Internet of Underwater Things (IoUT)

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Introduction to IoT and IoUT

- What is IoT?

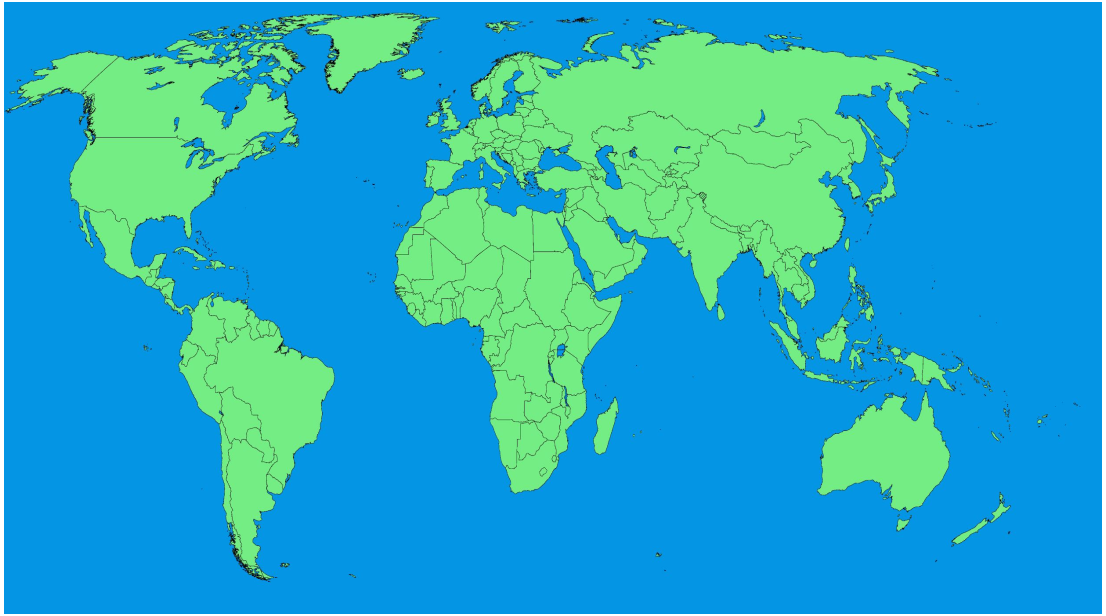
  A system of **Smart Objects** with **unique identifiers** and the **ability to transfer** data over a network without requiring human-to-human or human-to-computer interaction.

- What is IoUT?

  World-Wide network of **Smart Interconnected Underwater Objects** that enables the monitoring of vast unexplored water bodies or remote water bodies. A subclass of IoT.

  - Senses, interrupts, and reacts to the environment.
  - Combines powerful sensors and communication technologies.
  - Capable of synchronizing with terrestrial IoT.

Why Is IoUT Necessary?

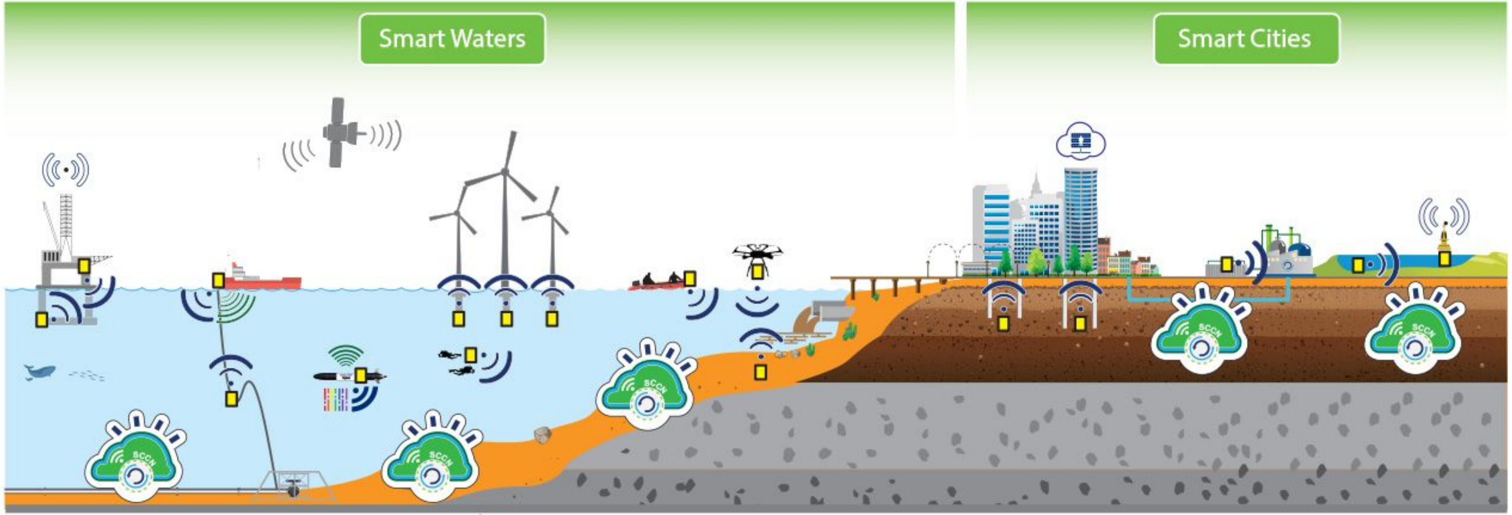


- 71 % of the earth's surface is made up of water bodies.
- Only 5 to 10 % of these water bodies have been explored.
- Water bodies and water itself play's a major role in our everyday lives..

