MEDITERRANEAN EUROCENTRE FOR UNDERWATER SCIENCES AND TECHNOLOGIES

Technical Design Report of the MEUST infrastructure

October 2013*

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The authors wish to thank E. Heine, S.Mos, J-W. Schmelling, G. Kieft and R. Coniglione for their contributions to several aspects of the design of the MEUST infrastructure.

Abstract

MEUST (Mediterranean Eurocentre for Underwater Sciences and Technologies) is a second generation permanent submarine observatory to be deployed offshore of Toulon, France, as a follow up of the pioneering ANTARES neutrino telescope. The MEUST submarine network has a modular topology designed to connect up to 120 neutrino detection units, i.e. ten times more than ANTARES. This may allow to instrument one km^3 of water for neutrino astronomy or, with a denser instrumentation, several Megatons for measurement of neutrino properties, and to deploy sensors for environmental sciences on an array of ten km^2. The topology and functionalities of the network comply with the specifications of the KM3NeT neutrino telescope, which plans to use MEUST as one of its 3 deployment sites, as well as with those of the environmental sensors developed for the Ligurian site of the EMSO submarine observatory network. The technical solutions developed for the MEUST infrastructure are adapted to any large deep sea detector array located within 50km from the coast. After a brief reminder of the MEUST scientific motivation and submarine sensors, this document details the technical design of the infrastructure and summarizes the organization of the project.

* This document is available on the IN2P3 EDMS server under reference EDMS I-035489, as well as on the KM3NeT web site.

Content

1. INTRODUCTION

MEUST (Mediterranean Eurocentre for Underwater Sciences and Technologies) is a permanent deep-sea submarine observatory to be deployed in the Mediterranean Sea 40km offshore of Toulon, France, at a depth of 2500 m. The submarine network has a modular multi-nodal structure with two main cables connected to the shore. It is dimensioned to host a neutrino telescope of up to 120 neutrino Detection Units and will provide Earth and Sea Science user ports for instrumentation of an array of several km^2. The topology and functionalities of the infrastructure comply with the specifications of the KM3NeT neutrino detection units and would allow deployment a full KM3NeT “Building Block” for neutrino astronomy. In a denser configuration they would allow instrumentation of several Megatons of deep sea water, offering new opportunities for a large scale neutrino detector and study of neutrino properties. The infrastructure is also compatible with the deep sea instruments developed for the Ligurian site of the European Multidisciplinary Submarine Observatory network (EMSO).

In the current prototype phase of MEUST, one MEOC terminated by one node will be installed offshore with the associated power system onshore. The infrastructure is expandable so that up to five additional nodes could be built and deployed at reasonable cost. The components of the infrastructure are designed for a life time of 15 years.

2. SCIENCE

The scientific motivation of the MEUST infrastructure is presented in details in the document submitted to the IN2P3 Scientific Council [1]. MEUST primarily aims at further developing neutrino astronomy, an emerging domain pioneered by the IceCube and ANTARES experiments, and further pursued by the KM3NeT Collaboration. In a denser configuration it would allow hosting a multi-Megatons neutrino detector for study of neutrino properties. The deployment of a permanent deep-sea infrastructure also offers unique opportunities to environmental sciences for monitoring of deep-sea processes. This results in a natural synergy with the network of submarine observatories being set-up along European coasts by the EMSO consortium.

2.1. NEUTRINO PHYSICS

MEUST provides technical solutions to deploy a neutrino telescope 10 times larger than ANTARES and is foreseen to host one of the three Mediterranean sites of the KM3NeT telescope [4]. The KM3NeT location in the Northern hemisphere makes its field of view complementary to that of IceCube which, combined with a 6 times higher sensitivity (for the full configuration), gives a high chance to discover neutrino sources within our galaxy. KM3NeT will also look for extra-galactic sources and further study the indication of high energy diffuse cosmic neutrinos recently reported by IceCube.

The MEUST submarine network is scalable such that a deep sea volume of several Megatons could be instrumented as a large low energy neutrino detector, by implementing a denser distribution of the detector lines and optical modules than for neutrino astronomy. In such a configuration, measurement of atmospheric neutrinos traversing the Earth (ORCA project [2]), or from a beam pointing to the telescope [3], would allow to investigate the properties of neutrinos and e.g. shed light on their mass hierarchy.

The design of the MEUST infrastructure allows both options (neutrino astronomy or ORCA) to be implemented using the same submarine network components.

2.2. EARTH AND SEA SCIENCES

Deep sea is still one of the least known domains on Earth despite the major role played by oceans in the evolution of climate and biodiversity via the interactions between physical and biological processes. Up to very recently submarine scientific observations were made only during short cruises or with autonomous sensors with limited data taking capacity. Cabled deep sea infrastructures give the promise to revolution the understanding of the abysses thanks to permanent deployment of high power / high data rate sensors on the deep seabed. This will allow a better monitoring of deep water flows and bio-geochemical processes associated to climate evolution. It will also allow to survey biodiversity with e.g. measurement of bioluminescent organisms or sound monitoring of marine mammals. Such sensors can also be part of alert networks for tsunamis and earthquakes.

In this domain MEUST will provide an enhanced platform compared to ANTARES, with several user ports allowing to instrument several km^2 of seabed. MEUST is planned to be part of the Ligurian site of the future European network of submarine observatories EMSO.

3. SCIENTIFIC INSTRUMENTATION

The functionalities of the MEUST infrastructure have been designed to comply with the specifications of the neutrino Detection Units (DU) developed by the KM3NeT consortium, and of the sea science instruments developed for the Ligurian site of the EMSO consortium.

3.1. NEUTRINO DETECTORS

The components of the neutrinos Detection Units designed by the KM3NeT consortium are described in the KM3NeT Technical Design Report [4]. Among the various options still open in this TDR, KM3NeT has selected the Digital Optical Module (DOM) concept and the mechanical string concept for its final DU design. The baseline design of a DU involves 18 DOMs vertically distributed, forming a ~800m (resp. ~250m) high detector line for the neutrino astronomy (resp. ORCA) option. Using small 3-inch photomultipliers in the DOM improves the directional resolution and efficiency of light collection such that the sensitivity of a KM3NeT DU is expected to be similar to that of an ANTARES DU despite a single DOM per storey instead of 3. The DUs will be laid down packed on the sea floor and will unfurl by themselves to their operational state.

3.1.1. Digital Optical Module

Figure 1: Picture of a prototype DOM

The DOM consists in a 17 inch diameter pressure resistant glass sphere equipped with 31 Photo Multiplier Tubes (PMTs) of 3 inches (figure 1). The PMTs are suspended in a plastic support structure: 19 in the lower hemisphere and 12 in the upper hemisphere. Optical contact between the PMTs and the glass sphere is provided by an optical gel. Each PMT is equipped with a low power base which provides an adjustable high voltage supply, amplifies the PMT signals and compares them to an adjustable threshold to provide TOT ("Time Over Threshold") digital signals. The TOT signals are sent to the DOM-logic electronic board, the Central Logic board (CLB), which converts them into time stamped hits. Data transfers to and from the DOM are performed with an optical fibre. Each DOM in a DU has a dedicated wavelength, provided by a laser implemented in the CLB, to be later multiplexed with other DOM wavelengths for transfer to the shore. The common clock which is needed for time stamping is embedded in the Gb Ethernet signals sent from shore and locally extracted in each DOM. Each DOM acts as an Ethernet node with direct communication with the shore station independent of other DOMs.

In addition to the PMT's, the DOM contains the following instrumentation: compass, tilt and piezo acoustic sensors in order to monitor the position and orientation of the DOMs with 10 cm accuracy; a nanobeacon LED which allows inter-calibrating the time references of the DOMs inside a DU with a precision of 1 ns; humidity and temperature probes.

A “mushroom” metallic structure glued on the sphere supports the electronic boards and ensures their cooling. The total power consumption of a DOM is specified to be 8 Watts with a maximum allowed value of 10 Watts.

3.1.2. Detection Unit Structure

A DU of the neutrino telescope consists in 18 storeys of one DOM with a buoy at the top and an anchor at the bottom (figure 2). The vertical distance between DOMs is 36m (resp. ~6m) for the neutrino astronomy (resp. ORCA) option. The structure of the line comprises two parallel Dyneema ropes (4 mm diameter) of the full height of the line on which the DOMs are attached. Some spacers are added in between the DOMs to maintain the ropes parallel.

The data and electric power transmission within the DU is achieved with one Vertical Electro-Optical Cable (VEOC) interconnecting the 18 DOMs and a base container located at the DU foot. The VEOCs will be a Pressure Balanced Oil Filled cable such that the 18 fibres and the 2 copper wires will operate under the ambient hydrostatic pressure. The multiplexing of the signals from the 18 DOM fibres into one fibre is done in the base container.

The anchor of the DU is the interface with the MEUST infrastructure. It houses the DU interlink cable equipped with a wet-mateable connector for connection of the DU on the seabed, as well as the DU base container with an AC/DC converter and optical components.

Figure 2: Schematic view of the lower half of a DU

3.1.3. Calibration Units

In addition to DUs some instrumented systems are necessary to monitor the sea environment and to host the DU calibration and positioning devices. This system is still under design by KM3NeT. It is foreseen to include Calibration Bases (CB) which will hold elements of the DOM acoustic relative positioning system and an optical laser beacon for time calibration of the whole detector. The CBs will host a CLB board to ensure the data communication and synchronization with the shore station. Some CBs could potentially be linked to an Instrumentation Unit (IU), a line hosting the instruments and sensors needed to monitor the sea environment parameters relevant for calibration. The use of an inductive line (as in the ALBATROSS ESS line, section 3.2.2) is under study for the IU. The principle is based on using the mooring cable itself as transmission medium, eliminating the need for additional cables along the line but requiring sensors to be powered with internal batteries.

3.2. EARTH AND SEA SCIENCE DETECTORS

The Earth and Sea Science (ESS) instrumentation to be connected to MEUST is based on two complementary components: an Instrumented Interface Module (MII) and an ALBATROSS mooring line.

3.2.1. Instrumented Interface Module

The MII consists in a frame laid down on the seabed and connected to a MEUST node (figure 3).

The MII can be instrumented with power consuming sensors and high data rate devices like video cameras. It integrates AC/DC converters and electro-optical components for interface to the MEUST network. All sensors embedded on the MII will be read in real time from the shore station through an Ethernet link. The MII will also host an acoustic modem designed to establish communication with the distant autonomous mooring line.

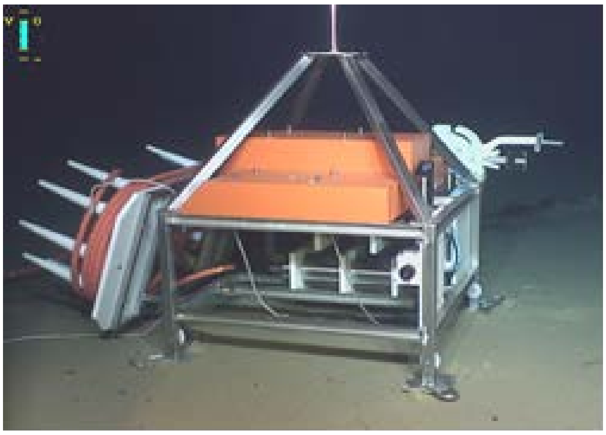

Figure 3: the MII connected to the ANTARES secondary Junction Box

3.2.2. Autonomous Mooring Line

The ALBATROSS mooring line (figure 4) is composed of a dead weight, an acoustic release system, two wire ropes (8.4 mm diameter and 1000 m length) and two instrumented buoys, one in the middle of the mooring line and the other at its top. This line will be deployed at a distance of 2 to 3 kilometers from the MII.

The mooring line will instrument the water column from the seabed to 500m below the surface with autonomous sensors distributed along its full height. These sensors are conventional oceanographic devices designed to monitor pressure, temperature, salinity, dissolved oxygen, sea current velocity and direction. The absence of a cabled connection will limit the line autonomy to one year. Nevertheless, this will allow a regular low cost recovery of the line in order to (re)-calibrate the deployed sensors and change the batteries. Within the mooring line, the sensors data are transferred through an inductive backbone (on wire ropes) to an embedded low power computer connected to an acoustic modem. Data retrieval will be done daily through this acoustic link to the MII and the MEUST cabled infrastructure. In addition to remote data readout, the system provides the required interactivity to adapt the sensors configuration and sampling frequency as function of the evolution of environmental factors like sea currents.

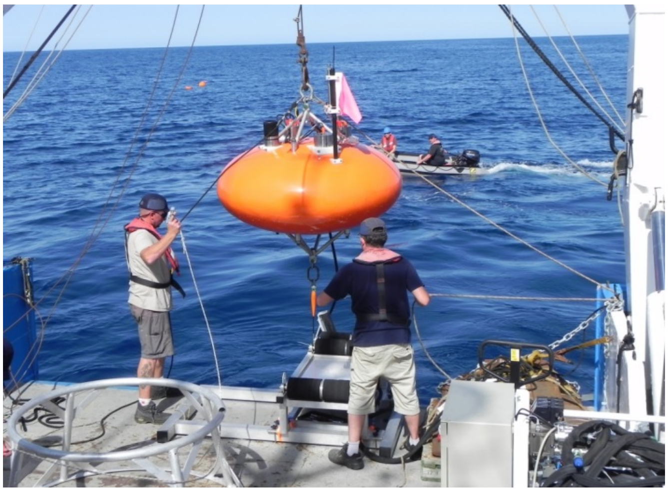

Figure 4: Deployment of a prototype of the MEUST ALBATROSS line

4. SUBMARINE SITE

The deployment of MEUST on the same site as ANTARES would not be convenient because of the space limitations related to existing submarine telecommunication cables (especially the CC5 cable from Toulon to Corsica) and the military restricted zone of the Levant Island. A new deep-sea submarine site had therefore to be identified offshore of Toulon. The choice of the site was a compromise between proximity to the coast (which minimizes power losses and deployment costs) and quality and stability of the deep-sea conditions (water transparency, currents, bioluminescence…). Two potential sites were evaluated: one located closer to the coast than ANTARES (so-called NEAR), and one further away (so-called FAR). In addition some measurements were performed at the same time on two other sites close to ANTARES (so-called NE and OPERA). The results of the investigations for the site selection are summarised in a technical note [5].

The site evaluation campaigns were performed with purpose-made autonomous lines equipped with:

- An Optical Module with 2 Hamamatsu 3’’ PMTs, an electronic board to read out the PMT signal (PMT rates over a preselected threshold), a data logger to store the data and a set of batteries.
- A current meter to monitor the sea current (amplitude and direction).
- A CTD to measure the sea water conductivity, temperature and depth, for monitoring of the flow of the different sea water layers.

Data analysis has shown that the OM rates are correctly measured up to 2.10^5 Hz but overestimated above, due to a shift of the PMT baseline at high drawn current. The measurements performed during more than one year did not show large differences between the various sites. The FAR site showed indications of a higher seasonal activity which led to discard it at an early stage. Since the differences between the coastal sites were not significant, the choice of the submarine site was mainly driven by logistics and operational considerations. The MEUST site was selected in the intermediate region between the NEAR and OPERA sites at the location 42°7.5’ N and 6°2.3 E (figure 7). Its location on the western side of the CC5 cable but at similar latitude as ANTARES leaves the possibility to redirect the ANTARES MEOC to MEUST after ANTARES decommissioning.

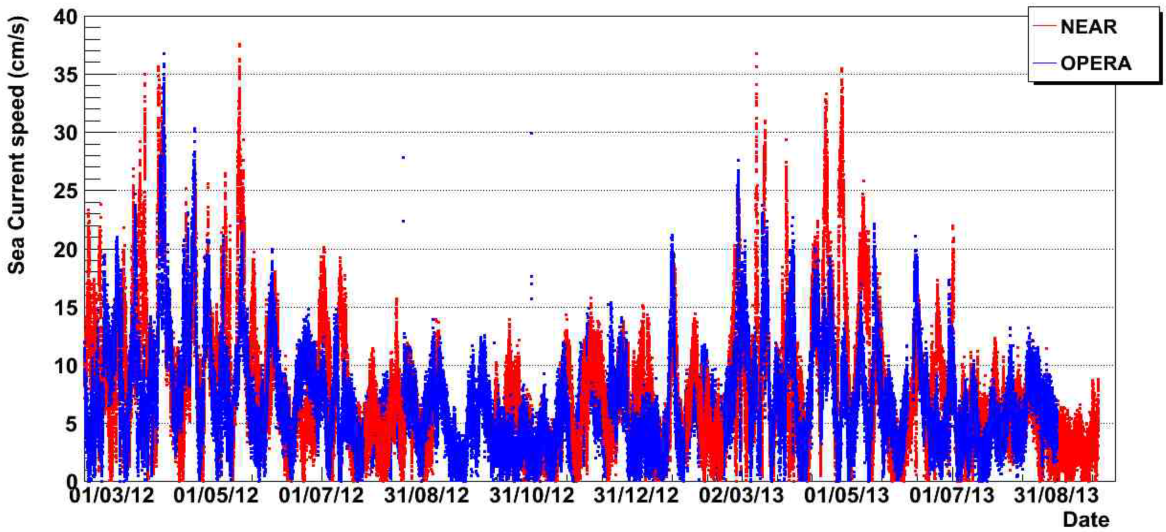

Figure 5: Sea currents recorded in 2012-2013 on the 2 points surrounding the MEUST site

After selection of the MEUST site, the monitoring of the NEAR and OPERA sites has been further pursued (figures 5 and 6) and will go on until at least end of 2013. For these measurements a new set-up with 2 optical modules vertically distant by 600 m has been built, in order to monitor the whole water column instrumented by a neutrino DU in the astronomy option. Preliminary results show that the difference between the OM counting rates at 800m and 200m is limited to ~15%.

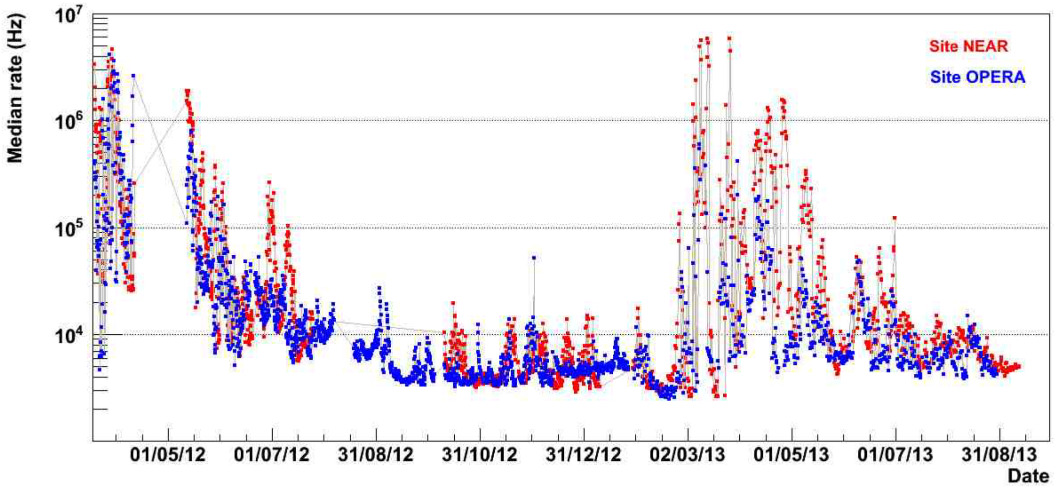

Figure 6: PMTs median counting rates of the 1 PMT per OM in 2012-2013 on the 2 points surrounding the MEUST site. Rates are correctly estimated up to 2.10^5 Hz and overestimated above this value.

A preliminary high precision bathymetry survey performed on a portion of the pre-selected area has revealed a very flat and clean zone. A complete survey, first acoustic and then visual, is planned before the deployment of the MEOC to have a high precision bathymetry of the area and to make sure that no dangerous objects are in the field of the infrastructure.

