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A Survey for the Design of Underwater Cognitive Acoustic Networks

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ABSTRACT

To develop an eco-friendly Underwater Cognitive Acoustic Networks (UCANs) with high spectrum utilization. The huge number of sensor networks is installed in the Underwater to enable applications for oceanographic data collection, pollution and corrosion monitoring, offshore exploration, disaster prevention, assisted navigation and tactical surveillance applications. For feasible applications, there is a need to enable the underwater communications among the underwater devices. The latest developments in the wireless communications cause the spectrum shortage problems in the oceans. Cognitive Acoustic (CA) is the enabling technology for supporting dynamic spectrum access technique in wireless communication. The CA provides the solution for spectrum scarcity problem that is encountered in many countries. In oceans, both the natural acoustic systems and artificial acoustic systems use acoustic signal for communication. To efficiently utilize the spectrum without interference with other acoustic systems, a smart UAN should be designed with aware of the surrounding environment and ability to reconfigure their operation parameters such as frequency band, modulation schemes and transmission power.

INTRODUCTION

In wireless communication systems, the right to access the spectrum is generally defined by frequency, transmission power, spectrum owner (i.e., license), type of use, and the duration of license. Usually, a license is assigned to one license, and the use of spectrum by this license must be conformed to the specification in the license. In the older spectrum licensing schemes, the license cannot change the type of use or transfer the right to other licensees. Moreover, the radio spectrum is licensed for larger regions and generally in larger chunks. All these factors in the current model for spectrum allocation and assignment limit the use and result in low utilization of the frequency spectrum. Because the existing and new wireless applications and services are demanding for more transmission capacity and more data transmission hence, the utilization of the radio spectrum needs to be improved [1]. To improve the efficiency and utilization of the radio spectrum, the above mentioned limitations should be amended by modifying the spectrum licensing scheme and adopting a dynamic spectrum management model. The basic idea is to make spectrum access more flexible by allowing the unlicensed users to access the radio spectrum under certain conditions and restrictions. Because the traditional wireless systems were designed to operate on a dedicated frequency band, they are not able to utilize the improved flexibility provided by this spectrum licensing scheme. Therefore, the concept of cognitive radio (CR) emerged, the main goal of which is to provide adaptability to wireless transmission through Dynamic Spectrum Access (DSA).

LITERATURE REVIEW

The main goal of the research is to develop an eco-friendly Underwater Cognitive Acoustic Networks (UCANs) with high spectrum utilization. Several marked differences in ecological and evolutionary processes exist between marine and terrestrial ecosystems as ramifications of fundamental differences in their physical environments (i.e., the relative prevalence of air and water) and contemporary patterns of human impacts.

During the past decade, underwater acoustic networks (UANs) have attracted major interests due to a wide range of applications including underwater environment monitoring, Distributed tactical surveillance, Assisted navigation, Disaster prevention, Undersea explorations, Mine investigation offshore structural health monitoring (SHM), target tracking and oceanography data collection.

However, the underwater acoustic environment is complex in oceans, where multiple acoustic systems might exist in the same area using sounds for communication, echolocation, sensing and detection.

The spectrum is a scarce resource heavily shared by underwater acoustic systems. Due to the frequency-dependent attenuation, the available communication frequencies in water are severely limited, usually from tens of hertz to hundreds of kilohertz. The majority of artificial acoustic Systems and natural acoustic systems utilize the frequency band from 1 kHz to 100 kHz, making the acoustic channel crowded. Yet, this valuable resource is still underutilized. In order to use the spectrum more efficient a smart UAN should be awake of the surrounding environment and dynamically reconfigure their operation parameters such as frequency band, modulation scheme, and transmission power.

