

**AI-DRIVEN ROUTING PROTOCOL IN THE UNDERWATER
ACOUSTIC SENSOR NETWORK FOR COMMUNICATION
SYSTEMS**

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Abstract

Wireless Sensor Networks (WSNs) are dynamic environments of sensor nodes that run on batteries, made possible by artificial intelligence (AI). WSN applications have increased due to recent developments in processing power and network connectivity. Applications for ocean exploration, including pollution detection, ocean resource management, underwater device maintenance, and ocean monitoring, have made underwater acoustic sensor networks (UASNs) increasingly significant. Researchers find routing protocol design to be an appealing issue in underwater acoustic sensor networks because it ensures dependable and efficient data transfer from the source node to the target node. In the last few years, numerous routing algorithms have been put out. We run comprehensive simulations in miscellaneous underwater environments to evaluate the effectiveness of these AI-based routing protocols. The findings show that AI-aided protocols outperform traditional approaches, especially when there are resource constraints and complex environmental dynamics. More dependable and effective underwater operations are made possible by this study's insightful analysis of the incorporation of AI technology into underwater communication networks. Our results lay the

groundwork for future developments in underwater communication systems and add to the expanding corpus of knowledge in this area.

Keywords: AI-aided protocols; Wireless Sensor Networks; underwater device; maintenance; acoustic sensor networks (UASNs).

1. Introduction

A significant portion of human and industrial demands will soon be met by the ocean: deep-water oil and gas extraction, the harvesting of renewable energy from the sea, etc. In addition, the seafloor will be mined for minerals like gold, silver, rare earth, nickel, copper, cobalt, and nickel. To do this, new port and marine facilities will need to be constructed, preserved, and maintained. However, because the ocean is large and we still don't fully understand the underwater environment, ocean monitoring and research are difficult. Furthermore, people should not deliver for extended periods underwater due to the immense stress found in deep water [1]. Scholars are attempting to replace conventional ocean exploration and monitoring techniques with wireless sensor networks due to their numerous applications. Because radiofrequency (RF) frequencies are significantly reduced in the watery surroundings, underwater sensors communicate with one another using sonic waves instead of RF waves. Underground acoustic sensor networks are a type of wireless sensor network.

Research of the underwater world is essential in many academic and practical fields, including exploitation of resources, environmental monitoring, and military applications, as oceans make up around 70% of the Earth's surface. These applications are greatly aided by underwater communication networks. Because it can travel vast distances and is appropriate for underwater conditions, underwater audio communication has become more popular than radio frequency (RF) communication. Mobile nodes, often autonomous underwater vehicles (AUVs), provide flexible design changes according to application requirements and enable three-dimensional (3-D) networked monitoring. These devices can also serve as ordinary sensor nodes, routers and switches, or destination nodes. Surface nodes (called sink networks in Figure 1) equipped with both RF and acoustic modems transmit the data gathered from underwater sensor nodes to shoreline control buildings for additional processing and analysis.

