# EXPANDING CABLED OCEAN OBSERVATORIES

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**Abstract:** As Cabled Ocean Observing Networks are being deployed around the globe their value is becoming better understood. Data generated through high bandwidth and high power cables, and continuous tele-presence are expected to provide a significant increase in the understanding of the many processes in play on and below the sea floor, throughout the water column, and on the surface.

These systems have been and will be deployed where there is a clear history or high potential for valuable science. Cabled systems are costly long term assets. Expansion of these systems could be confidently pursued after an interim or temporary presence is established in areas of potential interest. At the same time the science community will continue to explore and investigate the vast less known areas of the world's oceans with research vessels and continue the expeditionary missions it has employed for many decades. With cable observatories keeping watch on the historical sites, the community will be free to focus on searching for new areas of interest and discoveries.

This paper presents technologies to fill the gap between the long term tele-presence of cabled systems and the short term expeditionary nature of research cruises. By leveraging uncabled network technologies and wave energy techniques, we propose a capability to rapidly occupy new areas of interest identified by research cruises and augment cabled arrays. Through surface radio frequency, fiber extensions, optical communications, acoustic swarms and multihop mesh networks, we envision expanding cabled observatories and or land based links by hundreds of square miles, making use of the bandwidth and cyber infrastructure deployed as part of the cabled observatories.

We will provide examples showing how hybrid network architectures could rapidly and cost effectively provide a continuous tele-presence to new areas of interest. We also explore the scientific instrumentation and observations enabled by these technologies.

## 1 BACKGROUND

Cabled Ocean Observatories are a fairly recent and powerful tool in advancing knowledge of our planets oceans. Current cabled systems typically provide gigabits of bandwidth to multiple tens of gigabits. This order of magnitude increase in bandwidth is coupled with kilowatts of power and promises significant capabilities and a foundation for new classes of instrumentation.

 

Until observatories like LORI (Sea of Oman), DONET (Japan), Neptune Canada and soon the Ocean Observatories Initiative (OOI) Regional Scale Nodes (RSN), ocean science was conducted primarily through buoy observations and data collection via ship based expeditions.

Ship operations are costly, short term and dependent on weather. While extremely important for exploring and identifying valuable scientific locations, the quantity of data is limited to what the ship can collect during a given cruise as well as how much battery power and data storage devices left behind can support until a future cruise recovers the device.

Buoy observation platforms provide a valuable permanent presence. They provide a long time series of data important to the understanding of various ocean systems and cycles. Unfortunately, they are too limited by power constraints and bandwidth limitations of the geosynchronous satellites at rates in the Kilobyte range.

Buoy operations are also costly to maintain, operate and susceptible to severe weather. Increasing the power and bandwidth of buoys would cause them to be much more efficient and valuable.

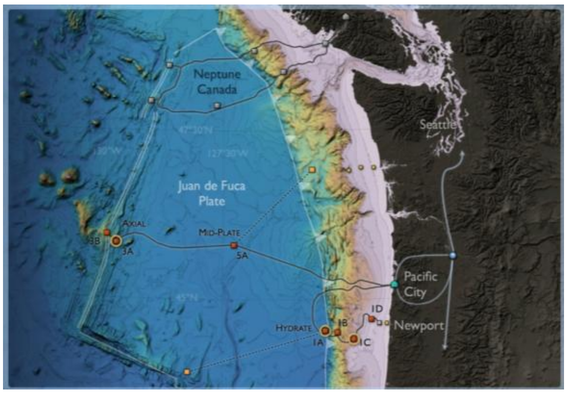


**Figure** 1 **: The RSN is an example of a cabled observatory**

## 2 EXPANSION OF EXISTING OBSERVATORY INFRASTRUCTURES

Funding large science programs is never easy, and current global economic realities have further increased the challenge. Risks versus rewards are being more closely analyzed. Current cabled observatories have been planned with expansion in mind. The RSN component of OOI, for instance, is designed to enable more than 30% expansion. However, the equipment and installation involved in expanding cabled observatories can be costly, time consuming and a challenge to justify in the current risk sensitive economy.

Adding a single new cabled instrument to an observatory will require, at a minimum, extended ROV and ship time for placing the instrument and running cables plus the cost of the cables and connectors themselves. For long cable extensions, route planning, cable ship installation, and new junction boxes may be required. Installation costs, therefore, tend to far outweigh the cost of the devices to be deployed. Adding cabled devices could also interrupt the existing data flow during implementation.

The following sections examine a number of technologies and conceptual integrations that could provide the ability to rapidly expand upon and/or augment cabled assets, temporarily or semi-permanently, in a cost effective way.

