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DBR-EC: A New Routing Protocol Based on DBR Applying Energy Criteria

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***Abstract*— Routing protocols in underwater wireless sensor networks (UWSNs) require the consideration of several aspects such as energy consumption, amount of packets delivered successfully (packet delivery ratio), network topology and propagation delay during the data transmission process. Once a wireless sensor network is deployed under water, it will be really difficult and costly to recover them for later battery repositions, mainly due to the issue that their location may not be accessed. For this reason, it is important to have a routing protocol that guarantees a long life time of the UWSN and also optimizes the use of the network by improving not only the network energy consumption but also the packet delivery ratio. In this paper a new routing protocol named DBR applying Energy Criteria (DBR-EC) is presented. This protocol is an improvement of the DBR protocol [1] by applying criteria of energy saving in each node that belongs to the network. DBR-EC guarantees a longer life time than other existent protocols showing up to 50% of energy saving, better packet delivery ratio and less propagation delay.**

Keywords*— Propagation delay; packet delivery ratio; energy consumption; routing protocol; Underwater Wireless Sensor Networks; UWSN

I. Introduction *(Heading 1)*

The utilization of UWSNs has been increasing due to the several applications in which this technology can be involved in order to execute specific tasks. Some of these applications can be ocean exploration to identify new or valuable minerals, and detect underwater oilfields, to predict tsunamis, tornados or submarine earthquakes based on measurement of seismic activities, to detect submarine contamination, or to monitor areas important for the government for example intrusion detection.

The design of wireless sensor networks here is a challenge because of the underwater environment in which they will coexist.

Also, for several reasons that have been widely explained in the literature, acoustic signals should be employed as the communication medium in the network transmission process instead of radio frequency signals.Ease of Use

Acoustic communications in the underwater environment is affected by several aspects such as multipath, Doppler spread, transmission loss, path loss, noise and propagation delay. As a result, a high packet loss ratio or amount of packet with errors is present and retransmission processes should be executed to send information through the network increasing the energy consumption among sensors in the network, which decreases the lifetime of the sensors. To perform successfully in any of the mentioned scenarios, then it is important that the UWSNs have an adequate design of their routing protocol to guarantee a long life time of the network.

This works proposes a new DBR-EC routing protocol for UWSNs, an improvement of the existent DBR protocol [1] that applies energy criteria to increase the life time of the network. The energy criterion is an indicator used in order to obtain which nodes will be involved in the final routing process for the data transmission.

The paper is organized as follows: Section II presents some related work in the area. Section III introduces the DBR-EC routing protocol. Section IV shows the performance evaluation and finally, Section V presents the conclusions and future work.

II. Related Work

The optimal energy consumption in UWSNS is one of the most important issues to be solved. Once the sensors are deployed it will be difficult to recover them in order to recharge their batteries once they have been consumed; as a consequence, the maintenance of these sensor networks will be costly. For this reason, it is imperative to develop a routing protocol that guarantees a long lifetime of the network based on the reduction of the energy consumption.

Several routing protocols for UWSNs have been developed in the literature and they have been classified in four categories [2]: flooding based, multipath based, cluster based and miscellaneous routing protocols. Each protocol uses its own technique for packet retransmissions.

For example, in the DBR protocol proposed in [1], packets are sent to the surface by using a greedy algorithm. In the packet sent to the destination there is field that keeps the last node in charge of resending the packet and the depth of the transmission. Once the packet is sent to the neighbors located in the transmission range, the protocol verifies which of those neighbors shows the least depth parameter than the one has stored in the packet, in order to use that node as the next in the path to resent the packet.

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In [3] a routing protocol named VBF is proposed. This protocol works basing on the geographic position of each node located in the network, as a main criterion to obtain a path (forwarding path) that will be used to send packets. This path will define a routing vector from the sender to the destination node. In other words, VBF consists on establishing a virtual tunnel with a radius that starts from the node that initially sends the packet to the target one. Only nodes covered by the virtual tunnel can be part of those that finally will send the packet.

Once the neighbors of the sender node receive the packet, they will verify how close they are to the routing vector by comparing with a threshold previously defined. If they are close, then will resend the packet otherwise the packet will be deleted from that node. Additionally, VBF includes an adapting algorithm to optimize the energy consumption in the UWSN; from those eligible nodes to resend the packet, only one will be chosen according to a desirableness factor defined in the algorithm [3], avoiding to send unnecessary packets in the network.

