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MIXED STRATEGY BASED APPROACH FOR LOCALIZATION IN UWSN

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Abstract

Underwater Wireless Sensor Networks (UWSN) is constructed to monitor the underwater environment. Sensor nodes are sparsely deployed in under water environment due to high deployment cost. In UWSNs location of a sensor node is determined by utilizing its spatio-temporal relation with the reference nodes. Spatio-temporal partitioning of the network topology is occurred with reference to the passive node mobility reasons. Localization schemes are used to assign the location for the sensor nodes in UWSN. Anchor based and Anchor free localization schemes are applied for the UWSN. The anchor-based schemes perform localization iteratively starting from the surface based anchors. Anchor-free schemes use mobile beacon Nodes to aid node localization.

Opportunistic Localization by Topology Control (OLTC) scheme is employed to achieve localization in sparse and partitioned UWSNs. The interaction between an unlocalized node and surrounding localized nodes is denoted as an oligopoly in OLTC. The OLTC is modeled as a Single-Leader-Multi-Follower Stackelberg game. In OLTC scheme any unlocalized node acts as the leader and any localized node acts as the follower. An on-demand topology controlled location beacon providing scheme is adapted for the one-time localized nodes. The localized nodes are act as potential anchors for the rest of the unlocalized nodes. Power aware localization is achieved by the OLTC scheme. Localized nodes algorithm and unlocalized nodes algorithm are applied in the OLTC scheme.

1. Introduction

Wireless information transmission through the ocean is one of the enabling technologies for the development of future ocean-observation systems and sensor networks. Applications of underwater sensing range from oil industry to aquaculture and include instrument monitoring, pollution control, climate recording, prediction of natural disturbances, search and survey missions and study of marine life.

Underwater wireless sensing systems are envisioned for stand-alone applications and control of autonomous underwater vehicles (AUVs) and as an addition to cabled systems. For example, cabled ocean observatories are being built on submarine cables to deploy an extensive fibre-optic network of sensors covering miles of ocean floor. These cables can support communication access points, very much as cellular base stations are connected to the telephone network, allowing users to move and communicate from places where cables cannot reach. Another example is cabled submersibles, also known as remotely operated vehicles (ROVs). These vehicles, which may weigh more than 10 metric tonnes, are connected to the mother ship by a cable that can extend over several kilometres and deliver high power to the remote end, along with high-speed communication signals. A popular example of an ROV/AUV tandem is the Alvin/Jason pair of vehicles deployed by the Woods Hole Oceanographic Institution (WHOI) in 1985 to discover Titanic. Such vehicles were also instrumental in the discovery of hydro-thermal vents, sources of extremely hot water on the bottom of deep ocean, which revealed forms of life different from any others previously known. The first vents were found in the late 1970s and new ones are still being discovered. The importance of such discoveries is comparable only to space missions and so is the technology that supports them.

Both the vehicle technology and the sensor technology are mature enough to motivate the idea of underwater sensor networks. To turn this idea into reality, however, one must face the problem of communications. Underwater communication systems today mostly use acoustic technology. Complementary communication techniques, such as optical and radio-frequency, or even electrostatic communication, have been proposed for short-range links, where their very high bandwidth can be exploited. These signals attenuate very rapidly, within a few metres or tens of metres, requiring either high-power or large antennas. Acoustic communications offer longer ranges, but are constrained by three factors: limited and distance-dependent bandwidth, time-varying multi-path propagation and low speed of sound. These constraints result in a communication channel of poor quality and high latency, thus combining the worst aspects of terrestrial mobile and satellite radio channels into a communication medium of extreme difficulty.

Among the first underwater acoustic systems was the submarine communication system developed in the USA around the end of the Second World War. It used analogue modulation in the 8–11kHz band. Research has since advanced, pushing digital modulation–detection techniques into the forefront of modern acoustic communications. At present, several types of acoustic modems are available commercially, typically offering up to a few kilobits per second over distances up to a few kilo meters. Higher bit rates have been demonstrated, but these results are still in the domain of experimental research.