 

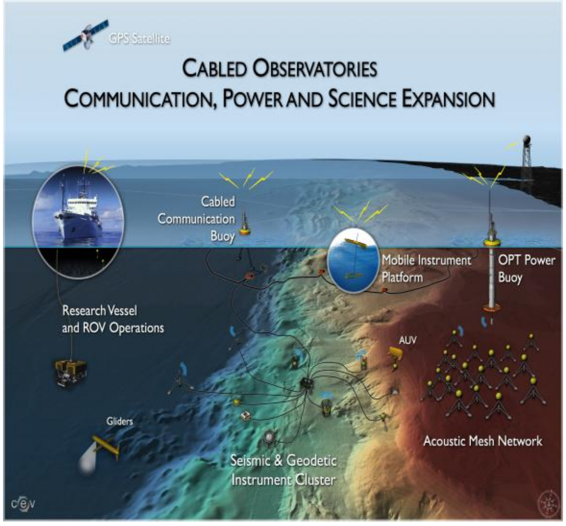


**Figure 2: Conceptual example of the integration of technologies**

## 3 ADDRESSING THE POWER CONSTRAINTS

Availability of electric power has been one of the key limiting factors to data rich, long time series monitoring and virtual interactivity programs. Historically, power management was driven by a need to extend the life of installed battery capacity. This power management took the form of significant limitation of sampling intervals as well as the inability to access the data or interact with the sensors in real time. Cabled observatories were the short term answer to solving both the power and communications issues. Cables allow large amounts of power in the order of 10kVA to be available on the seafloor, but with significant cost and practical limitations to geographic reach. New developments in wave energy technology are now enabling an ability to provide persistent, renewable energy at remote locations within the ocean basins.

Wave energy technology for the most part has been focused on the delivery of utility scale, grid connected power. An emerging market for wave energy is the provision of autonomous wave energy converters that are designed to provide persistent power at specified levels in remote locations. Unlike utility scale devices, autonomous devices require an onboard storage capacity such that power can be provided to instruments and communications systems during zero wave height conditions. One example of these new devices is Ocean Power Technologies APB-350. The APB-350 has been ocean tested and is capable of providing 350 Watts of continuous power. An electrical interface is provided for the mission payload, and can be configured to various voltages of AC or DC power. The system is also capable of supporting short term power surge demands in excess of the continuous 350 Watts. Power can be delivered at the surface, in the water column or on the seabed. At this power level, and a three year maintenance cycle, these devices are ideally suited for remotely powering distributed sensor arrays.

The provision of power in remote locations is required to establish a long term scientific presence. Autonomous wave energy converters can establish stand alone scientific outposts, or expand the geographic footprint of cabled observatories and dual use commercial communications cables. Expansion of geographic footprints can be implemented in a number of ways. Highest possible bandwidth and distance is possible by using the available power to support optical transceivers on fiber-only extension to existing cabled nodes. Microwave and high frequency links to either tethered buoys or other autonomous buoys (as repeaters or networked nodes) can also provide reasonable bandwidth and additional geographic coverage. Links to shore are also possible for both data and coastal radar systems expansion. Each autonomous wave energy converter can also provide an important interface to surface and subsea acoustic networks (e.g. gliders and UAVs).

Wave energy is addressing many scientific needs, not only for the large power intensive distributed sensor networks, but also lower power levels supporting communications gateway buoys.

## 4 DELIVERING BANDWIDTH

With sub-sea cabled infrastructure in place, at sea operators will need to connect to local instrumentation. In the past, the need for bandwidth at sea was dominated by email service and voice calls for marine traffic. The methods of bandwidth delivery that have provided adequate service for years have been High Frequency (HF) and satellite. While both technologies have served a need for global high bandwidth connectivity, their capabilities are limited. Satellite carries a high per-bit cost and can suffer from contention issues with other military/government users. HF offers high availability and low data rate services that are ideal for text-based email or basic telemetry.

A local connection to the sub-sea infrastructure via buoys tethered to the cabled observatory will link the cable network to the sea surface. From that point there are choices to be made for the next link or link technology (other non-tethered bouys, shore based assets, acoustic networks, etc…).

### 4.1 High Bandwidth

Although at high cost and with limited point-to-point capability, a high bandwidth microwave link is the best solution to tap into the capacity of a cabled network. The effort toward inexpensive, high capacity microwave links in global unlicensed 24 GHz band is being driven by the growing rural Internet delivery sector. A microwave radio, mounted to a tracking pedestal and receiving AIS transponder data could track a research ship and deliver up to 1.4 Gbps between two accurately aimed units. With such bandwidth, even trailing off to a few hundred Mbps at ranges of a few miles, the performance could be impressive considering the lack of a per-bit bandwidth cost. This would allow continuous streaming video feeds, transfer of large data sets, VoIP and video calling; all without the latency of satellite links.

