International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075, Volume-8 Issue-6S, April 2019

Routing Protocols for Underwater Wireless Sensor Networks

Seema S, R. Ambika

Abstract: Underwater wireless sensor networks (UWSNs) are extensively used in ocean exploration applications, such as ocean monitoring, pollution detection, ocean resource management, underwater device maintenance, etc. In underwater acoustic sensor networks, routing protocol design is an attractive research topic since it guarantees reliable and effective data transmission from the source node to the destination node. Out of many routing algorithms that have been proposed in recent years, energy efficient routing protocols are the challenge. In this paper, the challenging issues in designing the routing protocols that have been discussed, which can provide researchers with clear and direct insights for further research. In addition, this paper provides a survey of different simulation tools available for UWSN simulation.

***Index Terms*: Energy efficient, Routing protocols, Simulation Tools, Topology Control, Underwater wireless sensor networks.**

I. INTRODUCTION

Underwater wireless sensor networks (UWSNs) are newly emerged wireless networks, by providing the most promising mechanism for discovering the underwater environment very efficiently. UWSNs are used for scientific, military and commercial applications [1]. These applications range from tactical surveillance to the study of marine life and include unmanned vehicle communication, pollution monitoring, oil extraction monitoring and aquiculture monitoring. UWSNs are self-organized networks, which consist of sensors that perform collaborative monitoring tasks over a body of water. The data collected by the sensor nodes are sent to sink and then gets forwarded to the base station through radio waves. Electromagnetic waves, optical waves and acoustic waves have been successfully used in UWSNs. Nevertheless, radio frequency (RF) waves are affected by high attenuation in water (especially at higher frequencies), thus requiring high transmission power and large antennae. Optical waves can to achieve ultra-high data-rate communications (Gbit/s), but are rapidly scattered and absorbed in water, so they are used for short-distance links. In contrast, acoustic waves enable communications over long-range links because they suffer from relatively low absorption loss.

The major challenges in the design of UWSNs are limited on-board storage, limited battery power as batteries cannot recharge and solar energy cannot be exploited, limited bandwidth, dynamic network topology as nodes tend to be mobile due to their self-motion capability or random motion of water currents. High propagation delay, Connectivity loss and High bit error rates (shadow zones), the impaired channel due to multipath and fading. Energy efficiency has also been a major design concern for UWSNs since all sensor nodes used in UWSNs are battery operated and it is difficult to accomplish battery replacement and the sensors acoustic modems usually consume much energy on data transmission.

In UWSNs, one of the hot research areas is routing protocol design. A routing protocol guarantees reliable and effective data transmission from the source node to the destination node. Considering the differences between the terrestrial and the underwater environment, UWSN routing protocol design is more difficult and restricted than that of Wireless Sensor Networks (WSN) [2]. First, the continuously movement of nodes with water currents makes underwater routing highly unreliable; second, the high propagation delay in the underwater environment is inefficient; thirdly, the special characteristics of underwater acoustic waves and channels limit the application of UWSN technologies. Advance arrangements in the area of deployment is not possible, so the routing protocols should build highly reliable and effective communication links without any pre-arranged devices. Whenever the routing is broken during the data transmission, the routing protocol should able to repair or rebuild the routing in a timely way. The routing protocol must be robust and self-adaptive to operate in harsh underwater environments.

There are different aspects of the designing routing protocols, such as the network architecture, the data forwarding method, and the protocol operation data copies, the transmission method, clustering vs. non-clustering, single/multiple sinks, the cross-layer design routing and the non-cross-layer design routing. the control packets, etc.

II. ROUTING PROTOCOLS IN UWSNs

The process of forwarding data from source nodes to a sink when nodes are mobile is a very challenging task. And the major concern is to save energy and to handle the node mobility. Routing protocols are divided into three categories proactive, reactive and geographical. Proactive type effect a large overhead to create the routes, either periodically or every time when the topology modified. Reactive protocols cause large delays and require the source to initiate flooding of control packets to create the paths and are more appropriate for the dynamic networks. This makes both types of routing protocols unsuitable for UWSNs. Geographic routing considered the promising routing protocol for UWSNs. Geographical routing relies on geographic position information; hence the data packets are sent using its geographic location of the destination instead of the destination network address.

