



LUND
UNIVERSITY

Underwater Wireless Networks

MARIA KIHLM



Literature

- Gussen, et. al. "A survey of underwater wireless communication technologies." J. Commun. Inf. Sys. 31, no. 1, pp 242-255, 2016
- R. Petroccia, J. Alves and G. Zappa, "JANUS-Based Services for Operationally Relevant Underwater Applications," in IEEE Journal of Oceanic Engineering, vol. 42, no. 4, pp. 994-1006, Oct. 2017.
 - Chapters I and II.
- Domingo, Mari Carmen. "An overview of the Internet of Underwater Things." Journal of Network and Computer Applications 35, no. 6, pp 1879-1890, 2012.
 - Chapters 1, 2, and 3

Today's lecture: Underwater communication – challenges, applications, and some solutions

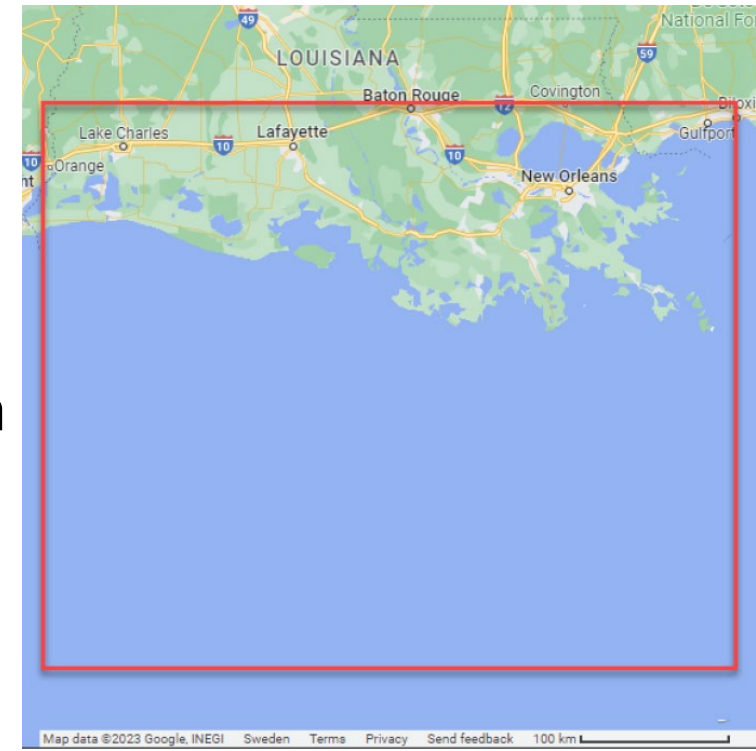


Today's scenario: Gulf of Mexico (America)

The Gulf of Mexico (GOM). requires an efficient, reliable, automated and cost effective method of monitoring for marine oil spills, especially given that most of the oil platforms in the GOM are unmanned and not connected to the electricity grid.

Your task is to develop a network architecture for oil spill trajectory monitoring of the waters outside New Orleans. You have access to the following equipment: (1) Oil detection sensors that can be installed on oil platforms and wherever needed in the ocean; (2) Small autonomous underwater vehicles (AUV) with a range of about 50km; (3) Small boats; (4) Trained dolphins.

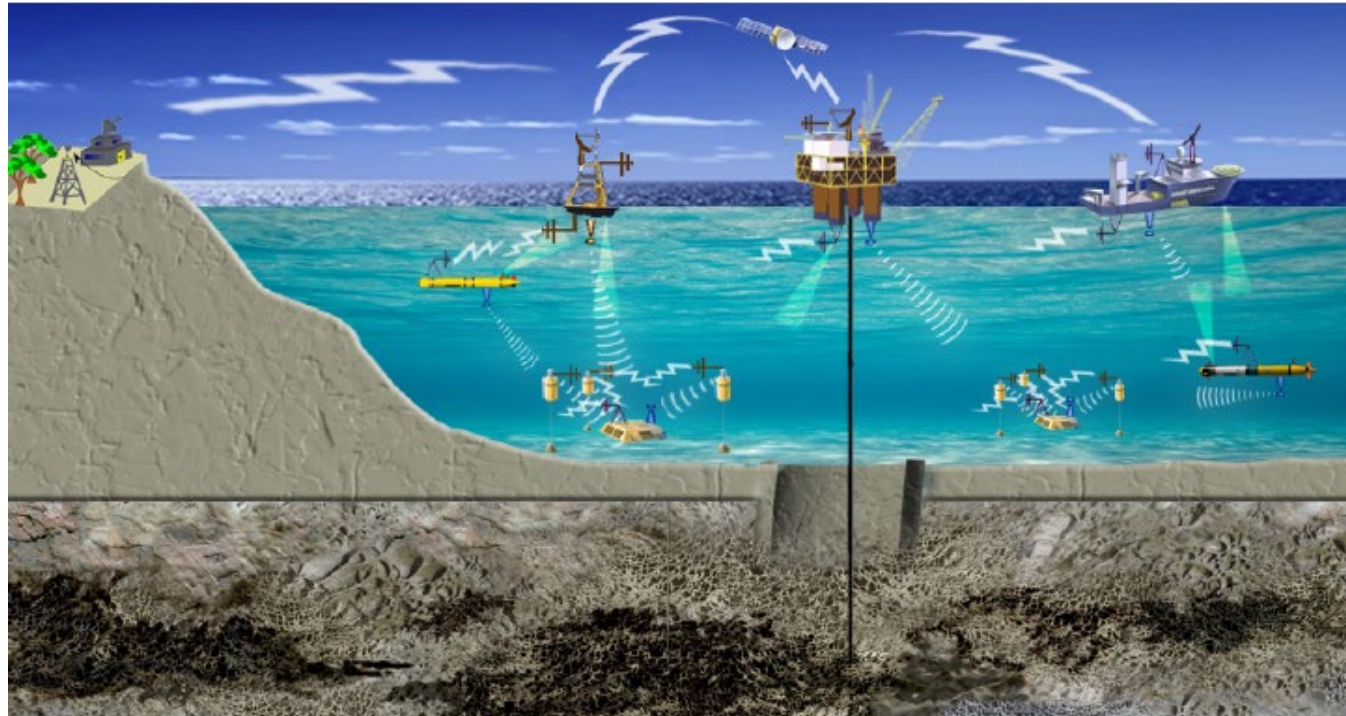
The goal of the system is to continuously monitor the waters outside New Orleans and detect any major oil spills coming from leaking oil platforms or ships. The objective of the system is to detect oil spills faster than today's solutions based on detecting oil spills when the oil reaches the coast or a passing ship. After detection, ships will be directed towards the area with oil spills.



