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Event Driven Application Specific Prioritized Data Transmission Approach for Underwater Wireless Sensor Networks

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The paper presents a novel framework based on prioritized event detection for Underwater Wireless Sensor Network (UWSN). The proposed approach named Event Driven Energy Balanced Routing (EDEBR) takes the routing decision based on oceanic environment parameters (temperature, density, salinity and pressure). The approach of EDEBR considers two routing phase based on annotated parameters of Critical and Non-critical event priority. Here critical data routing phase focuses on fast and reliable delivery of data and Non-critical data routing phase focuses on the network lifetime through energy balancing technique. The proposal is evaluated and compared against the standard state-of-art protocol on the basis of following three evaluation parameters i) end to end delay, ii) Network lifetime and iii) Throughput of the network. Here in case of critical data the end to end delay is reduced this satisfies the condition for fast delivery. In case of non-critical data, the energy is conserved this enhances the overall life time. Lastly the maximum throughput is achieved in cases of critical and non-critical. Thus the proposal describes a novel routing mechanism for different priority data based on annotated critical and non-critical priorities in underwater environment. The viability of proposal for both cases critical and non-critical is validated through the simulation.

Keywords: Delay sensitive, Depth based routing, Energy efficient, Mixed-hop transmission, Multi-hop transmission,

Introduction

Underwater Wireless Sensor Networks (UWSNs) is an emerging field of the research due to the wide variety of applications such as Oceanographic monitoring, tactical surveillance, oil and mineral fields, underwater disaster monitoring, moving object detection.[1] UWSNs entail of sensor nodes, which collaboratively sensed environmental as well as non-environmental data values throughout the application area and forward it to the surface station for processing and decision making purposes. Sensor node consist of one or more sensors, an embedded processor to process sensed data, a transceiver unit to transmit sense data, and a battery to provide power to each component of sensor node. The sensor node senses environmental water condition in terms of temperature, salinity, density, pressure and so on, and other inner water activity such as object motion, inner water surface fields. The sensed data then process through embedded processor initially for observing any changes, and then forwarded to the surface sink for further processing. Every sensor node acts both as a sender and as a receiver. But due to the harsh environment and underwater communication characteristics,[2] energy efficiency is much needed to live longer the network and to optimize the routing efficiency. Sometime critical events such as tactical surveillance and disaster prevention needs low response data communication to meet the application requirements. Which, in turn demand lower end-to-end delay and fast transmission. Therefore, besides imbalance energy consumption, end-to-end delay is also play an important role for time-critical applications like underwater object movement detection submarine and torpedoes, inner surface disaster prediction, and other security level surveillance, etc. Reliability of communication under acoustic channel[1] is affected due to water turbulence, Doppler effect, and path loss. Hence, despite of energy efficient approach, a delay sensitive,[2] fast transmission scheme also desirable for underwater communication. To overcome the deficiencies of underwater channel characteristics for communication, we proposed an application specific event driven routing approach, which uses energy balancing as well as delay sensitive routing mechanism based on the application scenario. In this

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paper, we propose an event detection framework for detecting the event on the basis of parametric measurement of environmental and non-environmental sensed value. The framework classify event priority based on four environmental data values temperature, salinity, density, and pressure by thresholding the upper and lower limits of parametric values based on the study provided by Puyate, Y. T.; for Atlantic Ocean[3]and shown in Table 1. The sensed activities, then classify as critical and non-critical events. The routing mechanism is than design for the specific event priority.

Many of the researchers[4-6] proposed energy efficient routing approaches to prolong the lifetime of network. Some researcher[7-9] follows the energy balancing approach to optimize energy consumption through network partitioning as traditional sensor network. On other hand, despite of energy consumption, researcher also suggests[10-12] delay sensitive routing for time critical application. But, in best of my knowledge, no one suggests routing based on event driven mechanism, which works for both time-critical events as well as non-critical events. Some approach[13-15] which focus on implementation of nanocomposite mechanism in network to optimize energy efficiency.

This article exhibits an event driven routing approach, in which the routing decision depends on the event priority; critical or non-critical. The proposal provides an event detection framework, which provide the priority to the event data as critical and non-critical based on underwater quality parameter values. The work in this paper propose different route setup phase for different priority data such as critical and non-critical. For critical data routing phase focus on fast and reliable delivery, and for non-critical data objective is to enhanced the network lifetime through energy balancing.