Challenges of IoUT

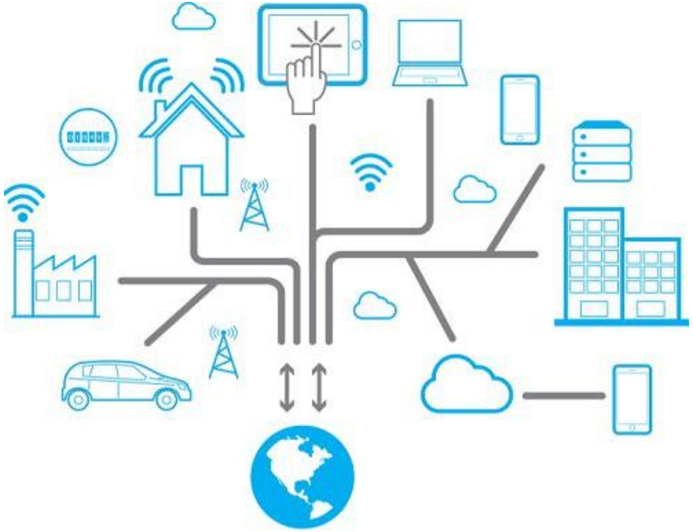
- Propagation of radio waves - The propagation range of RF waves in water is very limited.
- Energy harvesting - Unlike IoT, energy harvesting is difficult due to devices not being able to easily access sunlight or wind.
- Network density - The propagation of RF waves is limited, which results in the need for an increased number of transceivers and power consumption.
- Tracking and localization - Conventional IoT tracking techniques are not feasible due to signal propagation constraints that occur in water.
- Approachability - The devices are not as easily accessible as in the terrestrial IoT.

Characteristics of IoUT with Respect to IoT



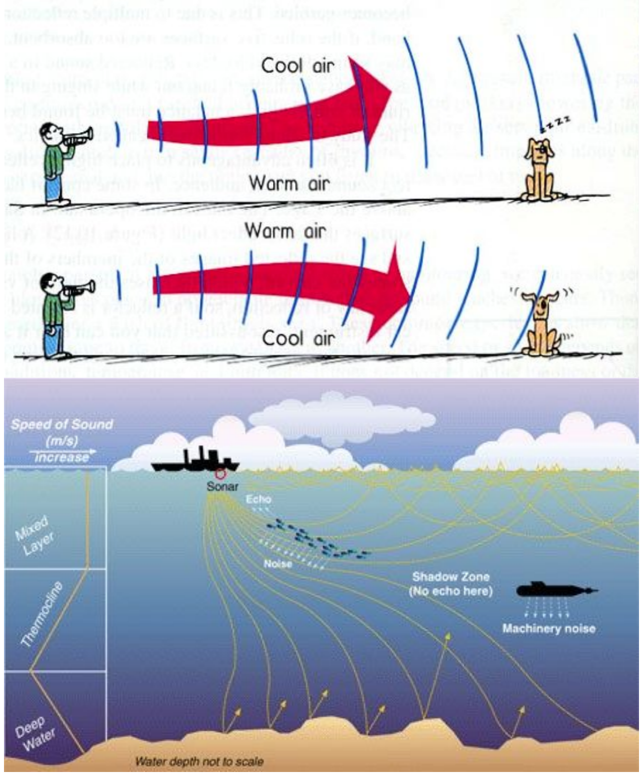
Communication Technologies

1. Internet of Things
   - RF communication.
   - Short, long, and very long range communication.
   - High frequency, low losses, and low latency.
   - Wifi, Bluetooth, NFC... etc.



Communication Technologies

1. Internet of Underwater Things
    - Acoustic wave communication.
    - Effective for short range communication due to the presence of propagation delays and attenuation.
    - Bit errors are a caused by propagation delays.
    - Loss of communication at greater depths due to shadow zones.



Shadow Zones are the regions where the communications is lost due to refraction of the signal.

Tracking Technologies

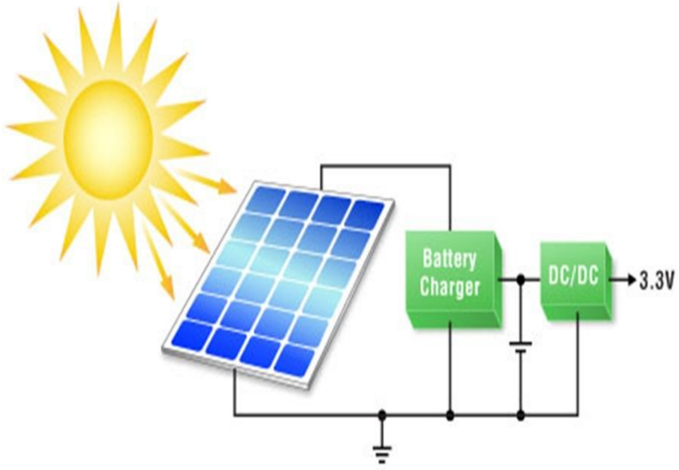
1. Internet of Things
   - Radio Frequency Identification (RFID).

2. Internet of Underwater Things

Characteristics	Types of tags		
	Acoustic tags	Radio tags	PIT tags
Freshwater	Yes	Yes	Yes
Seawater	Yes	No	No
Detection range	Freshwater: 1 km Seawater: 200 m	Freshwater: 10 m	Freshwater: 20 cm
Size			
Length	19–74 mm	20–80 mm	11–28 mm
Diameter	6–16 mm	9–30 mm	2–3.5 mm
Cost	Around $250	Around $250	Around $3
Battery	Yes	Yes	No
Battery life duration	19 day–4 years (depending on the tag ping rate and the battery size)	9 day–3 years (depending on the time between bursts and the battery size)	–
3-D position estimation	Yes	No	No
Store information	No	No	Yes
Need recapture	No	No	Yes

Energy Harvesting Techniques

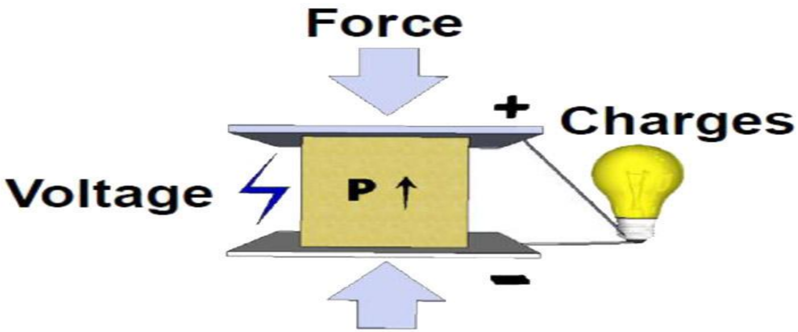
- Solar energy harvesting has been the predominant energy harvesting technique for IoT.
  - Available abundantly.
  - Can be accessible only during daylight.
- Indefinite range, use of MPPT (Maximum Power Point Tracking) is mandatory if we are using multiple panels.
- Wind, kinetic, and thermal harvesting are a few other techniques under development for IoT devices.

