Innovative Routing and Time Synchronization in Underwater Sensor networks

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Abstract: Time synchronization plays a critical role in distributed network system. Here, we investigate the routing and time synchronization problem in the context of underwater sensor networks (UWSN's). There are many time synchronization and routing protocols designed for terrestrial wireless sensor networks, but they cannot be directly applied on UWSN's because most of these protocols do not consider long propagation delays, configuration of nodes and sensor node mobility which contributes to the performance and scalability of the system. To overcome this we implement a new time scheduling and routing scheme for mobile UWSN's. We employ a DSR based Depth Based Routing approach for transmission of packets, which achieves very high packet delivery ratio. Then we propose a framework to estimate the Doppler shift caused by mobility, to refine the relative velocity estimation and to enhance the accuracy of the synchronization Kalman filter is employed. Finally, through simulation we show the energy efficiency of the proposed method.

Key Words: Time Synchronization, Underwater sensor networks, Doppler's shift, Kalman filter.

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Introduction:

Underwater sensor networks (UWSNs) facilitate or enable a wide range of aquatic applications, including coastal surveillance, environmental monitoring, undersea exploration, disaster prevention, and mine reconnaissance. However, due to the high attenuation of radio waves in water, UWSNs have to rely on acoustic communications. The unique characteristics of underwater acoustic communications and networking, such as low available bandwidth, long propagation delays, high error probability, and sensor node (passive or proactive) mobility (in mobile networks) pose grand challenges to almost every layer of network protocol stack and applications. We tackle the time synchronization and routing problem, which is critical to many UWSN design issues.

Furthermore, acoustic transmissions are power demanding, which requires high energy efficiency. All of these features in UWSNs bring new challenges for time synchronization algorithms. Recently, sometime synchronization algorithms, such as TSHL, MU-Sync, Mobi-Sync, and D-Sync have been proposed for UWSNs along with few routing techniques such as flooding technique, cluster based routing technique and multipath techniques

We propose a novel routing and time-synchronization scheme, which is a fundamental cross-layer-designed time-synchronization protocol specific for mobile UWSNs, with high accuracy and high energy efficiency as its major design goals. For routing we deploy a Depth Based routing protocol, which behaves like greedy algorithm.

2. Related work:

2.1 Routing protocols:

Routing Protocols for Under Water Sensor Networks: Major Routing Protocols Proposed for Underwater acoustic Sensor Networks are below:-

- **Vector Based Forwarding (VBF)**: - In VBF [1], for handling the problems of packet losses and node failures the data packets are forwarded along redundant and interleaved paths from the source to the destination. It is assumed that every node already knows its location and each packet carries the location of all nodes involved.
- **Hop by Hop vector Based Forwarding (HH-VBF):-** In this virtual concept is used [2]. Each forwarder is defined by per hop virtual pipe. Based on its current location,

every intermediate node makes decisions about the pipe direction. In HH-VBF the routing vector from each sender towards the destination is computed. Upon the receipt of a packet, a node computes a destination. Then the node calculates the distance between the computed vector and itself.

- **Focused beam routing (FBR)**:- This protocol [3] for acoustic sensor networks are intended to avoid unnecessary flooding of broadcast queries. In FBR, every node in the network is expected to be aware of its location and every source node is aware of its destination.
- **Reliable and energy balanced routing algorithm (REBAR)**:- It is a location based protocol [8]. Geographic information is used by the nodes between the sources and sinks to transfer the data. Each node is assigned a unique ID and fixed range REBAR is based on the following assumptions. Every node knows its location and of the destination through multi-hop routing.
- **Sector –based routing with destination location prediction (SBR-DLP)**:- SBR-DLP tries to achieve destination mobility by assuming that all pre planned movements are known to all nodes before the deployment. The sender decides which will be its next hop using information from the candidate nodes trying to eliminate the problem of having multiple nodes acting as relay nodes.
- **Direction flooding based Routing (DFR)**:- This Protocol enhances reliability by packet flooding technique. The assumption is that all nodes know about its own location, location of one hop neighbours and that of the final destination. This protocol enhances reliability by packet flooding technique
- **Location aware source Routing (LASR)**: - In this protocol two techniques are adopted for handling high latency of acoustic channels [13], namely link quality metric and location awareness. All the network information including routes and topology information are passed on in the protocol header. Resultantly header size increases as the hop count between source and sink increases.

2.2 Time synchronization techniques:

MU-Sync: MU-Sync design avoids frequent re-synchronization by estimating both the clock skew and offset. As underwater mobile networks experience both time-varying and long propagation delay, previous works that estimate the clock skew using a single least square error linear regression tend to be inaccurate. In the MU-Sync, the clock skew is estimated by performing the linear regression twice over a set of local time information gathered through message exchanges. The first linear regression enables the cluster head to offset the effect of long and varying propagation delay; the second regression in turn obtains the estimated skew and offset. With the help of MAC-level time stamping, we can further reduce the nondeterministic errors that are commonly encountered by those synchronization algorithms that rely on message exchanges. For example, the sensor may miss an interrupt while busy transmitting or receiving a packet, as described in.

