IOUT Enabled Underwater WSN Using Dynamic Adaptive Routing Protocol with Improved Reliability

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Abstract —In this paper, a trade-off between the energy consumption and network lifetime is considered. This paper proposes an optimal routing protocol called Energy Dynamic Adaptive Routing (EDAR) protocol. The DAR protocol maintains a tradeoff between the reliability or packet delivery ratio (PDR) of sensor nodes and Bit Error Ratio (BER) using optimal dynamic adaptive routing approach. The proposed approach operates on three different phases, namely, initialization, dynamic routing and transmission. During initial phase, all the nodes in the UWSN share location and residual energy information among all the nodes in the network. During dynamic routing phase, an optimal Directed Acyclic Graph (DAG) based route selection is exploited to select the neighbor and successor nodes. This facilitates the successive routing to transmit the packets from one node to another. Here, the cost function with directed acyclic graph is utilized for better transmission of packets. The experimental results show that proposed method encounters the issues raised in conventional protocol and improves the reliability of packets with higher BER.

Index Terms—Under water sensor network, internet of things, directed acyclic graph, dynamic adaptive routing

I. Introduction

The rapid devolvement in embedded electronics and wireless technology, the interest towards Wireless Sensor Networks (WSNs) has been in rise. The WSNs consists of nodes with limited computational capability and power due to smart sensors and embedded CPU. The sensors make the nodes to monitor several factors like vibration, pressure, heat and humidity. The WSN nodes have computing unit, sensor interface, power and transceiver unit. The sensor nodes perform more critical task, which makes the nodes communication with each other for transmitting the data between the sensors. The communication takes place mostly in a distributed environment and hence a centralized network is needed to improve the communication between the nodes in WSN. It has led to the adoption of Internet of Things (IoT), which provides fast access and high feasibility of environmental data. This could ensure higher efficiency, processing and productivity.

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The most important element in IoT is WSN and it helps to provide common services and collaborates with it when it works as a remote access heterogeneous system in adhoc environment. However, integration of IoT with WSN is not just a speculation, but it is supported by international companies and ensures better development and testability of the system. It helps to link the data generated by the sensor nodes with messaging features, social networks and web-based services.

Routing [1]-[3] is an important factor of WSN communication, which enables an effective communication to share the information between the nodes in the UWSNs. However, it is seen that no routing protocols exists in UWSN and hence the main focus of the paper is to provide trade-off between the network lifetime and energy consumption, which is estimated in terms of signal to noise ratio, bit error rate and packet delivery ratio.

Contributions:

In this paper, a novel optimal routing protocol, which adopts Dynamic Adaptive Routing method, is proposed.

- This DAR protocol is designed to maintain tradeoff between the reliability of packets in underwater sensor nodes (PDR) and network lifetime (SNR, BER) using optimal dynamic adaptive routing approach.
- The entire mechanism is operated in three different phases namely, initialization, dynamic routing and transmission.
- Further, the routing is established using an optimal directed acyclic graph (DAG) dynamic routing phase that helps to select the route between neighbor and successor nodes.
- Finally, the cost function with directed acyclic graph is utilized to find the nodes with higher residual energy for better transmission of packets.

II. Related Work

Many underwater WSN protocols have been proposed in conventional methods, some of which are discussed in this section. This includes the following

Adaptive hop-by-hop vector-based forwarding [4] eliminates null points, centered on the tracked field implementation sub cube tessellation and a linear system mixed integer optimization. It minimizes the amount of submarine sensors mounted inside the target field, guaranteeing the requisite control reliability and access to the network.

3D UWSN Deployment with heuristic based mixed integer linear program optimization [5] ensures the identification limit for river toxic substances. This guarantees full identification of chemical origins for toxins, while reducing costs of delivery. 2D-UBDA chooses, by taking into consideration the cross-section between the probable usage zones of all emission origin downstream of the target field deployment, a number of subzones in which chemical sensors are being installed based on the integer-linear scheduling algorithm.