A. Efficient depth-based forwarding protocol (EDBF)

The communication in the UWSN faces many challenges and it consumes

Revised Manuscript Received on December 22, 2018.

Seema S, Department of Electronics & Communication Engineering, Sir MVIT, Bangalore, India.

Dr. R. Ambika, Department of Electronics & Communication Engineering, BMSIT & M, Bangalore, India

much more energy while the packet delivery ratio is low. This protocol uses the weight to select the next hop for data forwarding, which takes full account of the depth factor, the energy ratio and the next hop forwarding quality [3]. First, the depth factor calculated by the relative depth is used for determining the forwarding direction. Underwater sensor nodes are embedded with pressure sensors and can accurately calculate their depth according to the measured water pressure:

$$d = p/\rho g \quad (1)$$

where d is the depth, p is the water pressure, ρ is the water density and g is the gravitational constant. Knowing the pressure of itself and neighboring nodes, hop count information, and two hops neighboring distances, it follows opportunistic directional data forwarding. Second, the energy ratio helps to ensure the load balance. Finally, the next hop forwarding quality is mainly calculated based on implicit acknowledgement (ACK) mechanism to avoid the worse links and the void areas. Besides, the EDBF protocol greatly reduces the use of control packets. Therefore, the EDBF protocol can timely update the routing table, which is well adapted to the dynamic underwater environment.

Packets in EDBF are of two types, hello packet and data packet. All packets use the same packet header which includes the Packet-type, Source-id, Packet-sequence, Forward-id, Depth, Energy and Next-id. This protocol adds the residual energy and depth into the header of the data packets which reduces the usage of the control packets for the packet designing. Each underwater node has a forwarding agent, which contains the next hop selection mechanism. The neighbor node with the largest weight will be selected as the next hop. For the data transmission, it uses the implicit ACK rather than the explicit ACK. Implicit ACK mechanism calculates the weight using depth factor, energy ratio and the forwarding quality of the neighbor nodes. The forwarding quality of neighbor nodes Q is an important factor in the weight calculation. The smaller value of Q indicates that there are more problems between N1 and N2, such as the link or node failure, the existence of void area around N2. If N1 receives the implicit ACK pkt from N2 for the first time, it will consider the strategy to be right and update Q12. However, if N1 receives the data packet from N2 again, it means that the further relaying of the packet is not smooth, so N1 will decrease Q12 and update it. The residual energy of the neighbor nodes is considered to improve the load balancing and the network lifetime. The neighbor information in the packet headers stored directly in one routing entry is only the neighbor node ID, while its depth, residual energy, and other factors are involved in the calculations of Q and W. Before sending the packets, some changes to the packet headers are necessary.

The EDBF protocol has less energy consumption, lower latency, higher delivery ratio in denser networks, and is more suitable for the complex and dynamic underwater environment.

