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Fault-resilient localization for underwater sensor networks

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ABSTRACT

Localization is one of the critical issues in underwater sensor networks (UWSNs) on grounds of environmental characteristics, mobility of sensor nodes, and lack of global positioning system (GPS) services. Mobility modeling and fault tolerance with respect to underwater characteristics are extremely difficult. In this energy constraint network, an adaptive localization scheme with minimum communication and GPS support is required. We propose a fault-resilient localization scheme, which provides good localization accuracy with minimal communication overhead. To resile from an anchor node failure, a sensor node predicts its position by learning the mobility behavior of its neighbors using multiple linear regression. Therefore, the data dissemination process can continue even after an unexpected case of anchor node failure. We simulate the network and analyze the localization accuracy. Several experiments with different test cases are conducted to analyze the validity of the location prediction system. Experimental results show that the last 10 location information from three immediate neighbors are adequate for accurate prediction and the localization scheme is well suited for medium-range UWSNs.

1. Introduction

Underwater sensor networks (UWSNs) have many aquatic applications such as oceanographic data collection, offshore surveillance, oil field detection, natural hazard detection, and pollution monitoring. Because of the lack of global positioning system (GPS) services in the UWSN domain, localization of nodes is very challenging. Moreover, the sensor nodes are dynamic in nature. The nodes can freely move in an underwater environment. The meaningful interpretation of the sensor data requires accurate information regarding the location.

UWSN is highly energy constrained because the sensor nodes are battery powered. Also, the communication channel is acoustic. These reasons urge the development of protocols with low processing power and communication overhead. Existing localization techniques for mobile UWSN follow trilateration, triangulation, and multilateration techniques [1–5]. These schemes require the support of three or more anchor nodes for a particular sensor node to localize. Flooding of packets to a sensor node leads to congestion and subsequently limits the network lifetime. Furthermore, the success of localization depends on the timely reception and processing of packets from anchors. In time critical applications, localization accuracy is very significant. As sensors are free to move along with water waves in the UWSN domain, their location data could change with time. If the localization process is long, it will result in erroneous estimation, because the current location of the anchors may differ from the collected value. In other words, localization accuracy depends on localization time. Hence, to achieve high localization accuracy, schemes with multiple anchors require timely and accurate reception of packets. But, timely reception is seldom possible because of the high propagation delay and packet loss of the acoustic channel [6–9]. Moreover, most of the existing systems assume either a random mobility model or follow a basic water wave pattern. The mobility behavior of sensor nodes in underwater domain is influenced by many parameters such as wind, rainfall, water wave, storm, marine vehicles, depth, and underwater animals. Unexpected weather conditions in the UWSN environment also influence the mobility of sensor nodes. Therefore, a general wave pattern would not be an accurate solution for modeling the mobility of sensor nodes. Hence, the development of an adaptive localization strategy without extra communication packets is vital.

In most of the existing systems, location tracking of the sensor nodes is carried out with the aid of anchor nodes. Hence, the success of localization completely depends on the anchor nodes and anchor node failure can stop the localization process. Also, the reliability of the communication channel is meager because of the high propagation delay and path loss. Hence, a node should be able

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to resile from an unexpected fault in communication with the anchor node to continue the data dissemination process.

In this paper, we propose the first fault resilient localization (FRL) for UWSN. Here, sensor nodes compute the coordinates by using a single anchor node packet. In addition, sensors are fault-tolerant. They are able to handle situations like anchor node failure, by intelligently predicting their location. A sensor node stores the recent location information of its immediate neighbors and observe their mobility behavior. Multiple linear regression technique is used for location prediction. In this technique, multiple features are considered for location prediction which facilitates the achievement of good localization accuracy. We conduct simulation experiments and evaluate the accuracy of localization. We model reference point group mobility model (RPGM) [10] in BonnMotion tool[1] to generate the mobility trace of nodes. We simulate the network and import the generated mobility scenario. The prediction phase is validated by running several test cases using output data from the simulator. The experimental results report that the proposed localization scheme is suitable for an anchor range up to 100 km and the last 10 location information from three immediate neighbors are adequate for accurate prediction. The major contributions in this paper are as follows:

- Proposed a novel fault-resilient localization scheme for UWSNs
- Conducted the experimental analysis of the different predictor models
- Analyzed the accuracy of localization and compared with the state-of-the-art techniques

The rest of this paper is structured as follows. Section 2 summarizes related works. Section 3 describes the proposed localization scheme. Section 4 describes the experimental results and discussions. Section 5 concludes the paper.

