# BGC Specification and design of a new Laser driven short range local communication system

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## Contents

# Specification and Preliminary Design of a new underwater optical link for wireless sensors network

## 1. Introduction and Purpose of this Document

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The development of remote operated vehicles (ROV) has provided access to deep-sea environments to a wide international scientific community. The study of these environments remains still very challenging and costly, however. It requires dedicated tools to measure, observe, and sample at depth, in a limited amount of time during a series of dives, or autonomously over longer durations in the context of seafloor observatories.
In order to maximize both the accessibility and efficiency of these tools, the development of modular interchangeable scientific tools adapted to different underwater systems for in situ biogeochemical studies has been proposed in the J2RA EUROFLEET FP7 project.

The design of an intelligent sensors network requires a very efficiency communication link.

Instead of using cables or acoustic modem, we plan to develop an underwater optical wireless link.

## 2. Underwater Optical Network

Wireless sensor networks (WSN) are the fruit of the new advances of wireless communication and the large success of wireless networks in recent years.
They consist of spatially distributed autonomous nodes to which a number of sensors are connected. These nodes are networked through wireless links and deployed in large numbers inside a studied phenomenon or close to it. They can be seen as small and basic computers formed by a central processing unit, a battery, a memory, and a communication device.

The present technology of acoustic underwater communication is a legacy technology that provides low-data-rate transmissions for medium-range communication. Data rates of acoustic communications are restricted to around tens of thousands of kilobits per second for ranges of a kilometer, due to severe, frequency-dependent attenuation and surface induced pulse spread. In addition, the speed of acoustic waves in the ocean is approximately 1500m/s, so that long-range communication involves high latency, which poses a problem for real-time response, synchronization, and multiple-access protocols. As a result, the network technology must be simple and goodput is low. In addition, acoustic waves could distress marine mammals such as dolphins and whales. So acoustic technology cannot satisfy emerging applications that require around the clock, high-data-rate communications networks in real time as network for monitoring biological, biogeochemical, evolutionary and ecological processes in ocean.
An alternative means of underwater communication is based on optics, wherein high data rates are possible. However, the distance between the transmitter and the receiver must be short, due to the extremely challenging underwater environment, which is characterized by high multi-scattering and absorption.
Although high data rates are threatened by extremely high absorption and scattering, there is evidence that broadband links can be achieved over moderate ranges up to a hundred meters.

## 3. Requirements for the optical link

The main objective of this system is to establish a bidirectional optical data link between an ROV and an scientific observatory node or between two nodes.
This optical link is line-of-sight and has to be transmitted through dome.
The line-of-sight is a basic condition to perform optical links; In case of hilly terrains, optical links cannot be easily used.

