SMART SUBMARINE TELECOMMUNICATION CABLES TO MONITOR GLOBAL CHANGE AND TSUNAMIS IN THE GLOBAL OCEAN

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Abstract: *More than a million kilometers of submarine cables traverse the world's oceans, bringing Internet service to billions of people. These remarkable systems connect people, nations, and economies, but this infrastructure could provide even more, adding invaluable environmental data for understanding the ocean above and the Earth beneath the seafloor. In light of this potential, an international joint task force (JTF) of three United Nations agencies (ITU/WMO/UNESCO-IOC) is working to incorporate environmental monitoring sensors into transoceanic submarine cable systems. Adding small external environmental sensors (e.g., temperature, pressure, acceleration) to the optical amplifiers/repeaters (spaced every ~65 km) of such systems would provide an unparalleled global network of real-time data for ocean climate and sea level monitoring and disaster mitigation from earthquake and tsunami hazards—a Science Monitoring And Reliable Telecommunications (SMART) network. The progress made in the last several years is reviewed, including ideas for a future implementation incorporating acoustics. (see http://www.itu.int/en/ITU-T/climatechange/task-force-sc).*

Keywords: *cabled ocean observatories, submarine cables, acoustic in ocean observing*

1. INTRODUCTION

One million kilometers of submarine cables forms the global telecommunications infrastructure backbone for business, finance, social media, entertainment, political expression, and science. Internationally, these cables are the physical layer of the Internet. The dependability of this infrastructure is so important that whole national economies are affected when problems arise.

These same submarine cables can also provide a platform for gathering deep ocean and seabed data for a range of environmental issues. Imagine environmental sensors spaced every 65 km along the seabed hosted by the cables connecting the continents, providing much needed data to better understand the environmental threats humanity faces, both immediate and long-term, such as tsunamis and climate change. Tsunamis have the potential to threaten many of the world's coastal communities within minutes or hours of a large seismic event. Reliable, robust tsunami-warning systems could save lives and property. Our oceans and climate are experiencing global changes, including warming, sea level rise and acidification, that all affect us now and in the future. SMART cables could make significant contributions toward meeting the United Nations Sustainable Develop Goal 13: Take urgent action to combat climate change and its impacts; Strengthen resilience and adaptive capacity to climate related hazards and natural disasters in all countries, and Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development; Increase scientific knowledge, develop research capacity and transfer marine technology.

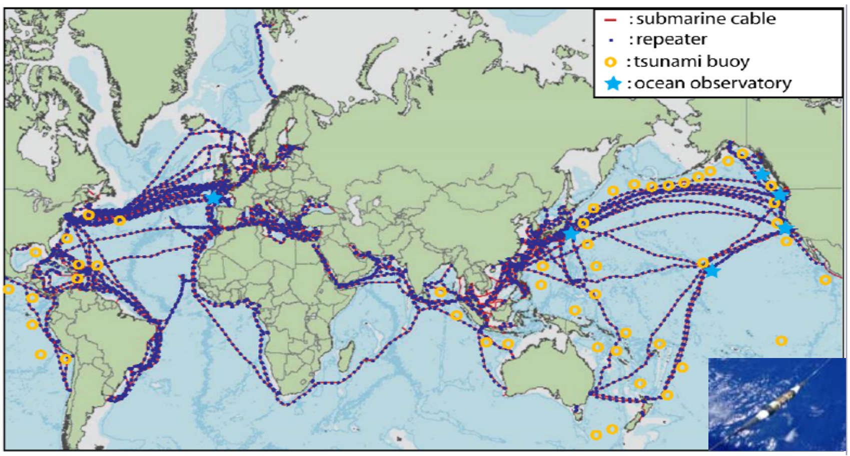

Fig.1: The submarine cable network (c. 2011); dots indicate sensor modules every 200 km; one is shown in the lower right (from [1]). Roughly 1 million km of cables with 20,000 repeaters are operational. Every 10-20 years these systems are refreshed as new technology is implemented to keep pace with the relentlessly growing bandwidth demands.

