Design and development of an underwater wireless sensor network for aquatic monitoring

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Abstract

There is a lot of potential for underwater study and application in the rapidly developing field of underwater wireless sensor networks (UWSNs). Because of the depth of node deployment, which makes it nearly impossible to capture solar energy, the sensor nodes in this case are battery-powered and challenging to recharge. Thus, system design requires an energy-efficient strategy. useful method for creating an energy-efficient UWSN is clustering. The grouping properties of UWSNs vary from those of earthly remote sensor networks due to the scanty node placement and dynamic nature of the channels. The goal of this work was to apply the hybrid CS approach to address the issue of huge data at cluster heads (CHs) when the sensing region is large. Additionally, this thesis uses cross breed CS for multi-hop based UWSNs, where correspondence can be acoustic, EM, or FSO, to do an insightful plan of all out energy utilization each round. The suggested model's performance is assessed in terms of network lifetime and energy efficiency.

Keywords: WSN, Aquatic ecosystem, Machine learning

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Background

An underwater wireless sensor network for aquatic monitoring is designed and developed. Given that two thirds of the planet is submerged under water, research on underwater wireless sensor networks, or UWSNs, is only getting started (Jaiswal and Pradhan, 2023; Vij and Prashant, 2024). Recent developments in technology have made it possible to use sensors for underwater exploration, which has drawn increasing study interest (Sun, 2024). In order to conduct cooperative monitoring over a certain volume, UWSNs comprise a number of sensor hubs scattered in a haphazardly disseminated way (Chen and Tian, 2023; Gladkova and Gladkov, 2021). These hubs assemble information and send it to the submerged base station (BS) (Sen and Malhotra, 2025). Uses of UWSNs incorporate route support, investigation (oils, minerals, and fish), strategic reconnaissance, calamity counteraction (ocean tremors, wave cautions), and sea climate checking (ocean flows, winds, fish following). For these applications, a way to transmit signals over the undersea medium is necessary (Abdul *et al.,* 2021; Azoury et al., 2024). Currently, acoustic waves, radio frequency (RF) waves, free space optical (FSO), and magnetic induction (MI) communication methods are used to implement underwater wireless communications (Zhang *et al.,* 2023). Conversely, the unfavourable underwater conditions present significant obstacles to effective networking and communication (Anny Leema et al., 2024). Two-dimensional and three-dimensional architectures are the two ways that underwater sensor networks can be deployed (Rastgoo, Kiani and Escalera, 2020). Sensor nodes are dispersed throughout a two-dimensional plane in a two-dimensional design, and they can interact with the base station (BS) via a single-hop or multi-hop method (Gangrade and Bharti, 2023; Castillo and Al-Mansouri, 2025). To communicate with the nodes, the BS uses a horizontal transceiver; to communicate with the surface station, it uses a vertical transceiver (Mirza *et al.,* 2022). The nodes in the three-dimensional constructions are submerged at varying depths to keep an eye on a particular activity (Rajan and Chawla, 2024). They can interact with the BS via a single-hop or multi-hop method (Escobedo et al., 2024). Long lifespan, vast and dependable network size, low power consumption, multi-hop communication capability, scalability, and other requirements are what the majority of UWSNs look for in a deployed network (Muneeb, Rustam and Jalal, 2023; Das and Ghosh, 2024).

Analysis And Design

Computational asymmetry, compressibility, stability, and robustness are the benefits of CS in UWSNs that make it applicable to UWSNs with limited resources (Gao *et al.,* 2022). However, the total number of packets that must be sent is still high when CS is applied to information assortment in UWSNs without considering the highlights and construction of UWSNs (Khomami and Shamekhi, 2021). Hence, in this work, we introduced a half and half CS approach that can essentially limit information transmission by utilizing information pressure with CS among CHs and information pressure without CS inside each group (Bhaumik *et al.,* 2023). In figure 1 display the Block diagram of proposed model.