B. Energy balanced unequal layering clustering protocol (EULC)

Underwater acoustic sensor networks (UASNs) are used extensively in activities such as underwater data collection and water pollution detection. Hence prolonging the battery life of UASNs by reducing their energy consumption is one of the means of mitigating this problem. The EULC algorithm designs UASNs with unequal layering based on node depth, providing a solution to the hot spot issue through the construction of clusters of varying sizes within the same layer [4]. The EULC algorithm divides UASNs into layers with an unequal layer spacing that gradually increases from top to bottom. The acoustic sensor nodes cluster exclusively within their layers with contending radii set based on the distances between the respective cluster-heads and the sink node. At the start of UASN deployment, the sink node broadcasts information to all nodes in the network; each node calculates its distance to the sink node based on the received signal power and then estimates its layer based on its depth. After layering, in accordance with their respective election thresholds and conditions the nodes in a given layer become cluster-head candidates, broadcasting cluster-head compete messages including cluster-head IDs, compete radii, weights, etc. The node with the largest weight is then elected as the cluster-head and broadcasts a message within it compete radius to announce its election. Upon receiving the successful cluster- head's election message the other cluster-head candidates join in the cluster, along with the non-cluster nodes within the layer. Within each layer, the node selected as the cluster-head must make note of its residual energy, node degree, and distance to the sink node. Within each cluster, non-cluster-head nodes send packets to the cluster-head node, which then integrates the packets and exports the result to the next cluster-head, which in turn further integrates and exports upwards to the sink node. It uses single- and multi-hop routing for intra- and inter-cluster data transmission respectively.

This algorithm reduces the cluster scale closer to the sink node, thus prolonging node lifetime and addressing the hot spot issue. To reduce energy consumption in inter-cluster communication, the next-hop node is selected in accordance with its residual energy and depth.

EULC outperforms the standard DEBCR and LEACH algorithms in terms of energy consumption, cluster- head numbers management, and network lifetime, thus verifying the energy efficiency of the acoustic sensors.

C. Void- Aware Pressure Routing protocol (VAPR)

This protocol directs a packet to any sonobuoy on the surface based on depth information available from on-board pressure gauges. The main challenge of pressure routing in sparse underwater networks has been the efficient handling of 3D voids. Available heuristics for 3D void recovery require expensive flooding [5]. VAPR protocol uses sequence number, hop count and depth information embedded in periodic beacons to set up next hop direction and to build a directional trail to the closest sonobuoy. Using this trail, opportunistic directional forwarding can be efficiently performed even in the presence of voids and attain loop freedom in static and mobile underwater networks to guarantee packet delivery.

In VAPR, each sonobuoy propagates surface reachability information to underwater nodes and each node updates its variables, namely minimal hop to the surface, sequence number, data forwarding direction, and next hop data forwarding direction. Based on the beacon sender's data forwarding direction, next-hop data forwarding direction is set. Then its local states are updated and by incrementing the hop count and setting its current depth, data

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

forwarding direction, and sequence number, each node prepares a beacon message to broadcast. This beaconing process will repeat, and all the nodes build directional trails toward their closest sonobuoys on the surface.

VAPR performs local opportunistic directional forwarding to deliver data according to the directional trails. The forwarding decision for routing is solely made based on the local state variables, namely the data forwarding direction and next-hop data forwarding direction and not on the hop-count information. If there is no void, packets can always be greedily routed via the upward direction, and we can solely rely on the data forwarding directions for routing. In presence of voids, there will be direction changes, and the next-hop forwarding direction is jointly used with the data forwarding direction to guide the routing direction.

VAPR ensures loop-freedom and outperforms HBR, DBR and HydroCast in terms of packet delivery ratio, average latency and energy consumption per message and significantly lowering the frequency of recovery fallbacks and by effectively handling node mobility.

D. Distributed Topology Control protocols

To impose the requirement of improvement in throughput efficiency of the network while conserving energy, two energy efficient geographic opportunistic routing protocols are proposed called improved Distributed Topology Control (iDTC) and Power Adjustment Distributed Topology Control (PADTC) [6].

iDTC provides void recovery through depth adjustment. In iDTC, each node locally determines if it is a void node or an isolated node. A node with no neighbor with positive ADV value is a void node and has no neighbor in its communication radius is an isolated node. In iDTC, only minimum transmission range is used. After a node determine that it is a void/isolated node, it attempts to move the node vertically to a new depth. Considering only the x and y coordinates, the new depth of a node is determined based on the Euclidean distance between node and closest sink. If this distance between node and its closest sink is less than the minimum communication range, displacement is computed. The difference between previous depth and displacement will be the node's new depth and it moves vertically to its new depth with a hope to find new neighbors who can forward the packet towards its destination. If the node is void region again, recovery procedure is computed again, and node is moved to another depth closer to sink. This procedure can provide a maximum displacement of a node towards sink equal to its transmission range.

