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An Optimized Time Synchronization Algorithm for Mobile Submarine Sensor Networks

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Abstract : Communication in submarine requires synchronization of nodes present in the network. Lot of time synchronization protocols have been proposed for wireless sensor networks in land cannot be directly applied to Underwater (Submarine) Sensor Networks (UWSNs). A synchronization method for UWSNs requires the consideration of some factors such as propagation delays and mobility of nodes.

This paper proposes a new scheduled synchronization algorithm for mobile undersea sensor networks. Novel time synchronization scheme with the use of mobile sync algorithm distinguishes itself from

former approaches by considering the vertical mobility and the spatial correlation among the sensor nodes in the networks.

***Keywords* :** Synchronization, vertical mobility, spatial correlation.

1. INTRODUCTION

Time synchronization is very important in undersea sensor networks for sleep scheduling, localization, and time stamping of sensor nodes in the network. In this article, the sensor nodes in the networks are to be synchronized in time by the use of propagation delay and the value of spatial correlation. The radio waves used for communication in terrestrial wireless sensor network are not suitable for UWSNs due to high attenuation rate in water, large antenna requirement and the demand of high transmission power. So, in submarines, acoustic signal is used for communication. In underwater sensor networks, the nodes move 1-3 m due to water current and in deep water, spherical waves are used.The size of the sensor used for UWSNs is large. These sensor nodes are electrified by the kinetic energy. Time synchronization plays an important role to use the energy efficiently. Typical travel time between the nodes are of many orders of magnitude larger than in RF networks and latency is one of the key factors in acoustic networks. The propagation delay is long and it is also highly variable when moving nodes are present in the network. When there are only stationary nodes, the propagation delay varies by a few percent throughout the seasons. Energy efficiency is an important design criterion, as the energy consumption of acoustic modems is generally in the range 1 – 100 watts during transmission. The recovery of underwater sensor nodes for battery recharge is an expensive process and modems are also a major burden for the limited battery capacity elements.

2. RELATED WORK

A number of time synchronization protocols have been proposed for earthly wireless sensor networks. They cannot be applied to UWSNs because most of them assume negligible propagation delay among sensor nodes whereas in UWSNs propagation delay plays an important role. In the Doppler based method, the synchronization is done based on the Doppler shift in underwater produced by the nodemovement. In D-sync the nodes are synchronized to a single beacon node within their transmission range. At high mobility, the performance is good and the error rate is small as network size increases. It avoids frequent resynchronization. Error is occurred in this

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process due to the Doppler measurements, which is not in continuous manner. MU-sync is a time synchronization method used in a cluster based UWSNs. It employs two ways of messaging to estimate the offset and skew and runs linear regression twice in order to estimate clock skew and offset. The main aim of this protocol is to minimize the drift between the nodes. The drift is evaluated in two phases. They are skew and offset acquisition phase and the synchronization phase. Since it uses large number of two way messages, it is not an e nergy efficient scheme. TSHL is designed for high latency networks to deal long propagation delays with efficient energy. In this synchronization, the protocol is designed with two phases. It introduces the post-facto synchronization, where correction of errors is allowed after data collection. It makes an assumption in which the distance and the propagation delay are considered to be constant and performs well for static networks. The performance of TSHL is poor, when the nodes move fast. Time synchronization scheme is proposed for undersea sensor networks. It is a pairwise synchronization method which effectively utilizes the Doppler effects and the relative speed of the transmitter and receiver to improve the propagation delay estimation. The frequency of resynchronization is determined by skew estimation accuracy. It uses kalman filter to improve the accuracy of propagation delay estimation in time synchronization.

3. SYSTEM SPECIFICATION

The architecture of submarine sensor networks consists of three types of sensor nodes. Each sensor node has a radio transceiver, antenna,microcontroller, an electronic circuit for interfacing with the sensors and an energy source, and a battery. The different types of sensor nodes are:

Surface buoys : Surface buoys are the nodes which are placed above the water with location tracker (Global Positioning System) to obtain global time references and perform localization. They behave as the satellite nodes in underwater environment.

Supernodes : Super nodes are powerful sensor nodes, which maintain synchronization with surface buoys. Moreover, super nodes can execute moving speed estimation as they are directly interfaced with the surface buoys to obtain real time location and global time information. These super nodes are unique as they are the only nodes that can communicate with both surface buoys and the ordinary nodes.