Through sensing the surrounding spectrum usage, CA users in underwater cognitive acoustic network (UCAN) are able to intelligently detect whether any portion of the spectrum is occupied, and change their frequency, power or even other operation parameters to temporarily use the idle frequencies without interfering with other networks.
By developing the sensing ability and configurability, the CA users can capture and follow the real-time spectrum variation in oceans.
The challenges in underwater communication includes limited frequency bandwidth for underwater communications, Constrained by this hardware limitation, long preamble and the transmission power adaptation and dynamic channel allocation may not follow the environment variation causing unexpected interferences.

The major contribution of this paper involves three parts Firstly, we investigate the spectrum usage of acoustic systems in oceans; Secondly, we discuss the unique features of underwater channel and acoustic systems. Finally, we analyze the grand challenges faced in the UCAN design and advocate some simple solutions. The remainder of this paper is organized as follows.

In Section III, we investigate the acoustic spectrum usage in oceans, which helps CA users to be aware of the potential channel competitors. The issues and challenges in spectrum sensing techniques are discussed in section IV. The underutilized spectrum is discussed in section V. The spectrum management framework is discussed in section VI. The spectrum decision and sharing are discussed in section VII and VIII respectively. The design challenges in underwater acoustic networks (UCANs) are discussed in section IX. Finally, Section X concludes this paper.

Differences between marine and terrestrial

Before examining where cross-domain collaboration can be most fruitful, it is worth considering why it has not been more common. The physical differences between air and water are summarized in, and their consequences for organisms living in these different environments, have led to claims of 'fundamental' differences between marine and terrestrial ecology. Certainly, the raw materials upon which biotic and abiotic forces can act are rather different in the two domains. The seas are immensely diverse in before examining where cross-domain collaboration can be most fruitful, it is worth considering why it has not been more common. The physical differences between air and water are summarized in, and their consequences for organisms living in these different environments, have led to claims of 'fundamental' differences between marine and terrestrial ecology. Certainly, the raw materials upon which biotic and abiotic forces can act are rather different in the two domains. The seas are immensely diverse in terms of higher taxa (most animal phyla have marine members, many exclusively so, yet species-level diversity has been higher on land for some 100 million years and, today marine species constitute only approximately 15% of all described species and 25% of predicted global species numbers. However, it is not clear whether these stark differences in diversity reflect fundamentally different ecological processes, or whether they are instead an incidental consequence of rather few chance evolutionary events.

Because many exploited species in marine ecosystems have profound influences on the communities they inhabit, these are mutually inclusive goals. For clarity, the comparisons and their implications we raise are summarized in

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Table 1. A rigorous analysis of the similarities and differences between marine and terrestrial ecosystems is clearly beyond the scope of this article. Our intentions are to highlight some of the perceived and largely supported differences asserted in the literature, provide references to direct the reader to the evidence upon which these assertions are based, and focus more on their implications for reserve design and application. There are, of course, numerous exceptions to almost any comparison (e.g., the relative ‘‘openness’’ of populations and communities) over such a tremendous variety of organisms and environments encompassed by terrestrial and coastal marine ecosystems [2].

Table 1. Key differences between terrestrial and marine ecosystems.

Feature		Terrestrial ecosystems	Marine ecosystems
Environmental	Prevalence of aquatic medium	less	greater
	Dimensions of species distribution	two-dimensional	three-dimensional
	Scale of chemical and material transport	smaller	greater
	‘‘Openness’’ of local environment	less	greater
Population structure	Spatial scale of propagule transport	smaller	greater
	Spatial structure of populations	less open	more open
	Reliance on external sources of recruitment	lower	higher
	Likelihood of local self replenishment	high	low
	Sensitivity to habitat fragmentation	greater	less
	Sensitivity to smaller scale perturbations	greater	less
	Temporal response to large-scale events	slower (centuries)	higher (decades)

The main differences between terrestrial and underwater sensor networks are as follows:

- **Cost:** While terrestrial sensor nodes are expected to become increasingly inexpensive, underwater sensors are expensive devices. This is especially due to the more complex underwater transceivers and to the hardware protection needed in the extreme underwater environment.
- **Deployment:** While terrestrial sensor networks are densely deployed, in underwater, the deployment is deemed to be sparser, due to the cost involved and to the challenges associated to the deployment itself.
- **Power:** The power needed for acoustic underwater communications is higher than in terrestrial radio communications due to higher distances and to more complex signal processing at the receivers to compensate for the impairments of the channel.