Table 1 — Ocean Parameter Range

fig	Range	Average Value
Temperature	-2^o c to 40^o c	3.5^o c
Salinity	0 g/kg to 42 g/kg	34.9 g/kg
Pressure	0 dbar to 11000 dbar	1850 dbar
Density	1000 to 1060 kg/m^3	1036 kg/m^3

Proposed Event Driven Energy Balanced Routing for Underwater Sensor Network (EDEBR)

This section describes the network model, estimation of energy consumption, event detection framework, route discovery model, and data transmission mechanism for prioritized data.

Network Model & Assumptions

A finite number of sensor nodes are distributed randomly throughout the interesting area with a sufficient intensity such that at least one sensor node is in communication range of the sender as shown in Fig. 1. An acoustic interface is equipped in each sensor node of the network. Each sensor node in network have fixed sphere-based communication range. All sensor nodes are supposed to have been fitted out with a sensor to measure the depth of the nodes from the surface sink. The interested area of the network is partitioned in 3-d slices of same width. Slice position is determined by the sink node communication range which is also equal to the distributed sensor nodes. It is considering that the slice width 'S' to be less than the transmission range 'R' ($S < R$), due to fact that the nodes in adjacent slices are in communication range of each other. The slice width 'S' is to be taken 2/3 of the range R for one hop communication.

$$S = \left(\frac{2}{3}\right) R \quad \dots (1)$$

Proposed Framework for Event Detection

To study the behavior of underwater conditions, parameters such as temperature, pressure, salinity, and density are observed periodically to collect

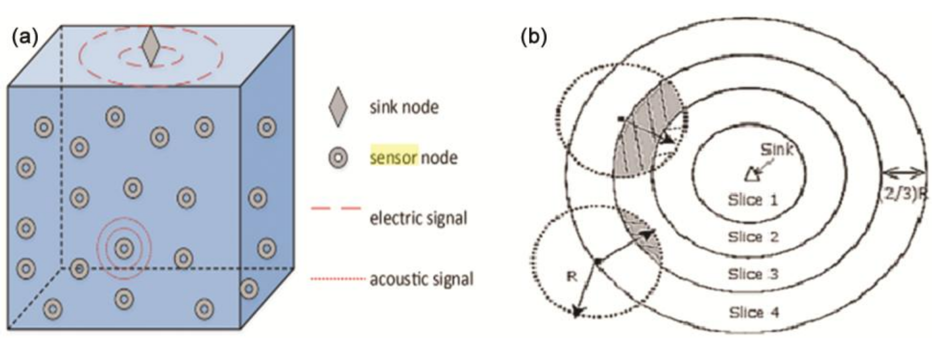

Fig. 1 — (a) Network Architecture& (b) Network Slicing

information regarding water quality, environmental changes, and underwater object movements. The sensed parameters are then compared with the threshold values to decide the occurrence of event. The proposal use a parametric decision based prioritized event detection model to classify event priority in three classes 0, 1 and 2 based on the changes in environmental as well as non-environmental parameters.

Based on the classification of events, the priority of event is calculated and data is transmitted according to the event priority. The detailed algorithm for prioritized event detection is shown below:

Algorithm1:Prioritized Event Detection

1. Input the environmental and non-environmental parameters values from sensor
2. Apply the depth based thresolding on parametric values
3. **IF** (Data within range to environmental threshold) **THEN**
4. Event priority is 0
5. **ELSE IF** (Data within non-environmental threshold) **THEN**
6. Event priority is 1
7. **Else**
8. Event priority is 2
9. **END IF**

The algorithm proposed in above segment would guarantee that all non-routine events are triggered and data reached to the sink basis on the priority of data packet. It also reducing the network traffic load in the UWSN overall by limiting the transmission of all non-routine events only.