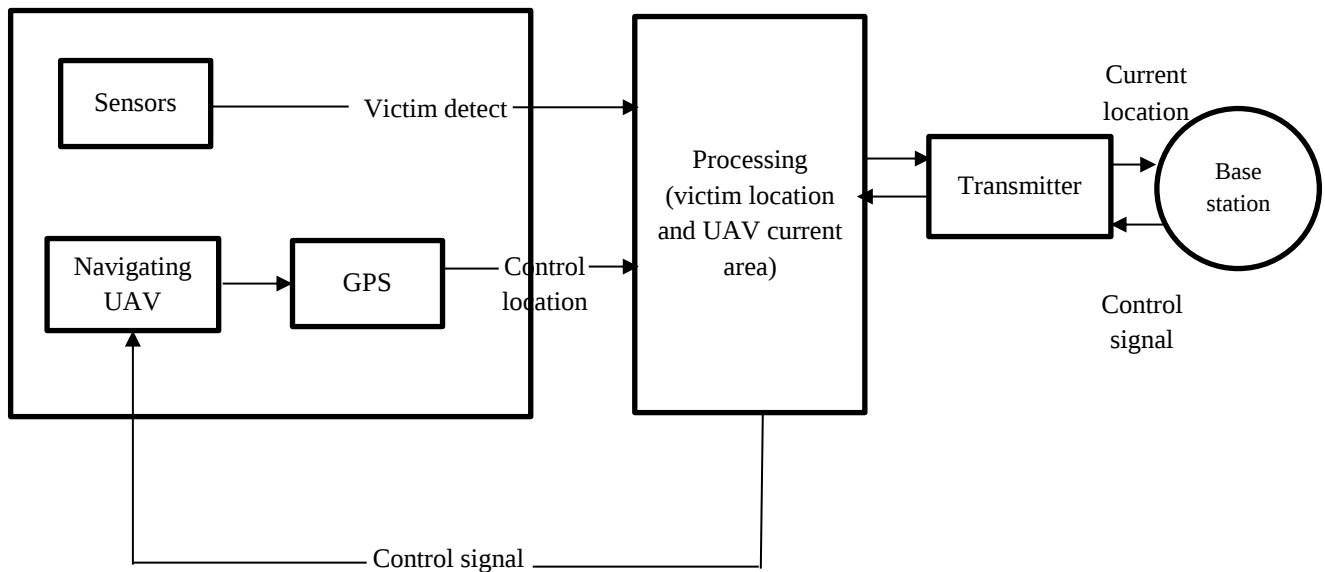


Figure 1. UAV platform block diagram

Among the difficulties with the submarine acoustic channel are its slow speed of propagation, limited communication rates, vulnerability to external impacts, extreme unidirectional pathways, and high consumption of energy [2]. When creating routing protocols for the UASN, these variables present several problems. Sound waves propagate slowly in water, which causes a powerful and prolonged propagation delay. The low communication rate for subsurface audio communication is caused by the restricted accessible bandwidth. Therefore, minimizing the data overhead for routing setup and upkeep is essential.

There are certain difficulties even though UASN is a young, exciting discipline that could aid in discovering what is concealed in the astoundingly unfathomable undersea realm. Since some of the occurrences are essentially distinct, not all UASN approaches and algorithms can be derived from the well-established land-based WSNs for setting up underwater applications [3]. Additionally, switching from the speed of light to the speed of sound alters the physics of communications, causing temporal synchronization and propagation delays. The sensors that are now on the market are vulnerable to common underwater problems, such as salt accumulation and algae formation on camera lenses, which can reduce their affectivity.

Last but not least, UASNs will demand different amounts of energy than terrestrial WSNs due to the bigger footprint of available underwater sensors, which use more power, and the expensive price of routine battery replenishment methods. The field of underwater acoustic network implementations has seen very little activity, leaving room for future study and opportunity.

The background of WSNs and a brief history of underwater sensing and UASSNs are covered in Section 2 of this work. The literature evaluation of specific research initiatives using UASNs for various purposes comes next (Section 3). Finally, Sections 4 and 5 discuss the ultimate conclusion and several research prospects in the field of aquatic sensor networks.

2. Related Works

Across shipping, offshore infrastructure, and naval operations, naval mines pose a serious hazard to maritime activity. The precise identification and categorization of these mines is essential for protecting ships and maintaining safe waters. The application of sonar technological advances, which have long been a crucial instrument in underwater surveillance, is one viable way to accomplish this [4]. Although the history of naval mine warfare dates back to antiquity, it rose to prominence in the nineteenth and twentieth centuries as technology advanced, taking on increasingly complex and elusive shapes. Conventional mine detecting techniques, such as electromagnetic and visual inspection, have drawbacks, especially in difficult settings like deep or murky waterways.

