# Optimizing Energy using Probabilistic Routing in Underwater Sensor Network

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Abstract: As the Importance of Applications, Such as Ocean Sampling, Environmental Monitoring, Disaster Prevention, and Distributed Tactical Surveillance, Has Recently Grown, the Need for Underwater Communication Has Become More Pronounced. unlike Terrestrial Sensor Networks, Underwater Sensor Networks (Uwsns) Have Different Characteristics Such as a Long Propagation Delay, a Narrow Bandwidth and High Packet Loss.Considering the Various Challenges Posed by the Underwater Environment, a Routing Algorithm Has Been Proposed in This Paper. the Algorithm Consists of Special Features, including Three Different Types of Nodes in the Architecture Proposed, a Mathematical Formula in Order to Select the next Node to Be Used for Transmission. the Major Aim of the Algorithm Is to Select the next Node to Be Used for Successful Data Delivery, and Ensure Minimum Energy Consumption. the next Node Is Chosen With Utmost Care in Order to Increase the Probability of Successful Data Delivery. the Packet Is Transferred from the Source to the Sub-Destination by Exploiting Minimum Energy of the Nodes. the Simulation Studies for the Protocol Were Conducted using AQUA-GLOMO Network Simulator. the Protocol Was Benchmarked With DSR Routing Protocol. the Matrices That Were Considered for the Simulation Study Were Throughput, PDR, Energy Consumption and Delay and It Was Observed That Our Proposed Model Performed Better in the Underwater Environment.

## 1 INTRODUCTION

Marine life is constantly being exploited by humans. Be it leakage of oil in sea waters while extracting crude oil from sea beds, dumping of industrial wastes or over fishing in a particular area. All these and several other human activities disturb the habitat of aquatic creatures. Since, one cannot afford more contamination of water resources, it is the need of the hour that there is continuous monitoring of the underwater environment of seas and oceans and reporting of undesirable activities taking place- whether human or natural.

Acoustic underwater ad-hoc networks need special attention, due to the uselessness of radio waves in water. This gives way to large propagation delays. The diverse topology accounts for connection impairment, high bit error rate, frequent temporary losses of connectivity, and loss of nodes due to erratic water currents. All the above mentioned points hinder us from developing a routing algorithm that ensures high probability of successful data delivery, minimum energy expenditure and lesser time delays.

The transmission of data packets is done in a hop-by-hop fashion. The major focus has been on the selection of the best suited next transmission node. This ensures efficient data delivery with optimized energy consumption. A mathematical model has also been proposed in order to achieve this goal.

The selection of the next node is done on the basis of the relative depth, and the energy and the distance of the nearby neighbouring nodes. The concept of VBR is also being applied in order to incorporate the variable “distance” (distance between sender nodes and other relaying nodes) in the protocol.

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The proposed algorithm is free of any table maintenance or time synchronization techniques. Hence, these features help in saving energy of the nodes up to some extent.

## 2 RELATED WORK

Underwater environment poses many problems for efficient routing in the underwater sensor networks. The routing procedures proposed for terrestrial sensor networks cannot be directly applied in the underwater scenario. Acoustic wavesare used for communication instead of radio waves which are used in terrestrial sensor networks. Acoustic wavesare better than radio waves in underwater environment due to its much lower attenuation as compared to radio waves in water. But acoustic waves have their disadvantages as well. They are characterized by low bandwidth, high propagation delay and high bit error rate. Energy efficiency is the major concern in underwater environment due to the use of acoustic signals and harsh conditions in underwater environment. This makes node replacement a difficult task and also results in a very unpredictable and dynamic topology of the network.

Recently, many routing protocols have been proposed to accomplish effective routing in underwater sensor networks in an energy efficient way.

In VBF (Vector-Based Forwarding scheme) (Xie et al., 2005), each of the sender nodes' one hop neighbour compete to be the next hop node of the route towards thedestination. Each neighbour computes its perpendicular distance from the virtual vector between the sender and the destination. This vector is known as the routing vector. A predefined radius forms the routing pipe around the routing vector. To be a candidate for next hop, a node must lie in the routing pipe formed. Multiple candidates compete among themselves to be the next relay node using the desirableness factor, which tells each node how long it must hold the packet before relaying it. The desirableness factor favours the node nearest to the destination. VBF has been extended to HH VBF (Hop-by-HopVector-Based Forwarding scheme) (Nicolaou et al., 2007) to overcome the shortcomings in VBF such as small data delivery ratio in sparse networks and sensitivity of the routing radius. Instead of using a single routing pipe between the source and the destination, HH VBF uses routing pipes in a hop by hop fashion which increases the packet delivery ratio.