The downsides of this method include the precise aiming and maintenance requirements, as both ends of a link would need to be aimed to within a few degrees while sitting on moving platforms. Constant tracking movement of a research vessel in range is also adds a maintenance component to consider. This method also leaves only one party served by the bandwidth unless multiple tracking antennas are installed and powered by the buoy.

### 4.2 Medium Bandwidth

While a research ship is being fed with high bandwidth point-to-point data, communication needs may still exist for other systems not be capable of supporting the physical or electrical requirements of a tracking pedestal and microwave radios. Smaller buoys with more modest power supplies, such as solar, wind, etc., may form a link between surface wireless connectivity and acoustic or optical networks. For this purpose, the main tethered buoys need to extend their wireless footprint beyond the radio horizon to cover the area of operation.

A 3 meter high buoy antenna has a radio horizon distance of 7km, although factoring in Fresnel zone limitations may considerably reduce the useful range. Using inexpensive buoys, with little power generating capacity, the range could be extended using multi-hop networking and inexpensive WiFi equipment. A ship moving outward from a main tethered buoy could form a buoy breadcrumb trail of networked buoys to extend the bandwidth availability out from the main buoy to the area of work; essentially deploying a wireless umbilical cord.

Using commercially available wireless equipment has the advantages of being inexpensive, widely deployed and tested, and uses frequencies that are globally unlicensed. The downside with 900 MHz, 2.4 GHz, and 5.8 GHz networking, especially for operation near water, is multipath interference. This issue is faced by long distance wireless providers and cellular operators in urban settings, as buildings and other structures serve as unwanted reflectors. The move toward Multiple In - Multiple Out radio architecture in both cellular (LTE) and WiFi (802.11n) largely mitigates this problem by using the reflections to its advantage. As wireless chipset hardware becomes more powerful and the number of spatial streams increase, the ability to deal with multipath and interference will improve. Other aspects of commercial WiFi networking solutions can be tuned to great advantage on a moving platform, such as transmit beam forming. This would enable the advantages of actively positioned directional antennas without the need for mechanical pointing system.

Traditional cellular and WiFi networks operate as single point of distribution to many end user devices. If the area of operation is within a few miles, typical WiFi, operating in a similar fashion, may provide adequate bandwidth outward from a tethered buoy. If the area to be connected is larger, an easily deployable, self-configuring mesh network could be used.

Mesh networks are self-organizing systems that can be deployed as needed with little pre-planning. A mesh node, consisting of a basic embedded computer and radio cards will find neighbor nodes shortly after being activated and configure routing information. This self-configuration allows nodes or, in this case, buoys, to be placed or moved as needed. The mesh network removes the need for IT staff to reconfigure equipment as deployments change. For example, operations in a 1km square area could have nodes placed at the corners and buoy placement leading back toward the nearest tethered bandwidth supply buoy. These semi-permanent buoys would need only low power generating capacity and storage, a low power CPU and antennas. About the same size and cost used for decades by fishermen to radio locate fishing nets, and deployed just as easily.

Despite deploying a network with useable bandwidth for a task, it is important to note a few technologies that may reduce the needed bandwidth for certain tasks. Compression algorithms can reduce bandwidth requirements by compressing datasets, trading bandwidth needs for power and time needed to perform compression.[1] Other methods of coping with low bandwidth links may be a modification of the 1980’s sneakernet.

With the price of memory falling, RAM, solid state and traditional hard drives, an option to having a wireless link could be a store and forward setup. An ocean filled with sensor equipment meeting up at random points could share data. When piece of equipment comes within contact range of a node or research vessel, it could upload not only its own data, but the data of the gliders it had communicated with during its mission. This method would bring a level of redundancy to data collection, as every member of the data collection program would be another path for data retrieval. Gliders and other equipment with large memory capacity could store data for other equipment for extended periods of time until it had received verification that data had been uploaded.[2]The downside to this method, if glider or other equipment meetings were not preplanned, is the inability to know exactly when data from any one piece of equipment will be uploaded.

To take this further, the undersea equipment could upload data to an isolated buoy, which could (via a low data rate link) request data retrieval by a surface ship sailing within wireless range, or an UAV.

## 5 DELIVERING SCIENCE

Cabled observatories are enabling new pathways of scientific discovery. The power and bandwidth provided by the physical connection to terrestrial networks allow for the development of a new generation of oceanographic sensors. In addition, the combination of high-frequency measurements and long-duration deployments allows for investigations of processes across times scales from milliseconds to decades. However, the high cost of cabled infrastructure limits the spatial resolution of observatories. As oceanographic processes occur across a wide range of scales in time, space and depths, it is critical to expand the geographic reach of cabled observatories so that advances in time domain observations are matched in the spatial domain.

