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Mobility Aware Strategy for Geographical Routing Schemes in Underwater Acoustic Networks

Manel Baba-Ahmed
Department of Computer Science, University of Djillali Liabes, Sidi Bel Abbes, Algeria
E-mail: manel_ba@hotmail.fr

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Abstract: In those last decades the Underwater Wireless Sensor Network (UWSNs) have become the commonly explored technology by the scientific community, for the numerous benefits that it can brings to the researchers, however the frequent movement of the underwater sensors due to their mobility or water current factor may severally affect the efficiency of the acoustic wireless communication and reduce it performance. In this paper a Mobility Aware Strategy for Geographical Routing scheme (MAGR-VBF) has been proposed for an early prevention from the mobile sensor during the packet transmission, the protocol is aimed to predict the mobility and switch to another candidate sensor enable to recover the data packet in order to mitigate the packet loss problem. Based on the well-known routing protocol for the UWSNs 'Vector Based Forwarding' (VBF) the proposed study has been implemented and designed using the NS-2 simulator and Aqua-Sim. The result has shown that the presented work (MAGR-VBF) has brings a good performance over the basic VBF, where the energy consumption and the average end to end delay have been reduced by 8.97 % and 5.55 % respectively, and an average of 6.16 % has been increased of packet delivery ratio metric.

Index Terms: Underwater Wireless Sensor Network, Mobility prediction, Recover algorithm, MAGR-VBF.

1. Introduction

The Underwater Wireless Sensor Network are a set of wireless devices deployed in a dispersed way, at different depth from the bottom to the surface in a marine environment [6], those devices are supporting wireless acoustic communication and are equipped with antennas which has the ability to sense and measure several water characteristics [7], the sensed event are processed and recorded by the sensor and communicated to a sink station located at the water surface in a multi path communication. UWSNs are applying and widely used for various underwater monitoring and exploration applications [8,31], such as environmental exploiting, the prevention against natural disaster as seismic activity, ocean monitoring and surveillance [33], however due to the various marine factors encountered by the UWSNs during their operation, as the high propagation delay and noises, the presence of some interferences, limited battery power, their costly deployment, the localization challenge due to the 3-Dimensional deployment, limited bandwidth [32], hence the efficiency of this technology can be severally affected and limited.

As the Underwater Wireless Sensor Network are a set of numerous wireless devices that can be fixed, anchored or mobile as well [9], the move of the underwater device during an exchanging data process, can affect the reliability of the data transmission, since the presence of the water current may affect the position of an anchored sensor that can drift, the localization process may results with inaccuracy [10], in addition the sensor devices that are mobile free can often change their locations and moves towards random regions, as it is difficult to maintain an underwater sensor at a precise locations, which results in unsteady topology [11] and in improper communication within the network [12], hence a sensor can easily quit the transmission range of it sender during a communication that can harshly affect and degrades the reliability of the receiving acoustic signal, as there may not be a persistent route from a source to a destination [13].

A robust and reliable mechanism that takes into account the continuous node movement during route selection and transmission process has to be designed by the scientific researchers to handle the frequent change of the topology in efficient way [14]. Several effects can be induced by the mobility and movement of the wireless sensor, as the inaccuracy of localization, the creation of void regions, a dynamic change of topology, and loss of connectivity.

In this research paper, the author has targeted the problem of the frequent mobility and movement of sensors that can causes several problems within a wireless sensor network as the inaccuracy of the sensor location information, void regions, acoustic signal attenuation and link failures problems, by offering and proposing a mechanism with the ability to prevent from the mobile sensors that may affect the reliability of the communication during the transmission cycle, based on the well-known routing protocol for underwater communication 'Vector Based Forwarding', a protocol that limits the forwarding process at only sensors that are located within a certain virtual pipeline defined by a radius value. Multiple studies have been conducted to solve the problem of the mobility and the non-uniform topology, where in [29,30] the proposed method are based on prediction model, a real-time prediction scheme based on the tidal mobility for the future position estimation of mobile nodes is proposed in [29], by analyzing the asynchronous communications between sensors and updating periodically the sensor positions, the obtained results demonstrate the accuracy of sensor prediction position, while in [30] authors measure the mobility of sensors by taken into consideration, mainly the dynamics of the underwater nodes with the water current forces, the gravitational force, the buoyant force, and the water resistance, based on the cited criteria an efficient path is selected, the presented results show good results with large water velocity. In [1-3, 14] the void region problem is addressed by several researchers, where each study has elaborated an efficient strategy to prevent from void holes, minimize it and alternate the transmission of data towards efficient path in order to preserve the network performances. The results in [3] shows a better performance for the reason that the method offers multiple benefits, while in [11,12,16] the authors have proposed methods to adjust and control the network topology and data packet transmission based on the mobility of sensors. As the performance simulations in [16] illustrates the effectiveness of the proposed method that avoids the re-clustering of the networks and solve the overloading and path disjoint problem in addition with the use of multiple Autonomous Underwater Vehicles (AUV) in order to support data forwarding in the underwater network [3], however the deployment of multiple Autonomous Underwater Vehicles (AUVs) in [3,16] can increase the energy consumption and reduce the network lifetime.

The approach was aimed to detect if a sensor may drift away from the virtual pipeline, and replace the concerned sensor node with a potential candidate node to achieve a better coverage area, the author uses a threshold predictive region defined from the original radius value, in order to determine if a sensor has a probability of a future mobility that may affect the transmission process once it is located inside this region, the approach uses an extrapolation formula to predict the future location of the sensor, however the method is divided into mainly two phases as follow : First, Sensor node movement detection : when the sensor node is located at the predictive region, it future location has to be determined to illustrate whether if the sensor may leave the virtual pipeline, or remain inside, if the sensor has a probability to leave the pipeline a recovery phase has to take place, otherwise the sensor can continue it forwarding process, secondly, the Recovery phase: if the sensor has a future probability to move outside the pipeline, another sensor that is less depth than the concerned, inside the pipeline and has already transmitted the current data packet has to replace the concerned sensor and forward the packet.

The paper is organized as follows: First start by presenting some works related to the proposed contribution in section 2, this is followed by a brief description and explanation of the VBF routing protocol in section 3. In section 5, the proposed protocol is presented and explained with details along with its performance that is evaluated and compared with the basic VBF in section 7. Finally, the author concludes the paper and presents some perspectives in section 8.

2. Literature Review

The following section is aimed to presents some of the realized works aimed to overcome the several effects caused by the mobility of the underwater sensors, certain works has been designed to overcome the problem of void regions (area where the acoustic signal is less attempted) that is created in a major time by the frequent mobility of sensors which significantly reduce the outcomes of a wireless network, some of the other works, the applied methods was to handle the non-uniform and unsteady network topology and prevent from damages that the mobility can causes. The main objectives of those researches were to handle a wireless network with mobile nodes by taken into consideration their movement and positions, and creates new routes to transmit data packet in efficient manner.

In [1] the authors have addressed the problem of the void regions that occurs when a node is unable to find the next forwarder node, the protocol is based on the Avoiding Void Holes Adaptative Hop by Hop Vector Based Forwarding routing protocol (AVN-AHH-VBF)[17] that is aimed to avoid transmissions towards void regions and select an alternate non-void node with the help of two hop information, in the proposed mechanism, a sensor node is selected as forwarder if it is within the transmission range of the source node and heading toward the destination node, instead of a sensor node that is in the region leading to the destination and has a minimum depth. The protocol includes in addition the deployment of a mobile sink in a sparse region to improve the collection of information in order to reduce the packet loss and the consumption of energy.

In [2], the author has proposed a Depth Adjustment and Void Aware Pressure (DA-VAP) routing protocol that uses a greedy forwarding technique to select the next forwarder node, the method consist to use beacon packets that includes the packet delivery probability, the sender’s depth, sequence number, hop count and current data forwarding direction, due to the harsh marine environment, a node can move or drift towards void regions, in this case the node fails to forward the beacon packet and it is switched to the void node recovery mode, where it has to send a void node announcement message, then a Particle Swarm Optimization (PSO) technique is used to determine the new depth with a minimum displacement such that the void node can moves toward it.

In [3] the authors addressed the problem of void area and proposed a relay-based void hole prevention and repair routing protocol that is aimed to prevent and mitigate the void holes, the methods includes different phases that cooperates to detect the void holes and avoid it, for that the Autonomous Underwater Vehicles (AUV) are used, and the network is organized as cluster, each cluster head CH has to forward the gathered data to the AUV through an optimal route, if any void hole is detected then the AUV has to selects the optimal relay node to recover the failed node , where the selection of the new relay node is based on the AUV trajectory distance factor from the detected void hole, and the data can be transmitted through the recovery route.

The localization inaccuracy may results in a major time with the mobility of sensors [4], the authors have proposed a Fault Resilient Localization (FRL) scheme, where an anchor node is failed, the method aims to recover from the unexpected fault and runs the fault-tolerance procedure, where each sensor has to store the recent collected position information of their neighbors and tracks their mobility behavior to predict their location using Multiple Linear Regression (MLR) to achieve a better localization accuracy and allow the data dissemination to proceed after that a fault is detected.

In [12] the approach has been aimed to address the problem of the mobility of sensors which results in improper communication, the main purpose was so that even if the nodes are changing their location, the communication within the network between the nodes can take place, for that, the area where sensor nodes are located is mapped into two dimensional space that is divided into four quadrants, the division is established for configuring and handling the mobility of the node during a packet transmission. The communication between sensors is always done in a cross quadrant, where a sensor node has to sense the nearest intermediary node in another quadrant before sending data, by computing the Euclidean distance.

