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Location error resilient geo-opportunistic routing for void hole avoidance in USNs

Mehreen Shah[1], Nadeem Javaid[2,], Arshad Sher[2], Zahid Wadud[3,4], and Sheeraz Ahmed[5,6]

1 The University of Lahore, Islamabad 44000, Pakistan 2 COMSATS Institute of Information Technology, Islamabad 44000, Pakistan 3 University of Engineering & Technology, Peshawar 25000, Pakistan 4 Capital University of Science and Technology, Islamabad 44000, Pakistan 5 Faculty of Engineering and Technology, Dera Ismail Khan 29050, Pakistan 6 Career Dynamics Research Center, Peshawar 25000, Pakistan ⁎ Correspondence: nadeemjavaidqau@gmail.com, www.njavaid.com

Abstract

Underwater sensor networks (USNs) are getting popular for the purpose of monitoring and exploration of undersea terrain. However, underwater communication channel characteristics limits data gathering capacity and duration of monitoring. Efficient routing protocols can improve performance of USNs having dynamic topology and localization errors. This paper presents LETR; a geo-opportunistic routing protocol that considers localization errors and communication void regions. LETR considers transmission range levels for finding neighbor nodes. Sensor nodes search for neighbors by adapting different transmission range levels. The performance of our proposed protocol is evaluated against different parameters through simulations. The simulation results show that LETR significantly improves network performance in terms of energy consumption, packet loss ratio, fraction of void nodes and the total amount of depth adjustment performed by sensor nodes.

Keywords: Underwater sensor networks, depth adjustment, geographic routing, mobile sink

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1. Introduction

Underwater sensor networks (USNs) recently came up with hundreds of applications like harbor monitoring, oceanographic data collection, seaquakes monitoring and submarine tracking etc [1]. The inherent challenges like high bit error rate, limited bandwidth and large end-to-end delay badly impacts deployment and the design of USNs. Acoustic signals are the most preferred way of communication in USNs. Radio waves get absorbed in water due to high frequency ranges whereas optical waves are applicable only to short range transmissions and face heavy scattering. Besides sensing, many senor nodes have the capability of locating themselves using positioning system. Global positioning systems provides an expensive and power consuming solution to the localization problem. Therefore, local positioning system is the most supported and cost effective technique for localization. However, erroneous nature of local positioning system affects communication between network nodes. One of the foremost challenges in USNs is the battery resource limitation. It is quite difficult to replace sensor node's battery in harsh aquatic environment. USNs need efficient and reliable routing mechanisms to ensure error resilient and energy efficient communication between sensor nodes. Geographic routing is considered as the most promising data transmission technique to address key USN's issues [2]. Complete route establishment and maintenance towards sink is not required. Locally optimal routes are selected at each hop till the packet reaches its destination. Geo-opportunistic routing adds more benefits for data transmission in terms of high packet delivery ratio and reduced energy consumption. In opportunistic routing, only a highest priority node transmits data where multiple neighbor nodes contain copy of the same packet. The neighbor nodes hear and suppress their transmissions to avoid interference. Although, geo-opportunistic techniques provide simple and energy efficient solution though, void hole problem severely impacts performance of these protocols. If a node is unable to locate any neighbor node within its vicinity, it is considered as a void node. Such communication void areas are major hurdles in successful data transmissions. In this situation, the routing protocols either route the data packets using some recovery mechanism or simply discards packet. In this paper, we propose Location Error Resilient Transmission Range adjustment (LETR) routing protocol for USNs. Our proposed protocol provides solution to localization problems as well as void regions recovery. LETR use location information of sensor and sink nodes to locate neighbor nodes set. To successfully deliver data packets and maximize network throughput along with energy efficiency, LETR calculates Mean Square Error (MSE). One of the most important feature of LETR is transmission range adjustment for void area recovery. Instead of message based void area recovery, we prefer to use transmission range adjustment and depth adjustment technology to recover communication void regions. If a node is unable to locate any neighbor within maximum transmission range, it adjusts its depth towards surface sinks. Simulation results proved that the LETR reduces packet drop ratio by considering location errors and packet delivery ratio. The rest of the paper is organized as follows: Section III describes existing work. In Section IV, problem statement is defined while Section V explains system model. Section VI illustrates the functioning of our proposed LETR. The performance of our proposed protocol is evaluated in Section VII over defined parameters. In Section VIII we conclude our work.