Underwater wireless communications

The underwater environment possesses a number of distinguishing features that make it unique and rather different from terrestrial radio propagation.

Under water, several phenomena may influence communications, such as salt concentration, pressure, temperature, amount of light, winds and their effects on waves.



Devices for communication

There are companies that specializes in underwater communications, and they develop modems and other communication devices.



Acoustic Underwater Wireless
Communication Modem



Acoustic deck unit



Ocean surface buoy

Underwater wireless communication

For underwater scenarios, there are three types of wireless communication technologies that are used:

- RF communication (radio)
- Optical communication (light)
- Acoustic communication (sound)

Each technology has advantages and disadvantages, and they are usually deployed for different scenarios.

RF communication

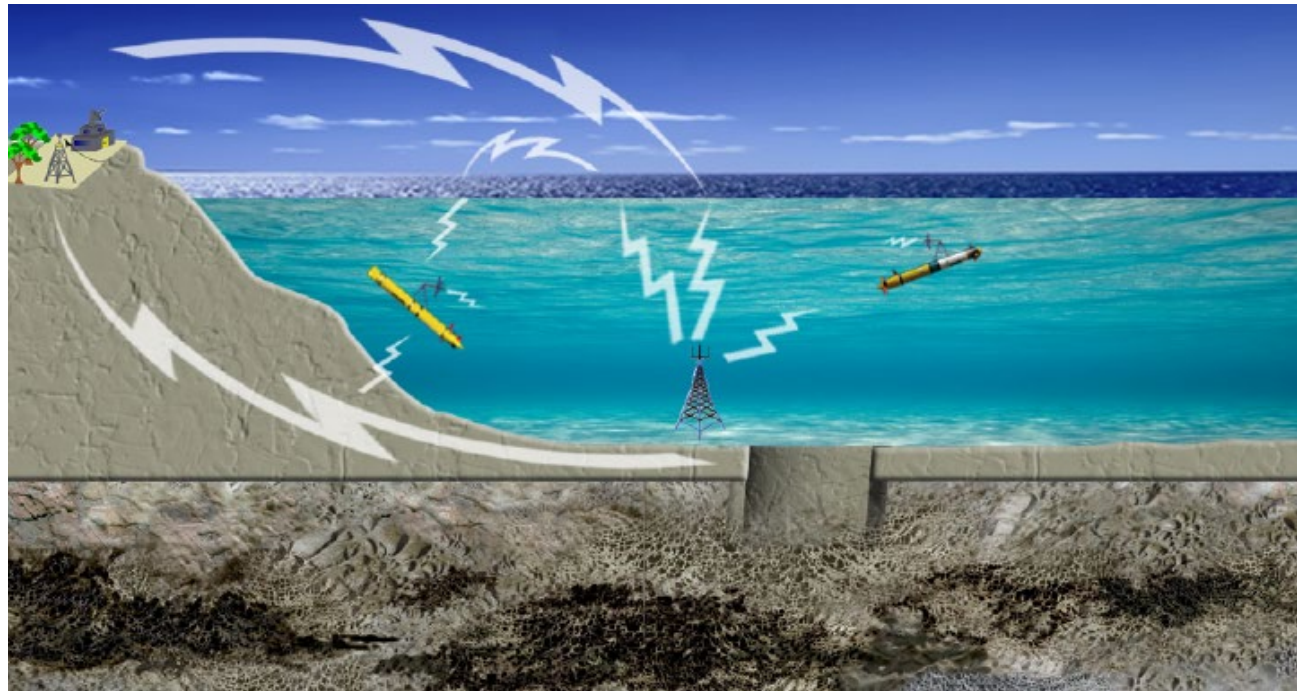
- The propagation of an RF signal in water depends on environmental conditions, such as salinity and temperature, and it is frequency dependent.
- Signals on low frequency bands (ELF and VLF) can have a range of several kilometers. Higher frequencies (VHF and UHF) may only reach about 10 meters.
- Propagation distance for a signal attenuation of 50 dB. Considering seawater, when **using frequencies in the order of MHz the propagation distance is on the order of centimeters:**

	Frequency						
	10 Hz	10^2 Hz	10^3 Hz	10^4 Hz	10^6 Hz	10^7 Hz	10^9 Hz
Seawater	4.4×10^2	1.4×10^2	4.4×10^1	1.4×10^1	1.4×10^0	4.4×10^{-1}	4.4×10^{-2}
Fresh water	2.9×10^4	9.2×10^3	2.9×10^3	9.2×10^2	9.2×10^1	2.9×10^1	2.9×10^0

- Low frequencies => Large antennas and low bit rates.

Multipath propagation for radio signals

- Underwater RF signals can travel through several paths: the signal can cross the water-air boundary and it can propagate through the seabed.
- The signal traversing the seabed or the air might suffer lower attenuation than the signal that propagates only in the water.