In order to estimate the position of sensor nodes, and their movement toward void region, the authors in [14] have proposed a Mobility-aware IMU-based Energy Efficient approach that addresses the neighbor node movement, due to the continuous movement of sensors, when a node is moving, the IMU (Inertial Measurement Unit) used to calculate the displacement acceleration of the sensor [15] generates a signal, then if this movement measurement is high than a predefined threshold, the node will broadcast a beacon message that contains the movement acceleration and direction information, the node compare the IMU value with previously stored information of this concerned sensor, if the value is quite large than the stored information, it means that the sensor is moving toward void region, it information is stored on a routing table with it ID, in other hand if the previously information of sensor does not exist it means that the sensor is moving toward the coverage area of this neighbor. In this way the void nodes present on the routing table are not selected as forwarders.

Due to the localization and topology uncertainty in the underwater sensor network, the authors in [11] have proposed a novel mobility aware medium access control to adjust the topology changes, the method is divided into two phases, the restructuring phase, where the mobile node has to send a request to join or leave the cluster, the second phase is the data transfer, where the cluster head has to compute the delay time of every sensor node before sending data, according to the computed delay, besides assigning slots by sending broadcast frame, the method includes a personalized time compensation mechanism to predict the current mobility status of the cluster head, when the latter's speed is inaccurate.

Due to the underwater environment interference, random deployment and mobility of sensors, in [16], the authors have proposed a new mechanism called fault resilient routing based on moth flame optimization (MFO) scheme that is aimed to overcome the problem of disjoint path, link failure and data overloaded produced by the frequent movement of sensors, The fault resilient protocol distinguish two different routing technique based on the MFO scheme, where the first one consist to transfer the packet directly to the AUV if the autonomous device is inside it range, otherwise if the AUVs are not inside the node's range, the packet is sent through neighbor, the process makes use the list of the neighbor nodes and choose the best node according to its highest fitness value, then the selected node will transfer the packet toward it nearest AUV. The approach avoids the overburden data and the re-clustering issue.

In [18], the study has targeted the link failure problem that can occurs due to many reasons such as mobility, the method has for purpose to detect accurately the location of the link failure or weaker link, and bring a recovery mechanism that creates a virtual route to transfer the data packet. Assuming that the network is organized as cluster under two-dimensional deployment, once that a fault link is detected, the authors employed an actor node that will replace the concerned node with the failure, which has not replied to the Route Request (RREQ) message, and issues a Route Reply (RREP) to the corresponding RREQ using a virtual links, The recovery process is repeated until the virtual links are replace with the original links and the network became steady.

3. Vector Based Forwarding Routing Protocol (VBF)

VBF is a routing protocol designed for the underwater wireless sensor network (UWSN), proposed and implemented by the authors in [19] based on the localization and the position information of sensors to forward the data packet, the protocol combines between the localization process and routing as well, while the nodes are deployed at different depth, the source node is located at the sea bed, and the destination (SINK) is deployed at the water surface, however the deployment of a dense network may involves several sensor nodes in the data forwarding, which may results in a high energy consumption of the network, in order to limits the number of forwarder nodes, a virtual routing vector formed by the source and destination node is used, and the nodes located near the vector at a certain predefined value are eligible to forward the packet coming from the source to the destination node in a hop by hop communication, those nodes are forming a virtual routing pipeline as a cylinder shape around the vector, nodes which does not belongs to this pipeline are simply ignoring the forwarding process.

During the transmission, each node carries in the position field of its packet the coordination of the source node OP, the destination node (target) TP and the forwarder node FP, beside that each packet contains a RANGE field used by the target to flood the received packet through an area controlled by this value. Another field is carrying by the packet which is RADIUS field, a predefined threshold value used by sensor to determine if they are closed to the vector. Once a packet is received by a node it will computes it distance with the vector if it is less than the mentioned RADIUS value, the node will then put its own position coordination in the packet and forwards it, otherwise the node will discard the packet [23].

3.1 Self-Adaptation Algorithm

The VBF protocol allows only the sensor nodes close to the routing vector located within the virtual pipeline to transmit and forward data packet, hence when the network is densely deployed, the virtual pipeline can contains a lot of sensor nodes involved in the forwarding process, that can generates a high energy consumption, for that the authors in [19] have proposed a self-adaptation algorithm based on the node density that will adjust the forwarding policy, in such a manner that each node will first estimates the density of it neighborhood before holding the packet a certain time according to it desirableness factor value, this value determines the suitableness of the node to forward the packet.

A. Desirableness factor

With the Fig. 1 given below, assuming that the routing vector is given by, where the source is S1 and the target is S0, the node A will first compute it desirableness factor to measure it convenience to forward the packet, which it is defined and calculated by the following formula:

$$\alpha=\frac{P}{W}\frac{R-d*cos\theta}{R} \tag{1}$$

Where P is the projection of the node A to the routing vector $\overrightarrow{S1S0}$, W is the radius of the virtual pipeline, R is the transmission range, d is the distance between the node A and the routing vector $\overrightarrow{S1S0}$, θ is the angle between the vector $\overrightarrow{FS0}$ and $\overrightarrow{FA}$.

By measuring the desirableness factor value of the node, it can determine if it is in the best position to forward or not, if the desirableness factor is large, it means that even the projection of this node to routing vector is large, the node is not in an optimal position and it is not desirable for it to forward. After that a node has received a data packet it has to determine if it is close to the routing vector, if it is so, it has to estimate it suitableness to forward, then the node hold and delay the packet a certain time interval according to it desirableness factor value, this time interval is defined as:

$$T_{adaptation}=\sqrt{\alpha} * T_{delay}\frac{R-d}{v0} \tag{2}$$

Where a is the desirableness factor, T_{delay} is predefined maximum delay, d is the distance between the node A and the forwarder F, v_0 is the propagation speed of the acoustic signal in the water (1500 m/s). When the desirableness factor value is small, the time to wait is less and vice versa [23].

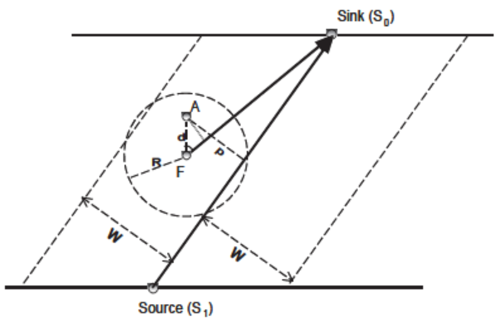

Fig. 1. The Desirableness factor

Even if VBF is robust against node failure, and it has the advantage to reduce the energy consumption by selecting the most desirable nodes, except that the protocol presents some weaknesses that can affect the reliability of the routing. The protocol does not have the functionality to re-transmit the packet, if the sensor node does not receives it due to weak received signal strength, or collision problem [20], due to the limited stored battery power of the devices, the sensor nodes that are frequently qualified to forward data packet can be easily exhausted and failed [21], the number of forwarding node are limited due to the routing pipeline radius, and more efficient path can exists outside the pipeline that leads to the sink node, hence the routing performance can be severally affected [21], in addition VBF suffers from void holes as the sensor nodes are deployed in a large environment, the void holes are the sensor nodes with no path leading to the next destination or forwarder node, that causes an important loss of data packet [22], When the sensor nodes forward their data packets, they does not takes into account the efficiency and quality of link with the next hop nodes, that generates at some point unnecessary transmission [23].

4. The proposed (MAGR-VBF) Routing Protocol

4.1 The network model

The Fig. 2 illustrates the Three-dimensional network architecture of the Underwater Wireless Sensor Network (UWSN), where the source node is fixed at the sea bed, the sink is located at the water surface, and the mobile sensors are randomly dispersed at different depth in Three-Dimensional (3D) space.

The underwater sensors are related to each other over a wireless communication support forming a wireless network, those devices are supporting wireless acoustic communication and are equipped with antennas that have the ability to sense and measure several water characteristics [7], the sensed event are processed and recorded by the sensor and communicated to the other sensors through multiple sensors, till it achieve the right destination, when the data reaches the sink, this one has the ability to convert the signal from acoustic to radio in order to communicate the information to a basic station located at the earth, a satellite, or another station laid in a surface buoy [24] UW sensors are applying and widely used for various underwater monitoring and exploration applications [8].

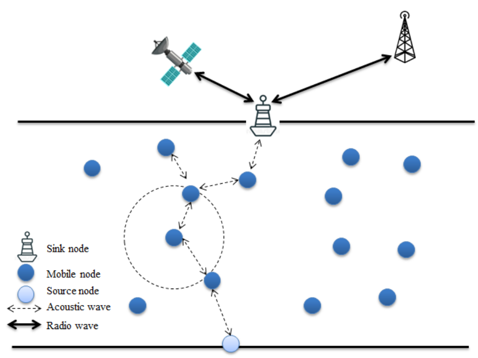

Fig. 2. Network architecture

4.2 The problem description

The UWSNs are facing several challenges and issues due to many factors encountered in the marine environment, in this paper the author has been interested and focused on the frequent nodes mobility and movement which results in inaccuracy of localization, creation of void holes, and loss of connectivity within a network. The mobility may have a several impact on the network performances, a high amount of transmitted data can be lost, the delay time may increase, and the consumed energy rises due to the continuous change of the network topology.

Based on the described routing protocol VBF , among the weaknesses and limits that the protocol is facing, is the sensitivity to the routing pipeline [21], which means that the protocol allows only nodes inside the pipeline to transmit data packets, hence when the pipeline contains a lack of sensor nodes, the routing may not be effective, for the reason that, the mobile sensor nodes could leave the pipe at any time during a transmission process which can create void zones with no available nodes to transmit, hence the proposed study brings a method that predicts the future sensor location due to their movement before that it can be selected as the next forwarder.