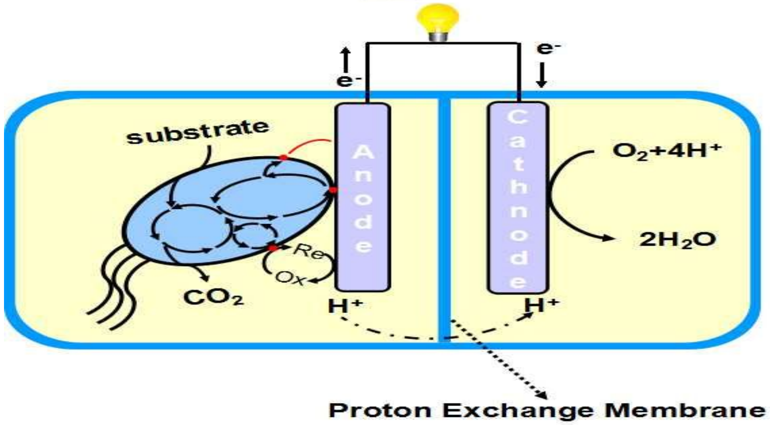


Energy Harvesting for IoUT

- Piezoelectric Harvesting
  - Converts mechanical flow created by currents to electric energy.
- Microbial Fuel Cell (MFC)
  - A technique which generates energy from biodegradable substrates.
  - Exploits metabolic activity of bacteria.
  - Great potential to power micro electronic devices.

There is ocean thermal energy harvesting as well.

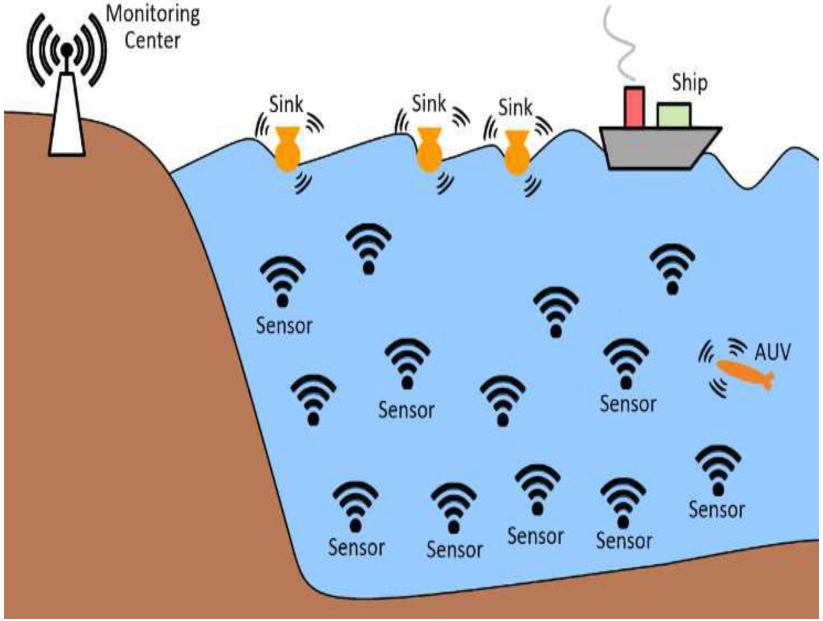




Microbial Fuel Cell Video

https://www.youtube.com/watch?v=ZotwUJAb8R4&feature=youtu.be

Underwater Wireless Sensor Networks(UWSNs)



- A promising network system for IoUT.
- Sensors are the nodes with acoustic modems that sense, relay, and forward data.
- Nodes communicate with one another through the aid of acoustic or sound communication techniques.
- Data is transferred to sinks that are located on the surface of the water via acoustic channels.

Underwater Wireless Sensor Networks(UWSNs)

- Can be static or mobile.
- Sinks are the nodes with both acoustic and radio modems.
- Collect data from sensors via an acoustic channel and forward them to the remote monitoring center through radio channels.

Challenges of UWSNs

- **Low data rate:** acoustic communication has short range and low frequency and has limited bandwidth.
- **Low propagation speed:** guaranteeing the bounded end-to-end delay is a challenge.
- **Long range transmission:** may cause more interference and collisions during the data transmission.

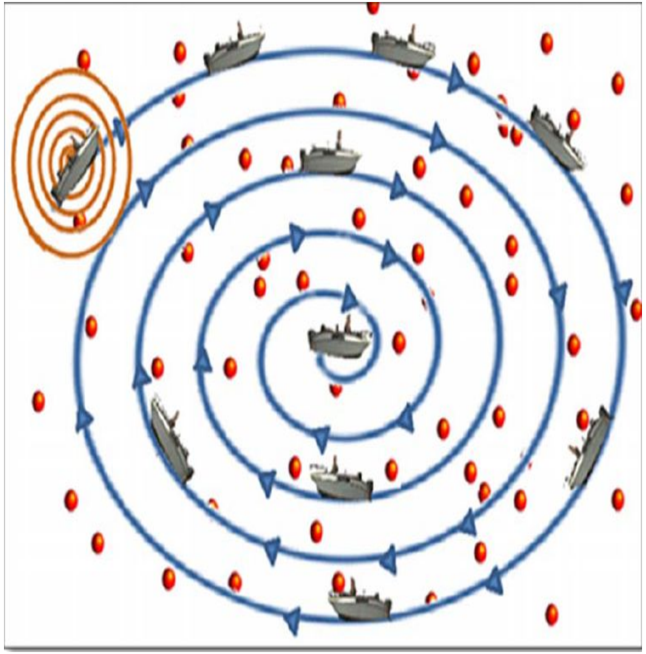
Features	TWSNs	UWSNs
Transmission Speed	250 kbps	10 kbps
Propagation Speed	300,000,000 m/s	1,500 m/s
Transmission Range	10-100 m	100 m -10 km

