Time Synchronization under Exponential Delays in Underwater Wireless Sensor Networks

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Abstract— For wireless sensor networks to operate effectively, time synchronisation is critical (WSNs). However, because to the harsh environment and the mobility of nodes, underwater WSNs struggle with temporal synchronisation (UWSNs). Large-scale networks are incompatible with existing UWSN time-synchronization technologies that are mostly based on point-to-point synchronisation. Some additionally need the use of specialised equipment and deployment conditions. In this case, we recommend TSUED, which stands for "time synchronisation under exponential delays." TSUED implements a sync communication mechanism by using the broadcast's acoustic communication capabilities. Due to Node clock skews, ROS considers all timing messages, including those on the downlinks of two-way timing message exchanges between active nodes. The JMLE and linear function techniques are used to compute skew and offset. Using a time estimate and MSVM technique, the time reference information from multi-source beacons is used to the greatest degree feasible. TSUED has a high degree of accuracy in terms of throughput and energy usage, according to simulated studies.

Keywords: TSUED, UWSN, MMLE, ROS, MSVM, Time Synchronization

I. INTRODUCTION

The availability of water is critical to human survival. Oil, natural gas, and mining have all sparked humanity's curiosity in the ocean's depths [1]. Humans have only recently been able to properly examine the ocean bottom due to scientific and technical developments. However, only around 10% of the 71 percent aquatic globe has been examined, leaving the remaining 61 percent unexplored. In recent years, sensor and communication technologies enabling autonomous exploration of the Earth's surface have grown in popularity [2]. [4] The primary purpose of sensor technology is to execute collaborative monitoring tasks in a certain area and communicate this information to the user using sophisticated wireless or wired communication technologies [5]. [6].

This issue has been intensively explored for many years and attracts a large number of researchers. [7] The energy consumption and accuracy of a synchronisation protocol are two of the most significant factors to consider while building one. In a terrestrial wireless sensor network, synchronisation energy accounted for up to 17% of total energy used by a node. Underwater, sound is the primary mode of communication; there is a significant rise in consumption. Nonetheless, batteries have a limited amount of energy and are difficult to replace or charge while moving, requiring the creation of a low-energy synchronisation method.

There are three basic synchronisation procedures, each of which use statistical methodologies to improve accuracy. When nodes exchange information on the arrival of broadcast messages from a single source, this is an example of Radio Resource Sharing (RRS). RBS is the most often used RRS-based protocol, which implies that all nodes get the broadcast almost simultaneously. Because delays are inherent in the message exchange process, ROS synchronisation accuracy diminishes as a result of signal processing's uncertainty regarding message delays.

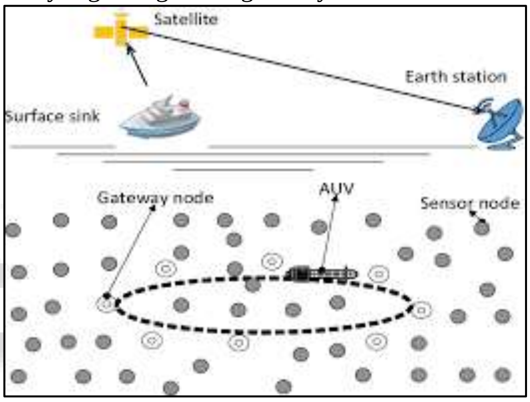

Fig. 1: UWSN Architecture

Sender-Receiver Synchronization (SRS) is used when two nodes interact with one another [8]. TPSN (Timing-synchronization Protocol for Sensor Networks), tiny-sync and mini-sync, and lightweight time synchronisation are examples of SRS systems (LTS). To lessen the uncertainty associated with delays, SRS-based synchronisation methods have recently added more complex statistical signal processing methodologies. Initially, an exponential delay model was used to construct a minimum variance unbiased estimate (MVUE) of clock offset variance, which was then used to unify all MLEs for clock offset variance based on Gaussian, exponential, or log-normal random delays [10]. Because the techniques described above do not account for clock skew, the re-synchronization interval must be decreased. Because of the considerable relationship between delays and distances between nodes, some researchers have adopted the notion of integrating synchronisation with localisation.

In this paper, the TSUED model is proposed for temporal synchronisation in UWSNs with exponential delays. TSUED employs a synchronisation communication approach that makes advantage of the acoustic communication properties of the broadcast. ROS considers clock skews on nodes as well as all timing messages, including downlinks, during two-way timing messages. Skew and offset are calculated using the JMLE and linear function approaches.