Moreover, as the sensor nodes must retain the data packet a certain time determined by the $T_{adaptation}$ formula described previously, the holding time depends on the factor of desirableness, which depends in turn on the projection distance of the sensor, as much as the projection is high the holding time will be large, and less the projection distance is, the holding time became small [19], hence the sensor nodes that are far from the vector and inside the pipe may create a large delay time for the received data packet, the proposed MAGR-VBF avoids the transmission through a sensors that are located at the limit of the pipeline and alternate the selection of the forwarder towards more efficient path.

The mobility can drive the sensors close to the routing vector, otherwise it can drive them away from the vector which results in a high delay time with a large routing pipeline. The Fig. 3 outlined the discussed problem, with a dense underwater wireless network deployed in a 3 Dimension space (X,Y,Z) with a large pipeline radius W , and the forwarder node F relay it received data packet, considering the following problem statements :

- First, the sensors within the transmission range of F that are (A, B) receives the packet, following the forwarding policy of VBF, the first node that will transfer the packet is the node B, it projection value is less than the others, after that the node A will relay the packet, however, since the node B is located at a high depth compared to node F, it is not preferred that B forward the packet due to its high depth value, for the reason that, when the forwarder node as selected based on the less depth value that they have the data packet can be delivered to the water surface [5], in shortest time.
- Second, the node A can forward the packet with a high delay due to its large projection, however if the node C is not eligible or failed due to battery constraints or hardware error, the node A become the first selected forwarder, which may result in a high delay time.
- Third, in other hand due to the mobility of sensors the node A may nearly quit the pipeline radius, in a case where there are no available other sensors, a void region is created and a large amount of packet may be lost.

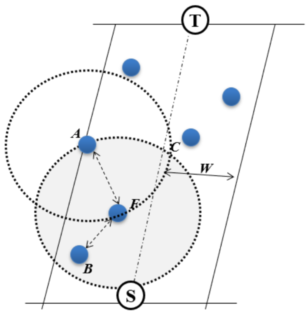

Fig. 3. The problem description

The author has proposed a method that is aimed to handle and overcome the mobility of sensors, by predicting at first the future location of a sensor node using an extrapolation formula, once the concerned sensor node is located at the predictive region zone $Pred_{TH}$ which consists of the pipeline limits, if the predicted location indicates that the sensor node will leave the pipeline, or it can simply remain at the pipeline limits, another candidate node has to be elected to proceed the data forwarding.

4.3 The proposed MAGR-VBF

In this section, the proposed solution is presented, as it is shown in the Fig. 4, considering that the node S is the source, T is the target, F is the current forwarder, A, B, and C are the received node, the notations used are described as follow:

- $\overrightarrow{TS}$ is the vector created by the node target T and the source S.
- P_A and P_B are the projection distance of node A and B respectively, to the vector $\overrightarrow{TS}$, which is computed using the basic orthogonal projection formula, assuming that a node A with the given coordinates $A(x_A,y_A,z_A)$, has a projection P_A to the routing vector $\overrightarrow{TS}$where S (x_S,y_S,z_S) is the source node and $T(x_T,y_T,z_T)$is the target,and $\overrightarrow{TA}$ is the vector formed by the target T and node A. The projection P_{TA} to vector ,$\overrightarrow{TS}$ is defined as follow :

$$\overrightarrow{TA}_{\overrightarrow{TS}} = \frac{\overrightarrow{TA}\overrightarrow{TS}}{\|\overrightarrow{TS}\|^2}\overrightarrow{TS} \tag{3}$$

Considering that $\overrightarrow{TA'}$ is the vector after projection of node A, the distance $D_{A'}^{A}$ is computed then with the Euclidean distance formula as follow:

$$D_{A'}^{A}=\sqrt{(x_{A'}-x_A)^2+\ (y_{A'}-y_A)^2+(z_{A'}-z_A)^2} \tag{4}$$

- D_A and D_B are the depth of node A and B respectively.
- W is the predefined radius of the pipeline used by the basic VBF.
- W_{TH} is the predefined threshold radius of the pipeline allowed for the proposed solution, where W_{TH} = W - $Pred_{TH}$
- PredTH is the predictive region which is a second virtual pipeline defined inside the main pipeline.

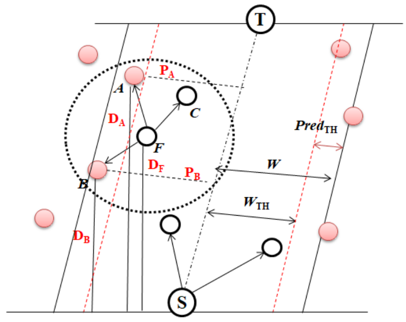

Fig. 4. The proposed solution

The VBF routing protocol is sensitive to the pipeline radius, which means that when a packet faces a void area in a pipeline, nodes outside the pipeline cannot bypass the void region [25], for the reason that the protocol limits the number of forwarder nodes, this strategy allow less consumption of node's energy besides that the network life time is maximized, however, this method brings better results in a case where the pipeline contains adequate number of sensors, otherwise it can severally affects the network performance when the pipeline has a lack of sensor nodes in such a way that the successfully delivered data packet is affected. The presented approach has been divided into two phases, where the first part consists to predict the sensor nodes movement.

A. The sensor node movement detection:

The movement of sensors inside the pipeline leads in somehow to the lack of present nodes and the creation of void regions within the routing pipeline. In order to prevent from such an event and handle the mobility of sensors in an efficient way, we defined a second virtual pipeline limited by a threshold distance inside the original pipeline, as it is shown on the Fig. 4, in such a way that when sensors are moving towards the regions defined by the threshold, the prediction of the future location of the sensor has to be computed using an extrapolation formula to determine if the sensor could leave the pipeline, or remains at this region, however in both cases a recovery phase is launched to switch toward another potential sensor inside the allowed pipeline radius W_{TH}, or the sensor can simply regain the pipeline and continue forwarding packets.

At first, When a sensor node receives a data packet, it has to verify in its packet's table (i.e. the table that contains the history of the previous forwarded packet), in the basic VBF when the received packet has already been transmitted before, the node deletes it, otherwise the packet is considered as a new packet to be forwarded and then the transmission of the packet starts, in this paper, when a sensor node receives a packet that has not been forwarded before, the node computes first it projection distance P_{Node} to the routing vector using it current position information Node (x,y,z), then if the projection distance P_{Node} is less than the original radius W and more than the predefined threshold radius W_{TH} as : $W_{TH} \leq P_{Node} \leq W$, the node is now within the predictive region, it means that the sensor should not participate in the packet forwarding and has to find an alternative node to continue the routing, hence a recovery phase has to take place to prevent and avoid from such a case.

Once the sensor node is located at the predictive region, the author used the extrapolation formula to predict the next position of the sensor, in order to distinguish whether the sensor will leave the pipeline, remain at the predictive region or simple regain the pipeline, the used formula is described as follow:

$$y(x) = y_{k-1} + \frac{x-x_{k-1}}{x_k-x_{k-1}}(y_k - y_{k-1}) \tag{5}$$

Where (x_{k-1}, y_{k-1}) and (x_k, y_k) are the respective data point, x is the point to predict, and y(x) is the predicted value of x.

Considering a node, A with its current respective coordination information (x_A, y_A, z_A) in the current time defined with t_1

Where its projection according to its current position is P_A, and its old coordination information (x_{oldA}, y_{oldA}, z_{oldA}) at time t_0 where t_0 is the t0= $current_{time}$-interval, where interval represents the required time for sensor to update its position information. The according projection is represented with P_{oldA}, applying the linear extrapolation formula with $P_A=y_k$, $P_{oldA}=y_{k-1}$, where the predicted projection E_{tPT} at time t_{PT} is defined as follow:

- $E_{(tPT)}$ is the extrapolation formula at the time t_{PT}.
- $x=t_{PT}$ is the predicted time.

$$E_{(tPT)} = P_{oldA} + \frac{t_{PT}-t_0}{t_1-t_0}P_A - P_{oldA} \tag{6}$$

Where the predict time $t_{pt} = t_1 + M_t$, and M_t is the average value of the measurement [22] calculated as follow :

$$M_t = t_1 - \frac{t_0+t_1}{2} \tag{7}$$

After that $E_{(tPT)}$ is determined, that represents the predicted projection distance of the node to the vector at time t_{PT} the value is compared with the radius W and the threshold radius W_{TH}, if the value is high than W, it can be conclude that there is a future probability that the node A will leave the pipeline, a recovery phase has to be initiated, in other hand if the predicted value is less than W and more than W_{TH} as follow : $W_{TH} < E_{(tPT)} \leq W$, the node A is remaining at the predictive region, the recovery process has to be initiated as well, otherwise if $E_{(tPT)}$ is less than W_{TH}, the node A can continue it forwarding process. The Pseudo code 1 outlined the process of the first phase of the proposed solution :

Sensor node movement detection Algorithm

Step 1 : Node A receives Pkt_i from F;
Step 2 : Check if the Pkt has already been forwarded in the Forwarded Pkt Table;
if the $Pkt_i \in$ Pkt Table of A **then** Delete (pkt);
else Calculate the Projection distance P_A;
if $P_A < (W\text{-}Pred_{TH})$ // the sensor node is located inside the allowed pipeline radius
else if $P_A >= (W\text{-}Pred_{TH})$ // the Node A $\in$ Predictive region
then Calculate Linear Extrapolation $E_{(tPT)}$;
if $W_{TH} < E_{(tPT)} \leq W$ **then** Initiate Recovery phase;
else if $E_{(tPT)} > W$ **then** The node A will leave the pipeline;
end
end
Forward Pkt;
Else Forward Pkt;
end
end

