Underwater Node Selection Algorithm for Multi Attribute Fusion Rating

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***Abstract* —The paper proposes a routing protocol for underwater sensor networks (UWSNs) based on the geographic location-opportunities according to the problems existing in UWSNs which is called group policy objective GPO-UWSNs protocol. When the sensor nodes need data packets, the UWSNs protocol will adopt ADV of the data packets to establish candidate forwarding set and then adopt NADV to evaluate the "moderation" for the nodes within the candidates forwarding set to become the next hop node. Also, according to NADV of nodes, ordering from high level to low level is realized so as to form an ordered candidate forwarding set. NADV is integrated by the quality information of distance and underwater channel link. Afterwards, the ordered candidates forwarding set will classify into different clusters so as to make all the nodes of the cluster be in the communication scope of one another. Next, the EPA of each cluster is calculated and the one with the biggest EPA becomes the next hop forwarding set. The simulation results show that the proposed GPO-UWSNS protocol can effectively enhance the transmission rate of data packets and reduce the number of redundant data packets.**

Keywords- UWSNs; GPO-UWSNs; acoustic communication; candidate forwarding set; EPA; transmission rate of data packets

I. INTRODUCTION

At present, acoustic communication is regarded as the only effective communication mode of underwater communication of UWSNs. Radio wave with high frequency is susceptible to water absorption and light waves suffer from severe scattering, so the wireless radio frequency communication is just limited to the visualization application in short distance. However, compared to wireless radio frequency communication, the underwater acoustic communication channel can lead to considerable and changeable delaying. The reasons are: the underwater sound velocity is about $1.5\times10^3\,\mathrm{m/s}$ while the light speed is up to $3\times10^8\,\mathrm{m/s}$. Additionally, there are some problems existing in underwater acoustic communication, such as loss of data packages and high level of noise and so on. Therefore, the routing protocol [3-6] has become the highlight for studying UWSNs.

The literature [3] has out forward that the DBR is the classic routing protocol for underwater sensor network. DBR makes the data packages transmitted to destination nodes above water by adopting the in-depth information of nodes and combining the greedy algorithm for data package transmission. Once the data package is received and it is closer to water surface, the node will become the candidate one for forwarding the data package, otherwise, the data package should be discarded. The literature [4] puts forward VAPR routing protocol in which the data package transmits data in the preset and unreal "routing pipe". When a data package is received, the node will calculate the distance to the forwarding vector. If the distance is smaller than the preset threshold, the data package will be forwarded, otherwise, it is discarded. From the VBF routing strategy, it is not hard to find out that when the network density is higher, more nodes will participate in the forwarding stage. Although it provides a multiple redundant paths and enhances the transmission rate of data package, energy consumption is enhanced as well.

Therefore, the paper puts forward a new GPO-UWSNs. In the protocol of it, each data package will be widely spread to forwarding set consisted by multiple nodes, while not just single forwarding node, which is quite different from opportunistic routing. The simulation results show that the GPO-UWSNs protocol put forward can effectively reduce the redundant data packet and enhance the transmission rate of data package.

II. SYSTEMATIC MODEL

In UWSNs, a large quantity of mobile underwater sensor nodes are distributed on the bottom of the sea while the sonar buoy(the destination node) is floating on the water surface. It is assumed that the node set of the whole network is *N*, the communication radius of each node is r_c, the set of sensor nodes is N_n and the sonar buoy set is N_s.

Additionally, the underground sensor nodes are able to adjust their depth in water according to the sonar buoy with the moving speed of nodes being $\upsilon = 2.4m/\min$ and the energy consumption for one meter being $E_m = 1500mJ/\mathrm{m}$.

III. GPO-UWSNS ROUTOR

A. Candidate Forwarding Set

When the sensor nodes need to transmit data package, it will decide which neighboring nodes are qualified to become the next hop forwarding nodes. GPO-UWSNs protocol is able to seek those neighboring nodes which can transmit data packages to destination nodes by adopting the greedy forwarding strategy. These neighboring nodes are called the candidate forwarding set.

