PRACTICAL METHODS FOR INTEGRATING SCIENCE SENSORS INTO SUBMARINE CABLE SYSTEMS

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Abstract: The scientific community has long viewed submarine cable systems as a potential infrastructure resource that could and should be used to host environmental sensors. The deep ocean environment is of critical importance in understanding global climate. Seismic monitoring and warnings are of vital importance in many parts of the world. A submarine cable system is not designed with data collection in mind, and efforts to integrate sensors have been slow to come to fruition. Despite the challenges, there are situations where the addition of scientific sensors, even on a limited basis, is desirable. In the near term, a number of methods for adding scientific capabilities to a submarine cable system are available. These range from simply sharing landing station facilities to wet plant designs involving dual conductor cable and spare fiber pairs. All of these methods allow one or more science nodes, which are power and communications hubs supporting a variety of sensors, to be connected to a cable system. By using proven methods that have already been successfully implemented, adding science functions can be practical in terms of time, cost and complexity. Sparing, marine maintenance and operational issues must also be considered and may affect the attractiveness of each alternative. Looking beyond the near term, capabilities such as power feed branching units and sensor-enabled repeaters will continue to be sought after but are likely to require substantial outside investment to ensure both system owners and suppliers have a viable business case for supporting those capabilities.

1. INTRODUCTION

Scientific observation of the world's oceans continues to attract interest at many levels. Changes in climate, ocean circulation, nutrient flows and chemical properties have local, regional, and global impact. Measuring these changes is a necessary step in planning for and mitigating their impact. Increasing awareness of Tsunami risk has led to the installation of new cable-based warning systems alongside buoyed systems. Education and outreach to generate interest in and awareness of our ocean surroundings remains a desirable objective as more and more people rely on the oceans for food, trade, and security.

While traditional, ship-based oceanography remains the most-used method of ocean observation, cabled ocean observatory systems also play a part. Europe's ESONet collaboration [1], Ocean Networks Canada [2], the U.S. Ocean Observing Initiative [3], Japan's DONET [4] and S-Net [5] systems, along with many smaller projects have clearly demonstrated the feasibility and utility of cable-based observing systems, and several other nations, most notably China and Indonesia, have initiated efforts to deploy cable-based observing systems. Many of these systems make use of telecommunications system components such as cable, repeaters, and branching units. Cable-ship installation methods have likewise been successfully employed in the creation of these cabled observatory systems.

Despite these synergies, scientific systems and telecommunications systems have remained separate and largely incompatible for a variety of reasons. Differences in funding sources, permitting requirements, reliability and performance objectives, maintenance arrangements, and even geographic location have stymied efforts to bring a closer integration between the submarine telecommunications and ocean observing communities.

Nevertheless, the submarine telecommunications industry continues to attract the interest of scientists and policy makers who see potential cost savings if scientific ocean observing efforts could leverage the resources and expertise that are routinely deployed in developing a submarine telecommunications system. From the standpoint of a cable system developer, the costs involved are usually too great, whether these are direct costs such as increases in the price of the cable system or indirect costs in the form of project delays, added effort and overhead. Policy changes, for example support for Tsunami warning systems, may encourage the addition of science capabilities to cable systems, but unless the costs of science functions are fully offset, cable system developers may find it difficult to embrace science and will need to carefully consider the pros and cons.

When faced with a request to support scientific observation, a cable system developer should consider the possible benefits. Whether it is merely to demonstrate "good citizenship" or because there is a viable business case to be made or something in between, adding a science component to a cable system may be advantageous. Many of the reasons for adding science are particularly applicable to island nations where tsunami risk, sea level rise and resource utilization are ever-present concerns and the desire to leverage limited funding to address societal needs is most pressing.

2. DESCRIPTION OF A SCIENCE OBSERVATORY

Before reviewing some of the options for integration of science and telecommunications, it is useful to identify the main components of a typical cabled observatory system. For simplicity, a system containing only one observatory node is considered, although this can be extended to several nodes without much difficulty. Observatory systems involving a higher number of nodes, ring or mesh architectures, or which are designed for high power capability are beyond the scope of this paper and would usually need to be considered as separate projects. A prototypical science observatory consists of a cable segment, cable termination assembly, and observatory node (Figure 1). Additional instrument platforms or extension cables may also be connected to the central node. The cable is normally a standard 17mm telecommunications cable although some specialty cable types have been used. Either constant current or constant voltage power feeding may be employed. In locations where the cable can easily be recovered to the deck of a vessel, a dry-mate connector may be used. In deeper water, the cable termination assembly has one or more ROV mateable connectors which allow the observatory node to be disconnected for servicing.