High Priority Critical Event Data Transmission Route Formation Scheme

This section addresses the routing requirements of critical data transmission. As discussed in previous section, the critical data is delay sensitive and needs reliable and real time transmission mechanism. To achieve this objective, the proposed approach uses proactive routing mechanism to store reserve route path at node itself for fast data transmission. The algorithm initiate at network setup phase, in which each node broadcast a *HELLO* packet shown in Fig. 2 to initiate the reserve route discovery procedure. After receiving *HELLO* packet from previous node all intermediate nodes add the residual energy grade RE_L into the packet and forward it to the neighboring nodes towards any one of the multiple sink nodes. The sink node decides the best route among all the hello packet received from the requesting node on the basis of maximum energy grade it receives as Eq. (2), and broadcast the best route throughout the network. Each sensor node participating in the discovery procedure store the next hop address in their reserve route entry field to transmit critical data.

$$RE_L = Max\{RE_1, RE_2, RE_3 - - - - RE_N\} \quad \dots (2)$$

The format of the *HELLO* packet is shown below:

P_{type} is one-bit field represent the type of packet- 0 represent query packet, and 1 represent reply packet. S_{id} is one-byte field represent the id of source node. Sl_{id} is one-byte field represent the slice id of source node.D_{sen} one-byte field represent the depth of the sensor node. REN_s one-byte field represent the summation residual energy of participating sensor nodes. $R_s$ten-byte field represent the route information at route discovery procedure. After reaching the request packet at sink node, it wait for δt time which is calculated as Eq.(3) to receive multiple request from same source and decide the route based on the maximum residual energy of the route. The sink node then broadcast the reply with maximum residual energy route information to all immediate neighbors. All node after receiving reply packet, extract the next relay node id from route information field and broadcast the reply to its neighbors. This process continues till the source receive the reply and set the next relay node in reserve route entry field. The process of reverse route request is depicted in Fig. 3.

P_{type}	S_{id}	Sl_{id}	D_{sen}	REN_s	R_s

Fig. 2 — Hello Packet Format

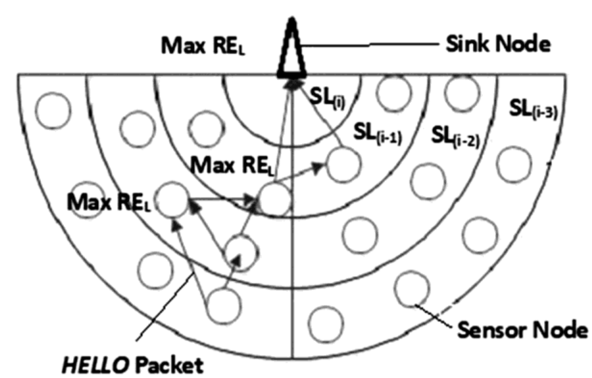

Fig. 3 — Reserve Route Request processing through query hello packet

$$\delta t = \frac{Communication \quad range \ R}{Signal \ \ Speed \ S} \quad \dots (3)$$

Low Priority Non-Critical Event Data Route Formation Scheme

In case of non-critical event data communication, as discuss earlier that, there is no time limits. That's why energy efficient or energy balanced routing approach is needed to prolonging the network lifetime. To achieve the same, the proposal uses reactive routing mechanism to decide energy balanced route setup at the time of transmission. If the event priority is 1, source node broadcast the request packet shown in Fig. 4 to its immediate neighbors with route information field as NULL, and wait for the reply. After getting first reply, it immediately forward data packet to that node. And then the node act as source and find the next relay node to forward data packets towards the sink. At intermediate node, after receiving request packet, waits for span called holding time *(HT)* before replying. The *HT* for a packet, is calculated based on the depth difference between previous node and the current node, represented by *Δd*. The proposal also considers another parameter such as residual energy of node RE_L, reliability factor *RF,* and waiting factor *WF* for calculating holding time and suppress the number of relay nodes as forwarder.

All nodes contending as relay node calculates their holding time, and which node have lessor holding time send the reply first to the source through broadcasting reply packet. After listening reply, through another node, all nodes discard their timer and wait for another event to be happened as depicted in Fig. 4.

