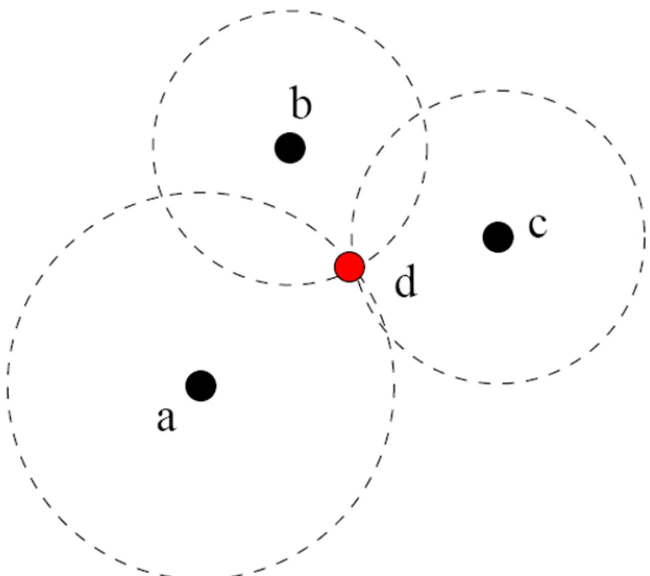
Position Computation

- **Determining Angles using Directional Antennas**
  - On the node
  - Mechanically rotating or electrically “steerable”
  - On several access points
    - Rotating at different offsets
    - Time between beacons allows to compute angles



Position Computation

- **Triangulation, Trilateration**
  - Anchors advertise their coordinates & transmit a reference signal
  - Other nodes use the reference signal to estimate distances from the anchor nodes



Localization Algorithm

- According to the ways of Sensors implementation, we classify the current wireless sensor network localization algorithms into several categories such as:
  1. Centralized vs Distributed
  2. Anchor-free vs Anchor-based
  3. Range-free vs Range-based
  4. Approximate Vs Precise
  5. Relative Vs Absolute
  6. Indoor Vs Outdoor
  7. Beacon-Free Vs Beacon based

Centralized vs Distributed

- Centralized

  All computation is done in a central server

- Distributed

  Computation is distributed among the nodes

Anchor-Free vs Anchor-Based

- Anchor Nodes:
  - Nodes that know their coordinates a prior
  - By use of GPS or manual placement
  - For 2D three and 3D four anchor nodes are needed