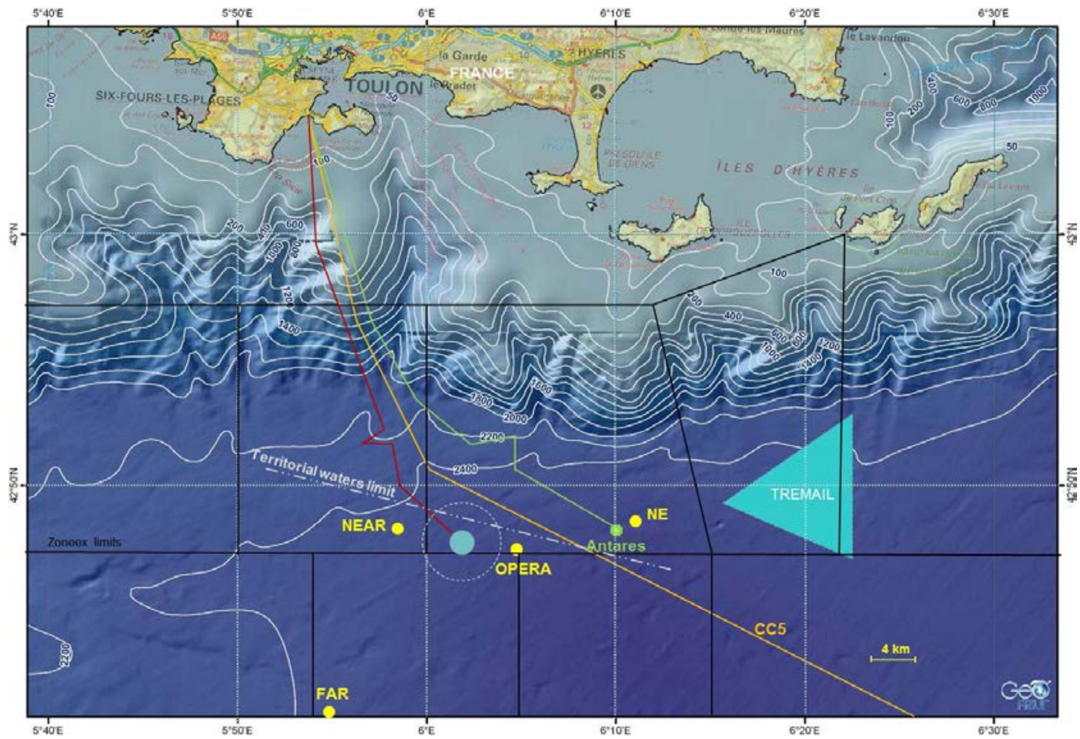

Figure 7: Location of the MEUST site (blue circle) together with the other investigated sites, the route of the MEUST MEOC (red line), the ANTARES MEOC (green line), the CC5 cable (orange line) and the western end of the Tremail military array (blue triangle).

5. SUBMARINE INFRASTRUCTURE TOPOLOGY

The topology of the submarine infrastructure is driven by two main constraints: the minimum area to be uniformly instrumented by neutrino DUs ("Building Block") for an efficient neutrino astronomy, and the technical issues for the construction, deployment and operation of the DU array. The KM3NeT Collaboration has defined a reference detector for neutrino astronomy, consisting in 6 Building Blocks distributed in 3 sites. A Building Block is composed of 115 DUs horizontally spaced by 90 m +/- 10 m.

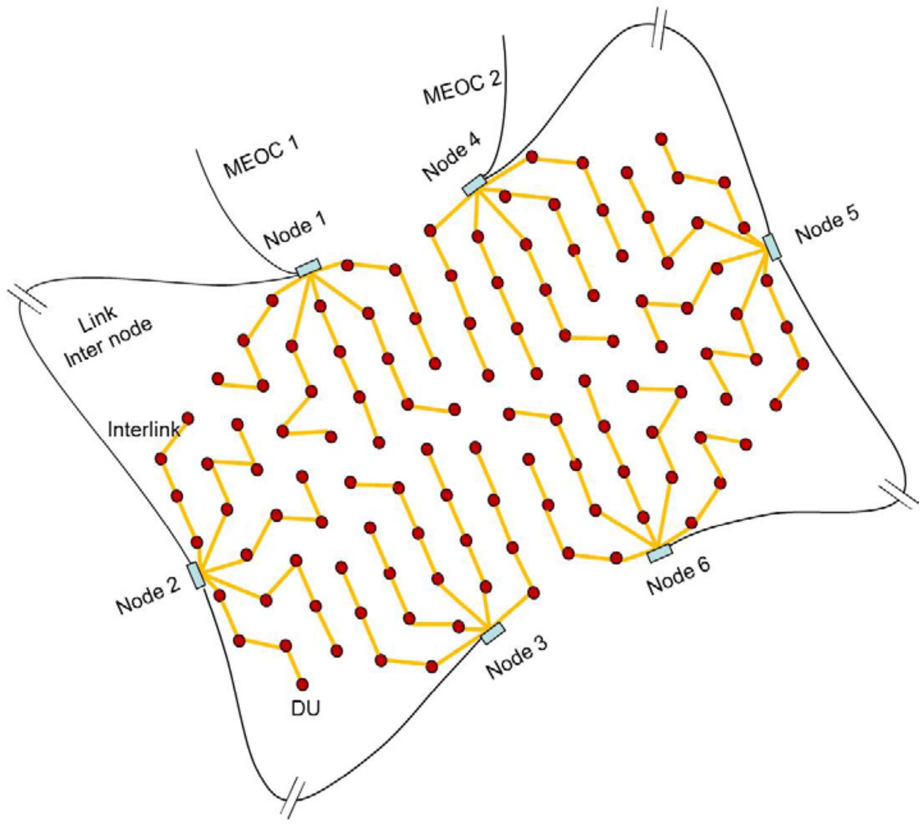

Figure 8: the MEUST submarine infrastructure layout

Taking into account these inputs as well as other parameters, the ''Marigold'' design described in [6] has been adapted while keeping the original concept of a ring. The seabed infrastructure (figure 8) comprises a modular open ring network for a Building Block of 120 DUs, well within the KM3NeT requirement. The open ring is connected to shore with two MEOCs. The complete network comprises 6 nodes distributed at the periphery of an ellipse shape of about 600 m x 1200 m. The infrastructure is scalable to a more compact detector to accommodate the ORCA option. In this case, the same submarine components can be used with DU interlinks lengths reduced to ~20m (together with a reduction of the DU height, see 2.1) and no change in the node configuration.

The submarine network allows connection of three types of devices: the neutrino DUs, the Calibration Units (CU) required for their calibration, and the ESS instruments.

5.1. DETECTION UNITS LAYOUT

A set of 20 DUs can be connected to each node, yielding a total or 120 DUs for the full Building Block. In order to simplify the configuration and sea operations with a ROV, a concept of DUs connected in series is implemented: a set of 4 DUs are linked together in a “4-DU chain”, this number being mainly driven by the fact that the data of 4 DUs (72 wavelengths) can be merged into 1 fibre to reach the shore through the MEOC (section 6.2.1).

The detailed footprint of the detector, shown in figure 9 for the neutrino astronomy option, is defined to avoid as much as possible symmetry and corridors in the DU array, to limit the lengths of the interlink cables to 110 m at maximum (corresponding to 95 m maximum distance between DUs), and to have a minimum distance of 80 m between DUs in any direction. The coordinates of the DUs and nodes in this option are given in Annex 1.

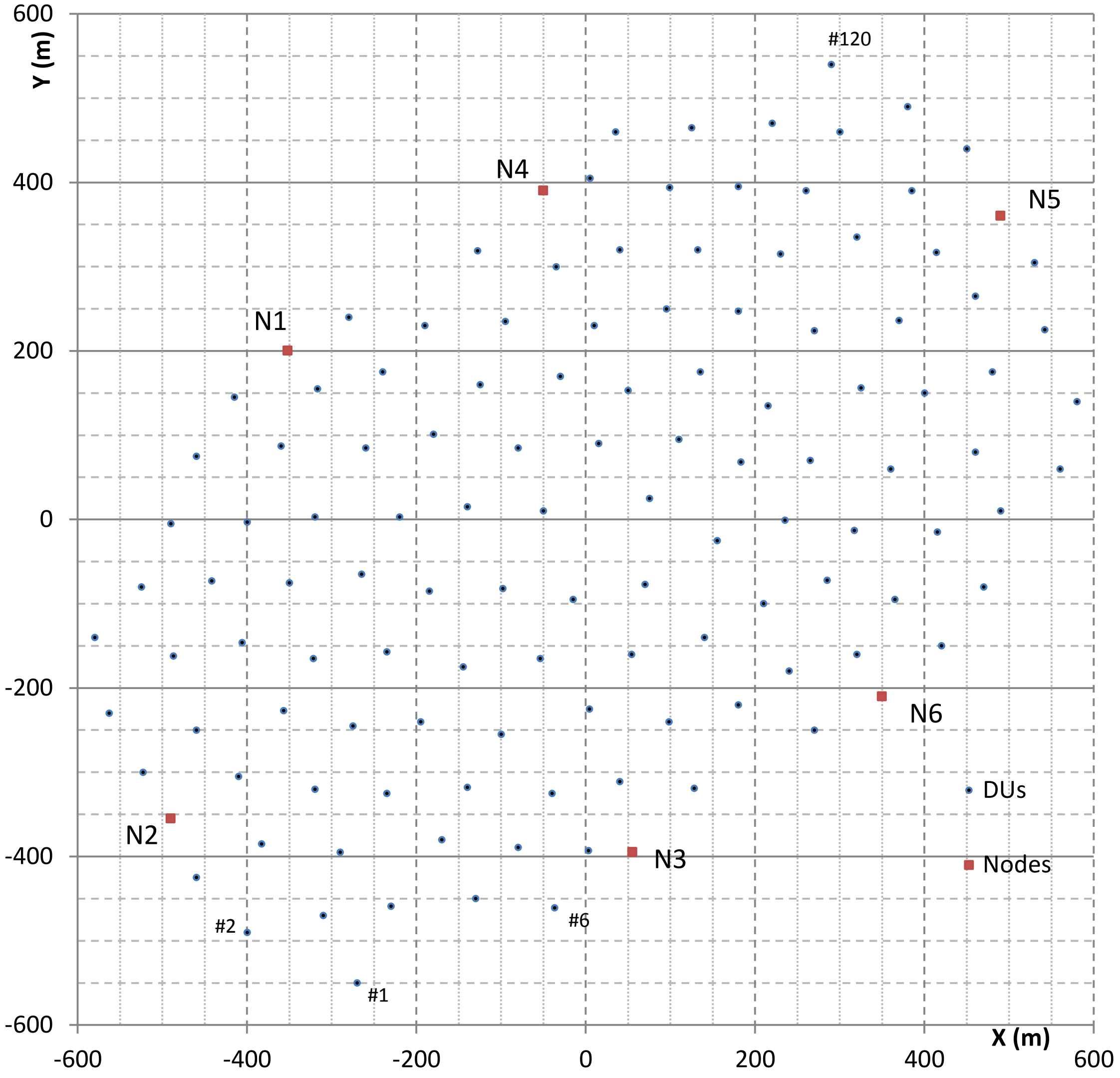

Figure 9: MEUST Building Block footprint in the neutrino astronomy option

5.2. CALIBRATION UNITS LAYOUT

The Calibration Bases (section 3.1.3) will be located in the field of the detector whereas the IUs will stand outside the DU array. One CB could be connected in series to the last DU of a 4-DU chain, or replace one of the DUs. It is not foreseen to have the possibility to recover the CBs because their instruments do not need any recalibration. Each IU will initially be linked to one CB via an Ethernet physical wire link which could later be replaced by an acoustic modem link. It is foreseen to periodically recover the IUs in order to recalibrate their sensors and to change the batteries.

5.3. EARTH & SEA SCIENCES LAYOUT

The ESS instrumentation (section 2.2) will be positioned outside the field of the neutrino DU array to avoid perturbations in the detector. The first instrumentation to be connected to the node is the MII module with the ALBATROSS line. The MII will be installed at about 50-100m from the node and the line up to 2-3 kilometers away.

5.4. CONNECTIVITY

The connection to each node of 20 DUs as five 4-DU chains together with one ESS instrument requires a minimum of 5 DU user ports and 1 ESS user port per node. For redundancy an additional spare DU user port is implemented. To further increase redundancy, the ESS user port is also connected to the DU optical network to shore, allowing connection of a 4-DU chain instead of ESS instruments if needed, and is duplicated. In summary, each MEUST node provides 8 user ports, 6 being devoted to the DUs (5 + 1 spare) and 2 for multi-purpose usage accommodating both ESS instruments and 4-DU chains.

This configuration provides a large redundancy and, in case all user ports are operational, would in principle allow connecting to one node more instruments that initially specified. The connection of additional instruments beyond the specifications may however be limited by the total electrical power available for the users of the node.

6. INFRASTRUCTURE SYSTEMS

The MEUST infrastructure provides three main systems which are largely independent from each other: the electrical power distribution system, the optical network for data transfers and detector control, and the Control Command (CC) for configuration and monitoring of the infrastructure network. Their functionalities are described hereafter.

6.1. POWER SYSTEM

6.1.1. Overview

The specifications of the power system are mainly driven by the consumption of the neutrino DUs. A KM3NeT DU holds 18 DOMs with a design power consumption of 8 W (10 W maximum) and a base container with a power consumption estimated to 40 W. The maximum total consumption of a DU is then 240 W including 20 W losses. The total consumption of a MEUST building block (120 DUs) is therefore ~29 kW at maximum. In addition ESS instruments are allowed a power consumption of ~1 kW per node, and the nodes themselves need ~1 kW each for their internal components. Taking into account offshore power losses (~10%), the maximum power needed offshore by a full MEUST Building Block is ~45 kW. Given the short distance from the shore to the deep sea infrastructure an Alternative Current (AC) distribution is chosen with the return current by sea. The offshore power losses remain acceptable at 10% level. The AC distribution presents the advantage of using standard and reliable components and profits from the successful experience of ANTARES. The total infrastructure power consumption is expected to be 85 kW including onshore components (e.g air conditioning, batteries…) and losses.

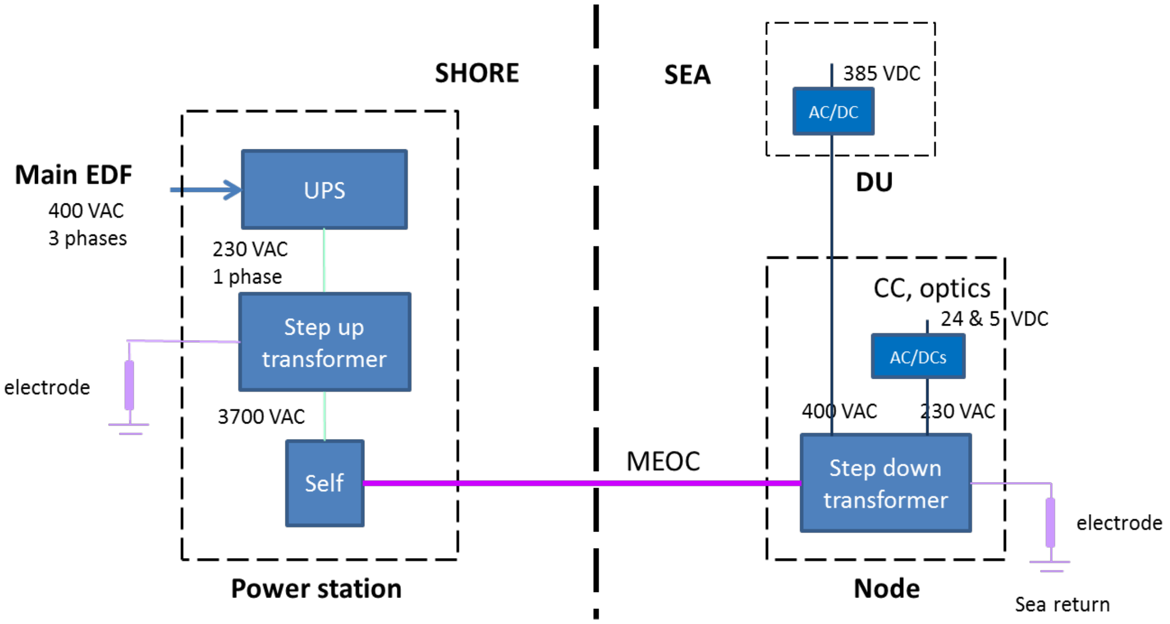

Figure 10: General scheme of the power system for one node

The global scheme of the power system is presented in figure 10. For power transport from shore to the offshore nodes, the 400 V voltage from the main supplier (EDF) is elevated up to 3700 V. In each node, it is again reduced to 400 VAC to feed the user ports. Finally, at the bottom of each neutrino DU, the current is converted to the specified KM3NeT 385 VDC. In order to reduce the reactive power due to the high capacitance of the MEOC, a self is installed at the shore end of the cable. An Uninterruptible Power Supply (UPS) is installed at the head-end of the network to compensate the disequilibrium between phases and to allow at least 10mins of autonomy in case of a main supply power cut.

Static quantitative simulations of the power system have been performed [7] and independently cross checked. A summary of the results is given in Table 1 for one MEOC with 3 nodes fully equipped. The second branch is expected to behave in a similar way as the first one, and may require an adaptation of the characteristics of the transformers depending on the MEOC which will be used. For a second branch the power station will also have to be upgraded. For the current prototype phase of MEUST one node will be installed, corresponding to the power distribution values of Table 2 for a full loaded node.

The grounding scheme is under study. Simulations are in progress to see the influence of the different configurations: no ground, node and/or DU base grounded through resistor/capacitor. Once the design of the full system is frozen and completed, dynamic calculations will be made in addition to the static simulations above.

The main parts of the power system are further described in more details in the following.

Parameter		U nom (V)	Power (k VA)	I nom (A)	Power losses (W)
Power Station	In	400	57.8	83.4	8140
	Out	3598	31.6	8.8	
MEOC		NA			1744
Node 1	In	3440	9.3	2.7	743
	Out total	400	6.8	16.9	
Node 2	In	3417	9.3	2.7	743
	Out total	400	6.8	16.9	
Node 3	In	3405	9.3	2.7	743
	Out total	400	6.8	16.9	
Node out 1user port		400	1.0	2.5	
DU base	In	377 - 393	0.25	0.65 - 0.69	25
	Out	370 - 400	0.22	0.55	

Table 1: Power distribution simulation for one MEOC and 3 nodes fully equipped. For the DU base the whole range of values in the 4-DU chains is given.

Parameter		U (V)	Power (k VA)	I (A)	Power losses (W)
Power Station	In	400	35.9	51.8	5427
	Out	3448	24.0	7.0	
MEOC		NA			619
Node 1	In	3440	9.3	2.7	767
	Out	400	6.8	16.9	
ILs		NA			497
DU base	In	377 - 393	0.25	0.65-0.69	25
	Out	370 - 400	0.22	0.55	

Table 2: Power distribution simulation for one MEOC and 1 node fully equipped. For the DU base the whole range of values in the 4-DU chains is given.

6.1.2. Power station

The electrical scheme of the power station [8] is shown in figure 11. The main power supply from EDF is presently set to 60kVA shared with ANTARES, corresponding to 44 kVA available for MEUST. The MEUST power hut (section 8.1) is designed to manage one MEOC. The second MEOC is expected to be managed in the ANTARES power hut after ANTARES decommissioning. The MEUST power station installed in the prototype phase will allow feeding at least one node fully equipped. Depending on future needs power can be increased.

