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Low-complexity time synchronisation for 3-dimensional underwater communications environment using estimated instantaneous node velocity ☆

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A B S T R A C T

Underwater time synchronisation is required to use the latest communication technologies. Because propagation time should be estimated to improve time synchronisation accuracy, node mobility is an important factor. In the subaqueous environment, furthermore, it is impossible to exclude the influence of the node movement occurred by environmental factors and underwater nodes could have self-mobility. Conventional time synchronisations have considered node mobility but have an unrealistic assumption of node movement and high computational complexity. In this paper, however, our novel method, Low-complexity time synchronisation for 3-dimensional underwater communications environment using estimated instantaneous node velocity based (V-Sync), shows high accuracy with low complexity and short processing latency. In this paper, it is supposed that mobile nodes could know their instantaneous speeds when they receive the synchronising messages. Time synchronisation errors, skew and offset, are estimated by the instantaneous speeds. The performance and analysis of V-Sync in the underwater mobile environment is demonstrated by simulation results.

1. Introduction

Time synchronisation should be processed first for using advanced technology of underwater wireless communications. However, the conventional terrestrial time synchronisation schemes [1–4] are not appropriate. The reason is that the electromagnetic wave cannot be applied for underwater wireless communications since it is easily absorbed and attenuated in water. For that reason, sound waves have been used instead of electromagnetic waves. However, it makes much more difficult to synchronise time in subaqueous environment due to long propagation delay of the sound waves. The first underwater time synchronisation scheme, which considers the long propagation delay, is time synchronisation for high latency (TSHL) [5,14]. Despite the advance of TSHL, this scheme has an obvious drawback for underwater networks since mobility of underwater nodes is disregarded. Consequently, some novel time synchronisation schemes are proposed recently to achieve higher accuracy in water [6–11].

Although those algorithms consider node mobility and even show enhanced performance, there are some inherent demerits. MU-Sync [6] is more accurate than TSHL but it assumes that the synchronising nodes remain stationary during message exchanges. Additionally, the performance of MU-Sync is influenced sensitively by the maximum relative speed of nodes. Mobi-Sync [7] estimates round trip time separately to improve accuracy. However, this scheme is appropriate for dense networks because three super nodes, which are close to the synchronising node, are needed. D-Sync, TSMU, DA-Sync and TS-MUWSN [8–11] shows advanced performances by estimating relative velocities from the Doppler shift. However, it is assumed that movement of underwater nodes is uniformly accelerated motion during round trip time of message exchanges. The round trip time is higher as propagation distance is further but the assumption of node motion is unrealistic when the propagation delay is long. Moreover, long processing time should be consumed due to those repetition processing.

Inaccuracy occurred by the unrealistic node movement assumption of those novel algorithms [8–11] are counterproductive. Thus, our low-complexity time synchronisation for 3-dimensional underwater communications environment using estimated instantaneous node velocity (V-Sync) is proposed with reducing computational complexity and the influence of distance between nodes. In V-Sync, a reference node broadcasts beacon messages periodically

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and received time intervals of adjacent beacon messages are used for time synchronisation. Since the time interval is not related to node distance and it can be sufficiently short, the assumption that nodes perform uniformly accelerated motion during short time interval is more realistic than the node movement assumption of existing schemes. In addition, V-Sync has the advantage of increasing energy efficiency in limited underwater environments by reducing the number of total message transmission and computational complexity.

This paper consists of six sections. In Section 2, fundamental background of underwater networks and time synchronisation is introduced. Our proposed time synchronisation scheme is explained in the following section. In the next section, we demonstrate simulation results to analyse the performance of V-Sync with comparing conventional time synchronisation schemes. Finally, we complete this paper with the conclusion and introduce future works.

2. Background

2.1. Underwater cellular network

Underwater cellular networks are the fundamental network structure for V-Sync. Underwater base stations are distributed on the surface or bottom of the ocean and some local nodes, such as divers, sensors and underwater vehicles, are located in cell areas of the base stations as illustrated in Fig. 1. Underwater base stations could be equipped with relatively better batteries than local nodes. Therefore, assigning more tasks on base stations is possible and reasonable. In this paper, base stations broadcast beacon messages periodically and local nodes transmit a sync-message only once. Thus, V-Sync could confirm better energy efficiency by reducing the overall number of transmitting messages in comparison with other schemes [6–11].