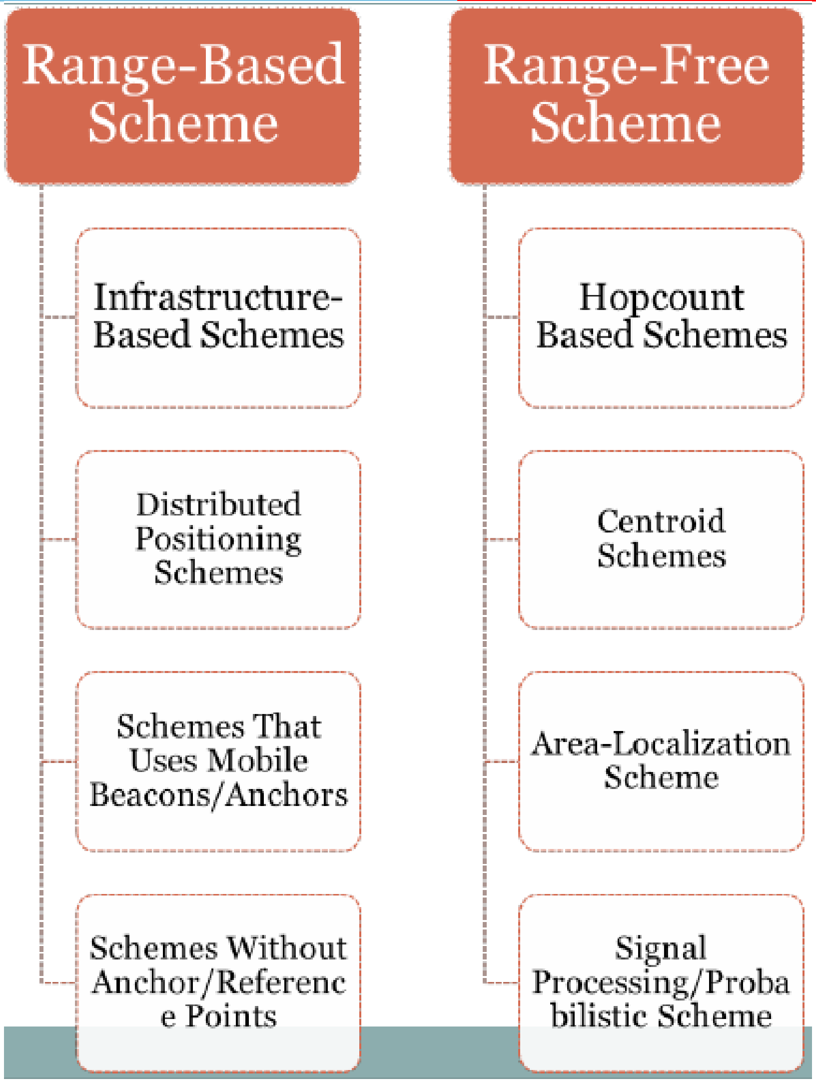
- Anchor-free

  Relative coordinates

- Anchor-based

  Use anchor nodes to calculate global coordinates

Range-Free vs Range-Based

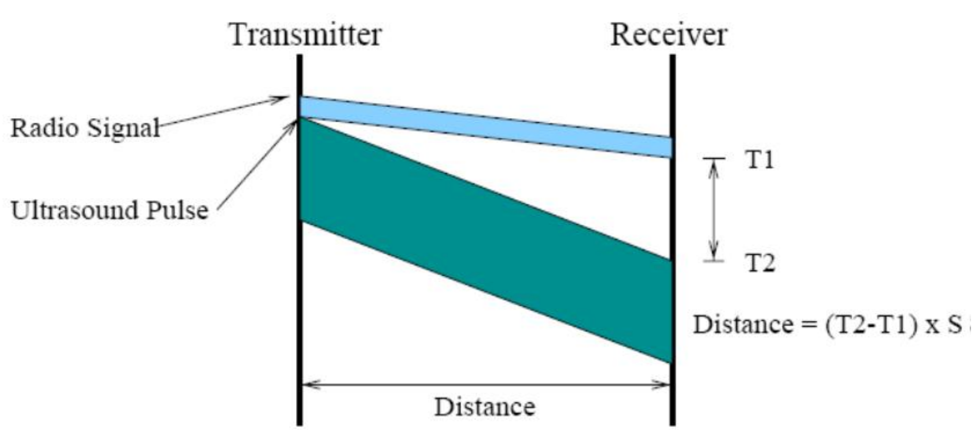


Range-Based

- Range-Based (schemes that use range or bearing information)
  - In range-based schemes, precise distance or angle measurements are made to estimate the location of nodes in the network.
  - It uses RSSI, TOA, TDOA, AOA to estimate their distances to other nodes in the system
  - Received Signal Strength Indicator (RSSI)
    - Send out a signal of known strength, use received signal strength and path loss coefficient to estimate the distance
  - Time of Arrival (TOA)
    - Use time of transmission, propagation speed, time of arrival to compute distance

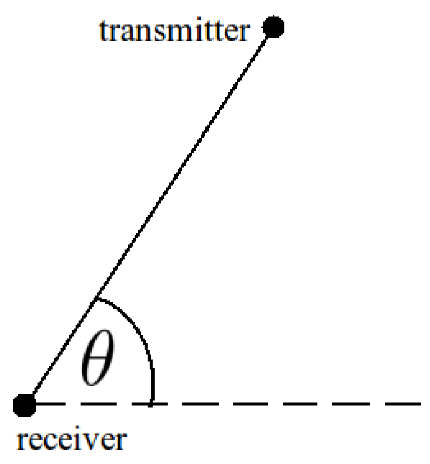
Range-Based

- Range-Based (continued….)
  - Time Difference of Arrival (TDOA)
    - Requires time synchronization
    - Use two different signals with different propagation speeds
    - Example: ultrasound and radio signal
      - Propagation time of radio negligible compared to ultrasound
    - Compute difference between arrival times to compute distance