Challenges of UWSNs

- <u>Dynamic topology change</u>: the underwater sensors may move with water currents causing dynamic topology changes
- <u>Unreliable communication</u>: causing frequent data retransmission, which would result in longer delay, higher bandwidth consumption, and higher energy consumption
- <u>Battery recharge or replacement</u>: energy harvesting is not possible under water, replacement and recharge is difficult and expensive operation

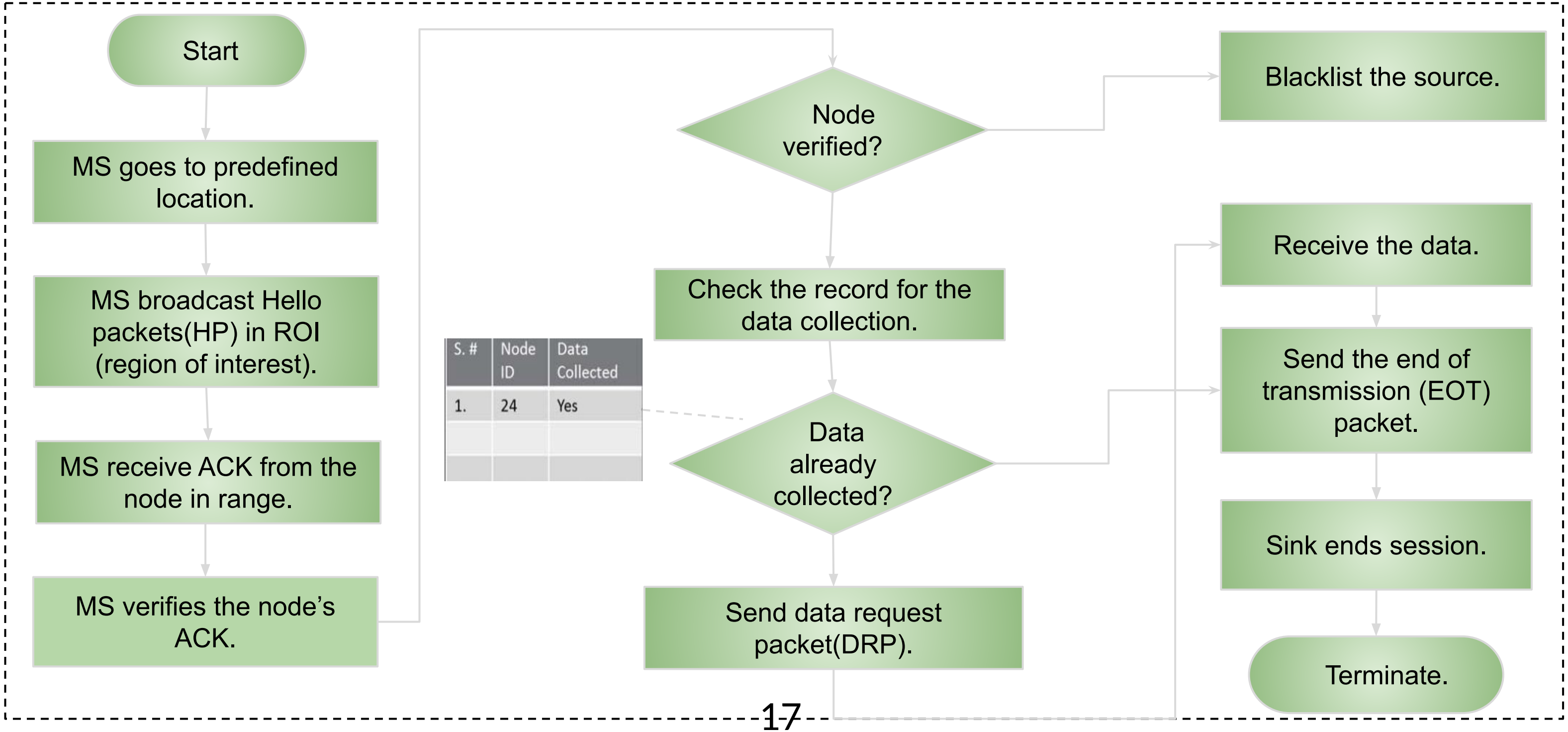
Features	TWSNs	UWSNs
Mobility (of Nodes)	Dependent on the Application	High
Reliability (of links)	Dependent on the Application]	Low
Difficulty of Recharge	Dependent on the Application	Difficult

Whirlpool Data Collection Technique in A UWSNs

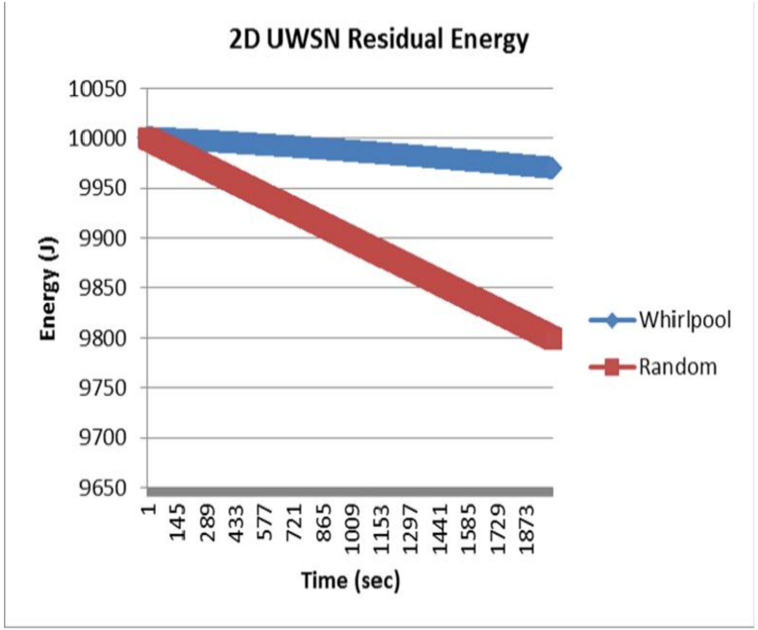


- A lightweight and robust data collection technique.
- Uses mobile sink (Autonomous Underwater Vehicle(AUV)) instead of static sink to collect data.
- The mobile sink moves in the shape of a Whirlpool on a planned predetermined path to collect data using the preloaded (saved) tabular data .
- The underwater sensor nodes are stationary.
- Point to point communication is used between the sink and the sensor node.