The process of candidate forwarding set is: it is assumed that the node n_i needs to transmit data packages, its neighboring node set is $N_i(t)$ and the known destination node set is $S_i(t)$. The ADV will be cited in literature [7] to decide on candidate forwarding set. ADV equals to the value which is result of the distance $d(n_i, D)$ between node n_i and the destination D subtracted by the distance $d(X, D)$ between the neighboring node X and the destination D. The neighboring node X is the destination node to the farthest distance of node n_i. It can be displayed in equation(1):

$$ADV_i = \left| d(n_i, D) - d(X, D) \right| \tag{1}$$

While node X :

$$X = \arg\min_{\forall s_j \in S_i(t)} \left\{ d(n_i, s_j) \right\} \tag{2}$$

Therefore, the definition of Γ_i which is the candidate forwarding set of n_i by combining with equation (1) and (2):

$$\Gamma_i = \left\{ n_k \in N_i(t) : \exists s_g \in S_i(t) \left| d(n_i, s_i^*) - d(n_k, s_g) \right| > 0 \right\} \tag{3}$$

Among them, s_i^* means the destination node closest to node n_i and s_g represents the purpose node of the data package.

B. The Next Hop Forwarding Set

GPO-UWSNs uses the opportunistic routing to deal with the characteristics of underwater acoustic channel. In the traditional protocol of multiple hop routing, only one neighboring is selected as the next hop forwarding node. If the channel link of the node is broken, the data package may be lost, while in the opportunistic routing, the shared transmission media is utilized fully so as to spread widely each data package to the forwarding set consisted by multiple neighboring nodes while not just one single forwarding node. Only in the circumstance that all the nodes within the forwarding set do not receive the data package, the data package will be re-transmitted. Certainly, there are defects for the forwarding strategy. On the one hand, the times of re-transmission is reduced so are the energy consumption in re-transmission and the probability of collision between data packages; on other hand, as the neighboring nodes need to wait for the data package to arrive in the next node, it increases the delay time for end-end transmission of data package[8].

In the GPO-UWSNs, for each re-transmission, the next hop forwarding set ψ is to be defined. The suitable node will be selected from the candidate forwarding set Γ_i to construct the next hop forwarding set ψ whose nodes are all able to receive the data re-transmitted by any node within the set so as to avoid problem of hidden terminal. Therefore, constructing the next hop forwarding set ψ is included in maximum clique problem [8]

GPO-UWSNs algorithm cites the normalized weight NADV to evaluate the "moderation" of the nodes to become the next hop forwarding nodes within Γ_i. NADV is integrated by distance and cost information of channel link within Γ_i. This is quite necessary. For each candidate forwarding node $n_c \in \Gamma_i$, the normalized weight $NADV(n_c)$:

$$NADV(n_c) = ADV(n_c) \times p\left(d_c^i, m\right) \tag{4}$$

Among them, the equation $ADV(n_c) = d\left(n_i, s_i^*\right) - d\left(n_c, s_c^*\right)$ represents the priority weight of data packet of the destination node s_c^* which is to the shortest distance of n_c. $p\left(d_c^i, m\right)$ represents the delivery probability of data packet with its definition being shown in chapter 2.3.

After the normalized weight of each node in Γ_i set is calculated, all the weights will be sequenced according to the value from the highest one to the lowest one so as to form the set $\hat{\Gamma}_i \subseteq \Gamma_i$. Next, the elements of the set $\hat{\Gamma}_i$ will be divided further into different clusters ψ_j to ensure that the nodes within the cluster are in the scope of monitoring of one another.

Firstly, the node with the biggest weight in set $\hat{\Gamma}_i$, that is to say the first node n_1 in set $\hat{\Gamma}_i$. Then, the node will be included in the cluster ψ_j (j=0), that is so say $\psi_j \leftarrow n_1$. Accordingly, the n_1 will be subtracted from $\hat{\Gamma}_i$, that is to say $\hat{\Gamma}_i \leftarrow \hat{\Gamma}_i - \{n_1\}$. Then, the nodes whose Euclidean distance to node n_1 is smaller than $\frac{1}{2} r_c$ in $\hat{\Gamma}_i$ is searched which will be transferred to cluster ψ_j (j=0), after which, the equation $j \leftarrow j+1$ exits. The above process is repeated to establish the second cluster ψ_j (j=1) up until $\left|\hat{\Gamma}_i\right| = 0$.