Algorithm 1: Pseudo-Code 1 of the sensor node movement detection phase

The following figure (Fig. 5) depicts the Algorithm 1 for the proposed protocol MAGR-VBF

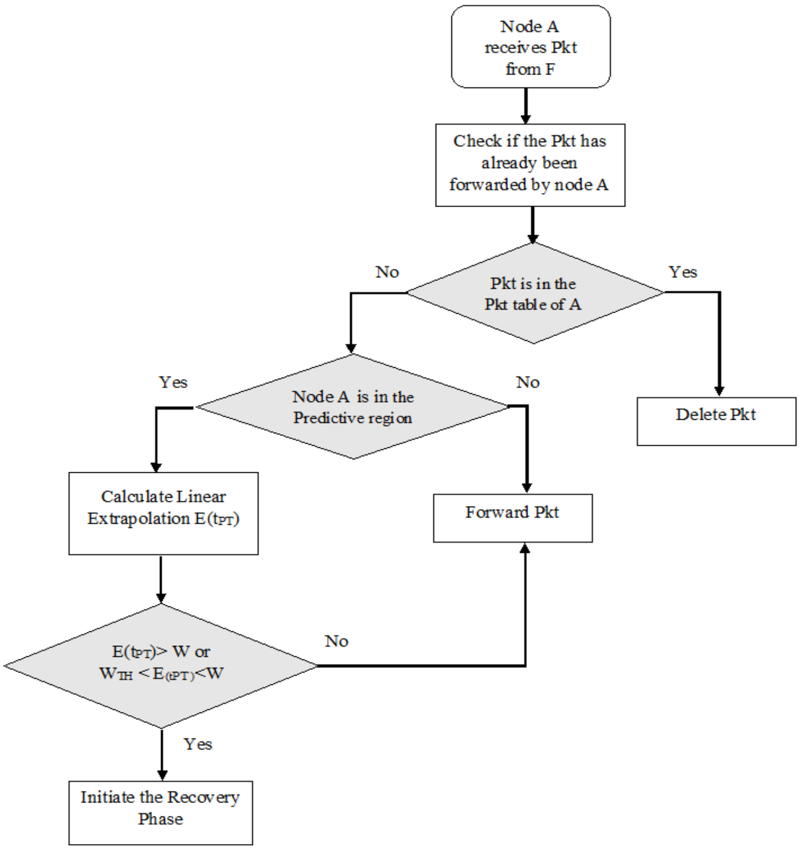

Fig. 5. The sensor node movement detection

B. Recovery phase:

The second phase consist of a recovery phase, where the methods allow the sensor nodes located at the predictive region to find another potential sensor in order to replace it, to prevent from loss of data packet, and reduce more the average delay. Once the $E_{(tPT)}$ value has been determined that it is likely that the node may leave the pipeline or still remains at the predictive region, the transmission data packet has to be switched to another qualified node, for that the node A computes first its depth according to its forwarder node F, in such a way that the depth of node A has to be less than the depth of the forwarder node F as follow: $D_A < D_F$, otherwise it simply discards the packet. If the node A is less deeper than its forwarder, then it should be replaced, for that, the author has created an additional packet named 'REPLACE REQUEST', that is broadcasted by the concerned node in a case when the current node has to be replaced with alternative sensors, hence the node A prepare a **REPACE REQ** the packet that contains the ID (idenfier) of the current node A, and the sequence number *seq* of the concerned packet that is currently holded by the node A as follow : Pkt(A_{ID}, *seq*), the desirableness factor is computed and then the packet is holding a time interval $T_{adaptation}$ following the VBF protocol policy and transmitted as a broadcast, otherwise, if the condition of the depth is not verified the node A will simply discards the concerned *Pkt*, and not participating at the forwarding process, nor at the broadcasting replace request packet, there is probably sensor nodes less deep that are requesting a transmission replace packet.

This mechanism has been designed in such a way to limits the replace request packet issued. Once the nodes that are located inside the transmission range of the node A, receives the **REPLACE REQ**, first, if the receiver is the source node S, the packet is immediately dropped, else if the receiver is the target node T, the packet is dropped as well, otherwise, the sensor node check if the sequence number *seq* of the concerned packet exist in its packet table, and has already been transmitted, if yes the node check if the target T has already receives the concerned packet, if yes the node delete the replace request packet, for the reason that the target T has already successfully receives the concerned packet, it is not suitable to retransmit again same packet in order to minimize collisions and packet duplication problem, however, if the target has not received it yet, the node verify the following criterion:

- If the projection of the current node is less than the threshold radius W_{TH}.
- If the depth of the current node is less than the depth of the request replace sender.

After that the above conditions are satisfied the node prepares a packet **DATA** which includes the ID of the node, and the concerned sequence number *seq* in the field of the sequence number of the data packet, as follow Pkt ($Node_{ID}$, *seq*), then the qualified node computes the factor of the desirableness and the $T_{adaptation}$ as well, holds the packet a certain time and forward it. The replace request packet is then deleted to minimize the overload on the concerned sensor node. Moreover, if the conditions are not satisfied the received replace packet is simply dropped by the sensors that received it. The Pseudo code 2 illustrates the process of the recovery phase.

Recovery phase Algorithm

Step 1 : Get the depth information of node A and F;
if $D_A < D_F$ **then** Prepare REPLACE REQ;
Calculate Desirableness Factor (A);
Calculate ($T_{adaptation}$);
Broadcast(REPLACE REQ);
Else Delete Pkt;
end
Step 2 : Node x receives the REPLACE REQ;
if node x is the Source S **then** Delete (REPLACE REQ);
else if node x is the Target T **then** Delete (REPLACE REQ);
End
Else Check if *seq* of Pkt ϵ Packet table of x;
Check if the Target T has not received Pkt before; // if the conditions are satisfied
if $D_x < D_A$ and $P_x < W_{TH}$ **then** Prepare DATA Pkt with the concerned *seq* number;
Calculate Desirableness Factor (x);
Calculate ($T_{adaptation}$);
Forward (DATA);
end
Delete REPLACE REQ;
Else Delete REPLACE REQ
End

Algorithm 1: Pseudo-Code 2 of the Proposed MAGR-VBF

The figure (Fig. 6) presents the adopted method for the recovery phase

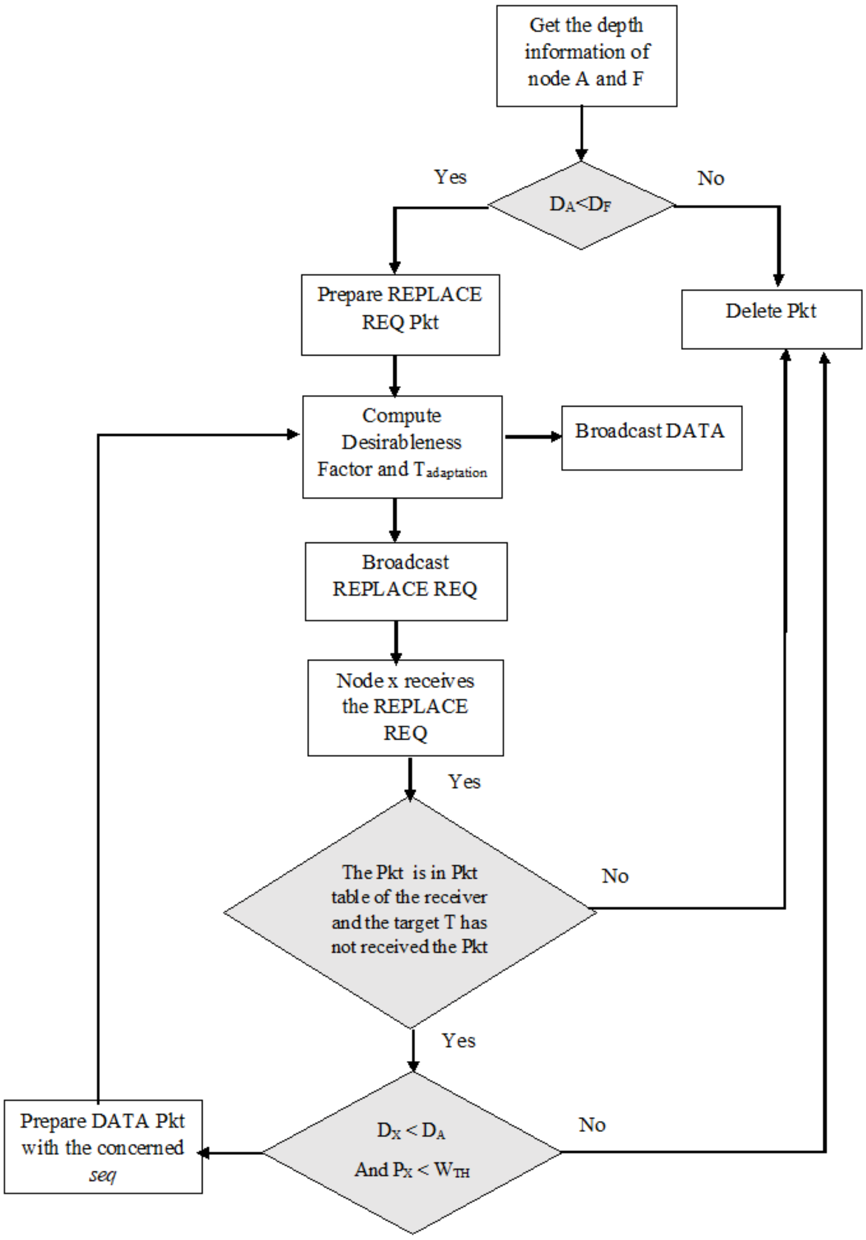

Fig. 6. The proposed solution (MAGR-VBF)

5. Summary

The author summarized the proposed routing protocol MAGR-VBF as follow:

- Predict the future localization of the node according to its projection value to the vector in order to determine if this latter may leave the pipeline or remain in the prediction region, or even move toward the vector and become closer.
- Send a request replace packet to switch to another alternative and eligible node able to forward the packet, if the concerned node may leave the pipeline or remain in the predictive region.
- Sensor nodes that may be located at the predictive region for the next forwarding process, has to be replaced in order to reduce the average delay for the received data packets.
- Sensor nodes inside the pipeline and less deep than the concerned node may be selected as the new qualified nodes to recover the data packet, and reduce more the delay time required to deliver the data packet.

