International Journal of Advanced Information Science and Technology (IJAIST) ISSN: 2319:2682
Vol.4, No.9, September 2015 DOI:10.15693/ijaist/2015.v4i9.53-59

A Novel time synchronization Algorithm for mobile under water Wireless Sensor Networks

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Abstract— **Time synchronization is an important requirement for many services provided by distributed networks. A lot of time synchronization protocols have been proposed for terrestrial Wireless Sensor Networks (WSNs). However, none of them can be directly applied to Underwater Sensor Networks (UWSNs). A synchronization algorithm for UWSNs must consider additional factors such as long propagation delays from the use of acoustic communication and sensor node mobility. These unique challenges make the accuracy of synchronization procedures for UWSNs even more critical. Time synchronization solutions specifically designed for UWSNs are needed to satisfy these new requirements. This paper proposes Mobi-Sync, a novel time synchronization scheme for mobile underwater sensor networks. Mobi-Sync distinguishes itself from previous approaches for terrestrial WSN by considering spatial correlation among the mobility patterns of neighboring UWSNs nodes. This enables Mobi-Sync to accurately estimate the long dynamic propagation delays. Simulation results show that Mobi-Sync outperforms existing schemes in both accuracy and energy efficiency.**

*Index terms - **Time Synchronization, Mobi-Sync, UWSNs, Propagation delay, Distributed Networks. Acoustic Communication, Spatial correlation***

I. INTRODUCTION

In recent years, Underwater Sensor Networks (UWSNs) have gained significant attention from academic and industrial researchers due to the potential benefits and unique challenges posed by the water environment. UWSNs have allowed a host of applications to become both feasible and effective, including coastal surveillance, environmental monitoring, undersea exploration, disaster prevention, and mine reconnaissance. However, due to the high attenuation of radio waves in water, acoustic communication is emerging as the most suitable media. Several characteristics specific to underwater acoustic communications and networking introduce additional design complexity into almost every layer of the network protocol stack. For example, low communication bandwidth, long propagation delays, higher error probability, and sensor node mobility are concerns that must be confronted. This paper addresses the time synchronization problem, a critical service in any sensor network. Nearly all UWSN applications depend on time synchronization service. For example, data mining requires global time information, TDMA, one of the most commonly used Medium Access Control (MAC) protocols, often requires nodes to be synchronized.

Numerous time synchronization protocols for terrestrial Wireless Sensor Networks (WSNs) have been proposed in the literature . Their synchronization accuracy and energy efficiency for land-based applications is cogent. However, most of these approaches assume that the propagation delay among sensors is negligible. This is not the case in UWSNs, which suffer from the low propagation speeds of acoustic signals (roughly 1,500 m/s in water). Sensor node mobility also contributes to long and variable propagation delay in UWSNs. These additional complicating factors render previous approaches less suitable for adaptation to UWSNs. Furthermore, the batteries of underwater sensor nodes are difficult to recharge and it is often impractical to replace due to their relative inaccessibility. This lack of serviceability imposes even more stringent requirements. The UWSN will need to be energy efficient. This set of distinguishing characteristics introduces new challenges into the design of time synchronization schemes for UWSNs. There are various time synchronization algorithms already proposed for UWSNs, including TSHL, MU-Sync and D-Sync. These algorithms effectively address the long propagation delays. However, they all exhibit particular shortcomings, for example, TSHL is designed for static networks. Therefore, it does not consider sensor node mobility. MU-Sync confronts the mobility issue, but it is not energy efficient. D-Sync overlooks the effect of the skew when estimating the Doppler shift. To overcome the limitations of existing approaches, this paper proposes Mobi-Sync, a high energy efficient time synchronization scheme specifically designed for mobile UWSNs. The distinguishing attribute of Mobi-Sync is how it utilizes information about the spatial correlation of mobile sensor nodes to estimate the long dynamic propagation delays among nodes.