Routing protocol HH-VBF [4] is an improvement of the original VBF and also it works using geographic localization in each node from its UWSN. Using HH-VBF it is possible to guarantee that there will be more possible paths in such a way that the probability of successful packet arrived to the target will be higher than in VBF. Not one but several tunnels will be created for each intermediate node to its neighbors when it has to resend the packet (VBF creates only one tunnel from the sender node to the target one). With this protocol, the energy consumption in the network is reduced but several unnecessary packets will be sent through the network making also needless energy consumption for some nodes.

The routing protocol proposed in [5] and named FBR works also based on the geographic location in each node in the network. Here, the routing process for sending a packet from the sender to the target tries to reduce the energy consumption in the network by regulating the power level of the signal transmission. Each node has the knowledge of its position and the position of the target, and the sender starts the transmission by sending the packet to its neighbors with less power level. Each power level has associated its corresponding transmission radius, and then only nodes in a delimited area defined by a cone with angle Φ that starts from the sender to the target could detect the packet. If a node is located in the transmission range, then it will detect the packet and will respond to the requirement from the sender. As a result, sender node will select the node that is closer to the target as the destination node to resend the packet. One of the problems of this protocol consists when a node wants to retransmit a packet. It will have to establish a communication with all its neighbors and they should respond with their position by sending back an answer packet. This process requires high energy consumption.

In [6], a routing protocol named H2 DAB is defined. It does not work neither with node position nor routing tables. The data transmission process is executed by assignation of identifiers (HopIds) in each node that belongs to the UWSN. With H2 DAB the transmission process includes two phases: the phase of dynamic assignation of the HopIds to the nodes in the network and the phase of packet transmission based on the HopIds. During the first phase, nodes in the surface (buoys) will send Hello packets to their closest nodes. After receiving the packet nodes then will assign itself a HopId consisting in a two-digit number, in which the more significant digit will represent the number of hops from the node to the buoy and the second digit will represent the number of hops to an alternative buoy. The more significant digit will represent the main path to the target and the second one will be an alternative path to the target (reservation path). Like the protocols explained before, this protocol wastes energy consumption, the reason is due to a transmission in double via between transmitter and candidates that should be established in order to select the next transmitter node that has to resend the packet.

Another routing protocol is described in [7]. Authors name the protocol as DLP and it is based on nodes position, each node knows its position but not the position of the rest of nodes in the UWSN including the target node position. Position of the target is calculated by predicting its movements, movements that are known by the transmitter. Before transmitting the data, the node sends a packet with its position to its neighbors. Each neighbor determines whether or not it is closer to the target node than the transmitter from it received the packet. If that is true, then the node sends an answer (control packet). Several nodes can answer generating possible collisions at the transmitter; due to this issue, there is a process to control collisions avoiding retransmissions. The node selected to resent the packet will be the shortest to the target. This protocol also wastes energy consumption in the process of sending control packets.

In Section III, a new approach based on the existing DBR routing protocol will be proposed, in which the new version will apply energy criteria in order to save energy consumption and as a consequence increase the life time of the UWSN.

III. The DBR-EC Routing Procotol

As mentioned before, one of the main problems in UWSN is that acoustic communications in the underwater environment are affected by several aspects such as multipath, Doppler spread, transmission loss, path loss, noise and propagation delay. This problem as a consequence affects all layer communications and creates high energy consumption reducing the lifetime of the network.

This works introduces a new routing protocol based on the existing DBR but optimizing the packet transmission in order to save energy extending the lifetime of the network. In the following subsections the protocol will be explained in details.

A. *DBR-EC network architecture*

Like in DBR, the proposed protocol needs a network architecture in which buoys are the sink nodes located in the water surface. These nodes have two types of communications, one by using RF signals in order to send the information to the final destination and acoustic signals to receive the data from de sensor nodes placed under water as shown in Figure 1.

Some of those sensor nodes works as intermediate nodes to resend sensed data from those placed at the bottom to the sink nodes (nodes located at the water surface).

B. *Description of the DBR-EC Routing protocol*

DBR applying Energy Criteria (DBR-EC) is an improvement of the DBR routing protocol by working with an indicator of energy consumption in each node that belongs to the UWSN as a condition to select adequate nodes to be involved in the routing process. In order to understand how DBR-EC works, it is important to explain the functionality of the DBR [1]. In the DBR algorithm, each node has a priority queue in which packets are temporally saved and a buffer to save historic information. The buffer information stores the IDs of the packet transmitted; once it is full, the oldest information is replaced.