The network layer's job is to determine the best route from the source to the destination while accounting for a variety of channel properties, including significant propagation delays and node energy. Finding the path from the source to the target in various underwater sensor network gateways has been the subject of extensive research. In [5], routing protocols for sensor networks and ad hoc wireless sensor networks are covered. However, existing underwater networks have several challenges due to the very different makeup of underwater environments. Three types of routing protocols now in use are geographical, reactive, and proactive routing. Storage and power are the two primary justifications for adopting proactive algorithms in underwater sensor networks.

The goal of the writers of "The Partial Power Control Algorithm of Underwater Acoustic Sensor Networks Based on Outage Probability Minimization" is to lower the UASN's energy usage. The channel's operation is represented as an auto-regression management [6], and the resulting data loss is estimated, reducing the outage risk in the network and reducing interference caused by high-power transmissions. The authors of the research paper "Optimization of LDPC Codes over the Underwater Acoustic Channel" propose a channel encoding technique that compensates for the considerable delay spread in the sales process using input from the channel normalization and the channel decoder. The final result is a low-density parity check decoder customized to the unique canal circumstances of the underwater acoustic route.

Since different nodes can serve as gateways to conventional networks and information can travel through several channels, there are several benefits to adopting a mesh network in this regard. Furthermore, the ability for any pair of nodes to share information enhances the network's performance and increases its computational capacity, which helps to construct distributed applications or information processing [7]. Peer-to-peer data-sharing methods are essential for UW-ASN node integration and cooperation. Applications can incorporate distributed data retention, failure tolerance, quick data exchange, and early warning broadcasts at the programming layer by supporting this kind of connectivity.

The hardware infrastructure is shared by the underwater communication system. Before deployment, the application system and associated protocol will be established in the

respective nodes [8]. UASNs are typically launched into the water by unmanned aircraft, tires, or autonomous underwater vehicles (AUVs). Once installed, the battery-operated underwater nodes are difficult to recover and reconfigure. Because of this, a tailored UASN is typically a disposable device that is made for a single underwater use and is difficult to use in other contexts. Furthermore, communication is challenging with underwater equipment (or nodes) from odd manufacturers since they differ. Temporarily, acoustic networks of different companies and technologies are quite bad at fostering adaptability and engagement.

Furthermore, over the years, shipping companies have reported that delays are typically the result of numerous disruptions and departures from the original plan [9]. Due to the extended idle periods of vessels waiting for port calls, these holdups result in poor port efficiency, market chain interruptions, and increased pollution, primarily greenhouse gas emissions and undersea radiated sound. We introduce a novel method for estimating the sailing time of vessels in port environments that combines pre-processing methods and AI designs, particularly ML. All of this is made feasible through the use of historical shipping data, including port-specific characteristics, flight patterns, and ship parameters. Additionally, an underwater acoustic diffusion model is developed for each ship along its route to investigate direct features of the underwater noise intensity in the port area.

Cyber-physical systems (CPS), which oversee intricate urban operations, rely heavily on Wireless Sensor Networks installed in urban settings. These networks gather data in real-time, which is essential for improving public safety and traffic control, among other city operations [10]. However, there are major barriers to the effectiveness and dependability of WSNs due to particular urban tests such as high-rise architecture, dynamic travel patterns, and dense construction sites. These elements frequently interfere with signal reception, create dynamic network topologies, and make routing more complex, which is necessary for accurate and timely data delivery. WSNs use a variety of routing methods, mostly divided into proactive and reactive strategies, to handle the difficulties of installation in urban settings.

3. Methods and Materials

3.1. Underwater Acoustic Communication

The data is collected by an underwater acoustic sensor system when events occur in the underwater environment; hence a reliable and effective path from the origin node to the destination node is needed [11]. Domestic routing methods are different from UASN routing protocols because of the differences between domestic and underwater settings, even though many routing algorithms have been proposed for terrestrial wireless sensors networks.. Some research into the features of underwater sound communication is required in order to better understand the distinctions between underwater and terrestrial communication as well as the challenges associated with designing routing protocols for underwater acoustic networks of sensors.