In future work, emphasis on how the varying propagation delay can be estimated more accurately, while maintaining low overhead results in better time synchronization algorithm.

Mobi-Sync: UWSNs have high requirements in network lifetime and synchronization accuracy. To satisfy these needs, innovative time synchronization solutions are demanded. This paper proposes a time synchronization scheme, called “Mobi-Sync”, for mobile underwater acoustic sensor networks. It utilizes the spatial correlation of underwater mobile sensor nodes to estimate the long dynamic propagation delays. TSHL is designed for high latency networks, which can manage long propagation delays and remain energy efficient. TSHL combines one-way and two-ways MAC-layer message delivery. One-way communication is used to estimate the clock skew and two-ways is to compute clock offset. TSHL works well for static underwater sensor network, but performs even worse than no time synchronization as described in with mobile nodes. MU-Sync is proposed to synchronize nodes in a cluster based UWSN. MU-Sync runs two times of linear regression. Although this aims to solve mobility issue in UWSNs, it requires relative high message overhead. Mobi-Sync is the first time synchronization algorithm which does not suffer but benefit from sensor node mobility and it is also the first one which resorts to geometry knowledge to do time synchronization. Mobi-Sync also yields to this pairwise synchronization approach. In the future, one can investigate other approach to estimate node moving velocity and further examine how the accuracy of Mobi-Sync will be affected.

D-Sync: Large propagation delay and substantial mobility are the challenges faced by the UWSN's during the synchronization process. Existing sync solutions address these challenges; they rely on heavy signaling, which is undesirable due to high energy costs. This paper introduces an approach that incorporates the estimate of the Doppler shift. Large Doppler shift has been identified as a major challenge to underwater communication, and current systems implement sophisticated solutions to estimate and track such Doppler shift for each data exchange. Specifically, it provides an indication of the relative motion between nodes. A new protocol, D-sync, strategically exploits this feature to address the timing uncertainty due to node mobility. It does not make any assumption about the underlying motion model nor does it require the motion correlation statistics of nodes for time synchronization. In addition, for Mobi-Sync [14], the network has to be densely deployed to ensure that each ordinary node maintainsconnectivity to at least three or more super nodes in order to have a good estimate of velocity.

3. Description of D-DBR Sync:

3.1 Overview of D-DBR Sync

D-DBR Sync (Doppler-Depth Based Routing) is an innovative technique for energy efficient communication in underwater. D-DBR Sync uses cross layered approach and provides a fundamental way for synchronizing the nodes in the network. In this technique we deploy five phases namely Information Gathering Phase, Velocity Estimation Phase, Delay Estimation Phase, linear regression and Routing.

Initially in the Information gathering phase node initiate synchronization messages to its neighboring nodes and record information regarding time-stamps and velocity (v_0 and v_1) with respect to each node. Then in phase 2, using Kalman filter the refined relative velocity (V_R) is obtained from the estimated velocity (v_0 and v_1) and it predicts the future state of nodes. In phase 3 delay estimation is done wherein we calculate 2 delays (D_1 and D_2) which is essential in mobile scenarios. Output of these phases provides us a relative velocity (V_R) and time stamp (T_S) values, further to obtain a single accurate value of time stamp linear regression procedure is used. By using (V_R) and (T_S) the nodes will be time synchronized.

Finally routing of the packets is done by employing DBR protocol.

Phase I: Information Gathering Phase

In the beginning, an ordinary node initiates message exchanges by sending a "Sync-Req" message to a neighbouring reference node. The ordinary node records the sending time stamp T1, obtained at the MAC layer, right before the message leaves. Upon receiving the Sync-Req message, the reference node estimates and records the ordinary node's relative moving velocity v0 with Doppler shifts as specified in Section 3. Meanwhile, it marks its local time as t2. Then, after a time interval tr (waiting for the hardware sending- receiving transition and avoiding collisions), the reference node sends back a "Sync-Res" message which contains t2, v0 and its sending time t3. When receiving the Sync-Res message, the ordinary node records its receiving time T4 and its relative moving velocity to the reference node, v1. Fig. 5.3 shows the message exchange process between the ordinary node and the reference node. After a couple of rounds of message exchange, the ordinary node collects a set of time stamps consisting of T1, t2, t3, andT4 and relative velocities consisting of v0 and v1.

Phase II: velocity estimation phase

Using the Kalman filter we refine the velocity that is obtained from the phase1 and eliminate the noise.Kalman filtering is used for many applications including filtering noisy signals, generating non-observable states, and predicting future states. Filtering noisy signals is essential since many sensors have an output that is too noisy too be used directly, and Kalman filtering lets us to account for the uncertainty in the signal/state. One important use of generating non-observable states is for estimating velocity. To fix this Kalman filtering can be used to estimate the velocity. Another nice feature of the Kalman filter is that it can be used to predict future states. This is useful when you have large time delays in your sensor feedback as this can cause instability in a motor control system.