Another location based routing procedure is the DFR(Directional Flooding-based Routing) (Hwang and Kim, 2008). In DFR packet transmission is achieved through scope flooding. The flooding zone is decided by the angles between FS vector and FD vector, where F is the node that receives a packet and S and D are source and destination respectively. F decides whether to forward the packet or not by comparing the SFD angle with the criterion angle (Base angle) which is included in the received packet.

In SBR-DLP (Chirdchoo et al., 2009) algorithm the sender node tries to find the next suitable relay node by broadcasting a check_ngb packet. All the nodes that hear this packet respond by sending *check_ngb_reply* to the sender. To reduce collisions at the sender node each neighbour node determines the sector in which it is in and then schedules the sending of *check_ngb_reply* accordingly. The transmission time of the *check_ngb_reply* depends on the priority value associated with each sector. Using the maximum possible relative velocity and propagation delay associated with the transmission of the *check_ngb_reply* packet the sender node filters out those nodes that may travel out of its range before being able to acknowledge the receipt of the packet. This algorithm takes into account the node mobility in undersea environments but the overhead associated with the generation and processing of mobility (velocity) information of the relaying nodes along with the location information is quite large and is not suitable in underwater environments.

All the above mentioned solutions make use of the location information of the nodes using the GPS. Use of GPSand the overhead due to the location information generated involves large energy consumption. A significant amount of node energyis consumed in finding its current location using the GPS system periodically.

In DUCS (Distributed Underwater Clustering Scheme) (Domingo and Prior, 2007), a GPS free scheme, the nodes organize themselves into local clusters and one node is selected as cluster head for each cluster. Each node in the cluster transmits its data to the cluster head and cluster head transmits it to the sink via the relays of other cluster heads. Cluster Head selection mechanism has a large overhead associated with it and is not energy efficient. Also, there will be collisions at cluster head when the cluster members send their data.

Another GPS free scheme for underwater sensor networks is E-ITRC (Energy efficiency & Innovative Time Reduction Communication) protocol (Donghoon et al., 2007), which is based on minimum response time between the surface station and the underwater sink node. That is, the fastest packet arrival time to a surface station from an underwater sink node is the standard to select routers among underwater relay nodes. This method also lacks energy efficiency as the node selection mechanism requires a large number of transmissions. This algorithm has an on demand element associated with it. On demand routing protocols are not suitable in underwater environments due to high node mobility and dynamic topology of underwater networks.

# 3 PROPOSED MODEL

*A. Assumptions*

Basically, we have two assumptions in this work.

-*General Information*

All nodes know their depth, their remaining energy and the quality of the link with their neighbors.

-*Link Quality*

All nodes can measure each link quality among neighbors.

*B. Protocol Description*

Types of nodes to be used:

1. Relaying nodes.
2. Sensor nodes deployed at the sea bed.
3. Floating nodes (the receivers).
4. Special underwater nodes (Dhurandher et al., 2008).

*Relaying Nodes* - These are the data forwarders and do the simple relaying function. These simply float underwater in the water column between the sensor and the floating receiver nodes .They Communicate using the acoustic channel.

*Sensor Nodes* - These are deployed at the seabed and are the data generators. These nodes perform the function of gathering information from the sea bed. They communicate with the relaying nodes using the acoustic channel.

*Floating Nodes* - These are deployed at the sea surface and are the data collectors. These are the destination nodes for the data generated at the sea bed in the sensor nodes. While communicating with another floating receivers these use radio waves and acoustic waves for communication with the relaying nodes.

*Special Nodes*(Dhurandher et al., 2008) - These are deployed along with the relaying nodes but are less in number as compared to them. Their function is to do all the processing on behalf of the relaying nodes regarding the selection of the next hop for data transmission. These have much more battery life than there laying nodes. They can deploy themselves according to pressure and come to surface when their power is low (Dhurandher et al., 2008) and hence are easy to replace.