3.1.1. The Characteristics of Underwater Acoustic Communication

The underwater environment presents a more challenging scenario for networking protocol development than terrestrial sensor networks that are wireless because of the varied transmission media [12]. We will provide a brief overview of these distinctions in the paragraphs that follow.

3.1.2. High propagation suspension

Instead of using radio frequency signals, underwater sensor nodes interact with one another using sound waves. Since radio frequency waves travel at a speed of roughly 200,000 times quicker in the air than underwater acoustic waves, underwater acoustic sensor networks will have significant propagation delays because their propagation time is 200,000 times longer than that of terrestrial wireless sensor networks. Furthermore, the rate at which underwater acoustic waves propagate can be impacted by variations in depth, temperature, and salinity. Designing routing protocols becomes more challenging in underwater situations due to the dynamic propagation delay.

3.1.3. High energy consumption

Underwater habitats have significant acoustic wave attenuation. In comparison to terrestrial systems, underwater acoustic transceivers require an order of magnitude more transmission power. Furthermore, the communication lines are readily damaged since undersea nodes are constantly moving. The bit error rate in underwater acoustic sensor networks is also significantly higher than that of wireless sensor networks on land. Numerous data packet retransmissions can result from all of these problems, wasting a significant amount of energy.

3.1.4. Low bandwidth and statistics rate

The transmission distance determines the acoustic waves' bandwidth. The bandwidth is between 1 kHz and 50 kHz. Additionally, only a few frequencies may be employed for long-distance communication due to the considerable power absorption of acoustic waves in the underwater environment. The acoustic wave's frequency range beneath water is a few Hz to tens of kHz; hence the speed of transmission can hardly surpass 100 kbps, which is incomparable to radio frequency waves in the atmosphere [13]. This is a significant drawback for the design of the UASN routing protocol, particularly given that the protocols for routing require a lot of information sharing for both routing discovery and network management.

3.1.5. High noise and intrusion

The noise level is significantly higher underwater than on land because of the water currents, machinery, and ships below. In addition, interference is more prevalent underwater than on land, mostly because of reflections off the water's surface, bottom, creatures, and contaminants. Furthermore, interference from multiple paths in undersea acoustic networks of sensors is more severe than in terrestrial wireless networks of sensors due to the significant underwater refraction.

3.1.6. Highly dynamic topology

The architecture only varies when new nodes join the internet or when existing nodes die because, once deployed, sensor nodes in a terrestrial environment are unable to move around freely and frequently. Nevertheless, the topology regularly changes in an underwater environment because the sensor nodes continually move with the water currents. This has a significant impact on the performance of the routing protocol. Table 1 illustrates how the terrestrial and underwater environments differ from one another. The typical routing techniques for wireless sensor networks cannot be easily applied to UASNs due to the significant variations.

Table 1. The differences between the underwater environment and the terrestrial environment

	Underwater Environment (Acoustic Wave)	Terrestrial Environment (RF Wave)
Propagation speed	Low (1200 m/s to 1400 m/s)	High (3×10^8 m/s)
Energy consumption	High	Low
Propagation delay	High	Low
Bandwidth	Low	High
Data rate	Low	High
Noise and interference	High	Low
Dynamics	High	Low
Reliability	Low	High

3.2. Acoustic Communication Underwater

Comparing wired and wireless communications across the environment to underwater wireless communications, new and unique obstacles arise. Even over short distances, underwater wireless communications require complex communication systems to achieve very low transmission rates. In fact, the undersea environment has several special features that set it apart from terrestrial radio propagation, which is where conventional communication devices are used [14]. A number of factors, including temperature, light levels, pressure, amount of saltwater, winds, and their impact on waves, can affect communications underwater. According to science, seawater has a high conductivity, which has a significant impact on how electromagnetic waves travel across frequency ranges used by satellite communications, TV, radio, and mobile services. Because of this, it is difficult to create communication links in the ocean at high frequencies or even at Very High Frequencies and Ultra High Frequencies for distances more than 10 meters. The electromagnetic-wave attenuation might be regarded as low enough at lower frequencies, specifically Extremely Low Frequencies (ELF) and Very Low Frequencies (VLF), to enable dependable communications across a distance of several kilometers. Regrettably, the frequency ranges of 3 Hz to 3 kHz and 3 kHz to 30 kHz are too narrow to allow for high data rate transmissions. Transmission loss has a significant impact on underwater radio frequency communication as well. These issues have resulted in significant limitations on data throughput and propagation

distances for technology. The limited number of devices that use RF communication technology to date can be attributed to these primary factors.