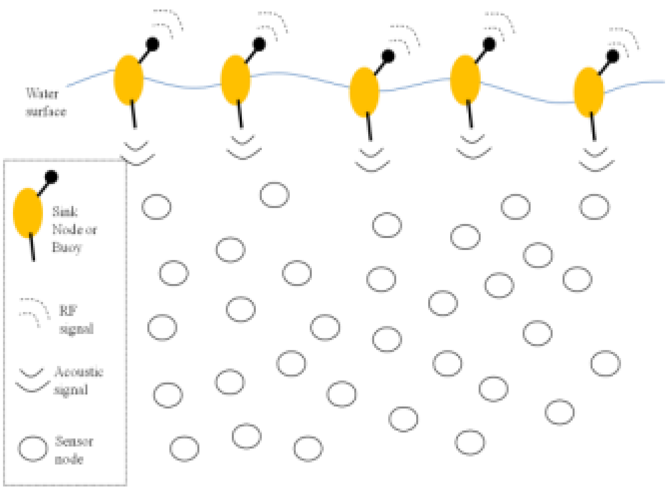

Figure 1. DBR-EC Network architecture

In DBR, to decrease energy consumption in the network it is necessary to decrease the number of times a retransmission for the same packet is executed because there are several paths and nodes send the packet also several times. To solve this, the priority queue in each node is used not only to reduce the number of paths but also the number of transmitters in the network. Data saved in each position of the priority queue contains the packet that will be sent and the time in which the packet will be transmitted. This time represents the priority of the packet being sent. When a node receives a packet, this packet will not be resent immediately; it will be retained for a short time named the holding time, and the time to be sent will be calculated based on this holding time and the moment in which the packet was received. To send a packet only one time during an interval of time, a buffer to save historic information is included, in which the id of the packet transmitted is saved.

A packet is included in the priority queue if it has not been sent yet and it has a lower depth value than the data belonging to a packet received before, which will be deleted from the queue; otherwise the received packet will be discarded. If other packet is received during the same holding time period and it comes from another node with less depth, then the packet will be discarded, otherwise the time of the packet to be sent will be recalculated and added to the queue; holding time period is used by the node to define the time for the packet to be sent. The packet will be deleted from the priority queue when is sent and a copy is included in the buffer. Here starts the main difference between de original DBR and the DBR-EC algorithm proposed in this paper because in the holding time is included a novel idea to penalize the transmission time used for the nodes in the network.

When a node has more energy from its battery available for the transmission then its penalization will be less than the case in which its reserves of energy is small. This guarantees a better balance in the energy consumption when nodes transmit information in the network, obtaining the reduction in the amount of packets to be resent, and also an increment in the lifetime of the UWSN.

C. *Calculating the holding time period*

Holding time is calculated taking into account a distance *d* obtained from difference between the depth of the node that already received the packet and the depth from the node which transmitted it. To calculate the holding time, this paper applies the same formula defined in DBR [1] but including the penalization function and a reward based on an energy factor defined in equation 1.

The energy factor is defined as the ratio between available energy and the initial energy in a specific period of time for a node as follows:

$$f(e) = \frac{e_a}{e_i} \quad (1)$$

where e_a represents the available energy in the node and is its initial energy.

The penalization function is defined as *p(e)* in the following equation:

$$p(e) = 1 - f(e) \quad (2)$$

When a node has more reserve of energy then the factor *f(e)* will be bigger and it will have a smaller penalty; otherwise factor will be smaller and penalty bigger.

Having the previous values calculated, the holding time period can be calculated as follows:

$$f(e,d) = p(e)\frac{2\tau}{\delta}(R-d), \delta \in (0,R] \quad (3)$$

The variable *R* represents maximum transmission range of the node, τ the maximum propagation delay in one hop, δ a parameter that represents the difference between depths of two neighbors and affects the holding time value, and *d* is the difference between the depth of the node that already received the packet and the depth from the node which transmitted it.

To control the number of nodes involved in the transmission process the algorithm uses a parameter named *Depth Limit (DL)* that is defined as the difference of the permitted depth between a candidate node and the transmitter in order that the candidate can decide if it is in that permitted limit or not. When a node is in the transmission range of the source node but it does not accomplish whit the *DL* criteria, then it will discard the packet received. The parameter can vary from *0* to *R*.