Optical communication

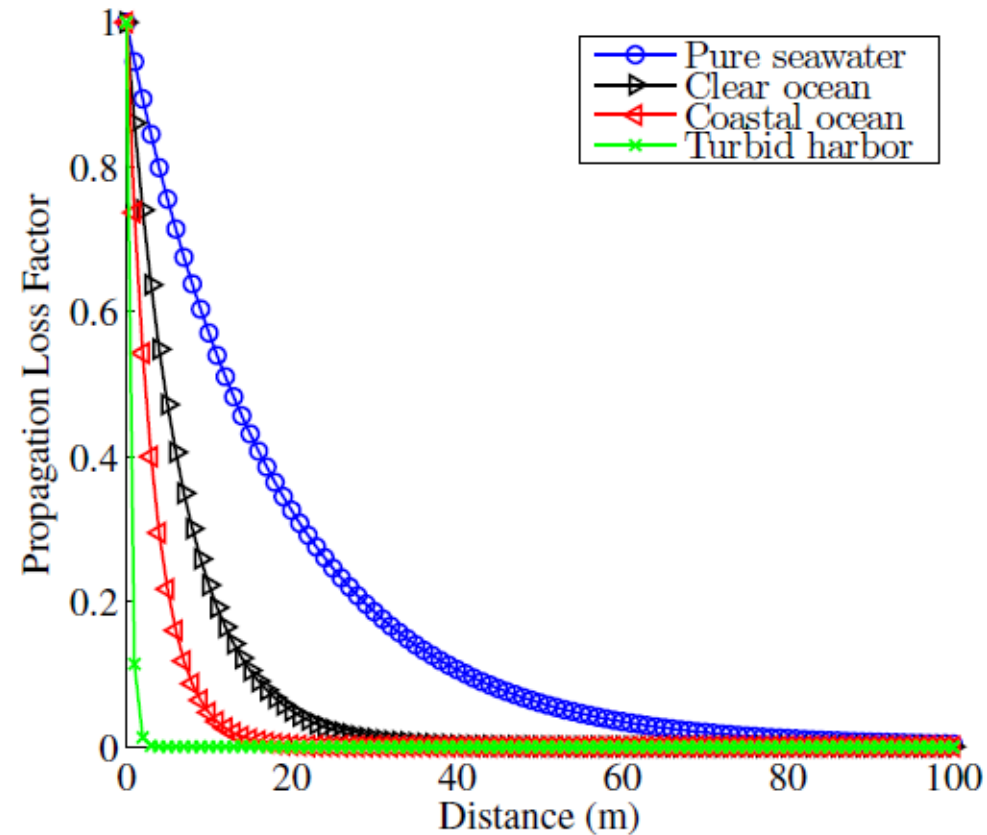
Optical communications usually **require line-of-sight between transmitter and receiver**, which entails some sort of direction tracking to maintain the communication link.

Optical signals are attenuated due to absorption and scattering:

- Absorption is the process that transforms electromagnetic radiation into heat, i.e., the energy that would be re-emitted is absorbed.
- The direction of the photons change due to scattering. Scattering can be originated by salt ions in pure water and by particulate matter.

Propagation loss factor

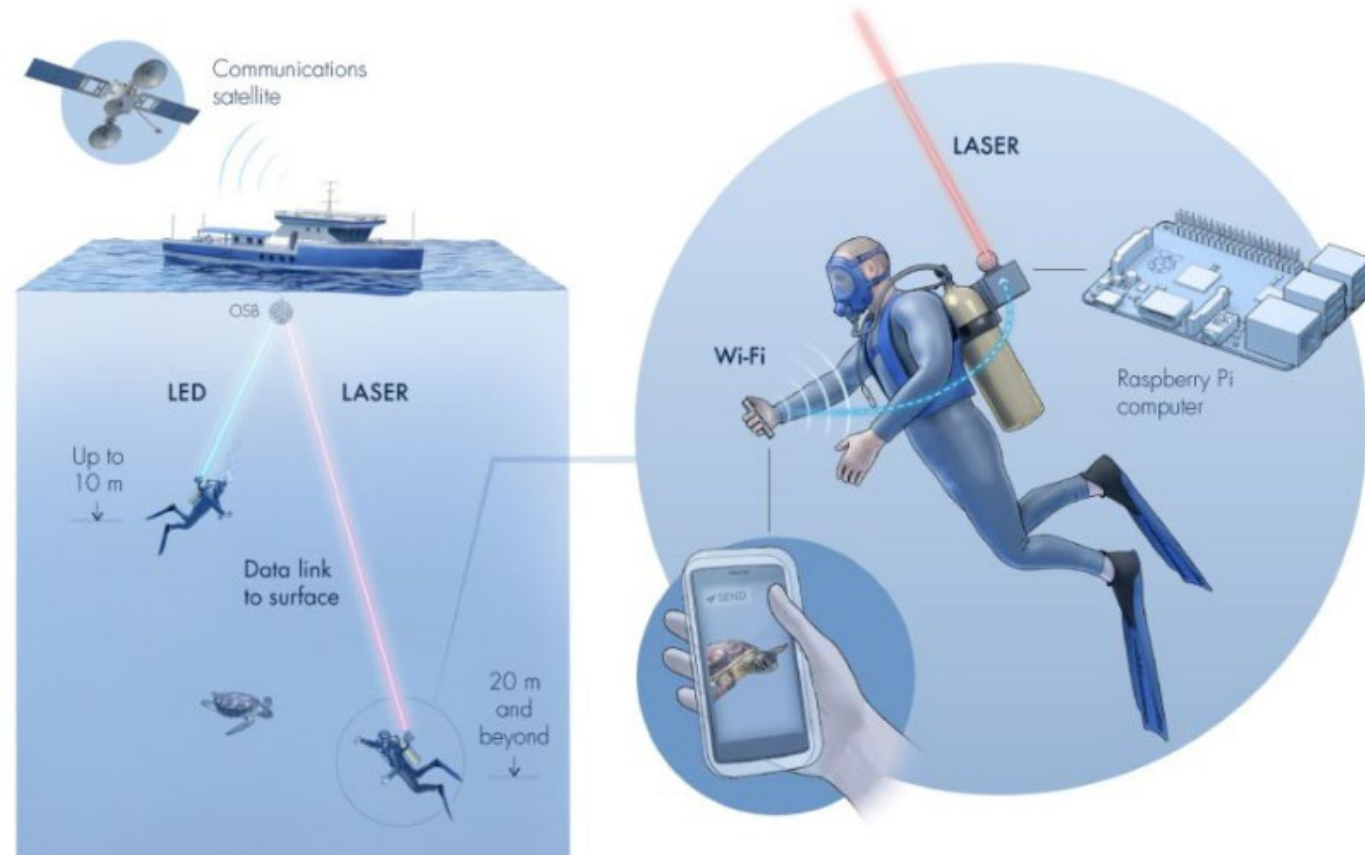
The **propagation loss factor** is a metric that defines how much of the optical signal is remaining after a certain distance.