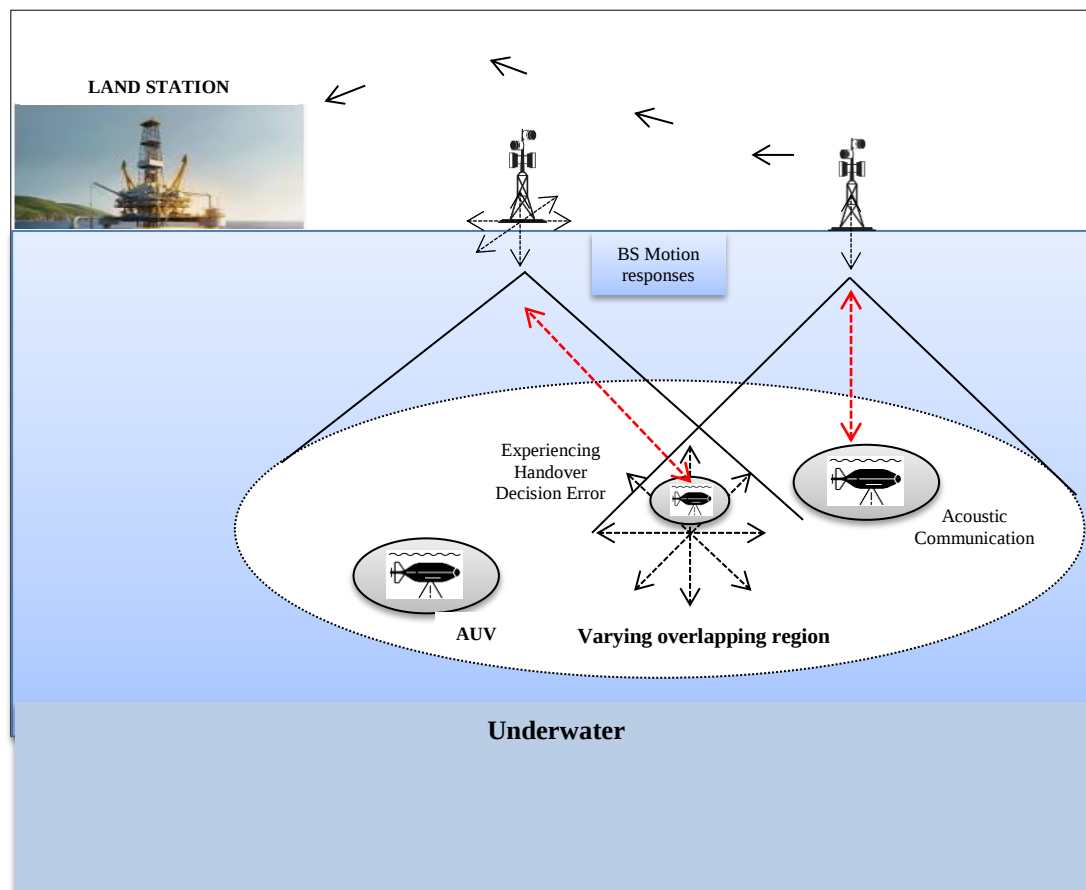


Figure 2. Possibility of Underwater Communication

Underwater wireless communications are necessary for a number of programs, including controlling devices remotely in the offshore oil industry, environmental systems monitoring pollution, gathering scientific data from Speech communication between divers, mapping the ocean floor for object detection and resource discovery, and ocean-bottom stations and autonomous underwater vehicles are all depicted in Figure 2 [15]. The scientific community has recently paid close attention to underwater acoustics (UWA) networks and communications because they allow information to be wirelessly transmitted from submarines to the surface, opening up a variety of ocean-related applications, particularly for the detection and tracking of seismic activity, oil spills, chemical pollution, and other issues. Radio waves, also known as electromagnetic radiation, are used in broadcasting. Sound waves are used in acoustic communication to convey information, whereas electromagnetic waves don't need a physical medium and can travel even in a vacuum, like space. Mechanical vibrations called sound waves travel through physical media like soil, water, or air.

4. Implementation and Experimental Results

The MNS-CBRP routing technique includes the development of an effective path to facilitate accurate data transfer evaluations at the surface sinks. The MNS-CBRP protocol requires that all node sources in a circular send information packets only to the cluster leader of the cube because of this limitation. The information gathered is then routed to the drains that are farthest away.