The time synchronization procedure consists of three phases: delay estimation, linear regression and Calibration. The underwater sensor network architecture is shown in fig: 1.

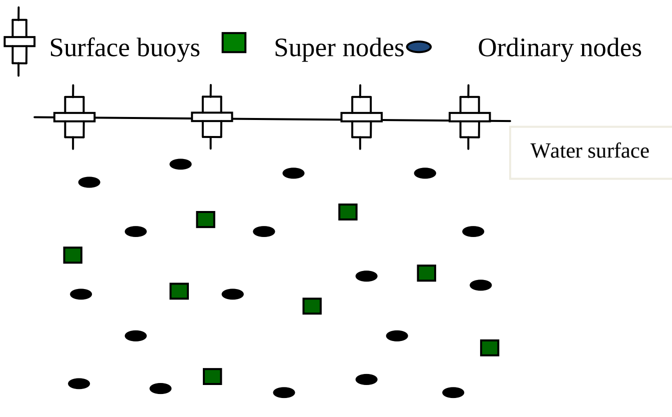


Fig: 1 Underwater sensor network architecture

The network consists of three types of nodes:

Surface Buoys: Surface buoys are equipped with GPS to obtain global time references and perform localization. They serve as the “satellite” nodes in underwater environment.

Super Nodes: Super nodes are powerful sensor nodes, working as reference clocks, as they always maintain synchronization with surface buoys. Moreover, super nodes can perform moving speed estimation as they can directly communicate with the surface buoys to obtain real time location and global time information.

Ordinary Nodes: Ordinary nodes are the sensor nodes aiming to become synchronized. They are inexpensive and have low complexity, cannot make direct contact with surface buoys and can only communicate with their neighboring ordinary nodes or super nodes. The lifetime of ordinary node is restricted by its limited battery supply.

A. Pair Wise Synchronization

In order to perform time synchronization for pairs of clocks, most existing algorithms rely on estimating the clock offset and skew, which present the relation between the times measured by two different clocks. In most cases, the time difference is captured by exchanging time-stamped packets, or “pings,” between nodes. Mobi-Sync also yields to this pair wise synchronization approach. In terms of time synchronization, an ordinary node is the clock aiming to get synchronized and a super node plays the role of the reference clock.

B. Spatial Correlation

Research in hydrodynamics shows that for certain underwater environments the movement of underwater objects exerts specific characteristics related to the surrounding environmental factors such as water current, pressure and water temperature. Generally speaking, there is no unified mobility model that can be applied for all underwater environments. However, some mobility models have been devised show that the movement of underwater objects is not in a totally random fashion. Temporal and spatial correlation is always inherent in such movement [14, 15].

Fortunately, this characteristic has a positive impact on Mobi-Sync as it can be used for an ordinary node to calculate its own moving velocity. In the network, each underwater node’s mobility behavior during a specific time period can be represented with a speed vector, V- [v(1), v(2); . . . , v(i); . . . ; v(k)]. Where v(i) is the average speed corresponding to a certain short time period. For each ordinary node, it cannot communicate with surface buoys, unlike super nodes. However, by taking advantage of sensor nodes spatial correlation characteristic, its moving velocity can be estimated as follows.[13].

Assuming an ordinary node j aims to compute its velocity [v_x (j), v_y (j)], where v_x (j)/v_y (j) denotes the current speed of node j in the x = y axis. If node j can obtain the velocities of its neighboring super nodes, its own velocity can be calculated as