One of the most important uses of real-time oceanographic observations is the incorporation of this data into ocean computer models. Data assimilation techniques allow for improved model accuracy and forecasting reliability. However, it is important to match the spatial resolution of the assimilated data to the model grid size; thus, observatory data is most valuable to the modeling community when multiple spatial scales can be resolved.

Because cabled infrastructure originates on land and extends into the ocean, the scientific goals (and node placements) are typically focused on the gradients associated with moving offshore and downslope. However, the flow of water is often along contour lines perpendicular to the slope (and to cabled infrastructure). Thus, in order to track a mass of water and investigate the processes associated its movement, many observatories must be expanded in the directions normal to the cable path.

The high power and bandwidth delivered by cabled observatories is critical to some infrastructure and instrument types (e.g. profiling moorings, high-definition cameras, seismometers, sonar and hydrophones, etc.). However, the current generation of oceanographic instruments has been largely designed around battery power and low bandwidth requirements. While newly developed sensors may be optimized for cabled attributes, there will continue to be instruments that are most cost-effectively deployed as uncabled assets within a cabled observatory. Several technologies may be used to extend data collection at cabled ocean observatories by providing complementary wireless communications paths that do not require costly new cable installations for each new measurement. In these scenarios, existing cables can be utilized as a backbone to relay near-real-time data to shore. Wireless range and bandwidth restrictions will determine which technology, or combination or technologies, best fits the desired application.

Acoustic communication is widely used in the ocean and reliable communications between two seafloor-mounted nodes 2 km apart were demonstrated in the past [3]. Further use of acoustic networks could enable large uncabled arrays capable of node-to-node ranging and low bandwidth data transfer over multiple acoustic “hops.”

Similar to RF mesh networks, in which each wireless node can communicate with all neighboring wireless nodes, acoustic mesh network arrays could provide monitoring over hundreds of square kilometers of seafloor. Because many acoustic communications devices can also be used for vehicle navigation [4], a large acoustic array could also provide navigation for Autonomous Underwater Vehicles (AUVs).

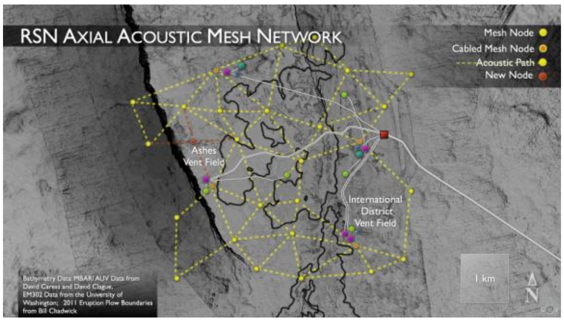


**Figure 3 : Depiction of an acoustic mesh network at a remote, cabled location**

Developments in wireless, underwater optical communication could enable remote high-bandwidth signals, such as video, to be transmitted wirelessly over tens of meters or more [5].

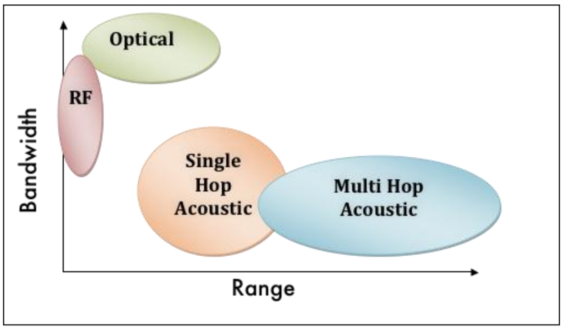


**Figure** 4: **Wireless subsea communication technologies provide options for meeting range and bandwidth needs**

Mobile platforms, including AUVs, gliders, and subsea robots further extend measurement capabilities throughout the water column. Remote AUV docking stations allow vehicles to recharge batteries and establish communications with a cabled backbone, thereby providing long-term operation in remote cabled areas. MBARI has demonstrated AUV docking that does not require metal-to-metal connector mating. Rather, the MBARI dock uses RF modems over a very short range for data transfer, coupled with inductive battery charging [6]. The communication link will also enable event-driven mission planning, in which vehicle operations can be customized based on local measurements. For example, during evidence of submarine volcanic activity, an AUV could be commanded to collect water column measurements over the volcanic plume.

## 6 CONCLUSIONS

Even in todays economically and politically risk sensitive environment, it should be possible to grow the scientific opportunities and value of cabled ocean observatories. Through the use and integration of various communications technologies, and smart planning new geographic areas can be studied.

Technologies discussed here could be permanent, temporary, or moveable, increasing their return on investment and mitigating risk. In some cases these non-cable expansions will justify replacement with cable.

As scientists continue to embrace the power and bandwidth capabilities of cabled observatories, new more complex and powerful instrumentation will be developed and deployed improving our quest to understand our planet.

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## 8 ACKNOWLEDGEMENT

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