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Ph.D. Research Proposal

Doctoral Program in “Department Name”

Multi-AUV Assisted Data Collection and Path Planning for Optimizing Movement in Three Dimensional Underwater Sensor Network

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I. INTRODUCTION / BACKGROUND

Underwater Wireless Sensor Network (UWSN) is an underwater environment consisting of oceanographic sensors and vehicles. It is a well-known fact that the 75% of earth is filled with water and it acts as the prime source of living beings. The water is present in the form of rivers, canals, seas, and oceans. Plenty of precious resources lie underwater which are required to be explored. The key to successful explorations has always been technology dependent. UWSN is a fusion of wireless technology with extremely small micromechanical sensor technology having smart sensing, intelligent computing, and communication capabilities. Underwater sensor nodes will find applications in many areas related to ocean. The components involving in this type of network are follows:

- Sensor nodes (sensing ocean information)
- Gateway nodes (buoy with acoustic link)
- Mobile nodes (AUVs)
- Mobile sink node (node without acoustic link like ship)

Moreover, unmanned or autonomous underwater vehicles (UUVs, AUVs), equipped with sensors enables the exploration of natural undersea resources and gathering of scientific data in collaborative monitoring missions. Underwater acoustic networking is the enabling technology for several applications. Underwater networks consist of a variable number of sensors and vehicles that are deployed to perform collaborative monitoring tasks over a given area. UWSN is a network of autonomous sensor nodes that are spatially distributed underwater to sense the water-related properties such as quality, temperature, and pressure. Underwater acoustic communication is a technique of sending and receiving messages below water. This underwater communication is difficult due to factors such as multi-path propagation, time variations of the channel, small available bandwidth and strong signal attenuation especially over long ranges. Compared to terrestrial communication, this underwater communication has low data rates as it uses acoustic waves instead of electromagnetic waves.

Recent advances in technologies have led the possibilities to do the underwater explorations using sensors at all levels which were not possible previously. Accordingly, underwater sensor network (UWSN) is emerging as an enabling technology for underwater explorations. The underwater sensor network is given in Fig. 1

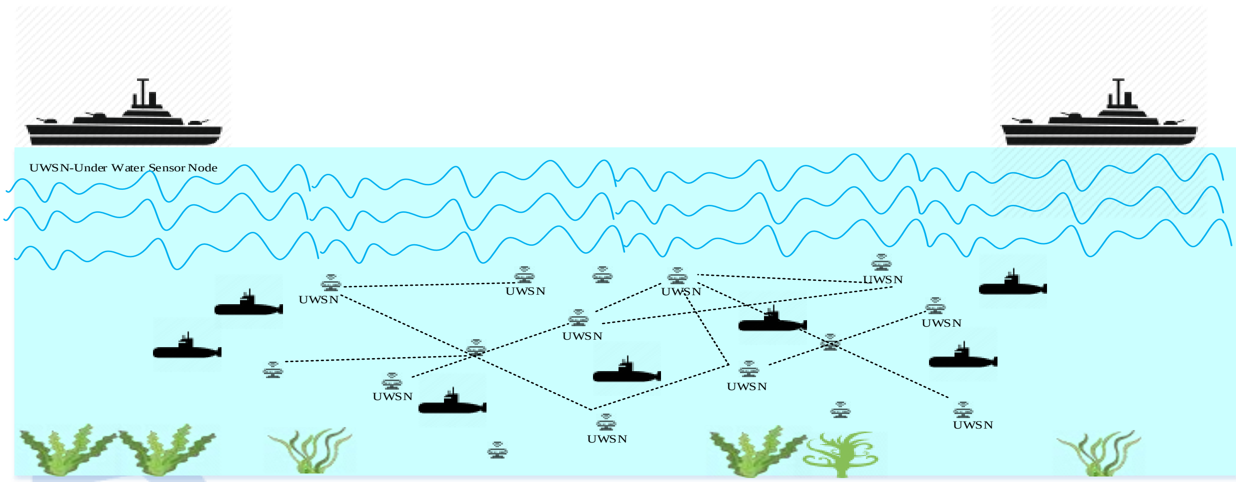


Figure 1 Underwater Sensor Network

UWSNs are utilized for a wide range of applications such as monitoring the marine environment for scientific exploration to commercial exploitation and coastline protection to underwater pollution monitoring, from water-based disaster preventions to water-based sports facilitation. UWSN offers a promising solution to ever demanding applications. However, UWSN applications are exciting but challenging at the same time. The reason lies in unpredictable conditions of water environment which creates serious constraints in the design and deployment of such networks. Some of the major application areas of underwater sensor network is provided in the Fig. 2

