Priority Enabled Distance-energy based Routing Algorithm for UWSN

C. P. Gupta[1], Mayank Bisht[1] and Arun Kumar[2]
[1]*Department of Computer Engineering, Rajasthan Technical University, Kota, India*
[2]*Department of Mathematics, Government College, Kota, India*

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Abstract: Underwater Sensor Networks (UWSNs) are being deployed for range of applications like collection of oceanic data for research, military surveillance, disaster prevention, underwater exploration etc. Characteristics such as use of acoustic signal for communication, 3D deployment, and higher losses make routing in UWSNs different from terrestrial sensor networks. In this paper, we present a location aware routing algorithm based on routing factor (Rf); a function of distance and energy. In our proposed algorithm, forwarding node is selected by sender amongst its neighbors depending on their distance from destination node and residual energy. To consider energy with distance, Energy scale value (Es) is used as a scaling range. Priority packets are also used for quick delivery of packets. Simulation results show improved performance of our routing algorithm in terms of network lifetime and end to end delay.

1 INTRODUCTION

Underwater Sensor Networks (UWSNs) provide huge potential for development & utilization of underwater resources. Sensor nodes & Autonomous Underwater Vehicles (AUVs) are envisioned to find application in the exploration of underwater regions for environmental monitoring, intrusion detection & surveillance, mine detection, assisted navigation, underwater exploration and seismic sensing (Hied. et al, 2012). But these potential applications are viable only if we have efficient underwater communication system.

Characteristics of UWSNs differ from terrestrial WSNs in terms of communication methods, network deployment and protocols etc (Davis and Chang, 2012). Since radio waves suffer from high attenuation in water, acoustic signals are used for communication in UWSNs. This renders terrestrial routing techniques unsuitable for UWSNs. UWSNs also suffer from high delays, transmission losses and node mobility due to water currents, which may result in loss of connectivity and node failures (Manjula et al., 2011). Routing protocols designed for sensor networks are based on characteristics such as type of signals used, available power & bandwidth, delays, losses, node deployment (Zaihan, 2008). However, advancement in semiconductor technology have overcome limitations of processing speed, storage in UWSNs, still underwater deployments occur over shorter periods (several days), rather than months or years common in terrestrial sensing. Efficient Routing techniques can improve the lifetime of the network.

In this paper, we propose a routing algorithm that considers both distance and energy of nodes for making routing decisions in a 3-dimensional UWSN. The proposal is a location based algorithm in which all nodes are aware of their position in the network. Routing decision is taken by the sender based on Routing factor (Rf); a function of neighbour's distance to sink and its residual energy. High priority packets are routed differently ensuring lower end to end delay. Routing tables are used to reduce packet transmissions among nodes and hence improve performance. Our simulations show improvement in lifetime & network throughput with satisfactory end to end delays.

Rest of the paper is organized as follows. In Section 2, we will review some existing routing protocols for UWSNs. Section 3 describes our proposed routing algorithm. Performance evaluation of the proposed algorithm is presented in section 4. Finally conclusions are drawn in Section 5.

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2 RELATED WORK

Vector Based Forwarding (VBF) (Xie et al., 2006) is a location based routing protocol involving only a fraction of nodes in routing. Packets are forwarded along a virtual tunnel from source to sink. A self adaptation algorithm for adjusting the forwarding policy based on node density was also proposed. The algorithm introduces desirableness factor in the range of (0, 3) to measure the suitability of a node to forward packets. Received packet is held by the node for a time period related to its desirableness factor, such that node with less desirableness factor will forward the packet earlier. However, redundant packet transmissions and packet delays cause energy losses requiring alternate measures.

Focused Beam Routing (FBR) protocol (Jornet et al., 2008) uses a distributed approach, in which route is dynamically established as the data packet traverses the network towards its final destination. For finding all the nodes in a cone with $\pm\theta/2$ emanating from the source nodes towards the destination nodes at the minimum distance, a *Ready_To_Send* (RTS) signal with minimal energy is transmitted. In case, no node responds through a *Clear_To_Send* (CTS) like packet, the power level and if required also value of θ is varied. The node closer to final destination is selected as the relay node for the next hop. However, performance of algorithm is heavily dependent upon collision of CTS packets at the source of RTS. End to end Delay is also high in FBR.

