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Utilization of Remote Sensing Network Systems for Applied Ecology and Marine Conservation Biology

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UTILIZATION OF REMOTE SENSING NETWORK SYSTEMS FOR APPLIED ECOLOGY AND MARINE CONSERVATION BIOLOGY

by

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EXECUITVE SUMMARY

Advancement in technologies and applications of remote sensing network systems has provided wealth in our lives in many ways. If we were to take full advantage of such technologies in constructive ways, we should consider applying such technologies to ecology and conservation biology. Marine ecosystems have not been fully comprehended compared to terrestrial environment, largely due to difficulty in accessibility and manageability. It is important for expansions in marine biology research and for a benefit to conservation policies to utilize new computing resources in order to advance the level of understanding of marine ecosystem and enhance efficiency and effectiveness in its conservation efforts. Specifically, technologies for underwater wireless network systems with sensing devices are reviewed, and suggestions are made in order to realize such a system customized to provide continuous real-time monitoring data of marine species and ecosystems. Utilization of multi-hop topology with wireless sensor capability is addressed as a key component of the system. Repurposing of retired submarine cables may help enhance the realization of the system. This paper also examines effectiveness of the system, technical challenges, and suitable system application scenarios for marine conservation.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

OBJECTIVE

The purpose of this paper is to examine how utilization of new technologies can be effectively used in the fields of advanced ecology, marine conservation biology and conservation policy-making. Specifically, technologies for underwater wireless network systems with sensing devices to provide continuous real-time monitoring data of marine species and ecosystems are covered in this paper. Although actual hardware designs necessary for the realization of the underwater network system are outside of the scope of this project, this paper outlines effectiveness of a system for marine conservation, suggestions for development of a remote sensing system for real-time continuous data, and technical challenges of such system. Suitable system application scenarios for marine conservation are also examined.

1. INTRODUCTION

Remote sensing network systems refer to instrument-based techniques used in acquisition, measurement, and data transport of spatially organized information such as the behavior or physiology of target animals. Recently, technologies for remote sensing networks have improved significantly for applications for terrestrial and ocean surfaces that produce a variety of environmental and biological data (Roughgarden 1991). However, the technology for remote sensing network systems for an underwater application seems rather backward in comparison mainly because of the acoustics technological challenges (Akyildiz 2005).

The oceans occupy approximately 71% of the Earth's surface, the deepest parts of the seafloor are almost 11,000 m from the sea surface, and only few parts of the ocean have been fully explored. And in many of those few parts that we know well, there is huge decline in the integrity of the ecosystems.

Many technological challenges must be overcome to develop an underwater remote sensing network system for underwater usage however, we know that such a system could provide a capability for us to acquire data that would not be possible to obtain with the conventional approaches used by field biologists and ecologists. Such precise continuous data in real-time can be essential to improving our understanding of species and ecosystems in the ocean, and therefore, to developing and to maintaining proper marine conservation policies.

2. IMPLICATIONS OF USING THE SYSTEM FOR ECOLOGY AND BIOLOGY

Remote sensing network systems and applications have revealed enormous potential benefits for scientific communities. They also allow scientists to expand their research to a new level where ordinary systems could not reach due to a limited accessibility of the targeted areas or the species, or due to other obstacles. As wireless sensor technology keeps improving, people in the scientific community should take advantages of such developments to realize the enhanced monitoring system that would bring the "unreachable" within our reach. Discussion of several advantages that can be achieved by remote sensing networks follows.

i. Multi scaled data – Spatial and temporal scale

Data collected by the system can be in a variety of spatial and temporal scales. A conventional system has limitations in order to collect data from many physical locations in large areas. It requires tremendous effort, manpower and time to gather such data. Remote sensing network systems allow scientists to reduce such human efforts in collecting data, and to obtain data efficiently without intensive maneuvers, rather like how we easily extract necessary information through the Internet in our daily lives. Also an ability of the system to cover wide spatial areas is an important feature in terms of the monitoring of unrestrained, free-ranging animals in the natural environment.

ii. Real-time and Continuous data

Many types of real-time data are available in different fields for different purposes. In some fields such as seismic research (Endo 1990), it is very critical to obtain real-time data; semi real-time data (meaning inclusion of a delay in data transfer) is adequate in some fields such as ecology and conservation biology. In this paper, the difference between real-time and semi real-time is not examined, and I use the word "real-time" include to "semi-real-time".