With the advances in acoustic modem technology, research has moved into the area of networks. The major challenges were identified over the past decade, pointing once again to the fundamental differences between acoustic and radio propagation. For example, acoustic signals propagate at $1500 ms^{-1}$, causing propagation delays as long as a few seconds over a few kilometres. With bit rates of the order of 1000bps, propagation delays are not negligible with respect to typical packet durations—a situation very different from that found in radio-based networks. Acoustic modems are typically limited to half-duplex operation. These constraints imply that acoustic-conscious protocol design can provide better efficiencies than direct application of protocols developed for terrestrial networks. In addition, for anchored sensor networks, energy efficiency will be as important as in terrestrial networks, since battery re-charging hundreds of metres below the sea surface is difficult and expensive. Finally, underwater instruments are neither cheap nor disposable. This fact may be the single most important feature that distinguishes underwater sensor networks from their terrestrial counterpart and fundamentally changes many network design paradigms that are otherwise taken for granted.

While today there are no routinely operational underwater sensor networks, their development is imminent. The underlying systems include fleets of cooperating autonomous

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vehicles and long-term deployable bottom-mounted sensor networks. Active research that fuels this development is the main subject of our paper. We also describe the currently available hardware and discuss tools for modeling and simulation, as well as testbeds

2. Related Work

The Opportunistic Localization by Topology Control (OLTC) scheme is enhanced with mixed strategy based localized approach. Shadow zone identification and resolution scheme is integrated with the OLTC scheme. Jamming and natural interferences are handled with dynamic transmission models. Autonomous transmission power assignment mechanism is adapted to the sensor nodes. Localization has been widely explored for terrestrial sensor networks, and a significant number of schemes have been proposed [1]. Generally speaking, these schemes can be classified into two categories: range-based schemes and range-free schemes. The former covers the protocols that use absolute point-to-point distance estimates or angle estimates to calculate locations while the latter makes no assumptions about the availability or validity of such range information . Although range-based protocols can provide more accurate position estimates, they need additional hardware for distance measures, which will increase the network cost. On the other hand, range-free schemes do not need additional hardware support, but can only provide coarse position estimates [2]. In this paper, we are more interested in accurate localization. UWSNs acoustic channels are naturally employed and range measurement using acoustic signals is much more accurate and cheaper compared with that in terrestrial sensor networks using radio [10], [12]. Thus, range-based schemes are potentially good choices for underwater sensor networks. Due to the unique characteristics of underwater sensor networks, the applicability of these existing range-based schemes is unknown.

Localization for terrestrial mobile sensor networks has also been explored recently. The authors propose a range-free localization scheme based on a sequential Monto Carlo localization method and show that their scheme can exploit mobility to improve the localization accuracy. The authors propose predictive protocols which can control the frequency of localization based on sensor mobility behavior to reduce the energy requirements while bounding the localization error. Both of these two studies assume that sensor nodes are moving randomly and the inherent properties of object mobility patterns are not explored.

There are a couple of studies on localization for underwater acoustic networks. These proposals are mainly designed for small-scale static networks. For example, underwater "GPS" systems have been proposed based on surface buoys and one hop communication. Localization for sensor nodes is centrally performed at surface buoys. A distributed protocol is proposed for multi-hop underwater robot networks. This protocol is based on the iterative multilateral methods and is suitable for small-scale static underwater networks. For large-scale mobile underwater sensor networks, this protocol is inefficient because of the high communication cost and low convergence speed.

3. Localization in Underwater Sensor Networks

Localization of c in event-driven sensor networks [3], [4]. In such networks, the sensed data render meaningful insights when they are tagged with location information. Location awareness is required in applications such as target tracking [5], [6], ocean monitoring, pollution

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control, or even for the execution of geographic routing protocols. UWSNs pose few unique challenges that differ from those of the terrestrial sensor networks in many respects. Unlike the terrestrial networks, Global Positioning System (GPS) is unsuitable for use in underwater environments due to high attenuation of radio signal. Also, the powerhungry nature of GPS makes it inappropriate for use in UWSNs. Alternatively, in UWSNs, location of a sensor node is determined by utilizing its spatio-temporal relation with the reference nodes. In many UWSN applications such as underwater surveillance, the nodes are sparsely deployed because of the high deployment cost [11]. Further, the presence of passive node mobility due to underwater currents renders spatio-temporal partitioning of the network topology. Consequently, most of the underwater sensor nodes lack the availability of required number of reference nodes in their communication range for aiding in localization. Also, the neighborhood of a node may change over time, and accordingly, the number of available reference nodes may also change.