Depth Based Routing (DBR) (Yan et al., 2008) requires only local depth information against the full location information required in VBF. DBR assumes multiple sinks deployed at the surface communicating with each other & Base Station through radio links. Each packet in DBR contains the depth information. On receiving a packet, node forwards it only if it is closer to sink i.e. situated at lower depth than sender node. Priority queue mechanism is used to reduce the number of forwarding nodes transmitting the same packet. Each node receiving the packet compute packet holding & scheduled sending time based on its depth such that the node at lower depth transmit the packet earlier than node at a larger depth. The algorithm requires synchronization of clocks to ensure that scheduled sending time is computed correctly by all the nodes. Also, it requires specific deployment with sink nodes floating on water surface.

An *Energy Efficient Localization free Routing Protocol* named EEDBR proposed by Wahid et al., 2012 also utilizes the depth of sensor nodes for forwarding data packets along with the residual energy of sensor nodes to improve the network lifetime. Sender node enquires depth information among its neighbours and according to their depths create prioritized node list. On receiving packet, each node holds the packet for some time on the basis of its priority in the priority list. The EEDBR results in improved network lifetime, energy consumption and end-to-end delays and offers comparable delivery ratio. However, the proposed algorithm requires sorting for assigning priorities which require more storage and computing power within the sensor nodes. Also it requires specific deployment with sink nodes floating on water surface.

SBR-DLP (Sector-Based Routing with Destination Location Prediction), proposed by Chirdchoo et al., 2009 is also a location based routing protocol for UWSN. SBR-DLP assumes sink node to be mobile with pre-planned path and schedule known to all other nodes in the network. The whole range of node is divided into a number of sectors. The sectors are prioritized based on angular differences from the virtual vector SD from the sender S to Destination D. Then according to sector priority, the node closest to predicted location of the mobile sink is selected as forwarder node. Latest network information is acquired each time before sending a packet using *chk_ngb* & *chk_ngb_reply* packets. Limitations of this algorithm include large delay between the packets due to *chk_ngb/chk_ngb_reply* packets.

More routing techniques for UWSN are discussed in (Wahid et al., 2010). Unlike location unaware routing algorithms DBR and EEDBR, our proposal does not require sinks to be floating on the surface. Our algorithm works even if the sink is mobile or at distant region of network deployment.

3 PROPOSED ALGORITHM

In our algorithm, routing decision depends on the amount of residual energy of the neighbour node and its distance from the destination node. Sender decides the next forwarder node from its neighbours and unicasts the packet to that node. Thus, our algorithm attempts to route the packet through a node which balances energy consumption in the neighbouring nodes while maintaining acceptable packet delay and delivery ratio. This avoids selecting a certain node or group of nodes every time to forward a packet. UWSN characteristics such as 3-D network architecture, node mobility, acoustic channels, and limited power availability have been taken into consideration in our proposal

Following assumptions have been made while designing the algorithm:

- Each node knows its location. It is required as the proposed algorithm location based routing algorithm (Vijay and Choo, 2006).
- Sinks are mobile and are equipped with navigational and propelling system (as like an Autonomous Underwater Vehicle). The trajectory of sinks is pre-planned and is known to all the nodes in the network. Sinks are allowed to deviate from the trajectory only within a range.
- All nodes other than sink node(s) have random walk dynamic mobility pattern.

3.1 Packet Formats

Three types of packets namely; *Hello, Ack and Routing* are used in our proposal. *Hello Packet* is broadcasted by a node to enquire about its neighbouring nodes in the network. *Ack* packet is sent by a node in reply to *Hello* packet. After receiving *Ack,* nodes update their neighbour table with the information contained in this packet. *Routing Packet* contains information about the packet and data to be sent from source to sink node. *Priority_Bit* sets priority with which packet is to be sent by the sender. It is 1 for priority packet and 0 for normal packet. The packet formats are shown in Fig 1.

Sender_Id (10)	Position (36)	Residual Energy(16)	Broadcast address (10)

(a) Hello Packet (72 bit)

Sender Id (10)	Position (36)	Residual Energy(16)	Unicast address (10)

(b) Ack Packet (72 bit)

Source Id (10)	Forwarder Id(10)	Sink Id(10)	Packet_Sequence Number(15)	Priority Bit (1)	Data

(c) Routing Packet (4800-bit)

Figure 1: Packet Formats.