- **Memory:** While terrestrial sensor nodes have very limited storage capacity, underwater-sensors may need to be able to do some data caching as the underwater channel may be intermittent.
- **Spatial correlation:** While the readings from terrestrial sensors are often correlated, this is more unlikely to happen in underwater networks due to the higher distance among sensors.

Spectrum usage in oceans

Driven by consumer's increasing interest in wireless services, demand for radio spectrum has increased dramatically. Moreover, with the emergence of new wireless devices and applications, and the compelling need for broadband wireless access, this trend is expected to continue in the coming years. The conventional approach to spectrum management is very inflexible in the sense that each operator is granted an exclusive license to operate in a certain frequency band. However, with most of the useful radio spectrum already allocated, it is becoming exceedingly hard to find vacant bands to either deploy new services or enhance existing ones. On the other hand, as evidenced in recent measurements, the licensed spectrum is rarely utilized continuously across time and space.

Spectrum utilization in the frequency bands between 30 MHz and 3 GHz averaged over six different locations. The relatively low utilization of the licensed spectrum suggests that spectrum scarcity, as perceived today, is largely due to inefficient fixed frequency allocations rather than any physical shortage of spectrum. This observation has prompted the regulatory bodies to investigate a radically different access paradigm where secondary (unlicensed) systems are allowed to opportunistically utilize the unused primary (licensed) bands, commonly referred to as white spaces. In particular, the Federal Communications Commission (FCC) has already expressed its interest in permitting unlicensed access to white spaces in the TV bands.

Issues and challenges in spectrum sensing

Several sources of uncertainty such as channel uncertainty, noise uncertainty, sensing interference limit etc. need to be addressed while solving the issue of spectrum sensing in cognitive radio networks. These issues are discussed in details.

Channel Uncertainty: In wireless communication networks, uncertainties in received signal strength arises due to channel fading or shadowing which may wrongly interpret that the primary system is located out of the secondary user's interference range as the primary signal may be experiencing a deep fade or being heavily shadowed by obstacles. Therefore, cognitive radios have to be more sensitive to distinguish a faded or shadowed primary signal from a white space. Any uncertainty in the received power of the primary signal translates into a higher detection sensitivity requirement [3].

Under severe fading, a single cognitive radio relying on local sensing may be unable to achieve this increased sensitivity since the required sensing time may exceed the sensing period. This issue may be handled by having a group of cognitive radios (cooperative Sensing), which share their local measurements and collectively decide on the occupancy state of a licensed band.

The detection sensitivity can be defined as the minimum SNR at which the primary signal can be accurately (e.g. with a probability of 0.99) detected by the cognitive radio, Where N is the noise power, Pp is transmitted power of the primary user, D is the interference range of the secondary user, and R is maximum distance between primary transmitter and its corresponding receiver. The above equation suggests that in order to calculate the required detection sensitivity, the noise power has to be known, which is not available in practice, and needs to be estimated by the receiver. However the noise power estimation is limited by calibration errors as well as changes in thermal noise caused by temperature variations. Since a cognitive radio may not satisfy the sensitivity requirement due to an underestimate should be calculated with the worst case noise assumption, thereby necessitating a more sensitive detector.

Aggregate interference uncertainty

In future, due to the widespread deployment of secondary systems, there will be increased possibility of multiple cognitive radio networks operating over the same licensed band. As a result, spectrum sensing will be affected by uncertainty in aggregate interference (e.g. due to the unknown number of secondary systems and their locations). Though, a primary system is out of interference range of a secondary system, the aggregate interference may lead to wrong detection. This uncertainty creates a need for more sensitive detector, as a secondary system may harmfully interfere with primary system located beyond its interference range, and hence it should be able to detect them.

