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MAEARP: Multi-AUVs Aided Energy Aware Routing Protocol for Underwater Acoustic Sensor Networks

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Abstract: ***Underwater Acoustic Sensor Networks (UWASN) face several challenges in designing a Medium Access Control Protocol with higher packet delivery ratio and smaller energy consumption. This Paper propose Routing Protocol named "Multi-AUVs Aided Energy-Aware MAC Routing Protocol" (MAEARP) which is Clustering by electing a Node based on node buffer size and residual energy, then electing the nearest AUV (Autonomous Underwater Vehicle) Based on this Collected data we create routes leading to the sink node. The expected functions of the protocol include self-organization of the routes, tolerance to failures and detection of isolated nodes. Via the implementation of MAEARP with NS3 and comparing to other protocols, performance results are obtained in different scenarios (varying both nodes and transmission range) that include parameters such as packet delivery ratio and energy consumption. Finally, the analysis and verification of simulation obtained show the effectiveness for our proposed MAEARP in UWASN.***

Keywords: multi-hop routing, transmission range, distance, Packet delivery ratio, Energy consumption, Inference System

1. Introduction and Motivation

The design of MAC routing protocol brings challenges in USWAN. MAC is widely used in the autonomous underwater resource motor vehicles because of its integrationcapabilities, which can be applied to achieve desired performance in any network. AUVs recently started participating in Underwater Acoustic Sensor Networks (UWASN) for the collection and transmission of their data, they act as mobile nodes, which carry several sensors, which are used to navigate and map features of the ocean autonomously. It is also referred to an unmanned underwater vehicle which is a marine robot that supports wide range of military and oceanic tasks such as tracking oceanographic features, inspection of submerged structures, undersea mapping, searching for download aircraft, laying undersea cable, ocean sampling networks and finding naval sea mines. Furthermore, it can be used in environmental monitoring, disaster prevention, assisted navigation, undersea explorations etc. In the global market, AUVs reached 671.5 million $ in 2017 and are expected to reach 835.0 million $ by 2022 [1], [2], [3], [4].

While considering AUVs, there are plenty of issues raised in underwater wireless communications such as limited energy of sensor nodes, limited bandwidth, node mobility, high propagation delay and high error rate. In UWASN, routing starts from surface of sink on sensor nodes that are deployed at various depths of ocean. The underwater sensor nodes are move with current of waters in horizontal plane with slight vibration in vertical direction. Hence, data packets are transmitted from sensor nodes to surface sink on the water at various depths.

We propose multi-AUVs aided Energy aware MAC routing protocol for UWASN (MAEARP).

The proposed MAEARP scheme is evaluated in terms of the Energy consumption, Packet Delivery Ratio on the links of node-to-sink (end-to-end).

Current research study in UWASN aims to reduce the energy consumption using single or multi-AUVs. Various dynamic modeling of the AUV have been proposed to saving the energy. As a consequence of AUV such as variable depths of ocean, time varying dynamic behavior, and uncertainties in hydrodynamic coefficients energy efficient and secure design MAC routing protocol is still challenging over long periods of time.

Based on the aforementioned discussions, we propose aided energy aware and secure MAC routing protocol based on multiple AUVs over UWASN. The simulation results prove our proposed scheme resolved all the shortcomings that are illustrated in [5], [6], [7], [8], and [9].

2. Related Work

The sensor nodes, which are nearer to surface of water, forward the data packets concurrently. Routing protocols need to be designed by means of delay aware, and energy aware also scalable, robust and adaptive [3,10]. Owing to this routing protocols lead to the high-energy consumption problem, insecure communication, and longer end-to-end delay and less packet delivery rate. A multi-packet transmission MAC protocol in UWASN has designed to reduce channel contention time for data transmission and improves the network performance. However, tune the parameters of individual nodes are important for data transmission [11]. A scalable and efficient data gathering scheme for UWSN with controlled mobility of AUV was observed which improves the network lifetime and also balances the energy consumption. At higher speed and longer direction of AUV, the transmission delay leads to high [12]. AUV-Assisted Energy Efficient Data Collection scheme is presented for the application of underwater cyber-physical system (UCPS). In order to balance the energy consumption and prolong the network lifetime, the energy optimization problem is formulated using min-weighted the sum of edge lengths of a particular graph. Here routing decision process has obtained using one-hop relay node and the data collection control of multiple AUVs have the challenging issues in terms of latency and the rate of data transmissions [13–15]. Ahigher number of routing protocols have proposed in UWASN. However, none of them has been designed MAC routing with security as an aim. A secured MAC routing protocol for UWASN can conserve energy. In this paper, we resolve aforementioned issues. Specifically, our primary goal in this paper is to design multi-AUVs aided MAC routing protocol that achieve higher packet delivery ratio, longer network lifetime and reduced energy consumption.