II. BACKGROUND STUDY

Y. Dong et al. [2] proposed a novel temporal synchronisation method that incorporates mobility prediction. Anchors may anticipate their velocity in this manner by utilising past data. Unsynchronized nodes use spatial correlation to calculate their velocity.

M. Faheem and colleagues [3] There have been suggested bio-inspired multi-objective evolutionary routing algorithms for event-driven applications employing UWSNs. To divide the network's data traffic load, the suggested solution employs a clustering mechanism that creates highly stable, dynamic clusters of varying sizes. The suggested routing technique provides a high level of connection quality stability across cluster heads, allowing for robust data transmission in UWSNs. The suggested solution eliminates data route loops and unnecessary multi-hop packet transmission by regulating data flow in the network's uphill and downhill directions. It significantly reduces energy consumption, faulty data packets, and network longevity.

The authors explained F. Hong and colleagues [5] MulSync, a mechanism that needs just a few beacons, may be used to synchronise UWSNs. MulSync estimates local skew or offset using three linear regressions rather than the acoustic signal component of previous techniques. The MulSync team also did not make any assumptions about hardware or deployment needs. MulSync has significantly improved synchronisation accuracy, message overhead, and time consumption, according to simulated data.

N. Ilyas and colleagues SMDBR (Sink-Mobility in Depth-Based Routing Protocol), a routing protocol for UWSNs based on node depth information, is provided by the authors [6]. When immersed, it employs the MS to enhance network lifetime and data collecting efficiency. The authors are aware of the significant distance that exists between the underwater sensor nodes and the surface sink. As a consequence, many transmissions and receptions use a lot of energy and have a long end-to-end latency.

Wang, S., and Gao, M. [7] offer a dynamic clock synchronisation method for use with the current ocean model. Unlike existing solutions for underwater sensor network clock synchronisation, this methodology uses a high-precision clock to rectify clock skew, removing the challenging linear estimation and correction. The flow velocity affects the subsea node's movement as well as its speed. The current ocean model was used to calculate the node's speed in water. The Doppler Effect determined both the relative velocity between nodes and the propagation delay at the same time.

Among those who have contributed to this work are B. Zhang et al. [9]. It was intended to locate just one normal node. However, energy constraints have limited the range of underwater acoustic transmission for large-scale UWSNs. As a consequence, discovering underwater nodes in large-scale UWSNs becomes much more challenging.

D. Zhang and colleagues [10] A long-term research on energy allocation for monitoring objectives in UWSNs with little energy harvesting was carried out. To improve tracking accuracy and efficiency, the authors began with a non-myopic energy allocation approach. Increasing the accuracy of tracking over time was a focus of the authors' study. Fisher Information Matrix (FIM) and quantized data were used to study energy allocation and tracking accuracy. FIM was used as a performance indicator in the energy allocation optimization challenge to maximise tracking performance under energy restrictions.

III. TIME SYNCHRONIZATION UNDER EXPONENTIAL DELAYS

There are both fixed propagation delays and random delays to consider due to the sequencing of message processing activities at the transmitter and receiver, as well as message queuing at the Medium Access Control (MAC) layer. To guarantee that all messages have the same propagation time, nodes must be situated at the same time. q is the passive node that just listens while the active nodes exchange N messages. The major goal of this project is to sync the clocks of both nodes. The ROS scheme's goal is to provide correct messages. The CVX toolboxes provide a computationally simple method for producing the same effect as the combined MLE of clock skew and offset for quiet and active nodes.

A. Network Model

As part of ROS' standard model, all timing messages, including those on the downlink of two-way timing message exchanges between active nodes, are included. The Support Vector Machine (MSVM) predicts the active node's clock offset and skew. MSVM is both accurate and durable in alg 1.

B. Modified Support Vector Machine Algorithm

Plot the decision boundary for a non-linear MSVM problem

```
def plot_decision_boundary(model, ax=None):
  if ax is None:
      ax = plt.gca()
    xlim = ax.get_xlim()
    ylim = ax.get_ylim()
    # create grid to evaluate model
    x = np.linspace(xlim[0], xlim[1], 30)
    y = np.linspace(ylim[0], ylim[1], 30)
    Y, X = np.meshgrid(y, x)
         # shape data
    xy = np.vstack([X.ravel(), Y.ravel()]).T
         # get the decision boundary based on the model
    P = model.decision_function(xy).reshape(X.shape)
    # plot decision boundary
    ax.contour(X, Y, P,levels=[0], alpha=0.5, linestyles=['-'])
```

C. ROS Model

Between the active nodes and node q, which is only listening to what's going on, there are N rounds of message exchange. P and Q are synchronised with node m using the standard clock as their target. Entire messages are replaced during message exchange cycles in the ROS system.