6. Simulation and Performance

To simulate and evaluate the performance of the proposed routing protocol MAGR-VBF over the basic VBF the open-source Network Simulator 2 (NS-2) is used, along with an extension Aqua-Sim which supports the acoustic signal communications in UWSNs, the extension provides a set of basic and numerous protocols for the underwater communication [28].

Table 1. Simulation parameters

Simulation parameter	Value
Deployment area	(1000 m x 1000 m x 1000 m)
Network topology	Random grid
Number of nodes	(100,200,300,400,500)
Routing Protocol	VBF, MAGR-VBF
Radius	200 m, 300 m, 400 m
Predictive region $Pred_{TH}$	4 m, 6 m, 8 m, 10 m
Range	100 m
Node speed	3 m/s, 4 m/s, 6 m/s, 8 m/s
Initial energy	10000 Joule
Packet size	50 Bytes
Number of Packet	2 Packet/s
Frequency	25 Khz
MAC protocol	UnderwaterMac
MAC layer bit rate	10 Kbps
Communication medium	Acoustic waves
Speed of sound	1500 m/s

The table 1. represents the set of the parameters used for the simulation part, a Three-Dimensional space (3D) is used with 1000 m x 1000 m x 1000 m dimensions in an acoustic environment with a speed of sound 1500 m/s, the sensors are randomly deployed within the network and their mobility is varied from 4 m/s, 6 m/s, and 8 m/s, the initial energy of a sensor is set at 10000 Joule, the packet size is fixed at 50 Bytes, the source sensor is fixed at the bottom while the target sensor is fixed at the top, the radius is varied from 200 m, 300 m, and 400 m to determine the impact of the pipeline width over the network performances. The MAGR-VBF has been implemented following the VBF protocol, the results have been obtained based on the presented parameters presented in (Table 1) through multiple simulations, the figure 7, shows the basic architecture of the NS-2 simulator. The trace files are generated with the execution of the script, that contains all the simulation information, mainly as the number of packets sent and received, the consumed energy through the transmissions, the ID of sensors that forwards packets, the required average time for successful packets to be received.

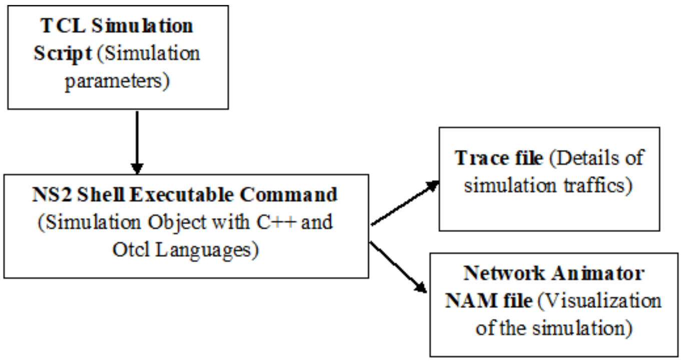

Fig. 7. Network Simulator 2 Basic Architecture

The obtained simulation traffics have been evaluated and analyzed based on the respective following metrics: The Packet Delivery Ratio, Average End to End Delay, and the Energy Consumption, Energy Efficiency, and Packet Loss Ratio.

1. The Packet Delivery Ratio (PDR) the metric gives the ratio of the number of delivered packets at sink node, according to the number of sending packets by the source node:

$$\text{PDR} = \frac{Received_{Packets}}{Sending_{Packets}} * 100 \tag{8}$$

2. The Average End to End Delay (AE2ED) the metric represents the necessary time of packets to reach their destination (sink):

$$\text{AE2ED} = \frac{\sum R_{time(i)} - \sum T_{time(i)}}{\sum Received_{Packets}} \tag{9}$$

Where $T_{time(i)}$ is the transmission time of the packets, and $R_{time(i)}$ is the received time.

3. The Energy Consumption (EC) represents the total difference between the initial energy E_0 and the residual energy E_r of each sensor nodes:

$$EC = \sum(E_0 - E_r) \tag{10}$$

4. The Energy Efficiency (EE): the successful delivery of data at the sink node over the amount of the consumed energy in the network (Ketshabetswe et al., 2019):

$$\text{EE} = \left(\frac{Success\ rate \times Total\ packet\ sent\ to\ the\ sink}{Total\ energy\ consumed}\right) \tag{11}$$

5. The Packet Loss Ratio (PLR): which represents the number of packets lost to the total number of packets sent by the source node (Khairnar et al., 2013)

$$\text{PLR} = \frac{Sending_{packet} - Received_{packet}}{Sending_{\ packet}} \times 100 \tag{12}$$

6.1 Result discussion

In the following part, we present a brief explanation about the obtained results, according to the given metrics, we varied the predictive region Pred_{TH} depending on the speed level, Pred_{TH} = 4m, 6m, 8m. The proposed approach MAGR-VBF is compared against the basic VBF by varying the speed level, s= 4m/s, 6m/s, 8m/s, the radius W is setting at 400 meters, to evaluate more the efficiency of the proposed protocol, we varied the radius W, W=200m, 300m, 400m, with a predictive region threshold at Pred_{TH}= 10 m, the speed is fixed a s= 3m/s.

A. The impact of the speed

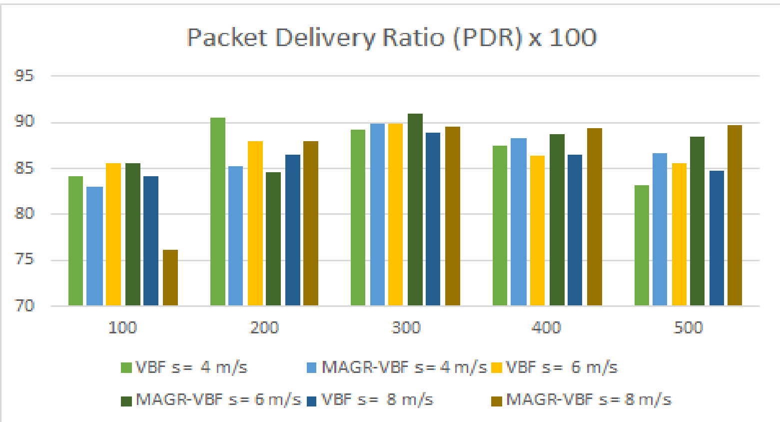

Fig .8. Packet Delivery Ratio W = 400 m

The Fig. 8 outlined the Packet Delivery Ratio according to the number of nodes, it is obvious that when there are more sensor nodes within the network, the ratio of the delivered data packet is high, for the reason that there will be more nodes that participate in the data packet routing. The figures below shows the obtained results of the MAGR-VBF over the basic VBF, at varied speed level, we can observe that the MAGR-VBF gave better results than the VBF in term of delivery ratio, for the fact that the proposed routing protocol prevent from nodes located at the preventive region that have a probability to leave the pipeline and provides a new mechanism aimed to refer and switch to another potential sensor node located at the predefined threshold radius determined by $Pred_{TH}$ in order to recover the data packet that has a high probability to be lost.

As the Fig.8 illustrates, the speed level has an impact on the successful delivery ratio, as it was explained previously, VBF is sensitive to the pipeline radius [21], that makes use a predefined routing pipeline that allow only the sensor inside the pipeline forward the data packet, increasing the speed level could have a bad or good impact on the routing performance, in such a way that the speed allows node to be more mobile and can leave the pipeline soon, in other way it can bring and drift other sensor nodes that were outside the pipeline inside it, such as the scenario with the speed level = 4 m/s, the PDR attempt it high value for the basic VBF at nodes number = 200, for the reason that the presence of nodes inside the pipeline was high that makes the PDR raises, however the value has decreased then till attempting it low value, due to the lack of sensor nodes inside the pipeline due to their mobility. The MAGR-VBF has proved it efficiency against the VBF in the scenario with speed level = 8m/s, where the value of $Pred_{TH}$ = 8 meters respectively, we can conclude that our proposed approach provides better merits than VBF at the speed level = 8m/s, MAGR-VBF prevent from mobile nodes which can leave the pipeline and bring a mechanism that recover from the packet lost using a replace request packet.

