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REVIEW ON RESEARCH CHALLENGES AND STRATEGIES IN UNDERWATER SENSOR NETWORKS

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Abstract- In this paper, some important key aspects of Underwater Sensor Networks are investigated. One of the essential tasks in the development of Underwater Sensor Networks is the maintenance of coverage and connectivity, which measures the network effectiveness and accuracy in the event detection. In this review, we highlight a number of important research challenges and major strategies that have been emphasized in the recent years in the research direction of Underwater Sensor Networks.

1. Introduction

1.1 Introduction to Underwater Sensor Networks

Earth is known as BLUE PLANET because 71% of outer layer of the earth is covered with water and about 97% of this can be found in the oceans. From the past few years wireless networking is used as a mean of information sharing but in under water we can’t use it because wired networking in underwater is not feasible in all conditions. The utilization of Underwater Sensor Networks is not so easy, fundamental defies are therefore required to be mapped just because the sort of settings of underwater [4, 36] [37]. In the recent years, Underwater Sensor Networks have attracted attention from the research and engineering community because of its growing list of applications.

As we know Underwater Sensor Networks and Wireless Sensor Networks are not similar just because of the distinctive individuality of water, there is a great chance of applying convinced aspects of Wireless Sensor Networks research to Underwater Sensor Networks.

The core diversities or dissimilarities between Underwater Sensor Networks and Wireless Sensor Network shows in the following table [4].

Table 1: Diversities between UWSNs and WSN

Diversities	Wireless Sensor Network	Underwater WSNs
Communication Technique	Uses radio waves	Uses acoustic signal
Outlay	More economical	Costly
Power	Less power	More power
Memory	Memory requirements are application dependent and these sensor nodes have finite storage capability.	Underwater sensors have to get hold of more data to the failure of data.

1.2 Research Challenges

Underwater Sensor Networks (UWSNs) is a developing zone of research within the whole Wireless Sensor Network (WSN) areas. Underwater Sensor network challenges are –

- **Fouling and corrosion**

Underwater Sensors are more inclined to failures because of fouling and corrosion. So it is required to devise timely cleaning mechanisms against corrosion and fouling, which may impact the lifetime of underwater devices. Underwater Sensor Networks also face the problem of impairing because of Multipath and fading [3, 32]. Moreover, Multi-path propagation accountable for severe deprivation of the underwater communication signal, since it produces Inter-Symbol Interference [13].

- **Costly devices**

The Underwater devices are more expensive because device protection or hardware protection is required in water as well as extra protective cover needed for sensors. Furthermore, a small number of suppliers are available only. So less expensive, robust nano -sensors are necessary to develop [4].

- **Doppler spread**

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Doppler frequency shift is generally different from path to path when signal reaches at the network receiver. Therefore, transmitted signal frequency will experience Doppler spreading and is seen as spectral widening or broadening in received signal power spectrum. This width of the spectrum is known as Doppler Spread [42].

- **Propagation delay**

It refers to the time lag between the departure of a signal from the source and the arrival of the signal at the destination [4, 31]. Many built in properties of acoustic channel are harmful transmission process, such as the long propagation delay. The speed of RF is 3x108 m/s while the acoustic signal propagation speed in an underwater acoustic channel is about 1.5x103 m/s. Propagation delay in underwater is 5 orders of magnitude greater than in Radio Frequency (RF) terrestrial channels and variable.

- **Bit error rate**

It is the number of bit errors divided by the total number of transferred bits during a time interval. In this high bit error rates and temporary losses of connectivity (shadow zones) can be accomplished. In Underwater Sensor Network high bit error rates mostly originate at the time of period [33, 35].

- **Bandwidth**

Bandwidth is defined as the difference between the highest and lowest frequencies of a given signal. In the Underwater Sensor Network (UWSNs) bandwidth is another major problem as the bandwidth size is limited. Due to limited bandwidth in underwater, data rate is tremendously low. Very low frequencies (10 to 30 kHz) are required for communication in the sea water (EM). The acoustic band under water is specific due to absorption. Most of the acoustic systems operate below 30 kHz. According to research commercial system is exceed 40km kb/s as the maximum attainable range rate product [12, 34].

- **Battery power**

In Underwater Sensor Networks nodes are battery operated. The battery charging in the underwater is almost unfeasible and its replacement is a very difficult and expensive operation. Therefore, transmission losses caused by message collisions should be avoided so that there will be no wastage of energy.
Battery is an electronic component, so it tends to degrade faster under tremendously low temperatures in the deep underwater. As the result, the USWNs lifetime is much smaller than the lifetime of an analogous TWSN. It causes increment in the replacement and maintenance costs. [12, 30] [50].