IV. PERFORMANCE EVALUATION

A. Scenario description

In order to evaluate the performance of the proposed protocol, the software *Aquasim* developed in *NS-2* [8] was used. This application has implemented some routing protocols for UWSNs and it permits the implementation of several scenarios defined under water. An amount of sensors were randomly created in a tridimensional scenario of *500x500x500m*^{3}, *5* sink nodes were placed in the water surface and each node in the network will have random movement patterns with a speed between *0* and *3m/s*. An only one source node at the bottom of the water is defined with a depth of *500m*, the maximum transmission range of each node is *100m*, energy consumption per data transmission is *2watts* and energy consumption per data reception is *0.1watts*.

To compare different routing protocols simulations were executed generating between *200* to *700* nodes in the network and varying other parameters such as *d* and the maximum depth between nodes.

B. Metrics applied for the performance evaluation

The following metrics will be used for the evaluation process of the DBR-EC protocol:

- *Packet delivery ratio:* it is defined as de amount of different packets successfully arrived to the sink nodes over the number of packets sent by the source node; this value will be between 0 and 1, in which 1 means that the 100% of the packets arrived successfully.
- *Propagation delay:* period of time a packet spends arriving to a sink from the source.
- *Energy consumption:* total energy consumption of the network, this consumption includes both transmission and reception energy consumption.

C. Evaluation comparisons

In Figure 2 it is shown the comparison of energy consumption between DBR-EC, DBR and VBF. Parameter δ has *25*, *50*, and *100*, and *R* is *100m*.

The graph shows that DBR-EC wastes less energy than DBR and VBF. It is clearer the advantage of DB-EC over the other protocols, meaning that DBR-EC networks will have as a consequence a bigger life time than the other routing protocols, DBR-EC works better in terms of energy consumption than DBR and VBF.

The behavior of DBR-EC and DBR are also analyzed when *DL* varies from *0* to *40m* and using *100m* as the maximum transmission range. As seen in Figure 3, in the case of *DL* is either *0* or *20* the energy consumption in both protocols are similar, but when *DL* is *40* the behavior is better for DBR-EF, meaning that the proposed protocol has less energy consumption than the original DBR.

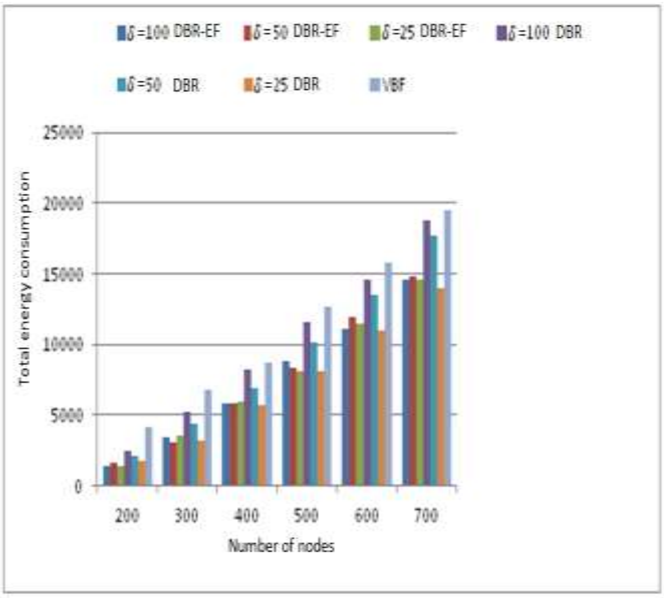

Figure 2. Energy consumption of DBR-EC, VBF and DBR varying parameter δ

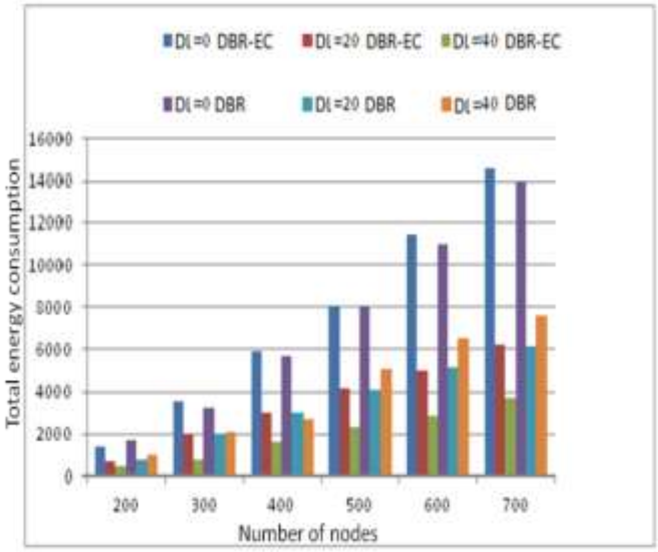

Figure 3. Energy consumption of DBR-EC and DBR varying parameter DL

To analyze the propagation delay simulations were executed again with *200* up to *700* nodes, Figure 4 displays the results in DBR-EC, DBR and VBF.