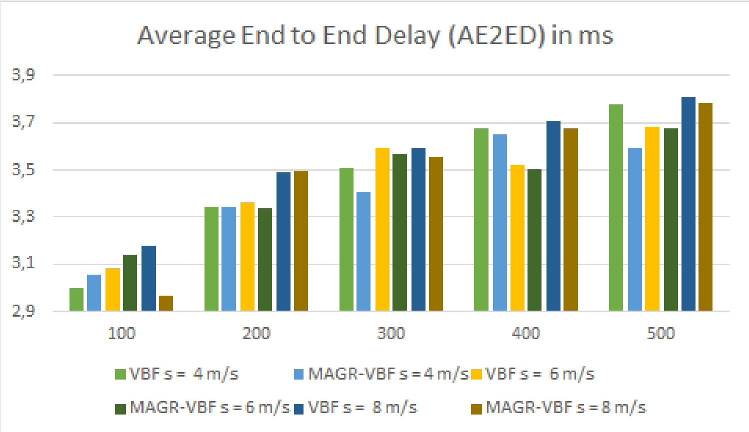

Fig. 9. Average End to End Delay (AE2ED) W=400 m

As it is shown on the Fig. 9 below, the schemes present the Average End to End Delay according to the nodes number, we can observe that when the number of nodes increases, the delay time increases as well, for the fact that the presence of more sensor nodes, will involves too many sensors in the forwarding process, which may increase the delay time of the arrived data packet. The results demonstrates both the routing protocol VBF and MAGR-VBF in term of average delay, at different speed level, as we can notice the proposed approach brings less delay time than the basic VBF, since that the delay time is increasing by the presence of a large number of forwarder, in other hand the sensor node lying far from the vector may affect the delay time, for the reason that, as much as the projection distance is high the holding time defined by $T_{adaptation}$ increases which results in a large average delay, however a high speed level affect the average delay in a case when sensor nodes are moving far from the vector, which may increase the holding time and results in a high delay time.

MAGR-VBF prevent from the mobile nodes that can leave the pipe, moreover, even the sensor lying at the predictive region has to refer to other potential sensor nodes within the pipeline determined by the predefined threshold radius W_{TH}, due to the large delay that it can causes. With the use of a large radius pipeline W (dense network), nodes located far from the vector are less desirable to forward according to the VBF protocol, but can still forward the packet after a certain time, but, the MAGR-BF provides a method to refer to other sensors and does not allow sensor with a large distance of projection to forward, in order to decrease the delay time. We can conclude that the proposed approach outperforms the basic VBF in term of AE2ED.

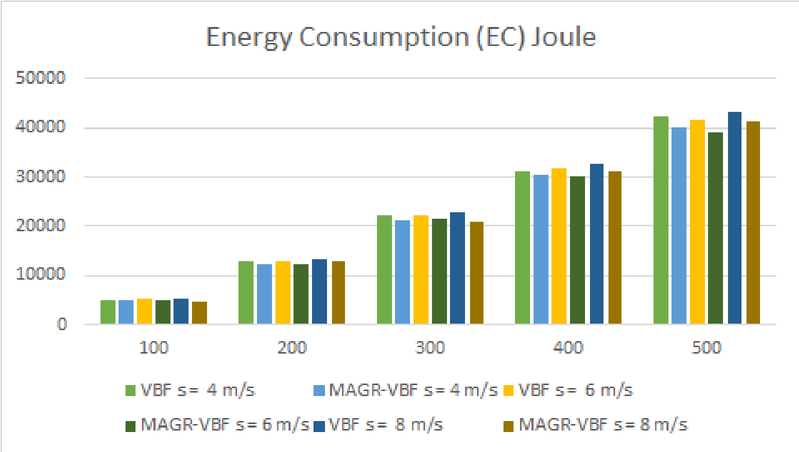

Fig. 10. Energy Consumption W=400 m

The Fig. 10 demonstrates the consumed energy through the simulation time, it can be shown that the consumed energy is impacted by the number of nodes, which means that, more sensors are involved in the transmission process, more the overall energy of the network is consumed, the results presents the energy consumed by MAGR-VBF and the basic VBF, according to different speed level, we can observe that the consumed energy has been enhanced by the routing protocol MAGR-VBF, for the fact that the proposed mechanism avoid unnecessary forwarding data packet by the sensor nodes that have the probability to leave the pipeline, the recovery mechanism has been adapted in such a way that the energy consumed is less, the method allow only the sensor nodes lying at low depth from their sender of the replace request packet to recover the transmission of the packet, moreover if the target node T has already receives the concerned data packet, the process is stopped, which results in more energy saving. MAGR-VBF has slightly improves the consumed energy against the basic VBF routing protocol.

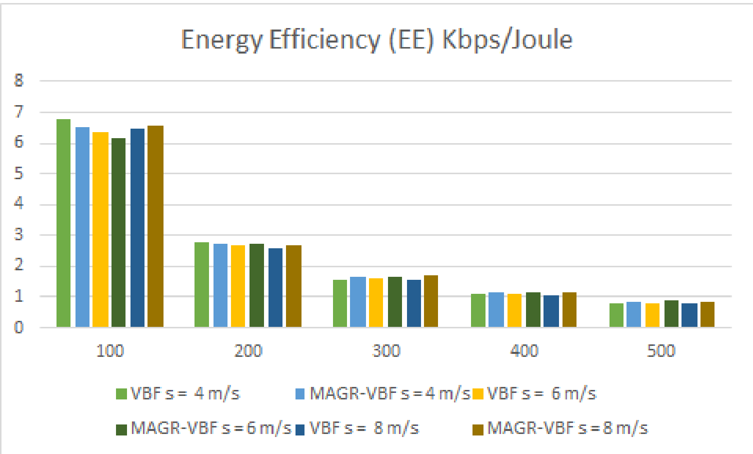

Fig. 11. Energy Efficiency W=400 m

The Energy Efficiency metric is presented in the Fig. 11, where the metric is significantly related to the number of successful delivered packet over the consumed energy, if the successful delivered packet is large and the according consumed energy is low, the metric is large, otherwise the EE metric is reduced when the PDR is low with a high consumed energy, in addition the metric can be reduced when the PDR and the consumed energy are large. Depending on the presented results in figures (Fig 8. And Fig 10), it can be concluded that as much as the consumed energy increased due to the numerous forwarder selections, the Energy Efficiency decreases, furthermore the sensors velocity may meaningfully impacts the energy, where the movement of sensors consumed moreover it energy that mainly impacts the performance of the network. The results demonstrates an improvement of the metric by the proposed protocol in some of scenarios, however, as it can be shown on the Fig. 11, that the EE metric does not presents a good results for the proposed protocol (MAGR-VBF), for the reason that, the protocol adopts a new method that consist to select other potential and alternative sensors to forward data packet, MAGR-VBF may exploits more sensors, that obviously causes an energy consumption which affects the metric of the Energy Efficiency in some of scenarios.

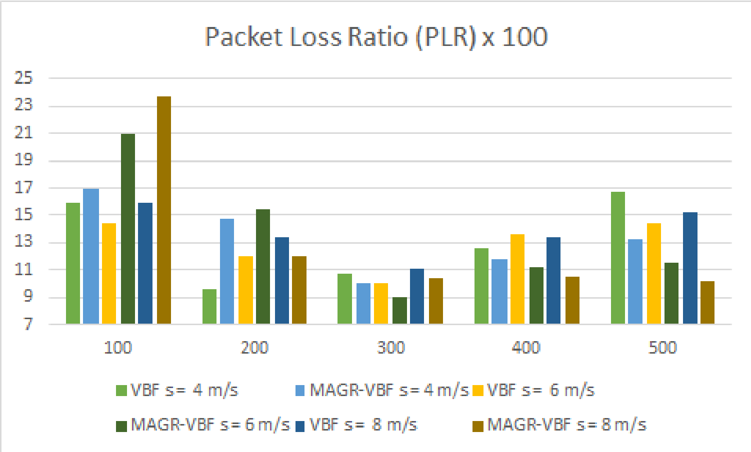

Fig. 12. Packet Loss Ratio W=400 m

The figure (Fig 12.) presents the Packet Loss Ratio metric, the packet loss can occur due to several reasons as the batter power depletion of the sensors, the frequent mobility, collisions and overload problems, it can be shown on the figure (Fig 12.) that the packet loss is high when network is less dense for both scheme, this is for the fact that when a wireless network contains a lack of sensors, the pipeline may have few sensors that could not forwards in efficient manner, which results in a large packet loss. When the network is densely deployed (number of nodes = 500), the probability of collision and network overload became large, which results in a large packet loss ratio. Sensor's mobility and movement induce to wireless link failures in a major time, nodes are frequently moving and the topology is intermittent that induce a loss of data packet. The proposed MAGR-VBF proves it efficiency in term of PLR metric, when the network contains more sensors there is more chance to select another sensor node as forwarder, since the applied method is aimed to recover the data packet through alternative candidate sensors, which minimize the loss of data packet, however it can be observed that the proposed work does not proves it efficiency within a network with a smaller number of nodes, the possibility to select alternative sensors is low.

B. The impact of the Radius

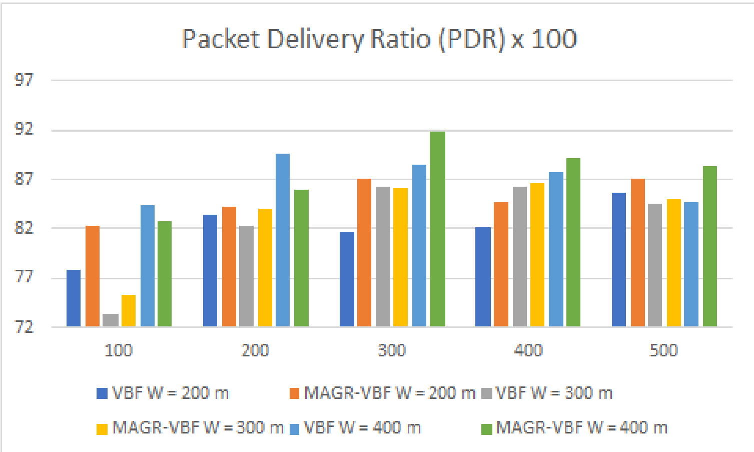

Fig.13. Packet Delivery Ratio s=3 m/s, $Pred_{TH}$ = 10 m

As it is shown on the Fig. 13 that represents the Packet Delivery Ratio over the present nodes number in the network, the successful delivered data increases according to the network's density, when more sensor nodes are deployed the delivered data ratio rises, however the movement of sensor nodes may affect the delivered data even if the network is dense, the mobile sensor may leave the pipeline and join the pipeline during the transmission as well, besides that a large radius has a significant impact on PDR, in such a way that more sensors are involved in forwarding process, although, in some scenario, it can be observed that even if the radius is large the PDR may decreases, this fact is due to the frequent nodes movement. The efficiency of the proposed routing protocol over the basic VBF is more illustrated when the network is less dense (W= 200 m) with a $Pred_{TH}$ set at 10 m, for the reason that when the pipeline is reduced the presence of sensor nodes at the predictive region may be large, hence the proposed MAGR -VBF predict and avoid the nodes present in the predictive region and recover the data through new select nodes, it can be concluding that the $Pred_{TH}$ should be increased according to the radius pipeline size, to exploit more the efficiency of the mechanism used in the proposed protocol.