- **Noise and Interference**

Underwater communication is affected by noises, such as reverberations caused by the transmission reflections in the underwater and offshore activities [12, 29].

Table 2: Recovering Techniques for Given Challenges

Challenges	**Recovering Techniques**
High Propagation Delay	PCAP(Propagation-Delay Tolerant Collision Avoidance Protocol), VBF [41]
Multipath Fading Problem	Rayleigh Model [21]
Doppler Spread	Compressed Sensing Techniques like OMP and BP [43]
Energy Conservation and Limited Bandwidth	VBF(Vector-Based Forwarding Protocol), QELAR [41,51]

2. Major Strategies in Underwater Sensor Networks

In this paper, we concentrate on coverage, connectivity, delay and energy conservation problems. Coverage and connectivity both are significant issues in Underwater Sensor Networks (UWSNs). Coverage can be defined as how well an area of interest is being monitored by the deployed network. It rely on sensing model that has been used to design the network model. On the other hand, connectivity make sure the formation of a link among two nodes. In an energy-constrained underwater system it is significant to discover techniques to increase the life expectancy and to minimize the delay of the network. [28, 52].

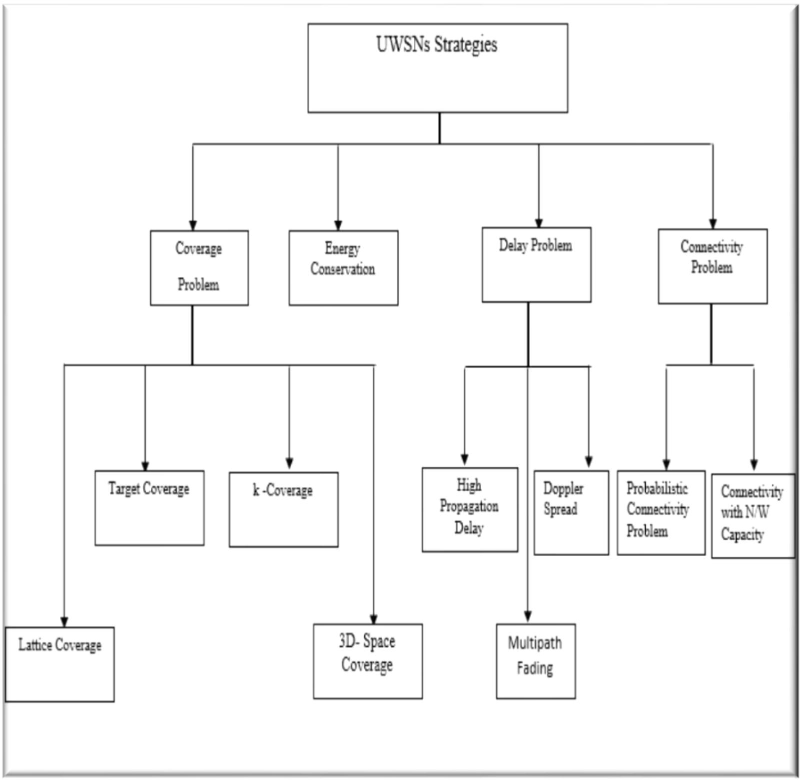

Figure 1: UWSNs Strategies

2.1 Underwater Wireless Sensor Networks with Coverage Problem

A discussion on coverage problem in UWSNs has been presented by Yusuf Mulge et al. in [5]. The coverage problem is relay on the coverage model of individual sensors and also on the locations of the deployed sensor nodes. A generally used sensor coverage model is the disk sensing model where a sensor can cover a disk centred at itself with a radius equal to a fixed sensing range. In [19] author discussed about disk sensing model that all events within the sensing range are deterministically detected by the sensor. On the other hand, events happening farther cannot be detected at all. The coverage under disk sensing model is often referred to as Deterministic Coverage. The disk sensing model make the coverage problem simple. In fact, optimal solutions for it can be achieved well.

In practice, the coverage usually consists of two basic facts [8]-

- How to evaluate the coverage performance when sensor nodes are deployed in a monitoring region?
- How to improve the coverage performance when underwater wireless sensor network cannot effectively satisfy application requirements?

Moreover, the shadowing environment also affects the coverage to a valuable extent. The authors have given a derivation of coverage probability in the presence of shadowing environment based on the received signal strength using a stated mathematical model. It is cleared that more be the coverage, the data reception by all the sensors that fall in its communication range also be much better [9].