$$v_x(j) = \sum_{i=1}^{m} \varsigma_{ij}\, v_x(i) \qquad \text{---[1]}$$

$$v_y(j) = \sum_{i=1}^{m} \varsigma_{ij}\, v_y(i) \qquad \text{---[2]}$$

II. Related Work

Underwater sensor nodes will find applications in oceanographic data collection, pollution monitoring, offshore exploration, disaster prevention, assisted navigation and tactical surveillance applications. Moreover, unmanned or autonomous underwater vehicles (UUVs, AUVs), equipped with sensors, will enable the exploration of natural undersea resources and gathering of scientific data in collaborative monitoring missions. Underwater acoustic networking is the enabling technology for these applications. Underwater networks consist of a variable number of sensors and vehicles that are deployed to perform collaborative monitoring tasks over a given area. In this paper, several fundamental key aspects of underwater acoustic communications are investigated. Different architectures for two-dimensional and three-dimensional underwater sensor networks are discussed, and the characteristics of the underwater channel are detailed. The main challenges for the development of efficient networking solutions posed by the underwater environment are detailed and a cross-layer approach to the integration of all communication functionalities is suggested. [1]

Large-scale mobile Underwater Wireless Sensor Network (UWSN) is a novel networking paradigm to explore aqueous environments. However, the characteristics of mobile UWSNs, such as low communication bandwidth, large propagation delay, floating node mobility, and high error probability, are significantly different from ground-based wireless sensor networks. The novel networking paradigm poses inter-disciplinary challenges that will require new technological solutions. In particular, in this article the authors adopt a top-down approach to explore the research challenges in mobile UWSN design. Along the layered protocol stack, they roughly go down from the top application layer to the bottom physical layer. At each layer, a set of new design intricacies are studied. The conclusion is that building scalable mobile UWSNs is a challenge that must be answered by inter-disciplinary efforts of acoustic communications, signal processing and mobile acoustic network protocol design.[2]

Underwater sensor networks have many potential applications, including seismic monitoring, equipment monitoring and leak detection, and support for swarms under water robots. In this paper, they briefly consider seismic imaging of undersea oilfields as a representative application. One major reason to choose this application is that underwater sensor network is able to provide significant economic benefits over traditional technology. Today, most seismic imaging tasks for offshore oil fields are carried out by a ship that tows a large array of hydrophones on the surface. The cost of such technology is very high, and the seismic survey can only be carried out rarely, for example, once every 2-3 years. In comparison, sensor network nodes have very low cost, and can be permanently deployed on the sea floor. Such a system enables frequent seismic imaging of reservoir (e.g. once every 3 months), and helps to improve resource recovery and oil productivity. [3]

In this paper, the localization problem in large-scale underwater sensor networks is studied. The adverse aqueous environments, the node mobility, and the large network scale all pose new challenges, and most current localization schemes are not applicable. The authors proposed a hierarchical approach which divides the whole localization process into two sub-processes: anchor node localization and ordinary node localization. Many existing techniques can be used in the former. For the ordinary node localization process, we propose a distributed localization scheme which novelty integrates a 3-dimensional Euclidean distance estimation method with a recursive location estimation method. The proposed solution can achieve high localization coverage with relatively small localization error and low communication overhead in large-scale 3-dimensional underwater sensor networks is proved through simulation. [4]

The authors presented a novel algorithm to automatically determine the relative 3D positions of sensors and actuators in an ad-hoc distributed network of heterogeneous general purpose computing platforms such as laptops, PDAs and tablets. A closed form approximate solution is derived using the technique of metric multidimensional scaling, which is further refined by minimizing a non-linear error function. The errors in localization due to lack of temporal synchronization among different platforms is accounted in this paper.
The theoretical performance limit for the sensor positions is derived via the Cramer-Rao bound ´and analyzed with respect to the number of sensors and actuators as well as their geometry.[5,6]

In the literature, there are various time synchronization protocols for distributed systems like terrestrial radio sensor networks, in which ordering of events is crucial. A landmark paper in computer clock synchronization is Lamport’s work that elucidates the importance of virtual clocks in systems where causality is more important than absolute time. It has emerged as an important influence in sensor works, in which many applications only require relative time instead of absolute time. The Network Time Protocol (NTP) is a widely used hierarchical protocol implemented to synchronize clocks in large networks like the Internet. NTP provides accuracy in the order of milliseconds by typically using GPS to achieve synchronization to external sources that are organized in levels called stratums. However, in underwater sensor networks, GPS may not be available for all the scenarios. Additionally, one-way delay estimated as one half of the round trip transit time brings significant errors due to the long propagation delay in UWSNs [10, 11].