Selection of relay node is based on Holding Time *'HT'*calculated as follows:

$$HT = Max\, waiting\ time \ \times \frac{\frac{1}{\Delta d}}{RF \times RE_L} \quad \dots (4)$$

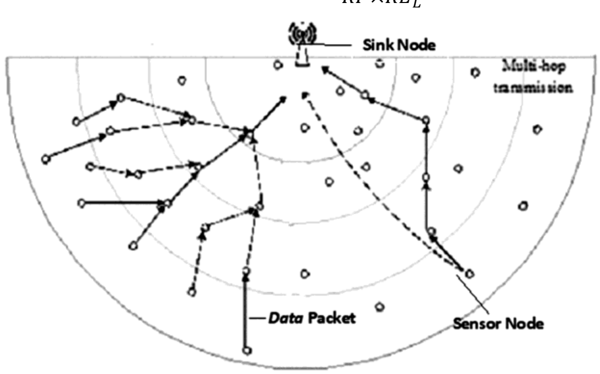

Fig. 4 — Route Setup for Non-Critical Data Transmission

where,

The factor *RF*represent reliability of communication in terms of ratio between packet received and successful transmission.

- The parameter Δ*d*indicate the depth difference of source node and contending node from surface.
- The parameter RE_Lgives the remaining energy of the contending node.
- The *Max waiting time* is user define parameter in seconds.

Estimation of Initial Energy

The initial energy of the node represented as *Et(t)* is comprised the estimation of Sensing Energy E_{sen}, Packet Reception Energy E_{Rx}, and Packet Transmission Energy E_{Tx}

$$E_T(t) = \ E_{sen}(l) + \ E_{Rx}(l) + E_{Tx}(l,d) \quad \dots (5)$$

The energy of each sensor node is divided in three different energy level which are reserved for sensing, receiving and transmission of data packets.

Transmission energy consumed to transmit *l* bits to a distance of *d* is:

$$E_{Tx}(l,d) = lP_o d^k v^d t \quad \dots (6)$$

where *t* is the time period in seconds, and P_0 is a constant term represent initial transmission power.

The reserve transmission energy is further divided into memory chunks of remaining energy levels RE_L as:

$$RE_L = \frac{E_{Tx}}{L} \quad \dots (7)$$

where *L*de note the optimal number of power levels.

Average RE_L of current node at a single round of communication calculated as:

$$RE_L = E_{TX}(r) - (No.\ of\ rounds \ \times \frac{E_{TX}(r)}{E_{TX}(R)} \quad \dots (8)$$

The reception energy at sensor node is calculated as:

$$E_{Rx}(l) = lP_r t \quad \dots (9)$$

Data Forwarding Scheme

The protocol intelligently use prioritized event based data forwarding scheme. For higher (critical) priority packet the reserve route entry field is used to select next relay node to forward data packet. For lower (non-critical) priority packet energy balanced routing approach is used to select relay node as per the algorithm 2 discussed below:

Algorithm2:Relay node selection

1. UponreceivingQuery Packet
2. **if** E_p = 0**then**

3. discard the data packet
4. **elseif** $E_p = 2$ **then**
5. Find the next relay node from Reserve Route Entry and send the data packet directly
6. **else**
7. **if** $P_{type}=0$ **then**
8. **if** $D_{rec}<D_{sen}$ **then**
9. **if** $\Delta d>d_{th}$ **then**
10. Compute Holding Time (HT) and start timer
11. After the timer expire
12. **if** d_q **then**
13. discard the packet d_q
14. **else**
15. reply d_q with source Id of Receiver Node and $P_{type}=1$
16. **end if**
17. **end if**
18. **end if**
19. **end if**
20. Find the next relay node from query packet d_q and send the data packet at source node
21. **end if**

The source node collects the prioritized data and then decide the data forwarding scheme based on the event priority. The data packet itself contain the event priority E_p. The data packet format is shown in Fig. 5. If the event priority is 0, source node simply discards the data packet and sense further. For event priority 2, source node immediately forward data packet to the next relay node, decided through reserve route setup phase. All intermediate nodes also get forward the data packet based on reserve route setup phase, if received data packet with event priority 2.

In the proposal, data packet itself contains the event priority along with data as shown below:

where:

S_{id} is one-byte field represent the id of source node. E_p one-byte field represent the event priority of data packet. Data forty-byte field used to carry payload of four parameters temperature, salinity, density, and pressure, 10-byte each.