Mobile Sink (MS) Working Mechanism in Whirlpool Data Collection Technique

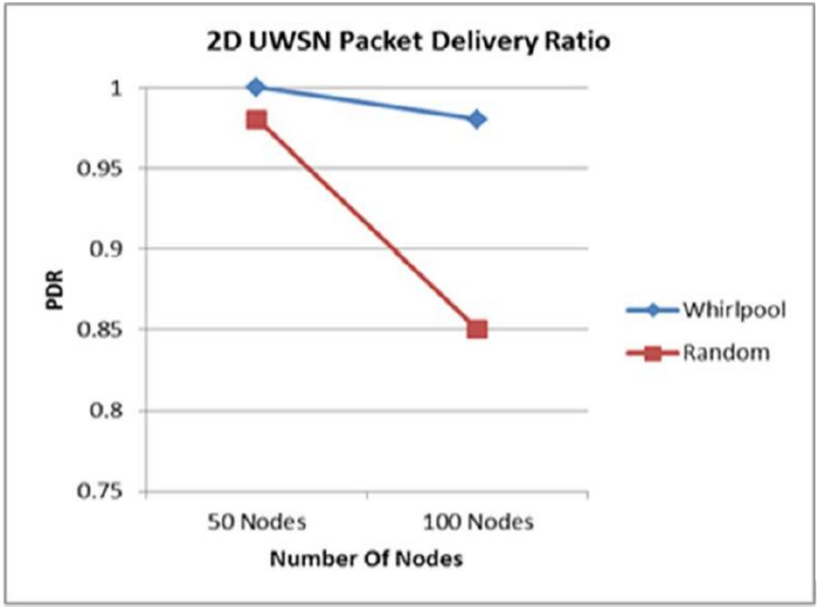


Simulation of Whirlpool Data Collection Technique in a UWSNs



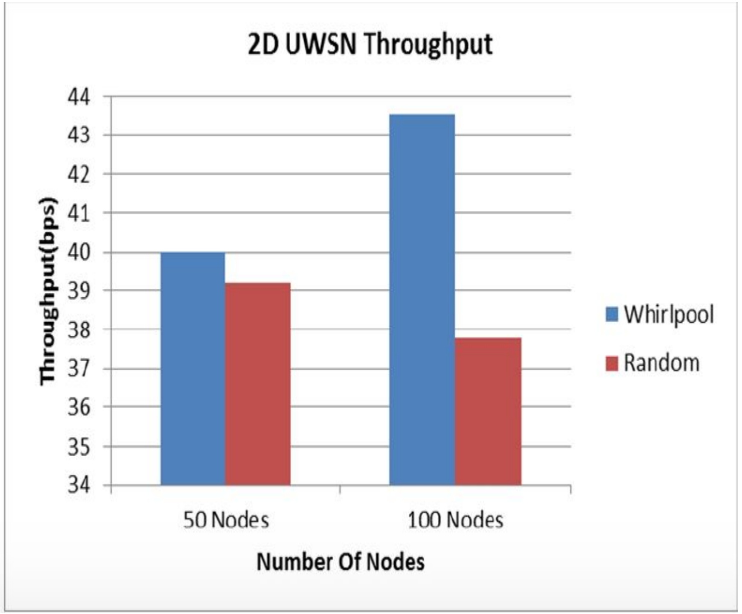
- Use network simulator and AquaSim to compared the Whirlpool and random data collection technique for a network of 50 and 100 underwater nodes.
- Residual energy
  - Residual energy with initial energy of 10000 J.
  - Considerable change in energy Whirlpool consumption due to planned data aggregation path in Whirlpool method because of predefined path.
  - More energy consumption in random technique due to multiple selection of single location, transmitting packet uselessly, and more travel.

Whirlpool Data Collection technique in a UWSNs



- Packet Delivery Ratio
  - All packets are delivered in the 50 node test case, but packet delivery success decreases with increasing number of nodes.
  - Random strategy does not provide good results.

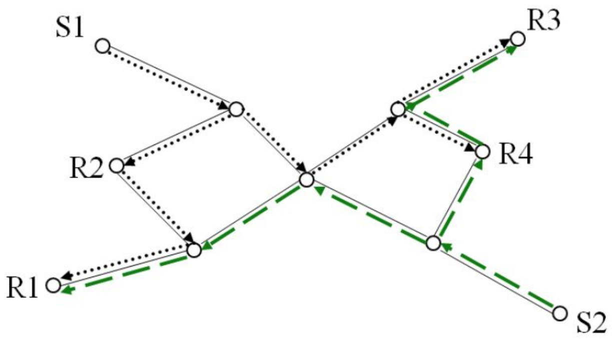
Whirlpool Data Collection Technique in a UWSNs



- Whirlpool technique shows promising network performance with increasing complexity of the network.
- Results of Whirlpool technique simulation
  - Reduced overall energy consumption.
  - Assured packet delivery to a certain extent.
  - Improved network performance.
  - Reduced routing overhead on sensor nodes, so increasing the overall lifetime of UWSNs.