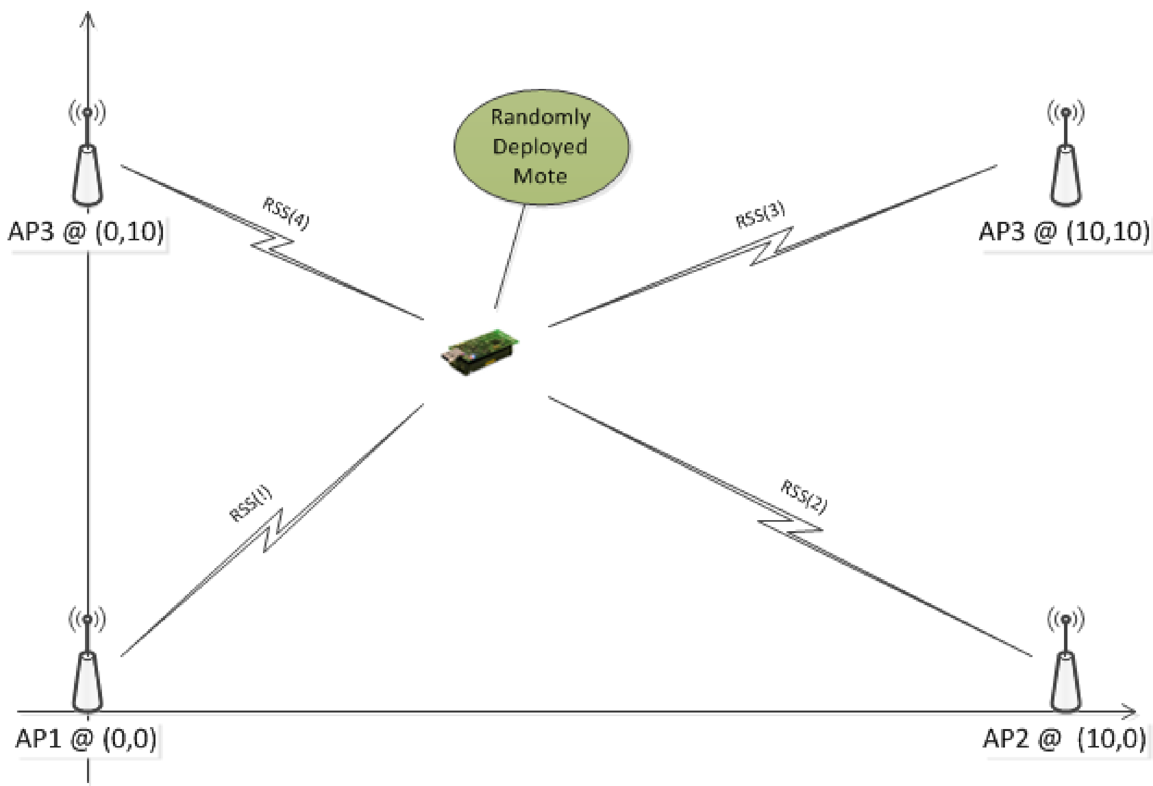
Range-Based

- Range-Based (continued….)
  - Angle of Arrival (AOA)
    - In this method we measure the angle between the transmitter{receiver line and the reference direction.
    - In order to do this we must use an anisotropic antenna.
    - Actually AOA measurements use either amplitude or phase response of the antenna.



Range-Based

- Example: Range Based Centralized Localization using Neural Networks



Range-Based

- Range-based schemes can be divided into four categories:
  - Infrastructure-based schemes,
  - Distributed positioning schemes,
  - Schemes that use mobile beacons
  - Schemes Without Anchor Node/Reference Points

Range-Based : Infrastructure-Based Scheme

- Infrastructure-based (anchor-based) localization systems are similar to the GPS scheme. In such a system, anchor nodes are deployed on the field at pre-determined locations.
- The distance to multiple anchor nodes is computed by using the propagation time of the sound signals between the sensor and the anchors.

Range-Based : Distributed Positioning Scheme

- Distributed Positioning Schemes are employed in cases where a positioning infrastructure is not available, i.e. anchor-free.
- In this scheme nodes are able to communicate only with their one-hop neighbors and compute the distances to their one-hop neighbors.
- Distributed positioning algorithms generally have three positioning phases:
  - The distance estimation phase, where nodes estimate the distances to their neighbors.
  - The position estimation phase, where a system of linear equations is generally solved using a least squares approach to estimate the position of the node,
  - And finally a refinement phase, where the accuracy of the algorithm is improved by using an iterative algorithm.

Range-Based : Schemes that use Mobile Beacons/Anchors

- In this scheme, a mobile beacon traverses the sensor network while broadcasting beacon packets which contain the location coordinates of the beacon.
- Any node receiving the beacon packet will be able to infer that it must be somewhere near the mobile beacon with a certain probability. RSSI measurements of the received beacon packets are used for ranging purposes.
- After a number of packets have been received from the mobile beacon, Bayesian inference is used to determine the location of the node.

Range-Based : Schemes Without Anchor/Reference Points

- The fourth class of schemes is different from the first three in that it does not require anchor nodes or beacon signals.
- In, a central server models the network as a series of equations representing proximity constraints between nodes, and then uses sophisticated optimization techniques to estimate the location of every node in the network.
- It is ,an infrastructure-less GPS-free positioning algorithm.