Result and Discussion

The outcome of the experimental results of the performance of the proposal are evaluated through simulation. The evaluation of the proposal Event Driven Energy Balanced Routing (EDEBR)is done on the three basic network parameters named; end-to-end Delay, throughput of the network, and network lifetime in terms of energy consumption. The performance of the EDEBR is compared against some recent advancement of energy controlled routing strategies named; BTM, EBET and EEBET. In the simulation setup, network is partitioned into slices of same with same width, which is equal to the 2/3 of the transmission range of the surface sink. The network consist 200 sensor nodes randomly distributed throughout the network in uniform fashion. The sensor nodes distributed uniformly in varying network radius ranging from 1 km to 5 km. The initial transmission range of the sensor node is taken 750 m, and the initial width of the slice is taken as 500 m, and each slice have identically equal number of sensor nodes. Each sensor has 175 J as initial energy and, the packet has of size 14-byte, which include priority of knowledge packet also. The proposal is analyzed in two parts, first for critical data priority names as C-EDEBR and second for non-critical data priority as NC-EDEBR.

Source Id	**E_p**	**Data**

Fig. 5 — Format of Data Packet

Impact of Variable Network Radius on End-to-End Delay

The transmission delay for diverse network range from 1 to 5 km in BTM, EBET, EBET, C-EDEBR, and NC-EDEBR is presented in Fig 6. C-EDEBR outperform other counterpart techniques in terms of delay. In C-EDEBR delay is lesser than others due to reduction in time to select next relay node in data transmission. C-EDEBR uses the reserve route information to forward packet towards sink, which in-tern reduce the overall time to finding routes in hop-by-hop fashion. NC-EDEBR have lessor delay in

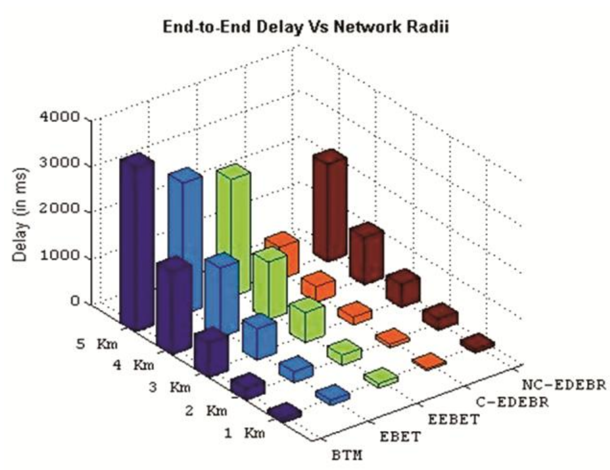

Fig. 6 — Plot representing comparison of end-to-end delay at different network radii

4 to 5 km range, because of use of shorter length control packet in deciding next relay node. Control packet has shorter size than data packet, and take less time to process and transmit.

Therefore, overall reduction in end-to-end delay by 60-75% to other counterpart techniques. The delay in BTM, EBET, and EEBET is lower in short range and higher in longer range network, because off increase in hop count. More hop count leads the energy consumption as well as the increases the transmission time overall.

Impact of Variable Network Radius on Network Throughput

The comparison of thenetwork throughput is shown in Fig 7. Both the proposals C-EDEBR and NC-EDEBR have upgraded throughput than BTM, EBET and EEBET. In C-EDEBR, the packet arrival rate is very low. Therefore, data transmission takes place randomly, and energy of nodes are less consuming, which overall increase the packet delivery ratio of network. NC-EDEBR also gives better network throughput through corresponding the energy depletion among nodes during transmission. The packet reception rate in in BTM, EBET, and EEBET is lessor in comparison to C-EDEBR and NC-EDEBR, due to depletion of energy at sensor node faster, which leads to network partitioning. The data packet transmission takes place at two hop distance mostly in EEBET, which consume more energy and leads no further transmission. In EBET and BTM, direct communication also leads more energy depletion, and less throughput due to shorter lifetime of network.