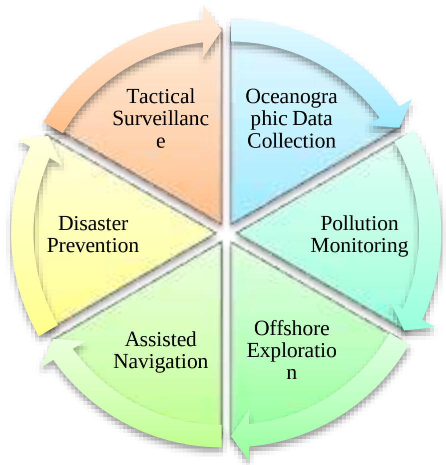


Figure 2 Applications of Underwater Sensor Nodes

1.1 Research Outline & Scope

Energy optimization and extending network lifetime for UWSN using multiple intelligent approaches under the multi-AUV deployed environment. This is achieved by best data gathering, path planning for AUV through optimal moving position decision making for AUV.

1.2 Research Objectives

The main objective of this research work is to minimize energy consumption compared to traditional approaches and decreases delay for emergency based data transmission from source node to AUV and then to surface sink.

II. RESEARCH GAPS

2.1 Common Problem Statement

In UWSN, continuous sensing of the environment consumes larger energy and transmission on multiple hops towards sink also consumes larger energy over all the nodes in the network that reduces network lifetime. In UWSN, using single AUV for data collection is not able to collect data in large scale environment which will increase delay and also it fails to deliver emergency data promptly. A pre-defined path planning of single AUV causes larger waiting time of nodes until the AUV reaches its nearer position.

2.2 Problem Definition

In [1] paper proposed a hybrid approach called spherical divisions and vector-based forwarding routing protocol for data forwarding and it addresses three critical issues of UWSN such as energy consumption, routing security and communication traffic. The objective of this paper is to improve the performance of routing in dense UWSN applications by spherical divisions and finally it obtained lower energy consumption, high network reliability and saturated level of PDR.

Problems Defined

- Vector-based forwarding (VBF) is the basic routing, which improved by spherical divisions. However, spherical layout is difficult to interpret for large scale networks, which consists of many long and overlapping edges

Solutions Proposed

- 3D space of UWMANET is considered, which considered three coordinates (x, y, z) of sensor node
- Energy efficient secure routing is considered by *Pigeons Swarm Optimization (PiSO)* which uses three metrics for routing: node residual energy, distance to depth of ocean, and relative mobility of node

With the rapid growth of security implications in UWSNs [2], various types of attacks (wormhole, selective forwarding, neighbor discovery, and sinkhole) are ensued. The agent-based secured routing scheme contributes two schemes: (1) secure neighbor discovery and (2) determines the prioritized optimal paths. Secured neighbors are discovered by direction of arrival estimation and authentication mechanism. The proposed secured routing outperforms in terms of energy consumption and overheads.

Problems Defined

- Complex manageability of network due to the presence of more agents (agents in security agency and agents in routing agency). Hence it is suitable for small scale UWSN.
- Energy and latency is high for large scale UWSN with poor scalability

Solutions Proposed

- We have simulate our proposed E2SCRP protocol under large scale networks and less complexity
- Cluster based secure environment improves energy efficiency and reduced latency

The objective of this paper is to [3] maximize the coverage area of UWSN. However, nodes are not scattered based on appropriate distance since it creates a large holes or gap in the deployment area. Hence considered node mobility is one of the solutions for sensors deployment. Firstly, deployment of mobile sensor nodes is performed randomly for better network coverage.

Problems Defined

- Clusters are generated based on distance between mobile sensor nodes and its residual energy, but does not considered relative mobility of a node, which increases energy consumption
- Clusters are unbalanced since it is not generated by the depth of water level.