Ordinary nodes : Ordinary nodes are the sensor nodes aiming to achieve synchronization. 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

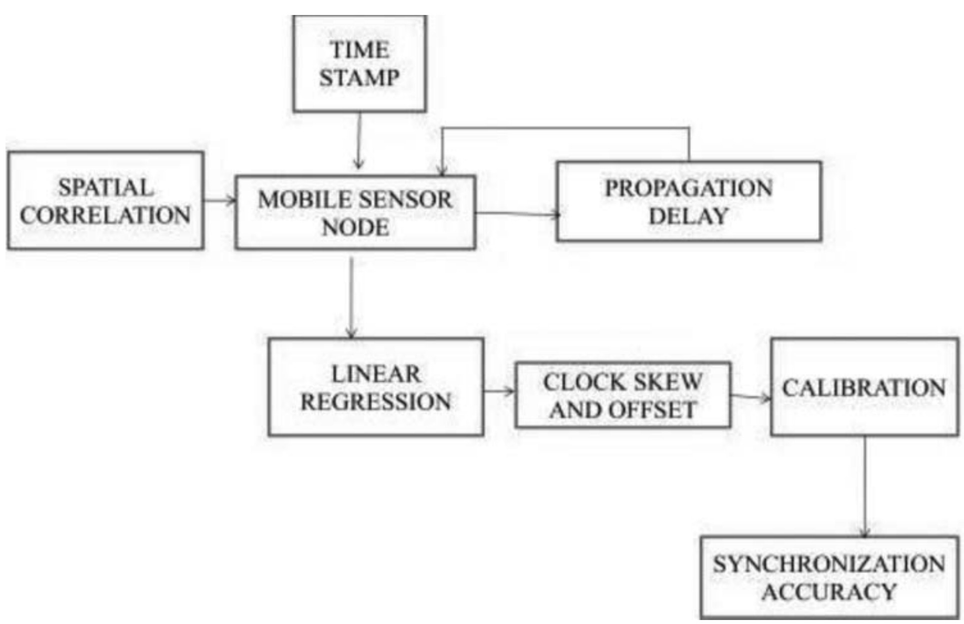


Fig. 1. Time synchronization algorithm

To evaluate the performance of the new time synchronization method, the system specification is made as follows. In the × simulation, 10 super nodes and 30 regular sensor nodes are randomly deployed once in every 100m region. One ordinary node is randomly picked as the sample node and it wishes to synchronize with its neighboring super nodes. Without loss of generality, the inherent skew of this ordinary node is defined as 50 ppm, and it remains unchanged ×10 during the time of synchronization. The clock offset of this ordinary node is initialized as 0.8 seconds and the propagation speed of an acoustic signal in underwater is about 1500 m/s and it remains constant.

4. METHODOLOGY

In this novel time synchronization method, the synchronization procedure consists of three steps. They are:

1. Delay estimation
2. Linear regression
3. Calibration.

De lay Es timation

Estimation of propagation delay can be performed in two steps :

1. Message exchange
2. Delay calculation

In the message exchange step, an ordinary node launches time synchronization by broadcasting a request message. After receiving the request message, each neighboring super node schedules two response messages. These response messages have the recorded velocity vector of the super node and its MAC layer time stamp. Propagation delay is explained as the length of time taken for the packet to reach its destination from the source.

The propagation delay is calculated by the expression,

Propagation de lay = *d*/speed of sound (ms)

Where, *d* is the distance between the source and destination and Speed of sound is 1500 m/s.

Linear Regression

Linear regression is the method employed to find the relationship between two variables. In this step the ordinary node performs the first round of linear regression with a set of time stamps received from the super nodes and their respective propagation delays. This provides an estimate of the draft clock skew and offset. The regression uses an advanced Weighted Least Squares Estimation (WLSE) procedure to diminish the impact of the assumption in delay estimation.

The linear regression can be calculated using the following expression,

$$\text{Linear regression } (y) = a + bx$$

Where, a is intercept, b is slope and x is the calculated propagation delay.

Spatial correlation interprets the relationship between the nodes in spatial domain. The propagation delay is calculated again with the help of linear regression value by using the spatial correlation between the nodes.

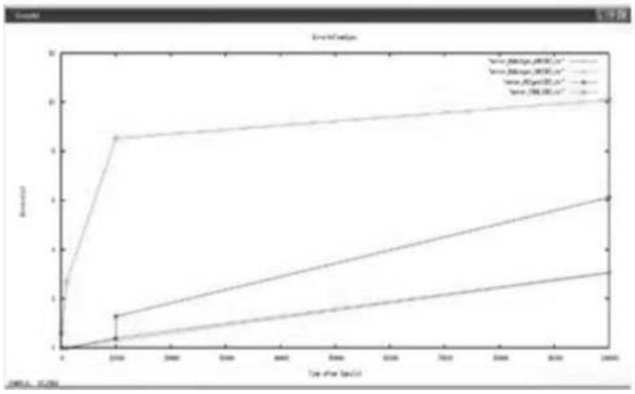
Calibration

In order to ameliorate the accuracy of synchronization, the ordinary node upgrades certain initial parameters such as initial skew and distance. Then it calculates the delay and performs the linear regression to acquire the final skew and offset.