In order to minimize coverage overlaps, nodes have to be located far enough from each other. In such case, the communication link between two nodes may be broken if they are not within each other's transmission range. On the other side, if all communication links of the initial network attempted to keep, there will be too many coverage overlaps. Hence, it is very crucial to decide which links are to be preserved while determining the depths of nodes for maximizing the coverage [11].

2.1.1 Lattice Coverage

Lattice coverage which applies to practical environmental monitoring applications such as in a lake or bay. The method can be applied to this topology with uniformly placed sensors to estimate the network battery life and power consumption. The battery life is longer in this topology than any other topology. The main application of this topology is environmental monitoring at uniform distances. These applications are based on the location determination of sensing nodes using sampling method in which coverage is determined by estimating the ratio of lattice points covered to the total number of lattice points [49].

2.1.2 Target Coverage

When a target is detected by Underwater Sensors, it will be captured or shot on video by multimedia sensors as needed. Target coverage can be well-defined as '*n*' sensor nodes are arbitrarily deployed to cover each and every movement of '*m*' target with known locations such that each target can be covered by at least one of these '*n*' sensors similarly we can define this coverage in underwater sensor network. When a target is detected using low-cost sensors, sleeping cameras can be activated to capture this target fully or partially. Subsequently, cameras can be randomly organized a solution is proposed that will identify the least number of cameras with the least cost movement based on the location of the target. In [47] authors have demonstrated an approach in which a camera relocation structure in UWASNs to maximize the coverage of detected targets with the smallest possible vertical camera movement is discussed. This approach evaluates the coverage of each acoustic sensor in advance by receiving the most applicable cameras in terms of orientation in 3-D that are protected by such sensors. Whenever a target is visible, this information is then used and shared with other sensors in order to identify the same target. Equated to a flooding-based approach, experiment outcomes specify that this proposed solution can rapidly capture the detected targets with the smallest camera movement [20, 46].

2.1.3 k-Coverage

k-Coverage in Underwater Sensor Networks ought to view as energy efficient performance. It is one of the technologies that are usually employed to improve network fault tolerance and robustness. In this approach, each target monitoring area is required to be covered by at least k-sensor nodes (k≧1), can achieve network redundancy detection for events. It is one of the technologies that are commonly used to improve network fault tolerance and robustness. In [24] authors have addressed a Dynamic k-Coverage Algorithms in which each management node chooses its sub- node by using a greedy algorithm. In this the remaining energy and conditions in which a node is selected by several events doesn't considered. This approach affects network energy consumption. Thus, this study suggests a Distributed and Energy-Efficient Event k-Coverage Algorithm (DEEKA). Subsequently, the network accomplishes 1-coverage, the nodes that detect the same event contend for the event management node with the number of candidate nodes and the average remaining energy. Second, each management node evaluates the probability of its neighbour nodes being selected by the event it achieves with the distance level and the number of dynamic coverage event of these nodes. In third, management node creates an optimization model that uses expectancy energy consumption and the remaining energy difference of its neighbour nodes and identifies the activities of the events it manages as targets. In conclusion, each management node uses a constrained Non-Dominated Sorting Genetic Algorithm (NSGA-II) to achieve the Pareto set of the model [22, 24] [25].

2.1.4 3-D Space Coverage

3-D space coverage approach can be used for Underwater Sensor Networks where sensor nodes transfer their data packets via the antenna in surface buoys, while sensor nodes are randomly deployed and their *x* and *y* coordinates cannot be organised, the sensors of these nodes can be dropped at any depth. Distributed scheme finds out an appropriate depth for each node such that the maximum 3-D coverage of the field is conserved. This scheme is distributed and adaptive which preserves a high coverage of the sensor space in the expense of suitable control traffic overhead [48]. Self-deployment of sensors with maximized coverage in Underwater Sensor Network is challenging because of access to 3-D underwater environments is difficult. The problem is become more complex if the connectivity of the final network is required [6]. To solve this problem one approach is to drop the sensors on the surface and then move them to certain depths in the water to maximize the 3-D coverage while maintaining the connectivity. Coverage control has been of much interest recently due to its requirement in many aerial, terrestrial, and underwater applications such as surveillance, search and rescue/retrieval, and distributed sampling [7].