Now our basic aim is to make acoustic routing more energy efficient, robust and efficient. To achieve the above we propose the following:

- There should be no on demand element in the routing protocol. We don’t have any route request and route reply phases in our routing as these are not desirable in highly dynamic underwater environments.
- Special nodes are deployed along with the underwater relaying nodes which do the processing involved in the selection of the next hop on behalf of the relaying nodes.
- The parameters used for the selection of next node are depths of the neighbour nodes, their respective energies and the route quality between them after assigning each parameter proper weight age.

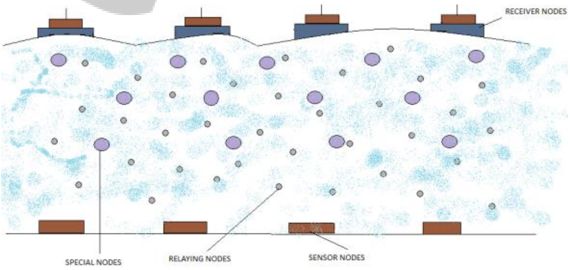



Figure 1: The architecture of the proposed model (Dhurandher et al., 2011).

- The next hop candidate nodes must lie in a virtual routing pipe of some predefined radius as decided by the special node and centered around it. This filters out those nodes that have the possibility of travelling out of the range of the sender node before the sender is able to acknowledge the receipt of the packet.
- Due to dynamic topology and node mobility due to the undersea currents we are bound to have link failures .To counter these and to achieve a near 100% data delivery, we have designed an efficient acknowledgement process. If the acknowledgement for a particular packet transmitted is not received in specific amount of

time then another transmission of the same packet is tried forwarding it to another node. This gives the element of multiple routing in our scheme.

- Multiple routing is done on the basis of priority of the information as decided by the sensor nodes.

The following packets are used in the protocol*:*

- *Request_next_node*packet (request packet to get the address of the next node)**–**The nodes on receiving this packet will shift them to the active mode. It will also contain the depth and energy of the node.
- *Info_node packet* (contains the node's information)– This packet will contain the data about the depth and energy of the relaying node sending it.
- *Data_packet* (contains the information that is to be transferred) **–** The data that is to be transferred is contained in this packet.
- *Transmission_confirmed* packet**-** Acts as a message to the sender node that the transmission has been done successfully and it can delete the data.

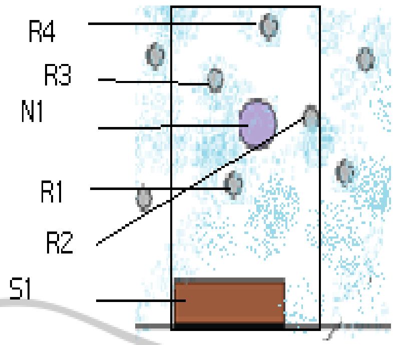
*C. Algorithm*

*Step 1:* Information (*inf*) is being collected by the sensor node. On the basis of the importance of the information the sensor node assigns a priority level to the data (*pri*). Node containing the data transmits *request_next_node* packet (request packet to get the address of the next node). Relaying nodes in the transmission area and the nearest special node receive the *request_next_node* signal. The Special Node on receiving this packet will send a packet to each node that it is the node acting on behalf of the sender node.

*Step 2:* The relaying nodes which hear the signal and are above the depth of node transmitting the request_next_node packet send *info_node* packet (contains the information about the depth and energy of the node) to the special node.

*Step 3:* A virtual pipe is created by the special node whose radius depends on*k* (number of relaying nodes sending the info_node packet to the special node) and depth of the special node from the surface due to currents. The nodes lying outside this virtual pipe are eliminated (i.e. not considered for transmission).

*Step 4:* The *route quality (RQ)*of the remaining relaying nodes is calculated on the basis of the formula. Now this RQ is compared for the relaying nodes and the *best node(R)* is calculated by this method for further transmission. The *data_packet* (the packet containing the information) is now transferred to the selected relaying node(R). The special node will now shift to promiscuous mode**.**




*S – Source Node, N – Special Node, R – Relaying Nodes.*

Figure 2: The construction of the virtual pipe to eliminate the nodes lying outside it.