PADTC is based on recovery procedure using increment in node's transmission range and depth adjustment. A void node increases its transmission range from minimum to maximum value and look forward to getting neighbor who can act as next hop forwarder using greedy opportunistic routing. When a void node fails to advance packet towards sink, it increases its transmission range to maximum value. The increased transmission range surely help to transmit packet towards destination, without costly depth adjustment operation. If incase, power increment is also helpless, PADTC executes depth adjustment procedure to move the node near sink to forward its packet directly to it.

Node displacement is a costly operation in terms of energy consumption. Therefore, displacement is minimized, and energy is saved. Increasing the transmission range is not as costly as moving the node vertically to a new location. In dense network scenario, most of the time next hop is found by incrementing the transmission range and there is no need to perform depth adjustment operation. However, in few cases, for example in low density networks, both range increment and depth adjustment operations are executed to forward packet towards sink.

Compared to DTC, iDTC and PADTC protocols guarantees the data delivery with much less energy consumption. Moreover, IDTC and PADTC perform minimum displacement in recovering a void node. The significant decrease in displacement leads to high packet acceptance ratio and less energy consumption.

E. Hydro Cast; hydraulic- pressure-based anycast routing protocol

This is a novel opportunistic routing mechanism to select the subset of forwarders that maximizes the greedy progress yet limits cochannel interference and an efficient underwater dead-end recovery method that outperforms the recently proposed approaches. Major challenges like ocean current and limited resources (bandwidth and energy) are addressed and the measured pressure levels are used to route data to the surface sonobuoys. It is stateless and completes its task without requiring expensive distributed localization [7]. Hydrocast nodes are equipped with a low-cost pressure sensor to measure their own depth locally. Many mobile sinks are also deployed on water surface, which move with water flow. To discover a positive progress area toward to the sink, this protocol exploits only the information that is estimated by measuring the pressure of water in different depths. In the first stage, forward selection set, an opportunistic forwarding mechanism is used to select a subset (cluster) of neighboring nodes with higher progress toward to the sink as the next hop candidates. The neighboring nodes that receive a packet will access their priority according to their distance to the destination; the closer to the destination the higher priority. In this subset, a back off timer is set which is set up proportional to the destination's distance and a node will forward the packet only when all nodes with higher priority progress to the destination. After receiving the data or ACK packet of a higher priority node, all other sensors with lower priorities will suppress their transmissions. By this way the possibility of collisions and redundant transmissions is minimized.

A distance-based timer is used to prioritize packet forwarding where the distance denotes the progress toward the surface. When the current forwarder broadcasts a packet, nodes that receive the packet set the timer such that the greater the progress, the shorter the timer. Among those that receive the packet, the highest priority node becomes the next hop forwarder. Then, the remainder of the lower priority nodes suppress their packet transmissions after listening to the next hop forwarder's data or ACK packet. Finding the optimal set for forwarding is computationally difficult, and thus, a simple clustering heuristic is proposed. To this end, the current forwarder requires the knowledge of the two-hop connectivity and neighboring nodes' pairwise distances.

In the second stage, called routing recovery mode, a local maximum recovery mechanism is introduced to deal with the communication void. A node is considered as a local maximum node if there are no neighbors with lower pressure levels. To overcome this problem, each local maximum node finds and stores a recovery path to a node whose depth is lower than itself and explicitly maintain a path to the node called as route discovery method. This node could be another local minimum where there is a new recovery path or the point where the greedy forwarding can be resumed. Whenever a packet hits a local minimum, it is rerouted along the recovery path either safely to a node that can resume greedy forwarding or to a new local minimum. To determine the recovery route, 2-D flooding approach is used, where nodes at the local minima perform expensive hop-limited 2-D flooding to discover the escape nodes where the greedy mode can resume or to locate recovery paths to better escape nodes. This flood involves a significantly more manageable set of nodes.