2.2 Underwater Sensor Network with Delay Problem

The delay of a network states that how long it takes for a bit of data to travel through the network from one node to another. It is usually measured in parts of seconds. All the packets in a network experience some delay. In some points of the network the delay is minor, it can just be ignored for practical purpose. But in some other cases delay is important, and we can't recover it. Some delay problems are specified as follows-

2.2.1 Underwater Sensor Networks with High Propagation Delay Problem

The applications in UASNs must be delay tolerant because long propagation delay is physically unavoidable. When the propagation delay rises much time is spent on transmitting/waiting control frames or sensing the carrier to avoid potential collisions therefore the throughput is decreases. Here, the authors have discussed about PCAP protocol that stands for Propagation-Delay-Tolerant Collision Avoidance Protocol. The main aim of PCAP is to fix the time spent on setting up links for data frames and to avoid collisions by arranging the activity of sensors. Subsequently, the propagation delay of underwater networks is long and unavoidable. It is possible for a node to be involved in transmitting other data frames instead of wasting its time when the signals propagate. The PCAP provides higher throughput than the protocols that are broadly used by conventional wireless communication networks and it makes the propagation delay predictable. The high propagation delay can significantly decrease the throughput of the system when typical networking protocols are used as presented in [41, 31].

2.2.2 Underwater Sensor Networks with Multipath Fading Problem-

Mari Carmen Domingo has defined the multipath fading [38]. The author has given a ray -theory-based multipath Rayleigh underwater channel model to solve this problem. In this paper, the author has provided a complete description of the underwater wireless channel and discussed the research challenges for an efficient communication in this environment. This model shows that the convergence zones and deep sound (SOFAR) channels will support communication improvement in the underwater whereas shadow zones, surface reflections and bottom bounces should be avoided. The near-surface shadow zones can be avoided for locating sources and receivers deep in the ocean. The communication performance is also affected by the depth. The study carried out also explains that the optimal position for the transceivers will be time-varying because the chemical and physical properties of water change with time and there is multipath fading. The outcomes acquired are significant for the foundations of UWCNs because they create the principles for attaining good underwater communication performance between transceivers which is crucial for the design of communication systems. The Multipath wave refraction are produced by sound speed variations with depth (acoustic waves always turn towards areas where the propagation speed is minimum). Multipath propagation can strictly fade the acoustic signal as it produces inter-symbol interference (ISI). The multipath geometry relays on the link configuration [53].

2.2.3 Underwater Sensor Networks with Doppler Spread -

The Doppler spread is an important strategy in Underwater Communication Channels that initiates a degradation in the performance of digital communications. Due to Doppler spreading two effects can be generated. These effects are a simple frequency conversion and a constant spreading of frequencies which creates a non-shifted signal. In these effects, the first one is simply compensated at the receiver while the later one is firmer to be compensated. Motion of the transmitter or receiver contributes additionally to the changes in channel response. This ensues through the Doppler Effect which effects frequency shifting as well as additional frequency spreading. The path-based channel model is used to simulate Doppler spread where each path is assigned a Doppler rate drawn from a zero mean uniform distribution. A zero-mean Doppler distribution can be chosen because a non-zero mean could be removed through the resampling operation. The compressed sensing based estimators are used to handle the significant Doppler spread corresponding to the channels [42-43] [49].

2.3 Underwater Sensor Networks with Energy Conservation Problem -

Peng Xie et al. [42] have proposed a novel routing protocol called Vector-Based Forwarding (VBF), to deliver robust, scalable and energy efficient routing. Sensor nodes are driven by batteries, which are challenging to replace or recharge. As underwater communications are severely affected by network dynamics, large propagation delays and high error probability of acoustic channels. Because of these reasons designing energy-efficient routing protocols for this type of networks is essential and challenging. In Underwater Sensor Networks, the power required for receiving is typically around 100 times less than the power essential for transferring. Consequently, one important objective of network design is to minimize the energy consumption of the sensor nodes. There is an analysis of two different scenarios: Shallow water and Deep water. The shallow water states to water with depth lower than 100 m though deep water is used for deeper ocean. In shallow water modelling of noise is challenging as compared to the deep water case. Subsequently, it indicates larger inconsistency in both time and location. Moreover, in the given paper the stated scenarios are carefully studied and worked out for the propagation of sound in the sea to derive a general expression of energy consumption. If we equate the outcomes acquired with the shallow and with the deep water scenario then we conclude that the routing protocols based on the clustering scheme save more energy and these protocols shows a better performance in shallow water. The energy is conserved via two methods: the first method is using data reservations to guarantee that no data packets are collide while second one is using wake-up tone hardware that determines reservation conflict with tremendously low energy cost. The stability and throughput efficiency are accomplished by using a technique that offers collision detection and competitor count permitting the usage of an intelligent back off technique which minimizes the overall time for fairly reserving data. [40, 42] [52].