Multicast-Tree-Based Protocol

1. Multicast-tree-based: built upon a tree topology for route optimization.
2. Advantages
   a. Minimal propagation delay between nodes
   b. Low energy consumption
3. Disadvantages
   a. Very unstable for mobile nodes
   b. Extra overhead for control signaling



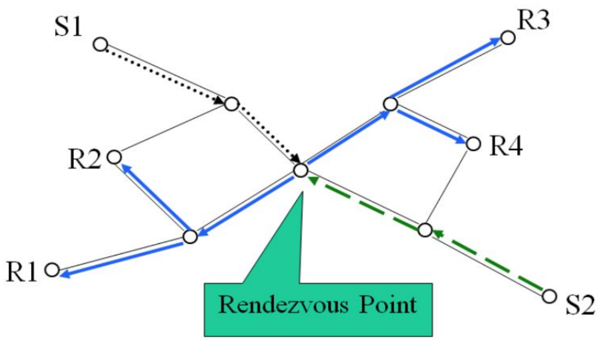
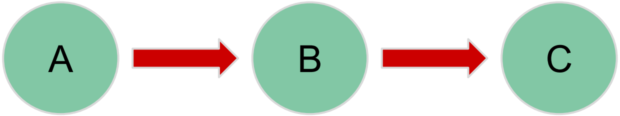


Table-Driven Protocol

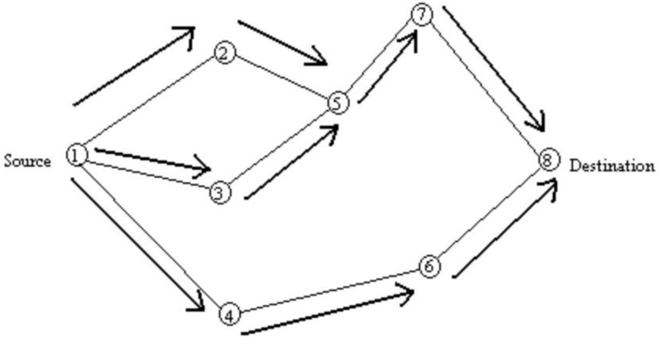
1. Table-driven: maintains records of destinations and their routes by periodically distributing routing information all the way through the communication network.
2. Advantages
   a. Appropriate for static networks
   b. Low latency for data packet transmission
3. Disadvantages
   a. A lot of time spent periodically transmitting control messages
   b. Slow error recovery
   c. High overhead for signaling
   d. High power consumption



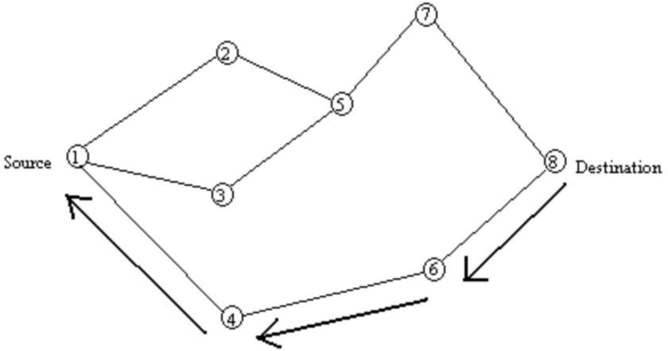
Destination	Next Hop	Number of Hops	Sequence Number	Install Time
A	B	0	A46	1000
B	C	1	B36	1200
C	A	2	C28	1400

On-Demand Protocol

1. <u>On-demand</u>: the route discovery process is only initiated by a sensor node when data needs to be transmitted.
2. Advantages
   a. Appropriate for dynamic networks
   b. Periodic exchange of control messages is not necessary.
3. Disadvantages
   a. Long latency for route discovery and data transmission.
   b. High overhead for route discovery.



(a) Propogation of Route Request (RREQ) Packet



(b) Path taken by the Route Reply (RREP) Packet

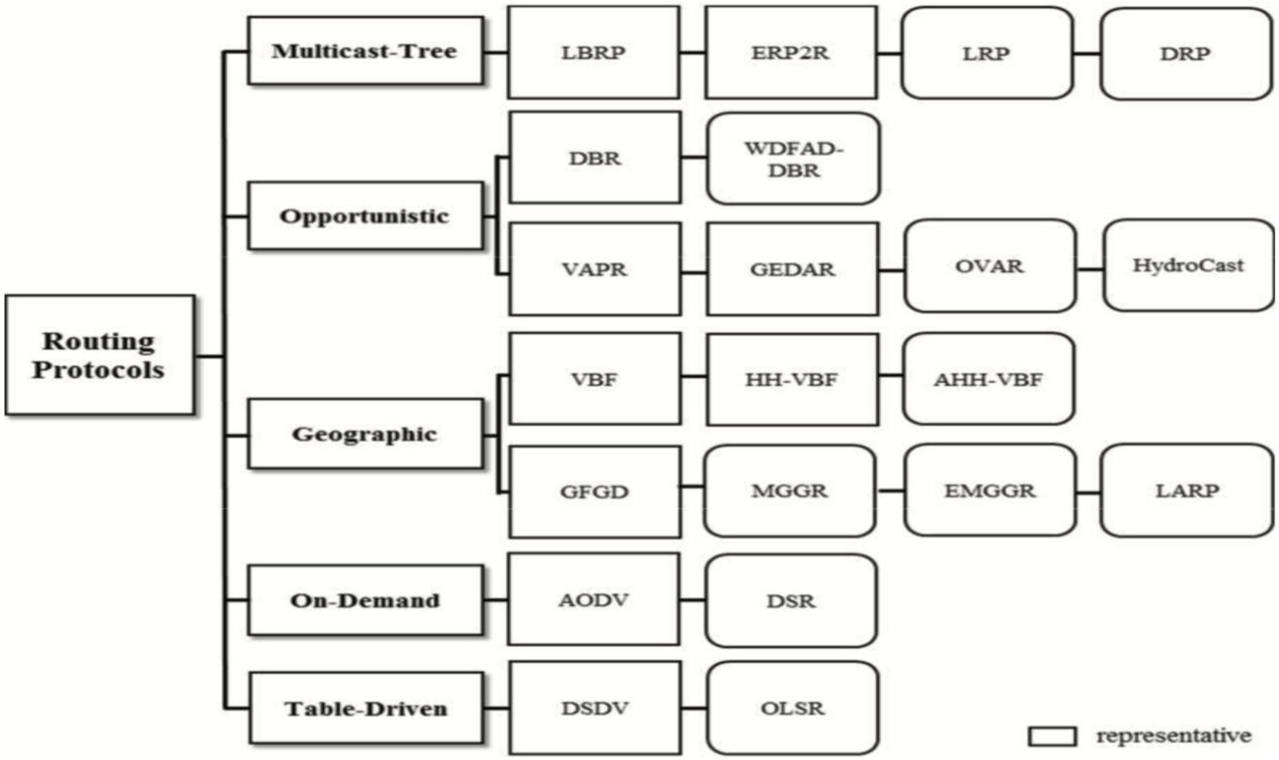
Geographic Protocol

1. Geographic: exploit geographical location information belonging to source nodes, neighboring nodes, and destination nodes. Categorized into greedy forwarding, restricted directional flooding, and hierarchical approaches.
2. Advantages
   a. Accuracy of data packet transmission.
   b. Low overhead for signaling.
3. Disadvantages
   a. Geographic information is necessary.
   b. Data packets can easily be lost in communication holes (localisation algorithm issue).