Node m broadcasts a message with its own time-stamp, T(s)1;i, and the time-stamp generated in d) at the (i-1)th round, T(s)4;i-1, both of which refer to the ordinary clock; Upon receiving the message from node m, node p records its current clock reading, $T(r)^2$;i; c) Node R replies to node m in a broadcast manner.

Node O records its local clock readings, $T(o)^5$;i and $T(o)^6$;i, when it receives messages from node R and node O, respectively, across the two-way link.

D. Multi-Hop Maximum Likelihood Estimation (MMLE)

Not every regular node in a more realistic multi-hop network will be able to reach three anchor nodes. A multi-hop approach is necessary in this case to offer network-wide localisation and synchronisation. In this part, we'll go through how to extend the network to include several hops, as well as how to deal with synchronisation and location issues at the network level.

Anchor nodes may not be able to cover all ordinary nodes that need synchronisation and localization in order to operate effectively. Additional reference points may be required to achieve multi-hop or even network-wide synchronisation and localisation. They might be probable candidates once three anchor nodes have found and synchronised ordinary nodes. As additional synchronised and localised nodes are added to the reference set, more than three reference nodes may cover an ever-expanding area. Given the broad network localization and synchronisation fault, the reference nodes must be chosen with care. Before it may assist other nodes in being synchronised and found quickly, a reference node must fulfil accuracy standards.

When it comes to network-wide synchronisation and localization, we provide a hierarchical strategy that splits the activity into a main and secondary process. In order for JMLE to identify and synchronise the ordinary nodes, at least three anchor nodes must be present. This is true for every single ordinary node.

Synchronization The accuracy method is utilised. Despite this, the TSUED strategy outperforms the other approaches in terms of synchronisation accuracy. This condition is compatible with the analysis after hypothesis, which asserts that clock measurements from the quiet node do not help in correctly predicting the clock parameters of the active node since they give more unknown variables than usable information. Furthermore, the TSUED technique is much more accurate than the JMLE method.

IV. RESULTS AND DISCUSSION

It usually refers to the consequences and facts generated by the gadget for many end-users. The output is the important reason for creating the device and the foundation on which they evaluate the usefulness of the application

The results of the simulation are positive concerning performance. The Proposed system has used the NS2 simulator to evaluate the DSR Routing protocol. The results are compared with the method of JMLE and TSUED methods.

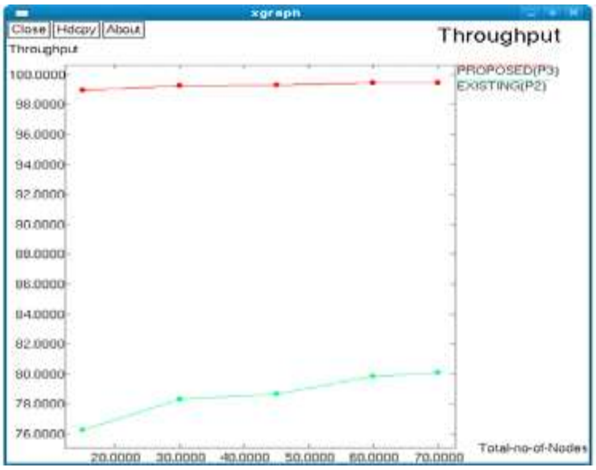

Fig. 2: Throughput Comparison for JMLE and TSUED Protocol

In Fig. 2 x-axis denotes the total no of nodes, and the y-axis denotes the throughput

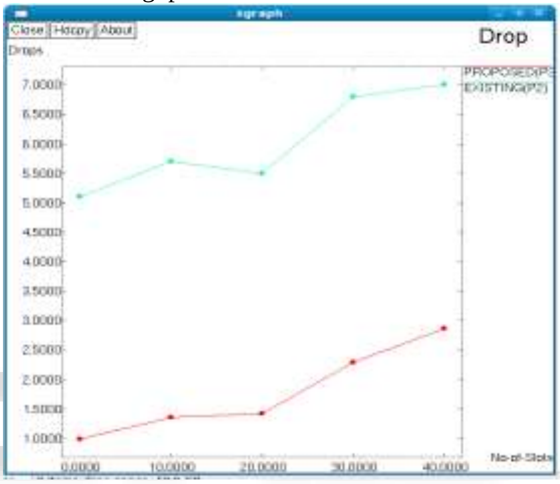

Fig. 3: Packet drop Comparison chart

Fig. 3 illustrates the packet drop comparison chart for the existing and proposed system. In x-axis denotes the no of slots, and the y-axis denotes the packet drop frequency.