III. SIMULATION TOOLS

In the underwater sensor network, the acoustic signals are used for communication among nodes because the radio signal works with additional low frequency and it cannot travel far away in underwater. Simulation-based testing can facilitate to signify whether the time and monetary investments are valuable [8]. Simulation is the most common approach for testing new protocol. Several advantages are like lower cost, ease of implementation, and realism of testing large-scale networks. Simulation is not as perfect as real environment. Thus, the designs of various simulators created are accurate and most useful for different situations/applications. The tool, which is using hardware as well as firmware to perform the simulation, is called an emulator. Emulation can unite both software and hardware implementation. Typically, emulator has greater scalability, which can emulate several sensor nodes at the same time.

A. Network Simulator-2

Network Simulators (NS) are a series of discrete event network simulators used in research and teaching. The core of NS-2 is in C++, with Object-Tcl (OTcl) based scripting. Linux operating system is the most compatible for NS-2. Due to lack of GUI, user should learn the scripting language and modelling techniques. NS-2.35 and above versions are used to model and simulate the underwater channel characteristics and propagation model. In NS-2 trace file is the output file generated after running a simulation and can be visualized in Nam. The trace file has a different format for wired, wireless, and mobile networks. To analyse the performance of the network, data from the trace file should be retrieved and analysed using awk scripts by setting the concerned performance metrics. An open source trace file analyser software named NS-2 visual trace analyser is also available to analyse trace files.

B. Network Simulator version-3

This is an open source, discrete event network simulator. It supports visualization and scripted using C++ and Python. The NS-3 Underwater Acoustic Network (UAN) framework can be used in modelling of underwater network scenarios. The UAN model has the channel, PHY, MAC and AUV models. Netanim is another visualization package which is integrated with the NS-3 package itself. Tracemetrics is a software developed to analyse the trace files. In NS-3 simulation, .pcap files can be generated and they can be imported to the well-known packet analyser software Wireshark.

C. Aqua-Sim

Aqua-Sim is a simulator for underwater sensor networks which is developed based on NS-2. It simulates acoustic signal attenuation and packet collisions in underwater environments. Aqua-Sim supports three-dimensional deployment and can be integrated with the existing codes in NS-2. Aqua-Sim and CMU wireless simulation package works in parallel. Aqua-Sim is independent and is not affected by any change in the wireless package. It can evolve independently because any change to Aqua-Sim is confined to itself and does not have any impact on other packages in NS-2.

D. Underwater Simulator (UWSim)

This is a tool for testing and integrating perception and control algorithms of real robots. It is used for marine robotics research and development. A virtual underwater scenario can be visualized and configured using standard modeling software. Controllable underwater vehicles, surface vessels and robotic manipulators, as well as simulated sensors, can be added to the scene and accessed externally through network interfaces. This tool provides an integration of the visualization tool with existing control architectures.

E. Desert

Desert is based on ns-miracle framework. It has c/c++ libraries to support simulation, emulation, test bed experiments and design of new protocols. It also supports cross layer protocol design and experiments. At the network layer, desert has modules for static routing, dynamic routing, flooding, and to assign IP addresses to nodes. It provides modules for six major MAC protocols in data-link layer. Desert offers three hardware platforms for emulation and test-bed experiments and different modules for simulating node mobility in both 2D and 3D scenarios.

F. QualNet

QualNet is a planning, testing and training tool that “mimics” the activities of an actual communication network. It gives a complete environment for design Protocol, creating and animating network scenarios. This consists of graphical tools that show more numbers of metrics gathered during simulation of network scenario. It maintains real-time speed to allow software-in-the-loop and can execute on a cluster, multi-core and multi- processor systems.