After analyzing the efficiency metrics of the 240-node MNS-CBRP network using the telnet, S-frame, and Gen-FTP apps for this study, we came to the conclusions shown in Tables 2, 3, and 4 below [16]. These are the outcomes figures for the Gen-FTP, S-frame, and Telnet programs running on the UWSN relationship:

Table 2. Evaluating parameters when implementing the STAR-LORA routing protocol via Telnet, S-frame, and Gen-FTP

Parameter	STAR-LORA		
	Telnet	S-Frame	Gen-FTP
Avg. txion delay (micro sec)	47	71	73
Rx power conception (mWh)	0.24	0.3	0.018
Tx power conception (mWh)	25	0.017	0.23
Idle power conception (mWh)	0.74	0.57	0.76
Time spent transmitting (m s)	37	61	51

Table 3. Evaluating variables when implementing the OLSR routing protocol via Telnet, S-frame, and Gen-FTP

Parameter	OLSR		
	Telnet	S-Frame	Gen-FTP
Average delay (micro sec)	74	68	78
Rx power conception(mWh)	0.26	0.035	0.43
Tx power conception (mWh)	0.13	0.18	0.04
Idle power conception (mWh)	0.74	0.64	0.77
Time spent transmitting (m s)	25	26	22

Table 4. Evaluating variables when implementing the LAR1 routing protocol via Telnet, S-frame, and Gen-FTP

Parameter	LAR 1		
	Telnet	S-Frame	Gen-FTP
Average delay	87	73	91
Rx power conception	0.23	0.045	0.087
Tx power conception	0.14	0.15	0.14
Idle power conception	0.76	0.86	0.74
Time spent transmitting (m s)	23	31	27