2 Literature Review

Vector based forwarding routing mechanism proposed by Xie et al. [3] for USNs. To forward data packets, VBF defines a virtual pipe of predefined radius between the sender and receiver. Each receiver node computes its position and determines whether it can transmit data by comparing its calculated distance with a pre-determined distance threshold. Packet gets discarded if the calculated distance is greater than the threshold value. In this way, VBF limits the number of hops involved in routing to minimizes energy consumption. DBR [4] is a pioneering depth based greedy routing protocol for USNs. Each sensor node broadcasts data packets to all neighbor nodes where only lower depth nodes are eligible forwarders whereas, a node at higher depth than the sender discards packet. Holding time is calculated to set the priority of forwarder candidate. A node having smaller holding time is the most eligible forwarder node. All other nodes overhears and suppress their transmissions. A geo-opportunistic routing mechanism VAPR (Void-aware pressure routing) proposed by Noh et al. [5] to perform greedy depth based routing. The VAPR also utilize depth information like DBR [4] to forward packets towards sink. The sensor nodes periodically broadcasts beacons to get information of complete paths towards destination. It helps to discover void regions. To select next hop candidate set, the forwarding direction of neighbor is considered as a selection parameter. All the nodes having same forwarding directions (upward or downward) are considered in a forwarding set. The work presented in [6] adjusts depth of sensor nodes to eliminate void hole problem in static USN architecture. The proposed centralized and distributed topology control mechanism determines isolated and void nodes to adjust depth of nodes to a new location. In GEDAR [1], a depth adjustment based geographic and opportunistic routing protocol is proposed. To select a set of neighbor nodes for forwarding data towards sink, location information of known sinks and sensor nodes is used. Each forwarder node is assigned a priority using advancement and packet delivery probability. GEDAR avoids redundant transmissions; only higher priority nodes transmit data while other nodes overhear and suppress their transmission. Geographic routing introduces location errors as discussed in [7] and [8]. The protocols proposed in these papers presents location error robust routing protocols to minimize energy consumption in geographic routing techniques. [7] selects node with minimum expectation value while [8] calculates Mean Square Error (MSE) to estimate location errors. The authors in the literature cited here worked for the void hole avoidance, however, none of the void hole avoiding algorithm implemented location error avoidance scheme. Also, the depth adjustment based routing protocols like [6] and [1] consumes abundance of energy during depth adjustment of sensor nodes. However, this excessive energy consumption issue has not been addressed in these papers. Therefore, the USN's lifetime is compromised. On the other hand, most of the location error robust protocols in literature, like [7] and [8] do not consider void hole problem. In these papers,the forwarder node discards data packet if it contains no neighbor in its range. In this paper, we present a novel location error aware transmission range and depth adjustment-based routing protocol to cope with both the void hole problem and localization errors in mobile USNs.