IV. CONCLUSION

Interest in UWSNs is increasing, and related research studies are in progress. However, underwater environment is a special environment that has many restrictions. Considering this restriction, many challenges face the design of the routing protocols of UWSNs. The routing protocols in UWSNs have the common objective of trying to increase the delivery ratio while decreasing the energy consumption and latency. However, current routing protocols have not designed to defend against security attacks that can block or degrade network

Published By:
Blue Eyes Intelligence Engineering & Sciences Publication

communication and performance.

In this paper, we introduced an overview of UWSNs characteristics, challenges and some of the UWSNs routing protocols and study their advantages and disadvantages. There are so many research challenges and open issues in routing protocol design for underwater wireless sensor networks, which needs to be investigated. Some of them are the propagation delay model, energy consumption, mobility, security, etc. The new research area is the utilization of intelligent algorithms in the underwater environment and how to use the intelligent algorithms to solve the issues in underwater wireless sensor networks has been a hot open issue in recent years.

Also, we provide a detailed survey on different simulation tools available to simulate underwater sensor networks. For each tool mentioned, its features, advantages and disadvantages are described so that a user can choose the best available tool to satisfy his research requirements.

REFERENCES

1. Akyildiz, I.F.; Pompili, D.; Melodia, T,” Underwater acoustic sensor networks: Research challenges”, *Ad Hoc Netw*. 2005, 3, 257–279.
2. Li, N.; Martínez, J.-F.; Meneses Chaus, J.M.; Eckert, M, “A Survey on Underwater Acoustic Sensor Network Routing Protocols”, *Sensors*, 2016, 16, 414.
3. Xiaoyang Liu, Peishun Liu, Tianli Long, Ze Lv, “An Efficient Depth-Based Forwarding Protocol for Underwater Wireless Sensor Networks”, *3rd IEEE International Conference on Cloud Computing and Big Data Analysis*,2018,467-475.
4. Rui Hou Liuting He, Shan Hu And Jiangtao Luo,” Energy-Balanced Unequal Layering Clustering in Underwater Acoustic Sensor Networks”, *IEEE Access*, 2018, Vol. 6, 39685 -39691.
5. Noh,Lee, U.,Wang, P., Choi, B.S.C., Gerla, M., “VAPR: Void-Aware Pressure Routing for Underwater Sensor Networks”, IEEE Trans. Mobile Comput., 2013, 12, 895–908.
6. Hina Nasir, Nadeem Javaid, Shaharyar Mahmood, Umar Qasim, Zahoor A. Khan, and Firqam Ahmed, “Distributed topology control protocols for underwater sensor networks”, International Conference on Net. Based Info. Systems, 2016, 429–436.
7. Noh, Y., Lee, U., Lee, S.,Wang, P.,Wang, P., Vieira, L.F.M., Cui, J., Gerla, M., Kim, K. “HydroCast: Pressure Routing for Underwater Sensor Networks”. *IEEE Trans. Veh. Technol.* 2016, 65, 333–347.
8. Anjana P Das,Sabu M Thampi,” Simulation Tools for Underwater Sensor Networks: A Survey”, *Network Protocols and Algorithms*, 2016, Vol.8, No.4.

AUTHORS PROFILE

Seema S received the B.E. degree in Electronics & Communication engineering from HMSIT, Tumkur, in 2007, M.Tech degree in Digital Electronics from SSIT, Tumkur in 2011.She is currently pursuing Ph.D. degree in underwater wireless sensor networks at Visveswaraya Technological University, Belgaum, India. She is working as Assistant Professor in the department of Electronics and Communication Engineering at Sir MVIT, Bangalore, India. Her research interests include under-water acoustic sensor networks, crosslayer design and performance evaluation of computer networks.

Dr. R Ambika completed her PhD degree in 2017 in the area of Network Security. Currently she is working as a Professor in the department of Electronics and Communication Engineering at BMSIT & M, Bangalore, India. Her area of interest includes Network Security, Underwater Communication and Machine learning.