Reference Broadcast Synchronization (RBS) is a well-known receiver-receiver synchronization algorithm. It completely kills errors that derive from the sender side, and it adopts the concept of post facto synchronization, allowing the time synchronization process to happen after data collection rather than ahead of time. However, RBS requires extra message exchange to communicate the local timestamps between any two nodes which intend to become synchronized.
The major idea of the RBS algorithm greatly depends on immediate reception of reference messages. Timing-sync Protocol for Sensor Networks (TPSNs is a sender-receiver time synchronization which employs a two-way message exchange for synchronization. Although TPSN takes care of propagation delays, it does not take the clock skew into account during synchronization period. Instead, it only computes offset, which severely limits its accuracy[7,8].

A. Need of Acoustic Communication In Underwater WSN

Underwater acoustic communication is a technique of sending and receiving message below water. There are several ways of employing such communication but the most common is using hydrophones. Under water communication is difficult due to factors like multi-path propagation, time variations of the channel, small available bandwidth and strong signal attenuation, especially over long ranges. In underwater communication there are low data rates compared to terrestrial communication, since underwater communication uses acoustic waves instead of electromagnetic waves [12,16].

Table 1: Difference between Underwater WSN Geographic Based WSN

Underwater WSN	**Geographic WSN**
Long propagation delay	Short propagation delay
Consists of moving or dynamic sensor nodes	Consists of static sensor nodes
Acoustic waves are used	Electromagnetic waves are used
Min Bandwidth	Max Bandwidth
Low data rate	High data rate

III. METHODOLOGY

The time synchronization procedure consists of three phases: delay estimation, linear regression and calibration. The propagation delay estimation performed in two steps, message exchange and delay calculation. In the message exchange step, an ordinary node launches time synchronization by broadcasting a request message. Upon receiving the request message, each neighboring super node schedules two response messages. These response messages contain the recorded velocity vector of the super node and its MAC layer time stamp. In the delay calculation step, by making a reasonable assumption, the ordinary node self-computes its velocity vector by utilizing spatial correlations contained in the velocity vectors of the neighboring super nodes[9]. The ordinary node continues to broadcast request messages until it obtains enough data points to perform linear regression. The ordinary node executes the first round of linear regression with a set of time stamps received from the super nodes and the corresponding propagation delays. This provides an estimate of the draft clock skew and offset. This regression employs an advanced Weighted Least Squares Estimation (WLSE) procedure to reduce the impact of the assumption.

Further improve the synchronization accuracy, the ordinary node updates certain initial parameters such as initial skew and initial distance, and recalculates the delay and re-performs the linear regression to obtain the final clock skew and offset. To further improve the synchronization accuracy, the ordinary nodes update certain initial parameters, specifically initial skew and initial distance. Delay calculation is performed again and a second round of linear regression obtains the final clock skew and offset estimates.