3.2 Routing Tables

Two tables are maintained by each node to minimize exchange of control packet (*Hello* and *Ack*), speed up packet transmission and reduce end to end delays.

(a) Neighbour Table: Neighbour table holds information of neighbours which is updated whenever the node has a packet to forward and is supposed to be stable for a predetermined duration based on intensity of water currents. Higher duration is set for networks deployed in still water. The neighbour table has the following structure

<Neighbour_Id, Position, Residual_Energy>

(b) Sink Table: Sink table holds the information of the sinks deployed in the network. It also stores information related to previously taken path by a packet from that node to each sink listed in table. The sink table stores the following information:

<Sink_Id, Position, Fwd_Id_nomal, Lf_n, *Fwd_Id_priority,* Lf_p*>*

Sink_Id and *Position* represents the position of sink node; *Fwd_Id_normal* & *Fwd_Id_priotity* represents the previous forwarder's Id in normal and priority modes; Lf_n & Lf_p are the time intervals called lookup factor for the validating the suitability of sending current packet through previous forwarder node to sink node.

Algorithm: Distance Energy based Routing Algorithm with Priority Handling.

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At Each Node:
1. If nbr_table == empty() OR $t_{nbr\_upd}$ is expired
   Create nbr_table
   i.Broadcast Hello packet
   ii. Analyze Ack packets replied by nodes.
   iii. Update nbr_table , $t_{nbr\_upd}$ & d_thresh.
2. If a node has packets to send/forward
   i.Create packet, set sink_id and priority.
   ii. In sink_table against the sink_id and
       packet_priority check Lf
   iii. If 'Lf' is not expired OR 'Lf' ! = NULL
        a. Schedule the packet for forwarding using
           previous forwarder node in sink_table.
   iv. If ' Lf ' is expired then
        a. Calculate the Rf for each neighbour node
        b. Select node with minimum Rf value as
           forwarder node to send packet
        c. Schedule the packet for forwarding.
        d. Update sink_table
3. If a node receives a packet
   i. If Hello packet then reply with a Ack packet
   ii. Else if routing packet then
        a. Extract source and sink information.
        b. If node_Id == sink_Id then
           i. Receive the packet
        c. Else forward packet by following step 2.
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3.3 Design of Algorithm

Design factors and elements of our algorithm are discussed below:

(a) Routing Factor (Rf) and Energy Scale Value (Es): Routing Factor (Rf) is computed by sender

node on the basis of distance between its neighbour & sink and neighbour node's residual energy such that the most suitable node for forwarding the packet has minimum *Rf*. Energy Scale Value (Es) is scaling range for node's residual energy to commensurate it with distance for computing Rf.

Let, Distance between neighbour & destination node = dist(n,d),
Energy Scale Value = Es,
Current residual energy level = E_{res}
Energy Difference or Initial Energy = E_{diff}

Then, Routing factor is given by:

$$Rf = dist(n,d) + Es * (1- E_{res}/E_{diff}) \quad (1)$$

This is the *Rf* for forwarding a normal packet. While forwarding a priority packet, '*Es*' is assumed to be 0. 'I' plays a major role in balancing the energies of candidate forwarding nodes. It adds up an extra value to *Rf* against node energy to make the routing decision dependent on energy also.

Fig.2 illustrates routing decision based on *Rf*. Distance d_i is distance of destination node D to neighbour node *i* and ed_i is scaled value of energy of neighbour nodes. Value of ed_i is less for node having high residual energy. From (1) we have *Rf* as the sum of d_i and ed_i. The node with minimum *Rf* is selected as next forwarding node by sender S.

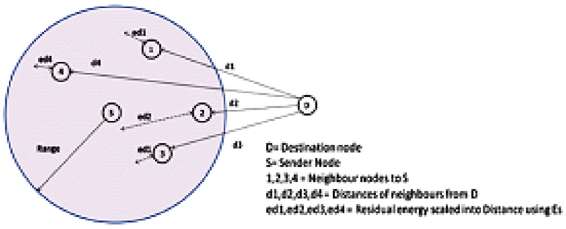

Figure 2: Illustration of routing decision.

In above figure, neighbour node 2 has minimum distance d_i but less energy (as ed_i is large) while node 3 has more distance d_i and more energy (as ed_i is small). The overall Rf is less for node 2 hence, node 3 is selected as forwarder. For a priority packet as only distance is considered for computing Rf so node 2 will be selected for forwarding the packet.

