Connecting long-term seafloor observatories to the shore

by Gary Waterworth, Alcatel Submarine Networks, England; Nazeeh Shaheen, Nuatronix Maripro Golta, USA and Steve Thumbeck, Ocean Design, USA

Since the 1800s, oceanographers have been exploring and sampling the Earth’s oceans using research vessels as their primary observation platform. Over time, this work has produced a vast amount of data with limited resolution. Analysis of this information has resulted in the growing recognition of how complex the process is that takes place in and below the world’s oceans.

This early work has been termed the “exploration phase,” and scientist now embark upon the new “understanding phase,” where the existing tools-of-the-trade cannot answer all the questions that have been posed. Scientists are beginning to observe Earth-ocean systems by entering the ocean environment for ever-increasing periods. Long-term access to the seafloor and water column is essential for the study and predictive modelling of temporal and episodic processes and events.

Cabled ocean observatories

In order to facilitate an efficient study of ocean sciences, a relatively new tool is being advocated with innovative facilities that will provide unprecedented levels of power and communication to access and manipulate real-time sensor networks deployed in many different seawater environments. These new facilities are cabled ocean observatories. These facilities accommodate real-time information flow, high power and associated data archives that will allow entirely new approaches to this corner of science. Cabled ocean observatories facilitate the possibility of bringing the seafloor to the student’s classroom or the general public’s own home, dramatically impacting the general understanding and attitudes toward the ocean sciences, and science in general.

Many ocean observatory programmes are well under way around the world, including some that plan to implement major cabled ocean observatory infrastructure. Programmes under consideration, or already being implemented, include the Advanced Real-Time Earth Monitoring Network in the Area (ARENA) around the Japanese Archipelago and the North East Pacific Time-Integrated Undersea Networked Experiment (NEPTUNE), located off the North America Pacific coast. The European Seafloor Observatory Network (ESONET) has several similar initiatives, including CELTNET, which plans to locate up to 15 observatory node locations around the Porcupine Sea Bight and Porcupine Abyssal Plain, 600 km off the southwest coast of Ireland.

Benefits of cabled observatories

Cabled observatories out-perform traditional short-term experimentation platforms such as moorings or landers in two main areas: power management and real-time communications. Power is supplied from the shore through a cable via a single conductor to the science node. The return takes place through the seawater using an electrode at the science node. The power requirements of a single science node observatory can be as much as 10 kW. This high-power capability is available for the complete system lifetime of 25 years using power feeding equipment in the shore station. Short-term observatories are limited to battery power of a few hundred amp-hours at low voltage. This limits the operation of cameras and lights that consume as much as 200 W, to only a few hours per mission before the observatory or modules are replaced. Logistics and costs often limit this replacement cycle to three or six months, resulting in the cameras and other power-hungry experiments being available for less than 0.1% of the year. The other area of high
performance that cabled observatories bring to the scientist is the ability to use the optical fibres of the cable for high-speed broadband communication to and from the shore. Optical fibres also minimise the transmission delay in sending data back to shore. Accurate timing distribution is, therefore, possible with fibre-based protocols such as network time protocol. With further enhancements, it might be possible to achieve a timing accuracy of 1 µs. This enables the synchronisation of monitored episodic events, such as seafquakes, which is crucial for some multiple node observatory concepts.

**Observatories’ infrastructure**

No two cabled observatory systems are the same. Some are short coastal systems with a single cable landing, one science node and limited instrumentation; other, so-called regional systems might have several cables coming ashore, multiple nodes and hundreds of science instruments. However, many of the elements and technology choices are similar. Most of these are also readily available as commercial off-the-shelf products. The key elements of a cabled observatory infrastructure are a shore station, submarine optical cable and installation, a science node and science instrumentation.

**Shore station**

A shore station is required to locate the medium voltage (up to 12 kV) power feeding equipment and the optical transmission line terminating equipment. This station can be close to the shore or several kilometres away from the point at which the cable lands; an ideal location is within a research institute’s premises. The data transmission lines can be back-hauled from the shore station to another location, or connected directly to the internet or private optical network via optical cross connects and routers.

**Submarine optical cable and installation**

Submarine optical cable connects the shore station to the science node, providing suitable protection to the integral optical fibres and the power conductor. The cable can house up to 48 fibres, the number depending on the degree of wavelength division multiplexing and redundancy that is employed. Submarine cables provide varying degrees of protection depending on the deployment depth, seabed conditions and local hazards. Where necessary, and where the seabed structure allows, the submarine cable is buried to depths between 0,8 and 4 m. Modern powerful installation vessels with 130 ton bollard pull are equipped with ploughs that can directly bury the cable quickly and safely down to 3 m during installation.