2. Related work

Most of the localization techniques proposed for UWSNs considered either static UWSNs or UWSNs with static and mobile nodes [11–17]. Localization techniques for mobile UWSNs can be categorized into range-free and range-based techniques. Range-free methods usually provide ambiguous location estimates. Range-based techniques can be categorized into autonomous underwater vehicle (AUV) aided and non AUV aided. Schemes with AUV support [4,18–20] use considerable energy for the working of AUVs, and hence, we focused on schemes without AUV support.

Mirza and Schurgers [21] introduced a centralized anchor-free motion-aware, self-localization scheme. Every node estimates the distance from its neighbors and passes the information to a central station. The problems with this scheme are the lack of real-time localization and high communication overhead because of the distance estimation. The authors have introduced a collaborative localization scheme in that all nodes are equipped with GPS receivers, and the scheme is architecture dependent [22]. Senlin et al. [23] introduced a positioning scheme which does not require an even distribution of anchors. Beniwal et al. [24] discussed a time synchronization independent localization scheme. In [25], the authors introduced an energy efficient localization. Although the system is anchor-free, each subset node selection requires an independent broadcasting which causes high communication overhead.

Gomez et al. [26] proposed a location tracking system for near-surface networks based on the sunlight intensity measurement. Chen et al. [27] proposed a localization scheme that utilizes signal strength and open air characteristics. Park et al. [28] discussed a positioning scheme based on the received signal strength. However, these systems are suitable for near-surface networks only.

Isbitiren et al. [29] introduced a three-dimensional target-tracking scheme that follows trilateration and requires the support of three anchor nodes. Han et al. [30] proposed a collaborative localization scheme with multiple anchor nodes. Liu et al. [3] discussed a multihop fitting approach that also follows trilateration and leads to high communication overhead. Das and Thampi [31] introduced a single anchor support localization for mobile UWSNs. To estimate location, a sensor node demands angle of arrival (AOA) and time of arrival (TOA) values from an anchor node. The estimated coordinates were updated periodically by following the mobility behavior of objects in ocean waves. Although it is an energy efficient strategy, a general mobility model is infeasible.

Zhou et al. [2] proposed a mobility prediction based localization scheme. Every node predicts its future mobility pattern and estimates its location on the basis of its previously known location data. The scheme provides an efficient location tracking service in large-scale UWSNs; however, it requires multiple anchors and relatively high communication overhead. Zhang et al. [32] proposed the particle swarm optimization based localization. Liu et al. [[33]] considered the stratification effect of underwater medium in localization. Ojha and Misra [1] proposed a distributed three-dimensional localization scheme. They exploited the spatially correlated mobility behavior of objects in the UWSN domain. In addition, Meiqin et al. [34] discussed a spatial-correlation based distance mobility prediction. However, by adopting trilateration technique, localization service generates high communication overhead in the network.

The aforementioned techniques do not offer a trusted, fault-resilient, localization scheme for mobile UWSN with minimal communication overhead and high localization accuracy. Kakamanshadi et al. [35] discussed various fault-tolerant techniques in WSN. They classified fault-tolerant schemes as redundancy-based, clustering-based and deployment-based. Hind et al. [36] discussed fault-tolerant routing techniques in WSN. Xue et al. [37] introduced a fault-tolerant routing technique for mobile ad-hoc networks. Qiu et al. [38,39] introduced self-organizing protocols for internet of things to improve fault-tolerance. Qiu et al. [40] proposed a greedy model to improve robustness of heterogeneous internet of things. Even though fault tolerance and fault management are well discussed in the case of surface WSN [41,42], fault-resilient localization is least explored.

Therefore, we designed a fault-resilient localization scheme for mobile UWSN. Sensors estimate their location with an anchor message. Hence, the scheme requires minimal communication overhead. Sensors are able to handle faults, by intelligently predicting their location once a fault is detected.

3. Proposed fault-resilient localization

3.1. Network architecture

Network architecture consists of an anchor node and sensor nodes. Fig. 1 depicts the network model of UWSN.

- Anchor node (A-node) : It is the base station. It has GPS receiver and acoustic and radio frequency transceivers. It is time-synchronized with all other nodes.
- Sensor node (S-node): S-nodes are sensors that are randomly deployed in an underwater domain. It is assumed that each S-node is equipped with a directional antenna and a depth sensor.

Fig. 2 illustrates the control flow diagram of the proposed localization system. The A-node periodically transmits a broadcast message that contains its location information. An S-node accepts the broadcast packet when it tracks an unusual event or senses a significant environmental data. Fig. 3 depicts the format of the

[1] http://sys.cs.uos.de/bonnmotion/index.shtml