A 2-Dimensional Underwater Barrier Deployment Algorithm is modeled in [6] where the underwater source is isotropically radiates acoustic interference and radiation and uses the signal collecting information from the different UWSN sensors to actively approximate the origin location. Next, we choose the node whose power is the highest reference node in accordance with our past work, which splits the energy output of the sensor into pairs. Second, the least square one-step approach is verified, and another definition centered on the position estimator for the highest probability origin is given. Second, to cover the non-convex problem into the convex optimization problem, a semi definite programming approach is developed.

A convex optimization problem with one-step least-square method [7] is built to extend UWSNs ' lives. The BEAR protocol suggested is in three steps: (1) initialization, (2) building of the list, and (3) transfer of information. Both nodes share information regarding their remaining energy level and position during the initialization process. During the tree construction phase, our planned BEAR takes advantage of the location information to pick adjacent nodes and to choose supporting and subsequent nodes depending on the cost benefit.

An adaptive hop-by-hop vector-based forwarding [8] stops null nodes from using the median path and weighted the RLS, enabling each direction to be the direct route for UWSNs.

A median and reversed reverse localization scheme [9] incorporating direct and relay forwarding structures to transfer packets from origin to destination. The method of relaying requires selecting the right relay in a series of relay nodes. The optimal relay criterion is a relay node that is less remote from the origin to the destination and has a minimum number of adjacent nodes.

An energy efficient, interference and route aware protocol (EEDBR) [10] reduces the number of transmitting nodes and prolongs the existence and utilization of the network.

An Energy Efficient Depth Based Routing [11] improves the UWSN reliability, network existence and performance. The system includes adaptive sink versatility in a manner that falls into the densest part of the network. The relocation of the sink to a high-density location allows optimal data collection.

Dynamic Sink Mobility Equipped Depth Based Routing [12] that increases the packet delivery ratio as well as conserves limited energy by optimal assignment of member nodes with GN. In contrast, the AUV adjustable stay interval reduces the packet fall ratio and thus maximizes network efficiency [13].

ARCUN [14] increases single-antenna node interaction efficiency. This uses the wireless medium's transmitted nature and transmits the proximate sensor nodes as relays together.

An error control and adjustment method [15] improves the accuracy of the sensor position. We use distance data between nodes to create a model of the network error change that increases localization precision and guarantees a stable position error.

Energy efficient chain-based routing protocol [16] manages the load on nodes. The interaction based on distance is focused on position-conscious nodes and can be used in monitoring domains in a continuous state but in a fluid system and therefore free communication of location is required.

A slotted CSMA based reinforcement learning approach [17] uses a training algorithm and a multiple access system slotted carrier sensor. The proposed system will refine its parameters in order to adapt to the underwater condition once it has been implemented, due to its improving training algorithm.

A fault-resilient localization scheme [18] offers good position precision and reduced overhead interaction. A sensor node predicts its location, by studying how its neighbors are mobile through multiple linear regression, in order to avoid an anchor node error.

All the above methods provide data reliability, energy efficiency and secured routing in underwater sensor network. However, to the best of our knowledge, the use of IoT to improve the communication between the sensor nodes is not addressed, which is the core aim of the proposed method.

III. SYSTEM MODEL

The reliability of links on underwater IoT communication is estimated using a channel model, which is placed in an underwater scenario. The main aim of the model is to estimate successful delivery of packets over each UWSN link. The successful delivery of packets to the destination node estimates the packet reliability and this is considered as an advantageous one for modeling a reliable protocol for communication using our model. There are several elements in the underwater channel model, where the channel is divided into two main parts. Initially, the relationship between transmitting power and SNR is modeled and then the relationship between PDR and SNR is modeled. This helps to calculate the reliability of packets transmitted over IoUT links.