A. Proposed System

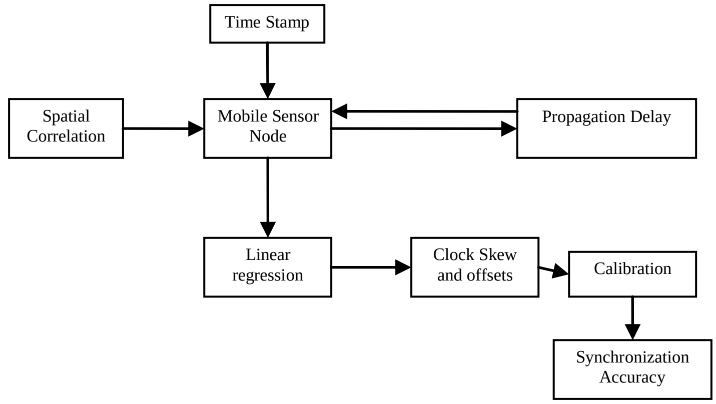


Fig:2 Steps involved in Time Synchronization Algorithm

IV. RESULT ANALYSIS

Output for simulation between a few pair of nodes is shown in the pictures below as an example. for carrying out the process , first the program is run in the cygwin and NS2 module. When the execution starts, it will ask the user for the source and the destination node number for the transfer of packets. After running the simulation, the propagation delay, linear regression will be calculated. The figure shows Propagation delay is 0. ms, the linear regression value is 32.22 and the calibration output is 0.0190 ms. The figure shows Propagation delay is 0.299 ms, the linear regression value is 52.184 and the calibration output is 0.132 ms.

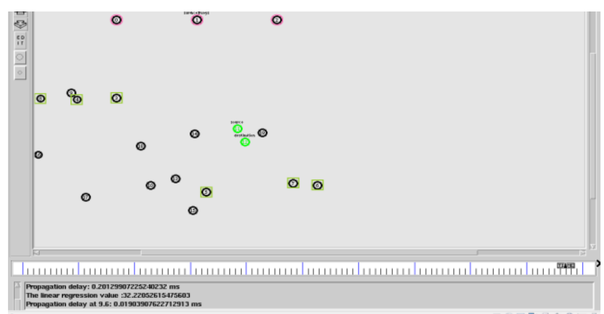


Fig: 3 Output for source node 13 and destination node 15

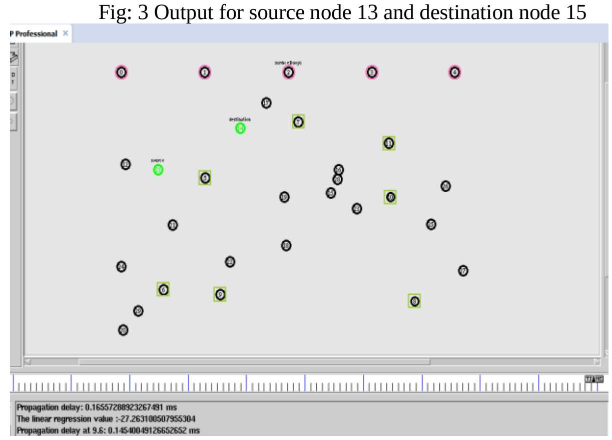


Fig:4 output for source node 13 and destination node 14

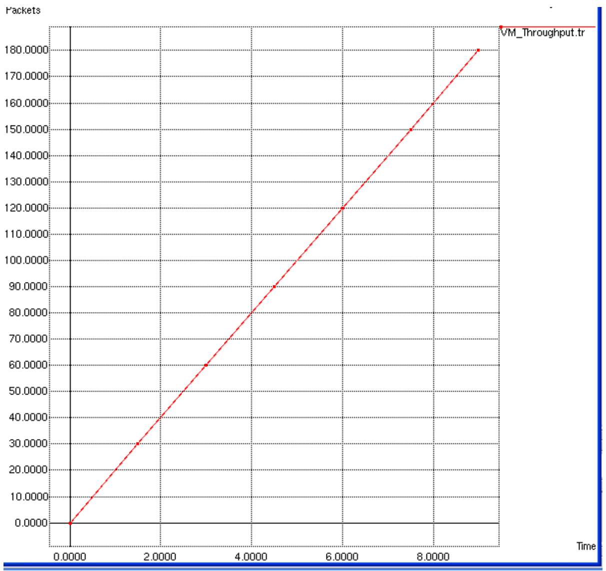
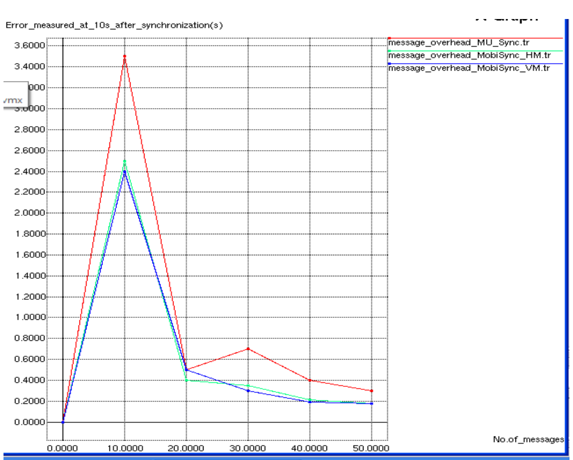