Example: The Aqua-Fi system

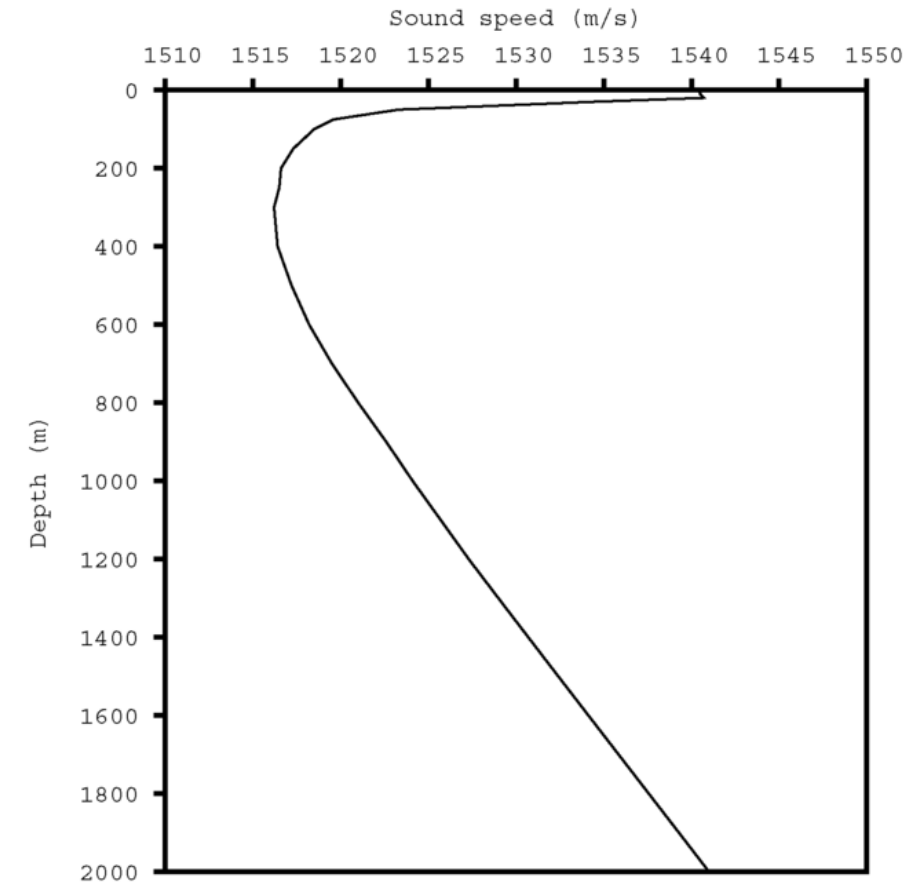
Aqua-Fi is a proposed underwater communication system based on optical communication.

- Aqua-Fi uses an LED or laser to support bidirectional wide-range communication services.
- LEDs introduce robust short distance solutions with low power requirements.
- Laser extends the communication distance and improves the transmission rate at the cost of higher power requirements.



Acoustic communication

- Acoustic communication is currently being the dominant technology for wireless underwater communications.
- The speed of propagation, c , of acoustic waves in fluids is very limited. The parameters affecting the speed of propagation play a major role in acoustic-based communications.
- c mainly depends on the depth, but also temperature and salinity.
- Spreading and scattering contribute to the **path loss**. For low frequencies, the path loss is approximately the same for different distances.
- **Path loss increases considerably when the frequency and the distance between transmitter and receiver increases.**



Doppler effect

- The Doppler effect (or the Doppler shift) is the change in frequency of a wave in relation to an observer who is moving relative to the wave source.
- The Doppler effect is particularly noticeable when communicating using pressure waves, due to the relatively low speed of propagation of the wavefront.
- The effect is even more pronounced for underwater acoustic communication, since in this case, buoys and vessels which host transmitter and receiver are seldom at absolute rest.
- **Therefore, most acoustic communication links demand mitigation of the Doppler effect.**

Example: POWERCOM

Acoustic communication system for divers developed by Ocean Technology Systems.



Protocol standard for acoustic communication: JANUS

- For a long time, there have been no standards for underwater communications. Each manufacturer has developed their own technologies and protocols.
- **JANUS was adopted in 2017 by NATO** to help unify all underwater communications and allow for devices made by different manufacturers to cross-communicate.
- JANUS is an underwater protocol based on **acoustic communication**.
- JANUS allow for **devices to announce themselves** on a commonly-used frequency, 11.5 kHz.
- When two devices have agreed to connect (i.e forming an **ad-hoc connection**), they can switch to a different frequency or transmission method for faster data rates.

JANUS medium access control

There are two key built-in mechanisms in JANUS to handle the medium access: **a channel reservation feature, and a built-in medium access control (MAC).**