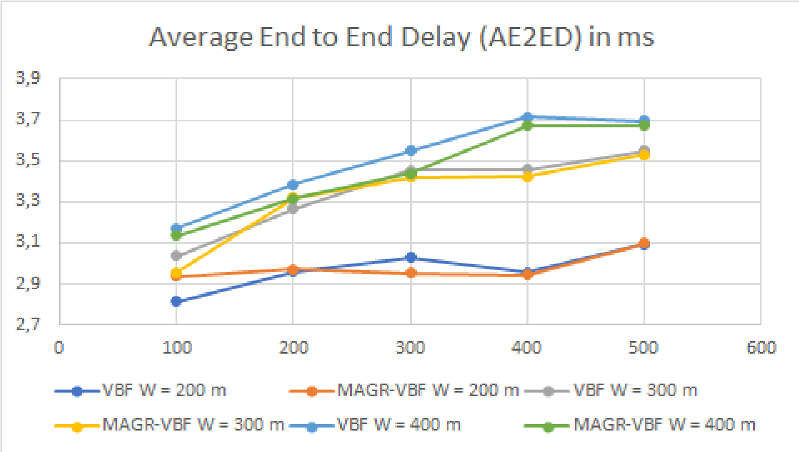

Fig. 14. Average End to End Delay s=3 m/s, $Pred_{TH}$ = 10 m

The results in the Fig. 14 illustrates the average end to end delay according to the nodes number, it is obvious that the delay is impacted by the density of network, for the reason that the presence of a large number of nodes will involves many forwarding nodes in the relay packets, which results in a high average delay, as it is shown on the Fig. 14, the pipeline radius has a high impact on the average delay, since the sensor nodes located at a large distance of projection from the vector have more time to delay the packet, that increases the delay time,

MAGR-VBF has bring better performance with a large pipeline radius, due to the fact that the proposed protocol aims to avoid sensor nodes located at the limits of the pipeline which is defined by the predictive region $Pred_{TH}$, to participate in the forwarding process, that reduced the average delay time. It can be concluded that the proposed mechanism brings better performance in term of AE2ED with a large pipeline radius value.

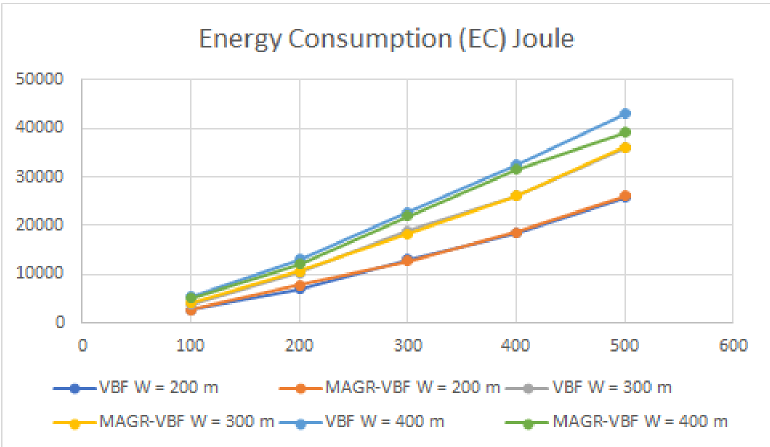

Fig. 15. Energy Consumption s=3 m/s, $Pred_{TH}$ = 10 m

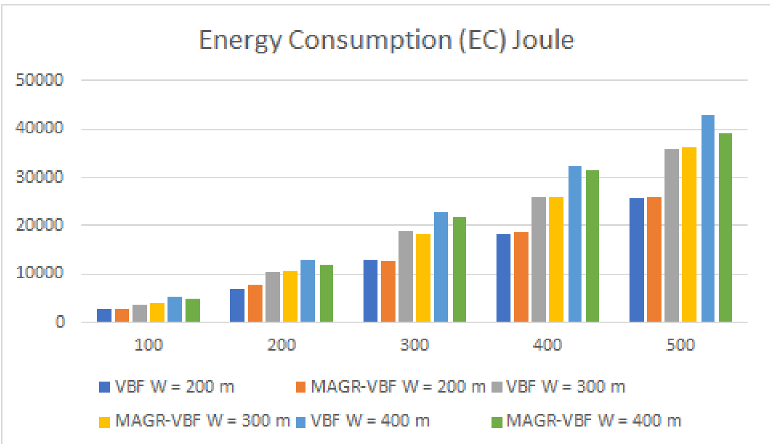

Fig. 16. Energy Consumption s=3 m/s, $Pred_{TH}$ = 10 m

The consumed energy is represented in the Fig. 15 And the bar char (Fig. 16), the energy is more consumed where the network is dense, as much as the sensors are participating in the forwarding process, more the energy is consumed, as it is shown on the Fig. 16 below, the proposed mechanism brings better performance in term of energy consumption with a large pipeline radius W, for the reasons that, the sensor nodes located at the pipeline limits can transmit the packet to sensors that are outside the pipeline, their transmission range could include nodes that are not eligible to transmit, hence MAGR-VBF does not allow sensors located at the pipeline limits to forward, thus saves more energy. It can be concluding that MAGR-VBF has brings better performance in term of energy consumption within a dense network.

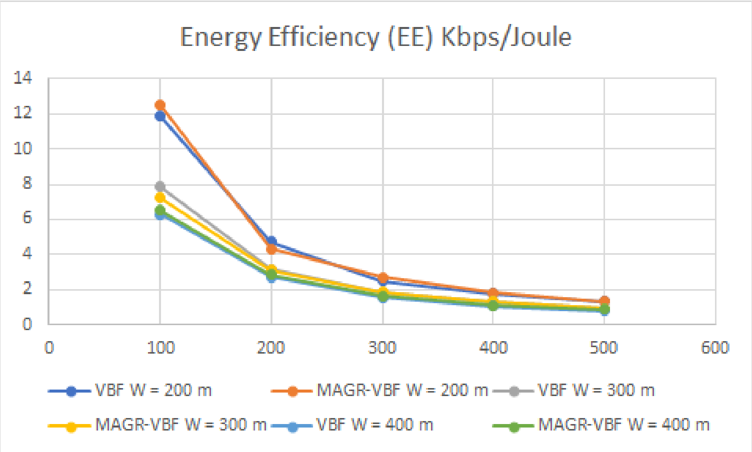

Fig. 17. Energy Efficiency s=3 m/s, $Pred_{TH}$ = 10 m

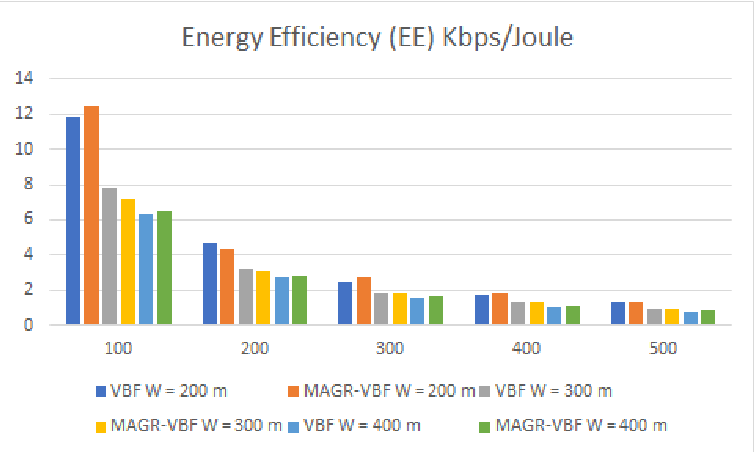

Fig. 18. Energy Efficiency s=3 m/s, $Pred_{TH}$ = 10 m

The presented results in figure (Fig. 18) illustrates the obtained results in figure (Fig. 17), as it is observed, the radius of the pipeline involves several sensors for the forwarding process, that induce in multiple forwarder selection, overloading and packet collisions which increases the energy consumption that affect the metric of the Energy Efficiency. It can be shown that in some of scenarios the proposed works may not proves it efficiency in term of EE in some of cases, for the fact that the protocol tends to select more forwarder nodes than VBF, moreover sensors that are positioned in the pipeline limits are not suitable to forward for the delay time that they can increases and they are replaced with qualified nodes which may consumes more energy and impact the EE metric.