*Step 5*: The*best node(R)* will now transmit *request_next_node* packet which will be heard by the special node that was involved in its selection .This acts as *acknowledgement (ack)* for the delivered data_packet. If the acknowledgement (*ack*) is not received up to a certain time limit then depending on the priority (*pri*) of the information (*inf*) the algorithm will either repeat itself by making S1 select the second best node or the data_packet will be dropped.

*Step 6*: Steps 1 to 5 will be repeated until the data is received by the floating receiver node. In order to remove ambiguity when two special nodes act on behalf of sender node they first send a packet to sender node asking for confirmation. If the sender node receives one such request then it does not send any packet to the special node. Otherwise, it sends a packet to the node that is farther than the sender node asking it not further transmit any packet. The special node will wait for some time before sending the packet that it is acting on the sender's behalf. If it receives no packet for a time it transmits the packet assuming it has to act. Else, if it receives a packet it will shift to promiscuous mode.

This is the basic pseudo code of the routing protocol. It has the following terminologies:- *inf(*information*),pri(*priority level to the data),*request_next_node packet(*request packet to get the address of the next node*), info_node packet (*contains the information about the depth and energy of the node*), transmission_confirmed packet(*Acts as a message to the sender node that the transmission has been done successfully and it can delete the data*), k (*number of relaying nodes sending the info_node packet to the special node*),RQ (*route quality*), R(best node), promiscuous mode(*where the node can only listen*),ack (*acknowledgement), *ptr* (is a pointer variable that stores the address of the current node).

Each node stores its own depth and energy (refer *subsection A* of section III). The special nodes in addition to this store the *route quality* (RQ[r] based on the previous transmissions) between the nodes lying in its transmission area. Information (inf) is being gathered by sensor nodes. After a certain period of time routing procedure initiates. Figure 3 contains the pseudo code which explains the working of the algorithm.

Priority (pri) of the information (inf) is calculated by the sensor node.

- Do(while ptr!= address of the floating node)
- Let the node which has data be A.
- Declare ptr = address of A.
- Request_next_node packet is transmitted by node A.
- Relaying nodes in the transmission area and the nearest special node (S1) receive the request_next_node packet.
- The relaying node which receives the request_next_node packet and are above the depth d of the node having the inf. (i.e. A) send info_node packet to the special node (S1).
- Now the virtual pipe is created whose radius depends on k and height of S1 from the surface (it is taken due to the effect of current).

$$\mathbf{R = Tr/k + s. (H - H_{n1}) + D_{n1\text{-}s1}} \qquad (1)$$

*R: Radius of the virtual pipe*
*Tr: Transmission radius of the nodes involved.*
*H: Depth of the sea bed*
*Hn1: Depth of node n1*
*S: Constant factor which brings down the value of H comparable to Tr*

- The nodes outside this virtual pipe are not considered for transmission. The nodes left after this elimination are (r1, r2,……..rk).
- Declare depth of each node as d[k] and energy of each node as E[k]in the memory of the special node (S1).
- The route quality (RQ[r]) between each two node is already stored in the special node S1.
- Quality of each node Q is calculated for the selection of the best node depending on the formula:-

$$\mathbf{P[r] = {}^{n}C_{k}\, p_{r}^{k}\, q_{r}^{n-k}} \qquad (2)$$

$p_r = \{[(dep_r)^a. (en_r)^b] / \text{summation of}[(dep_r)^a. (en_r)^b]\}$
*$p_r$: probability of selection of relaying node r in one trial.*
*$Q_r = (1-p_r)$*
*P[r]: probability that a particular node will be selected exactly k times in n trials.*

$$\mathbf{Q[r] = m.P[r] + n.RQ[r]} \qquad (3)$$

- Q[k] of each node is calculated.
- Best node is calculated by comparing Q[k] let it be R.
- S1 unicasts the next_node packet containing the address of R to A.
- Declare i=0.
- Do While(i!=pri)
- Node transmits data_packet.
- If(S1 receives a request_next_node packet from R in time<=t_timeout)
- S1 transmits transmission_confirmed to A.
- A deletes the data.
- Break. *[End of if structure]*
- Else
- S1 transmits next_node packet having the address of next best node to A.
- i++ *[End of inner while]*
- ptr=R *[End of outer while]*

Figure 3: The Pseudo Code.