Access to deep ocean and seabed environmental data through an ocean scientific observing system, co-existing with the primary telecommunications system, could assist in the monitoring and management of these environmental threats. Accordingly, with access to the seafloor for fundamental oceanographic and seismic measurements, we can start to quantify and respond to the risks to human lives and the natural world we live in.

To bring this concept to fruition, the international Joint Task Force of three United Nations agencies (International Telecommunication Union, World Meteorological Organization and Intergovernmental Oceanographic Commission of the UN Educational, Scientific and Cultural Organization; ITU/WMO/UNESCO-IOC JTF) is working towards incorporating environmental monitoring sensors into transoceanic submarine cable systems. A standard telecommunication system includes an electro-optical seabed cable with optical repeaters every ~65 km. By adding environmental sensors to the repeaters, we could have access to a global network of real-time data for environmental threats such as sea level rise, ocean climate, and disaster mitigation such as earthquakes and tsunamis. This JTF initiative called SMART Cables (Scientific Monitoring And Reliable Telecommunications) is exploring the engineering requirements for building these systems, funding options, collaborative partnerships with industry, the legal framework and outreach and capacity building opportunities. The JTF is an international effort in the truest sense, with people (largely volunteers) from several dozen countries and 80 organizations representing science, observing system managers, industry, government agencies and sponsors.

There already exist environmental oceanic observation systems that are owned and operated by academia and government agencies, and are utilized over short distances for research purposes. In the case of the SMART Cables, the submarine telecommunications cable systems are installed, operated and maintained by the private sector. Thus, working together with the private sector industry is vital for the success of this environmental monitoring initiative, and a collaborative approach to understanding the needs, challenges and ways forward is imperative.

Through the series of meetings and workshops with academic and government scientists and the telecommunication industry since 2011, the scientific foundations are laid and a growing consensus is being reached to assuage the technical, legal, and permitting hurdles facing SMART systems. White Papers and workshop reports documenting the scientific and societal needs, legal framework under the UN Convention on the Law of the Sea, and technical feasibility have been produced (see [1-12]). The concept of a "wet demonstrator" to show the return of scientifically useful data in a system with the same mechanical footprint has been put forth to address the effectiveness and practicality of the proposed SMART approach. A modest-scale pilot system has been proposed in the South Pacific linking several islands; this would validate a complete system with sensors fully integrated.

From the workshops, it has become clear that a partnership with humanity—society, science, the telecommunication private sector, and governments—can bring forth submarine telecommunication cables which are environmentally aware. We look to a future where SMART cables serve a dual purpose, both as communications infrastructure and a scientific backbone for monitoring tsunamis, earthquakes and the world's ocean climate and circulation providing scientific monitoring and reliable telecommunication services.

A relatively straightforward complement of instrumentation—accelerometers, high-resolution pressure gauges (=acoustics), thermometers—will answer many of the basic science and societal needs as well as provide for the monitoring of the physical state-of-health of the cable system itself. Technological advances have made it possible to integrate basic sensors with repeaters on submarine telecommunication cables at intervals of about ~65 km, at a small fraction of the total cost of a new cable system deployment. We expect the unit cost of a single sensor package to be on the order of $0.2M; a modest system such as the proposed pilot with up to 20 repeaters/sensor modules mentioned above should be under $10M, with an expected life longer than 25 years. We can slowly achieve global coverage as new systems are continually being installed on time scales of a decades as technology and user demand drives the deployment of new systems long before the end of useful life.

From the start, a number of sensors/measurements and infrastructure elements were suggested to be included: temperature, salinity, pressure, hydrophones, seismometers, acoustic modems, and plug-in "node" capability. However, in keeping with the KISS principle, it was decided to emphasize temperature, pressure, and acceleration as the very simplest and basic measurements to begin with in the initial discussions and implementations, and this remains the case today (one of course should regard "low" frequency pressure as acoustics).

Here though, the intent is to look forward to a subsequent phase when additional capability likely will be possible, specifically including acoustics, both passive and active. The next section gives a brief technical overview of relevant cable system details, and then the subsequent sections describe acoustical oceanography and infrastructure possibilities.