A. Relationship between Transmission Power and SNR

The main aim is to find the relationship between SNR and the transmission power. Here, the SNR is divided based on four regions, namely: source, transmission loss, directivity index and noise level, which is given by

$$\gamma_{dB} = S_{level,\,dB} - T_{loss,\,dB} - N_{level,\,dB} + D_{index,\,dB} \quad (1)$$

The SNR is thus expressed as,

$$\gamma = S_{level} - T_{loss} - N_{level} + D_{index} \quad (2)$$

The relationship between the SNR (γ) and transmitter power (P) is thus expressed as:

$$\gamma = 10\log(P) - \log(4\Pi r^2) - \log(0.67\times10^{-18}) - 20\log d + 18\log f \quad (3)$$

B. Relationship between SNR and PDR

The second goal of the channel model is to estimate the PDR over IoUT. To achieve this, the modulation is chosen as BPSK modulation and Rayleigh fading channel is used for signal propagation that supports multipath effect in shallow and deep water. Based on this, the BER of BPSK in is derived as,

$$BER(\gamma) = 0.5\left\{1 - \sqrt{\frac{10^{o.1\gamma}}{1+10^{0.1\gamma}}}\right\} \quad (4)$$

For a given SNR (γ), the PDR with size m bits is estimated as,

$$P_{success}{}^{m}(\gamma) = \{1 - BER(\gamma)\} \quad (5)$$

$$P_{success}{}^{m}(\gamma) = \left[0.5 + 0.5\sqrt{\frac{10^{0.1\gamma}}{1+10^{0.1\gamma}}}\right]^{m}$$

IV. Proposed Protocol

The proposed protocol uses three phase to provide successful delivery of packets, namely, initialization, tree construction and transmission phase, which are given below:

A. Initialization Phase

In this stage, the sink node broadcasts the packets to intimate the other nodes regarding the total available nodes and to then it informs the start and stop time of the initialization phase. The nodes further estimate the following,

- Comparative location
- Comparative distance from the sink node
- Identification of the sector, where the nodes are located.

B. Tree Construction Phase

In this stage, the construction of tree is done in two stages. Initially, the entire nodes find the neighbor node and finally, it chooses its successor to facilitate the nodes from its neighborhood nodes.

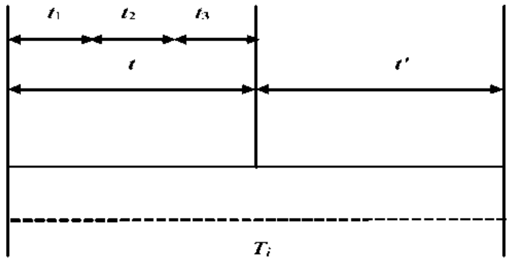

Fig. 1. 4-way handshake time slot.

- Neighbor Finding

At this stage, the lower depth node is searched within its sector and the root node is established towards the sink. The nodes are allocated with a time slot based on the sink for better communication e.g. 4-way handshake time slot (Fig. 1).

The time slot (Ti) is divided into two segments with a maximum length equal to four-way handshakes. Here, the deployment of node is done in a random way and hence the node does not have a neighbor and during that instances, second time slot (t') is used for discovery of neighbors. The entire process is shown in Fig. 2.

Initially, a broadcast hello packet is broadcasted with the transmission range or the threshold range within the sector. The nodes lying inside the range reply with an ACK1 message and provision for a node is made to select only one neighbor from the sector of next hop that lies at lower depth (Fig. 3). Once the ACK1 is received, the node i broadcast the neighbor request near nodes, which has replied with ACK1 message. Further, the intended nodes accept acknowledge and incoming request from ACK2 packet.

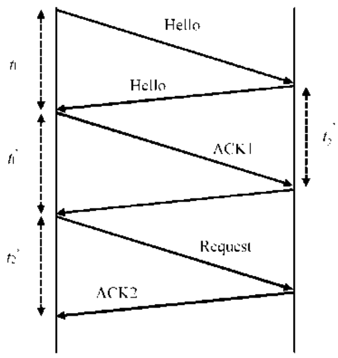

Fig. 2. Mechanism of handshaking method.

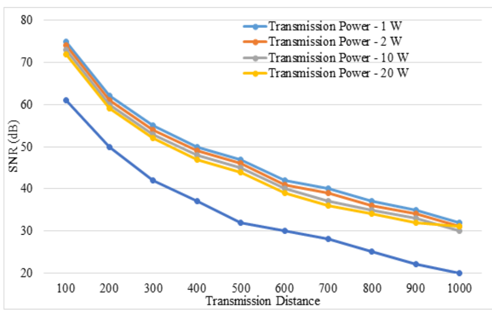

Fig. 3. Results of SNR by applying channel models with different transmitter powers and distances.