2.2. Time synchronisation error

As demonstrated in Fig. 2, time synchronisation error is occurred by skew and offset, which are generated by different oscillating frequencies and booting times at each node, respectively. Since sound waves are used in underwater wireless communications, the propagation delay is considerably increased. Therefore, estimation and compensation of skew error become crucial in underwater time synchronisation because the influence of skew error is increasing as time passed. We considered skew and offset as characteristic parameters of individual nodes. If skew is constant, the ratio of clock oscillating frequencies of each node is also fixed. Thus, it is linearly increasing as shown in Fig. 2. Additionally, the sources of the message delivery delay, which is related to the non-determinism causing time synchronisation error, are defined in [12,13].

2.3. Notation

It is assumed that reference nodes, such as underwater base stations, know the reference time and local nodes have individual local times, which are different against the reference time due to skew and offset. In this paper, the reference time and local time are symbolised by t and T, respectively. Their relational expression can be defined by

$$T = s \times t + e_O \tag{1}$$

where s and e_O indicate skew and offset, respectively. For simplification, there are only one reference node and one local node in this paper and the location of reference node is fixed.

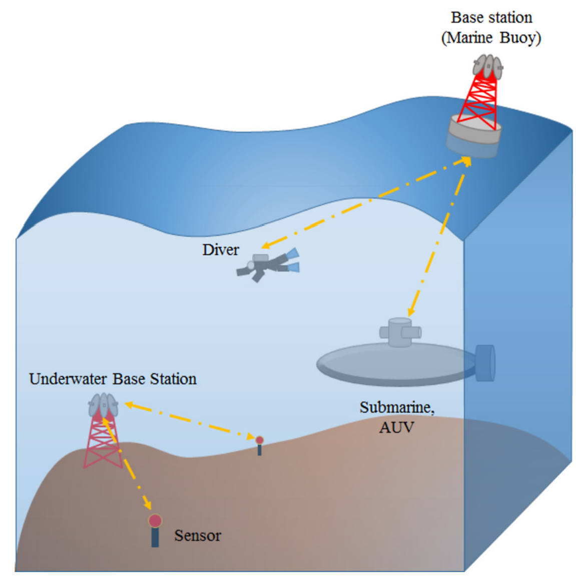

Fig. 1. Underwater cellular network concept diagram.

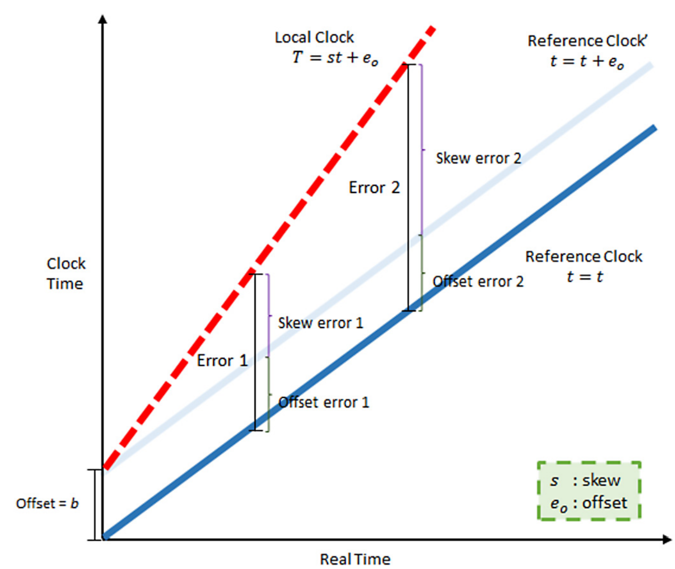

Fig. 2. Skew and offset error.

2.4. DA-Sync protocol

TS-MUWSN [11] is the novel and accurate underwater time synchronisation protocol. TS-MUWSN uses also DA-Sync protocol [10] but its contribution is betterment of accuracy of relative node velocity measurement. While a bank of autocorrelators with a well-designed preamble is used in DA-Sync, other Doppler scale factor estimation method, such as pure tone Doppler shift estimation, S&C CFO detection and preamble/postamble Doppler scale estimation, are employed in TS-MUWSN. However, the estimation method of node velocities in physical layer is not considered in this paper. Additionally, error of relative node velocity measurement is well compensated as well shown in [15,16] and the influence of velocity measurement error could be reduced as shown in [11]. In this paper, thus, the influence of velocity error is ignored.