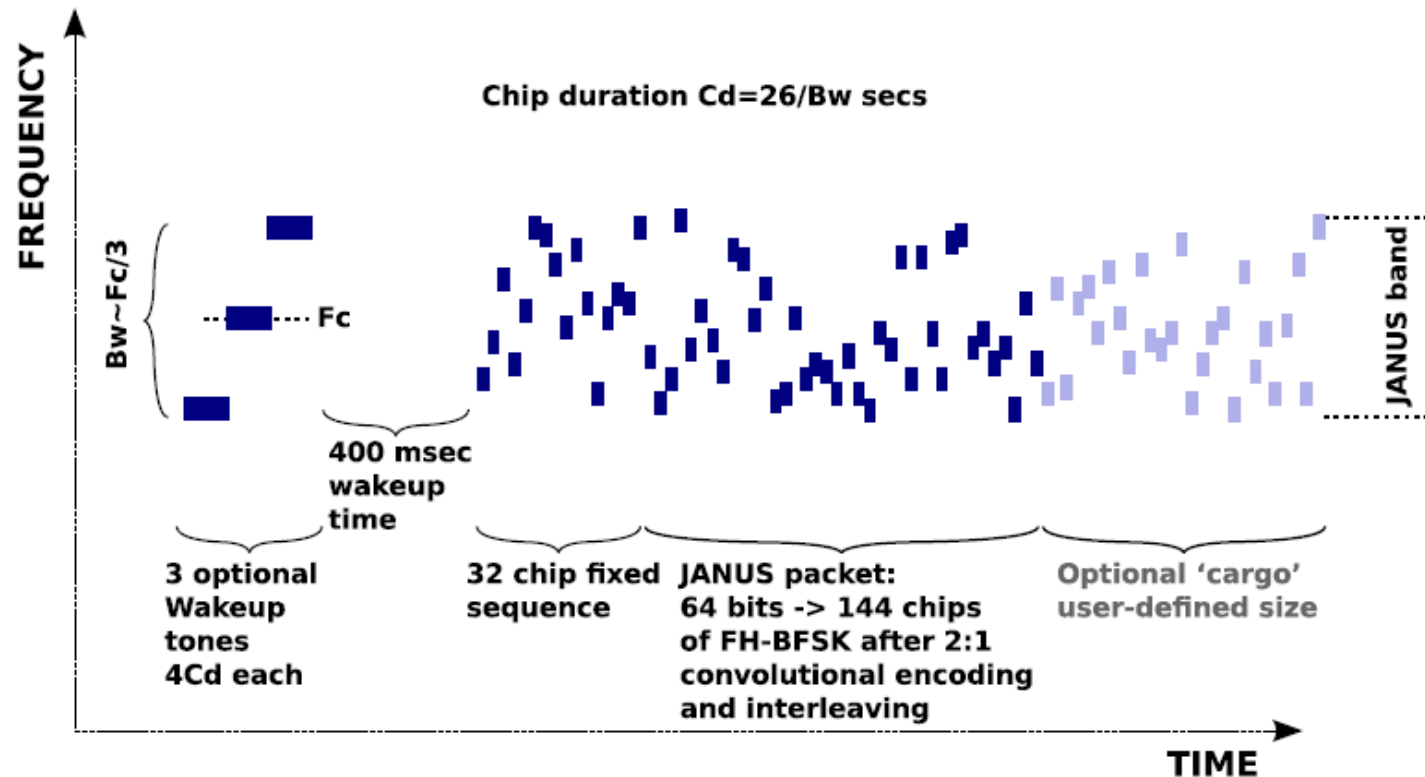
- By setting certain bits in a baseline JANUS packet, a JANUS node can request “silence” from its neighbors for a defined period of time.
- The MAC component of JANUS was specifically introduced to minimize the risk of collisions between JANUS and legacy technologies operating in the same band (such as underwater telephones (UT)).
- The task of the **JANUS MAC is similar to CSMA**. A JANUS node measures the energy in band while keeping track of the background noise level. In case other energy sources are detected in the occupied band, precedence is offered to these sources.

JANUS data transmission

- A data transmission starts with three “wake-up” tones that are intended for use in the cases where a modem needs to wake up from a low power sleep mode.
- The tones are followed by a short time to activate the receiver electronics, which precedes a fixed sequence of 32 chips. This sequence is used as a detection and synchronization preamble.
- Once the fixed preamble phase of the waveform is complete, the dialogue enters the message section, which is composed by the “baseline JANUS Packet” followed by an optional “Cargo” section.

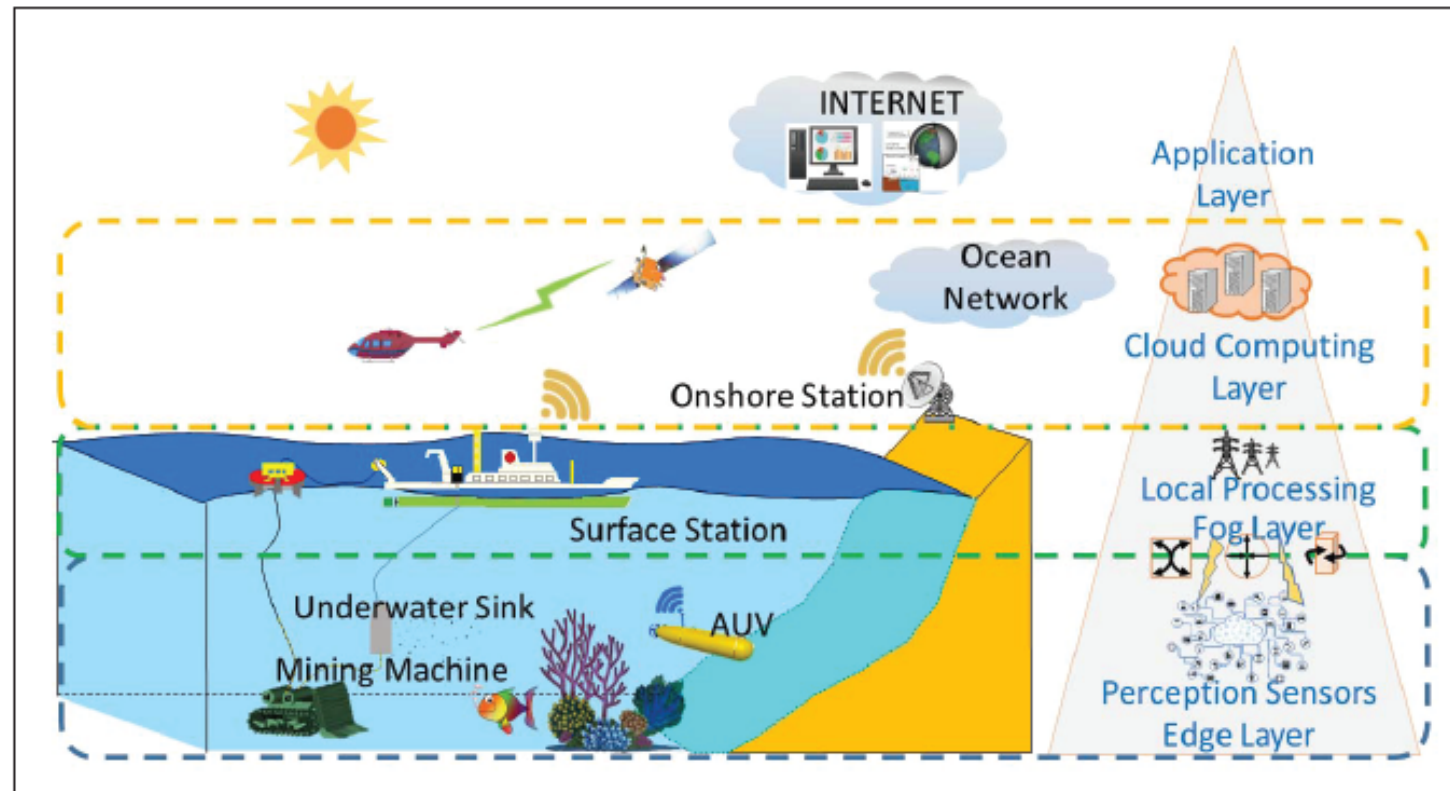
JANUS data transmission

For the initial JANUS specification, a center frequency of 11 520 Hz was chosen, resulting in a frequency band between 9400 and 13 600 Hz and in a **bit rate of 80 b/s**.