In conservation biology and applied ecology, obtaining real-time and continuous data can be useful for monitoring target animals. Current tag systems allow one to monitor the migration behavior of tagged animals; however, a tag provides only discrete bits of information at certain times and thus one will always lack information between the sampling times. If the system provides real-time continuous data, we can eliminate unknowns associated with those periods when target animals are not monitored. The application to migration behavior of targeted animals will be discussed more under Section 4 - Possible Application Scenarios. Biological real-time data combined with real-time data from different fields such as oceanographic data can produce useful information for scientists. Utilizing and combining physical oceanographic data with location information of migrations could reveal a key to understand what circumstances arouse animals to migrate. Also, target animals do not need to be retrieved for scientists to obtain data, which is the practice with the typical tag system currently used, since data are available for real-time retrieval through a network system.

iii. Collection of data under severe conditions

Once sensor nodes are set and links of a network system are established, data collectors do not need to be at site all the time. This is especially useful in certain natural conditions such as extreme heat, high surf and underwater (Porter 2005).

iv. Handling and storage of large amounts of data, and allowing retrieval at a convenient time

A system with some types of storage capability could handle an enormous amount of data, and a user of the system could retrieve data at a convenient time, which leads to an important concept for long-term observation of ecological systems. The majority of ecological changes happen over a long time, and if scientists would like to monitor the change, the lifetime dedication of one scientist will not be long enough. Long term observations over 100 years or more need to be considered for a new level of research, and many fields demand the design of a system that allows one to retrieve and maintain data for such long time periods (Baker 2000).

3. IMPLICATIONS OF USING THE SYSTEM FOR CONSERVATION POLICY AND POSSIBLE APPLICATIONS

Remote sensing network systems provide real-time continuous data that are precise and accurate. In this section, the implications of the eventual realization of the system for marine biological conservation and policy-making are analyzed.

Uncertainty in marine population and ecosystem dynamics is a central difficulty in marine conservation. The status of two-thirds of exploited species is simply not known according to C Roberts (2003). Dynamic populations of most marine species are poorly known largely because the geographic scale of such populations requires intense research over large distances (Palumbi and Hedgecock 2005). This challenge may have contributed to the fact that only as little as one hundredth of one percent of the sea is protected from all fishing, equivalent to just half the area of Africa's Lake Victoria (C. Roberts 2003). Terrestrial species are much easier to count and track than marine species. We would only recognize an extinction if it occurred to a few species with well-studied taxonomy, such as fishes or whales. Even for the few areas that are regularly surveyed, such as the shelf areas of the North Atlantic, near extinctions of large, distinctive, and formally common species can occur without anyone's knowledge (Myers 2003). Rare species and species with less economical importance, as well as areas currently untouched by researchers, require more intensive sampling to obtain reliable data. One of advantages of using remote sensing networks is to be able to cover large-scale spatial areas, including remote locations, with limited accessibility.

Continuous data retrieved by the system can be useful not only for the improvement in biological research on species or marine ecosystems, but also for marine conservation such as determining a marine reserved area (MRA) and a marine protected area (MPA). It is a challenge for us to set up the right boundary for a MRA and MPA. As Hooker et al. (2002) noted, surrounding areas may provide crucial food subsidies to species that forage above fixed features, so incorporating protected buffer areas around features to be protected will provide needed insurance for fixed protected ecosystems in the open ocean. Keystone species are strong interactors that have an unexpectedly large impact on food web structure and function given their abundance (Crowder 2003). Monitoring keystone species using the system that provides continuous data in a potential MPAor MRA will likely provide sufficient information on the condition of the food web of surrounding areas so that we can determine the proper boundaries.

Another potential area to which the system can be productively applied is a long-term observation of ecological or biological shift. For instance, most modern reef ecology focuses on the last 50 years, but reef systems in the Caribbean have undergone several hundred years of change and loss of their megafauna before scientists began careful observations or experiments (Jackson 1997). It is often the case that observation and research are launched with acceptance of conditions of the marine systems as a baseline, and the same baseline is not used by following researchers of the next generations. This inconsistency results in a lack of continuously comparable data on the same baseline over the history of observation. The system with a capability of providing continuous long-term data collection and storage allows us to maintain and analyze data longer than the typical dedicated period of one scientist, which would reduced the possibility of the shifting baseline syndrome (Pauly 1995). The shifting baseline syndrome is a gradual shift of the baseline in terms of what species were caught and at what levels of abundance in the past. This matter is typically not the concern of the fisherman who lacks a sense of history for periods longer than his career. When the system is once installed, the data can be continuously retrieved beyond typical terms of a project without additional substantial cost, making the system suitable for long-term observation, thus avoiding the baseline shift.

Continuous data with spatial information can be also used to analyze both direct and indirect impacts of human interactions. Pollution, which could alter the reaction of species to predators and influence their reproductive ability; population changes as a result of over-exploitive fishing; and physical and sometimes psychological damage (caused by fishing when the fish avoid the capture) are all among the impacts on marine species that are associated with human interaction. Migration pathways as well as individual behaviors could also be affected due to various human interactions (Parrish 1999). When the system obtains continuous data monitoring capability, the precise migration behavior of the organisms can be assessed. This will not only allow the assessment of the migration behavior, but also help establish a proper MPA or MRA for the species throughout its migration pathways when continuous monitoring data are combined with other oceanographic data.

When the continuous monitoring system is equipped with an ability to transfer the data in real-time, we can further predict the timing of migration of organisms along the pathway. The real-time location data transferred from the monitoring sensor devices will facilitate the prediction of the migration of the target animals in a timely manner. With multiple aspects involved in a marine system that could impact the precise timing and the location of the pathways, the comprehensive and accurate prediction of migrating pathway is extremely difficult without such data. This ability to predict could not be achieved with conventional tagging devices that store data for a certain period until the content of data is manually retrieved. Additional studies of tagging devices are needed to further define the activity patterns and migratory behavior of highly migratory species (Sedberry and Loefer 2001). If we have comprehensive observations of changing conditions of the ocean, scientific understanding about habitat needs, and the wealth of knowledge about the migration pattern of species, then we could predict the actual timing and location of the migration of the target species. How we can effectively utilize such important information for conservation is a key issue for consideration.