(b) Distance Threshold (d_thresh) and Packet Burst Size (bs): Distance threshold is a function of time used to cancel out the motion effect of nodes that may move out of the range of sender before t_{nbr_upd} expires. Whenever t_{nbr_upd} is set, value of d_thresh is set to minimum value. As the time progresses, d_thresh increases. "*d_thresh*" is the maximum motion of nodes after 't' units of time. For finding suitable forwarder then, node decreases its range by *d_thresh*. Packets are generated by nodes in burst of 1 to 4 packets depending on size of information to be sent. Packet can be generated by any node in the network (except sink node).

(c) Priority handling and Routing Decision: Routing decision is taken by the source or intermediate sender node itself depending on type of packet, by accessing the neighbour information in neighbour table or previous forwarder information in sink table. The packets can be forwarded as normal or priority packet as decided by source. Priority packets is an arrangement of sending packet with minimum end to end delay by considering only distance information for urgent information. Priority packets are not targeted to balance energy and are given priority among other packets at each node in the network.

(d) Packet Acknowledgements: Acknowledgements can be carried out in two ways. First way is to use acknowledgements from sender node and forwarder node in a hop by hop fashion. Secondly, we can use packet acknowledgement from sink node to source node on successful delivery of packet. Size of these acknowledgements is very small so they can be easily used in the network and can even be piggybacked by other packets. However, due to node motion, it is difficult to provide second type of acknowledgements. Hence, we use hop by hop acknowledgements to ensure successful delivery of packets.

4 RESULTS AND ANALYSIS

We simulated our routing algorithm on a simulator program created in C++ and use aqua3d animator to visualize the simulations and working of our algorithm (Tran, 2009). Simulations were performed a large number of times and the results were averaged from all results. Table 1 list the parameters used in our simulations. For evaluation of our proposed routing algorithm, we use following performance metrics.

Lifetime: Network Lifetime is the time before first node die in the network. We considered lifetime as the time until a number of nodes die in the network.

End to End Delays: It is the time taken by a packet to reach from source node to destination/sink node.

Packet Delivery Ratio: It is the ratio of number of unique packets successfully delivered at the sink

Table 1: Simulation Environment.

SIMULATION SETTING	**VALUE**
Node Deployment Area	1000 x 1000 x 600 m^3
Deployment Type	Random deployment
Node Speed	1 to 3 m/sec (random direction)
Modem Type	Acoustic Modem
Antenna Type	Omni-directional
Transmission Range	300 metres
Data Rate	15000 bps
Speed of Sound	1500 m/sec
Size of Data Packet	4800 bit
Size of Control Packets (Hello & Ack)	72 bit
Energy Scale Value	300
Packet Burst Size	1 to 4 packets
Neighbour Update Time (t_{nbr_upd})	4 sec
Lookup Factor (Lf_n & Lf_p)	2 sec
Number of Sink Nodes	6
Number of Total Nodes	Variable (60 to 120)

4.1 Performance Evaluation

(a) Lifetime: We evaluated lifetime of the network against percent of nodes dead in the network for both the proposed routing scheme and SBR-DLP.. Comparison of overall lifetime in both the routing schemes is shown in Fig 3. We observe an increase in lifetime by a factor of 2 with respect to SBR-DLP. This is because SBR-DLP always enquires about neighbouring nodes before sending a packet hence nodes die soon (Chirdchoo et al., 2009). Our routing technique employs balanced energy consumption and thus improves network lifetime. The lifetime of SBR-DLP does not much deviate even after increase in node density as the number of transmissions to find neighbour nodes also increases.

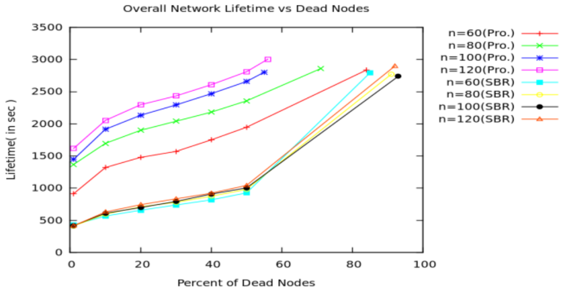

Figure 3: Comparison of Overall Lifetime with SBR-DLP

(b) Packet Delivery Ratio: Comparison of overall PDR in both schemes is shown in Fig. 4 below. Overall PDR decreases rapidly as the dead nodes increase in the network. At lower network densities, delivery ratio of SBR-DLP is much higher than our proposed routing. However, at high densities we observe a comparable overall PDR in both the routing schemes. SBR-DLP performs well in case of PDR than our routing because it utilizes latest network information while performing but it costs more energy usage and hence the lifetime of the network (Chirdchoo et al., 2009).