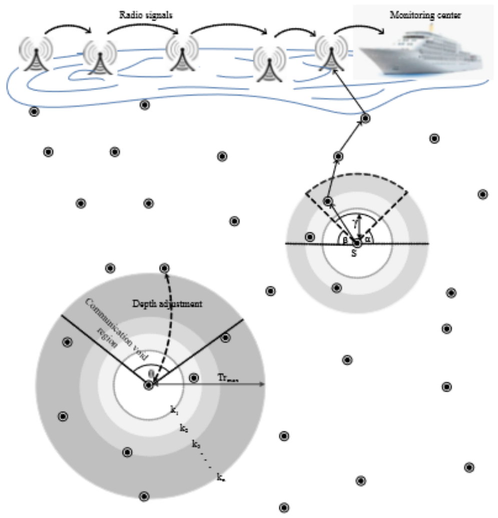

Fig. 1. Network model

3 Problem Statement

GEDAR [1] proposed geo-opportunistic routing protocol for void recovery. However, the depth adjustment procedure in GEDAR negatively impacts the network performance in terms of lifetime, energy consumption and topology configuration. Whenever a sensor node discovers itself to be in a communication void region, it calls depth adjustment procedure and moves to a new depth. This high amount of energy consumption during displacement ultimately shortens network lifespan. Also, after certain amount of time during network operation, the areas nearer to sink become sparse due to node movement towards bottom. Thus, reception of data packets at sink is no more possible. Many location error resilient protocols born to tackle localization issue. Authors in [9] provides location error aware protocol to handle energy consumption and increase packet delivery probability in sensor networks. However, most of the protocols dealing with location errors do not implement mechanisms for void hole recovery [10], [3]. GEDAR implements geographic routing with no mechanism to cope with the erroneous location information. Such a limitation severely affect network communication and throughput. The aforementioned limitations need to be addressed through novel routing protocols.

4 System Model

We consider a multi-sink underwater network architecture where the sensor nodes are randomly deployed in a targeted network area A ∈ R3 and the sink nodes are placed at the water surface as shown in Fig. 1. Sink nodes are equipped with both radio and acoustic modems. Sink nodes are also provided with GPS facility to determine their location. Sensor nodes use acoustic signals for data transmission while sinks mutually communicate through radio waves. The sensor nodes sense and transmit data periodically. Data received at any sink is considered successfully delivered to data center. Sensor nodes exploits depth adjustment technology (winch-based apparatus or inflatable buoys). The velocity for sensor's vertical movement is 2.4 m/min at an energy cost of 1500 mJ/m. We denote the network topology as an undirected graph G(t) = (V,E(t)) where V corresponds to sensor nodes and E(t) = $e_{uv}(t)$ denotes the links between any pair of sensor nodes u and v at time t.

5 The Proposed LETR

This section provides detailed functioning of our proposed protocol. LETR amalgamates geographic and opportunistic routing by incorporating transmission range and depth adjustment capability while coping with location errors.

5.1 Controlled Beaconing Algorithm

In this paper, we implement controlled beaconing procedure. After network initialization, each sensor node and sink broadcasts beacon message. Each sink broadcasts beacon only once while sensor node broadcasts beacon periodically or when it adjust depth. Initially, each node embeds its current location, timer (specify time for expiry of information within beacon) and Current Clock Time (CCT) (helps to identify recent beacon from a node) in beacon message and broadcasts it. When the timer expires each sensor node rebroadcasts beacon containing most recent location information. Also, when a node identify itself as a void node, it adjusts its transmission range. However, the probability of being void node with maximum transmission range is very small, therefore, beaconing happens rarely.

5.2 Neighbor Set Selection

After network convergence, each node selects a set of neighbor nodes in order to choose suitable forwarder for data transmission.

Angle based neighbor selection A sensor node select its neighbors by calculating its angle with all its in-range nodes. However, we define upper and lower bounds (α and β respectively) for defining angle θ as provided in equation 1.

$$\alpha < \theta \leq \beta$$

We also define a threshold such that its value is less than or equal to the distance between sender and neighbor node. The transmission range of each sensor node is divided into k levels. Initially, a node checks its forwarder within first transmission level. If no eligible forwarder found within first level, node adjusts its transmission power and continues the process within second transmission level and so on till it finds neighbors within range. One of the reasons behind angle based neighbor node selection is to overcome hidden terminal problem.