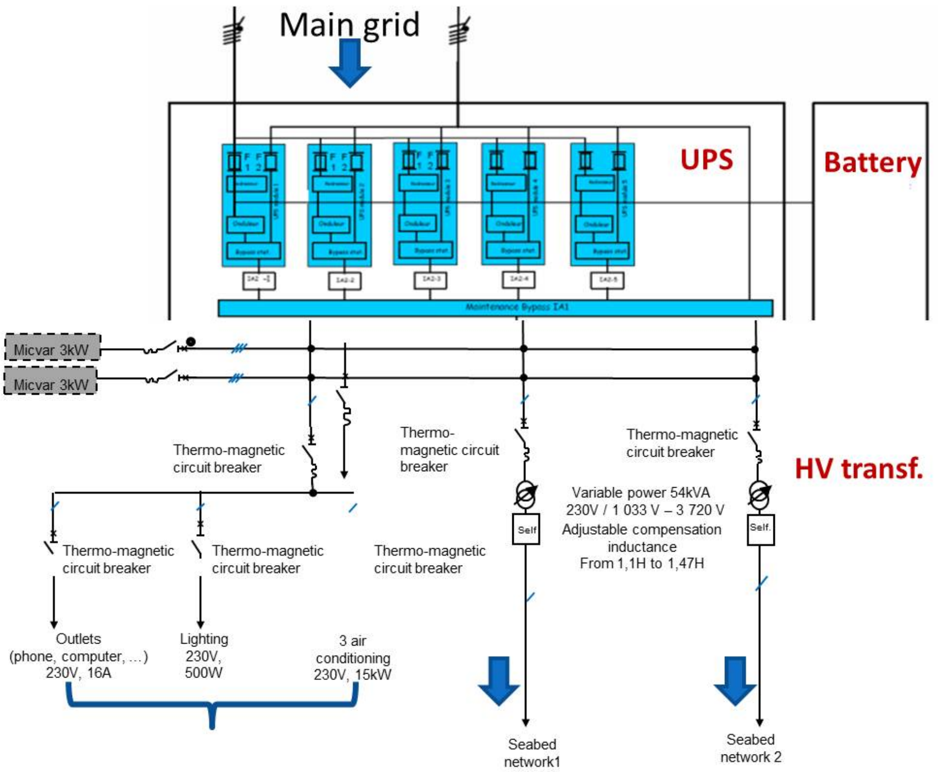

Figure 11: Electrical scheme of the MEUST power station

The MEUST power station hosts the Power Feed Supply (PFS) composed of an UPS and one step-up transformer with a self. The UPS reference UPGRADE DPA 250 kVA from S2S Onduleur Company is modular and can be equipped with up to 5 identical modules of 30 kVA, 40 kVA or 50 kVA for 3 phases. It is presently equipped with 3 modules of 30 kVA (reduced to 24 kVA due to a bad cosφ) necessary to operate a full node and feed the power station. With one node installed the power budget is driven by the onshore parts and, depending on the total load and the cosφ, one UPS module out of the 3 can provide redundancy. The variable power 63.5 kVA from Bernard Bonnefond Company (figure 12) is an inductive regulator, controlled by a MICVAR rack, associated to a step-up transformer of 54 kVA and a compensator of inductance made of a self. This allows increasing the voltage from 230 V to 3700 V with a regulation under load of +/- 130 V. The self has 2 positions: 1.1 H or 1.47 H. The setting of a position is manual and depends on the load connected offshore.

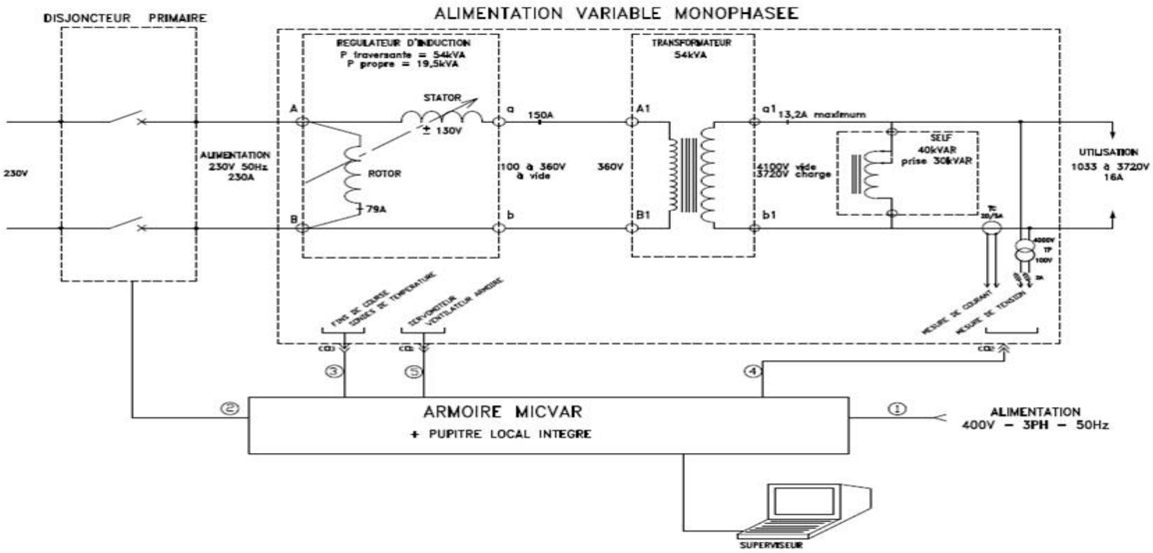

Figure 12: Electrical scheme of the variable power

6.1.3. <u>Node</u>

The electrical scheme of the node is shown in figure 13 and corresponding components are listed in table 3. The main functionality of the node power system is to provide, with the associated protections, 400V AC to the user ports and 230V for services inside the JB, and to feed the incoming HV current to the next node. The HV coming from shore is decreased in a 12 kVA step-down transformer from RAE Company equipped with 2 secondary outputs: 11 kVA at 400 V for the user ports and 0.9 kVA at 230 V for services in the node. The full specifications of the transformer are given in note [9]. The electrode for sea return is connected to the primary of the transformer. It is a titanium coated electrode (40 mm diameter, 1.8 m long) from Magneto Company, identical to the ANTARES one. The HV link can be switched off in the node to isolate the transformer or the next node. The switches (so-called artery cut) are specified to a voltage of 1000V only, i.e. lower than the incoming HV of 3700 V. This means that current has to be switched off before operating them. The command of the artery cuts without voltage implies the use of a battery to provide power. In stable operation however, the artery cuts can be used at 3700 HV in a unipolar way with all the poles connected in series.

Each user port is protected with a controlled breaker set to 4A. The output voltage of 400 V allows using standard breakers. In addition, to avoid too frequent use of the breakers, head contactors are installed to control a set of several user ports.

Voltage and current monitors are implemented to monitor the behaviour of the power system. Voltage sensors monitor each input/output of the AC/DC converters, the outputs of the transformer and the output of the battery. Current sensors monitor each user port, the HV links, the outputs of the transformer, the outputs of the AC/DC converters and the output of the battery. The temperature of the transformer is monitored by temperature sensors consisting in 4 thermocouples type K located in the secondary coils.

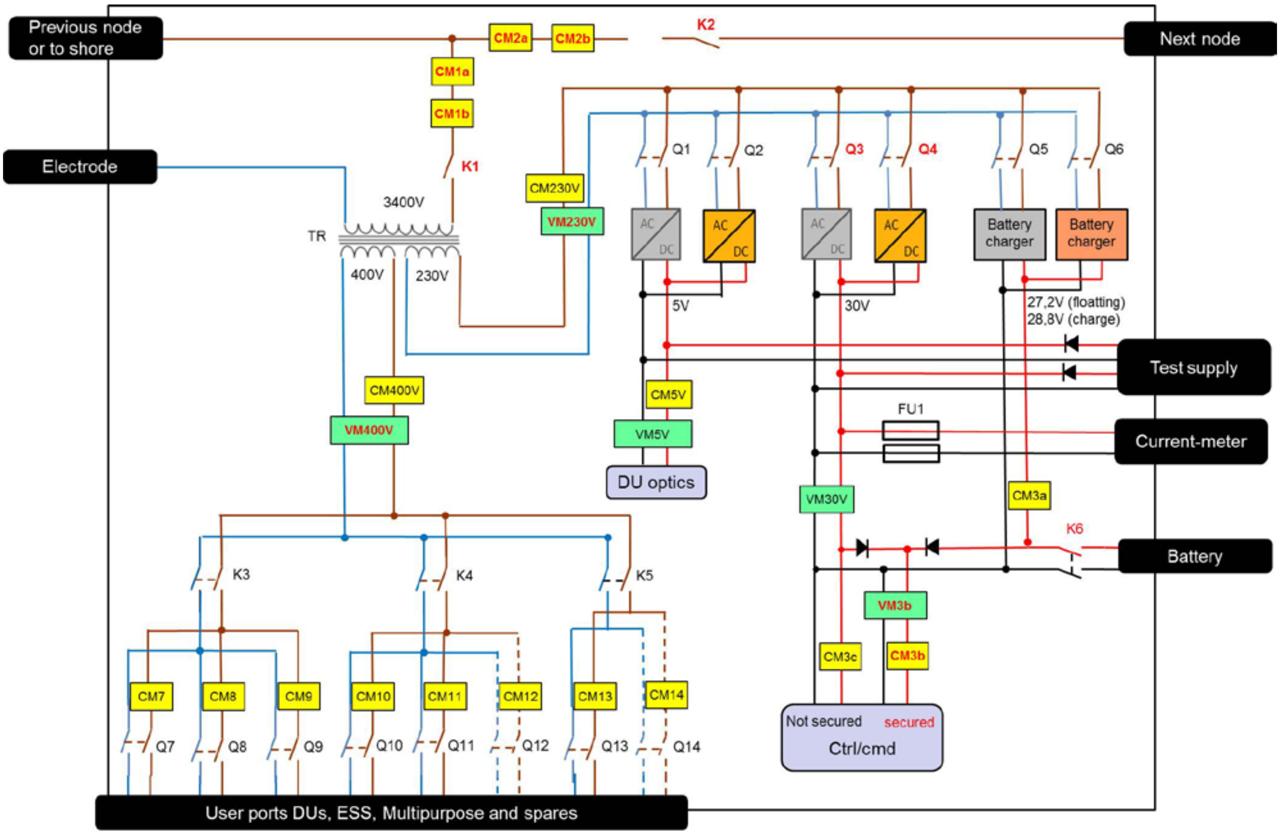

Figure 13: Electrical scheme of the node

The 230 V service supplies 3 sub-systems: the Control Command with its instrumentation, the optical components of the DUs network and the battery system. Two different user voltages are needed: 5 V for the optical amplifiers of the DUs network and 30 V for the Control Command. The 5V AC/DC delivers a power of 50W, while the 30 V AC/DC delivers a power of 300W. The choice of 30 V voltage (instead of the common 24 V) is driven by the backup battery: in normal operation the AC/DC voltage must be above the voltage level of the battery to avoid drawing current from it. Two sets of AC/DC are installed for redundancy. Only one is used in standard operation but they can run simultaneously if needed. The input of each AC/DC is protected by a controlled breaker. In order to charge the battery 2 sets of chargers are installed for redundancy. Only one is used at a given time and the second one is a spare. They are protected by a controlled breaker.

A lead battery is chosen for simplicity of operation despite its lower life time and bigger weight than a Lithium battery. The selected battery is a commercial deep-sea battery with a capacity of 40 Ah @ 24 V.

Designation	Label	Reference	Supplier
Artery cut	K1, K2	LC1D1150046BD	Schneider
User ports switch	K3, K4	LC1DT40BL	Schneider
User ports switch	K5	LC1DT32BL	Schneider
Battery switch	K6	ST2-DC24V-F	Panasonic
Breaker AC/DCs	Q1, Q2, Q3, Q4	356258	ABB
Breaker battery charger	Q5, Q6	356252	ABB
Breaker user port	Q7 to Q14	356257	ABB
AC/ DC 5 V	NA	SNT8005	FEAS
AC/ DC 30 V	NA	SNT11524	FEAS
Battery charger	NA	2043	Mascot
Battery	NA	SB-24/40	Deep Sea & Light

Table 3: Item list of power system components in the node

The estimated autonomy is about 30 hours and the life time 3-5 years. It is exchangeable by ROV operation (section 7.4.5). The battery powers some parts of the CC to manage the artery cuts, a few relays and readout of some sensors when the power supply from shore is switched off. In order to avoid a complete discharge of the battery, it can be isolated using a one shot switch controlled by the CC. In addition an automatic system, implemented on the backup board, disables the battery if its voltage becomes too low, avoiding a complete discharge and associated damage. The battery is put back to the circuit at the next onshore power on.

6.1.4. DUs

The AC/DC in the base container of the DU is in charge of MEUST as it is needed to comply with the DC current specification of the KMN3eT DU. Its electrical characteristics are driven by the MEUST power system for the input, and the DU power system for the output. Its dimensions are also important as it has to be integrated in the DU base container and must therefore be as compact as possible. The detailed specifications are under finalization [10] and a call for tender will be launched. The main parameters are:

- Input voltage: 350-450 VAC
- Output voltage: 385 +/- 3% VDC
- Power: 240 W

6.2. DATA TRANSFER

The data transfers for the neutrino DUs, the ESS instruments and the infrastructure Control Command are done through three separate optical networks, with a repartition of fibres summarized in figure 14. Within one MEOC the DUs network requires 10 fibres per node, the ESS network 2 fibres for 3 nodes and the CC network 2 fibres for 3 nodes. With 36 fibres available in the MEOC and in the inter-nodes links, there remain 2 spare fibres in the MEOC, 12 spare fibres between node 1 and node 2, and 22 spare fibres between node 2 and node 3.

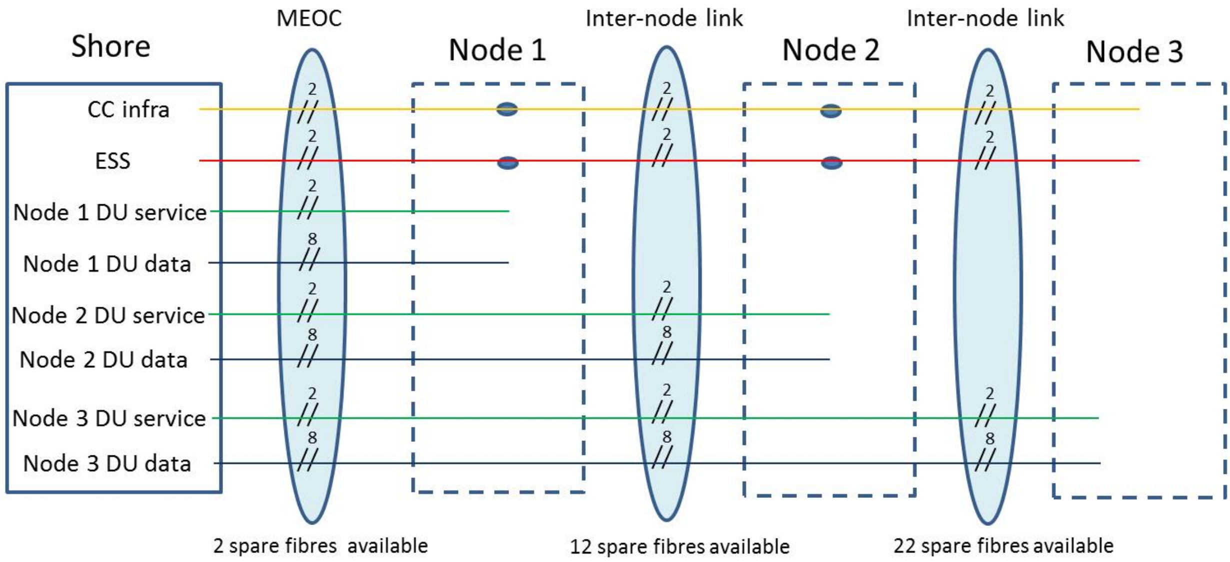

Figure 14: Optical fibres repartition in the MEOC and the inter-node links

The routing of the optical fibres within a node is sketched in figure 15 (see also section 5.4 for the connectivity of the node). Out of the 10 fibres dedicated to the node neutrino DUs, 2 fibres (including one spare) are dispatched on the 8 user ports for control of the DUs, and 8 fibres (one per user port) are used for the upstream flow of the DU data to shore. The DWDM multiplexing (section 6.2.1) allows each user port to receive data from 4 DUs connected in series (4-DU chain). The 2 fibres dedicated to the ESS instruments are split and connected to 2 user ports. These 2 user ports are therefore multi-purpose and can be used either for ESS instruments or neutrino DUs. The 2 CC fibres (including one spare) are directly connected to the CC Ethernet switch within the node (section 6.3.2).

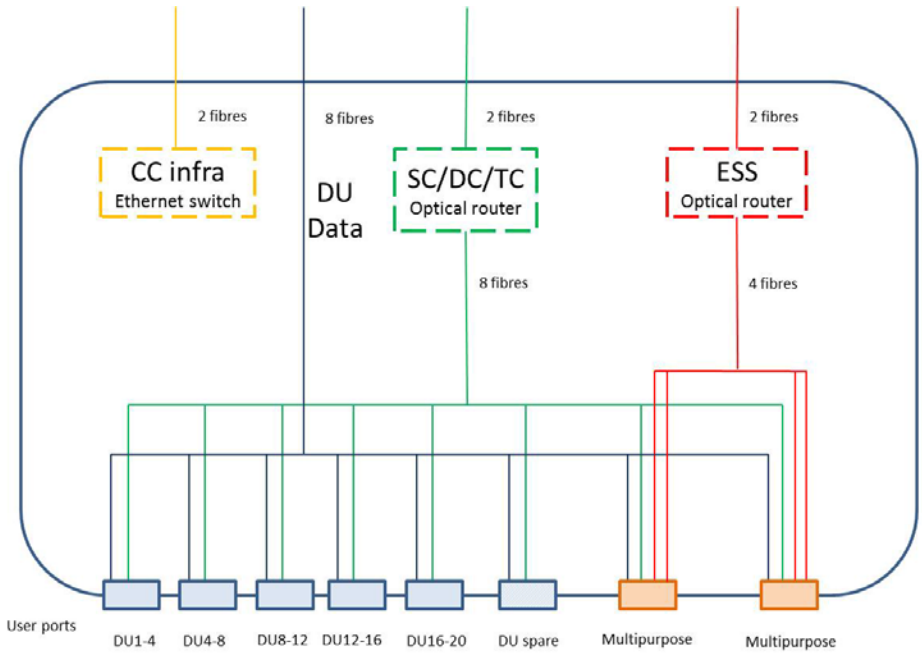

Figure 15: Optical fibres distribution in one node

6.2.1. Neutrino DUs optical network

The optical fibre network for neutrino DUs is designed along the KM3NeT optical requirements for data transfer and control. The optical network fulfils 4 main functions: the DOM data transfer, the DOM Slow Control, the Timing calibration and the Detector Control. The DOM data transfer uses dedicated upstream fibres, while the other 3 functions are performed through a single ‘’service’’ fibre (duplicated for redundancy) using different wavelengths for each of them. The nodes are independent from each other and have their own dedicated fibres for service and data transfer (figure 14).

The DU optical network from shore to the node is sketched in figure 16.

The DOM data transfer uses point-to-point Ethernet connections between the DOMs and the shore. The data transfer from DOM to shore uses 8 mono-directional fibres, one fibre per user port. The intermediate nodes are totally passive with a direct connection from the user port to the MEOC. The high data flow of ~20 GBytes/s (for the full Building Block) is sustained with 1 Gbit/s Ethernet using a dense DWDM multiplexing with 50 GHz spacing in the C band (1530 nm-1566 nm). This ITU-grid allows merging the data of up to 80 λ in a single fibre. In practice it is foreseen to use a maximum of 76 λ per fibre, including the data of 4 DUs (72 λ) and those of possible CUs added to the 4-DU chains (section 5.2).

One bidirectional service fibre, duplicated for redundancy, contains the DOM Slow Control, the Detector Control and the Timing Calibration. Within the node, the fibre is split to each user port to broadcast the signals to all 4-DU chains. The intermediate nodes are mainly equipped with passive components in order to minimize failure risks. The only active components are optical amplifiers EDFA which are duplicated for redundancy. The wavelength pattern of the service fibre is as follows:

- The Slow Control for the DOMs is broadcasted from shore to each DOM on one wavelength.
- The Detector Control is broadcasted from shore to each DU base on one wavelength while the return path uses one wavelength per DU, so 21 wavelengths are needed in total for one node.
- The Timing Calibration signal is broadcasted from shore to each DU base on one wavelength and the return is done on one different wavelength identical for all DUs (which implies to perform the time calibration of DUs sequentially one by one).