MRAs or MPAs is an effective tool for recovery of the marine system in the area and the target species. However, it is not practical or feasible to protect entire areas of the marine ecosystem based on the precaution principle, which could be an ideal solution for biological conservation per marine biologists and scientists in general. At the same time, MRA and MPA must accommodate the changing habitat use by organisms with complex life cycles and associated migration and dispersal behaviors. As such, E. Norse et al. (2005) have proposed an idea to implement shifting MPAs as an alternative solution. If we could precisely predict the pathway of migratory species, then it would be possible to protect their shifting habitats as they move, reflecting decadal, inter-annual, seasonal, lunar, or even daily shifts in pelagic habitat. This knowledge will enable us to protect the feeding area, breeding area, and the migration route of this species while putting far less of the ocean off limits. This can be considered as a way to thus provide near-maximum conservation benefits while reducing regulation consistent with achieving conservation objectives and reducing adverse economic effects.

Also important is the fact that real-time monitoring systems will enable the continuous assessment of suitability of the MPA and MRA and the proper enforcement of effective management of the areas. Ensuring that the area provides the expected benefit to the marine system or target species by analyzing the data will be essential for the success of the area. Also any improper actions conducted in the area by humans such as illegal fishing could be detected through changes in the marine system that can be monitored simultaneously. Therefore, the system will help assure that corrective management measures take place when needed.

Applying the real-time continuous data monitoring system to species that are targeted by fishing as well as their by-catch species would have another benefit for conservation. It will enable the fishing industry to more accurately analyze the behavioral differences among species including daily activity patterns, seasonal migratory patterns, and reactions to fishing gear and/or predators. This will help prevent by-catch of undersized and non-target fish that are reported to accounted for a large percentage of total catch. The species-specific knowledge will benefit both the conservation of species by eliminating undersized and non-target fish and the fishing industry by increasing efficiency.

Being able to combine data obtained from the system with data available in other fields such as oceanographic research is another key benefit of the real-time monitoring and data retrieval system. Both researchers and policy makers typically focus on single issues and concentrate efforts on understanding, and if possible, eliminating or reducing stressors that have strong effects. D. Breitburg (2005) has noted that among the most important challenges facing conservation biology today is the problem of predicting, understanding, and reducing effects of multiple stressors. When studies focus too narrowly on a single stressor, they could miss the simultaneous influence of other stressors, thus compromising the utility of results. Similarly, policies that focus on single stressors can also be less successful or cost-effective than actions that use a more holistic approach. Often oceanographic data such as salinity, water temperature, chemical concentration levels and the current speed can be obtained continuously via real-time data retrieval systems developed in recent years. When the monitoring system for marine biology can use real-time data retrieval functionality, it would most effectively be utilized by combining the data for analyzing multiple stressors that may have caused the particular result.

Whole system manipulations with installation of the real-time monitoring system for marine biology could enable the assessment of the importance of stressor interactions at large spatial areas over long periods. Having such a holistic system will eliminate a need for many assumptions or limiting conditions that are basic in most such research so that major conclusions of the researchers will be much more accurate and reflective of the real condition of the marine system. Similarly, eliminating uncertainty is a key for decision makers. When policies are developed, it is to everyone's interest to properly reflect the real conditions and the need for improvement rather than to base these decisions on the results of research and studies that contain various uncertainties, assumptions, and estimates. Uncertainty about the level of population risk often leads to delays in management action because it provides the basis for continuing denial of a problem (Botsford et al 2005). It is also reported that explicit analysis of the sensitivity of outcomes to large amounts of uncertainty in data-poor situations could reveal that more data are needed to justify any decision on reasonable basis (Botsford et al 2005). Precise information on the condition of the marine system obtained through installation of the real-time marine biological data monitoring system will minimize such uncertainty as well as the delays in management action.

At last, when the system is developed, it could be easily applied to a large number of species and marine systems in a large scale over a long period of time, although the initial investment to realize such a system could be astronomical. The amount of information available varies globally from one country to another depending on financial resources and resource management infrastructure. By eliminating the need to manually and physically retrieve the sensing devises that stored the data, by wirelessly transmitting the obtained data simultaneously, the operating cost of the system can be much reduced compared to the conventional system for the same level of the task. When the system is applied to a large number of species or areas of marine systems over a long period, the benefit of the system can be optimized and may not be as expensive as it may appear considering all the benefits that the system could bring to marine biology and conservation.

4. POSSIBLE APPLICATION SCENARIOS

Underwater sensor networks will find applications in many fields including oceanographic data collections, pollution monitoring, offshore exploration, earth study, unmanned or autonomous underwater vehicles and monitoring living organisms. The system will enable the exploration of natural undersea resources and the gathering of scientific data in collaborative monitoring missions.