Solutions Proposed

➢ Clusters are formed using trust value of sensor node, distance between neighbors, relative mobility and node buffer size (CH storage threshold is monitored at time t) using Type-2 Fuzzy Logic

In [4] paper proposes an enhanced lawn mower pattern path (ELMPP) to assist long-range AUV for effective data gathering. The path planning is followed as straight line segments and turning line segments. From the starting point i.e. waypoint of the current node, the yaw rate is estimated and then AUV is moved to next waypoint. Further the relay node is established with communication link with the prediction of RSSI value.

Problems –

- Larger energy consumption in the relay node, since it will be frequently selected as relay due to the fixed path of AUV based on line segments.

- However RSSI is an important measure, it is required to consider other sensor parameters since RSSI gives only the strength of the communication link but not the strength of the node.

Proposed Solutions –

- The path of AUV is not fixed and it is dynamically determined based on the current ability of CH.
- There is no need for relay selection, since the members sense and deliver the data to CH which in turn waits for the arrival of AUV and if exceeded, then inter-cluster route is selected by gateway. In case of emergency a next forwarder CH is selected by weighted value and then the data is transmission.

In this paper [5] authors focuses AUV path prediction for collecting sensor data by developing bipartite K-means algorithm for clustering and a target selection algorithm. Here AUV are considered to be the edge devices which are responsible to collect data and deliver to sink. A target node is selected from which the data has to be collected by AUV is selected based on the residual energy and distance of node.

Problems –

- The target nodes are selected one after the other i.e. the AUV has the capability to collect data from multiple nodes, but here the data from CHs are collected one at a time which increases delay in data delivery. The path prediction of AUV is based on the determination of the shortest data collection time; however use of single AUV increases travelling distance that eventually extends delay. In case of an event message, it fails to deliver the message at prompt time.
- The cluster construction time is large since, initially the clustering is performed with random centers and then again the cluster centers are reselected based on the distance metric.

Proposed Solutions –

- The path of AUV is predicted Two-Factor Soft Actor Critic based Path Prediction which takes in account of significant constraints of the CH.
- The optimal selection of CHs joins the nodes as its cluster members that are present within its communication range. A position is selected in common of four CHs and hence the AUV is capable to collect data from four CHs. By estimating the mean mid-point, AUV collects data from the CHs which reduce data collection delay.

III. RESEARCH CONTRIBUTIONS

The proposed M-AUV:3DUWSN architecture is designed with the aim of solving the major challenging issue of energy consumption and time delay in data gathering. However, these two challenges are widely concentrated in many previous works; it was existed with certain limitations. In this proposed work we propose the following solutions to achieve the above mentioned challenges,

- *Clustering with optimal head selection* (Reduces energy in data gathering)
- *Scheduling* (Reduce energy consumption in sensor nodes)
- *Optimal movement of AUV* (Reduces delay in data gathering)
- *Routing between CHs* (Reduces delay in data gathering)

M-AUV:3DUWSN architecture is composed of sensor nodes, two AUVs, super nodes and surface sink. The data from the sensor members are gathered by the corresponding cluster head (CH) and then it is forwarded to AUV. The CH sensor node wait for a particular time to transmit the data to AUV, if the time exceeds then it requests for a route to super node and transmits the data via the route. As per the depth of the underwater, the sensors are deployed in two levels (Level I and Level II) in which each level is managed by individual AUV.

1) Clustering and Scheduling

The process of clustering is initiated by the selection of CHs using **multi-objective spotted hyena optimization** (MO-SHO) algorithm. The sensors node's key constraints as *node lifetime*, *node degree* and *closeness centrality* is estimated in fitness function. The higher reporting sensor node is selected as CH. After selection of CH, the nodes within its coverage range are defined as cluster. The CH is responsible to gather data, assign sleep time slots and deliver the data to AUV. A **member balanced scheduling** is proposed in which the CH puts half of its member to sleep and other in wake-up. During wakeup mode, the sensor nodes perform sensing as well as transmission. The nodes are taken to sleep mode based on their *energy* and *number of hops* with the CH. The nodes in sleep node enable to mitigate the consumption of energy. In general the data redundancy is a common issue while gathering data from sensor node, so it is reduced by CH by using distance based similarity measure. **Hassanat distance** is determined to mitigate redundant data which eventually speeds up data delivery to AUV.