# 4 PERFORMANCE EVALUATION USING SIMULATION ANALYSIS

To compare the routing protocol, and in order to replicate the underwater environment, acoustic communication based AQUA-GLOMO (Dhurandher et al., 2012) simulation tool for underwater networks, is used. AQUA-GLOMO is a simulation tool based on Glomosim for large wireless networks in the underwater scenario. Dynamic Source Routing (DSR) (Johnson et al., 2001) protocol is taken as benchmark and the results are compared to it

*A. Simulation Setup*

We focused on three performance measurements to compare the routing protocol: Packet Delivery Rate (PDR), Energy consumed by the network and average end-to-end delay for a packet. The comparison has been done for both static and mobile scenarios, with and without the acknowledgement process.

The three parameters in the experiments are defined as follows:

I.) Packet Delivery Rate: Packet delivery rate is the ratio of the number of user packets successfully delivered to a destination to the total number of user packets transmitted by source nodes.

II.) End-to-end Delay: The average time from the beginning of a packet transmission at a source node until packet delivery to a destination node. The time when the last packet is delivered is recorded. The average end-to-end delay is found by dividing the above recorded time by the number of packets received.

III.) Energy Consumed: The total energy consumed by the network in transferring 100 packets from source to the destination. We have considered that the nodes consume 1J of energy in transmitting data packets, broadcasting *Hello Packets, sending Loc and Ack packets*. It is also assumed that 0.5J of energy is consumed by a node in doing calculations such as calculating distance, updating table, etc.

In the analysis, one hundred (100) packets of 512 bytes each were sent from source to destination at a time interval of 480ms.

### *B. Simulation Results*

The simulation has been carried out in both static and mobile scenarios.

*Static Scenario*

The terrain dimension was fixed to 900m x 900m. The placement of the nodes was uniform and the transmission power of each node was set to 3dB. All the nodes were fixed at their respective locations. Values for the three above mentioned performance metrics were noted and the graph is plotted for81, 100, 169, 256, and 289 nodes. For each number of nodes, the measurements are done with and without the acknowledgement.

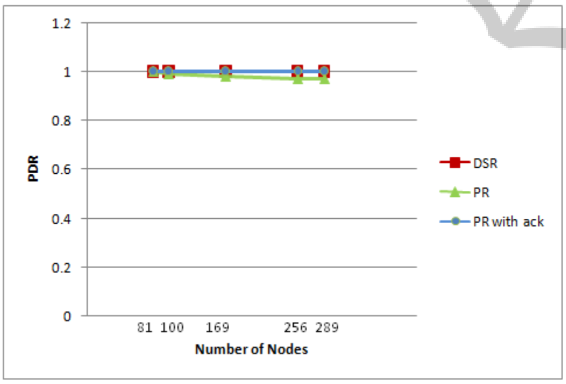



Figure 4: PDR vs. number of nodes in static scenario.

Figure 4 shows the metric PDR for the two protocols DSR and Probabilistic Routing algorithm. In static scenario almost all the packets are received at the destination nodes in both cases. Hence, PDR has a value of almost 1.0 for both the protocols.

Figure 5 shows the total energy consumed in the network in transmitting 100 packets from source node to destination node. It is clearly visible from the figure that the energy consumption in PR is much less than DSR. As the PDR is almost 1.0 for the PR without *Ack*so there will be almost no difference between the energy consumed for the with and without *Ack*algorithm as no packets will be retransmitted.

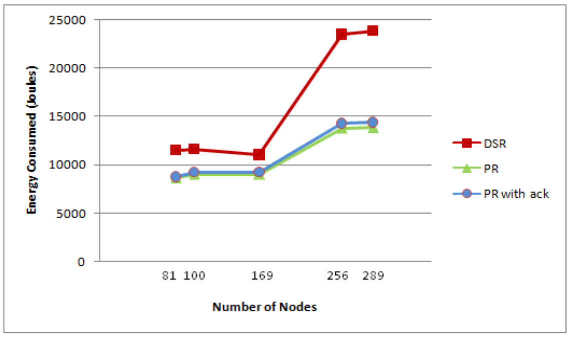



Figure 5: Total Energy consumed in the whole network vs. the total Number of Nodes present in the network for static scenario.