Sensing interference limit

Primary goal of spectrum sensing is to detect the spectrum status i.e. whether it is idle or occupied, so that it can be accessed by an unlicensed user. The challenge lies in the interference measurement at the licensed receiver caused by Primary goal of spectrum sensing is to detect the spectrum status i.e. whether it is idle or occupied, so that it can be accessed by an unlicensed user. The challenge lies in the interference measurement at the licensed receiver caused by transmissions from unlicensed users. First, an unlicensed user may not know exactly the location of the licensed receiver which is required to compute interference caused due to its transmission. Second, if a licensed receiver is a passive device, the transmitter may not be aware of the receiver. So these factors need attention while calculating the sensing interference limit.

The detailed classification of spectrum Sensing techniques. They are broadly classified into three main types, transmitter detection or non-cooperative sensing, cooperative sensing and interference based sensing. Transmitter detection technique is further classified into energy detection, matched filter detection and cyclostationary feature detection some of the most common spectrum sensing techniques in the cognitive radio is:

- Energy detector based approach which is also known as radiometry or periodogram, is the most common way of spectrum sensing because of its low

- Computational and implementation complexities. It is more generic method as receivers do not need any knowledge on the primary users' signal. The signal is detected by comparing the output of the energy detector with a threshold which depends on the noise floor.

Matched-filtering is known as the optimum method for detection of primary users when the transmitted signal is known. The main advantage of matched filtering is the short time to achieve a certain probability of false alarm or probability of miss detection as compared to other methods. Matched-filtering requires cognitive radio to demodulate received signals. Hence, it require perfect knowledge of the primary users signaling features such as bandwidth, operating frequency, modulation type and order, pulse shaping, and frame format [4].

Cyclostationarity feature detection is a method for detecting primary user transmissions by exploiting the cyclostationarity features of the received signals. Cyclostationary features are caused by the periodicity in the signal or in its statistics like mean and autocorrelation or they can be intentionally induced to assist spectrum sensing.
High sensitivity requirements on the cognitive user can be alleviated if multiple CR users cooperate in sensing the channel. Various topologies are currently used and are broadly classifiable into three regimes according to their level of cooperation.

Decentralized uncoordinated techniques: The cognitive users in the network don't have any kind of cooperation which means that each CR user will independently detect the channel, and if a CR user detects the primary user it would vacate the channel without informing the other users. Uncoordinated techniques are fallible in comparison with coordinated techniques. Therefore, CR users that experience bad channel realizations detect the channel incorrectly thereby causing interference at the primary receiver.

Centralized coordinated techniques: In such networks, an infrastructure deployment is assumed for the CR users. One CR that detects the presence of a primary transmitter or receiver, informs a CR controller which can be a wired immobile device or another CR user. The CR controller notifies all the CR users in its range by means of a broadcast control message. Centralized schemes can be further classified according to their level of cooperation as: Partially cooperative where network nodes cooperate only in sensing the channel. CR users independently detect the channel and inform the CR controller which then notifies all the CR users; and totally cooperative Schemes where nodes cooperate in relaying each other's information in addition to cooperatively sensing the channel.

Decentralized coordinated techniques: This type of coordination implies building up a network of cognitive radios without having the need of a controller. Various algorithms have been proposed for the decentralized techniques among which are the gossiping algorithms or clustering schemes, where cognitive users gather to clusters, auto coordinating themselves. The cooperative spectrum sensing raises the need for a control channel, which can be implemented as a dedicated frequency channel or as an underlay UWB channel.

Benefits of cooperation: Cognitive users selflessly cooperating to sense the channel have lot of benefits among which the plummeting sensitivity requirements channel impairments like multipath fading, shadowing and building penetration losses, impose high sensitivity requirements inherently limited by cost and power requirements.