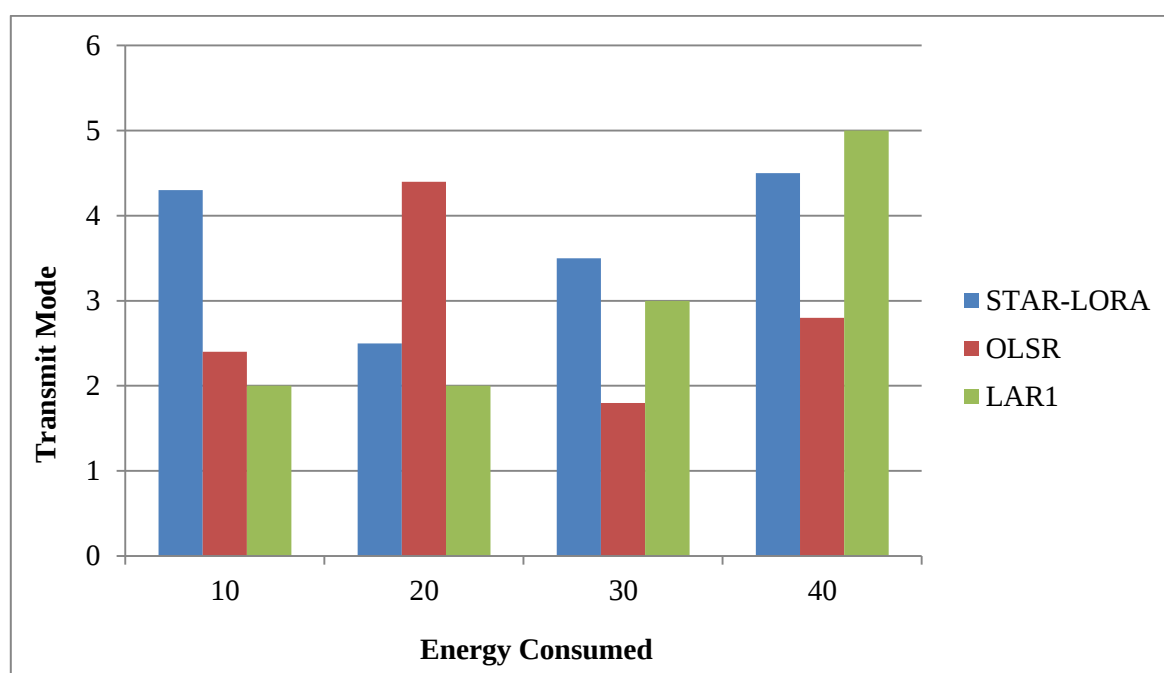


Figure 3. Energy Consumption

4.1. Energy Availability When Using Telnet, S-Frame, and Gen-FTP in the STAR-LORA, OLSR, and LAR1 Routing Protocols' Transmission Phase

The amount of energy utilized by 260 terminals when STAR-LORA, OLSR, and LAR1 are combined with Telnet, S-frame, and Gen-FTP is shown in Figure 4. Table 5 illustrates that the minimum transmission energy needed for LAR1 in the S-frame installation scenario is 0.008 mWh [17].

Table 5. Analysis of parameters for the STAR-LORA, OLSR, and LAR1 routing protocols when using Telnet, S-frame, and Gen-FTP

Parameter	Routing Protocol								
	STAR-LORA			OLSR			LAR1		
	Telnet	S-Frame	Gen-FTP	Telnet	S-Frame	Gen-FTP	Telnet	S-Frame	Gen-FTP
Average delay	67	71	73	74	76	58	87	53	78
Rx power conception	0.24	0.3	0.028	0.44	0.035	0.24	0.23	0.025	0.086
Tx power conception	0.25	0.037	0.23	0.13	0.18	0.13	0.12	0.015	0.14
Idle power conception	0.76	0.74	0.76	0.56	0.84	0.65	0.76	0.84	0.94
Time spent transmitting	37	61	53	25	28	13	12	31	26

4.2. Energy Availability When Using the STAR-LORA, OLSR, and LAR1 Routing Protocols in Idle Mode with Telnet, S-Frame, and Gen-FTP