A possible application with the system being proposed in this paper for applied ecology and conservation biology can be a location awareness system for ethologic study on a targeted animal in selected areas, such as seasonal movement, spawning behavior, travel speed, and diving behavior. Archival tags or satellite tags such as pop-up or splash tag for large pelagic fish or marine mammals are currently available have been used for research on the migration behavior of fish (Block et al 1998); however, such tags do not provide real-time continuous data for the observed period. A sensor device with a network capability will allow scientists to monitor continuously through seasons. A tagged fish in proposed system will be an integral part of the network while being monitored as a proxy for many fish in natural environment. How environmental changes affect dynamic population of target fish can be also observed by combining with real-time continuous oceanographic data over the same period. Such observations will play an important roll in marine conservation.

i. Assessments of MRA and MPA

The system can be used to obtain information to assess the efficiency of MRA or MPA. Tags could be placed on keystone species within the MRA or MPA and monitor for their behaviors including boundaries of territories and key areas where they tend to stay. If they tend to stay outside of the MPA or MRA, then that is an indication that ecosystems outside of the MPA or MRA may be healthier or have more importance to the keystone species than the MPA or MRA. The result may suggest that further research on the local ecosystem or some assessments of the efficiency of the MRA and MPA (for necessary relocation of the areas) are needed.

ii. Migration pattern recognition applications

Data will be delivered to scientists without recapturing tagged fishes or the targeted marine species through the network system. Moreover, when sensors are equipped with a capability for measuring environmental attributes such as water temperature, salinity, light intensity, the system will produce important information to help understand the basis of mysterious migrations of animals or interactions of multiple stressors in general. For example, when we do research in the migration behavior of species, we usually depend on literature data taken from previous years. However, migrations reveals slightly different pattern every year since migrations are affected by many physical oceanographic phenomena. However, if we have real-time continuous data, and we could tell where a school of target fish was two weeks ago, where a school of target fish was one week ago, and if we could tell where they are now, then we could predict where they will be next week. The data are continuous rather than the result of human intervention to connect the dots of data based on assumptions. If we know their migration behaviors for spawning, then we could suggest creating a temporal protected area and implement temporary restrictions for fishing for fixed time of period. As was discussed in the previous section for policy making, creating temporary MRA or MPA would be effective way for marine conservation strategies to go especially if the goal is to protect areas used for ovipositional behavior. Using real-time continuous data will facilitate procedures for creating such temporary areas and the associated policy.

Combining physiological sensors on the above applications, i and ii, allows scientists to conduct research with more depth in many ways (Bridger 2003).

iii. Security

In recent years, underwater wireless acoustics system has also been developed for the fields of underwater security (Rice 2000). Once the core technology of underwater wireless acoustics systems is established, the technology can be applied to control illegal fishing. For example, if a regulation on commercial fishing required all vessels and fishing gears such as nets to have small hardware communication devices, and if we could set up a security link with RF over MRA or MPA, the system will allow us to detect poachers coming into a MRA for illegal fishing. This type of application can be implemented based on same technologies with behavior monitoring applications. This demonstrates a great example of system reusability.

5. SYSTEM DESIGN OF UNDERWATER ACOUSTIC SENSOR NETWORKS

In this section, the system attributes that will provide continuous real-time data connected through a wireless framework in the underwater environment will be examined. The basic underwater network connection will be achieved with acoustic technology utilizing the multi-hop (mesh network) topology in the proposed system. Acoustics technology typically needs to be used to establish underwater wireless network connections since radio waves simply do not work well in the underwater environment due largely to the attenuation of radio waves in water. Also the propagation speed of acoustic signals in water is much slower than the propagation speed of radio waves in air (Table 1), which causes latency time when acoustic signals are utilized for underwater. Other challenges for developing an underwater wireless network includes attenuations, noise redundancy, Doppler affects, etc. However, acoustics technology for underwater networks has received a lot of attention in some fields such as oceanographic data collection, underwater development operations and communication systems for underwater vehicles. Therefore, the technology has improved significantly.

	Acoustics in saltwater	Radio waves in air
Typical speed of propagation	1.5 km/s	300,000 km/s

Table 1. Comparison of propagation speeds

A basic underwater acoustic network can be formed by establishing two-way acoustic links between various transmitter and receiver instruments such as sensor devices and other hardware communication devices such as routers or repeaters. Then the network is connected to a surface station that can further be connected to Internet backbones or a satellite system with radio frequency communication technology (RF). RF technology for land usage application has been improved and allows us to reach a new level of scientific research; however, underwater acoustic network systems are quite different from RF technology in many respects.