2) Optimal movement of AUV

The AUV is capable to predict the moving path dynamically by using **Di-factor actor critic path prediction method**. This is a reinforcement learning widely using for decision making. In this work, to utilize the complete capability of the AUV, it predicts a position to collect data from four CHs simultaneously. The metrics that are computed for path prediction are CH's *buffer*, *data collection delay*, *RSSI* and *data size*. On computing these constraints for four CHs, the AUV decides whether to move or not. If yes, then the mean mid-point is determined and then the AUV moves accordingly to gather data. Hereby, the collection of data from four CHs reduces data gathering delay and also it visits all the CHs in short period of time than in visiting each CH one after the other.

3) Inter-Cluster Routing

Inter-cluster routing is performed only when the arrival time of AUV exceeds. **A three-step inter-cluster routing method** is proposed that involves (1) route discovery, (2) elimination of longer paths and (3) route validation. The CHs are constructed as an undirected graph and maintained in the gateway, since this entity is responsible to select routes for inter-cluster routing. Searching for a route with limited knowledge of other CHs will tend to consume larger energy and delay, so that gateway is employed for selecting a route. In first step the available routes are selected and then the routes with *longer distance* and *hop counts* are eliminated. Then finally the filtered routes are validated using **Two Stream CNN**. For this validation, the key constraints of the CHs are taken in account as *average energy consumption*, *fairness*, *synthesis speed* and *node efficiency*.

4) Emergency Event

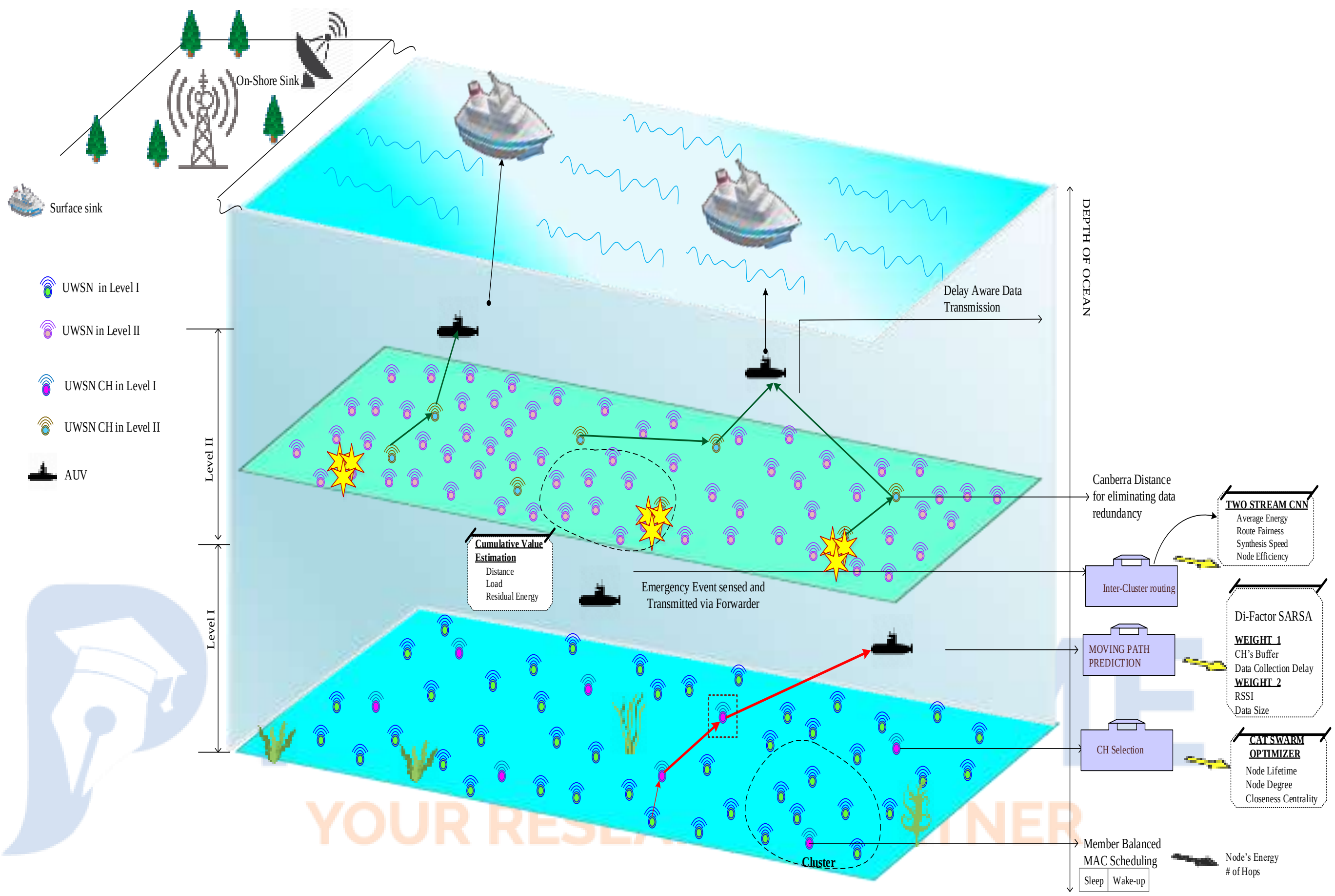
The development of this network is to significantly support many critical applications as pipeline monitoring, disaster prediction and more. So, there is possible to predict any event which is not majorly concentrated. This type of sensed information is more important than the periodical information and hence a forwarder (neighboring CH) is selected based on **weighted method** that computes weight based on *distance*, *load* and *residual energy*. The higher weighted CH is selected as forwarder, in this way the emergency message reaches AUV.