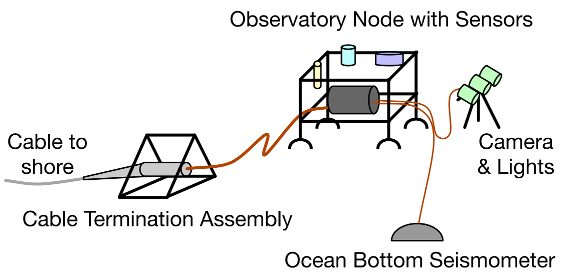

Figure 1: Typical ocean observatory node showing connection of the CTA, node with junction box and external sensors.

The observatory node consists of a frame, junction box, and scientific sensors. The junction box provides power conversion and communications multiplex functions. DC-DC converters provide 5V to 48V supplies to the sensors regardless of the voltage and current supplied on the cable. Communications interfaces from the sensors may be Ethernet or serial data; these are converted and multiplexed onto a single optical Ethernet uplink or a pair of protected links. The junction box may also provide capabilities to monitor power consumption, detect faults in the sensors or related cabling, and to isolate malfunctioning sensors. Commonly used sensors include bottom pressure recorders, conductivity sensors, temperature sensors, current profilers, cameras, both still frame and video, hydrophones and ocean bottom seismometers. Depending on location, oxygen, nitrate, and nutrient sensors may be added.

Science observatory nodes are most often bespoke constructions, developed for and adapted to the specific observations to be undertaken. Although commercial examples exist, universities and research institutions often develop their own observatory nodes both to save cost and as a means for teaching the skills necessary for engineering underwater equipment. Potential science users may wish to contact one of the existing observatory operators for assistance in developing suitable observatory nodes.

3. INTEGRATION OF A SENSOR NODE INTO A TELECOMMUNICATIONS CABLE

The level of integration between the telecommunications project and science project will need to be determined on a case-by-case basis. At the simplest possible extreme, providing space and power in a cable landing station may be useful to a local university or research effort. The next step would be sharing terrestrial facilities and a beach manhole with a separate science system. Another example worth mentioning at this stage is to transfer an out-of-service cable to a university or institution; the ALOHA Cabled Observatory (ACO) operated by the University of Hawaii [6] is a good example of this approach. While the main focus of this discussion is on adapting the wet plant to support one or more science observation nodes, these less intrusive methods of collaboration may be of interest or could be considered as alternatives (Figure 2).

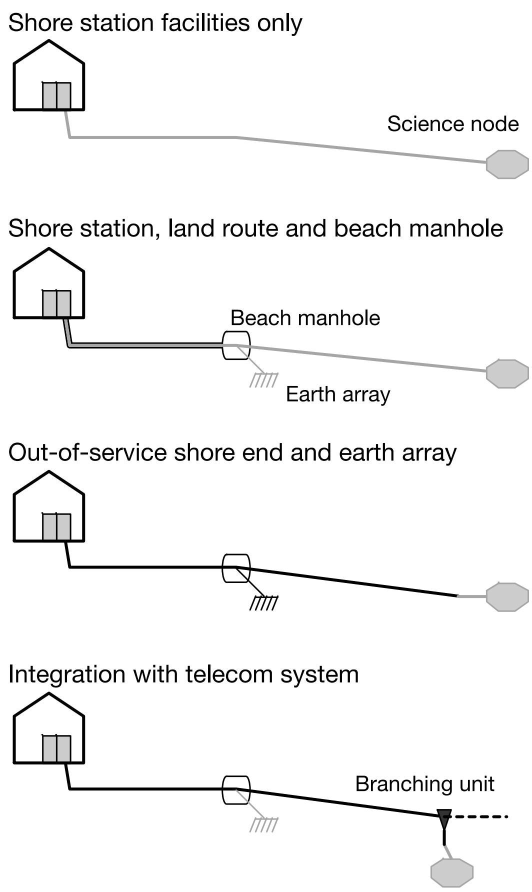

Figure 2: Options for support of science observation showing shared infrastructure in black and infrastructure provided for science in grey.