After the cluster is constructed, the EPA of the expected data package in each cluster set ψ_j according to the literature [9], which is shown in equation (5). The purpose of greedy opportunistic forwarding strategy is to construct $\psi_j \subseteq \Gamma_i$ so as to make EPA reach the maximum value. Finally, the cluster $\hat{\psi}_j$ with the biggest value of EPA will be the next hop forwarding set.

$$EPA(\psi_j) = \sum_{l=1}^{k} NADV(n_l) \prod_{j=0}^{l-1} \left(1 - p\left(d_i^j, m\right)\right) \tag{5}$$

C. Transmission Probability of Data Packet

In the chapter, the transmission probability of underwater data package will be estimated with the equation being formed as well. For any pair of nodes in the distance d of each other, the packet transmission probability of transmission bits is shown as $p(m,d)$. Taking the underwater acoustic channel model of literature [10-11], the path loss of each transmission path with no obstacles is $A(d,f)$.

$$A(d,f) = d^k \alpha(f)^d \tag{6}$$

Among them. f is the signal frequency and k is the spreading factor. $\alpha(f)$ is the absorption coefficient. In simulation, k =1.5. The definition of $\alpha(f)$ is shown in equation (7).

$$10\log\alpha(f) = \frac{0.11\times f^2}{1+f^2} + \frac{44\times f^2}{4100+f} + 2.75\times10^{-4} f^2 + 0.003 \tag{7}$$

Average signal-to-noise ratio SNR $\Gamma(d)$ of paths with the distance of d is:

$$\Gamma(d) = \frac{E_b / A(d,f)}{N_0} = \frac{E_b}{N_0 d^k a(f)^d} \tag{8}$$

Among them, E_d and E_d are constant and they respectively represent the average energy consumption and noise power density of unit bits.

The Rayleigh fading model is cited and the probability distribution of SNR is:

$$p_d(X) = \int_0^\infty \frac{1}{\Gamma(d)} \exp\left(-\frac{X}{\Gamma(d)}\right) \tag{9}$$

Bit error probability:

$$p_e(d) = \int_0^\infty p_e(X) p_d(X) dX \tag{10}$$

Use BPSK modulation mode to show the bit error probability of paths to the distance d between one another:

$$p_e(d) = \frac{1}{2}\left(1 - \sqrt{\frac{\Gamma(d)}{1+\Gamma(d)}}\right) \tag{11}$$

Therefore, for any pair of nodes to the distance d between them, the transmission rate of data package for transmitting m bits is shown as $p(m,d)$:

$$p(m,d) = \left(1 - p_e(d)\right)^m \tag{12}$$

IV. PERFORMANCE ANALYSIS

MATLAB R2012b is used to establish the simulation platform with the area $1500m\times1500m\times1500m$ being taken into consideration. The number of destination nodes $|N_s| = 45$ while the sensor nodes $|N_n| = 150$ to 450. The generation rate of each sensor node is subject to Poisson distribution and parameter $\lambda = 0.15 pkts/\min$. Node transmission radius is $r_c = 250m$ and the data generation rate is 50kbps. Each experiment will be repeated for 100 times and the average value will be regarded as the final data with the simulation time being 300 seconds.

In order to analyze the routing performance more sufficiently, the typical DBR and VAPR protocols are selected to compare with the GPO-UWSNs protocol put forward by the paper. It mainly takes into consideration of the following data: the average end-to-end delay, packet transmission ratio and the number of redundant packets; among them, the average end-to-end transmission delay represents the average time from the source node to the destination node. Packet transmission rate refers to the value of the ratio of the number of packets received by the destination node divided by the number of packets transmitted by the source node. The higher the packet transmission rate is, the more reliable the network transmission will be. The number of redundant data packets refers to the number of packet copies when transmitting a data package. The simulation results are shown in Fig.1 and Fig.2.