Performance Evaluation

The key goal of this M-AUV: 3DUWSN architecture is to use AUV for data gathering by reducing the energy consumption and time delay in data gathering. The efficiencies of this proposed architecture is evaluated in terms of the following parameters as,

1. Number of nodes and Simulation Time with respect to,
   - ✓ Data Gathering delay
   - ✓ Energy consumption
   - ✓ Network lifetime
   - ✓ Packet delivery ratio
   - ✓ Tour length
   - ✓ Residual Energy per packet
2. Hop count vs. End-to-End delay

SYSTEM ARCHITECTURE



IV. RESEARCH NOVELTIES

- The designed M-AUV:3DUWSN with multi- AUVs are incorporated with the aim of delay aware data gathering by optimal positioning of AUVs and using inter-cluster routing in case of exceeded waiting time. To assist a large scale network and faster data gathering two AUVs are employed. Incorporation of sleep time for sensor nodes reduces energy consumption.

- The optimal selection of CH using MO-SHO ensures with prolonged sustainment of CH and the reduction of redundant data improves delivery time. Then data gathering of AUV from for CHs at optimal position reduces delay. Here fuzzy-LeNet is used which performs faster and results with appropriate solution.
- In condition of delayed arrival of AUV, the gathered data is transmitted to AUV via an inter-cluster route. This is performed in order to make free space in CHs to gather upcoming sensed information from CHs.
- The sensors not only sense normal data, it also senses critical emergency data which is sent immediately by selecting a forwarder which sequentially reaches the AUV and then to the surface sink.

V. PREVIOUS WORKS & LIMITATIONS

Paper 1

Title – Energy Efficient Data Collection over AUV-assisted Underwater Acoustic Sensor Network

Concept - This paper considered the energy-constrained problem in acoustic communication. However, UAN is challenging to collect data and it is used autonomous underwater vehicle (AUV) to collect fused data. AUV contains more energy and easily rechargeable which is used to fetch data from sensor nodes. To consume more energy, min-weighted rigid graph based topology optimization scheme is considered.

Limitations

- Single-AUV aided Data Collection does not improves energy efficiency, which increases end-to-end delay in specific it is not suitable for event based application

Paper 2

Title – A Novel Node Sinking Algorithm for 3D Coverage and Connectivity in Underwater Sensor Networks

Concept

This paper studied the network deployment problem (connectivity and coverage) for an underwater network comprised on anchored nodes. The sensor nodes are deployed randomly on the ocean surface. The contributions of this paper are threefold: efficient three dimensional sphere packing pattern to choose the first batch of sinking nodes, secondly, sank nodes connectivity are verified and thirdly fix coverage holes by already sank nodes.

Limitations

- Node sinking algorithm does not effective for large scale 3D underwater sensor networks

Paper 3

Title – A High-Efficiency Uneven Cluster Deployment Algorithm based on Network Layered for Event Coverage in UWSNs

Concept

In this paper an uneven cluster deployment algorithm based network layered for event coverage. The energy consumption of the communication load at different depths of the underwater network is analyzed. The network is divided into multilayers using uneven clusters and the heterogeneous communication radius of the nodes can improve the network connectivity rate.