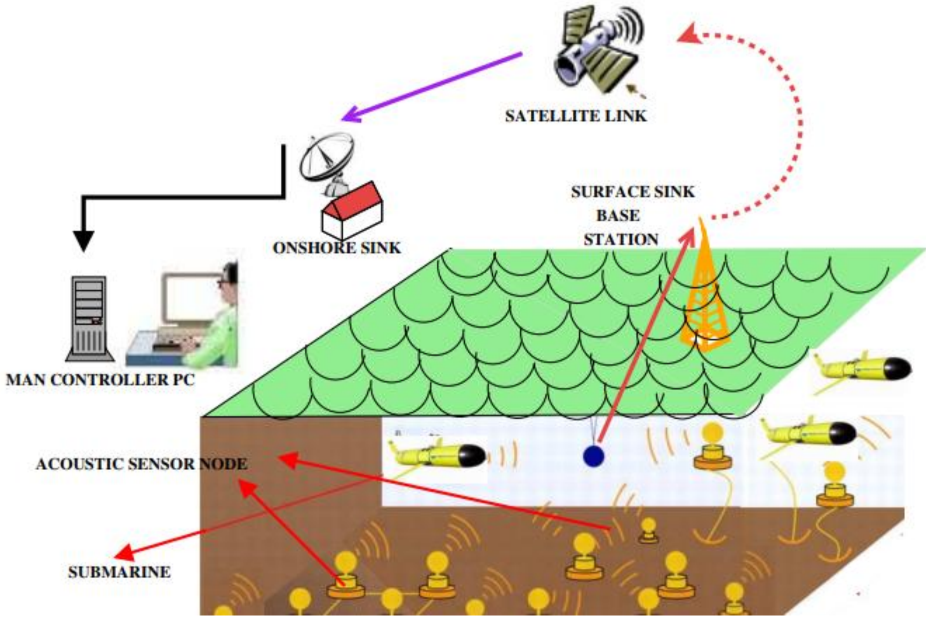

Figure 1: Block diagram of proposed model.

The sensing region is separated into square-shaped clusters using the energy-efficient clustering technique (Lv *et al.*, 2021; Rastgoo, Kiani and Escalera, 2023). According to the literature, data is typically collected in each cluster at CH using the standard method, which does not use CS technique, while data is collected between CHs using CS technique (Gao *et al.*, 2023). As network scalability increases in this current data collecting paradigm, more CS measurements (I) will be required, requiring CH to transfer more packets and adding redundant information in the process. We suggested a novel compression technique known as the hybrid CS method to lessen this issue in clustered UWSNs (Rehman *et al.*, 2020). This approach states that data will be sent to the CHs within a specific cluster via a single hop without the need of CS techniques. If the length of the bundle is more modest than the length of the result estimations (I), CHs move the assembled information to the following upper layer CH without utilizing the CS procedure. The CS approach will be utilised to collect data if the packet length is more than or equal to the measurements' length (Sharma *et al.*, 2022). For clustered UWSNs, the suggested approach uses less energy than the traditional data collection method.

Requirement Resources and Results

We evaluated the multi-hop hybrid CS's overall energy consumption with that of standard multi-hop correspondence for every one of the three of the ongoing specialized techniques — acoustic, electromagnetic, and FSO — in our recommended approach. MATLAB R2019b software is used to obtain the simulation results.

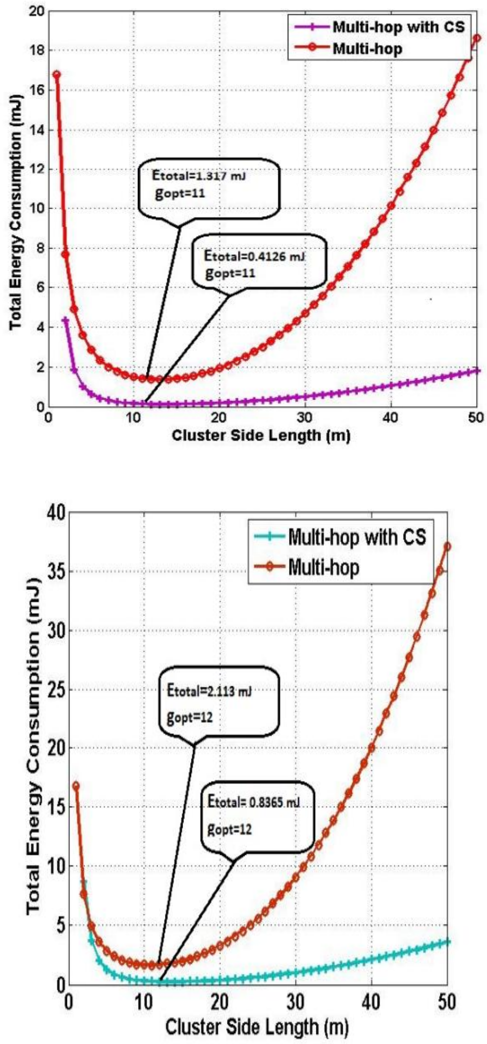

Figure 2: Complete energy utilization versus group side length for acoustic.