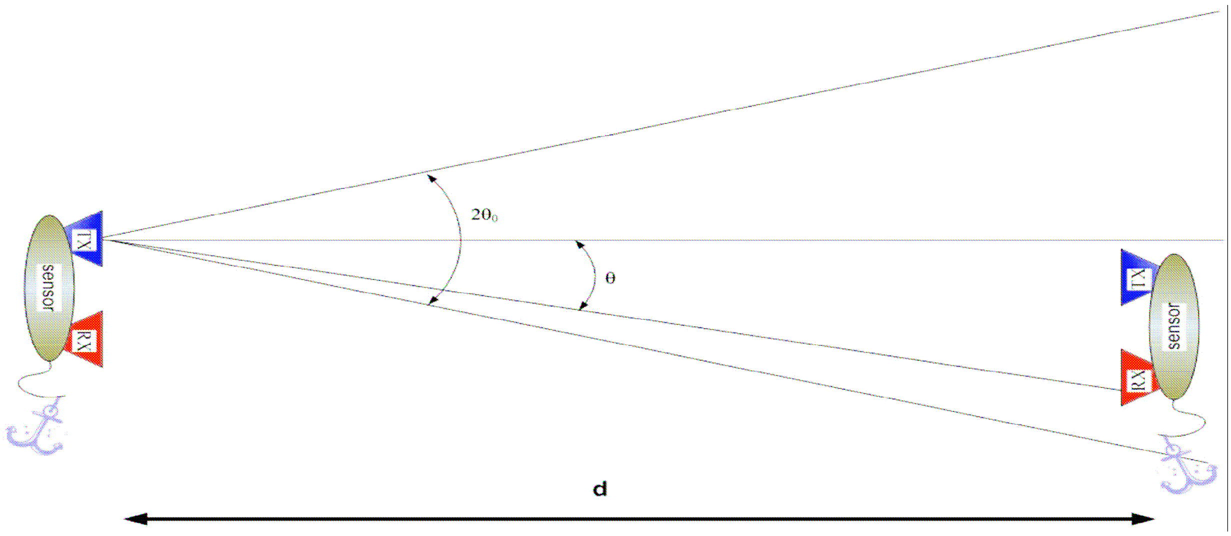


fig 1

### 3.1 Requirements

Reliable data transfer

- Data transmission must face high error-rates, and propagation time that is larger than the transmission time; this will lead to the "bandwidth-delay" problem. An efficient coding scheme is the one that could achieve high reliability and at the same time reduce data transfer time by suppressing retransmission.
- Data rate
  This link has to get the maximum data rate of 10Mb/s.
- Depth
  The system operates at 6000m depth.
- Tracking (fig 1)
  The transmitter beam divergence angle $\theta_0 < 10°$
- Distance
  The distance between the 2 sensors d 5 to 10m.
- Compact low power
  This optical link with the transmitter and the receiver has to be very compact and very low power

### 3.2 Deployment

Usually, an ROV places the nodes in their place on the seafloor. In this case, the disposition can be done using a lift to load the nodes to the sea bottom. Then, the ROV can place them in their predefined position using its controlled arm.

The nodes can be placed at 6000m below the sea level but they must be approximately at the same depth and in line-of-sight of each others. The sensor network can cover an area of 50 to 100 $m^2$.

### 3.3 Topology

Several topologies can be applied to an underwater wireless network with a different degree of success. Linear architecture networks are suitable for heavy loads and for addition and suppression of additional nodes, but a node failure or a cable break might shut down the entire network. And a ring topology is easily affected by the addition, suppression and malfunctioning of nodes. Furthermore, a tree topology is difficult to configure in the water and it requires a complex connection link system.

-A topology that might be suitable for an Underwater Optical Sensor Network might be the star topology. This network architecture consists of a central hub which acts as a clusterhead and a set of nodes communicating strictly with it.

The star topology seems to be the most appropriate to the underwater conditions and the sensor network characteristics.

First of all, this architecture is adaptable to the node failure, and it enables adding and removing nodes relatively easily. In addition, the energy consumption needed to send the preprocessed data to the clusterhead is minimal compared to a linear or a ring topology. In fact, this centralized architecture minimizes the number of connections and eliminates the multi-hoping though reducing the energy consumption for data transmission to the main node.

Once placed, the nodes organize themselves automatically using a star topology around a clusterhead to which all the data should be sent ( Fig2).

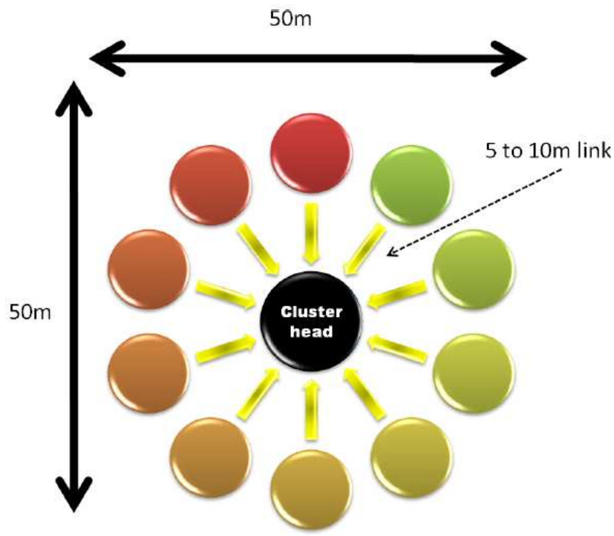


Fig2 10 nodes around a clusterhead forming a typical star topology UWSN

# 4. Properties of the optical Underwater Channel

Water is modestly transparent to visible light and an optical signal can be attenuated and scattered depending on the wavelength and the water types. But, this is enough to enable high data-rate communication over acceptable transmission ranges (Up to 100m).