Employing cooperation between nodes can drastically reduce the sensitivity requirements up to -25 dBm, also reduction in sensitivity threshold can be obtained by using this scheme; agility improvement: all topologies of cooperative networks reduce detection time compared to uncoordinated networks.

Disadvantages of cooperation: The CR users need to perform sensing at periodic intervals as sensed information become obsolete fast due to factors like mobility, channel impairments etc. This considerably increases the data overhead; large sensory data: since the cognitive radio can potentially use any spectrum hole, it will have to scan a wide range of spectrum, resulting in large amounts of data, being inefficient in terms of data throughput, delay sensitivity requirements and energy consumption. Even though cooperatively sensing data poses lot of challenges, it could be carried out without incurring much overhead because only approximate sensing information is required, eliminating the need for complex signal processing schemes at the receiver and reducing the data load. Also, even though a wide channel has to be scanned, only a portion of it changes at a time requiring updating only the changed information and not all the details of the entire scanned spectrum.

Interference based detection: In this section, we present interference based detection so that the CR users would operate in spectrum underlay (UWB like) approach.

Primary receiver detection

In general, primary receiver emits the Local Oscillator (LO) leakage power from its RF front end while receiving the data from primary transmitter. It has been suggested as a method to detect primary user by mounting a low cost sensor node close to a primary user's receiver in order to detect the local oscillator leakage power emitted by the RF front end of the primary user's receiver which are within the communication range of CR system users. The local sensor then reports the sensed information to the CR users so that they can identify the spectrum occupancy status. We note that this method can also be used to identify the spectrum opportunities to operate CR users in spectrum overlay.

Interference temperature management

Unlike the primary receiver detection, the basic idea behind the interference temperature management is to set up an upper interference limit for given frequency band in specific geographic location such that the CR users are not allowed to cause harmful interference while using the specific band in specific area. Typically, CR user transmitters control their interference by regulating their transmission power (their out of band emissions) based on their locations with respect to primary users.

This method basically concentrates on measuring interference at the receiver. The operating principle of this method is like an UWB technology where the CR users are allowed to coexist and transmit simultaneously with primary users using low transmit power that is restricted by the interference temperature level so as not to cause harmful interference to primary users.

Underutilized spectrum in oceans

Although the underwater acoustic spectrum is heavily shared by various acoustic systems in oceans, it is actually underutilized from both temporal and spatial perspectives.

Temporal spectrum utilization: In an interested area of oceans, some frequency bands might be only temporally utilized but vacant most of the time. We call these frequencies as temporally underutilized acoustic spectrum. Temporal underutilization of acoustic spectrum might be caused by the mobility and low duty cycle of acoustic systems.

Mobility: When frequencies are occupied by marine mammals, sonars on ships or AUVs, the usage of these frequencies in a target region might be neither long nor continuous - they will be released with the movement of mobile systems. In oceans, if we allocate any exclusive frequencies (frequencies that can be only used by specific users in a certain region) to mobile systems, the spectrum might be temporally underutilized.

Low duty cycle: Generally speaking, neither natural nor artificial acoustic systems would stay active all the time. The spectrum will be vacant when the users are idle causing temporal spectrum underutilization. The low duty cycle is the nature of both natural and artificial systems, since neither one can stay active all the time. In applications such as environment monitoring, offshore structure flaw detection and data collection, users only need to periodically wake up and suspend in the rest of time to save the energy. Meanwhile, the activity of artificial acoustic users is constrained by the limited power supply in oceans [5].

Spatial spectrum utilization

In oceans, acoustic frequencies might be fully utilized in some crowded areas, but vacant in other regions. We call these frequencies as spatially underutilized acoustic spectrum. Both the nonlinear sound propagation and directional communication of acoustic systems lead to a spatially underutilized acoustic spectrum.