Moving onto the wet plant itself, the main requirements for support of a science node (or nodes) is delivery of power and communications. The most straightforward method of providing communications is the provision of additional fibers for the science node. Depending on the distance to the science node, these may pass through one or more repeaters. Transponders with forward error correction may be needed, although standard 1 Gb/s or 10 Gb/s optical Ethernet signals can often pass through a few repeaters and still provide acceptable performance; in any case, the transponder selection and link design should be reviewed to ensure the selected solution is suitable. One or two channels could be dropped from the telecommunications fibers using Optical Add Drop Multiplexing (OADM). For power deliver, the most straightforward method is also to provide a dedicated power conductor. In the case of an unrepeatered system (or an unrepeatered branch from a larger cable system), the single conductor can be made available for use by the science observatory. (Note that the shore end will be powered by the science equipment, so this conductor will be monitored at least as far as the BU.). For a powered telecommunications system, Dual Conductor Cable (DCC) can be introduced to provide a secondary power path which connects only to the science nodes. The Poseidon system installed off the coast of Cyprus in 2014 used both optical Ethernet on dedicated fibers (passing through several repeaters) and dual conductor cable to support a series of science nodes. This system has operated reliably since installed and demonstrates that these methods can provide a practical solution.

The topology of the underwater plant must also be considered. In the simplest case, the science observatory is connected to a branch. Both the extra fibers and secondary power conductor leave the main cable at that point and are terminated at the CTA to which the science node is connected (Figure 3). A slightly more complex arrangement involves two or more BUs with the secondary power conductor and extra fibers travelling up and down each branch. Configurations with more than one science node on a single branch are also possible. Note that in all cases, the BU which joins the science branch to the trunk cable is passive; because there is a separate power conductor to supply the load on the branch, there is no need for switching the main (telecom) power feed path. A number of suitable topologies have been developed by the supplier community. [7,8]

Identifying responsibility for each component will require interaction among the cable system owner, science user, and their respective suppliers. The science observatory node or nodes, scientific instruments and sensors, terminal equipment, including transponders, power feed, and some form of supervisory equipment, will typically be provided by the scientific users, leaving the cable system developer to supply only standard wet plant components. Items such as land cable plant and the ground bed/earth array will require some discussion to determine whether these should be part of the cable system supply or part of the scientific system. This basic model can be varied as appropriate for individual projects, for example in cases where the cable system supplier offers options for DC-DC conversion or other functions necessary for the operation of the science node.

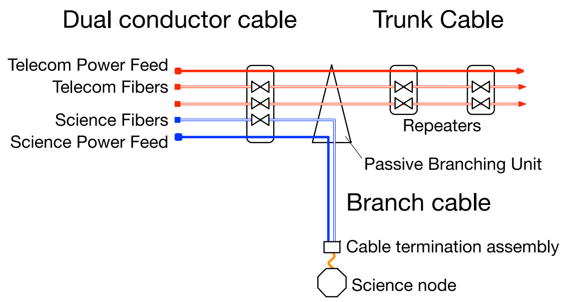

Figure 3: Simplified diagram showing connection of a science observatory node to a commercial cable system.

Permitting is often cited as one of the issues preventing closer integration between telecommunications and scientific cable systems. Depending on jurisdiction, the process for seabed access for scientific

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observation can be more rigorous than for telecommunications cables, as there are often concerns about what data may be released. In some cases, two sets of permits may be required: one for science and one for telecommunications. This issue can be mitigated to some extent provided the science observatory node remains within the Exclusive Economic Zone (EEZ) of one country and data is sent only to the shore station within that country, as it is clear there are no scientific functions or data gathering outside the country which has granted permission. Regardless of the location, permitting requirements should be considered early and advice should be sought from appropriate specialists.