## 4.1 Light propagation in water

Light propagation in water is affected by two processes :
-**Absorption**: It is an irreversible loss of power as light travels in the medium. It depends on the index of refraction of this medium. The absorption is due to the interaction of light with water molecules and particles.
-**Scattering**: It refers to the deflection from a straight-line propagation path. In an underwater environment, deflections can be due to particles of size comparable to the wavelengths of traveling light (diffraction) or to particulate matter with refraction index different from that of the water (refraction). "a(λ)" is the absorption factor and "b(λ)" is the scattering factor. One can notice that both absorption and scattering are wavelength dependent.

The absorption and the scattering cause the attenuation of the propagating signal. The attenuation coefficient "c(λ)" has the following equation

$$c(\lambda) = a(\lambda) + b(\lambda)$$

## 4.2 Water types

The sea water characteristics affect deeply the propagation of optical waves in it. In fact, in addition to the wavelength, both the absorption and the scattering are affected by the sea water characteristics and the particles in solution or in suspension in this water .
-**Pure water**: Absorption in pure water is wavelength dependent. It is large for large wavelengths ($\lambda > 600$ nm). This limits the possible use of optical waves to lower wavelength ranges.
-**Sea water**: The sea water, with its salinity and temperature fluctuations, affects mostly the absorption.
-**Planktonic matters**: The planktonic components in the water especially at the surface affect both the scattering and the absorption of the light. The absorption is more pronounced for lower wavelength ($\lambda < 450$).
-**Detrital and mineral components**: The detrital and mineral components in sea water affect the absorption and the scattering of optical wavelength.
-**Colored dissolved organic matters (CDOM)**: The dissolved organic matters affect deeply the absorption especially at the water surface and in the estuaries. Two components constitute the CDOM: fluvic and humic acids. The concentration of these dissolved matters varies considerable from one location to another.
In conclusion, when operating in a turbid water medium, scattering is the main limiting factor. In fact, photons are scattered out of the main path due to the suspended and dissolved particles. This leads to the same problems as the multipath reflections in acoustic signals.
However, scattering relaxes the pointing requirements since the optical signal approaches that of an isotropic source. So it is better to receive the scattered light and perform the required signal processing on it to improve the performance of the optical link in turbid waters.
On the other hand, in clear sea water (As it is the case in the deep-sea), the absorption is the main limiting factor with increasing distance. In this case, the laser source should have an optimized wavelength (the blue-green range). Furthermore, the transmitter and the receiver should be well aligned because the beam propagates approximately in a straight line in clean water. This will impose extra pointing requirements on the system.

# 5. Preliminary design of this optical Link

We plan to develop an optical modem system.
This system is composed of two modules the transmitter and the receiver which is interfaced with an embedded controller, the heart of the node sensors.
Herein we present the architecture of the system.

## 5.1 Nodes Sensors

### 5.1.1 Central processing unit

The CPU is the main unit in each node. After retrieving the data from the sensors, this unit shall treat them before either storing them in the local memory or sending them to the main clusterhead. Usually, the clusterhead CPU should be more elaborated. In fact, It should assemble all the pre-processed information from all it cluster nodes, remove the redundant data, process the information and store it in its memory. In addition, the clusterhead interacts with the ROV to upload the gathered data and download the main commands.