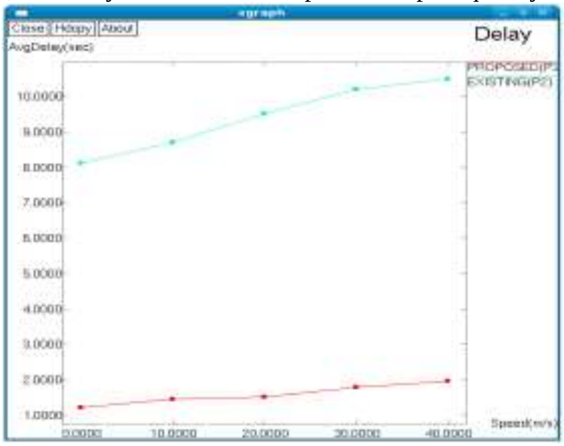

Fig. 4: Average Delay Comparison chart

Fig. 4 illustrates the average delay comparison for the existing and proposed methods. In x-axis denotes the packet speed in milliseconds. And y-axis denotes the Average Delay in seconds.

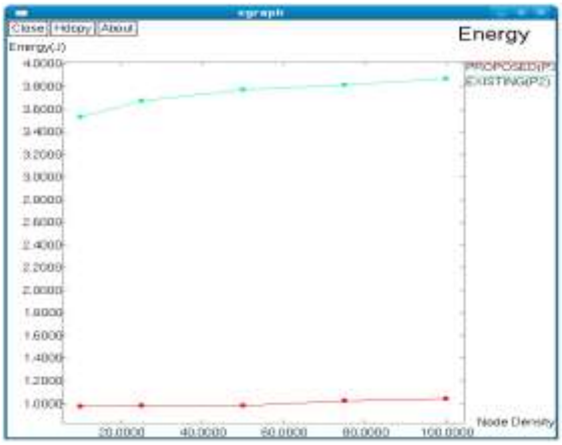

Fig. 5: Energy comparison

Fig. 5 illustrates the energy comparison for the existing and proposed methods. In x-axis denotes the Node density, and the y-axis denotes the Energy.

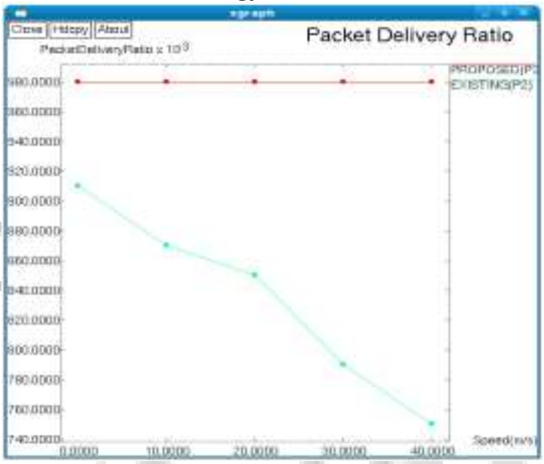

Fig. 6: Packet delivery ratio

Fig. 6 illustrates the packet delivery ratio comparison for the existing and proposed system. The X-axis denotes the delivery speed in milliseconds, and the y-axis denotes the PDR.

V. CONCLUSIONS

In this paper, we present TSUED for time synchronisation in UWSN delays. It makes advantage of ROS to prolong the network's life and gather data more effectively under adverse underwater circumstances. By integrating MSVM, Time estimation, and Linear Functions algorithms, the TSUED technique increases time efficiency. As a consequence, data transfer is much faster than with traditional JMLE approaches. An underwater sensor network would benefit from obtaining information about the ocean bottom in terms of danger alarms and reaction time. When utilised with an underwater sensor network, the experimental results indicate that TSUED outperforms existing techniques. In the future, the work will be expanded in two ways: 1) compare our architecture to various underwater mobility patterns, including one that incorporates vertical movement; and 2) analyse the effect of errors on supernode localization and velocity estimates, as well as MAC layer activities like packet loss and re-transmission.

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