The existing works (e.g., [13], [8], [9], [7]) on underwater localization considered various constraints of UWSNs except the sparse and network partitioning scenarios. Cheng et al. considers a scenario which requires at least three anchors for initiating the localization process. The lack of required number of reference nodes or the variability of the available reference nodes affects the execution of any localization scheme. The existing localization schemes are broadly classified into two categories—anchor-based and anchor-free. The anchor-based schemes perform localization iteratively starting from the surface based anchors. Unfortunately, these schemes fail to function in sparse and partitioned deployment scenarios. Anchor-free schemes use mobile beacon nodes to aid node localization. These additional devices increase the implementation cost of these schemes. Furthermore, these schemes exhibit performance challenges attributed to low success rate in sparse UWSNs. Therefore, it is required to design a scheme which is capable of localizing the sensor nodes by exploiting the available opportunities to fulfil the required number of reference nodes in sparse UWSNs.

In this paper, we propose Opportunistic Localization by Topology Control (OLTC), a localization scheme specifically designed for sparse and partitioned UWSNs. In OLTC, we depict the interaction between an unlocalized node and surrounding localized nodes as an oligopoly. We model the scenario as a Single-Leader- Multi-Follower Stackelberg game, where any unlocalized node acts as the leader, and any localized node acts as the follower. In such oligopolistic environment, the unlocalized node is referred to as the Stackelberg firm, by following the nomenclature used in micro-economic games. Further, the existing localized nodes, which help an unlocalized node to localize it, are referred to as the Cournot firms. Any unlocalized node exploits its available opportunities to interact with potential reference nodes to get localized with minimum localization delay. The localized nodes, on the other hand, decide an optimal transmission power to maximize their individual utility. In summary, the contributions of this work are as follows.

- We formulate the interaction between an unlocalized node and potential reference nodes as a Single-Leader-Multi-Follower Stackelberg game. This game model establishes the broader scope for opportunistic localization in sparsely deployed UWSNs by instrumenting topology control mechanisms.

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- We propose a model for the unlocalized nodes to exploit the possibilities of opportunistic localization— a mechanism that helps in addressing the challenge of finding maximum available reference nodes.
- We present an on-demand, topology controlled location beacon providing scheme for the one-time localized nodes, which act as potential anchors for the rest of the unlocalized nodes. This fabric is usable for enforcing power awareness in the localization process.

4. Problem Statement

Opportunistic Localization by Topology Control (OLTC) scheme is employed to achieve localization in sparse and partitioned UWSNs. The interaction between an unlocalized node and surrounding localized nodes is denoted as an oligopoly in OLTC. The OLTC is modeled as a Single-Leader-Multi-Follower Stackelberg game. In OLTC scheme any unlocalized node acts as the leader and any localized node acts as the follower. An on-demand topology controlled location beacon providing scheme is adapted for the one-time localized nodes. The localized nodes are act as potential anchors for the rest of the unlocalized nodes. Power aware localization is achieved by the OLTC scheme. Localized nodes algorithm and unlocalized nodes algorithm are applied in the OLTC scheme. The following drawbacks are identified from the existing system.

- Shadow zones are not considered
- Jamming disturbances are not handled
- Transmission power level estimation is not adapted
- Natural interference handling is not supported.