### 5.1.2 Peripheries

Several peripheries are implemented around the main processing unit.
**-Ports**: Sensors are connected through wired links to the node's ports. Depending on the application and the type of instruments used, the node shall have several external ports:
(USB, firewire, Serial port, parallel port). An Analog/digital converter is used to convert the analog data retrieved from the sensors into bits streams that are processed by the CPU.
**-Memory**: The memory is an essential part in UWSN and especially in the clusterhead node. This is where all the collected data are stored. The memory size depends mainly on the application type, the sensors used, the duration of the mission and the data hovering frequency during this mission.
**-Synchronization clock**: It ensures the synchronization between all the network nodes. This is a basic feature for enabling a good data transmission and reception.
**-Battery**: nodes are strictly power supplied by their own batteries. These batteries cannot be replaced easily especially in deep-sea applications. The battery size depends on the modulation technique, the mission duration, the sensor types, etc. On the other hand, a sensor node is light it is can be easily transported from its original position by underwater currents and mud movements. For this reason, the battery can be used as an additional weight to face the currents and turbulence and though fix the node in its position. This additional weight provides an extra energy resource and autonomy for the node and enables longer observations and further data processing.

## 5.2 Modulation

An underwater wireless optical communication system must adopt a simple and effective modulation technique. This is why a non-coherent modulation technique is better to be adopted. In fact, FSK (Frequency shift keying) and PSK (phase shift keying) techniques are difficult and complex to implement.

### 5.2.1 On-Off Keying

On-Off Keying (OOK) is the simplest form of Amplitude Shift Keying (ASK) modulation [38].
This non-coherent modulation represents digital data as the presence or absence of a carrier wave. In its simplest form, the presence of a carrier for a specific duration represents "1", while its absence for the same duration represents "0". Some more sophisticated schemes vary these durations to convey additional information.

For this study, the OOK will be considered as the standard modulation method to which all other techniques will be compared.
An underwater optical wireless system uses the OOK modulation because it is power efficient and easy to use

### 5.2.2 Pulse Position Modulation

Pulse-Position Modulation (PPM) has L message bits that are encoded by transmitting a single pulse in one of 2L possible time-shifts. This is repeated every T seconds. The bit-rate is L/T bits/s.
The PPM is useful for optical communications where there are little or no multipath interferences.
The design of a PPM demodulator is simple and suitable for underwater applications. For a fixed transmission distance, PPM modulation consumes less energy compared to OOK.

### 5.2.3 Modulation summary

The following table is a comparison of the performance of different modulations schemes for water communications.

| modulation | Complexity | multi-path delay sensitivity | Power | Bandwidth |
|---|---|---|---|---|
| OOK | simplest | general | $P_{OOK}$ | $2R_B$ |
| FSK | most complex | least sensitive | $0.5P_{OOK}$ | $2R_B + \|f_1 - f_0\|$ for 2FSK |
| DPSK | complex | more sensitive | $\frac{1}{8\sqrt{\ln 2}}P_{OOK}$ | $2R_B$ for 2DPSK |
| PPM | simple | general | $\frac{2P_{OOK}}{L}$ | $\frac{L}{\log_2 L}R_B$ |

In general, OOK is a great and efficient modulation technique to be used in underwater communication systems. But for advanced designs, PPM may lead to better results.

## 5.3 Transmission/reception system

For each node, a low-energy optical transmission system should be used to connect the different network nodes to the clusterhead.

Once coded and modulated, the signal should be amplified and then transmitted in the water channel using a powerful high data-rate source.
A blue-green range wavelength (532 nm per example) shall be used for packets transmission. In fact, the e-folding scale of this band is 20-50m in clear water.
On the other side, a photodiode, or better an avalanche photodiode, with a relatively wide angle should be adopted to retrieve the transmitted signal that was attenuated and scattered during its propagation in the water.
After being received, the signal is amplified then despreaded, demodulated, demultiplexed, channel decoded, decrypted and source decoded to retrieve a digitized signal that theoretically should correspond to the emitted signal on the transmitter side.
There are different choices for the receiver and the transmitter.
At this stage the choice is always opened.

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