5.3 Forwarder Set Selection

LETR implements opportunistic routing for forwarder selection using packet advancement and node priority value.
Packet *advancement-based selection* the packet advancement-based forwarder selection criteria is applied using equation 2 on the set of neighbor nodes,

$P_{adv} = \omega(R-d_{s,n}) + d_{n,sink}(1-\omega)$

where R is the transmission range of a node, ω is a constant, ds,n and dn,sink are the distances between sender s and neighbor n and the distance between neighbor and sink node respectively. The list of neighbors are sorted on the basis of minimum Padv value.
Location error based selection Due to low energy cost and overhead, geographic routing seems to be an attractive option for sensor networks, however, it is ineffective in realistic localization conditions. In an unpredictable environment such as underwater, the probability of location errors is very high. Sensor nodes slightly drift with water currents which leads to packet drop and energy wastage in location based routing. We incorporate location error resilient technique using MSE in our proposed LETR to maximize its energy efficiency and packet delivery ratio. We calculate MSE in equation 3 in [8]:

$$MSE_{p,q} = E(\hat{d}_{p,q} - d_{p,q})^2$$

Optimal forwarder selection using packet delivery ratio and MSE LETR finds appropriate forwarder on the basis of equation 4 as below:

$$NPV = \frac{P_{adv} \times \rho(d,m)}{MSE_{p,q}}$$

where NPV denotes the Node Priority Value. The delivery probability of m sized packet over distance d can be expressed as:

$$\rho(d,m) = (1 - \rho_e(d))^m$$

Equation 4 helps to select a node with minimum MSE in order to minimize packet drop ratio, energy consumption in retransmissions and the number of collisions. Thus, a sender node selects forwarder with highest NPV .

Transmission range adjustment Void hole being an inherent problem in USNs, significantly degrades network performance in terms of network lifetime and throughput. In our proposed scheme, we implement novel hybrid adjustment based technique i.e. transmission range adjustment and depth adjustment to overcome void hole problem. The transmission range of each node is divided into k levels, where (k = k1,k2,...,kn). Initially, every node search for forwarder node within k1, if no eligible forwarder found within specified range, it adjusts its power accordingly to transmit data to some node within k2. The process continues up to km i.e. maximum transmission level. The power adjustment of sensor nodes consume more energy, however, message based void hole recovery procedure incorporates high overhead. A sensor node S initially search for forwarder node within k1. It successfully finds a forwarder and transmit data to node v, where node v is unable to find any forwarder within k1, thus transmits data to some node w by adjusting transmit power. We declare a node as a void node if it is unable to find any forwarder within k_m..

5.4 Controlled Depth Adjustment

We optimize traditional depth adjustment procedure defined by GEDAR. Displacement procedure initiates when a node is designated as a void node. Each void node broadcasts its status. The predecessor of void nodes transmit data through any other in range forwarder node. The amount of displacement is set according to the transmit power level of node i.e. initially a node moves upward and covers distance equal to the initial transmission range. It checks for forwarder node using transmission range adjustment procedure, upon failing to find any forwarder till km, void node again adjusts depth. The same process is repeated until a node finds a forwarder. We avoid node displacement towards bottom to ovoid dynamic topology occurring due to the depth adjustment of predecessor nodes of sender. Also, due to high energy consumption during network operation, number of void nodes are greater, thus, all the sensor nodes sit in water bottom. Thus, no data reception at sink.

6 Performance Evaluation

In our simulations, the sensor nodes range from 150 to 450 and are deployed randomly in 1500 m3 network field. The number of on-surface sinks are 25. We set the same maximal transmission range for all nodes as 500 m which is divided into M levels [11] while the minimum transmission range is 250 m. Data rate is 50kbps. Each node generates 200 bits packet having 50 bits of control field and 150 bits of data field.

6.1 Impact of varying node density on packet loss ratio

In Fig. 2, we simulate packet loss ratio of GEDAR and LETR by increasing node density. GEDAR incorporates high packet loss ratio due to its long hop paths formed during depth adjustments in order to circumvent void regions. When the number of hops increases, acoustic channel becomes more overloaded hence packet loss ratio increases. High amount of node displacement leads to highly dynamic network topology, thus throughput is decreased. Also, if a node fails to locate any forwarder after depth adjustment, it just discards the packet. GEDAR provides no mechanism to alleviate location errors, thus, localization problem leads to packet losses. In our LETR, we dilute depth adjustment procedure with transmission range adjustment. The major reason behind minimum packet loss ratio in LETR is the consideration of location errors.