Range-Free vs Range-Based

- Range-Free (schemes that do not use range or bearing information)
  - They do not make use of any of the techniques mentioned above (ToA, TDoA and AoA) to estimate distances to other nodes.
  - The advantage of these schemes lies in their simplicity. Range free schemes only provide a coarse estimate of a node's location.
  - Range-free schemes can be broadly classified into :
    - Hop-Count Based Scheme, Centroid Scheme, Area-Localization Scheme and Signal Processing/Probabilistic Scheme

Range-Free : Hop-Count Based Scheme

- DV-Hop is one of the most basic range-free schemes, and it first employs a classical distance vector exchange so that all nodes in the network get distances, in number of hops, to the anchor nodes.
- Each node maintains a table and exchanges updates only with its neighbors.
- Once a landmark (i.e. an anchor) gets distances to other landmarks, it estimates an average distance for one hop, which is then propagated as a correction to the entire network.

Range-Free : Centroid Scheme

- In this scheme, anchor nodes are placed to form a rectangular mesh. The anchor nodes send out beacon signals at periodic intervals with their respective locations.
- From the beacon signals received, a receiver node infers proximity to a collection of anchor nodes.
- The location of the node is then estimated to be the centroid of the anchor nodes that it can receive beacon packets from.
- A high concentration of anchor nodes is required for this scheme to work well.

Range-Free : Area-Localization Scheme

- ALS is a centralized range-free scheme that provides an estimation of a sensor's location within a certain area, rather than the exact coordinates of the sensor.
- Anchor nodes send out beacon signals at varying power levels and based on the ranges of the different power levels of the anchor nodes, the grid is divided into multiple smaller areas.
- The sensors measure the lowest power level that they receive from each anchor node and this information is forwarded with the sensor data to the sink for processing.
- This information is represented by an n-dimensional coordinate, where the ith coordinate represents the lowest power level from the ith anchor node.

Range-Free : Signal Processing/Probabilistic Scheme

- Instead of exploiting signal timing or signal strength, this scheme relies on the received signal structure characteristics to do localization. By combining the multi-path pattern with other signal characteristics, the algorithm creates a signature unique for every given location in the area.
- This can be achieved by driving a vehicle through the area and acquiring the signal characteristic information. By comparing the received signal characteristic to all the fingerprints in the database, a node's location can be determined.
- The major drawback of this technique is the substantial effort needed for generation of the signal signature database. Hence, it is not suited for the ad hoc deployment scenarios in consideration.

Beacons

IR

RF

Ultrasound

UWB (3.5Ghz- 10Ghz)

Wi-Fi

Wireless Technologies for Localization

Name	Effective Range	Pros	Cons
Wi-Fi	50m-100m	Readily available; Medium range	Low accuracy
Ultra Wideband	70m	High accuracy	High cost
Bluetooth	10m	Readily Available; Medium accuracy	Short range
Ultrasound	6-9m	High accuracy	High cost, not scalable
RFID & IR	1m	Moderate to high accuracy	Short range, Line-Of-Sight (LOS)
NFC	<4cm	High accuracy	Very short range

Table 1. Comparison of different localization schemes

Schemes	Range based or Range Free	Accuracy	Distributed or Centralized	Placement of anchor nodes	% of anchor nodes	Additional Comments
Infrastructure based positioning systems	Range based, ToA, TDoA	Accurate: 1 to10 m for 3 km × 4 km area. Accuracy depends on area size	Distributed	At the corners of a square grid	Small	Requires placement of anchor nodes on sea-bed
Distributed positioning	Range based, ToA, TDoA	Not Accurate: 0.5*(Radio Range) to 1*(Radio Range)	Distributed	Distributed randomly	High (5% to 20% of nodes)	Requires placement of anchor nodes on sea-bed
Mobile Beacons	Range based, ToA	Accurate: < 1 m, for shallow water of <500 m (Sonardyne)	Distributed	Only one anchor	Low	The mobile beacon could be a ship equipped with GPS, or an AUV/ROV whose location is known
DV-Hop	Range Free	Not Accurate: 0.5*(Radio Range) to 1*(Radio Range)	Distributed	At the corners of a square grid	Low	Simple to implement
Centroid based localization	Range Free	Not Accurate: 0.5*(Radio Range) to 1*(Radio Range)	Distributed	In a grid structure	High (High for good performance)	Simple to implement, but requires placement of anchors in a square mesh
ALS	Range Free	Not Accurate: 0.5*(Radio Range) to 1*(Radio Range)	Centralized	At the corners of a square grid	Low	Anchor nodes must be able to cover area in consideration. Simple to implement
APIT	Range Free	Not Accurate: 0.5*(Radio Range) to 1*(Radio Range)	Distributed or Centralized	Randomly distributed	High (High for good performance)	Anchor nodes must be able to cover area in consideration. Simple to implement
Fingerprinting, Signal Processing based schemes	Range based, RSSI	Accurate, but only good for small areas	Centralized	No anchor nodes	N/A	Very difficult to implement in the underwater domain because of training phase

THANK YOU!!!!!