A. Packet Transmission Ratio

The change curves of transmission rate of data packets in four protocols with the change of density of nodes are shown in Fig.1 form which, we are able to know that transmission rate of data packets increases with the increasing of density of nodes, the reasons are that: when the density increases, the number of nodes participating in the routing is more and the communication link between nodes is more stable so as to improve the packet transmission rate. Compared to VAPR、DBR and GPO protocols, the packet transmission rate of GPO-UWSNs protocols put forward is the highest, which is attributed to the matter of fact that GPO-UWSNs protocol uses the next hop forwarding node set and these nodes are able to monitor each other and decide whether or not the data packet is forwarded. Additionally, compared to DBR and GPO protocols, the performance of packet transmission rate of VAPR protocol in low density environment is improved, the reason is that they have different strategies for tackling the routing holes. When the DBR and the GPO protocols encounter the holes, the data packets will be discarded while the VAPR protocol makes bypass communication based on directional trajectory so as to avoid routing holes.

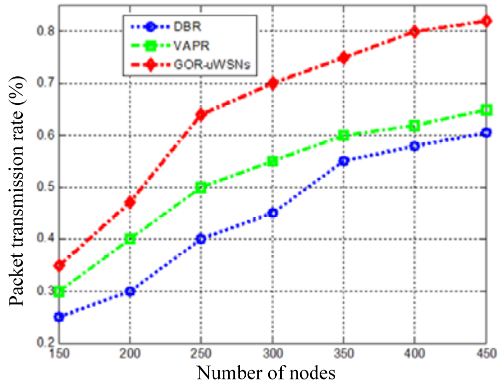

Figure 1. Packet transmission rate

B. *The Number of Redundant Data Packets*

Fig. 2-the number of redundant data packets describes the number of redundant packets. From Figure 2, we can see that the number of redundant data packets in DBR and VAPR protocol increases with the increasing of network density. In the DBR protocol, the redundant data packets mainly come from the multipath packet transmission and in the process in which it fails effectively suppresses the packet retransmission. In the VAPR protocol, the nodes with low weight can not monitor the transmission of nodes with high weight with the number of redundant packets being increased as well. Additionally, the numbers of redundant data packets of GPO-UWSNs protocol and GPO protocol are similar to each other and they do not change with the passing of time. The reason is that the number of redundant packets is derived from the broadcast characteristics. But the number of redundant packets is lower than that in DBR and VAPR protocol.

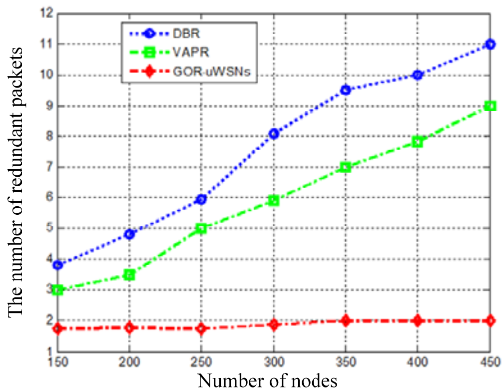

Figure 2. The number of redundant packets

V. CONCLUSION

The GPO-UWSNs is put forward based on the geographic locations according to the problems existing in UWSNs. GPO-UWSNs protocol is a hybrid routing protocol which is integrated by manycast, geographic locations and opportunities. When the nodes need to forward packets, the GPO-UWSNs protocol will firstly use the prioritized weight ADV of data packet so as to select a part of the node from the neighbor node as the candidate forwarding set. After that, the normalized weights NADV of all nodes in the candidate forwarding set are calculated and the nodes in candidate forwarding set are sequenced according to NADV so as to form an ordered candidate set. After that, an ordered candidate set is divided into different clusters to ensure that the nodes within each cluster are in the scope of communication of one another. Finally, the expected value EPA of each cluster is calculated and the cluster with the largest EPA is selected as the forwarding set of the next hop node. The simulation results show that the proposed GPO-UWSNs protocol can effectively reduce the number of redundant packets and improve the packet transmission ratio.

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