Limitations

- Uneven cluster deployment strategy increases end-to-end delay and increases energy consumption

Paper 4

Title – An Architecture for Using Autonomous Underwater Vehicles in Wireless Sensor Networks for Underwater Pipeline Monitoring

Concept

In this paper, the authors have proposed UWSN especially for pipeline monitoring using AUV. The sensor data is collected by AUV and then it is forwarded to surface sink. Further the sink node uses wireless technologies to transmit the data to the network control center. The AUV follows linear sensor network segment model to gather the data sequentially. In case, if the sensed data is emergency, then the AUV skips the entire intermediate sensor and reaches the event sensed sensor to gather its data. Hereby, the emergency data is provided with higher priority, however only one AUV may not be sufficient to support large-scale network.

Paper 5

Title – Data collection from underwater acoustic sensor networks based on optimization algorithms

Concept

This paper presents with a hybrid optimization algorithm for predicting an optimal solution for AUV tour. The proposed work integrates quantum-behaved particle swarm optimization with improved ant colony optimization to predict a shorter tour path. Initially the least number of waypoints are generated and the points to be visited are selected using optimization algorithm. The shortest path is chosen using ACO algorithm which extends the network lifetime by reducing the trajectory length.

Paper 6

Title – Efficient Routing Protocol Based on Reinforcement Learning for Magnetic Induction Underwater Sensor Networks

Concept

In this paper, Q-learning is presented for designing an efficient routing protocol for delivering the sensed data to sink. Initially, each sensor's information is gathered and then the Q-table, reward is computed based on single hop bonus (distance and energy). When a next hop is available, then an optimal path is selected by selecting the next action else it selects a nearby node with higher energy. In this way, the sensed data packet is sent to sink.

Limitations

- Use of Q-learning is a slower processing which in turn increases delay in data transmission to the other end destination.
- Almost all the CH has to participate in transmitting the sensed data to the sink due to the absence of AUV in the network. The data gathering by sink node from its position in this way consumes larger amount of energy among the underwater sensors.

Paper 7

Title – An Energy-Efficient Redundant Transmission Control Clustering Approach for Underwater Acoustic Networks

Concept

This paper proposes a two-level redundant transmission control (RTC) approach to measure the similarity of the data. Here mobile sink is used to gather data from the CH. An additional region head is used in this work for controlling communication as well as identifying the redundant transmission between CHs. CHs are selected based on the residual energy and then they assign TDMA timeslots to their members. After gathering the packets from members, the similarity is verified by checking the ID. Then a honestly significant difference test is applied in region head to determine the correlation between data and eliminate the redundancy.

Paper 8

Title – Adaptive Node Clustering Technique for Smart Ocean under Water Sensor Network (SOSNET)

Concept

This paper proposes an adaptive node clustering technique for smart ocean UWSN that is represented as SOSNET. Moth flame optimization algorithm is applied for optimal performance routing. CH is selected by estimating transmission range, residual energy, node density and load balance factor. The fitness value for the optimization algorithm is computed using residual energy, distance with the neighbors, load balancing factor and weight value. Based on this fitness value, the optimal number of clusters is defined for the process of routing.

Paper 9

Title – QERP: Quality-of-Service (QoS) Aware Evolutionary Routing Protocol for Underwater Wireless Sensor Networks

Concept

A QoS aware evolutionary cluster based routing protocol (QERP) is developed in this paper. This work designs a 3D environment with randomly deployed sensor nodes. The operators in genetic algorithms are involved as crossover and mutation. The key constraints that are taken in account are identity, energy and RSSI. The evolutionary genetic algorithm is time consuming and also it is tedious when multiple sensor nodes are participated.

Paper 10

Title – An Energy Balanced Efficient and Reliable Routing Protocol for Underwater Wireless Sensor Networks

Concept

The authors of this paper have proposed a depth-based routing mechanism i.e. named as energy balanced efficient and reliable routing ($EBER^2$) protocol. A forwarder is selected using three constraints as weighted depth difference, potential forwarder node (PFN) and residual energy. On determining these metrics, a forwarder is selected and the sensed information is transmitted. In this work, two sink nodes are deployed for mitigating the hot spot problem. So the data transmitting nodes estimated the distance and it selected the nearest sink to deliver the data.