5. Game Theory Model for Localization Process

We assume a 3D UWSN consisting of mobile nodes (N) represented as a graph G(N,E(t)), which are affected by passive node mobility due to waves and underwater currents. For any node i, $\{N_{br}(i)\}_{pi}$ denotes the set of its neighbors for transmission power pi, and $P_i(t)$ denotes the action space of available power levels at time t. Initially, all the nodes transmit in the same and minimum power level p_{min}. Here, the minimum transmission power is p_{min} = in{(P_i(.)) and maximum transmission power is p_{max} = sup(P_i(.)) for any node i. Changing the power level of a node corresponds to changing its transmission range. Let $R_i(t)$ represent the set of transmission ranges of a node at time t. Therefore, P_i (.) and R_i(.) possess an one-to-one bijective mapping, i.e., f : P_i(.) -> R_i(.). Accordingly, $P_i(.)= [p_1, p_2 . . . , p_k]$ and $R_i(.)= [r_1,r_2 . . . , r_k]$, where k is the number of transmission power levels, and it is defined as k = $|P_i(.)|$, where | . | denotes the cardinality of a set. In the assumed deployment, j £ $\{Nbr(i)\}_{pi}$ in the network graph G(N,E(t) iff (i,j) £ E(t), and the distance between i and j is $d_{ij} \leq r_i$ for r_i 2 R_i(.). Whereas the unlocalized nodes are submerged into water throughout the network, the localized sensor nodes or anchors are positioned on the water surface. The dotted circles area covered by the nodes with transmission range r_i = rmin. We list the assumptions made in the design of the proposed work.

- A sensor node is aware of its depth.
- Nodes are time-synchronized.
- They have knowledge about various cross-layer information such as topology, connectivity, and residual battery status.

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- Anchor nodes, which act as initial reference nodes, are deployed on the water surface.

6. UWSN Localization Using Mixed Strategy

The Underwater Wireless Sensor Network (UWSN) is constructed and managed with localization features. Bandwidth coverage and node density factors are integrated with the localization approach. Message communication process is handled with energy consumption levels. The system is divided into six major modules. They are UWSN Initialization, Partitioning Process, Anchor Assignment, Localization Process, Localization with Shadow Zones and Mixed Strategy Scheme.

UWSN initialization process manages the sensor node deployment operations. Sensor nodes are grouped under the network partitioning process. Anchor nodes are selected under the anchor assignment process. Localization process is designed to assign location for the sensor nodes. Coverage problems are solved under the localization with shadow zones. Jamming and natural disturbances are handled in mixed strategy based scheme.

6.1. UWSN Initialization

Sensor nodes are placed under the UWSN initialization process. Monitoring area and depth levels are considered in the deployment process. The nodes are updated with unique identification values. The nodes are assigned with coverage and initial energy levels.

6.2. Partitioning Process

The UWSN is partitioned into several zones. Node density factor is considered in the partitioning process. Partition refreshment is initiated with reference to the node mobility conditions. Area and node information are updated in periodic intervals.

6.3. Anchor Assignment

Anchor nodes are used to assign location for unlocalized nodes. One time localization process is carried out using on-demand topology controlled location beacon providing scheme. Localized nodes are assigned as anchors for network. Anchor nodes are assigned for each partition level.

6.4. Localization Process

The localization process is performed using Opportunistic Localization by Topology Control (OLTC) scheme. Single-Leader-Multi-Follower Stackelberg game model is adapted for the localization process. Leader and follower roles are assigned with location information. Location information is updated with reference to the anchor nodes.

6.5. Localization with Shadow Zones

Coverage information is analyzed to estimate the shadow zones. Shadow zone identification and resolution tasks are integrated with the OLTC scheme. Localization is tuned for the out bounded nodes. Beacon messages are used to identify the shadow zones.

6.6. Mixed Strategy Scheme

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Shadow zones and jamming problems are solved in mixed strategy model. The OLTC scheme is also tuned to handle natural interferences. Power consumption level analysis is also carried out under the mixed strategy based model. Location reassignment is initiated with reference to the mobility conditions.

7. Conclusion

Underwater Wireless Sensor Networks (UWSN) are deployed to monitor the Ocean environment. Opportunistic Localization by Topology Control (OLTC) scheme is adapted to support localization in UWSN. Mixed strategy based mechanism is integrated with the OLTC scheme to improve the localization process. Shadow zones, jamming and natural interference problems are handled with improved OLTC model. The system achieves high localization coverage levels. Power optimized localization mechanism is adapted to achieve the high coverage levels. The system supports dynamic network condition handling mechanism. Localization is obtained in Natural interference handling with power efficiency.

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