This is done while the identity of the sensor node is recorded within its sector. Once the ACK2 is received, the identity of neighboring node is stored, this responds with the help of ACK2 message, and it intimates the sink node with a handshake.

- Search for Energy Efficient Path

In DAR protocol, the entire communication is overseen by the descendant and helping nodes. Hence, the main task is to select the descendant and helping nodes, since it consumes lesser energy for transmission. Consider a cost function (Qij) when a node i communicate with node j, then the cost function is given by,

$$Q_{ij} = \alpha \times d(i, j) + (1 - \alpha) \times d(j, sink) \quad (6)$$

where, d (i, j) defines the distance between node i and j, and d (j, sink) defines the distance between the sink and node j.

The cost function is calculated by the broadcasting function for the neighbor nodes. After the estimation of cost function, the cost function is sorted out in ascender order, where the node id is belonging to the 1st value is considered as the descendent node and the node id belonging to 2nd value is considered as helping node.

At each round, the broadcast node estimates the distance from sink and when the distance is less than the transmission range, the packet is transmitted directly to the sink. On contrary, when the node lies outside the sectoring range, then the comparative energy of the descendant node is checked with average comparative energy and the value of comparative energy is greater than average comparative energy, then the packet is transmitted to the descendant node. In case if the second checking of distance is failed, the comparative energy of helping node is checked by the broadcast node and it transmits the data packets to the helping node. However, if the node lies inside the range, it is transmitted directly.

- Transmission Phase

The distance of the broadcast node is checked at regular intervals from the sink and when it is lesser than the threshold range, the direct transmission is possible towards the sink. On the other hand, when the distance is greater than the threshold range, then the comparative energy of next node is checked. When the energy of neighbor node is greater than average comparative energy, the successor receives the packet. However, when there is a failure in second check, the broadcast nodes estimate the comparative energy and upon meeting the required condition, the packet is transmitted towards that node or it is broadcasted directly over the sink.

V. RESULTS

The performance evaluation is conducted using C++ and the underwater sensor is simulated over Rayleigh Fading channel using BPSK modulation. The parameters are set, the transmission power is set between 1-30W, the frequency is set as 10 KHz, and the packet size is set as 3 KB. Finally, the performance metrics is measured in terms of SNR, BER and PDR.

A. *Evaluation of SNR*

The results of SNR are shown in Fig. 3, which plots the BER as a function of distance that varies between 100 m to 1000m and the transmitter powers are set between 1W and 30 W.

The result shows that whenever there is an increase in transmission distance, the SNR reduces. This is mainly due to loss in transmission, which is considered as major essentials of the SNR. With increasing distance, there is an accumulation of transmission losses and this creates a negative impact on SNR. Hence, in underwater WSN, the transmission distance is inversely proportional to the SNR and this is true in case of various transmission powers. This confirms that the proposed channel model for estimating the SNR is valid for various transmission powers.

In addition, the increase in transmitter power effectively increases the SNR value. This case is true as the distance of transmission is same, the power of the transmitter from low to high SNR are 1 – 30 W. Since, source level power is considered as major factor due to SNR, the source level power may become high when the transmitter power is high. Hence, it could be regarded that the transmitted power is directly related with SNR, since the SNR value is consistent for all transmission distances and it finally confirms that the proposed model is applicable for various distances.

B. *Evaluation of BER*

The results of BER is shown in Fig. 4, which plots the BER as a function of distance that varies between 100 m to 1000m and the transmitter powers are set between 1W and 30 W.

The result shows that as transmission distance increase, the BER increases. This is due to loss in transmission, which is considered as major essentials of the SNR, which increases the BER. With increasing distance, there is an accumulation of transmission losses and this creates a negative impact on SNR, which leads to increase in BER. Hence, in underwater WSN, the transmission distance is inversely proportional to the SNR and this is true in case of various transmission powers. This confirms that the proposed channel model for estimating the BER is valid for various transmission powers.