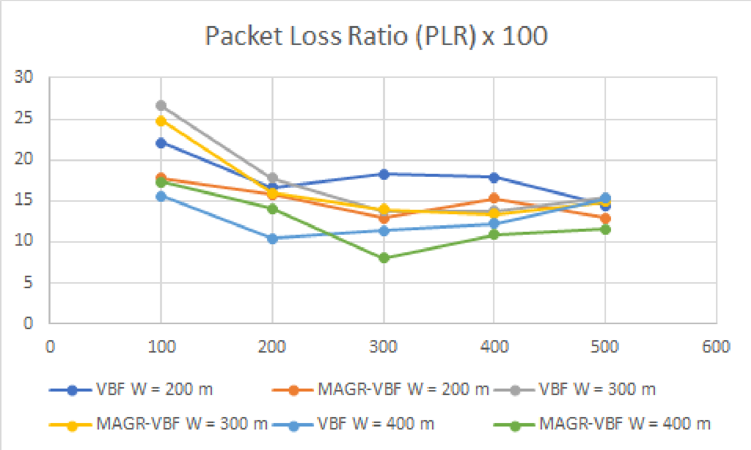

Fig. 19. Packet Loss Ratio s=3 m/s, $Pred_{TH}$ = 10 m

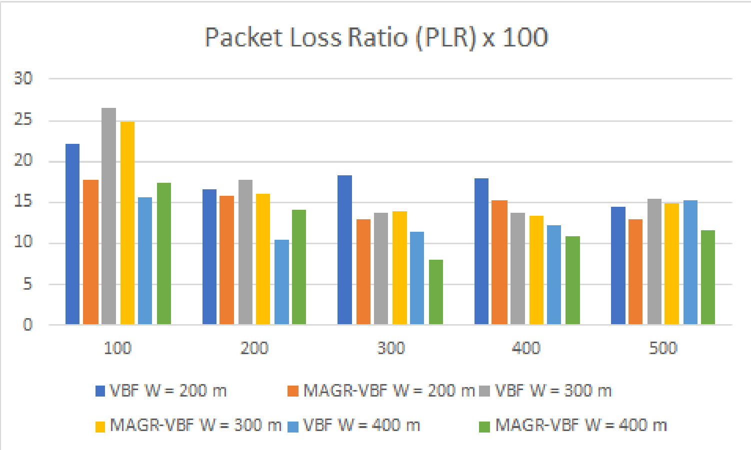

Fig. 20. Packet Loss Ratio s=3 m/s, $Pred_{TH}$ = 10 m

The figure (Fig. 20) illustrates the obtained results in the figure (Fig. 19), where the Packet Loss Ratio is presented. As it is demonstrated the MAGR-VBF has decreased the PLR, with a pipeline radius W = 200m, 300 m, and with a pipeline radius W = 400 m where the number of nodes is more than 200 nodes, the adopted mechanism was aimed to prevent from the packet loss causes by mobile sensors and recover data packet through qualified nodes. In some of cases, sensors may move through other regions and in the meantime still located within the pipeline, the proposed MAGR-VBF does not take an action in such a case, the implemented method operates when sensors are moving outside the pipeline or located at the limit of the routing pipeline, in addition the presence of void regions inside a large pipeline (W = 400 m) decreases the possibility to select alternative sensors which explains the obtained results of PLR with a radius W = 400 m when the number of nodes = 100, 200 nodes.

C. Comparison between the impact of speed and radius

The following *table 2*. summarizes the simulation results that represents the performance of the proposed routing protocol MAGR-VBF against VBF in term of the five metrics, the represented results show the gain that the protocol has achieved in different scenarios from the basic VBF.

As it is shown in the *table* 2., it can be concluded that the efficiency of the proposed mechanism is acquired in term of PDR, AE2ED and PLR with a high speed level = 8 m/s ($Pred_{TH}$ = 8m) in a large pipeline radius (W=400 m), with a moderately reduction of the energy consumption EC and energy efficiency EE, moreover, the PLR metric achieved 21.12 % of gain with a pipeline radius W= 400 m which explain the gain of the PDR that achieved till 5.6 %, for the reason that the velocity of sensors induces the movement of nodes outside the pipeline so that MAGR-VBF operates frequently. However, the gain in term of energy efficiency metric achieved 3.13 %, since the metric is highly depending on the consumed energy and the successful delivery packet, it can be observed from the obtained results of the energy consumption that the according value reach till 6.07 % that explains the gain of the EE metric.

While the represented results in Figure (Fig. 13, Fig. 14, Fig. 15, Fig. 17, Fig. 19) demonstrates that the proposed study brings a better performance in term of PDR with a small pipeline radius, a moderately reduction of the average delay, and a large reduction of the consumed energy, in addition, the simulation results shows that the gain of the PLR metric reaches the highest value of 24.24 %, according to the achieved successful data packet results of 6.16 % with a radius value = 200 m and a fixed predictive region of 10 m, in addition the gain in term of energy efficiency with a radius value = 200 m achieved 5.06 % with an energy consumption value = 1.4 % and PDR value = 6.16 %.

Table 2. Simulation results

Radius, W = 400 m, Pred$_{TH}$= 4m/s, 6m/s, 8m/s														
PDR			**AE2ED**			**EC**			**EE**			**PLR**		
4 m/s	6 m/s	8 m/s	4 m/s	6 m/s	8 m/s	4 m/s	6 m/s	8 m/s	4 m/s	6 m/s	8 m/s	4 m/s	6 m/s	8 m/s
3.89%	3.13%	5.6%	4.97%	0.96%	5.55%	5.92%	6.07%	4.44%	1.51%	3.13%	2.34%	20.78%	13.6%	21.12%
Speed, s = 3 m/s, Pred$_{TH}$= 10 m														
PDR			**AE2ED**			**EC**			**EE**			**PLR**		
200m	300m	400m	200m	300m	400m	200m	300m	400m	200m	300m	400m	200m	300m	400m
6.16%	2.12%	4%	2.4%	2.22%	2.97%	1.4 %	1.73%	8.97%	5.06%	0.73%	3.6%	24.24%	6.96%	21.36%

From the table below, it can be observed that the protocol brings better results when the radius W = 400 m, s = 3 m/s and Pred$_{TH}$ = 10 m than the results with a radius W = 400 m, s = 4 m/s, 6 m/s, and a Pred$_{TH}$= 4 m, 6 m for all metrics, even if the velocity is varied, in other hand the results are better in term of PLR, EE and EC compared with radius W = 400 m, s= 8 m/s, Pred$_{TH}$ = 8 m and radius W = 400 m, s = 3 m/s, and Pred$_{TH}$=10 m, as more as the sensors are mobile and moving through different position the proposed protocol operates frequently and select alternative routes to minimize the data packet loss and reduce the average delay for the nodes that are located at the pipeline limits, which can induce more energy consumption that affect the energy efficiency metric, however the results with speed = 3 m/s has more gain in term of energy consumption and efficiency, for the fact that the wireless sensors are less prone to frequently move. Furthermore, a small pipeline radius threshold involves a smaller number of forwarders due to the lack of sensors, however the results with a radius W = 200 m, s = 3 m/s and Pred$_{TH}$=10 m illustrates a better gain in term of PDR EE PLR, the adopted method in the MAGR-VBF has selected alternative sensors according to 10 m of Pred$_{TH}$ which has enhanced the gain of the delivered packet. The simulation with radius W = 300 m, s = 3 m/s and Pred$_{TH}$ = 10 m, does not bring a good gain compared with the presented simulation outcomes, it can be induced that the routing pipeline might have void regions within the network, that affected the performance of the network, since the proposed MAGR-VBF does not handle the void holes. Hence it can be induced that the proposed MAGR-VBF is applicable with a predictive region distance that is adjusted depending on the velocity of sensor nodes and the radius of the virtual pipeline as well, as long as the predictive region and the velocity are, the proposed protocol proves it efficiency.

7. Conclusion and Future Works

The sensors mobility is a major issue inside a wireless network, which can significantly reduce it performances through the transmission, whereas several studies have been conducted to deal with the mobility and position inaccuracy problems.

In this paper the author has proposed a new mechanism which is based on the well-known protocol for the underwater wireless sensor communication (VBF), the purpose was to enhance the routing technique followed by the VBF protocol that consists to limits the number of forwarder nodes, and allow only sensor nodes located within the pipeline to transmits the data packet, however, when the sensors are more prone to move towards different locations, there is a high chance that the sensor node may leave the pipeline which results in a loss of data packet, otherwise, the fact that the node has to hold the packet a certain time interval defined by the $T_{adaptation}$ before forwarding it, this delayed time is severally impacted by the distance of the node projection to the vector, the MAGR-VBF provides a new method which defines a predictive region that has for purpose to re-valuate the importance of the mobile sensor node before forwarding it, in such a way that nodes with a probability to leave the pipeline has to transmit a replace request packet to ask for an alternative node, which has enhanced the packet delivery ratio and decreased the consumed energy that can be caused due to unnecessary transmission through forwarders that have a probability to leave the pipeline moreover, the sensor nodes located at the predictive region has to send a replace request as well, due to the use of a large radius pipeline W, nodes located far from the vector are less desirable to forward, even if the basic VBF allows it after a certain time, the MAGR-VBF provides a method to refer to other sensors, hence, it has been shown from the results that it helps to reduce in addition the average delay time.

MAGR-VBF protocol has enhanced the performance of the basic VBF by taken into consideration the sensors nodes with a possibility to leave the transmission area, the results indicated that the proposed work could improve more the performance of VBF protocol with a a network that involves a high sensor velocity, a large radius pipeline and predictive region. As a future work the author could enhance the proposed protocol by adjusting the predictive threshold radius according to the pipeline radius size to acquire better results, and includes a method to by-pass the void regions within the pipeline.

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Author's Profile

Manel Baba-Ahmed received her MS in Computer Science from the Djillali Liabes University (UDL) of Sidi Belabbes, Algeria in 2017. She is pursuing PhD in Computer Science and Engineering from the Djilali Liabes University. Her current research areas include computer communication (networks), underwater sensor network, routing protocols. She is a member of the 'Evolutionary Engineering and Distributed Information Systems' laboratory (EEDIS) in Sidi BelAbbes.

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