The ideal group side length and all out least energy utilization esteem, while utilizing half breed CS information gathering in multi-hop communication, are both equivalent to 11, 0.4126 mJ, which is the most minimal worth when contrasted with straightforward multi-hop communication without crossover CS, as displayed in a similar Figure 2 (A). Likewise, we can express that we can save much more energy for acoustic communication by utilizing the cross-breed CS information assortment strategy. Moreover, Figure 2 (B) shows that the ideal group side length and generally speaking least energy utilization worth will be equivalent for multi-jump correspondence and multi-jump correspondence with half and half CS information assortment method when the quantity of hubs is expanded to 600. Therefore, it is evident from the research above that the hybrid CS data collection technique uses less energy while communicating with several hops.

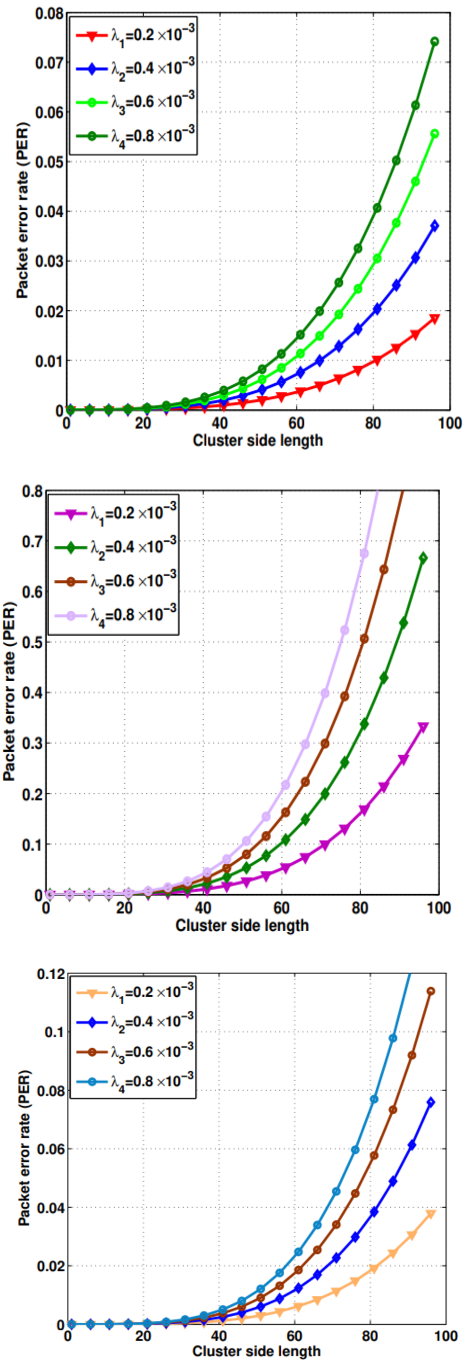

Figure 3: Complete packet error rate versus cluster side length for acoustic.

Additionally, it has been noted that, of all the communication methods, acoustic communication dissipates less energy than FSO communication. Moreover, a for every examination is performed for every one of the three specialized techniques. In figure 3, Out of the three specialized strategies, the reproduction discoveries for PER versus bunch side length show that acoustic has the highest PER while EM at the CH has the lowest PER.

Conclusions

The most popular technology in underwater media is audio communication. The underwater acoustic communication system transmits information from one node to another using low range electromechanical frequencies (few Hz), similar to acoustics. Acoustic waves are better suited for long-distance communication applications such as ocean depth investigation and monitoring since they employ low frequencies. However, acoustic wave propagation is significantly hindered by ambient noise and excessive water turbidity. Acoustic waves typically travel through water at a speed of about 1500 m/s. Thus, high bit error rate (BER) and substantial propagation delays result from the low acoustic wave propagation speed. The most often used technique, acoustic communication, has several drawbacks, including a low transmission data rate (measured in kbps) and a significant communication delay (measured in seconds). As a result, it is not suitable for real-time applications that necessitate the interchange of massive amounts of data. Acoustic waves have the drawback of being difficult to get through the water/air barrier.

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