Nonlinear sound propagation: Unlike radio signals, which propagate straight in air, the actual propagation path of acoustic signals in water is modeled as a curve, especially in long range communication over 2 km. This nonlinear propagation feature originates from the fact that sound speed is not constant but varies with the water pressure, salinity and temperature. The acoustic signal always bends toward the medium with slower sound speed according to the law of Snell-Descartes.

Directional communication: In conventional underwater Medium Access Control (MAC) protocol design, we usually assume omnidirectional transmissions and receptions. With this assumption, the transmission range and interference area of these users can be modeled as circles. However, both the transmission and reception of acoustic systems, such as marine mammals and sonar, are highly directional in the real world.

CR networks impose unique challenges due to their coexistence with primary networks as well as diverse QoS requirements. Thus, new spectrum management functions are required for CR networks with the following critical design challenges:

- **Interference avoidance:** CR networks should avoid interference with primary networks.
- **QoS awareness:** To decide on an appropriate spectrum band, CR networks should support QoS-aware communication, considering the dynamic and heterogeneous spectrum environment.
- **Seamless communication:** CR networks should provide seamless communication regardless of the appearance of primary users.

The spectrum management framework for CR network communication. It is evident from the significant number of interactions that the spectrum management functions require a cross-layer design approach. In the following sections we discuss the four main spectrum management functions.

CR networks require the capability to decide which is the best spectrum band among the available bands according to the QoS requirements of the applications. This notion is called spectrum decision and constitutes a rather important but as yet unexplored topic in CR networks. Spectrum decision is closely related to the channel characteristics and operations of primary users. Furthermore, spectrum decision is affected by the activities of other CR users in the network. Spectrum decision usually consists of two steps: first, each spectrum band is characterized, based on not only local observations of CR users but also statistical information of primary networks. Then, based on this characterization, the most appropriate spectrum band can be chosen. In the following we investigate the channel characteristics, decision procedures, and research challenges in CR networks.

Because available spectrum holes show different characteristics that vary over time, each spectrum hole should be characterized considering both the time-varying radio environment and spectrum parameters, such as operating frequency and bandwidth. Hence, it is essential to define parameters that can represent a particular spectrum band as follows:

- **Interference:** From the amount of interference at the primary receiver, the permissible power of a CR user can be derived, which is used for the estimation of channel capacity.
- **Path loss:** The path loss is closely related to distance and frequency. As the operating frequency increases, the path loss increases, which results in a decrease in the transmission range. If transmission power is increased to compensate for the increased path loss, interference at other users may increase.
- **Wireless link errors:** Depending on the modulation scheme and the interference level of the spectrum band, the error rate of the channel changes.
- **Link layer delay:** To address different path loss, wireless link error, and interference, different types of link layer protocols are required at different spectrum bands. This results in different link layer delays. It is desirable to identify the spectrum bands that combine all the characterization parameters described previously for accurate spectrum decision. However, a complete analysis and modeling of spectrum in CR networks has not been developed yet.

After the available spectrum bands are characterized, the most appropriate spectrum band should be selected, considering the QoS (Quality of Service) requirements and spectrum characteristics. Accordingly, the transmission mode and bandwidth for the transmission can be reconfigured. To describe the dynamic nature of CR networks, a new metric primary user activity is proposed, which is defined as the probability of a primary user appearance during CR user transmission. Because there is no guarantee that a spectrum band will be available during the entire communication of a CR user, it is important to consider how often the primary user appears on the spectrum band. However, because of the operation of primary networks, CR users cannot obtain a reliable communication channel for a long time period. Moreover, CR users may not detect any single spectrum band to meet the user's requirements. Therefore, multiple noncontiguous spectrum bands can be simultaneously used for transmission in CR networks.

This method can create a signal that is not only capable of high data throughput, but is also immune to interference and primary user activity. Even if spectrum handoff occurs in one of the current spectrum bands, the rest of the spectrum bands will maintain current transmissions.