Paper 11

Title – HAS^4: A Heuristic Adaptive Sink Sensor Set Selection for Underwater AUV-aid Data Gathering Algorithm

Concept

This paper proposed a Heuristic Adaptive Sink Sensor Set Selection (HAS^4) to enrich network lifetime by saving sensor nodes energy. This HAS^4 is developed for centralized and distributed environment in which the sensor lifetime plays a key role. Sensor lifetime is the only metric that is computed and sorted among all the sensor nodes and then a set of sensor are selected that are to be visited by AUV. The AUV tour selects sensor nodes from minimum lifetime.

Paper 12

Title – Prediction-Based Delay Optimization Data Collection Algorithm for Underwater Acoustic Sensor Networks

Concept

A prediction-based delay optimization data collection algorithm (PDO-DC) is presented in this paper to mitigate the collection delay. This work concentrates on clustering and path planning of AUV. The clusters are created and then they are updated, further an AUV path is predicted. According to this work, the data collected CH has to request the AUV to collects the gathered data. Based on the received request, the AUV traverse towards the requested CH for data collection. Data collection by this way, will certainly increase the traveling length and aslo more than one CH may request at a time.

Paper 13

Title – Self-Organizing and Scalable Routing Protocol (SOSRP) for Underwater Acoustic Sensor Networks

Concept

The authors of this paper have proposed a self-organizing and scalable routing protocol (SOSRP) that majorly takes in account of the hop count and distance. The proposed protocol is composed of the following phases as network initialization, neighbor discovery, path selection criteria and packet transmission. The neighbors are discovered by exchanging messages and then hop count, distance is estimation for path prediction. The path selected with shortest hop count is used for data transmission.

Paper 14

Title – Improved energy-balanced algorithm for underwater wireless sensor network based on depth threshold and energy level partition

Concept

An improved energy-balanced routing (IEBR) is proposed in this paper that is presented with route establishment and data transmission. In routing, the relay nodes are selected by computing neighbor depth and number of hops. The relay node table is constructed with the entities of successor node, number of predecessors and energy level. A threshold is determined based on the depth which enables to limit number of neighbors. Since, this network is constructed as ring sectors, the proposed IEBR selects relay in each ring that are situated at lesser depths.

Paper 15

Title – E^2MR: energy-efficient multipath routing protocol for underwater wireless sensor networks

Concept

An energy-efficient multipath routing (E^2MR) is developed in this paper which presents selection of forwarding nodes from the constructed priority table. More than one sink node is employed in this architecture with the ability of communication with radio frequency as well as acoustic frequency. By exchanging control packets the priority table is constructed with the entities of residual energy, distance and priority value. The priority value is computed based on the energy and the depth of the sensor. The node with higher priority value will be selected as a forwarding node and then data transmission is performed.

BIBLIOGRAPHY

Mohammed Reza Khosravi, Hmaid Habib Rostami, "Efficient Routing for Dense UWSNs with High-Speed Mobile Nodes using Spherical Divisions", The Journal of Supercomputing, Vol. 74, Issue 2, PP. 696-716, 2018

Sunil kumar S. Manvi, Manjula R. Bharmagoudra, "Agent based Secure Routing for Underwater Acoustic Sensor Networks", International Journal of Communication Systems, Vol. 30, Issue.13, PP. 1-19, 2017

Guilista Khan, Rakesh Kumar Dwivedi, "Autonomous Deployment and Adjustment of Nodes in UWSN to Achieve Blanket Coverage (ADAN-BC)", International Journal of Information Technology, PP. 1-10, 2018

Heungwoo Nam, "Data-Gathering Protocol based AUV Path-Planning for Long-Duration Cooperation in Underwater Acoustic Sensor Network", IEEE Sensors Journal, Vol. 18, No. 21, pp. 8902 – 8912, 2018.

Shaobin Cai, Yong Zhu, Tian Wang, Guangquan Xu, Anfeng Liu, Xuxun Liu, "Data Collection in Underwater Sensor Networks based on Mobile Edge Computing", IEEE Access, Vol. 7, pp. 65357 – 65367, 2019.