**Science node**

The submarine cable is connected to the science node via a cable terminating assembly, which provides safe optical and electrical connectivity and adequate axial and torsional strength, even when articulated through 90°. A typical science node consists of the following main elements: a trawler-resistant frame, electrical power converters, data communications equipment, as well as multiple science instrument and extension ports.

**Trawler-resistant frame**

The science node equipment and instrument ports are protected by a fabricated framework with sloping sides to deflect bottom-trawled fishing equipment such as otter boards or beams when the observatory is in less than 2 000 m water depth. This trawler-resistant frame must also provide remotely operated vehicle (ROV) access to the science instrument ports.

**Electrical power converters**

Power supplied from the shore at 10 kV or 400 V must be converted down to a lower voltage for the operation of science experiments and the internal data communication equipment. These power converters must work reliably and efficiently inside pressure-resistant housings. The size of the pressure-resistant housing impacts the overall weight, size and cost of the science node. Therefore, there are significant limits placed on the volumetric space and diameter of the sub-sea power converters. At 90% efficiency, up to 1 kW of locally dissipated power is required to be transferred to the external seawater heat sink, in order to maintain internal component temperatures to around 50°C. As maintenance at the bottom of the ocean is a costly and reasonably complex task, all active and passive components of the science node must meet higher reliability standards than those of their onshore counterparts. This is achieved by way of careful physical design, built-in redundancy, component and assembly selection, construction and qualification. The design of a compact and highly reliable converter is important to a successful science node design.

**Data communications equipment**

Data transport requirements from science experiments, cameras and sensors back to the shore may vary.
from a few megabits per second to 20 Mbps, with an aggregate data rate of up to 1 Gbps from a single node. In addition to this, an overhead needs to be included for system functions such as framing, error retransmission and a time synchronous clock. Data transport from the shore to command cameras, lights, autonomous underwater vehicles and other interactive experiments is also a requirement. In a multi-science node system, the node might also have to handle the system backbone aggregate data of up to 8 Gbps. There are several technologies available with their associated pros and cons. Direct science node-to-shore communication using a few pairs of optical wavelengths and synchronous optical network or synchronous digital hierarchy wavelength division multiplexing transport over distances of less than 500 km without underwater amplification, and up to 13 000 km with amplification, is one option. Shore station to science node, or science node to science node communication using multiplexed channels over gigabit Ethernet links of up to 120 km is another option.

Science instrument and extension ports
To facilitate flexible connectivity to science experiments and sensors, a number of pre-installed and configured science instrument ports are required. These are safely housed and protected within the trawler-resistant frame. A door is provided to allow access to the ROV for connection of the science experiment to the port. The need for flexibility of experiments in terms of duration, type, evolving technology and demands results in a simple-to-reconfigure architecture. Each port is equipped to provide low-voltage power and serial or Ethernet data communications to science experiments or sensors up to 1 km from the science node. They can also be configured to provide optical channels and sufficient power to extend the observatory to remote locations hundreds of kilometres away.

Serviceable science module
It is not economically possible to develop specialist subsea equipment with very low FIT rates. Therefore, some subsea communications or power converter equipment failure is expected over the 25-year lifetime of a system. The science node is designed so that the active communication and power modules can be recovered to the surface for repair or replacement. This is achieved by mounting the serviceable units within an integrated, detachable, neutrally buoyant module. A repair operation would begin with an ROV disconnecting underwater wet-mate optical and electrical connectors that link the cable terminating assembly to the science module before docking with the module and recovering it to the surface. This leaves the trawler resistant frame, cable and cable terminating assembly in place on the seafloor. Once the science module is onboard the vessel, it can be repaired or replaced with a spare module following a reverse procedure.

Wet-mate connectors
Underwater connectors are now available which can provide repetitive mating and unmating of electrical signal, electrical power and optical fibres. The architecture of the science node utilises these connectors in providing flexible connectivity to the science experiments, enabling the science module to be serviceable at sea and enabling the network to be readily extendable.

Conclusions
Long-term cabled observatories are now being planned and built using robust industry-available products and solutions. These cabled observatories bring new and powerful facilities into the reach of those studying the ocean margins and the deep sea, from the principal investigator to the student in the classroom. Continuous real-time communications with accurate timing and abundant electrical power are available at costs similar to those of ongoing uncabled studies. Cabled observatory designs include science node architectures which support the rapid development of science experiment sensors and their relatively short life spans. Sensors can then be replaced as required and do not have to meet the high-reliability requirements of the cabled observatory backbone infrastructure. Cabled observatories with their high-power capability and fast broadband communications are now readily available and represent the future of seafloor science.

For more information, oceanbiz@sea-technology.com.

Contact Hugh Wylie, Alcatel,
Tel (011) 542-3000,
hugh.wylie@alcatel.co.za

A typical science node developed for the Monterey Bay Aquarium Research Institute’s Monterey Accelerated Research System observatory. (Reprinted with permission from Nautronix MariPro.)