Suggested principles of the system in this project consist of 3 tiers and each constituent and its challenges are discussed in the following section. Such constituents are: physical layer, data-link layer, and the network layer utilizing multi-hop network topology. However, designing hardware components such as an AD-converter and acoustic modem to develop an underwater wireless acoustic system is outside of the scope of this project, although a brief overview of physical devices is addressed.

i. Physical devices

Sensing devices in a multi-hop network, which are discussed under the section "Network topology and Algorithm", for underwater are not quite ready for marketing. However, devices with the capability of RF multi-hop networking for a land use have become available in the market recently. This type of sensing device is predicted to drop in cost to about $10 per unit and in size to about 2 cubic mm without batteries (Hellerstein et al 2003). Functionality of sensing devices should be considered for important aspects required for the underwater application to use in research and projects in biology and conservation. The key aspects for any specific application include affordability, energy efficiency, robustness, high sensitivity, accuracy and physical size.

ii. Physical layer

This layer conveys the bit stream of signals through the network at the electrical and mechanical level. Underwater acoustic wireless network systems need to overcome many challenges such as noise reduction, reflections, propagation delays, attenuation such as loss of data pass, and Doppler effects that would otherwise limit the data communication rate of the system. Propagation distance is also an important consideration for the system as Sozer (2000) pointed out. Long-range systems that operate over several kilometers may have a bandwidth of only few kHz, while short-range systems may have more than hundred kHz of bandwidth (Table 2). In both case, low bit rate will be an issue for existing devices and it is important to wisely select a digital modulation system in the physical layer of devices. Orthogonal frequency division multiplexing (OFDM) is one of modulation techniques for wireless transmission among other techniques such as Phase-shift keying (PSK), Frequency-shift keying (FSK), and Amplitude-shift keying (ASK). OFDM can mitigate existing challenges for the physical layer since it offers advantages in noise and reflection reductions comparing digital modulations listed above (Kong, et, al. 2005). OFDM also uses multi-carrier digital modulation systems that allow each frequency to be mutually overlapped. Therefore, communication bandwidth is normally bigger than typical frequency division multiplex, which helps the common problems of narrow band in an acoustics communication system.

	Range (km)	Bandwidth (kHz)
Very Long	1000	< 1
Long	10 – 100	2 – 5
Medium	1 – 10	≈ 10
Short	0.1 – 1	20 – 50
Very Short	< 0.1	> 100

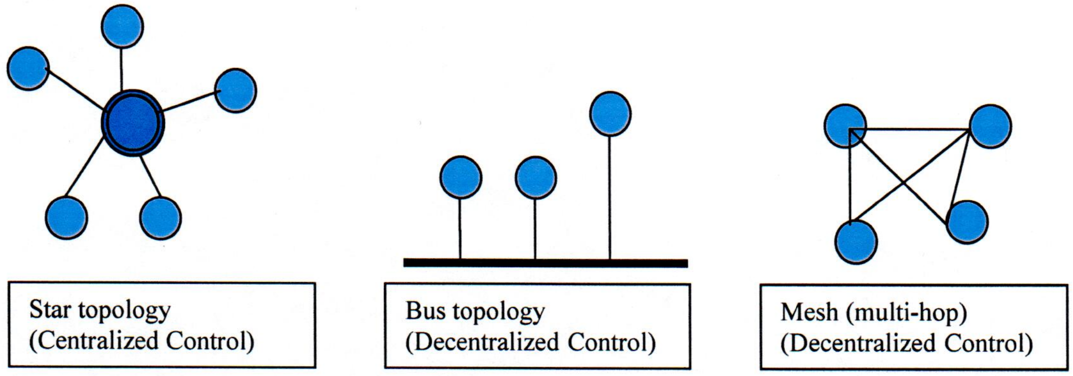
Table 2. Available bandwidth for different ranges in acoustics channels

iii. Link layer

One of the functionalities in this layer is to determine who is allowed to access the physical media at any one time. This is called access control. There are three major access control methods – Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), and Code Division Multiple Access (CDMA). CDMA is known as the spread spectrum methods in which energy generated at a single frequency is deliberately spread over a wide band of frequencies. CDMA can be considered as a choice for underwater wireless network system since it is quite robust against frequency selective fading caused by underwater multi-paths since it distinguishes simultaneous signals transmitted by multiple devices (Akyildiz 2005). CDMA also allows reducing the number of packet retransmissions which results in reduced power consumption. Within CDMA methods, there are two different types of methods – Direct Sequence Spread Spectrum (DSSS) and Frequency Hopping Spread Spectrum (FHSS) (Jordan and Abdallah 2002). One attractive access technique in the recent underwater literature combines multi-carrier transmission with the DSSS CDMA (Kalofonos 2003) as it may offer higher spectral efficiency than its single carrier counterpart, and increase the flexibility to support integrated high data rate applications with different quality of service requirements(Sozer et al 2000).

iv. Network Topology and Algorithm

The pattern of configurations of links between nodes in a network is called the network topology, and it can be mainly divided into three groups: centralization, decentralization and hybrids of centralization (Figure 1). Centralization topology such as a star topology has several advantages: 1) simplicity for implementation and extension, 2) a failure of a non-central node will not have major effects on the functionality of the networks as a whole, 3) no data collision, and 4) secured implementation. Disadvantages include restriction with cable length, and a failure of the central node causing the failure of the entire network. Decentralization topology such as multi-hop networks has advantages of data path assurances, resilience, flexibility of network, energy efficiency and cost advantage to build a network (Cormen et al 1990).