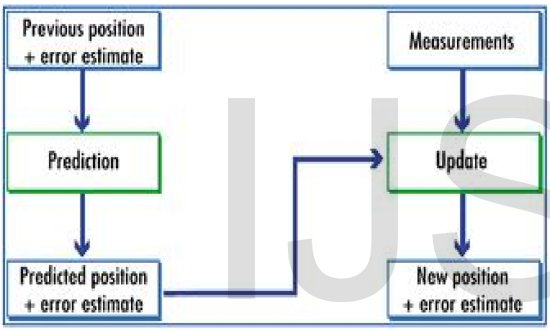

Figure 3.1: Kalman filter

Phase III: Delay estimation:

Phase III aims to estimate the long and dynamic propagation delays. In this, two propagation delays need to be estimated, i.e., D1 and D2. In terms of delay estimation, many other time synchronization protocols take half of the two-way round trip time as one-way propagation delay, which means that D1 is equivalent to D2. In this method, by leveraging relative moving velocities obtained from the physical layer, we can differentiate D1 and D2, which is required in mobile scenarios. Regarding the velocity, in Time-Sync, only one dimension is considered. That is because, to estimate the propagation delay, only the relative velocity is demanded. The amazing thing is that the velocity estimated by utilizing the Doppler scaling factor is exactly what is needed, i.e., the relative velocity. Therefore, the velocities obtained from the physical layer can be directly applied in the proposed method.

Phase IV: Linear Regression:

Phase IV aims at obtaining final time stamp value by performing a linear regression on the time stamp values gathered during phase I.

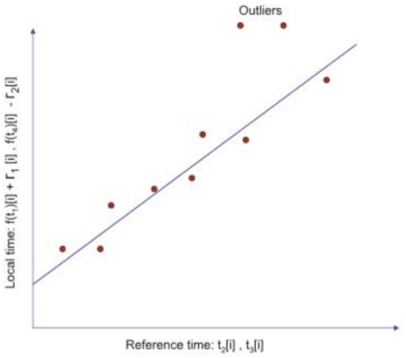

Figure 5.4: Linear regression

There are several ways to perform linear regression. Ordinary least- squares estimation (OLSE) is one of the most popular approaches. Essentially, it makes each sample point have the same opportunity to affect the estimating value. Therefore, in Fig. 5.4 the variance of residual error should not be constant for all values of the independents, and it is possible that in some extremely bad cases, sample points are far away from what are expected. To reduce the impacts from those outliers, besides OLSE, WLSE is also adopted. WLSE is an approach for correcting the problem of heteroskedasticity by log-likelihood estimation of a weight that adjusts errors of prediction. It performs better than OLSE because it introduces an extra functional coefficient "weight" to module the power of each sample data.

Phase V: Routing and Transmission:

DBR is a greedy algorithm that tries to deliver a packet from a source node to sinks. During the course, the depth of forwarding nodes decreases while the packet approaches the destination. If we reduce the depth of the forwarding node in each step, a packet can be delivered to the water surface (if no "void" zone is present). In DBR, a sensor node distributive makes its decision on packet forwarding, based on its own depth and the depth of the previous sender. This is the key idea of DBR.

In DBR, upon receiving a packet, a node first retrieves the depth $d_p$of the packet's previous hop, which is embedded in the packet. The receiving node then compares its own depth d_c with d_p. If the node is closer to the water surface, i.e., $d_c < d_p$, it will consider itself as a qualified candidate to forward the packet. Otherwise, it just simply drops the packet because the packet comes from a (better) node which is closer to the surface. It is not desirable for the receiving node to forward the packet.

It is very likely that multiple neighboring nodes of a forwarding node are qualified candidates to forward a packet at the next hop. If all these qualified nodes try to broadcast the packet, high collision and high energy consumption will result. Therefore, to reduce collision as well as energy consumption, the number of forwarding nodes needs to be controlled. Moreover, due to the inherited multiple-path feature of DBR, a node may receive the same packet multiple times.

Conclusion and Future enhancement

Time synchronization is essential in order to provide an effective quality of service, i.e., data from the source node to the destination has to be sent without any packet loss or jitter. The existing system used for time synchronization have several drawbacks such as inaccurate velocity estimation, message overhead, packet loss and less energy efficient.

Our proposed system uses Kalman filter along with the Depth based routing protocol to overcome issues of existing system. This approach can achieve high accuracy with low message overhead, energy efficient and less packet loss guarantees the timely and efficient delivery of packets and reduces the nondeterministic errors that are commonly encountered by time synchronization algorithms which rely on message exchanges.

In future, one can work on implementing a protocol which can reduce the delay obtained in the present system during request packets transmission.

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