Jing Yan, Xian Yang, Xiaoyuan Luo, Calian Chen, "Energy Efficient Data Collection over AUV-assisted Underwater Acoustic Sensor Network", IEEE Systems Journal, PP. 1-12, 2018

Zhongsi Wang, Bang Wang, "A Novel Node Sinking Algorithm for 3D Coverage and Connectivity in Underwater Sensor Networks", Ad Hoc Networks, Vol. 56, PP. 43-35, 2017

Shanen Yu, Shuai Liu, Peng Jiang, "A High-Efficiency Uneven Cluster Deployment based on Network Layered for Event Coverage in UWSNs", Sensors Basel, MDPI, Vol. 16, Issue.2, PP. 2016

Imad Jawhar, Nader Mohamed, Jameela Al-Jaroodi, Sheng Zhang, "An Architecture for Using Autonomous Underwater Vehicles in Wireless Sensor Networks for Underwater Pipeline Monitoring", IEEE Transactions on Industrial Informatics, Vol. 15, No. 3, pp. 1329 – 1340, 2019.

Mingzhi Chen, Daqi Zhu, "Data collection from underwater acoustic sensor networks based on optimization algorithms", Computing, Springer, pp. 1 – 22, 2019.

Sai Wang, Yoan Shin, "Efficient Routing Protocol Based on Reinforcement Learning for Magnetic Induction Underwater Sensor Networks", IEEE Access, Vol. 7, pp. 82027 – 82037, 2019.

Gulnaz Ahmed, Xi Zhao, Mian Muhammad Sadiq Fareed, Muhammad Zeeshan Fareed, "An Energy-Efficient Redundant Transmission Control Clustering Approach for Underwater Acoustic Networks", Sensors, MDPI, Vol. 19, No. 19, 2019.

Mehr Yahya Durrani, Rehan Tariq, Farhan Aadil, Muazzam Maqsood, Yunyoung Nam, Khan Muhammad, "Adaptive Node Clustering Technique for Smart Ocean under Water Sensor Network (SOSNET)", Sensor, MDPI, 2019.

Muhammad Faheem, Gurkan Tuna, Vehbi Cagri Gungor, "QERP: Quality-of-Service (QoS) Aware Evolutionary Routing Protocol for Underwater Wireless Sensor Networks", IEEE Systems Journal, Vol. 12, No. 3, pp. 2066 – 2073, 2018.

Zahid Wadud, Muhammad Ismail, Abdul Baseer Qazi, Farruk Aslam Khan, Abdelouahid Derhab, Ibrar Ahmad, Arbab Masood Ahmad, "An Energy Balanced Efficient and Reliable Routing Protocol for Underwater Wireless Sensor Networks", IEEE Access, Vol. 7, pp. 175980 – 195999, 2019.

Xingwang Wang, Debing Wei, Xiaohui Wei, Junhong Cui,Miao Pan, "HAS^4: A Heuristic Adaptive Sink Sensor Set Selection for Underwater AUV-aid Data Gathering Algorithm", Sensors, MDPI, Vol. 18, No. 12, 2018.

Guangjie Han, Songjie Shen, Hao Wang, Jinfang Jiang, Mohsen Guizani, "Prediction-Based Delay Optimization Data Collection Algorithm for Underwater Acoustic Sensor Networks", IEEE Transactions on Vehicular Technology, Vol. 68, No. 7, pp. 6926 – 6936, 2019.

Sateesh Kumar Hindu, Waheeduddin Hyder, Miguel-Angel Luque-Nieto, Javier Poncela, Pablo Otero, "Self-Organizing and Scalable Routing Protocol (SOSRP) for Underwater Acoustic Sensor Networks", Sensors, Vol. 19, No. 14, 2019.

Pan Feng, Danyang Qin, Ping Ji, Min Zhao, Ruolin Guo, Teklu Merhawit Berhane, "Improved energy-balanced algorithm for underwater wireless sensor network based on depth threshold and energy level partition", EURASIP Journal on Wireless Communications and Networking, 2019.

Muhammad Khalid, Farah Ahmad, Muhammad Arshad, Waqar Khalid, Naveed Ahmad, Yue Cao, "E^2MR: energy-efficient multipath routing protocol for underwater wireless sensor networks", IET Networks, Vol. 8, No. 5, pp. 321 – 328, 2019.