Star topology (Centralized Control)

Bus topology (Decentralized Control)

Mesh (multi-hop) (Decentralized Control)

Figure 1. Network topologies

For underwater wireless network systems, it is extremely important that the system is robust and reliable since human efforts to maintain the underwater system is more expensive than for terrestrial systems. The system reliability will be increased by using a multi-hop network with an assured data path system on the networks. Flexibility of range of the network is also important for underwater network especially for an application to monitor movements of animals in natural environments. In order to monitor and record natural behaviors of animals in natural environments, the system or devices should restrict animal behavior as little as possible. The flexibility of the network allows the system to keep track of animal behaviors in a large spatial area with less restriction. Multi-hop networks also have an advantage in flexibility because they will be able to extend the range of the network by utilizing neighbor nodes within the range to transmit the data from one node to the other.

Minimizing energy consumption, which can be achieved by using multi-hop network topology, is also an important aspect for the underwater network system. If each end node in a network transmits only to its nearest neighbor node, energy consumption will be less than static network connections. Therefore, transmission utilizing multi-hop network minimizes energy consumption with capability for longer distances with flexibility.

In consideration of all the above factors, a multi-hop network topology is suggested for end-node connection within the underwater wireless network system. Master nodes within the end-node connection will communicate with other master nodes in different subsets of networks or middle nodes connections, which consists of other hardware communication devices. (Figure 2) This middle node network could be connected by centralization networks to repeaters or gateways on the surface of ocean.

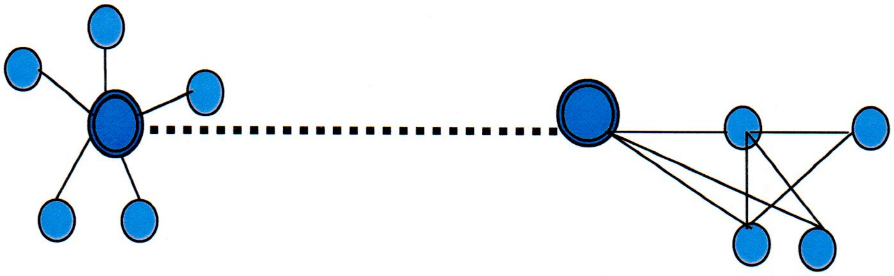


Figure 2 One mesh network is linked with the star network by master nodes

In summary a multi-hop network topology is suggested for use in the end node network, and centralization or a combination of centralization and decentralization topologies will be used for the middle node connection and for the entire network system connection.

An algorithm to determine the path from master node to all slave nodes is also important for a multi-hop network (Abolhasan et al 2004). An unsophisticated algorithm could select an inefficient data path route between nodes and result in unnecessary energy consumption and latency. Many different types of algorithms for multi-hop networks can be found, but most of them are categorized into either Proactive or Reactive protocol. They are routing protocols defined by Mobile Ad-hoc Network working group (http://www.ietf.org/html.charters/manet-charter.html).

Proactive protocols maintain routing table information all the time by broadcasting a control packet that contains routing table information. This provokes a large signaling overhead to establish a route of a network for the first time and at each time the network topology is modified if node failures or entry of new nodes occurs.

Reactive protocols perform route discovery processes only when a request command is sent. A multi-hop network cannot send data without having a routing table, which contains information of routing path from node to node, so reactive protocols deal with higher latency. Once a route has been established, it is maintained by a route maintenance procedure until it is no longer desired.

Proactive protocols are useful for a system that needs to know the exact network topology all the time. This protocol has higher energy consumptions since it updates routing tables all the time. Reactive protocols have higher latency since they do not update routing tables all the time but they are energy efficient. There are some trade-offs between the two protocols, however; typically underwater multi-hop networks are more suitable with reactive protocols because of high-energy efficiency and because that frequent broadcasting for routing tables is not required all the time (Sozer 2000).

Another important point is that even though RF network technology is not suitable for underwater network systems, designing an underwater acoustic network system must follow the form of layered network architecture known as Open System Interconnection (OSI) as defined by International Standard Organization (ISO). OSI layer (Figure 2) has been used for a land network system in order to establish interoperability between the systems on land and underwater (Figure 2).

Application
Presentation
Session
Transport
Network
Data link
Physical

Table 3. ISO OSI model layers

v. Retired Submarine Cables

Submarine cables are fiber optic undersea telecommunication cables owned by telecommunication companies (Figure 3). The previous generations of the cables, such as Trans Pacific Cable 4 (TPC-4) that spans the North Pacific, are now being retired. In general, the life span of such cables is about 25 years; however, many cables get retired 10 to 15 years earlier than the end of their life span because newer generation optic cables are so much faster with upgraded capability that they make the previous generation cables less economical to transmit the same amount of data (Butler 2003). These retired cables can provide sufficient power for many underwater operations and sufficient data transport speed for many underwater network systems

(Tables 3). Reusing newly retired optic cables provides a great opportunity for the scientific community (www.IPCP.org). Using an Internet Protocol (IP) as a communication method with retired submarine cables has been already considered, and IP based communication can be realized by adding a Field Programmable Gate Array (FPGA) to modify the hardware system on the repeater of TPC-4 cables (Asakawa and Shirasaki 2003).