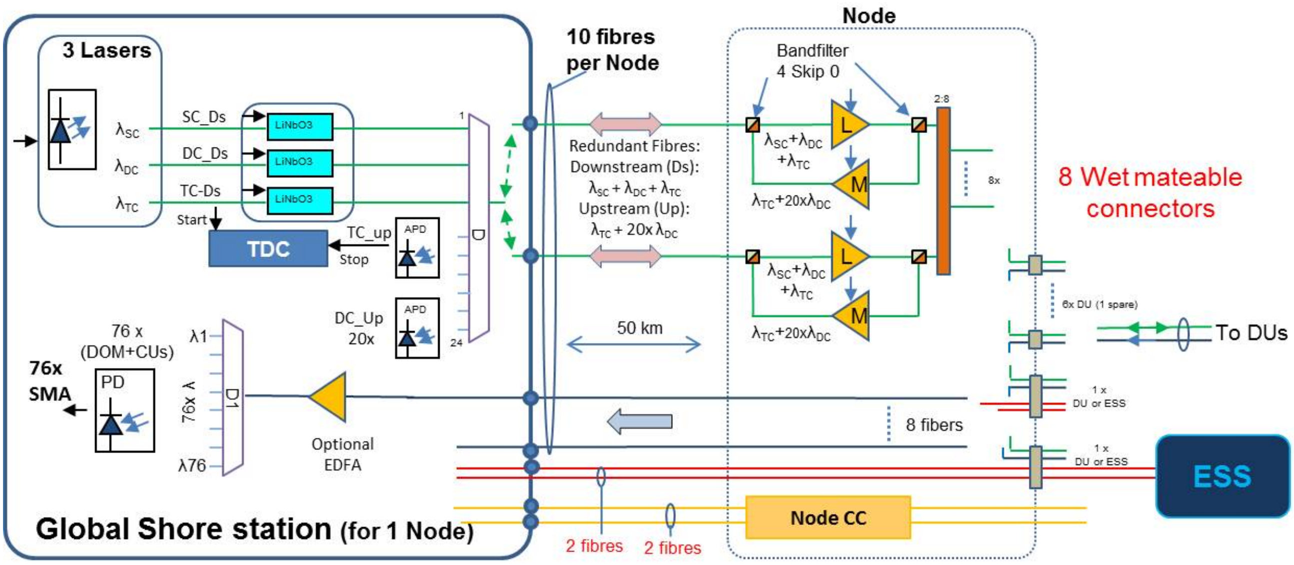

Figure 16: Neutrino DUs optical network from shore to the node

Each DU user port interfaces a 4-DU chain with one service fibre and one data transfer fibre. The optical sub-network of the 4-DU chain is sketched in figure 17. The connection in series of 4 DUs implies to have more optical components in the base container of the 1st DU than in the other DUs.

For the DOM data transfer, the 18 wavelengths on a 200GHz ITU-grid, provided by the lasers of the DOM SFP modules and corresponding to the 18 DOMs in the DU, are merged in the DU base container using a DWDM filter, in order to exit the DU on one fibre. They pass through the previous DUs in the 4-DU chain. All DOM data of the 4-DU chain are merged into 1 fibre in the base of the 1st DU of the chain before reaching the node. A set of interleavers insert the 72 λ's in one fibre and an additional optical amplifier EDFA increases the power level to compensate the optical losses in the circuit.

The service fibre is split in each DU base, using splitters with different ratios to equalize the losses between DUs, and goes to the next DU in the 4-DU chain. The different wavelengths used for SC, DC and TC are then extracted from the fibre using band filters. The DC and TC are directly connected on SFP modules to interface the corresponding electronic boards in the base container. The SC wavelength is amplified with an optical amplifier EDFA before being sent on the 18 DOM fibres in the VEOC. In the DOM the SC wavelength is extracted from the DOM VEOC fibre connected to the optical receiver of the SFP module.

The number of fibres used in the interlinks of a 4-DU chain varies from 2 to 4 depending on the position of the DU in the chain, but all interlinks are ordered with 4 fibres for uniformity.

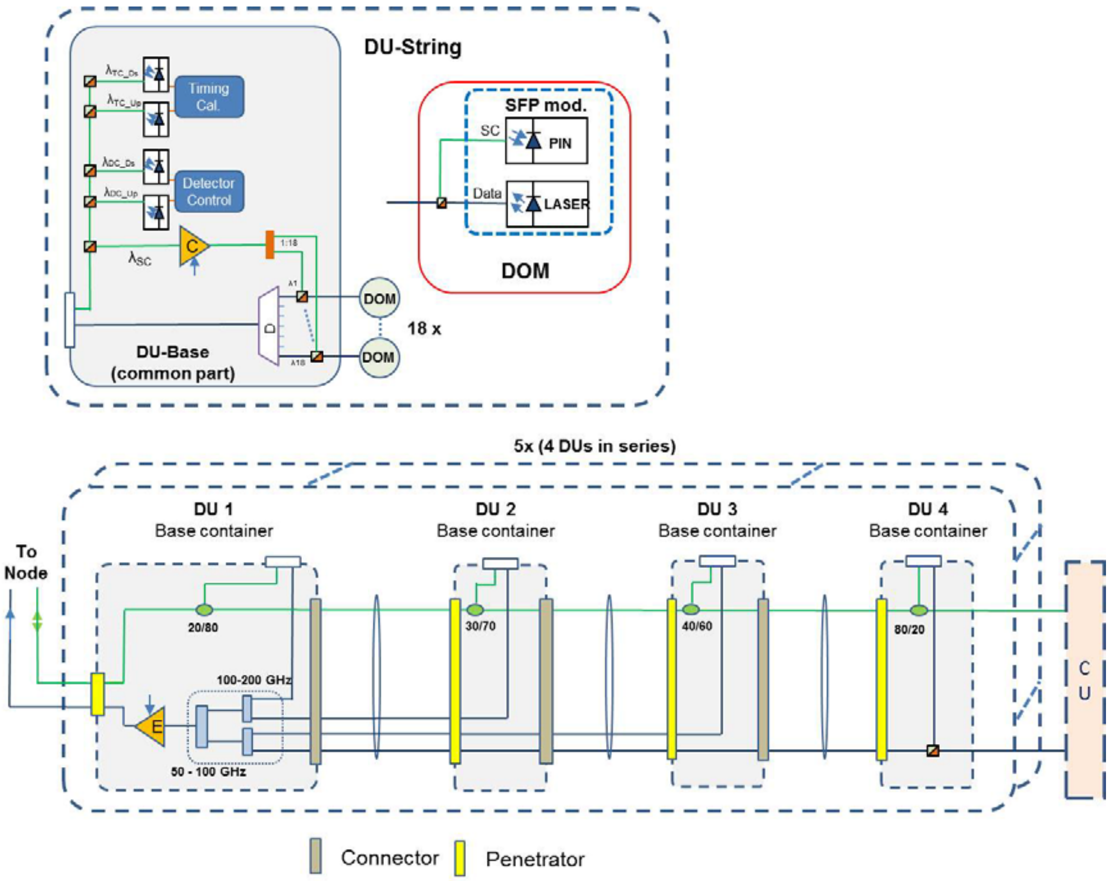

Figure 17: Optical sub-network for a 4-DU chain.

6.2.2. Earth and sea sciences optical network

The ESS instruments use a bidirectional CWDM optical network designed to maximize redundancy and flexibility (figure 18). The network is based on 2 optical fibres split to each of the 2 multi-purpose user ports within the node, before continuation to the next node. In each node, 2 wavelengths are used for transmission of the data (Tx) and reception of control parameters (Rx). The (Tx, Rx) wavelengths are different for each node and have the values summarized in Table 4.

	ʎ Tx (nm)	ʎ Rx (nm)
Node 1	1510	1530
Node 2	1550	1570
Node 3	1590	1610

Table 4: ESS wavelengths for each node

The use of CDWM wavelengths with a grid of 20 nm provides the possibility to create optical sub-networks from each multi-purpose user port, using more wavelengths with a denser DWDM grid (1.6 or 0.8 nm). This flexibility potentially allows adapting to complex arrays of ESS sensors.

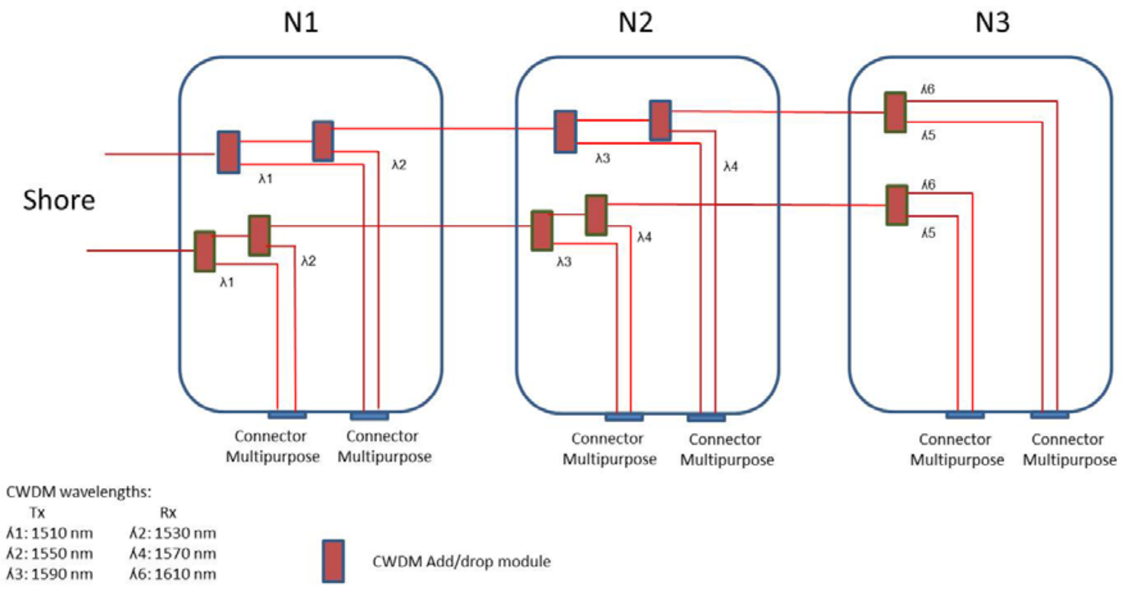

Figure 18: ESS optical network

6.3. CONTROL COMMAND

6.3.1. Overview

The CC manages the power, optical and monitoring systems of the infrastructure. This includes: control of the onshore Power Feed Supply and of the offshore electrical switches and breakers; readout of the node voltage, current, temperature and humidity sensors; readout and setting of the node current meter and optical amplifiers. The CC is independent from the user control of the neutrino and ESS instruments, e.g. Slow Control of the DOMs or Detector Control of the DUs feet, and its communication is based on 2 dedicated bidirectional optical fibres (figure 14).

The CC network (figure 19) is built as a ring topology with industrial Input-Output (IO) modules from the MOXA Company to provide robustness and reliability. These modules are compatible with Linux for software developments. The communication is based on the Ethernet protocol. In each node, each CC fibre is connected through small form-factor pluggable transceivers (SFP) to an Ethernet switch which communicates with the IO and serial link modules. For redundancy the network is doubled both for optical transmission, Ethernet switches and IO Modules. This allows multi-routes in case of failure of one IO module or of a data transmission link.

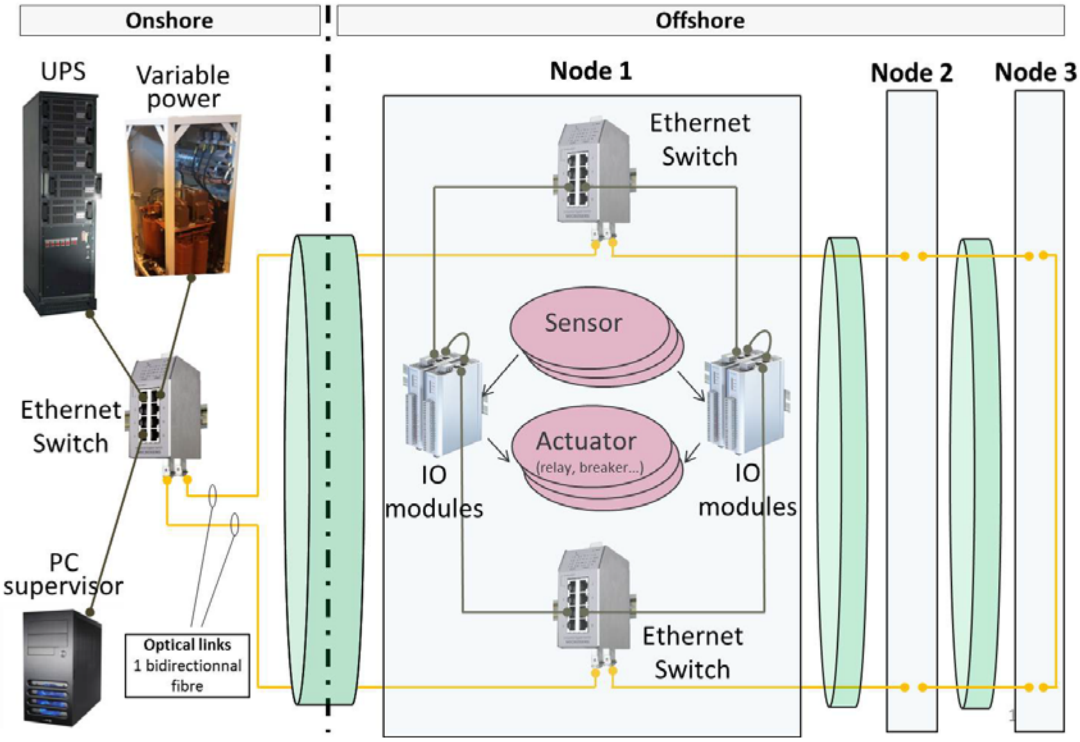

Figure 19: General scheme of the CC

6.3.2. Node

Figure 20 gives an overview of the CC architecture within the node [11], and the corresponding components are listed in Table 5. The Ethernet switches are connected to the different IOs modules with an electrical Ethernet link (RJ45), and to the shore optical network with an SFP module. The SFP modules are specified for Gigabit Ethernet WDM 1,25GB single mode 1570 nm and 1490 nm. Two types of SFP modules are used, one specified for a 80 km link (LD) from the shore to the 1st node and one specified for a 20 km link (SD) between nodes.

Different types of IO modules are used in the node:

- Analogue modules to readout sensors.
- Digital modules to drive the different switches (breakers, contactors…) and to read out their status.
- Thermocouple modules to readout temperature sensors.

- Serial link (RS232) modules to control the optical amplifiers of the DUs optical network and the sea current-meter.

The signals of each sensor or actuator are sent in parallel to 2 IO modules for redundancy. Most of the relays are directly activated from the modules but some high-power relays require an intermediate relay implemented on the CC interface board.

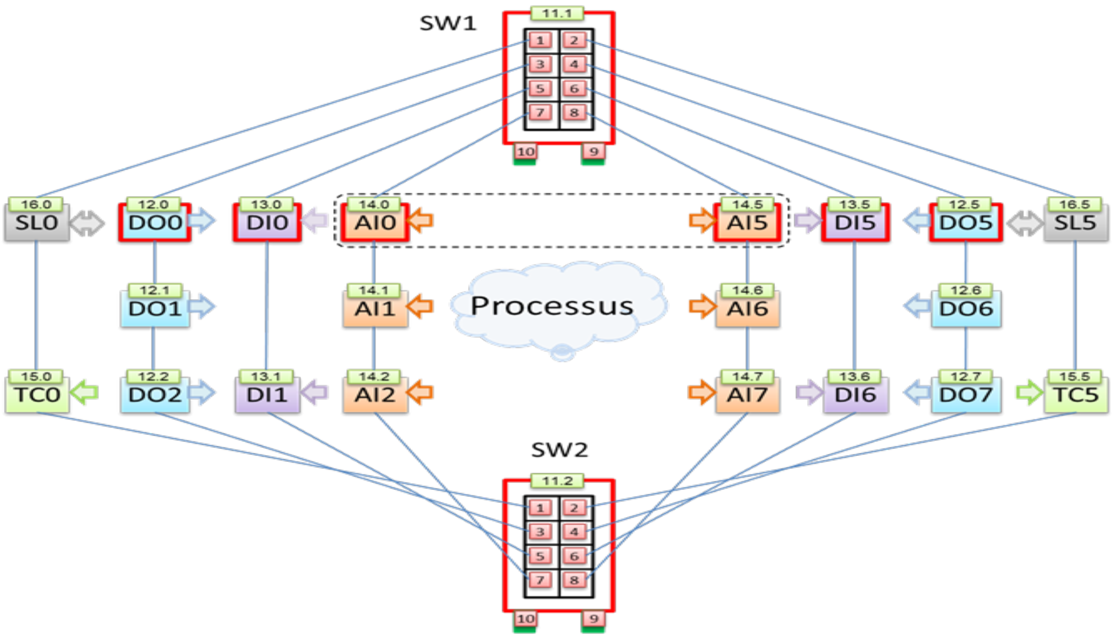

Figure 20: CC architecture within a node

Module type	I/O available	Supplier	Reference	Nb of modules
Ethernet switch (SW)	8	Microsens	MS650869M-V2	2
SFP modules for Ethernet switches (LD)	NA	Microsens	Tx: MS100228DA Rx: MS100228DB	1/switch
SFP modules for Ethernet switches (SD)	NA	Microsens	Tx : MS100222DA Rx: MS100222DB	0 to 2/switch
Digital outputs (DO)	16	MOXA	E1211	6
Digital inputs (DI)	16	MOXA	E1210	4
Analogue inputs (AI)	8	MOXA	E1240	6
Thermocouple (TC)	8	MOXA	E1262	2
Serial link (SL)	4	MOXA	IA5450AI	2

Table 5: list of the node CC Modules

All CC components are powered at 30 VDC from an AC/DC converter. Some modules as well as some sensors and switches are connected to the secured power network of the battery, in order to be able to activate them after a power off of the infrastructure.

6.3.3. Power station

The onshore Power Feed Supply has its own control command which is partly accessible from the infrastructure CC through an Ethernet link. This allows to report the necessary information (sensor values and alarms) and to control the system (power on/off, setup of the voltage level in the MEOC…) from the Control Room. The connection of the power station equipment to the CC network requires a unique Ethernet switch in the power station.

6.3.4. Software

All CC components (onshore and offshore) are network reachable, allowing CC actions to be performed from a unique standard PC in the Control Room.

The software environment is Scientific Linux 6.2 (kernel 2.6) and the programming interface is Qt 5.1. This environment offers all the required functionalities, ranging from graphical tools for user interface to real time functions like threads and timers. The software architecture (figure 21) is foreseen as a graphical human-machine interface supervising all control command hardware through customized drivers.

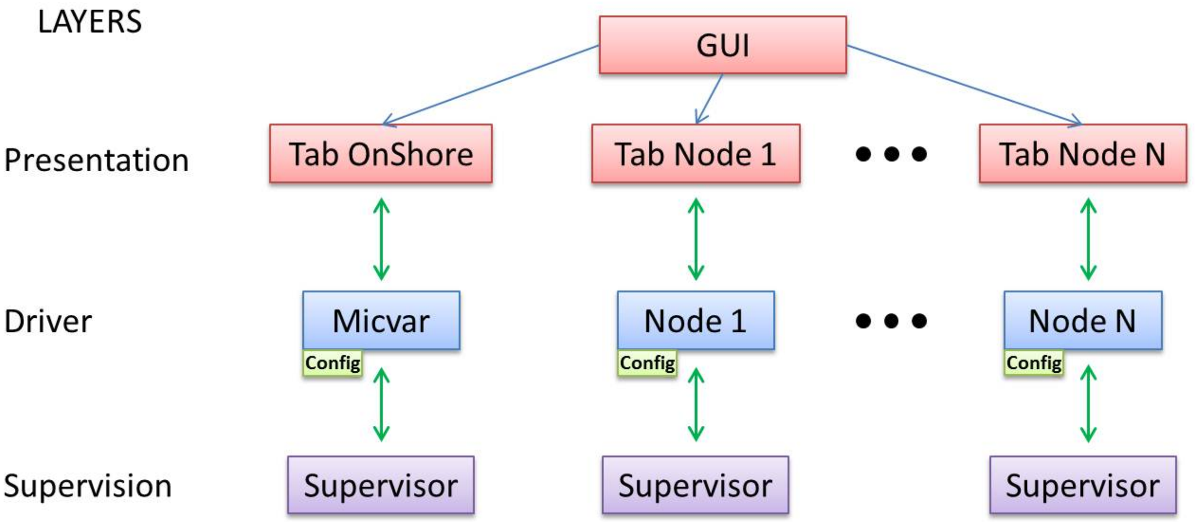

Figure 21: CC software architecture

6.3.4.1. Drivers

The drivers are developed in the application layer, not in the kernel. They are threaded, i.e. live in their own time reference, not interfering with each other or with other tasks. In all drivers, data from hardware sensors are regularly updated and are available at any time (mutex protected) for any interrogating task. The drivers act as self-controlled drivers, allowing supervising tasks to reach available data and send commands without waiting for their execution.