5. SIMULATION RESULTS

Simulation of submarine acoustic networks is a relatively recent area and it can be simulated by using Aqua sim. Aqua sim is developed on the basis of NS2 where it can effectively simulate acoustic signals. Further, it also supports three dimensional deployments and can be easily integrated with the existing codes present in NS2.

The above graphs exhibit the analysis of the undersea sensor networks for different algorithms used for time synchronization. The comparison graph shows that the error and the message overhead occurred in the proposed method are minimal than the previous methods and the precision of time synchronization is improved in novel time synchronization method. i.e. the new method performs the time synchronization on the nodes which travels vertically in the sensor networks and achieves high accuracy with low message overhead and error.



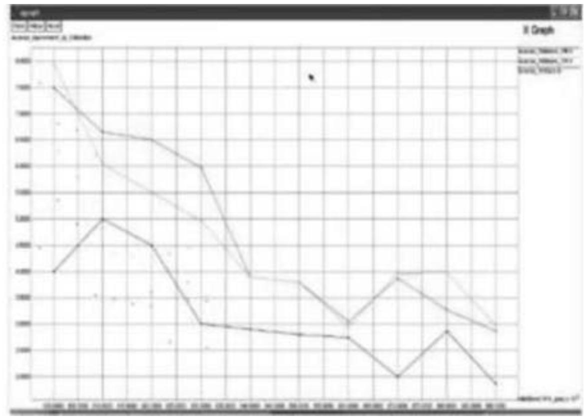


Fig. 2. Error analys is Fig. 3. Accuracy

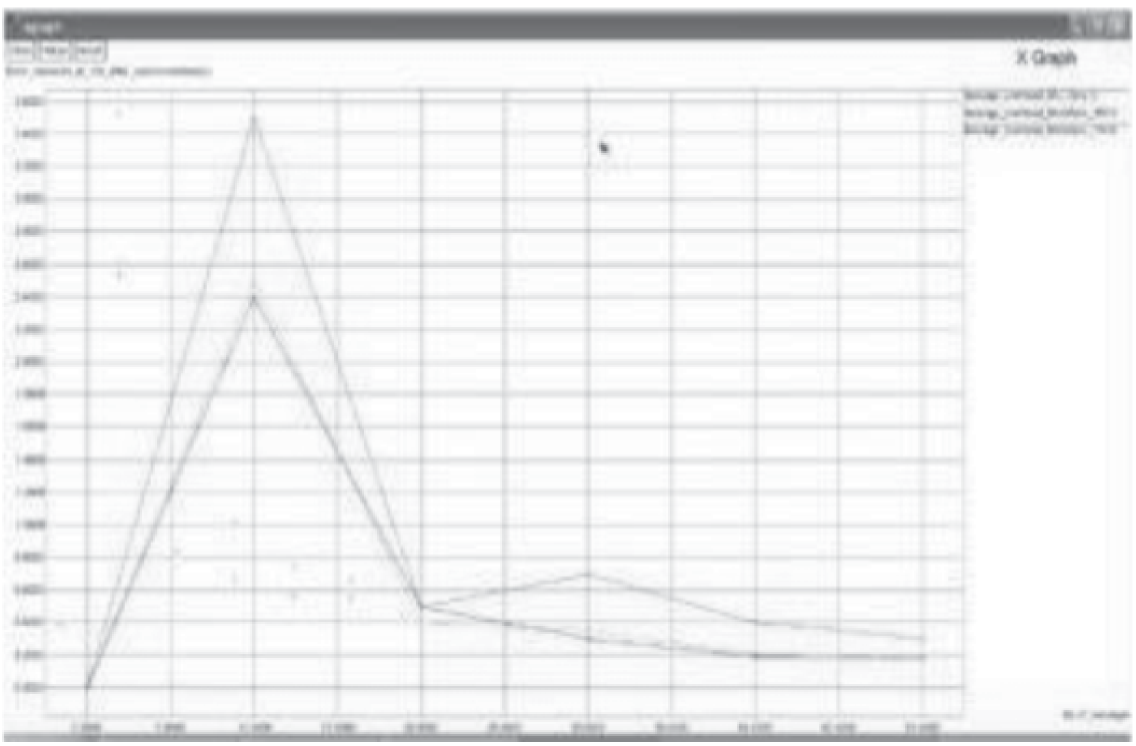


Fig. 4. Message overhead

6. CONCLUSION AND FUTURE WORK

This paper presents a novel time synchronization method for mobile submarine sensor networks which considers the spatial correlation and the vertical movement of the nodes in the network. From the simulation results, it can be seen that this new approach results in high accuracy with low error and low message overhead. Also, this method is used for the communication between different layers in the undersea sensor networks. In the future, this work can be further extended to analyze the influence of errors on super node localization as well as velocity estimation.

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