2. CURRENT STATE OF SMART CABLE SYSTEMS

The engineering feasibility of incorporating science instruments into submarine cable systems is discussed in detail in the Engineering Feasibility Study [4] and two subsequent documents [8,9]. Modern submarine communications cables use laser light transmission over optical fibers. The basic cable spanning the ocean basins between continents is only ~20 mm diameter containing: optical fibers in a small steel tube, a pressure vault of steel strength wires, a copper sheath, and polyethylene insulation. Every 65 km or so, the signal needs to be boosted in "repeaters" that contain erbium-doped optical amplifiers (Fig. 2). They obtain ~20-100 W from the single copper high voltage (up to 15 kV) conductor in the cable.

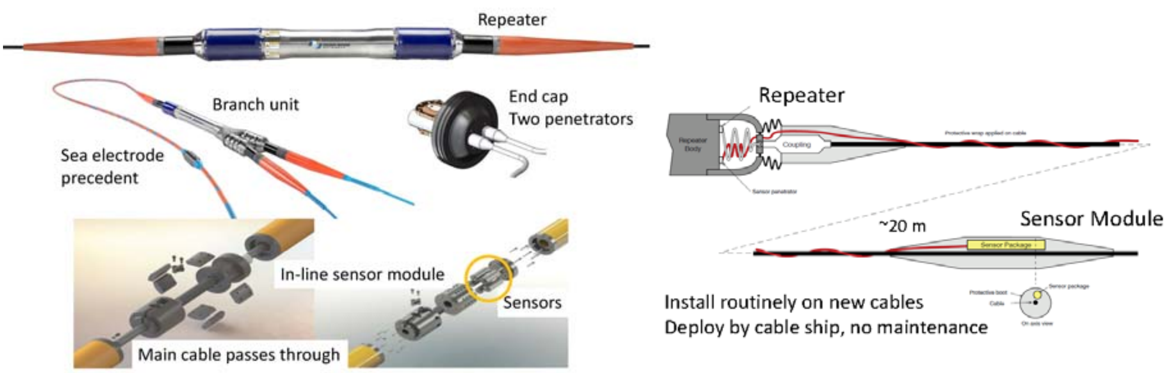

Fig.2: Repeater plus the sensor module. (left) Shown are the various constituent components, including the endcap with two penetrations and the sea electrode module with main cable pass-through, which are the qualified precedents for the mechanical aspects of the sensor module. (right) The connecting cable (red), suitably protected between the repeater and the sensor module; latter shows the main cable passing through the module, with sensors surrounding the cable but mechanically supported and protected.

The essence of the SMART cable concept is to extract several watts of electrical power for instrumentation and to tap into the communications system (likely using a low-bandwidth shoulder of the optical spectrum, and/or the supervisory channel). Whether this is done at each repeater or at selected ones is to be determined. The specific implementation method(s) are still undecided, though one possibility is shown in Fig. 2. Related systems have been deployed with weight/buoyancy distributed to achieve a specific "up" direction when deployed on the bottom. A significant constraint is the system must be deployable using existing cable ship technology; instrumentation must survive the associated rigors.

3. ACOUSTICAL OCEANOGRAPHY POSSIBILITES

Over the last decades there has been continuing discussion of the role of acoustics in observing the ocean [13-15]. In the context here, there are several important applications, including passive monitoring of marine life and physics, and various forms of long range acoustic navigation, communication and tomography.

Most of the SMART cable repeaters will on the deep ocean floor and will experience RAP (reliable acoustic propagation) conditions, i.e., sound generated (at the surface) within a ~30 km radius will reach the receiver without either surface and/or bottom interaction; sound coming from more distant sources will likely have experienced boundary interaction.

Passive Acoustic Monitoring. The most obvious acoustic sensor to add is a hydrophone (or perhaps a vector sensor), ideally as broadband as possible. Of any ocean sensor, hydrophones are the most proven and reliable. Exactly how one would be mounted will require thought given the proximity of the pressure case and the bottom. Some applications are described below.