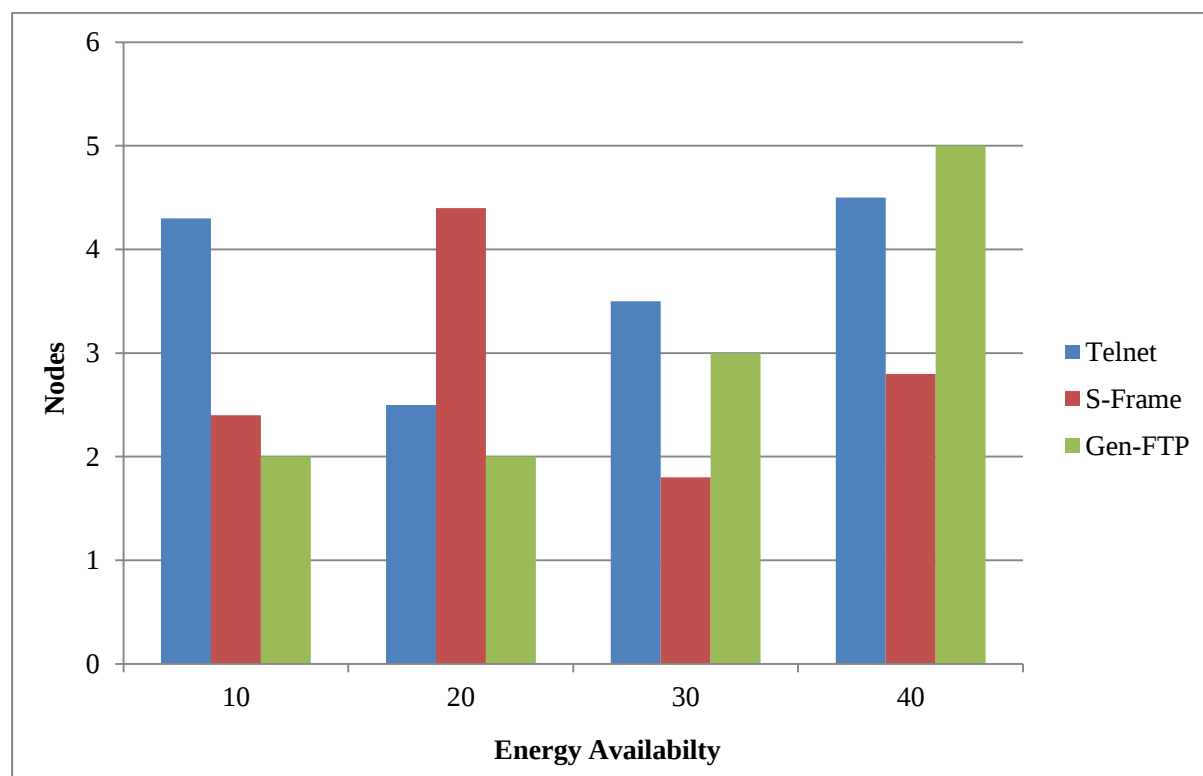


Figure 4. STAR-LORA, OLSR, and LAR1 routing protocols' energy supply when using Telnet, S-frame, and Gen-FTP in idle mode

The power consumption of 340 nodes when STAR-LORA, OLSR, and LAR1 are utilized in combination with Telnet, S-frame [18, 19], and Gen-FTP is shown in Figure 4. As shown in Table 4, OLSR in the Telnet deployment application requires a minimum of 0.75 mWh of idle energy, while STAR-LORA in the S-frame installation app requires a least of 0.75 mWh.

5. Conclusion

Sensor networks installed underwater may open up previously unimagined uses. Enabling connectivity between underwater devices will make these possible uses feasible. Sensors and vehicles placed underwater and connected by acoustic links will make up underwater acoustic sensor networks, which will enable cooperative monitoring operations. We have introduced the fundamental conceptual architecture of an underwater acoustic sensor ecosystem in this research. The undersea channel's attributes and the difficulties it presents have been covered. Additionally, the study problems and difficulties of every tier in the underwater sensor network's network protocol stack

Data examination, marine life nursing, and military preparation are all related to ocean floor research. This is due to the fact that all three of these processes require submerged conditions. The UWSN's battery life is given priority due to the constraints placed on the system by its limited capabilities. A number of widely used routing protocols, including Gen-FTP, S-frame, and Telnet, are examined and contrasted in UWSN networks under various deployment scenarios. Energy consumption during dissemination, standby, and receiving it, as the metrics that was looked at was the average transmission time for transmitted bytes. Furthermore, STAR-LORA transmission delay for UWSN via the Telnet deployment program is 60 ms. Furthermore, LAR1 dedicates 11 msec to the Telnet deployment program.

In conclusion, the present research shows how artificial intelligence has the potential to significantly enhance underwater communication networks. This has demonstrated how to combine adaptability with methods such as deep learning, reinforcement learning, and machine learning to address the issue that base stations encounter in underwater environments. In order to effectively control latency, future research must enhance machine learning integration, develop complex reinforcement learning algorithms, and improve adaptive techniques.

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