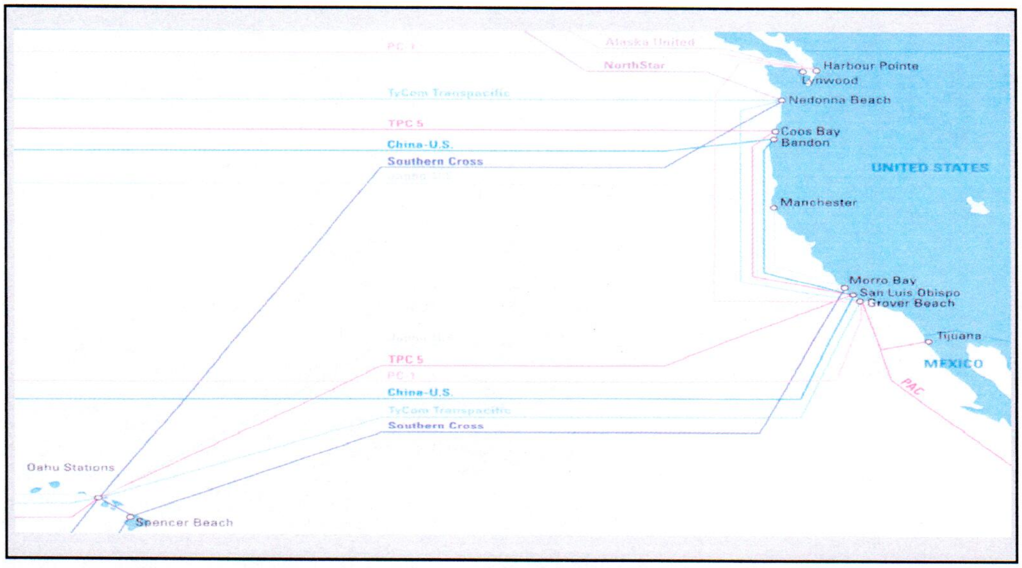


Figure 3. Submarine cable map (Pacific)

Transmission Capacity	560M bps
Maximum Supply Voltage	15,000V
Actual Operating Voltage	12,676V
Estimated fluctuation of	300V
Available Voltage = **(a)-(b)-(c)**	2,024V
Supply Current (A)	1.6A
Available Power (W=V*A)	3,238W

Table 4. Power supply and transport rate for TPC-4

6. RECOMMENDED SYSTEMS

Two possible systems are being considered in this project. The first scenario uses a multi-hop network topology for both end nodes and middle nodes network (Figure 4). The end node network consists of end-node sensor devices that consist of master nodes and slave nodes. Master nodes have a functionality to control the routing paths of the end nodes connected to them, and master nodes also can communicate with other master nodes located outside of the end nodes network. The hardware communication devices have the functionality necessary for acoustical communication such as filtering, CODEC, AD-coveter, amplifier and etc. Middle node connections to link between communication hardware devices and necessary repeaters for signals are also accomplished with a multi-hop network. Such links will be connected to gateway devices located on objects at the surface such as a buoy so that RF can be utilized for further data transmission. Advantages of this system include network flexibility for its range and the fact that less intensive human involvement is required in physical cable construction and in the repair of physical cables, which would reduce destruction of the marine environment from installation of the system. This system is a future model for various kinds of acoustical underwater multi-hop communication networks even though technical challenges that are listed in the previous sections are still significant and technological breakthroughs for hardware devices are required.

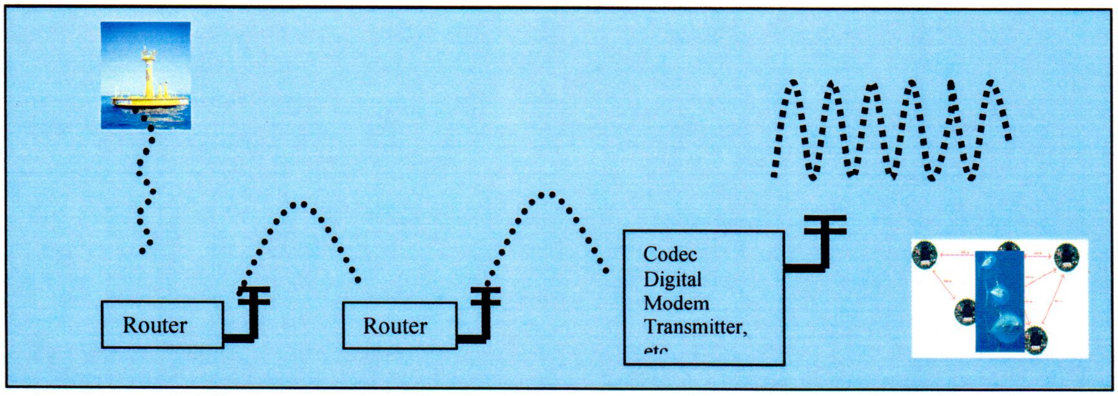


Figure 4. Scenario-1: Multi-hop acoustic wireless communication system

The second scenario is similar to the previous suggested scenario in that a multi-hop network topology at the end node connections is used between master nodes and slave nodes. However, hardware devices on middle nodes will be connected with retired submarine cables (Figure 5). The cables will transfer the data sensed by end node devices to gateways or access points located at various places on land while providing an energy source for the system at the same time. Even though the second scenario requires physical construction to install the system on the retired submarine cables owned by telecommunication companies and will need a specialized ship with appropriate tools owned by the companies to do so, this scenario eliminates power source issues and offers a faster data transfer rate, so this scenario is more realistic for actual implementation.