Internet of Underwater Things (IoUT)

- Internet of Underwater Things (IoUT) can be defined as a network of smart interconnected underwater objects with a digital entity.
- Other terms for basically the same concept is **Underwater Wireless Sensor Networks (UWSN)** or just Underwater Wireless Networks (UWN).



Tracking technologies

In IoUT systems, things (usually fish) are tracked with different technologies depending on the fish size and species, type of data to be collected and habitat utilization.

- **Acoustic tags** are sound-emitting devices. They have large detection ranges (up to 1km in freshwater).
- **Radio tags** transmit a radio-frequency signal detectable through a system of one or more antennas and receivers. They have limited ranges (around 10 m in freshwater) and cannot work in seawater.

Example: Acoustic fish tags

- **Acoustic fish tags** are used to monitor and track fish movements.
- Small tags are surgically implanted, injected, fed (via baited fish), or externally attached to a fish.
- The tags **transmit a high frequency “ping”** which can be heard as far as half a kilometer away.
- **Acoustic receivers** are strategically placed around the area of interest to listen for these pings. The receivers can be placed on anchored buoys, cabled underwater arrays, or existing oil and gas platforms, as well as integrated into ocean gliders, or even carried by other marine animals, such as elephant seals.



Power management of devices

- Underwater objects are prone to failure due to fouling and corrosion. Their battery capacities are limited; compared to most terrestrial IoT objects it is more difficult (sometimes impossible) to recharge or replace them.
- IoUT devices usually cannot be powered by solar cells, as many IoT devices. There are several proposed solutions for this challenge, for example:
 - Piezoelectric energy harvesting of surroundings.
 - Ocean thermal energy harvesting.

Localization techniques

- GPS uses radio waves in the 1.5 GHz band that do not propagate in water.
 - Therefore, if an underwater sensor needs to know its location, there are large technical challenges.
- Usually solved with some type of beacons, sent out by mobile nodes or so called anchors.

DTN solutions for UWSNs

The unique characteristics of the underwater communication channel impose many challenges, such as:

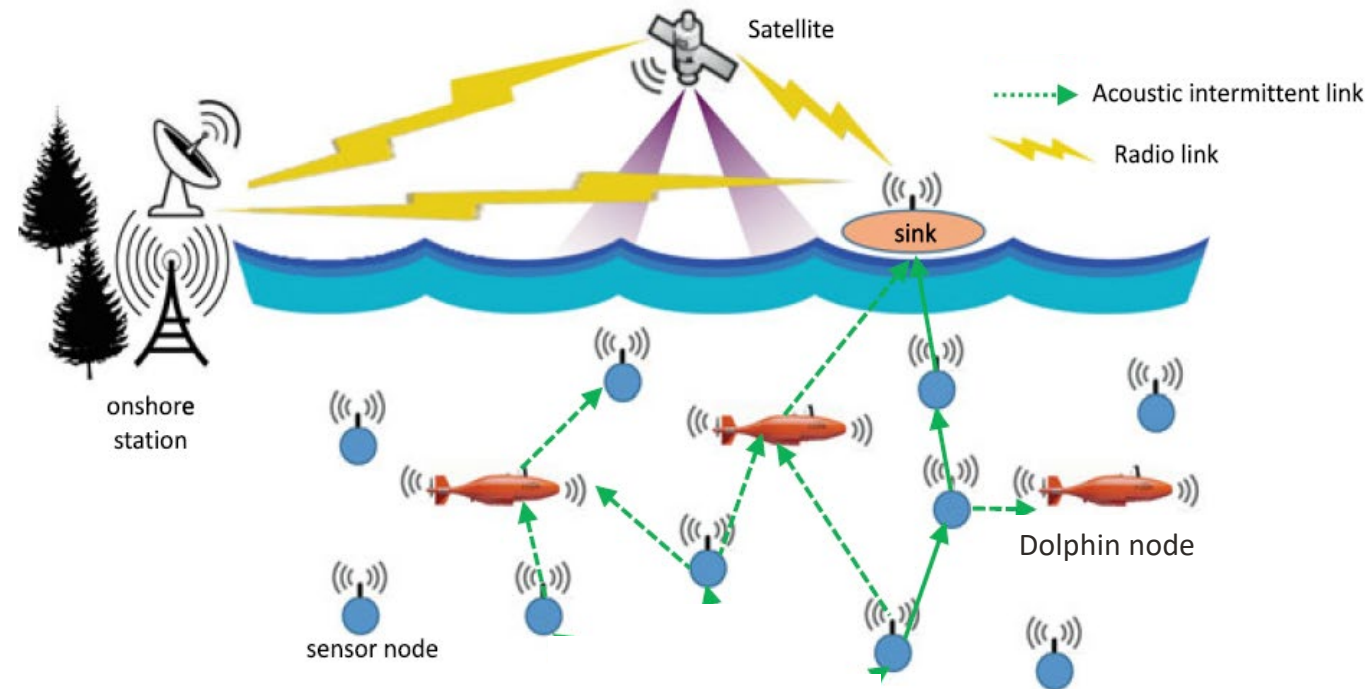
- For acoustic communication, the **propagation delay** is five orders of magnitude higher than in RF terrestrial channels, and variable. This is due to the low speed of sound under water (approximately 1500 m/s).
- For low frequency bands, as often used underwater, the **bandwidth is extremely limited**, which causes the data rate to be low.
- The **channel is impaired** by path loss.
- **Limited battery** power for devices.
- **High bit error rates and temporary loss of connectivity.**