Fig: 5 Throughput performance for 30 nodes

Table :2 Throughput

TIME(ms)	NO OF PACKETS
2	40
4	80
6	120
8	160

Fig:6 Message overhead for 30 nodes



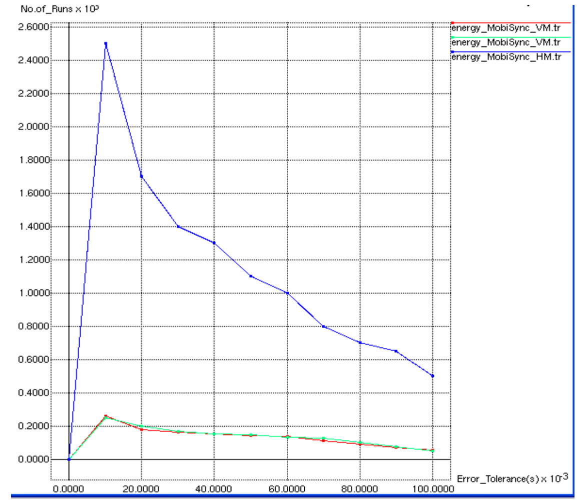


Fig:7 Energy mobi sync for 30 nodes

Fig:8 Accuracy for 30 nodes

TABLE: 3 Mobi-sync accuracy and MU sync accuracy

Initial skew x 10^{-3}(ppm)	Mobi sync Accuracy	MU sync Accuracy
900	8	4
920	5.5	4.5
940	3.9	2.8
960	3	2.7
980	4	2.9

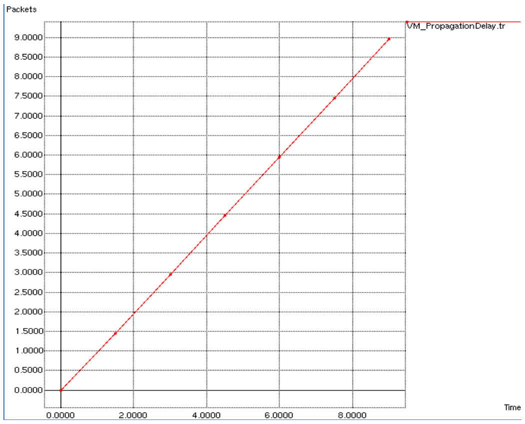


Fig: 9 Propagation delay for 30 nodes

TABLE: 4 Propagation Delay

TIME(ms)	PACKETS
2	2
4	4
6	6
8	8

V. CONCLUSION

This paper presents Mobi-sync, a time synchronization scheme for mobile UWSNs. Mobi-sync is the first time synchronization algorithm to utilize the spatial correlation characteristics of underwater objects, improving the synchronization accuracy as well as the energy efficiency. the simulation results show that this new approach achieves higher accuracy with a lower message overhead.

VI. FUTURE WORK

In the future, the work will be extended in two directions:

1) Explore other underwater mobility patterns, including one that involves vertical movement to examine the suitability of our design

2) Investigate the influence of errors on super node localization as well as velocity estimation, and also the influence on MAC layer activities such as packet loss and re-transmission.

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