3. Model Description

To improve the routing process, we design the concept of multi-AUVs-aided MAC routing in UWASN. Our proposed system model is shown in Figure 1.

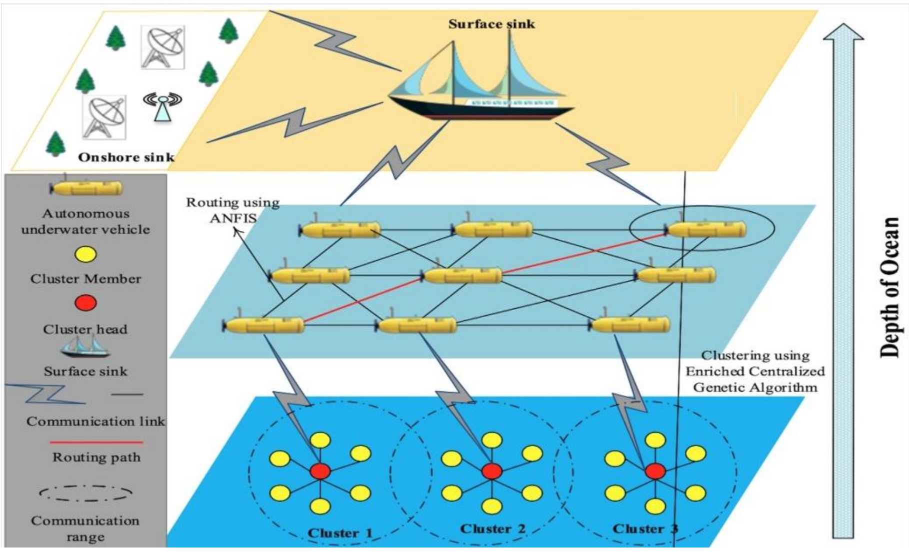

Figure 1: System Architecture

MAEARP include: Underwater Sensor Node (UW-SN), Underwater Cluster Head (UW-CH), Autonomous Underwater Vehicles (AUVs), and Surface Sink (SN). The UW-SN and UW- CH are deployed at the bottom region. We employ multiple AUVs as the homogeneous mobile nodes. AUV can move from one key point to another, which can be updated periodically and it collects sensing data from cluster heads. Once the data collection mission is end, AUV carried out the collected sensed data to the surface sink, first Data is sensed and collected and forward to the CH from the SN. Underwater Cluster Headacts as a gateway to informs each node about slots in which it should listen to other nodes transmission and aboutthe slots in which node can use its own transmission. The cluster head elects nearest AUV (One-hop/ multi hop) to forward data to the surface sink. Here we use Dynamic TDMA based MAC protocol. The node mobility and transmission rate are tuned to improve the data transmission n for individual nodes since depth of theocean and ocean currents have changed continuously and Finally, the data send to the surface sink.

a) Clustering

The clustered UWASN consists of grouping sensors in several clusters so that data collected by the sensors is communicated to its cluster head (CH) and each cluster has a single cluster-head and several cluster members. Each cluster member (CM) sends the collected information to its CH, which in turn transmit it to t AUV. In a clustered UWASN environment, the best clustering process should bein optimizing the following: 1). The number of CHs, 2). CH positions and 3). Less energy consumed. In specific, a sensor node can be upheld to CH based on several parameters.

$$Input\ Params = \{N_{BS}, N_{RE}\} \quad (1)$$

Where N_{BS} is the node remaining buffer size and N_{RE} is the node residual energy.