The difference of propagation delays between DBR-EC and the rest of the protocols is due to the existing penalization function in nodes with less energy than others, favoring nodes with more energy to participate in the routing process. On the other hand, there is a reduction of the amount of transmitted packets, and the waiting times in the queues are less than in the other routing protocols. Therefore, DBR-EC presents a better performance in terms of propagation delay than DBR and VBF.

To see the behavior of the packet delivery ratio metric, results are displayed in Figure 5.

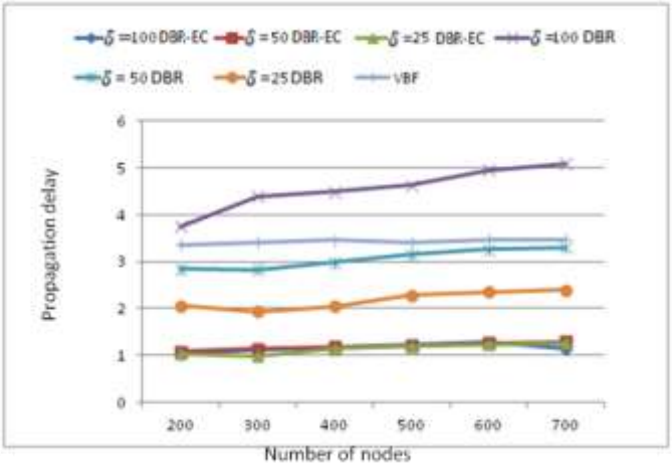

Figure 4. Propagation delay of DBR-EC, VBF and DBR varying parameter δ

As seen in the graph, with a small sensor network then few packets will be delivered. The reason is that there will have zones/places in which nodes will not have neighbors to resend the packet. Bigger is the amount of nodes in the network, nodes density will be higher; this will guarantee that a node will have more neighbors and the probability of resending packets will be higher.

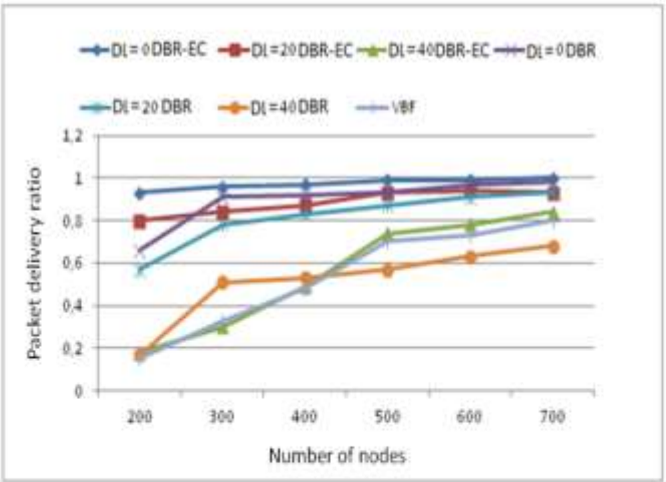

Figure 5. Packet delivery ratio of DBR-EC and DBR varying parameter DL

Packet delivery ratio in DBR-EC is larger than the presented in DBR and VBF, even though simulation was executed with different values of the parameter *DL*. VBF presents an acceptable packet delivery ratio only when the amount of sensors in the UWSN is big. When *DL* is *0* packet delivery ratio is high because there will have more candidate nodes to resend packets, however DBR-EC continues showing the best percentage.

V. CONCLUSSIONS

An energy efficient underwater routing protocol based on nodes depth information was proposed. This protocol was developed from the existing DBR protocol adding a penalization function strategy to save energy. The system performance was evaluated for different amount of nodes in the network. Different metrics such as packet delivery ratio, propagation delay and total energy consumption were applied to compare the proposed protocol with the original version of DBR and VBF, indicating as a result that DBR-EC, the proposed protocol, is better in all scenarios. In terms of energy consumption DBR-EC has up to *50%* of saving energy than the other protocols, propagation delay is *3*or *4* times less than DBR and VBF, and the packet delivery ratio is also bigger than the indicated by the rest of the routing protocols. In general, and as a consequence of the results, the proposed protocol guarantees a bigger life time of the network.

Future work involves comparisons with other routing protocols, as well as validation with other type of scenarios. Different MAC protocols and their effect over DBR-EC can be also analyzed.

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