Opportunistic Protocol

1. Opportunistic: use probability models and predetermined conditions to generate a data path.
2. Advantages
   a. Each sensor node has the ability to decide whether or not to re-broadcast data packets.
   b. Appropriate for dynamic environments.
3. Disadvantages
   a. Very low efficiency in high density networks.
   b. Data packet collision is very likely due to each node being able to re-broadcast data.

Examples of Each Routing Protocol



Relationship between IoUT Challenges and Protocols

Protocol	Delay	Reliability	Bandwidth	Energy	Mobility
DSDV [7]	✓	✓	×	×	×
OLSR [8]	✓	✓	×	×	×
AODV [9]	×	✓	△	△	✓
DSR [10]	×	△	△	△	✓
VBF [11]	✓	△	△	△	✓
HH-VBF [12]	✓	△	△	△	✓
GFGD [13]	×	△	✓	✓	×
MGGR [14]	×	△	✓	△	△
EMGGR [4]	×	△	✓	✓	△
AHH-VBF [15]	✓	△	△	△	✓
LARP [16]	×	✓	△	△	△
DBR [17]	✓	△	×	×	✓
VAPR [18]	×	✓	×	×	✓
GEDAR [19]	△	✓	×	×	✓
WDFAD-DBR [20]	✓	△	×	△	✓
OVAR [21]	✓	✓	×	×	✓
HydroCast [22]	✓	✓	×	△	✓
ERP2R [23]	✓	×	✓	✓	×
LBRP [24]	✓	×	✓	✓	×
DRP [25]	✓	△	✓	✓	×
LRP [26]	✓	△	△	✓	×

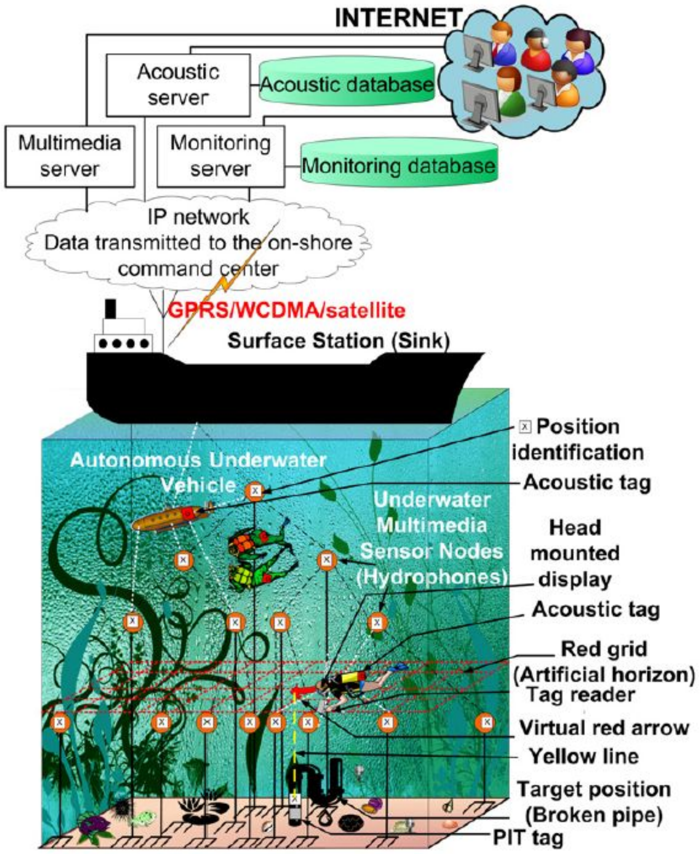
IoUT Architecture

Three Layered Architecture

- Perception Layer
- Network Layer
- Application Layer

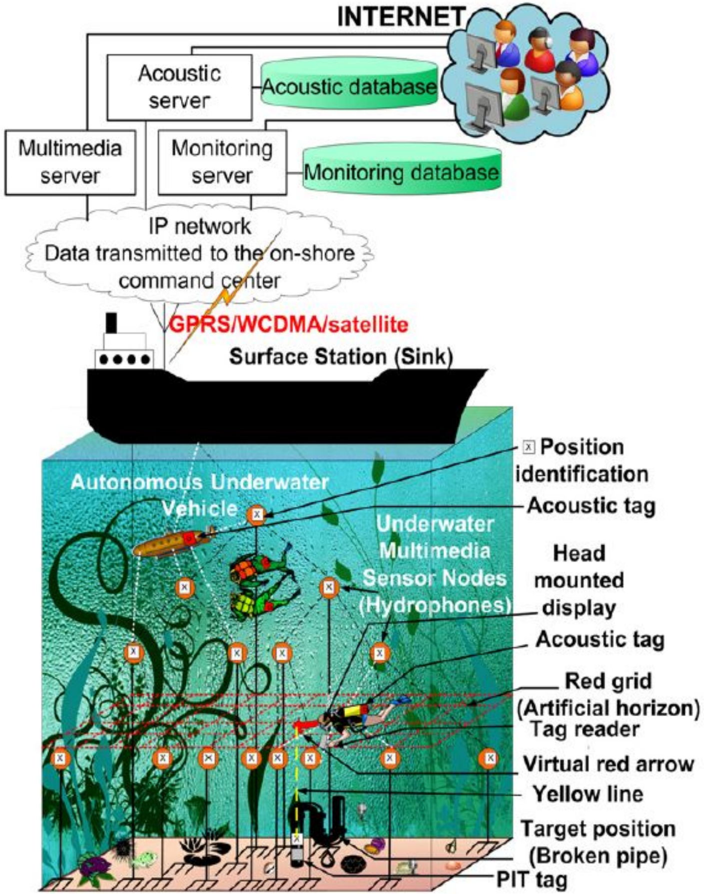
Perception Layer

- Distinguishes different components in the system.
- The subsystems present in perception layer are
  - Sensor nodes
  - Autonomous Underwater Vehicles (AUV)
  - Underwater Drones
  - Surface Sink (Ships, Float Transceivers)
- This layer uses all the tracking tech mentioned before in the characteristics if IoUT.
- The data transfer is possible only through the different transceiver nodes.
- Sink is the final stage of this layer where the data is sent to the gateway.