In the development of the spectrum decision function, several challenges still remain unsolved:

- **Decision model:** Spectrum capacity estimation using signal-to-noise ratio (SNR) is not sufficient to characterize the spectrum band in CR networks. Also, applications require different QoS requirements. Thus, design of application- and spectrum-adaptive spectrum decision models is still an open issue.
- **Cooperation with reconfiguration:** CR techniques enable transmission parameters to be reconfigured for optimal operation in a certain spectrum band.
- **Spectrum decision over heterogeneous spectrum bands:** Currently, certain spectrum bands are assigned to different purposes, whereas some bands remain unlicensed. Thus, a CR network should support spectrum decision operations on both the licensed and unlicensed bands.

The shared nature of the wireless channel requires the coordination of transmission attempts between CR users. In this respect, spectrum sharing should include much of the functionality of a MAC protocol. Moreover, the unique characteristics of CRs, such as the coexistence of CR users with licensed users and the wide range of available spectrum, incur substantially different challenges for spectrum sharing in CR networks. The existing work in spectrum sharing aims to address these challenges and can be classified by four aspects: the architecture, spectrum allocation behavior, spectrum access technique, and scope.

The first classification is based on the architecture, which can be centralized or distributed:

- **Centralized spectrum sharing:** The spectrum allocation and access procedures are controlled by a central entity. Moreover, a distributed sensing procedure can be used such that measurements of the spectrum allocation are forwarded to the central entity, and a spectrum allocation map is constructed. Furthermore, the central entity can lease spectrum to users in a limited geographical region for a specific amount of time. In addition to competition for the spectrum, competition for users can also be considered through a central spectrum policy server.

- **Distributed spectrum sharing:** Spectrum allocation and access are based on local (or possibly global) policies that are performed by each node distributively. Distributed solutions also are used between different networks such that a Base Station (BS) competes with its interferer BSs according to the QoS requirements of its users to allocate a portion of the spectrum. The recent work on comparison of centralized and distributed solutions reveals that distributed solutions generally closely follow the centralized solutions, but at the cost of message exchanges between nodes. The second classification is based on allocation behavior, where spectrum access can be cooperative or non-cooperative.
- **Cooperative spectrum sharing:** Cooperative (collaborative) solutions exploit the interference measurements of each node such that the effect of the communication of one node on other nodes is considered. A common technique used in these schemes is forming clusters to share interference information locally. This localized operation provides an effective balance between a fully centralized and a distributed scheme.
- **Non-cooperative spectrum sharing:** Only a single node is considered in non-cooperative (or non-collaborative, selfish) solutions. Because interference in other CR nodes is not considered, non-cooperative solutions may result in reduced spectrum utilization. However, these solutions do not require frequent message exchanges between neighbors as in cooperative solutions. Cooperative approaches generally outperform noncooperative approaches, as well as closely approximating the global optimum. Moreover, cooperative techniques result in a certain degree of fairness, as well as improved throughput. On the other hand, the performance degradation of non-cooperative approaches are generally offset by the significantly low information exchange and hence, energy consumption. The third classification for spectrum sharing in CR networks is based on the access technology:
- **Overlay spectrum sharing:** Nodes access the network using a portion of the spectrum that has not been used by licensed users. This minimizes interference to the primary network.
- **Underlay spectrum sharing:** The spread spectrum techniques are exploited such that the transmission of a CR node is regarded as noise by licensed users. Underlay techniques can utilize higher bandwidth at the cost of a slight increase in complexity. Considering this trade-off, hybrid techniques can be considered for the spectrum access technology for CR networks.
- **Finally, spectrum sharing techniques are generally focused on two types of solutions:** spectrum sharing inside a CR network (intranetwork spectrum sharing) and among multiple coexisting CR networks (internetwork spectrum sharing), as explained in the following:
- **Intranetwork spectrum sharing:** These solutions focus on spectrum allocation between the entities of a CR network, as shown in Fig. 6. Accordingly, the users of a CR network try to access the available spectrum without causing interference to the primary users. Intranetwork spectrum sharing poses unique challenges that have not been considered previously in wireless communication systems.
- **Internetwork spectrum sharing:** The CR architecture enables multiple systems to be deployed in overlapping locations and spectrum. So far the internetwork spectrum sharing solutions provide a broader view of the spectrum sharing concept by including certain operator policies.