2.4 Underwater Sensor Networks with Connectivity Problem

Along with coverage the concept of connectivity is equally important in Underwater Sensor Networks. The network connectivity is another essential problem closely associated to coverage in Underwater Sensor Networks. Network connectivity can be defined as the minimum number of sensors whose failure disconnects the network. A network is connected if every pair of nodes can communicate with each other [19, 26]. Due to the large number of sensor nodes in a UWSN, the total cost could be high for the whole network though the cost of each individual sensor is low. Thus, it is important to discover the minimum number of nodes necessary for a UWSN to achieve specified connectivity. Connectivity is one of the key factors to achieve quality of service. It enables the sensors to communicate with each other so that their sensed data can reach to the sink. To ensure data delivery, multiple paths between a source and destination may be available [10, 27]. When the number of connected components are small in number, then the connectivity is getting better correspondingly. The motion of the underwater sensors in the ocean is control either by oceanic streams or tidal currents. The tidal currents apply to shallow water deployments.

Connectivity indicates whether all the nodes in the network have a path to the surface station or not. For good connectivity, it is required that all the nodes connected to the surface station. To check this connectivity, the authors have run a depth first search on the resultant topologies and calculate the number of connected components. If this number is 1, the network is connected. Otherwise, the network will be disconnected but the number of connected components will give us further idea about the number of disconnected nodes in the network. The number of connected components in final network topology shows amount of connectivity of that network [11].

2.4.1 Probabilistic Connectivity Problem

When connectivity among some of the sensor nodes is essential to complete a given function, the problem of estimating the prospect that the network achieves such connectivity arises. In this paper a parameterized probabilistic connectivity problem has expressed that serves this purpose when the network contains both sensor nodes and relay nodes. The precise probabilistic connectivity can be calculated efficiently for tree-like Networks. In this authors have considered semi-mobile and mobile networks. Conserving connectivity in such networks is an essential feature for any task requiring node association [44].

2.4.2 Connectivity with Network Capacity

Network capacity is an important term concerning to the connectivity of sensor networks. In sensor networks the increase of the transmission power can increase the probability of network connectivity [27]. Though, the large power results in severe interference within the network which reduces the network capacity and the performance of decoding at receivers. If the transmission range is reduced by decreasing the transmission power can limit the interferences, but it reduces the probability of connectivity and increases the number of hops required to reach the destination.

2.4.3 k-Connectivity

A sensor network is said to have k- connected if removal of any (k-1) nodes does not render the underlying communication graph disconnected. In latter sections, the authors have provided the formal definitions of k-connectivity and k-coverage from graph theory perspectives. Like single degree of coverage, single-node connectivity is not ample for a lot of sensor network applications because failure of a single node would render the network disconnected. It should be noted that robustness and throughput of a sensor network are directly related to connectivity. If a network is k-connected ($k \geq 2$), it has improved fault-tolerance than if it is just 1-connected. Guaranteeing k-connectivity prolongs the network lifetime if nodes fail at random times. The connectivity of an underwater sensor network is affected by time as the energy of the sensor node reduces and the node become dead at the end resulting into the network disconnection. k-connectivity is an essential QoS metric of network for fault tolerant system therefore, improves the communication consistency. k - connectivity denotes the property of an arbitrarily selected sensor node that has at least k neighbours. That is, in k connectivity, if $(k - 1)$ node fails, then connectivity still holds. Since underwater channel is affected from several environment deficiencies, thus k-connectivity performance is estimated under log-normal shadowing model [5, 10].

3. Conclusion and Future Scope

In this paper, we have overviewed the main research challenges for efficient communications in Underwater Sensor Networks. We have also described the strategies posed by the individualities of the underwater channel. Further, it is noticed that some remarkable properties that hold for wireless sensor network cannot simply applicable to underwater sensor network, but some may be. The ultimate objective of this survey is to get together researchers from different areas related to underwater networks and to inspire research efforts to lay down fundamental bases for the development of new advanced communication techniques for effective underwater communication.

This work will improve the reliability over the network. It is essential to design real time underwater communication system with degenerated energy outlay. There are many directions in which we would like to expand this research, like shadowing environment and 3-D space. This paper creates the extension of the analysis of k-coverage and k-connectivity from WSNs to UWSNs.

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