Impact of Variable Network Radius on Network Lifetime

The network lifetime in both the proposals C-EDEBR and NC-EDEBR is much longer than the BTM, EBET, and EEBET, which is clearly shown through the Fig 8. This is due to two reasons. First, network partitioning in slices, where communication existing in one hop distance. Reduced hop counts also leads the network lifetime through reducing the overall energy consumption. Second; energy balanced approach, which balanced the energy consumption throughout the network and leads the lifespan of the network. C-EDEBR also consume less energy due to the lower packet reception rate. In real time scenario, there are less chance of critical event happening. Therefore, less number of data packet transmitted and less energy consumption, which prolong the network lifetime. Energy balanced approach based on residual energy and depth of the sensor nodes in NC-EDEBR, leads better energy utilization and longer network lifetime. Each sensor node in NC-EDEBR consume linear energy for data packet transmission and leads the node life longer, and in-tern longer lifespan of network.The network partitioning in terms of Ring and Sectors also enhance the network lifetime of EEBET. But due to two hop transmission, in long range network, EEBET performance degraded due to imbalance energy consumption. Direct transmission and routing loops in case of EBET, and BTM, degrade the performance in terms of network lifetime. Direct transmission leads more energy ingesting and rise the chance of sensor node expiry, which leads imbalanced energy consumption.

The above simulated analysis verifies the performance of both proposals C-EDEBR and NC-EDEBR, in terms of network lifetime, network throughput, and end-to-end delay.

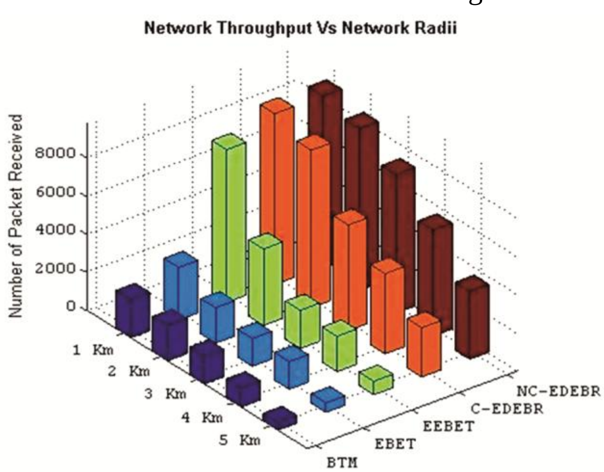

Fig. 7 — Plot representing comparison of network throughput at different network radii

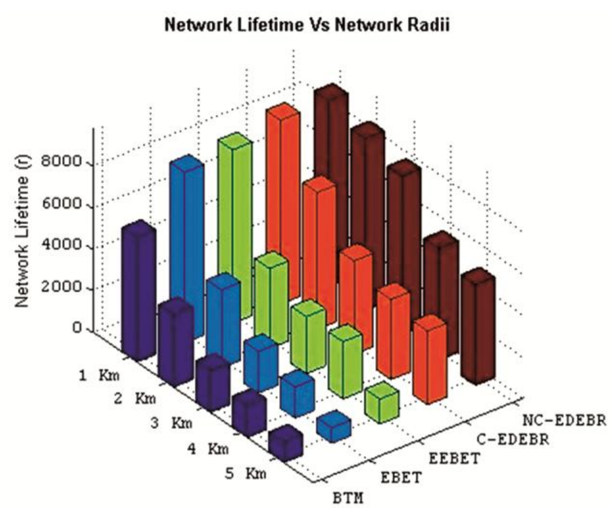

Fig. 8 — Representation of network lifetime at different network radii

Conclusion

This article proposed an application specific event driven routing approach, in which routing decision takes place on the basis of data priority. A novel framework is presented to triggered an event based on underwater environmental and non-environmental data. The priority of non-environmental data considered as critical and environmental data as non-critical. Based on the data priority event classification is done as Class0 (No Event), Class 1(Non-critical Event), and Class 2 (Critical Event). Based on the class of event, routing decision takes place. For Class 0, no transmission done, which overall reduce the energy consumption. For Class 1, energy balanced approach is used to route the packet towards sink node, and for Class 2, time critical reserve route based routing is proposed to transmit data packets towards sink node. The objective of the work is to provide application specific routing mechanism, and prolong the network lifetime through balanced energy consumption. Simulation results verify and validate the performance of the proposal against counterpart techniques in terms of lower end-to-end delay, better throughput, and increase in network lifetime. The scalability of protocol also verified through varying network radii. Future enhancements can be included in implement void handling using dynamic convex hull principles with energy balanced routing mechanisms to recover from void and to meet QoS requirements of UWSN.

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