Underwater acoustic sensor networks

In this section we describe the design challenges of underwater acoustic sensor networks. In particular, we itemize the main differences between terrestrial and underwater sensor networks, we detail key design issues and deployment challenges for underwater sensors, and we give motivations for a cross layer design approach to improve the network efficiency in the critical underwater environment.

The typical internal architecture of an underwater sensor. It consists of a main controller/CPU which is interfaced with an oceanographic instrument or sensor through a sensor interface circuitry. The controller receives data from the sensor and it can store it in the onboard memory, process it, and send it to other network devices by controlling the acoustic modem.

The electronics are usually mounted on a frame which is protected by PVC housing. Sometimes all sensor components are protected by bottom-mounted instrument frames that are designed to permit azimuthally omnidirectional acoustic communications, and protect sensors and modems from potential impact of trawling gear, especially in areas subjected to fishing activities. In, the protecting frame is designed so as to deflect trawling gear on impact, by housing all components beneath a low-profile pyramidal frame. Underwater sensors include sensors to measure the quality of water and to study its characteristics such as temperature, density, salinity (interferometric and refractometric sensors), acidity, chemicals, conductivity, pH (magnetoelastic sensors), oxygen (Clark-type electrode), hydrogen, dissolved methane gas and turbidity. Disposable sensors exist that detect ricin, the highly poisonous protein found in castor beans and thought to be a potential terrorism agent. DNA microarrays can be used to monitor both abundance and activity level variations among natural microbial populations. Other existing underwater sensors include hydrothermal sulfide, silicate, voltammetric sensors for spectrophotometry, gold-amalgam electrode sensors for sediment measurements of metal ions (ion-selective analysis), aerometric micro sensors for H_2S measurements for studies of an oxygenic photosynthesis, sulfide oxidation, and sulfate reduction of sediments. In addition, force torque sensors for underwater applications requiring simultaneous measurements of several forces and moments have also been developed, as well as quantum sensors to measure light radiation and sensors for measurements of harmful algal blooms.

The challenges related to the deployment of low cost, low scale underwater sensors, are listed as follows:

- It is necessary to develop less expensive, robust ‘‘nano-sensors’’, e.g., sensors based on nanotechnology, which involves development of materials and systems at the atomic, molecular, or macromolecular levels in the dimension range of approximately 1–500 nm.
- It is necessary to devise periodical cleaning mechanisms against corrosion and fouling, which may impact the lifetime of underwater devices.
- There is a need for robust, stable sensors on a high range of temperatures since sensor drift of underwater devices may be a concern. To this end, protocols for in situ calibration of sensors to improve accuracy and precision of sampled data must be developed.

- There is a need for new integrated sensors for synoptic sampling of physical, chemical, and biological parameters to improve the understanding of processes in marine systems.

CONCLUSION

Cognitive Acoustic (CA) is a promising technique to develop environment-friendly and spectrum efficient underwater acoustic networks. In this paper, we first dissect the spectrum usage in oceans, results of which demonstrate that the precious spectrum resource is underutilized temporally and spatially. The potentials of Underwater Cognitive Acoustic Networks (UCANs) in improving the environment-friendliness and spectrum utilization are then described. In addition, we investigate unique features of underwater channels and acoustic modems. The significant affects of these characteristics on the UCAN design are further analyzed. The unsolved issues and challenges identified in this paper may be used as a starting point of future research on UCANs. The ultimate objective of this paper is to call for research efforts on tackling unique underwater challenges to achieve efficient and environment-friendly spectrum utilization in UCANs.

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