6.2 Impact of depth adjustment on energy consumption

Fig. 3 illustrates the percentage of energy consumption in physical actuation by the sensor nodes in both GEDAR and LETR. Energy consumption due to physical activity of sensor nodes decreases while increasing node density as shown in the Fig. 3. Sparse networks amalgamate more communication void regions relative to denser network fields. Therefore, more energy is consumed in depth adjustment based technique like GEDAR. When 150 sensor nodes are deployed in the network, approx 80 percent of energy is consumed in depth adjustment activity as shown in Fig. 3, while the graph has decreasing behaviour at higher node densities. In denser fields, the probability of void regions is very small which ultimately leads to fewer depth adjustments. Each sensor node consumes 1.5 mJ/m during depth adjustment. Therefore, high energy is consumed in lower densities due to high depth adjustment.

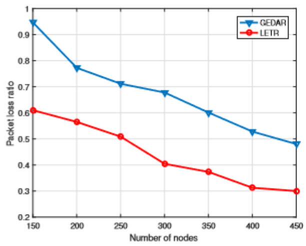

Fig. 2. Packet loss ratio

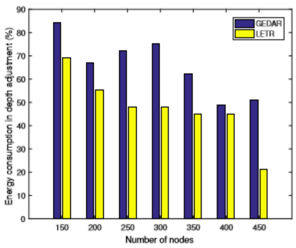

Fig. 3. Energy consumed in depth adjustment

LETR consumes relatively less energy in void hole avoidance using depth adjustment technique. This is because, fewer depth adjustments are required in our proposed technique.

6.3 Impact of varying node density on fraction of void nodes

Fig. 4 plots the fraction of void nodes against total number of nodes deployed in the network field. As shown in the figure, number of void nodes decrease with increase in network density. LETR achieves best results due to transmission range adjustment and controlled depth adjustment of sensor nodes. In GEDAR, each void node moves downward in order to transmit its data either through its predecessor node or any other in range node. Such displacement of nodes disturbs whole network topology and increases the probability of void nodes in the network. On the other hand, when LETR is applied, the proposed transmission range adjustment along with depth adjustment mechanism reduces 85 percent the fraction of void holes at medium and high node densities.

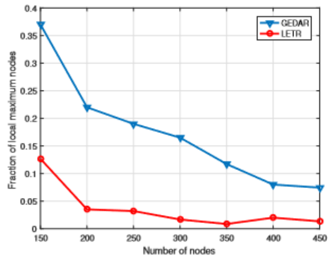

Fig. 4. Fraction of void nodes

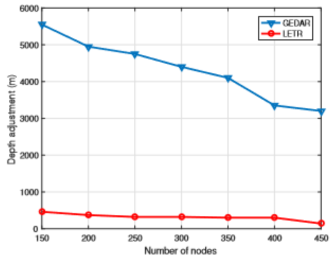

Fig. 5. Depth adjustments in the network

6.4 Impact of varying node density on node displacement

Fig. 5 provide depth adjustments performed by all the sensor nodes in the network. As corroborated by Fig. 5, the amount of displacement decreases while increasing node density. In sparse scenarios, more void areas exists whereas in dense networks the probability of occurrence of void regions decreases due to less distance between nodes. Fig. 4 supplements our results and discussion in this section. In GEDAR, the total depth adjustment is very high as compared to LETR. Each node moves to a new location whenever it locates itself in a communication void region. Also, every void node adjusts its depth until it finds a forwarder node or it has no space for further displacement. This sufficiently increases the amount of displacement of sensor nodes in the network which contributes to high energy consumption and more void nodes.

7 Conclusion

In order to make geographic routing protocols more energy efficient and suitable for large scale networks, its necessary to cope with location errors. This paper presents a geo-opportunistic routing protocol for void hole avoidance using transmission range and depth adjustment technology. A major contribution of this work is to tackle location errors in traditional geographic routing along with void hole avoidance. The simulation results proves that the location error resilient void hole avoidance technique increases network throughput and conserves energy as compared to traditional geographic routing techniques.

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