Two drivers were developed for the onshore Power cabinet (MICVAR) and the node MOXA Ethernet/IO modules respectively. For both, a collection of functions allow any presentation task to control/command the hardware.

Onshore power cabinet (MICVAR) driver:

Control: Data from hardware are updated using an infinite loop.

Command: Functions to execute commands are provided, being launched from any other task. The driver immediately returns control.

Node CC (MOXA modules) driver:

Control: Data are pushed from boxes to the CC PC, where they are collected through an internal asynchronous callback function.

Command: Idem MICVAR.

6.3.4.2. Supervision layer

The role of this task is to monitor the large amount of variables controlling the status of the infrastructure. During operation the online data are regularly compared to their respective limits specified at configuration of the system with associated severity levels. The data from most variables will be regularly stored in a database at a frequency to be defined. Specific actions (alarms, shutdown…) are taken in case the parameters get out of range. As soon as an alarm appears a logging is made and messages are displayed to the operator. Depending on the severity, mails and SMS are sent and/or (part of) the detector can be shut down.

6.3.4.3. Presentation layer

The presentation layer provides interface with the operator. It constantly displays a graphical image of the most recent status of the infrastructure, receives and displays messages from the supervisor task and allows the operator to change the infrastructure status at any time. The presentation layer is event driven and always available to the operator since drivers update their data and receive commands asynchronously.

Each command requires a confirmation before executing the action. For some specific items (like artery cut, battery disable) an additional second level of safety (e.g. by password) will be implemented. The presentation layer is implemented as a main window housing a tab array, where each tab provides a graphical interface to part of the control command. The present tab list includes “Onshore”, “Node1” up to “Node N”, “Optics”, “Expert”, and can be extended if needed. As an example the tab ‘’Node 1’’ is shown in figure 22.

6.3.4.4. Configuration layer

A dedicated file is used to configure all the control command software, and the corresponding configuration parameters will be stored in a database. A dedicated software is being developed to allow a user friendly update of the configuration file.

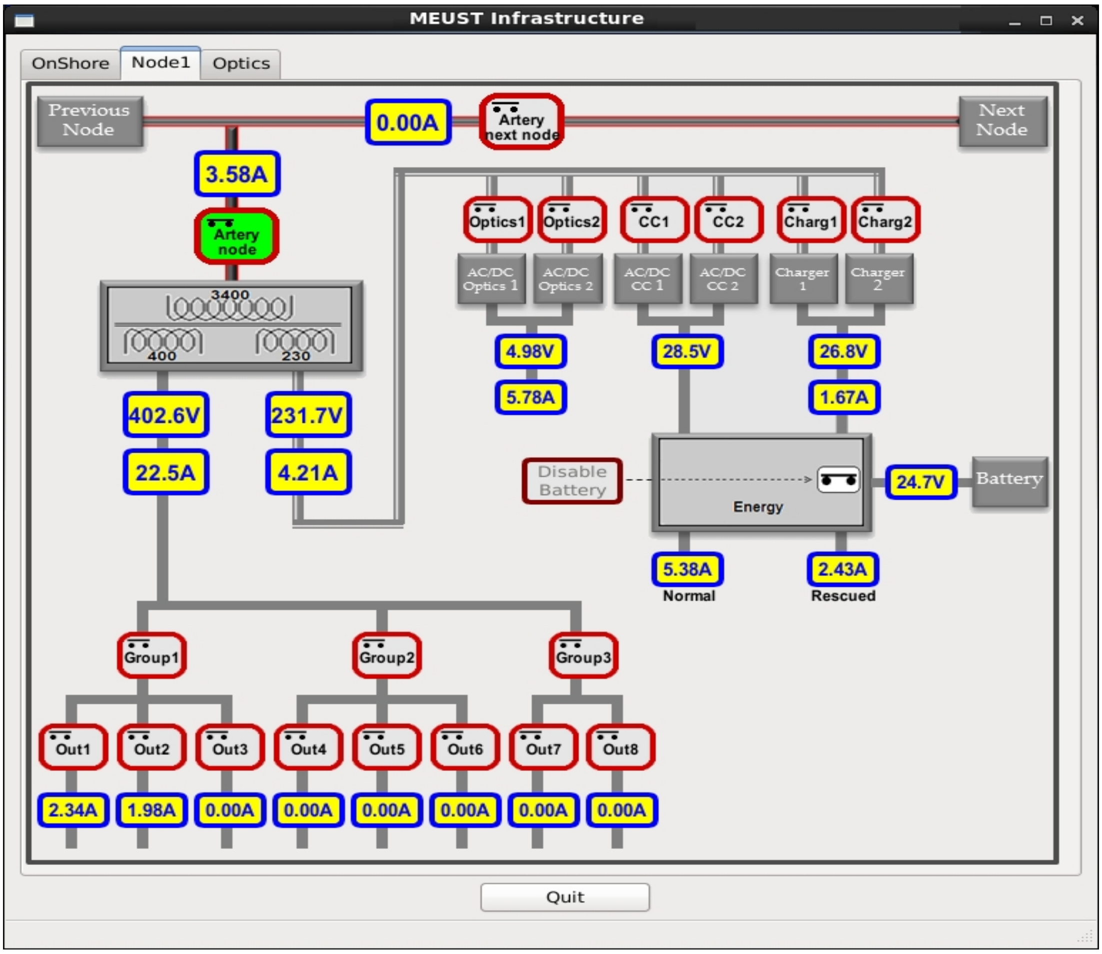

Figure 22: Window tab of node 1

7. OFFSHORE COMPONENTS

7.1. MAIN CABLES

Two Main Electro Optical Cables to shore (MEOC) are needed to feed the full array of detectors. The first MEOC installed for half of the ring is a new one specifically ordered. For the second MEOC, two options are possible: purchase of a second identical cable or re-use of the ANTARES cable which has a similar structure (reference URC3 from Alcatel with 48 optical fibres). After decommissioning of the ANTARES telescope, its MEOC could be redirected to the MEUST site. This operation has been successfully studied by ORANGE MARINE [12] and the compatibility of the ANTARES MEOC to the MEUST requirements in term of electrical and optical properties will be studied. The following description concerns the first MEOC ordered for MEUST.

The MEOC provides an electrical power link (one conductor) and a data link (36 single mode optical fibres) between the shore and the submarine infrastructure. The cable length from the power station to the 1st node is 38 km. The cable selected from a public tender is a standard telecommunication cable from Alcatel (reference OALC-7). The choice of this type of cable has many advantages: it is commonly used in the field with very good reliability, a wide range of standard accessories are available and maintenance operations can be quickly performed at relatively low cost within the MECMA consortium (as for the ANTARES cable).

The cable is made with 3 different armours (figure 23) to withstand the constraints of the seabed configuration along the cable route. A double armour (DA) is used near the shore, a single armour (SA) in the break shelf and a light weight protection (LWP) in the safe flat deep-sea area. A total length of 60 km of cable was ordered, allowing installing up to 3 nodes while leaving 8 km as spare for possible future repairs. In addition 10 Universal Joints (UJ) for cable jointing have been purchased.

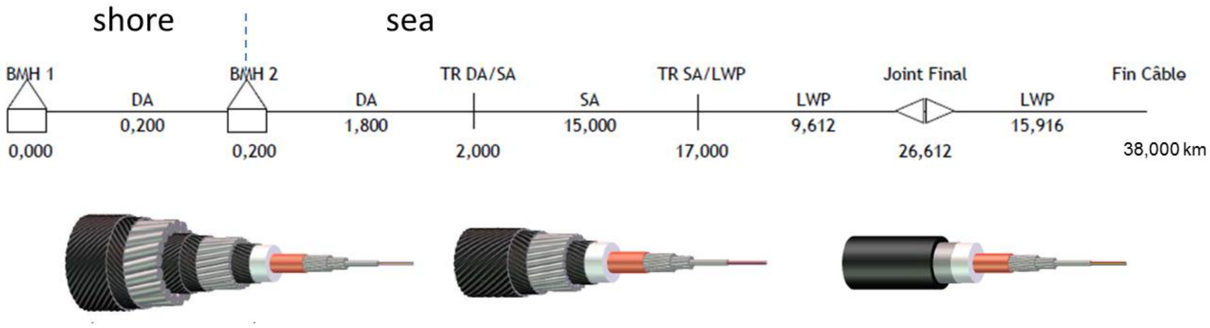

Figure 23: MEUST MEOC configuration

The full specifications of the MEOC are given in technical notes [13] and [14] and its main characteristics listed in Table 6.

The optical fibres in the MEOC (LEAF-EP type from Corning) are especially designed for long haul using DWDM transmission. Their main specifications are the following:

- Optical attenuation @ 1550 nm: < 0.25 dB/km
- Chromatic dispersion @ 1550 nm: -4 ps/nm/km

The results of the final acceptance tests of the MEOC, performed after its manufacture, are summarized in note [15].

Maximum voltage	10 KV DC
Wire resistance	0.7 ohm/km
Capacitance	0.18 μF/km
Self (@ 25 Hz-theoretical value)	1920 μH/km
Number of fibres	36
permanent tension acceptable (LWP)	25 kN

Table 6 : Main characteristics of the MEUST MEOC

7.2. MEOC TERMINATION

The MEOC interface with the JB inside the node is an electro-optical penetrator from Seacon Company. The choice of a penetrator instead of a connector (like in ANTARES) is driven by the goal to simplify the sea deployment of the nodes using standard cable jointing only. This avoids the risk of bad optical connection on the boat where a repair would not be possible. The installation of the penetrator on the JB is done onshore and allows testing the node in its final configuration.

The penetrator (figure 24) is watertight in both directions to avoid water propagation in the cable or in the JB in case of water leak. The penetrator body is in titanium and the cable moulding in Polyethylene to ensure the water tightness with the necessary life time. A Polyurethane moulding surrounds the polyethylene to act as protection. The penetrator is moulded on a 80 m length of MEOC cable to allow jointing to the MEOC and inter-node links during sea operations.

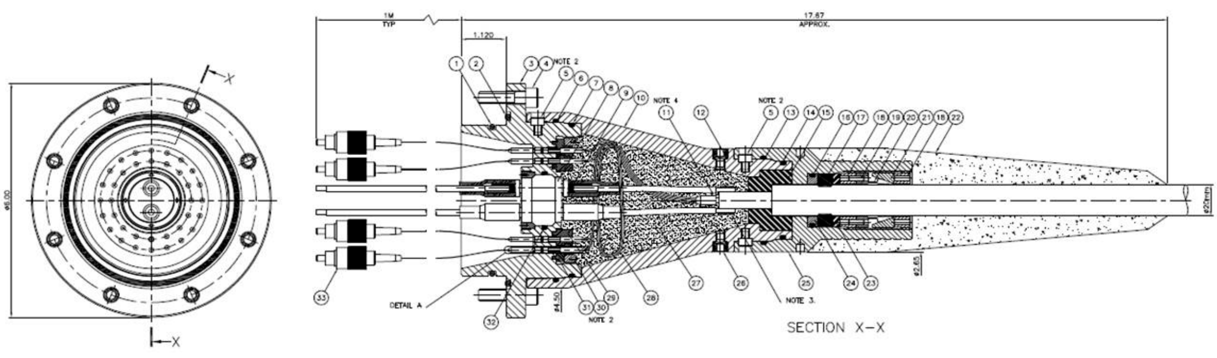

Figure 24: General drawing of the penetrator

The full specifications of the penetrator are given in technical note [16] and its main characteristics are:

- 36 optical paths: optical attenuation < 0.2 dB @ 1550 nm
- 1 electrical path: voltage 5000 VAC, current 30 Amp.
- Water tightness in both directions
- Dimensions: external diameter: 150 mm, length: 450 mm

A prototype penetrator is being built and will stand a set of qualification tests in resistance to pressure, vibrations and thermal shocks before manufacturing the final ones.

7.3. INTER-NODE LINKS

The inter-node link is the section of cable joining two adjacent nodes. Its length is set to 6 km to accommodate the water column height when retrieving a node. It is made of two identical parts of 3 km attached to their respective nodes and joined to each other on the boat during installation of the nodes (section 9.3). There are 3 joints on the inter-node link (figure 25): two close to the node penetrators and one in the middle of the link. The inter-node link is composed of the same components as the MEOC: Alcatel cable ended by the Seacon penetrator at both end (cf § 7.2). Jointing uses the standard UJ parts.

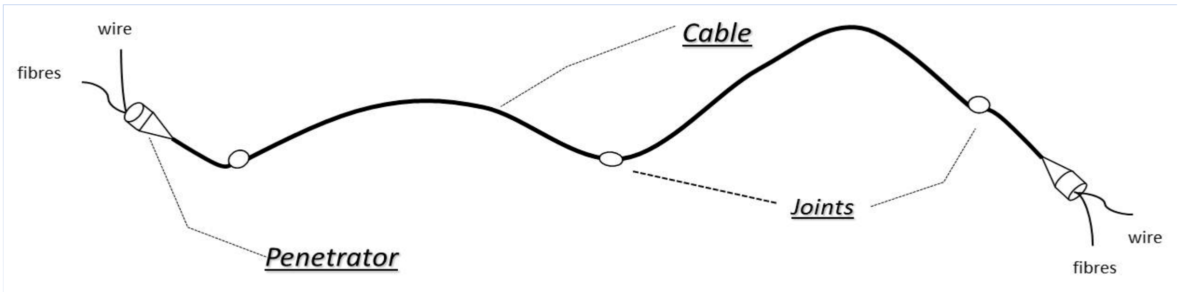

Figure 25: Layout of the inter-node link

7.4. NODE

The node is the interface between the MEOC (or the inter-node link from the previous node), the inter-node link to the next node, the neutrino DUs, their calibration devices and the ESS instruments. All nodes are identical but the configuration of their internal components can be adjusted. The general layout of the MEUST node is shown in figure 26. The dimensions of the structure of the node are driven by the capabilities of the vessel used for its installation and by the mechanical stresses induced during deployment. The choice of the materials is a key parameter for the node life time, leading to use mainly titanium and plastic. The node components include the MEOC and inter-node link interfaces, the Junction Box (JB), the user ports and their jumpers to the JB, some instrumentation and a mechanical frame equipped with a sea return electrode and a battery.

7.4.1. <u>MEOC and inter-node link interfaces</u>

The design of this part is still being finalized. The cables of the MEOC or inter-node link are connected to the JB through Chinese fingers fixed to the horizontal axis of the node mechanical frame. A bending limiter is implemented to keep the bending radius of the cables above the minimum specified value whatever the load applied in both directions, in order to avoid possible damages of the cables. The penetrators are provided with 80 m of cable which will be stored on a specific storage support to be designed. This temporary support will be used up to the loading of the node on the vessel.

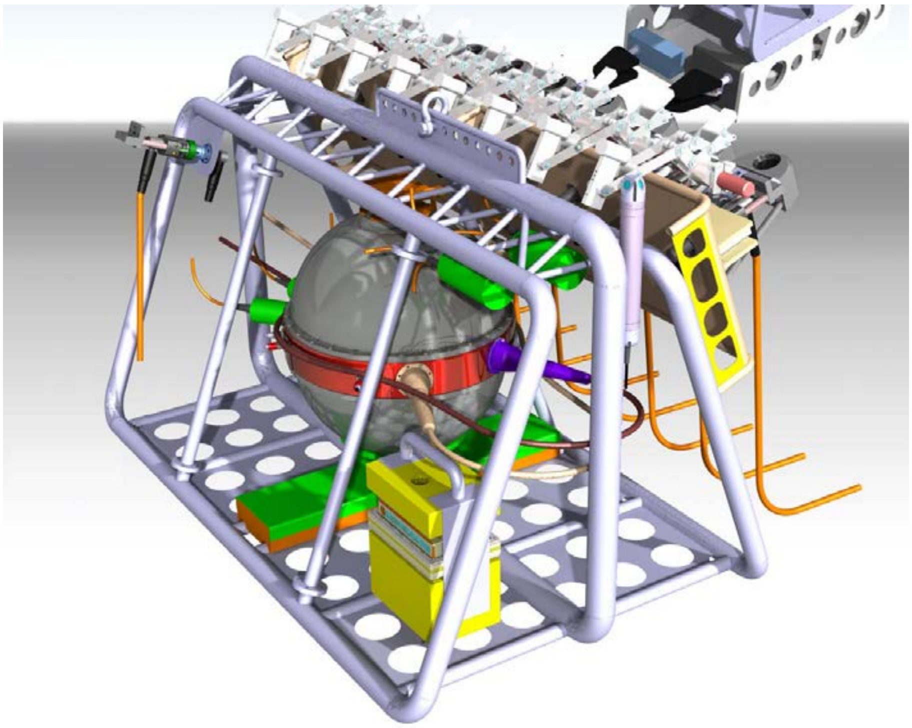

Figure 26: General configuration of a MEUST node

7.4.2. Junction Box

The JB houses the components of the power, optical and control command systems. It is a water pressure resistant titanium (BT3-1 alloy) sphere made of 2 hemispheres with 885 mm internal diameter and 20 mm thickness, separated by an annulus spacer as shown in figure 27. The detailed documentation and drawings of the sphere are available in note [17]. The sphere is rated for 4000 m depth and has been pressure tested by the manufacturer before its delivery. Its internal structure is shown in figure 28. The upper part is in dry air at atmospheric pressure while the bottom part is filled with oil for cooling purpose. A diaphragm performs the separation between the upper and lower parts.

The upper part contains all components that must operate in air. The volume is separated in four areas with dedicated trays to host the optical components, the electrical components, the control command and the battery chargers respectively. The optical tray hosts the 4 optical amplifiers EDFA, a 2:8 splitter, 4 band filters and the protection splices. The electrical tray hosts the contactors of the user ports, the breakers and the different sensors. The control/command tray hosts the Ethernet switches, the IO modules and the interface and backup boards. The chargers tray hosts the 2 chargers for the battery.

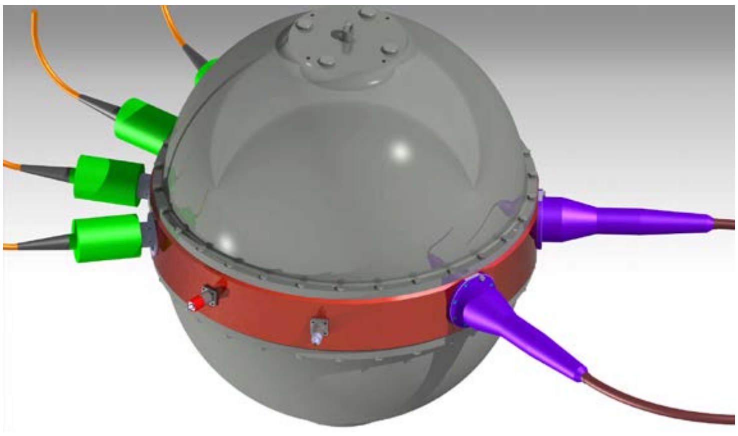

Figure 27: External view of the JB

The lower part contains the step-down transformer, 2 AC/DCs and the 2 contactors (artery cuts) to switch the HV link. The silicone oil (reference XIAMETER PMX-561 from Dow Corning) is a liquid designed for electrical transformers. It has been selected for its insulating and cooling properties as well as for its low environmental impact.