Delay- and Disruption-Tolerant Networks (DTNs)

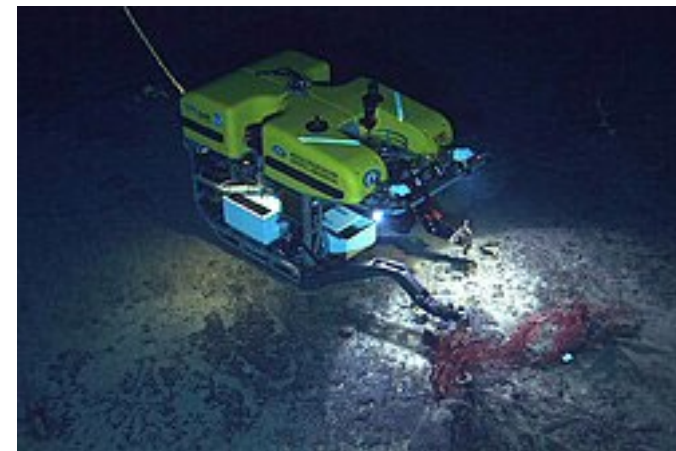
DTN architecture for UWSN

- Sensors collect data. Sensors are energy and memory limited.
- Mobile nodes collect data from sensors and transport data to a sink.
- Mobile nodes are supposed to have large memory and better access to energy compared with sensors.



Solutions for mobile DTN nodes

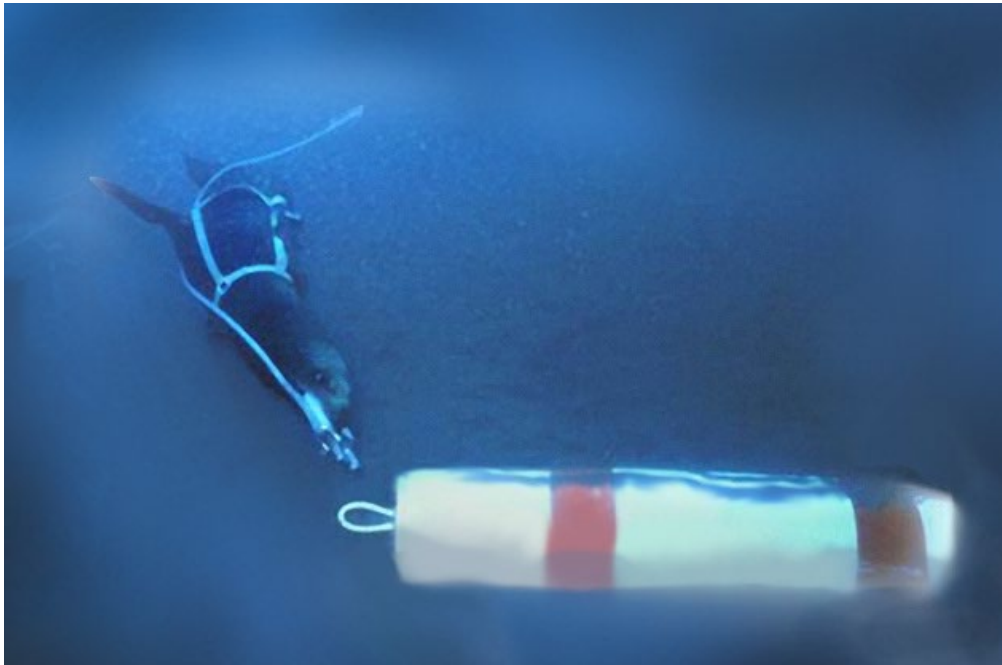
- **Autonomous Underwater Vehicle (AUV)**
 - An AUV is an underwater robot that travels underwater without requiring continuous input from an operator.
- **Remotely Operated Vehicle (ROV)**
 - A ROV is a free-swimming submersible craft. ROVs typically rely on a wired connection to transmit power, video, and data signals, ensuring reliable operation even at great depths.



Other potential solution for mobile nodes:

US Navy - Trained mammals ☺

Trained underwater mammals, as dolphins and sea lions, have been used by the US Navy since 1959.

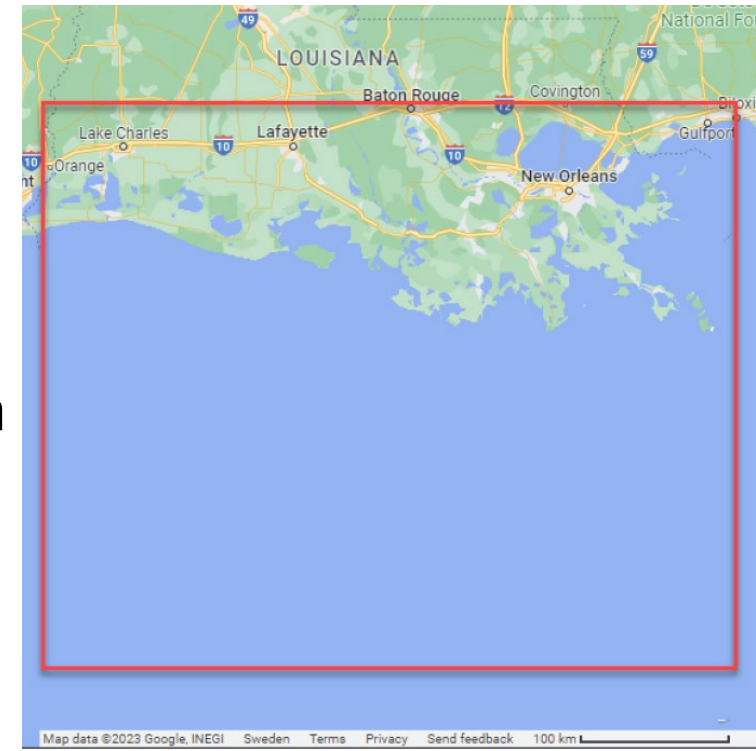


Today's scenario: Gulf of Mexico (America)

The Gulf of Mexico (GOM). requires an efficient, reliable, automated and cost effective method of monitoring for marine oil spills, especially given that most of the oil platforms in the GOM are unmanned and not connected to the electricity grid.