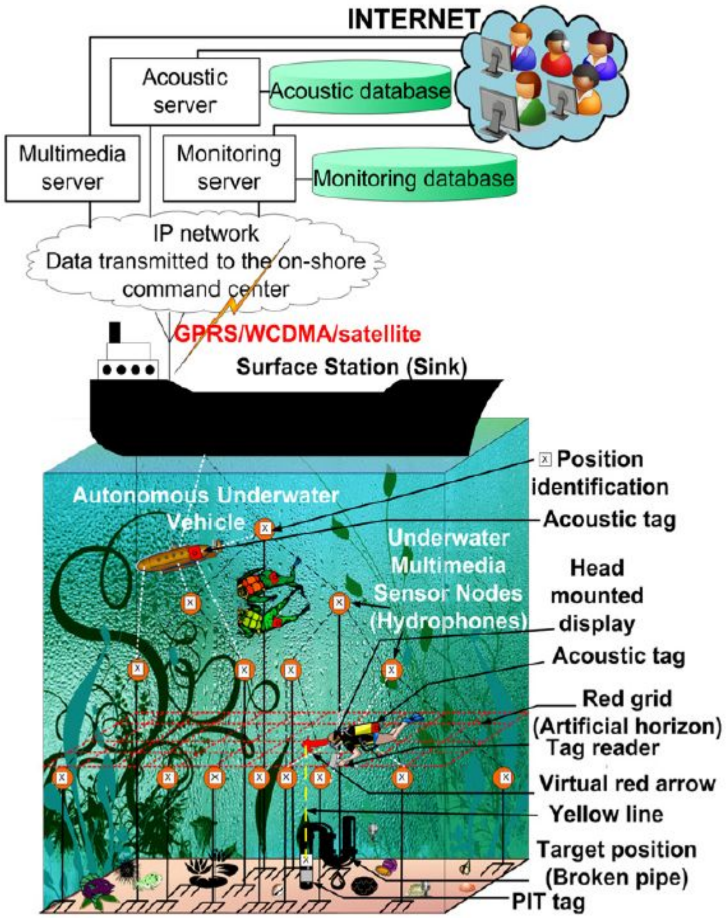
Network Layer

- Uses a heterogeneous network system.
- Sink communicates to the offshore station using General Packet Radio Service (GPRS) or Wide Code Division Multiple Access (WCDMA)
- IP is recommended, but not all underwater nodes support IP.
- Delay Tolerant Network (DTN) addresses the lack of connectivity and delays caused by the communication techniques. https://en.wikipedia.org/wiki/Delay-tolerant_networking
- Also called "Store And Forward" type networking.

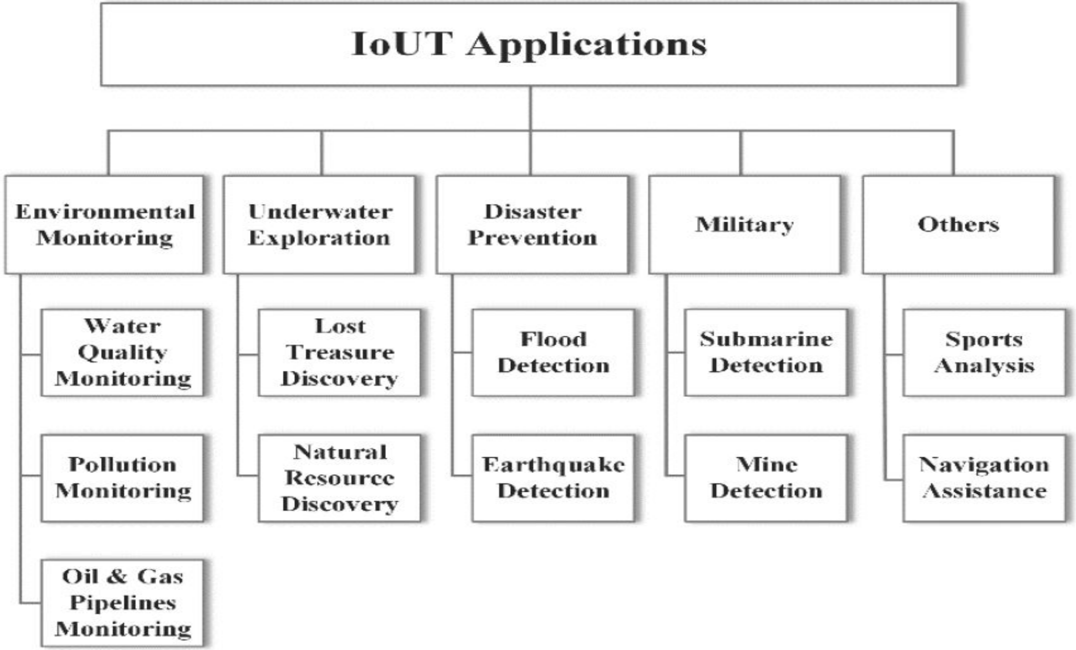


Application Layer

- Uses Representational State Transfer (REST) Architectures.
- Consists of clients and servers.
- Client initiates request to server and server responds with appropriate information or data.
- Hypertext Transfer Protocol (HTTP) is used by the client to access resources provided by the server.
- Used in IoUT as all nodes can request and provide services.
- Resource Classification
  - Periodic Sensor Data.
  - Static environmental maps or network configurations.
  - State of resources and interrupts.



Applications



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Questions?