The diaphragm is a circular plate of 8 mm thickness in stainless steel. It is attached to the annulus spacer with screws and the tightness is achieved with an o'ring seal made of Viton. The diaphragm supports all components: the transformer and other devices on the bottom part and the 3 trays of the upper part. In addition it houses the feed-throughs listed in the Table 7 to perform the connections between the 2 parts of the JB.

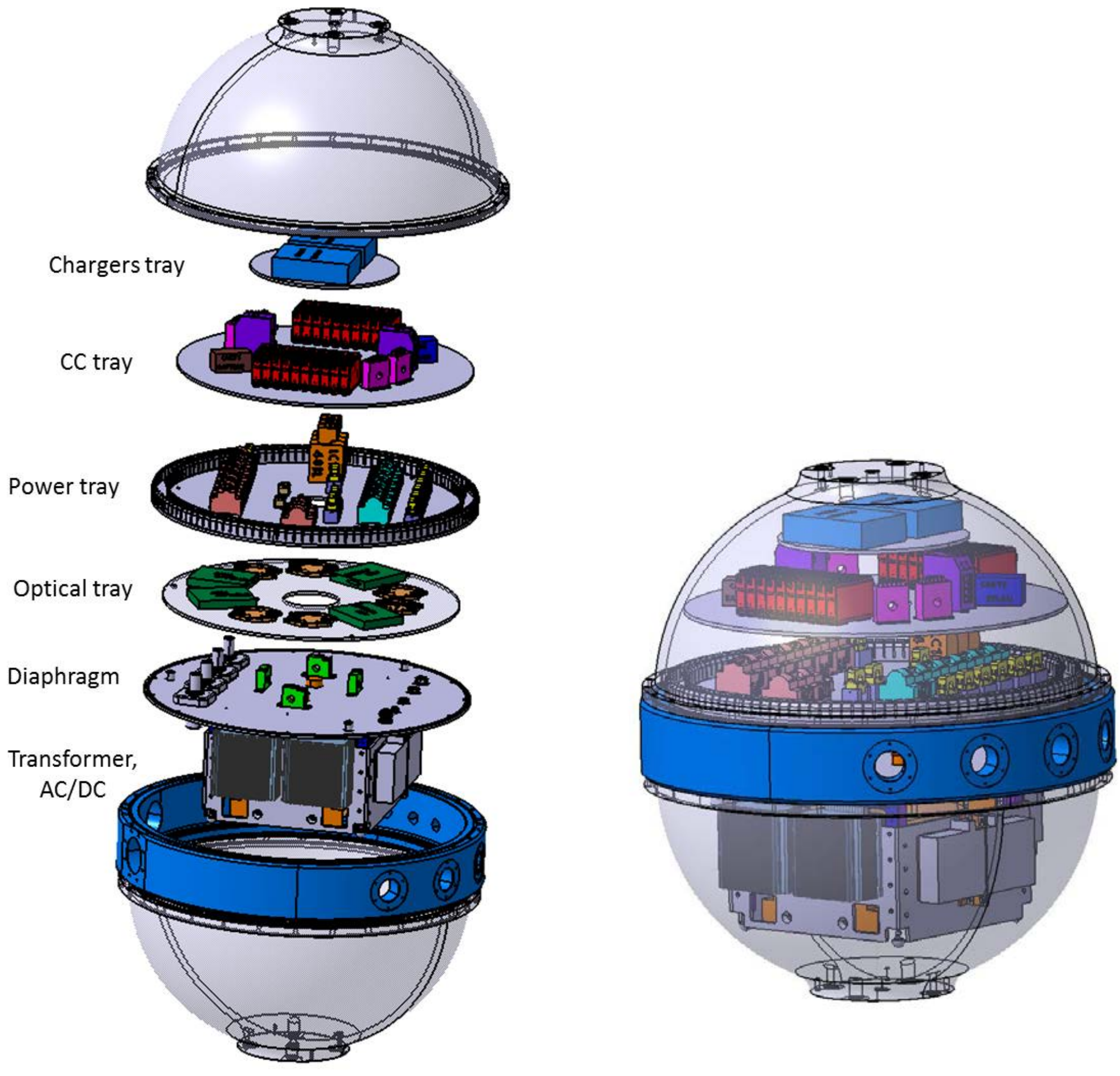

Figure 28: Internal structure of the JB

Designation	Feed-through type	reference	Supplier	Quantity
HV	Isolator	IPEq 20/250 (tbc)	Isoelectric	4
Thermocouples	Connector 5 sensors	851-07R1210P50	Souriau	1
Power 400 V & 230 V	Feed-through	52015831	LAPP cable	1
CC 230 V	Connector 10 pins	851-07A1811P50	Souriau	1
CC 30 V	Connector 8 pins	851-07A168P50	Souriau	1
CC 30 V	Connector 16 pins	851-07A2016P50	Souriau	1

Table 7: Characteristics of the feed-throughs of the JB diaphragm

The annulus spacer (figure 29) is made in Titanium grade 5 and has the following dimensions:

- Height: 160 mm
- External diameter: 992 mm
- Internal diameter: 882 mm

The annulus spacer houses the different connectors/penetrators to interface the JB as listed in Table 8.

A pressure test at 310 bars (120% of operating pressure) of the sphere with the annulus spacer is planned before starting the integration of the internal parts of the JB.

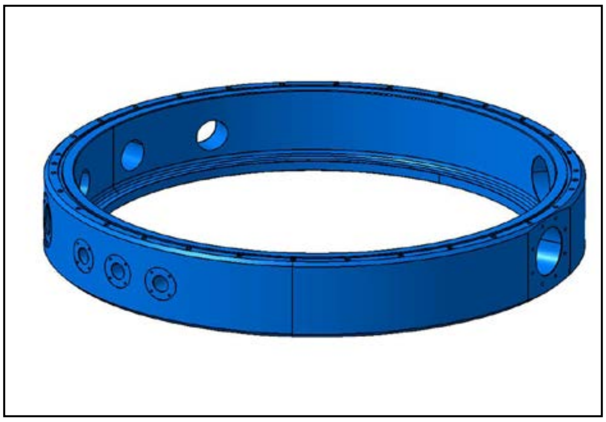

Figure 29: Drawing of the annulus spacer of the JB

Designation	Type	Reference	Supplier	Quantity
MEOC-inter-node link	Penetrator	NA	Seacon Europ	2
Electrode	Connector	FCR 2003M-TI	Subconn	1
Current meter	Connector	FCR 2410-TI	Subconn	1
Supply	Connector	FCR 2003M-TI	Subconn	1
Jumpers	penetrator	NA	ODI	4

Table 8: Characteristics of the JB connections through the annulus spacer

7.4.3. User ports

The user ports are hybrid wet mateable connectors reference NRH from ODI Company. The 8 sockets for DUs and multi-purpose users are identical. They are located on a panel on one side of the node frame.

Since connections are expected to be performed by a light ROV, a specific tool (figure 30) is under validation to help the connection. The main functions of the tool are to guide the connection and to decrease the required force using a reduction system. It will also ease the inspection and cleaning of the connectors by the ROV.

All user ports will be equipped with long term plugs to protect the connectors until an interlink is plugged.

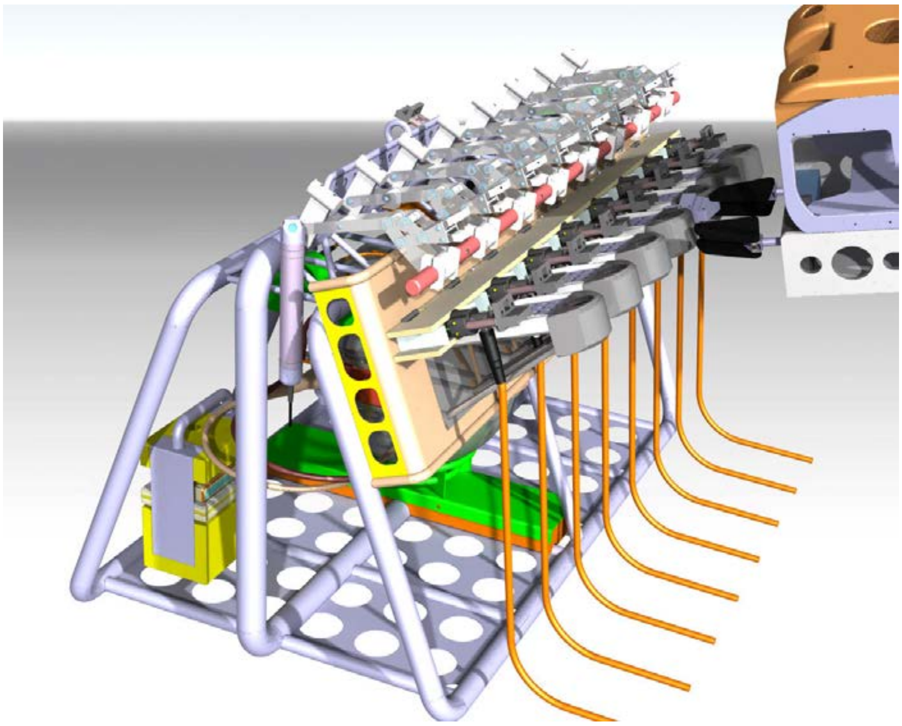

Figure 30: Layout of the connection tool implemented on the node

7.4.4. Instrumentation

In order to control the parameters in the node, sensors are installed inside the JB and readout by the CC. They are listed in Table 9.

In addition a current-meter is installed on the frame of the node to measure the intensity and the direction of the sea current. The Doppler current meter selected is the Aquadopp 6000 (version with a single battery pack case) from Nortek company. The Aquadopp 6000m was preferred to the 3000m version due to the housing case in titanium. Since it has to be powered by the 30V AC/DC of the node, an additional internal DC/DC converter was required to lower the voltage to 12 V. This modification was made by the manufacturer. The Aquadopp will be readout in real time by the CC through a module converting its RS232 serial link to Ethernet.

It is expected that the second node which will be built will be equipped with more instrumentation for positioning (hydrophone) and calibration (laser beacon). These devices have not yet been implemented because their readout requires a CLB which is not yet available.

Parameter	Sensor type	Reference	Supplier	Characteristics	Quantity
AC current	Hall probe	AK50C10	LEM	Range: 50A Accuracy: 1%	4
AC current	Hall probe	AT10 B10	LEM	Range: 10A Accuracy: +/-1.5%	8
AC current	Hall probe	AT20 B10	LEM	Range: 20A Accuracy: +/-1.5%	1
AC current	Hall probe	AT50 B10	LEM	Range: 50A Accuracy: +/-1.5%	1
DC current	Hall probe	S764-20	AAC	Range: 20A Accuracy: +/-1%	4
AC voltage	Transformer & divisor bridge	NA	CPPM		
DC voltage	Divisor bridge	NA	CPPM		
Temperature	Thermocouple	Type K			5
Humidity	Capacitive	Linpicco A05	IST	Range: 100% Precision: 3% Output: 0-5 V	1

Table 9: Characteristic of the monitoring sensors of the JB

7.4.5. Mechanical Frame

The node frame is under design and will take into account the specifications given by ORANGE MARINE for deployment and recovery. The maximum dimensions of the frame imposed by the equipment of the ORANGE MARINE vessel are: 3 m long, 1.85 m width and 1.9 m height. The weight in air should be lower than 2.1 tons to simplify transportation onboard, but ORANGE MARINE could accomodate a higher weight. It is planned to build the structure of the frame in titanium to ease the fixation of the components. This will avoid need of insulators to decouple different metallic materials and will prevent corrosion. The frame houses the lateral front panel user ports with the connection tool, the jumpers, the JB, the battery, the current meter and the sea-return electrode.

The sea return electrode cannot be installed from start in its final position due to the ORANGE MARINE requirements for node manipulation. Two possible solutions are under study: installation at the sea surface once the node is launched from the vessel, or deployment on the seabed using the ROV. The electrode is positioned on the frame in such way that it is nowhere closer than 1 m from conductive parts.

The battery is installed in the frame in a such way that the ROV can access it for replacement. The battery will be made lighter (from 19 kg to less than 5 kg in water) with syntactic foam to allow its handling for replacement by the ROV. A dedicated electrical wet mateable connector is installed to connect the battery to the JB. It is a ‘’Nautilus’’ connector provided by the same company as for the user port connectors. The battery port is also equipped with a connection tool like the user ports.

7.5. DU INTERLINKS

The DU interlink is a cable equipped with wet mateable connectors in order to link a 4-DU chain to the node or two DUs of a chain to each other. The interlink specifications result from the topology of the MEUST layout and from the goal to perform DU connections with a light ROV. Due to the relative short length of the link it has a penetrator on one end and a connector on the other end. In the astronomy option, the length of the interlink is 110m within a 4-DU chain, and 80 m, 110m or 140m between the node and DU1 of the 4-DU chain, depending on the position of the chain in the DU array (figure 9). In the ORCA option the length of the interlink will be ~25 m. Interlinks with all sets of lengths will be ordered to accommodate the different distances. The Interlink cable is rolled on the base of the DU for deployment and will be unrolled by the ROV for its connection (section 9.4).

The main specifications of the interlink as extracted from the CCTP [18] are the following:

- 4 fibres reference smf 28
- 2 wires of 2 mm^2
- Voltage: 400 VAC
- Current: 3.5 A max
- Outer diameter of the cable: < 25mm
- Dry cable or equipressure
- Length: 25m, 80m, 110m, 140m

The main specifications of the hybrid wet mateable connectors are:

- 4 optical contacts
- 2 electrical contacts
- Connection/disconnection force: < 60 kg
- Back reflection optical contacts: < -40 dB
- Optical attenuation: < 1 dB

The schematic layout of the DU base with its interlink is shown in Figure 31. In order to avoid an extra hole in the base container of the DU the connection to the next DU is made through a second exit on the interlink penetrator.

In order to decrease the costs in the future, R&D is currently being performed for low cost hybrid connectors. This is based on a patent by CPPM and capitalizes on the development of wet-mateable electrical connectors performed together with industry within the project POWERMATE.

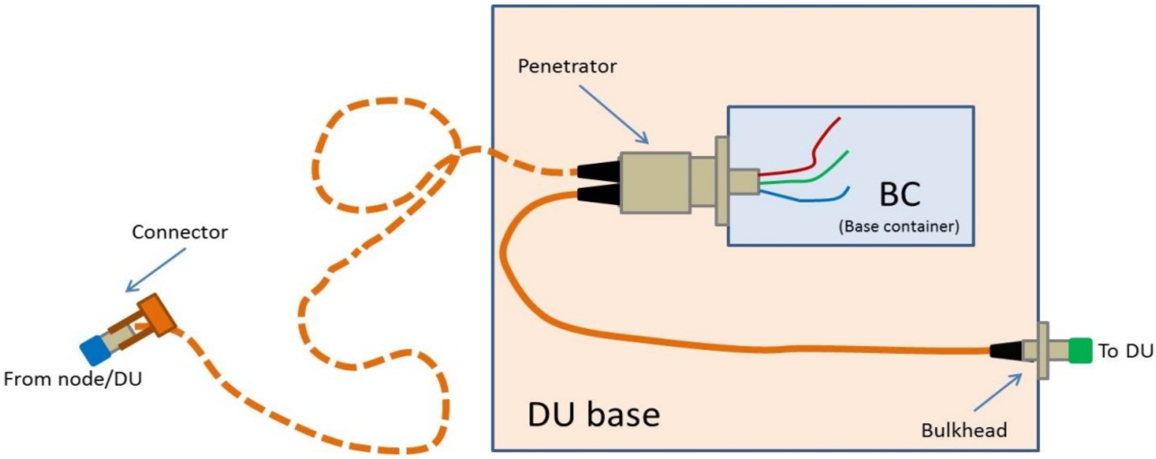

Figure 31: Schematic layout of a DU base with its interlink

8. ONSHORE INFRASTRUCTURE

8.1. POWER STATION

The power station is the shore end of the MEOC and is located near the Sablettes beach. A new power hut has been built close to the ANTARES one (figure 32) to host the PFS and to interface the MEOC optical fibres to those of the land cable leading to the Control Room. The internal dimensions of the building are: 5.6m long, 2.9m width, 2.5m height.

MEUST will use the ANTARES sea return electrodes (4 items in parallel) which will be shared by the two infrastructures until ANTARES is decommissioned.

In order to dissipate the heat generated by the power system an air conditioning system is installed. The total heat to dissipate will be about 20 kW at full load (6 nodes). Presently two air conditioning systems of 12 kW each are installed, which provides one spare for a system limited to 3 nodes. The building has two internal zones (figure 33): a controlled and secured one for the HV power supplies, and another one with free access.

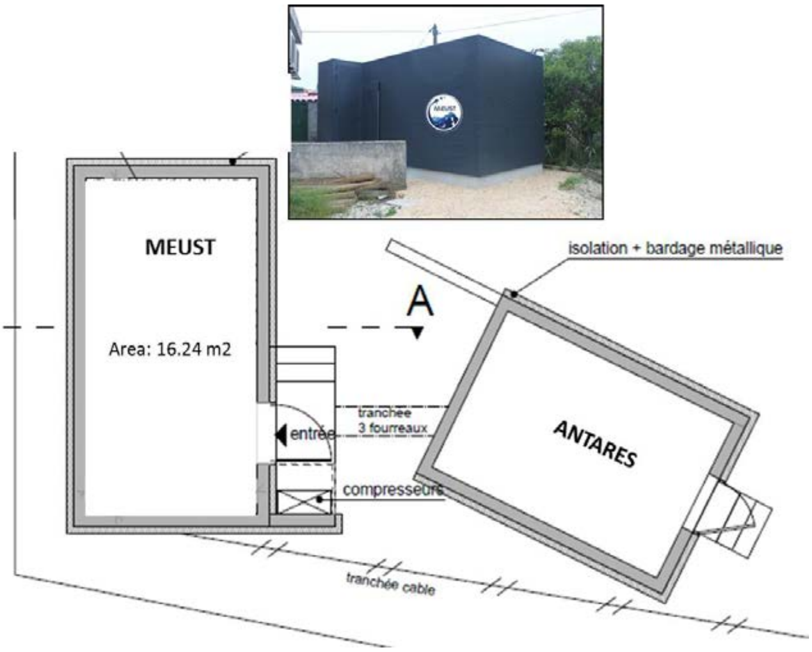

Figure 32: The MEUST power station

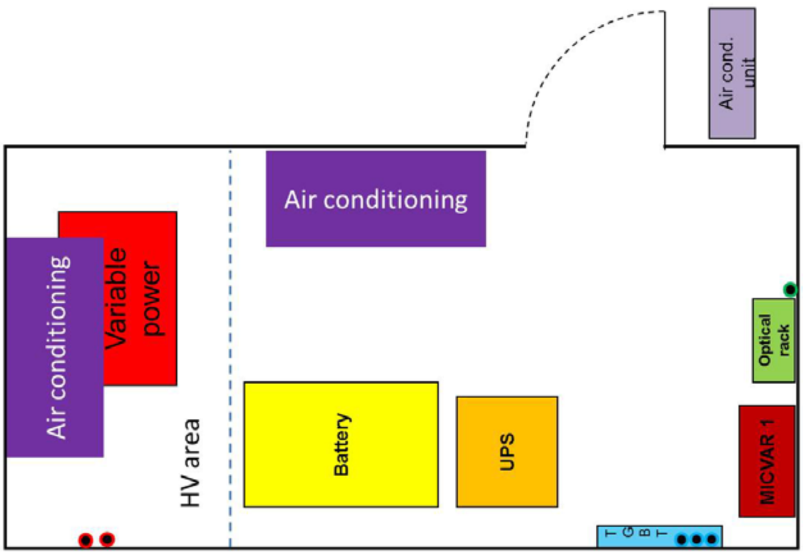

Figure 33: MEUST power station implantation

8.2. CONTROL ROOM

The role of the Control Room is to host the online filtering computer farm and local data temporary storage, and to provide user interfaces to operate and control the infrastructure, the neutrino telescope and the ESS instruments. For a complete MEUST Building Block of 120 DUs, the Control Room should offer:

- Online reception of the MEUST data through an optical cable connected to the shore station and providing the same number of optical fibres as the MEOCs.
- A computer room able to host a PC farm (~100 PC's).
- Connection to the outside world by a 1 Gb/s Ethernet connection, in order to transfer the processed data to the offline storage devices in the IN2P3 Computing Centre (CC-IN2P3 in Lyon).
- Local temporary disk storage of a few tens of TB to account for temporary interruptions of the outside link.