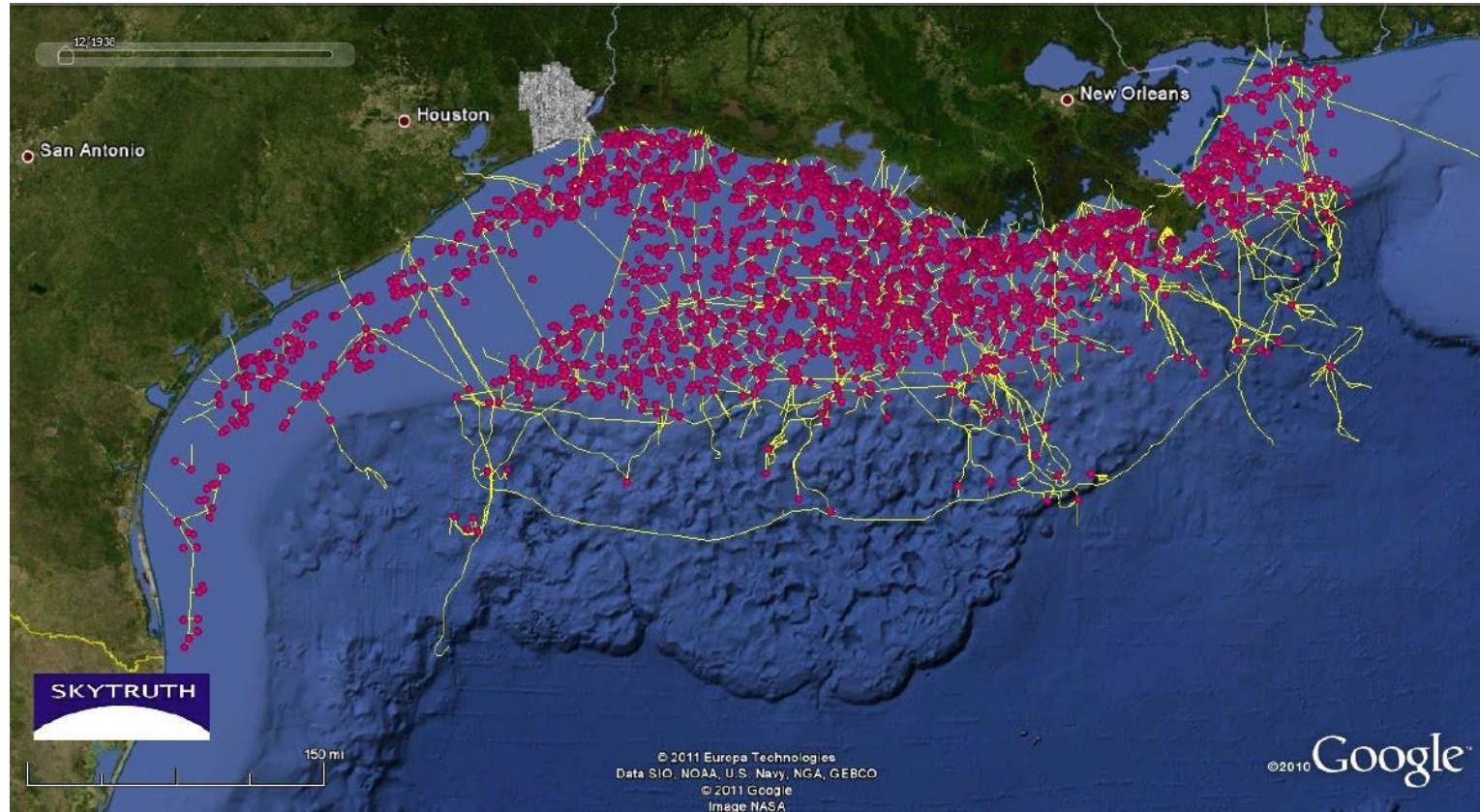
Your task is to develop a network architecture for oil spill trajectory monitoring of the waters outside New Orleans. You have access to the following equipment: (1) Oil detection sensors that can be installed on oil platforms and wherever needed in the ocean; (2) Small autonomous underwater vehicles (AUV) with a range of about 50km; (3) Small boats; (4) Trained dolphins.

The goal of the system is to continuously monitor the waters outside New Orleans and detect any major oil spills coming from leaking oil platforms or ships. The objective of the system is to detect oil spills faster than today's solutions based on detecting oil spills when the oil reaches the coast or a passing ship. After detection, ships will be directed towards the area with oil spills.



Scenario: Detection of oil spills

- 2000-4000 active oil platforms outside US coast (depending on where you have found the information).
- + thousands of kilometers of pipeline within the Gulf of Mexico.
- In the Gulf of Mexico the maximum depth until which the oil platforms penetrate under sea to extract oils is approximately 7800 feet.



General advice for underwater scenarios

- Ordinary network technologies for use on land, such as 4G/5G, LoRa etc, do not work underwater.
- For underwater communication, you do not need to specify a specific network standard, since they do not exist.
 - You need to include a communication technology (radio, optical or acoustic).
 - You need to include a data forwarding strategy (routing protocol).
- Focus on the end-to-end system architecture and how to transfer and disseminate data. Examples:
 - What type of nodes and where?
 - Communication technology (Radio, Acoustic, Optical or a combination)?
 - Data dissemination methods (single-hop, multi-hop, routing algorithm)?
 - Conversational protocols or DTN solution?
 - For DTN solutions: Describe the DTN architecture.

Some solution recommendations

- This is a complex non-critical IoT scenario with underwater environmental monitoring. It is specified which type of equipment you have access to.
- This is not a remote area, and the oil platforms have power supply.
- In your solution, you need sensors, gateways, and a data dissemination strategy.
 - The sensors and gateways must have a power supply, and the gateways need a backhaul link.
- Argos cannot be used as backhaul, since it has a very limited data rate.
- You should give a suitable complete and coherent system architecture that captures the important things of the scenario.
- The data dissemination strategy can use DTN.
 - In this case, you need to include mobile DTN nodes (with power supply) and explain the DTN architecture.
- You have access to some trained dolphins. Dolphins are mammals and do not live all the time underwater.



LUND
UNIVERSITY