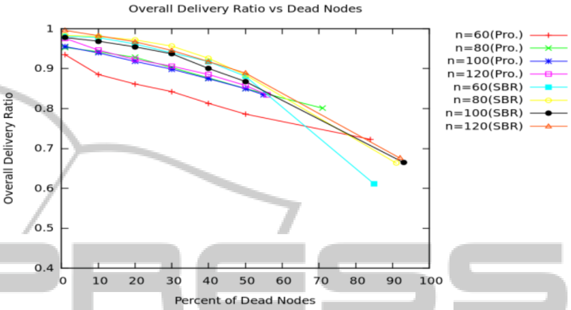

Figure 4: Comparison of Overall PDR with SBR-DLP.

However, number of packets actually delivered should also be considered before accounting for higher delivery ratio in SBR-DLP. Because more the number of packets send, higher are the chances of packet loss, hence lesser delivery ratio. Fig. 5 shows packets delivered in both routing schemes. Number of packets delivered increases with increase in network density. In our routing scheme number of packets delivered is much more compared to that in SBR-DLP. In SBR-DLP, energy drains out in successive transmissions in finding network information before sending each packet. Increase in number of packets generated and delivered decreases the delivery ratio in our proposed routing algorithm.

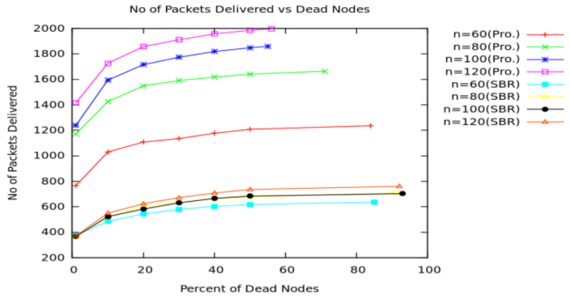

Figure 5: Comparison of Number of Packets delivered with SBR-DLP.

(c) Overall End to end Delay: E2E Delay in both the routing schemes is shown in Fig 6. We observe comparable delays in both the routing schemes. At adequate node densities our algorithm performs better than SBR. However, at low densities, due to inadequate routing options we observe some increase in end to end delay. Also, delays are dependent on node motion and neighbor density which can be highly unpredictable at times.

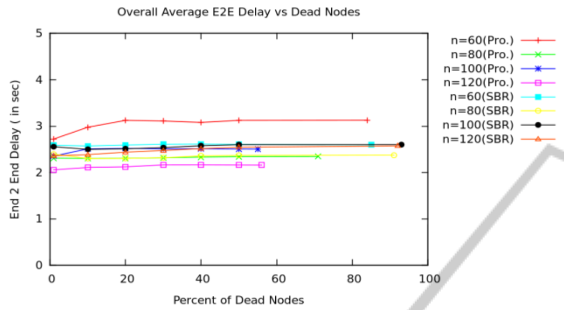

Figure 6: Comparison of Overall Average E2E Delay with SBR-DLP.

5 CONCLUSIONS AND FUTURE WORK

Energy efficiency is one major issue in UWSNs. In this paper we proposed distance energy based routing algorithm which improves the lifetime of underwater networks by utilizing location and residual energy information to route a packet. Simulation results shows that the proposed routing algorithm improves the network lifetime with satisfactory packet delivery ratio and end to end delays. Also it has the priority concerns for a packet which allow the packet to be forwarded with the shortest path possible with high priority and minimal waiting time. The simulation results are analysed on various performance metrics and the results were satisfactory.

Our routing algorithm needs to be developed further so that it complies with optimality constraints on Energy Scale and mobility. Complex routing scenarios like void prevention, looping of data packets, packet collisions also need to be addressed. Other improvements include minimizing overheads, increase channel utilization, self configuring nodes, incorporating the localization algorithm as a part of routing algorithm. Developing this algorithm as a part of open source software like NS2 will make it susceptible with networking standards.

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