Additionally, the increase in transmitter power effectively increases the SNR value with reducing BER. This case is true as the distance of transmission is same, the power of the transmitter from high to low BER are 1 – 30 W. This is clarified based on the relationship between the BER and SNR. From Figure 3, it is concluded that as the power of transmission is high, SNR increases and hence BER reduces. Consequently, the power of transmission is inversely proportional to BER. Since, source level power is considered as major factor due to BER, the source level power may become low when the transmitter power is high. Hence, it could be regarded that the transmitted power is directly related with BER, since the BER value is consistent for all transmission distances and it finally confirms that the proposed model is applicable for various distances.

Further, it could be seen that the transmission distance of 1W and 2W leads to higher BER than other transmission distance. However, it creates a computational burden with more expensive implementations compared with light weight implementation of other transmission distances.

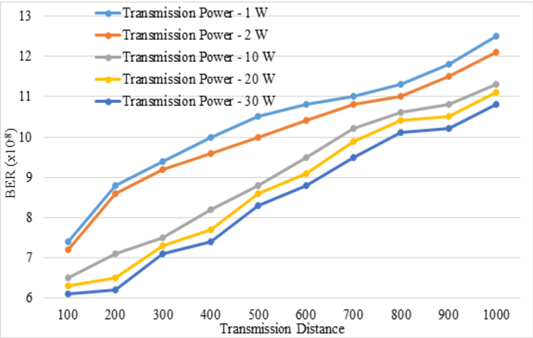

Fig. 4. Results of BER by applying channel models with different transmitter powers (x10-8) and distances.

C. Evaluation of PDR

The results of BER is shown in Fig. 5, which plots the PDR as a function of distance that varies between 100 m to 1000m and the transmitter powers are set between 1W and 30 W.

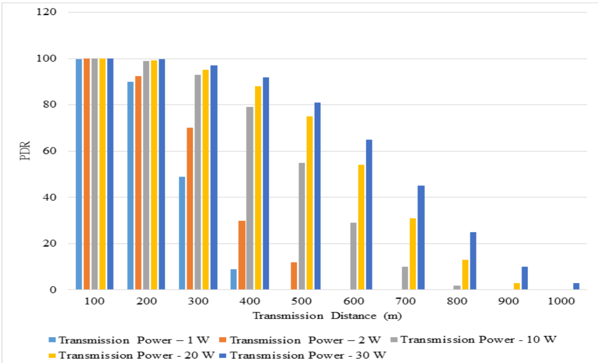

Fig. 5. Results of PDR with different transmitter powers and distances (a) 1 W (b) 2 W (c) 10 W (d) 20 W (e) 30 W.

It is clear from the figure that as the distance of transmission increases, the PDR reduces. This is due to the fact as the transmission distance increases; there is a reduction in SNR and increase in BER. The increase in BER is due to more bits received is altered due to interference, noise, synchronization errors and distortion. Also, if a whole packet is been transmitted, high BER leads to less PDR. In short, as the distance of transmission increases, SNR reduces with increase in BER and hence PDR reduces, which is true for all transmitter powers. As the transmission power increases, it could be seen that the PDR increases with higher SNR and lower BER, which ensures low probability of misleading packets during transmission. This leads to higher delivery of packets towards the destination node. It is confirmed from the results that the proposed channel model is applicable for various transmission power.

VI. Conclusion

This paper provides a new class of IoUT model in Underwater WSN with DAG routing protocol. The proposed routing protocol in underwater WSN proves that the channel model is practical and can be made applicable for varying transmitting power and distances. In specific, as the power of transmission is high, the SNR is high and BER is low, which turns out to be successful PDR. However, as the distance in SNR and PDR reduces as there in an increase in BER. The results confirm that the channel model designed is reasonable and helps the future research to test the IoT model in various other underwater scenarios. In future, we tend to improve the routing in UWSN using artificial intelligence techniques.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

The Author A devised the project, the main conceptual ideas and proof of outline. A and B worked out all the technical details and the parameters to be compared. C and D evaluated the performance with the help of A and B. All the authors contributed for the paper and approved the final version of the paper.

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