ANTARES experience has shown that most operation shifts can be performed remotely, which minimizes the user space and number of user terminals to be located in the Control Room.

It was initially foreseen to start MEUST operation with a Control Room located in the same building as ANTARES, the Institut Michel Pacha in La Seyne/Mer (IMP). However a very recent tribunal decision has retro-ceded the building from the Lyon University, who had put it at disposal of ANTARES, to the heirs of Michel Pacha. The modalities and schedule of this retrocession are not yet defined, but it is unlikely that the building can be used by MEUST in the long term.

Operation of the components deployed in the MEUST prototype phase (one MEOC, one node, one engineering neutrino DU and ESS instruments) can be performed from the shore power hut, implementing an external Ethernet connection to the CPPM and the CC-INP23.

Figure 35: Location of the new Brégaillon building in La Seyne / Mer.

For the longer term, construction of a new CNRS building is expected in the coming years. The building will be shared between the CNRS institutes INSU and IN2P3 and will be located near IFREMER/DT-INSU in the Brégaillon area of La Seyne sur Mer (figure 35). It will provide direct access to the sea. Part of the building will be dedicated to MEUST, including a control room, some offices and a small workshop for a total surface area of 160 m^2. A shared part of 1400 m^2 will comprise a computer room for the PC farm, a hall to perform integration activities and additional meeting rooms.

9. INFRASTRUCTURE DEPLOYMENT

9.1. ADMINISTRATIVE PROCEDURES

The detector is installed in the French Exclusive Economic Zone (EEZ), while the cable is mainly in the territorial waters. The installation of an infrastructure on the seabed requires some authorizations from the French administration. A specialized company, In Vivo, has been appointed to help identifying the procedures to apply for authorizations, constitute the files and follow the administrative process. The procedures have been launched beginning of July 2013 with an expected duration of 10 months minimum [20]. They are limited to the prototype phase of MEUST with one MEOC, one node, one DU and one instrumentation line. Once the actual detector array to be deployed on MEUST is defined, a new authorization procedure will have to be launched in similar conditions.

The on-going administrative procedures include two main streams:

- A ‘’demande de concession’’ [21] to get authorisation to use the public domain on the seabed.
- A ‘’Loi sur l’eau’’ request [22] to check the environmental impact of the infrastructure.

The two procedural streams are based on a common impact study which has been completed in June 2013 [21, 22]. In addition to bibliographic compilations, field measurements have been performed, including a survey of the posidonia area in the Sablettes bay and a ROV survey of the MEOC route down to a depth of 500 m.

9.2. MAIN CABLE

The installation of the MEOC will be done by ORANGE MARINE, the company selected after public tender. Sea operations will involve the R. Descartes or R. Croze ships which are specialized in telecommunication cable laying and repairing. The route of the cable (figure 36) has been defined by ORANGE MARINE [23] to account for the seabed profile and existing cables in an optimal way. An extra length of about 4000 m of cable is added in a ‘’S’’ shape to allow a safe recovery of the cable in case of repair, and to avoid a displacement of the nodes in such a case. A bathymetric survey of the full route is expected by the end of 2013 for its final validation.

The MEOC installation is done in two steps chained in the same marine operation: from the ‘’S’’ shape (about 20 km from shore, 2500 m depth) to shore, and then from the node position to the ‘’S’’ shape. The two cable sections are then jointed using a Universal Joint, the standard joint used to repair telecommunication cables. This sequence simplifies the lay down of extra cable length on the seabed.

The detailed deployment sequence is the following:

- Cable end at the ‘’S’’ shape position is installed on a buoy.
- Cable laying up to the shore.
- Onshore connection in the power station.
- Ship route to node position.
- Cable end (terminated) laid on the sea floor with over length.
- Cable laying up to the ‘’S’’ shape position.
- Jointing of the 2 parts of the cable onboard.
- Electrical and optical tests from shore.
- Cable laying at the “S” shape position.

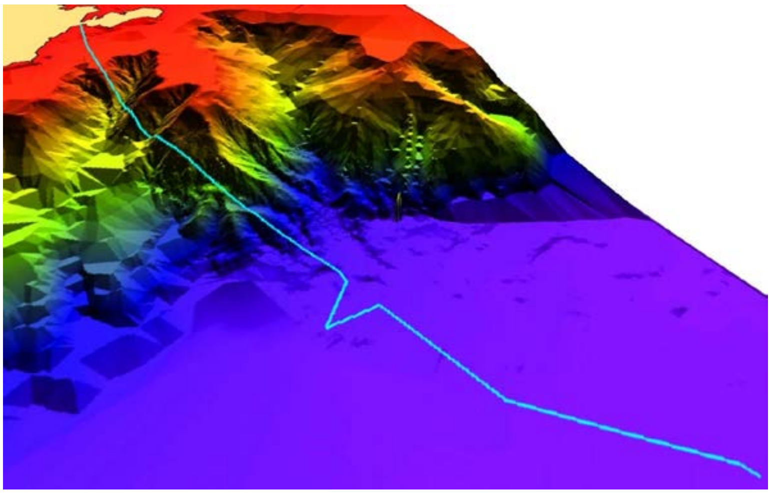

Figure 36: the MEUST MEOC route

The expected duration of the MEOC deployment is 3 days including the onshore infrastructure work on the beach and the connections in the power station. Due to the impossible Sablettes beach access during summer the cable installation cannot occur from ~mid-June to ~mid-September. In case the first node is not deployed at the same time as the MEOC, a deep sea plug made with a UJ will terminate the cable and the fibres will be spliced in order to make a loop for an onshore monitoring.

For maintenance it is planned to introduce the MEUST MEOC into the MECMA agreement as was done for ANTARES. This allows a quicker and cheaper repair of the cable in case of failure.

9.3. NODES

The deployment of the MEUST nodes will be done by ORANGE MARINE. The installation of the first node could be done together with the MEOC installation, or later independently. The main issues for this operation are the management of the two cables connected to the node, and the precise positioning of the node on the seabed. The procedure to deploy the node has been studied by ORANGE MARINE [24]. For the first node, the main sequence of the procedure is the following (figure 37):

- The MEOC end is dragged from the seabed (if it was previously deployed) and attached to a buoy.
- The end of the inter-node link to the next node is weighted and laid on the seabed with a dragging tail, keeping on board the other end of the link.
- The MEOC node end is recovered on the boat.
- The 2 cables (MEOC and inter-node link to next node) are joined on the boat with the two 80 m cables of the node using UJs.
- Functional tests of the node and the MEOC.
- Launching of the node in the sea.
- Descent of the node on the seabed.
- Tests from shore and release of the node if tests are successful.

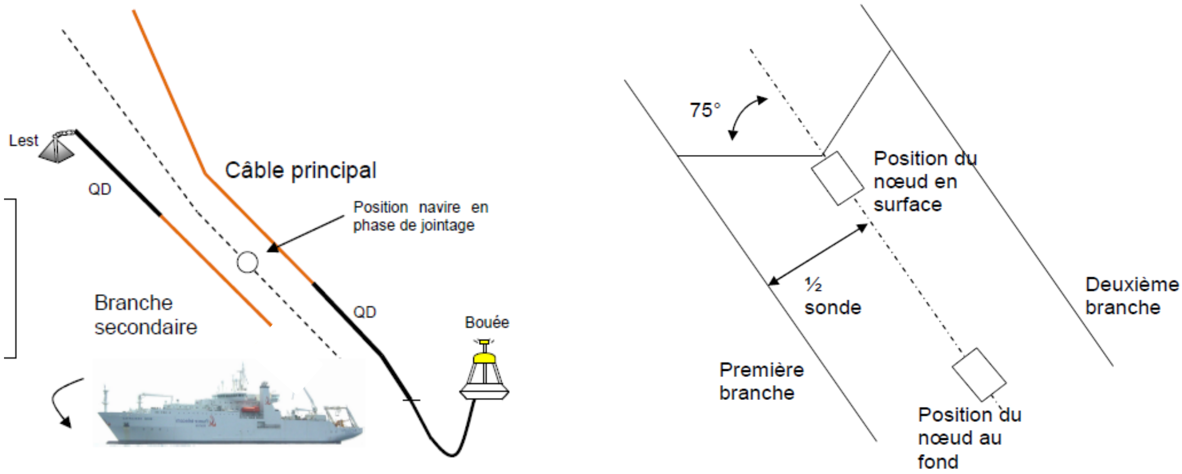

Figure 37: Configuration during node deployment

For repair purpose it is considered to have the possibility to retrieve a node. After disconnection of the user ports and installation of a recovery line by a ROV, the node is brought to the surface. Adjacent inter-node links are collected simultaneously when the ship is moving according to the winch speed, in order to ensure a return pose of the node and its adjacent links.

Tests with a preliminary mock-up of the node have been performed on the R. Croze vessel in the harbour to verify the deployment sequence up to the sea surface (figure 38). A set of two tests at sea, first at 1000m depth and then at 2500 m, are planned with a mock-up of the final node to validate the full procedure and to check the behaviour of the node and cables during the operation in the final configuration.

Figure 38: Handling tests with a node mock-up

9.4. DETECTION UNITS

The installation of the neutrino detection array has to be made sequentially, with the DUs deployed and connected in a defined order to allow the full array to be deployed without the ROV entering the field of the DUs. Each 4-DU chain is deployed starting from the DU closest to the node (DU1) and ending with the most distant one (DU4). Depending on the node, deployment of the 4-DU chains has to start from the middle 4-DU chain or from a side 4-DU chain. For safety, after deployment of the full array, ROVs will not be allowed to go inside the DU field, which implies no maintenance of the DUs or CUs.

9.4.1. DU deployment

The DU is deployed packed in a specific frame, the LOM (figure 39), designed for this purpose. Once on the seabed the DU is connected to the node or the previous DU using a ROV and then functionally tested from shore. If the test is successful, the unfurling of the DU is triggered by an acoustic signal from the surface. Otherwise the DU is recovered for repair. It is not foreseen to recover unfurled DUs except for prototypes.

The development of the LOM and associated deployment procedures is made by NIOZ/Nikhef. If necessary the generic procedures will be adapted to the specificities of the actual vessel used for deployment.

The installation of the DUs will be performed under the responsibility of the MEUST team. It is planned to use the Castor II vessel from Foselev Marine Company, the same boat as used for deployment of the ANTARES lines. The deck of the vessel is large enough to allow deployment of several DUs in a single operation.

The deployment sequence is as following:

- The LOM is taken by one of the 3 cranes of the ship.
- The LOM is launched in the sea.
- The deep sea winch is attached to the LOM and the crane disconnected.
- The LOM is lowered until it arrives at 100m from the seabed.
- If necessary the vessel is moved to reach the target mooring point thanks to the navigation positioning system (section 9.5).
- When the DU is at its expected position, the LOM is further lowered under transponder and tensiometer control until the base touches the bottom.
- The ROV performs the connection and some functional test of the DU are performed.
- If tests are successful, the transponder is released and the deep sea winch cable is recovered on board.

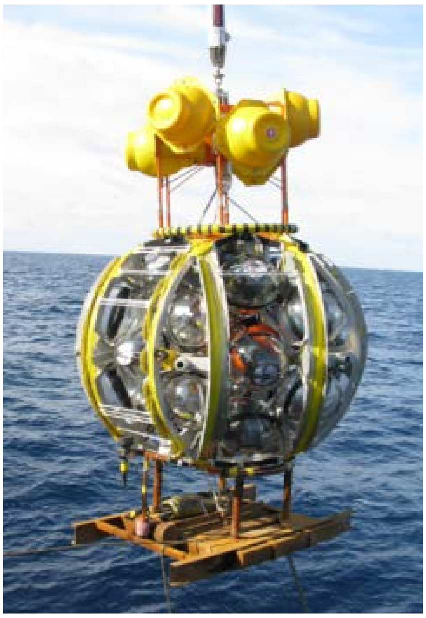

Figure 39: The prototype LOM during DU deployment tests

9.4.2. DU Connections

The connection of the DU interlink to the infrastructure is made with a ROV. Contracts have been signed with Comex for the APACHE light ROV and with IFREMER for the Victor 6000 work class ROV. IFREMER is also developing a new Hybrid ROV (light ROV) which is expected to be available in 2014 and could be an alternative solution for the future. Use of light ROVs is the preferred solution to connect the DUs since they offer a better availability and lower operation costs. This however requires some specific connection tools to be developed (section 7.4.3) in order to ease the operations. The simplified procedure for connection is:

- The ROV takes the interlink stored on the DU base.

- The ROV moves in direction of the connection point at a sufficient altitude to keep the cable floating and minimize the effort.
- Once near the connection point, the ROV goes down to the sea bottom.
- The ROV puts the interlink connector on the cleaning support.
- Inspection and cleaning of the connector with a water jet.
- Removal of the plug, inspection and cleaning of the bulked connector.
- The ROV takes the interlink connector and puts it on the guide in front of the bulkhead (ROV in flying mode).
- The ROV takes the connection tool and connects the connector (ROV in flying mode).
- The connection is checked from control room (OTDR measurement for optics).
- The ROV performs a survey of the interlink to check that everything is clear.

The validation of the use of a light ROV for this sequence of operations is being made by steps. A light ROV was successfully used for the first time for the connection of the ANTARES ESS line early 2013, using a purpose made connection tool. For MEUST, a prototype connection tool has been built based on the same concept as for the ANTARES ESS line. It has been tested in lab and shallow water tests (figure 40) and will undergo final validation in deep sea tests.

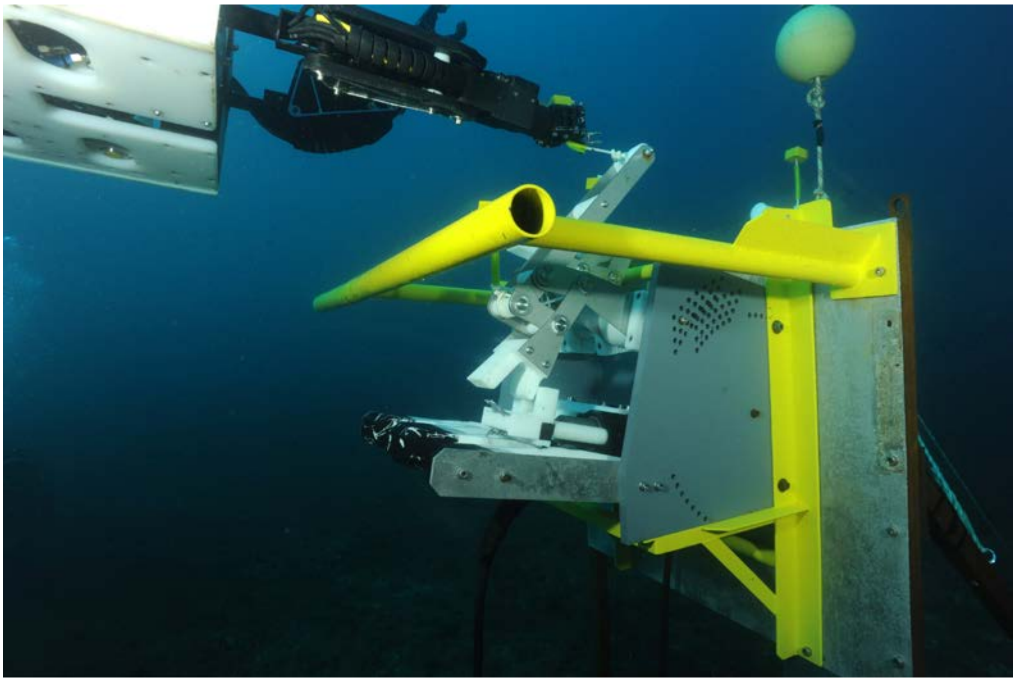

Figure 40: MEUST prototype connection tool and Comex ROV during shallow water tests

9.5. NAVIGATION POSITIONING SYSTEM

Two acoustic positioning systems are needed for MEUST: one used during detector installation (navigation positioning system) for real time measurement of the positions of objects under sea with a precision of a few meters, and one used during detector operation (relative positioning system) for high precision monitoring (< 10 cm) of the relative position of the DOMs in space. The latter is not part of the MEUST infrastructure and is under the responsibility of KM3NeT, but it could require installation of autonomous transponders until a sufficient number of Calibration Bases is connected to the infrastructure. The main functions of the navigation positioning system are:

- To monitor the position of the ROV in operation with an accuracy of a few meters with respect to a known reference;
- To monitor the position of the DUs during their deployment in order to place them as close as possible to their nominal geographic position. The required accuracy is a few meters with respect to a known reference.
- To precisely measure the absolute geographical 3D-position of the DUs once anchored on the seabed.

The main requirements for the navigation positioning system are a range higher than 3000m, a real time precision better than 5m ($\sigma < 3$m) for navigation, and a precision better than 1m for objects fixed on the seabed.

Two commercial systems are currently available: the Ultra Short Base Line system which is very attractive as it is cheap and simple to use (1 emitter and 1 compact set of receivers) but at the edge of the required precision, and the Long Base Line system which is more expensive, requires several transponder beacons but provides a better precision. The latter has been used in ANTARES up to now but the former is now the most commonly used in the field and the preferred solution for MEUST. A tender will be launched in fall 2013 to buy a complete system including the control and calculation software.

10. PROJECT ORGANIZATION

The MEUST project is presently approved for its prototype phase, including deployment of one MEOC, one node, one neutrino engineering DU and ESS instruments. This prototype phase is expected to end in 2015. Its organisation is described in the following.

10.1. ORGANIZATION STRUCTURE

The MEUST prototyping phase is structured as shown in figure 41 to manage the various work packages. The interface with KM3NeT is done through the KM3NeT-Fr site manager, member of the KM3NeT management team, and the communication with EMSO is made through the INSU project leader.

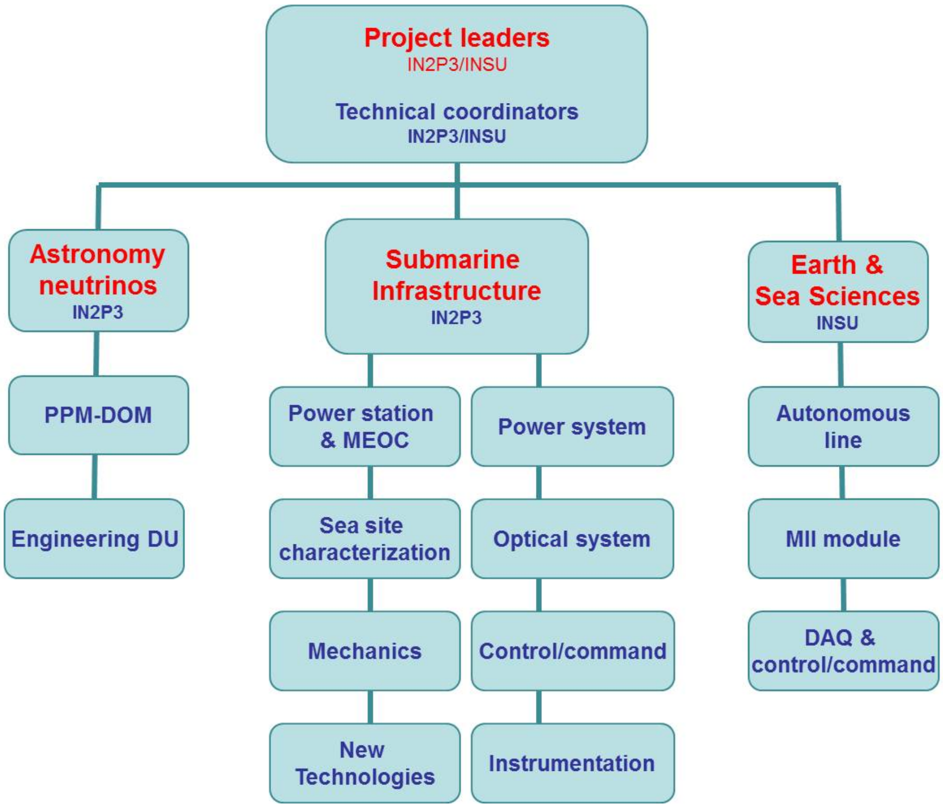

Figure 41: Organigram of the prototype phase of the MEUST project

10.2. SCHEDULE AND DEVELOPMENT PLAN

The schedule for development and installation of the MEUST infrastructure is given in figure 42. The design and realization of the MEUST infrastructure benefit from the return of experience of ANTARES, which has been using similar components. However the overall system is quite different and the new solutions which are implemented need to be carefully validated. This is made step by step, from qualification of the bare components up to qualification of the systems, including realization of prototypes when needed. This process is ended by a Product Readiness Review (PRR) to validate start of production. Off the shelf components are tested in operational conditions to verify their performances. Specific products or tools (MEOC penetrator, wet-mate connection tool, etc…) pass through a qualification process to validate them.