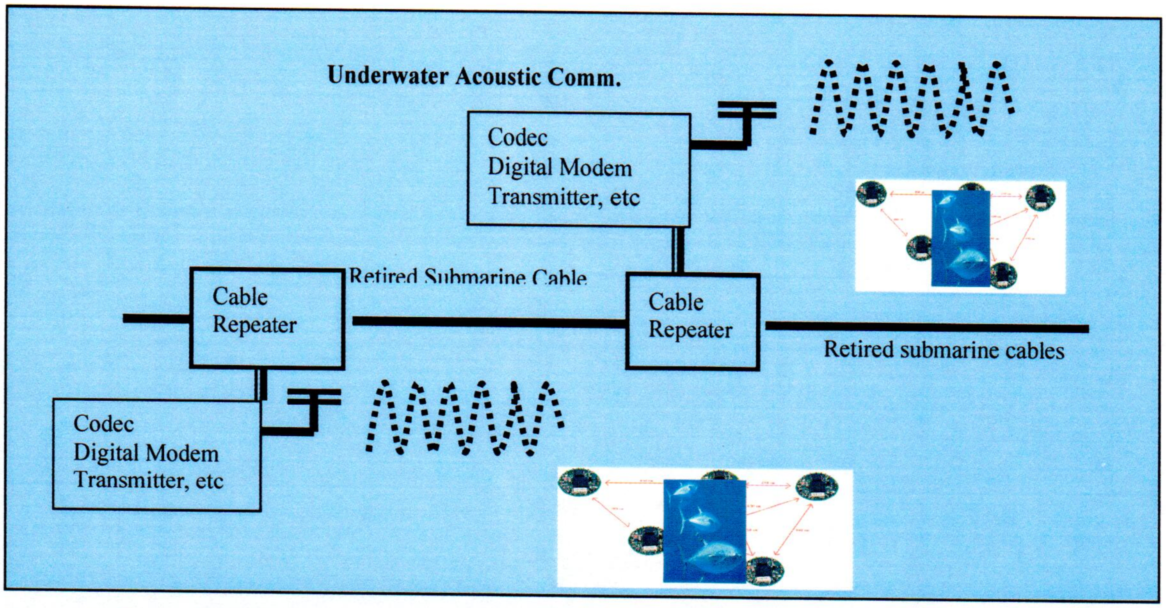


Figure 5. Scenario-2: Multi-hop acoustic wireless communication system with retired submarine cables

7. CONCLUSIONS

Remote sensing systems and wireless technology have facilitated and advanced research strategies in many ways. Applying a remote sensing system for underwater situations is relatively new in any field of science, but the emergence of new technologies for sensors, data sampling and computer communication is enabling scientists to exploit available technologies to establish monitoring sensor networks for conservation purposes.

Underwater acoustic wireless communication systems do not directly solve a problem existing in the conservation of marine ecosystems. However, information that will be provided by the systems can be extremely useful by leading to new levels of research and conservation policy-making by providing accurate information about the condition of marine ecosystems and species. By utilizing information retrieved by the system, new findings in ecology or biology can be expected, and such information is important and powerful for use in conservation and for policy-making to properly protect endangered species and establish or enhance policies for conservation. Remote sensing systems for terrestrial use already have proven useful for scientific research. Unlike many terrestrial systems, most species that are endangered in marine ecosystems could potentially recover sufficiently to restore function to degraded marine ecosystems (Crowder 2004). Whether our tinkering in marine ecosystems has been intelligent or more likely not, we still have most of the parts and could choose to rebuild these systems to restore their original function (Crowder 2004).

There are many demands from a variety of fields of study in both terrestrial and underwater environments to develop a remote sensing wireless system with similar technology. Such fields include medical equipment (Malan et al 2004), environment sensor networks (Mainwaring 2006), and underwater multi-hop networks (http://www.nopp.uconn.edu/). Therefore, technology for this type of system will improve in many aspects.

Developing the underwater system with functionalities similar to those of terrestrial remote sensing real-time continuous data system for underwater biological and conservational research needs to be done, because the system will provide information that ordinary systems do not provide. We have so much unknown in our oceans, and the system provides information that can open new levels of research and discovery in the ecological and biological fields. Developing the system is a potential contribution for conservation and therefore, for our future.

We cannot talk to animals, but we can learn from them by monitoring their behavior and finding out what they need. In order to lean from them, we need a tool. Wireless communication systems are great tools for acquiring data on natural behaviors and for us to understand animal needs. It is our human nature to pay more attention and be more concerned about the condition of creatures about us when we know about it. When we eliminate the unknowns in our understanding of the oceans by utilizing the proposed systems and have alerted policy makers and have made the public feel more familiar with the marine environment and more likely to care for the health of the marine ecosystem, the real-time monitoring system may truly have completed its mission.

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