Responsibility for installation must also be clearly identified. The availability of cable ships and the ability to reduce or avoid mobilization costs are among the main motivations for science observatory projects seeking to participate in telecommunications cable projects. Accordingly, establishing the portion of mobilization costs that will be borne by the science budget and the amount of installation vessel time that will be made available for installation of science components are key considerations. In most cases, it will make sense for the cable system installer to take the lead and install all components up to an agreed demarcation point (which may or may not correspond to the operational demarcation point discussed later). If the science observatory equipment is jointed directly to the cable, then it may be possible for the main lay vessel to install the science observatory. When a CTA is used, installation of the science node itself will often require an auxiliary vessel equipped with a suitable ROV. The time for these tasks must be considered in the overall work plan so that delivery dates for the telecommunications system are still satisfied.

4. OPERATION OF A COMBINED SYSTEM

One of the chief areas of concern when sharing a submarine cable system or providing support to a science observatory is the operation and maintenance methods to be employed. Several measures are proposed to address these concerns.

First, the financial obligations of each party must be clear, not only as they pertain to the project budget but also in regard to both routine and unplanned maintenance costs. Added costs such as spare BUs, spare CTAs, and any other special components must be considered. Ongoing training and support must be addressed. If DCC cable is used, the marine maintenance provider must be prepared to perform repair joints and ongoing qualification of jointing technicians must be addressed.

Second, the expectations of each party regarding performance and availability must also be defined at the outset. Generally, the science functions will be less reliable than the telecommunications functions. Methods for carrying out repairs to the science node(s) without impacting telecommunications operations should be planned in advance. The most common operations will be to disconnect and recover either individual sensors or the entire science platform and to replace these after they are refurbished. In the event of a cable fault, the first objective will be restoration of the telecommunications functions, with the science functions being a secondary priority. The science functions may be interrupted at any time to carry out fault finding or repairs of the telecommunications functions, regardless of whether or not the science functions are directly affected. A fault affecting only the science functions may not be immediately addressed but may be left until a more convenient time. These general guidelines serve as a starting point and may require modification depending on the situation, for

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example, in a case where the science capability includes Tsunami warnings or other critical functions. The obligations of each party regarding maintenance responsibilities, repair, and availability can be captured in a service level agreement or other contractual document.

Finally, clear demarcation of responsibility must be established, particularly for the wet plant. Although the CTA seems a natural point for demarcation, the cable system owner may regard the CTA as part of the science system and something that is beyond the scope of a standard marine maintenance agreement. A point three to five water depths away may be a more amenable demarcation point, as everything upstream of that point is standard (or nearly standard) telecommunications wet plant.

5. FUTURE DEVELOPMENTS

The installation of each individual ocean observing node is a valuable contribution to science and society. However, observations on a much larger scale are needed to fully address concerns such as Tsunami warning and climate models. Adding one, two or even five observatory nodes to every new cable landing would only begin to address these broad objectives. Large scale deployment of ocean sensor networks will be costly, but through small, incremental steps, new approaches can be developed, tested, demonstrated and ultimately qualified for widespread use. Innovations such as power feed branching units would allow sensor nodes far from shore without the expense of dual conductor cable. Equipment developed for use in oil and gas fields could be adapted to support sensor nodes. The use of telecommunications components (cable, repeaters, BUs etc.) to construct dedicated sensor systems, particularly for seismic monitoring and Tsunami warnings, is well proven and is likely to continue, even if this represents only a small fraction of the submarine cable systems being installed. Integration of sensors into repeaters is a visionary objective, as this could facilitate widespread deployment of key sensors, but many technical and commercial issues remain to be resolved.

6. CONCLUSIONS

The use of commercial telecommunications cables to support science observatories continues to attract attention, and suitable projects do arise from time-to-time. Both project developers and the science community should be aware of the available technical solutions and the potential commercial issues. Early interaction and planning are essential, as science projects move at a different pace from commercial projects and must satisfy a different set of stakeholders. Once a decision is made to proceed, clearly defining roles, responsibilities, and service levels should be the first order of business. Technical solutions should not be regarded as high risk, as a number of existing systems have demonstrated all of the necessary capabilities. The solutions proposed here are seen by some as an interim step towards more complete integration but can still provide a valuable contribution towards scientific observation of the world's oceans.

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