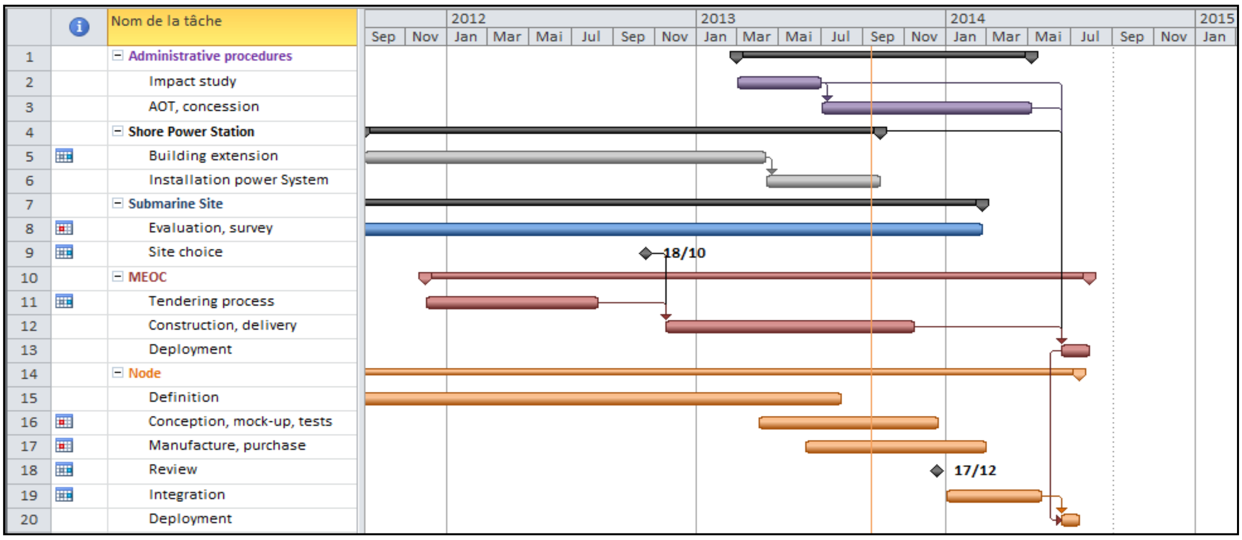

Figure 42: Planning of construction of the MEUST infrastructure

At present the power system has been partially tested [25] using the final Power Feed Supply, a simulated MEOC, a node transformer and resistive loads to simulate the DUs. The calculations and overall behaviour of the system are validated. The optical network components for the DUs are under finalization, test benches will be built to test the data transfer first with one wavelength and then with about 15 wavelengths. This test is expected to be done with the support of a specialized laboratory in optics. The control/command components have been chosen, a test bench built and the system has been under tests for a few months. Part of the system has been used for the power test above.

The validation of the final configuration of the JB is presently being done using an operational mock-up with final components, which allows verifying the mechanical assembly and performing some functional tests of the power system with the control/command. For the final JB, the design of the internal parts allows independent pre-assembly of the lower part and of the trays of the upper part. The JB assembly is simplified by the fact that nothing is attached to the hemispheres but that all the components are fixed on the diaphragm with connections to the annulus spacer. Before final closure the upper part of the JB will be filled with dry air. The detailed assembly procedure of the JB, including acceptance tests, will be documented.

The node assembly will be performed in the CPPM hall in a dedicated and delimited area. A special care will be taken for the handling and cabling of optical fibers and the installation of the wet mateable connectors. All items to be integrated must have their follow-up card mentioning their readiness for integration. The node assembly does not raise major issues and will be documented.

Installation in the sea requires some training and tests as the operations are complex. Handling of the node on the vessel has been validated in a harbour test performed with a preliminary mock-up. A mock-up of the final node will be built to perform sea tests in shallow water and then in deep sea before the deployment of the operational node. Dedicated tests have started and will go on to fully qualify the APACHE ROV for the expected connection operations. The deep sea tests with the DU connection tool are expected to be completed before end of 2013.

Within the MEUST prototype phase, deployment of the MEOC is planned before summer 2014, and the first node should be installed shortly after. Connection of engineering prototypes of one KM3NeT DU and of EMSO instruments is foreseen latest beginning 2015 in order to fully validate the functionalities of the infrastructure.

10.3. RESOURCES

10.3.1. Financial resources

The budget of the MEUST prototype phase is 7 M€, equally shared between CNRS and the European Regional Fund (FEDER), within a CNRS-FEDER agreement signed in 2011. Additional financial support was also granted by Aix-Marseille University and the city of Marseille at a lower level. The deadline for spending the funds is mid June 2015 and the technical devices must be ready for deployment by end of 2014. The budget covers the infrastructure with one MEOC and one node (5 M€), the development of the neutrino DUs with one engineering DU installed (1 M€), and some instrumentation for Sea Sciences with one Interface Module and one mooring line (1 M€). The financing of the new CNRS building is outside the CNRS-FEDER agreement. It is expected to be provided by CNRS and local funds.

Building and deploying an extra node would cost about 0.6 M€, whereas installing a second MEOC is estimated to 0.1 M€ (ANTARES MEOC rerouting option) or 1.8 M€ (new MEOC option).

10.3.2. Human ressources

The development of the MEUST infrastructure is in charge of IN2P3 with a contribution of about 13 FTE per year. It is performed in collaboration with INSU and with subcontracts to industry. MEUST also benefits from the KM3NeT Collaboration technical support on optics, power and detector footprint.

10.4. QUALITY

The MEUST infrastructure must operate without maintenance for at least 15 years at a depth of 2500 m in an aggressive deep-sea environment. Meeting these requirements requires a high level of quality. Main focus is made on the traceability of products, documentation and risk analysis.

A PBS (section 10.5) has been set-up. It is the base for the identification of products and for the item list.
The traceability of products is achieved by:
- labelling each product with a PBS number and a unique serial number,
- recording the product arrival in a form,
- releasing a follow-up card which accompanies the product up to its integration and its registration in the Oracle database designed by KM3NeT,
- documenting each technical test with a test protocol report and a test result report,
- implementing a system for the management of non conformities using a dedicated template.

Reviews will be organized before launching construction of the main items and after the main sea operations, for example the MEOC or node deployments. Assembly procedures of the main components will be documented. Actions on risk analysis have been started and have to be completed.

The documentation of the MEUST project is stored in the EDMS/IN2P3 data base with restricted access. An arborescence has been set-up to ease the storage and recovery of the documents. Those which are useful for KM3NeT are also stored in the KM3NeT document server.

A quality plan describing the organization of the project and the quality procedures associated to each action will be written.

10.5. PBS

A Product Breakdown Structure of the MEUST infrastructure has been defined and is given in Annex 2. It includes the base of the DU since this component is the DU interface to the infrastructure.

11. ABBREVIATIONS

AC: Alternative current
CB: Calibration Base
CC : Control Command
CLB : Central Logic Board
CTD : Current Temperature Depth
CU : Calibration Unit
CWDM : Coarse Wavelength Division Multiplexing
DC : Direct Current
DOM : Digital Optical Module
DU: Detection Unit
DWDM : Dense Wavelength Division Multiplexing
EDFA: Erbium Doped Fibre Amplifier
EDMS: Engineering Data Management System
EEZ: Exclusive Economic Zone
EMSO: European Multidisciplinary Seafloor Observatory
ESS: Earth & Sea Sciences
HV: High Voltage
IMP: Institut Michel Pacha
IO: Input Output
ITU: International Telecommunication Union
IU: Instrumentation Unit
JB: Junction Box
KM3NeT: KM^3 Neutrino Telescope
LOM: Launcher for Optical Module
MEOC: Main Electro-Optical Cable
MII: Module d’Interface Instrumenté
OTDR: Optical Time Domain Reflectometer
PBS: Product Breakdown Structure
PFS: Power Feed Supply
PMT: PhotoMulTiplier
PRR: Product Readiness Review
ROV: Remote Operated Vehicle
SFP: Small Form-factor Pluggable
TOT: Time Over Threshold
UJ: Universal Joint
UPS: uninterruptible Power Supply
VEOC: Vertical Electro-Optical Cable

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ANNEX 1 : Coordinates in m of the DUs and nodes presented in the figure 9.

DU#	x	y
1	-270	-550
2	-400	-490
3	-310	-470
4	-230	-459
5	-130	-450
6	-37	-461
7	-460	-425
8	-383	-385
9	-290	-395
10	-170	-380
11	-80	-389
12	3	-393
13	-523	-300
14	-410	-305
15	-320	-320
16	-235	-325
17	-140	-318
18	-40	-325
19	40	-311
20	128	-319
21	-563	-230
22	-460	-250
23	-357	-227
24	-275	-245
25	-195	-240
26	-100	-255
27	4	-225
28	98	-240
29	180	-220
30	270	-250
31	-580	-140
32	-487	-162
33	-406	-146
34	-322	-165
35	-235	-157
36	-145	-175
37	-54	-165
38	54	-160
39	140	-140
40	240	-180
41	320	-160
42	420	-150
43	-525	-80
44	-442	-73
45	-350	-75

DU#	x	y
46	-265	-65
47	-185	-85
48	-98	-82
49	-15	-95
50	70	-77
51	210	-100
52	285	-72
53	365	-95
54	470	-80
55	-490	-5
56	-400	-3
57	-320	3
58	-220	3
59	-140	15
60	-50	10
61	75	25
62	155	-25
63	235	-1
64	317	-13
65	415	-15
66	490	10
67	-460	75
68	-360	87
69	-260	85
70	-180	101
71	-80	85
72	15	90
73	110	95
74	183	68
75	265	70
76	360	60
77	460	80
78	560	60
79	-415	145
80	-317	155
81	-240	175
82	-125	160
83	-30	170
84	50	153
85	135	175
86	215	135
87	325	156
88	400	150
89	480	175
90	580	140

DU#	x	y
91	-280	240
92	-190	230
93	-95	235
94	10	230
95	95	250
96	180	247
97	270	224
98	370	236
99	460	265
100	542	225
101	-128	319
102	-35	300
103	40	320
104	132	320
105	230	315
106	320	335
107	414	317
108	530	305
109	5	405
110	99	394
111	180	395
112	260	390
113	385	390
114	450	440
115	35	460
116	125	465
117	220	470
118	300	460
119	380	490
120	290	540

node#	x	y
1	-352	200
2	-490	-355
3	55	-395
4	-50	390
5	490	360
6	350	-210

ANNEX 2: PBS of the MEUST infrastructure

1	Onshore Infrastructure						
		1 Shore Station					
			1 Civil Infrastructure				
				1.1.1.1 Building			
				1.1.1.2 Electricity			
				1.1.1.3 Air Conditioning			
			2 Telescope DAQ				
				1.1.2.1 Hardware			
					1.1.2.1.1 Monitoring and Control Server		
					1.1.2.1.2 Data Filter Server		
					1.1.2.1.3 Data Storage		
					1.1.2.1.4 Database Server		
					1.1.2.1.5 Quasi-online Reconstruction Hardware		
					1.1.2.1.6 Clock System		
						1.1.2.1.6.1	GPS System
					1.1.2.1.7 Backup System		
				1.1.2.2 Software			
					1.1.2.2.1 Operation System		
					1.1.2.2.2 Run Control		
					1.1.2.2.3 Data Filter		
					1.1.2.2.4 Data Writer		
					1.1.2.2.5 Database		
					1.1.2.2.6 Quasi-online Reconstruction Software		
					1.1.2.2.7 Slow Control		
					1.1.2.2.8 Detector Monitoring		
					1.1.2.2.9 Clock Control		
				1.1.2.3 Firmware			
			3 ESS DAQ				
				1.1.3.1 Hardware			
				1.1.3.2 Software			
			4 Infrastructure Control Command				
				1.1.4.1 Hardware			
				1.1.4.2 Software			
					1.1.4.2.1 Power Station		
					1.1.4.2.2 Node		
					1.1.4.2.3 Optics		
						1.1.4.2.3.1	Optical Control
			5 Network Infrastructure				
				1.1.5.1 Optical Network			
					1.1.5.1.1 Laser Bank		
					1.1.5.1.2 Modulator		
					1.1.5.1.3 Optical Timing Electronics		
					1.1.5.1.4 DWDM		
					1.1.5.1.5 Optical Amplifier		
					1.1.5.1.6 Optical Receiver		
							1 Receiver for DC and TC
							2 Receiver for data from DOM
				1.1.5.2 Electrical Network			
					1.1.5.2.1 Shore Station Crate		
					1.1.5.2.2 Ethernet Backbone		
					1.1.5.2.3 Ehternet Switch		
			6 Access & Security Service				
				1.1.6.1 Security System			
				1.1.6.2 Access Control			
				1.1.6.3 Auxiliaries			
			7 Mains Power System				
				1.1.7.1 Power Backup System			
		2 Power Feed Station					
			1 Civil Infrastructure				
				1.2.1.1 Building			
				1.2.1.2 Electricity			
				1.2.1.3 Air Conditioning			
			2 Power System				
				1.2.2.1 UPS			
				1.2.2.2 Variable Power			
				1.2.2.3 Electrodes			
			3 Control System				
				1.2.3.1 Ethernet Switch			
		3 Onshore Interconnection					
			1 Cable				
			2 Power Feed Station Termination				
			3 Shore Station Termination				

2	Deep Sea Network					
	1 Link Sea-Shore					
		1 Main Electro-Optical Cable (MEOC)				
		2 Sea Termination				
		3 Shore Termination				
		4 Joint				
	2 Inter-Node Link/JB Link					
		1 Cable				
	3 Junction Box (JB) or Node					
		1 Mechanics				
			2.3.1.1 Frame			FR
			2.3.1.2 Support			
				2.3.1.2.1 JB Container Support		
				2.3.1.2.2 Electrode Support		
				2.3.1.2.3 Battery Support		
				2.3.1.2.4 Jumper Support		
				2.3.1.2.5 Current Metre Support		
			2.3.1.3 Interface and Auxiliary			
				2.3.1.3.1 Wet-Mate Connector Panel		
				2.3.1.3.2 Stress Relief Device		
				2.3.1.3.3 MEOC Bending Limitor		
		2 JB Container				
			2.3.2.1 Hemisphere			
				2.3.2.1.1 Upper Hemisphere		
				2.3.2.1.2 Lower Hemisphere		
			2.3.2.2 Container Screw			
			2.3.2.3 Annulus Spacer			
			2.3.2.4 O-Ring Seal			
			2.3.2.5 Diaphragm			
			2.3.2.6 Support			
				2.3.2.6.1 Transformer Support		
				2.3.2.6.2 Optical Tray		FR:OPTTRAY
				2.3.2.6.3 Power Tray		FR:POWTRAY
				2.3.2.6.4 Control Tray		FR:CTRLTRAY
				2.3.2.6.5 Charger tray		
			2.3.2.7 Oil			
		3 Instrumentation				
			2.3.3.1 Current Meter			
				2.3.3.1.1 Sensor		
				2.3.3.1.2 Cable		
			2.3.3.2 Internal Sensor			
				2.3.3.2.1 Current Sensor		
				2.3.3.2.2 Voltage Sensor		
				2.3.3.2.3 Temperature Sensor		
				2.3.3.2.4 Humidity Sensor		
		4 Power Component				
			2.3.4.1 HV Circuit			
				2.3.4.1.1 Transformer		
				2.3.4.1.2 Interrupter		
				2.3.4.1.3 Electrode		
			2.3.4.2 Secondary Circuit			
				2.3.4.2.1 AC/DC Control		
				2.3.4.2.2 AC/DC Optics		
				2.3.4.2.3 Contactor		
				2.3.4.2.4 Breaker		
			2.3.4.3 Secured Circuit			
				2.3.4.3.1 Battery		
				2.3.4.3.2 Battery Cable		
				2.3.4.3.3 Charger		
				2.3.4.3.4 Backup Board		
		5 Control Command System (CC)				
			2.3.5.1 Ethernet Switch			
			2.3.5.2 Analog Module			
				2.3.5.2.1 Input Module		
				2.3.5.2.2 Output Module		
				2.3.5.2.3 Thermocouple Input Module		
			2.3.5.3 Digital Module			
				2.3.5.3.1 Input Module		
				2.3.5.3.2 Output Module		
				2.3.5.3.3 Serial Link Module		
			2.3.5.4 Interface Board			
		6 Optical Component				
			2.3.6.1 Optical Amplifier			
			2.3.6.2 Splitter			
			2.3.6.3 Optical Filter			
				2.3.6.3.1 DWDM/DWDM Filter		
				2.3.6.3.2 CWDM/CWDM Filter		
		7 Connection				
			2.3.7.1 Jumper			
			2.3.7.2 Diaphragm Connection			
				2.3.7.2.1 HV Insulator		
				2.3.7.2.2 Thermocouple Connector		
				2.3.7.2.3 Power Feed-Through		
				2.3.7.2.4 CC Connector		
					2.3.7.2.4.1 230V 10-pin Connector	
					2.3.7.2.4.2 30V 8-pin Connector	
					2.3.7.2.4.3 30V 16-pin Connector	
			2.3.7.3 Annulus Spacer Connector			
				2.3.7.3.1 Current Meter Connector		
				2.3.7.3.2 Electrode Connector		
				2.3.7.3.3 Test Supply Connector		

3	Detection Unit					
	1 Interlink Cable					
		1 Inter-DU Cable				
	2 Detection Unit Foot					
		1 Structure and Dead Weight (DW)				
			3.2.1.1 Mechanics			
				3.2.1.1.1 LOM Support		
				3.2.1.1.2 Wet-Mate Connector Tool		
				3.2.1.1.3 Interlink Storage		
				3.2.1.1.4 Container Support		
				3.2.1.1.5 Dead Weight		
				3.2.1.1.6 Recovery Hooks		
			3.2.1.2 Interface			
				3.2.1.2.1 Interface with Rope		
				3.2.1.2.2 Interface with VEOC		
		2 Base Container				
			3.2.2.1 Container			
				3.2.2.1.1 Cylinder		
				3.2.2.1.2 Tape		
						TAPE1 Tape 1
						TAPE2 Tape 2
				3.2.2.1.3 Internal Supports		
			3.2.2.2 Optical Component			
				3.2.2.2.1 Optical Splitter		
						SPLIT1TO2 Splitter 1:2
						SPLIT1TO20 Splitter 1:20
				3.2.2.2.2 Optical Amplifier		
				3.2.2.2.3 Optical Interleaver		
						50TO100GHZ 50-100GHz Interleaver
						100TO200GHZ 100-200GHz Interleaver
				3.2.2.2.4 Optical Filter		
					1 Add-and-Drop filter DC	
					2 Add-and-Drop filter TC	
				3.2.2.2.5 DWDM		
			3.2.2.3 Electronic Component			
				3.2.2.3.1 Electronics for DC		
				3.2.2.3.2 Electronics for TC		
				3.2.2.3.3 Power Converter		
						ACDC AC/DC Converter
						DCDC DC/DC Converter
				3.2.2.3.4 Power Conversion Board (PSS)		
				3.2.2.3.5 Power Control System (PCS)		

5	Sea Operation System		
	1 Sea Surface Operation		
		1 Surface Vessel	
		2 Deployment Tool	
	2 Deep Sea Operation		
		1 Deep Sea Submersible	
		2 Deep Sea Tool	
	3 Navigation Positioning System		