Rainfall and wind. The measurement of rainfall at sea is especially important because of the extreme difficulty in measuring it with point sensors at or near the sea surface. Accurate measurements of precipitation are essential to understanding the global hydrological cycle for climate studies [16]. Acoustic sensors on moorings and Argo floats have been used to validate satellite rainfall measurements; see Yang et al. [17] for a recent description of measurements in the North Pacific.

Surface wave phenomena. Wind-generated waves are either produced locally (seas) or by distant storms (swells), and have peak periods ranging from ~0.1 to 25 seconds. The non-linear pressure fluctuations linked to the interaction between wind waves traveling in opposite directions can be recorded at any depth [18,19]; there is much interest in this as the high frequency shorter waves are intimately tied to heat, mass and momentum transfer at the air-sea interface. Longer period infragravity waves are generated by swells breaking at distant coastlines, radiate back into the deep ocean and can then travel across ocean basins. Recent papers by Arduin et al. describe data analysis and global-scale modelling efforts [20-21], partially motivated by the need to account for these waves in altimetry data.

Marine Animals. The use of acoustics to understand marine mammals began with trying to understand navy surveillance data in the 1950s. The science discipline began to develop in the 1990s because of the Heard Island Feasibility Test and the Acoustic Thermometry of Ocean Climate project. Many papers have been published demonstrating the utility of acoustic listening for mammals [23].

Ocean circulation and climate. If acoustic sources are installed for basin scale underwater navigation, communications, and thermometry, these hydrophones could hear their signals (assuming propagation and signal-to-noise are favourable) and participate in ocean acoustic tomography, per the original intent of the ATOC (Acoustic Thermometry of Ocean Climate) project [24]. A possible new development that may bear fruit in the coming years is to use ambient noise interferometry to infer speed of sound (temperature) and current between receivers, e.g., [25].

Other processes. Volcanos and earthquakes produce sound that is then coupled into the ocean sound channel to form "tertiary" T-phase signals. Sea ice as well as icebergs, moving glaciers on coastal land, and glaciers calving all make sound that can be used for better understanding of the processes. And of course, anthropogenic sources of sound include shipping and oil and gas exploration. Many of these could also be detected on "low" frequency pressure sensors.

Active Acoustic Monitoring. Adding an active acoustic transducer within the constraints imposed by the cable system will be challenging, but we should begin to consider the possibilities and determine how to accomplish this, as the payoffs are significant. Consider a transducer with an upward facing hemispherical beam pattern transmitting (and receiving) at ~4 kHz. Such a transducer can serve both as a science sensor as well as an infrastructure element. As a sensor, it can function as an inverted echosounder to measure the roundtrip travel time to the surface, and thus the depth-averaged speed of sound and temperature, directly relevant for ocean circulation and climate studies. Given acoustic propagation conditions, it may be possible for nearest neighbour repeaters to "hear" each other via a single surface bounce and thereby create a linear tomography array, determining along path average temperature between repeaters as well as water velocity (sound travels faster with a current than against).

At the same time, these units can serve the infrastructure role of wireless communication, as an acoustic modem to nearby vehicles and instrumentation, as well as providing navigation beacon signals over RAP ranges. In the more distant future, it may be possible to use SMART cables, or others, to support lower frequency, longer range acoustic sources that could provide basin scale coverage as mentioned above [26].

4. CONCLUDING REMARKS

Significant challenges remain before the SMART cable concept can come to fruition. In the future, incorporating acoustics into the SMART cable concept will be invaluable because it extends the spatial footprint of the ocean and earth sampling. It can provide remote, integral measurements of wind and rainfall, surface wave processes, and ocean heat content and velocity, complementing, supplementing and extending other observing systems. It can assist in the tracking of marine animals and the quantification of their populations and behaviour. The implementation, coupled with the ultra-high reliability telecommunications mission, can provide a long and enduring component of the overall global ocean observing system, not just with sensors, but additional infrastructure. It would be one additional step to extending terrestrial infrastructure subsea.

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