*Mobile Scenario*

The results have been taken after the mobility of the simulation is set to 2.0 m/sec.

Figure 6 shows the PDR in the mobile scenario. The difference between DSR and PR algorithm is quite remarkable and also when the *Ack* process is used the PDR can further be improved.

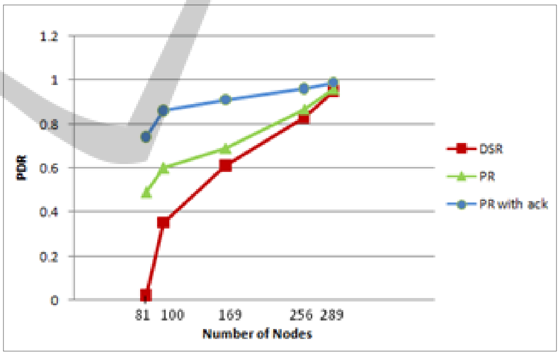



Figure 6: PDR vs. number of nodes when nodes are moving at a speed of 2 m/sec.

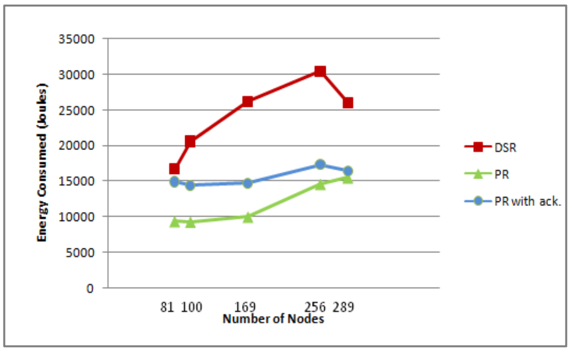



Figure 7: Total Energy consumed in the whole network vs. the total Number of Nodes present in the network for static scenario.

Figure 7 shows the total energy consumed by the network in mobile scenario for 100 packets it can be clearly seen that the energy used by PR is almost half to that used by the DSR. Also in the case of PR with *ack*some packets are retransmitted depending on their priority due to quite a difference in PDR and hence there is a small increase in the energy consumed as compared to PR without *ack* though it is still very less as compared to DSR.

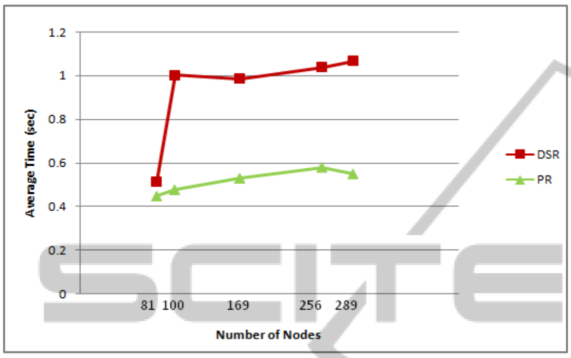



Figure 8: Avg. End to end delay vs. the total Number of Nodes.

In Figure 8, end to end delay of the PR is recorded for the underwater environment and is compared with DSR. As it can be clearly seen from the graph for small number of nodes the end to end delay is almost same for the PR and DSR but as the number of nodes is increased the end to end delay of PR turns out to be almost half to that of DSR.

## 5 CONCLUSIONS

In this paper we have proposed a Probabilistic Routing algorithm which is suitable for mobile underwater acoustic sensor networks where the nodes can move along in the network.Its design takes into consideration the unique characteristics of such networks, namely, long propagation delay, node mobility, high channel error rate, and low data rate.

The DSR protocol has been implemented and compared with the PR protocol. It is found that the PR has a better performance with respect to energy consumption, end to end delay and throughput as compared to DSR in UWSN. From the simulation results it is concluded that the lifetime and packet delivery ratio of the network is improved, with the reduction in end to end delay for the proposed protocol over the existing DSR protocol.

The algorithm also ensures quite high PDR with low energy utilization and does not involve any multi-path routing or time-synchronization techniques. The PR algorithm is simple and easy to implement. Hence, the algorithm is suitable for real-time implementation as well.

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