The node remaining buffer size is computed by its available buffer size at time t and the node residual energy is computed at time *t* is computed as follows:

$$\tilde{E}_i(t) = E_i(o) - \sum_{i-1}^{t} E_i(i) \quad (2)$$

Where E_i (0) is the initial energy of the node i and t is the time in term of transmission rounds. The residual energy of every node is updated in each round. Procedure for cluster formation using enriched centralized Genetic Algorithm (GA) [10],

A dynamic clustering is considered to avoid early death of sensor nodes. The proposed Enriched Centralized GA is executed at the Surface Sink that means it is centralized. The centralized clustering overcomes the several limitations i.e. node spatial distribution is arbitrary (i.e. there is no coordination). In a UWASN, GA must be "Codified". For this reason, we represented nodes in a binary form i.e. node is denoted either by 0 or 1. If a node binary value is 0, it will actacluster-memberandifitis1.

1) Selection- This process is promoted to select the best set of chromosomes from a generation. The Roulette Wheel Algorithmisusedtoperformtheselection.
2) Crossover- In crossover operation, we select two arbitrary chromosomes from a generation and also select two random positions in the selected chromosomes. We used 2- point crossover to generate two new offspring's that belongs to the nextgeneration.
3) Mutation- To apply mutation, we change each chromosome and their arbitrary bit to choose the best-run chromosome. It avoids the super chromosome problem. Therefore, the best crossover and mutation probabilities are 0.75 and 0.2 respectively.

Based on the above discussion, each chromosome is then computed with a fitness function f which attributes a higher opportunity to the best solutions. The fitness value (f) of a node (i) can be mathematically computed as follows:

$$f_i = \alpha x N_{BS} + \beta x N_{RE} \quad where\ \alpha > \beta \quad and\ \alpha + \beta = 1 \tag{3}$$

In eq.3 α, β represents the weights that are assigned to NBS and NR respectively. The node with high NBS and NR will select for cluster head and the remaining nodes are act as cluster member.

b) Route identification

We propose an ANFIS algorithm for routing packets to the final destination (surface sink). Considering 4 input variables i.e. (projection, valid distance, speed and transmission delay) as fuzzified variables which are computed periodically at every node. The computation of each parameter as follows:

The valid distance (VD) between any AUVs (AUVi, CHi) is formulated using the Euclidean distance which is expressed as follows:

$$d(AUV_i, CH_i) = \sqrt{(X_{AUV_i} - X_{CH_i})^2 + (Y_{AUV_i} - Y_{CH_i})^2} \tag{4}$$

The projection (P) of the node means the degree of closeness of the node to the shortest path and it is defined by directly between two nodes projected line. The starting (source) or an ending position does not appropriate to a node of the sensing range. Hence, a node projection is necessary to calculate the nearest AUV for each shortest path computation. The distance of Ci to the routing vector r_1 r_0 is computed as:

$$p = \left|\overline{r_1 C_i} \, x \, \overline{r_1 r_0}\right| / \left|\overline{r_1 r_0}\right| \tag{5}$$

Then we compute projection by:

$$p = p/\omega \tag{6}$$

Where ω in the formula represents the threshold of the pipe and projection attains its minimum P = 0 when C_i lies on the line from the source to destination. The motivation of this projection in this paper is to create the data forwarding path not too much deviate from the routing vectors between neighbors. The node speed (S) directly impacts the network. Basically, the node speed is computed by:

$$S = d/et \tag{7}$$

Where (d) is the distance traveled and (et) is the elapsed time. For this distance value, the positions of nodes are known. The traveled distance is computed using Eq.7.

The node transmission delay is defined as the expected time required to deliver the data packet from source to destination. It is express as follow:

$$delay = (p^{AT} - p^{GT})/H \tag{8}$$

Where pAT, pGT and H represents respectively packet arrival time, packet generated time and hop count. The fuzzy inference system (FIS) is considered by tuning parameters of ANFIS. It is utilized to shape parameters of the membership functions of fuzzy antecedent parameters and linear request parameters of fuzzy rules for "TakagiSugeno". The refinement process allows the fuzzy system to learn from input values that is modeled. Our routing process is based on four inputs, and 81 rules (i.e. 43). The four inputs are node speed, node projection, transmission delay and valid distance. And given single fuzzy system results probability values according linguistic variables low, high and medium. The input variables and its linguistic variables are illustrated in table.1

Table 1: Fuzzy Rules with Linguistic Variables

Rules	Input Variables				Output
	Projection	Distance	Speed	Tx Rate	
1	*High*	*High*	*Low*	*Low*	*Medium*
2	*High*	*High*	*High*	*High*	*Low*
3	*High*	*Medium*	*Medium*	*Medium*	*Medium*
4	*High*	*Low*	*Low*	*Low*	*High*
5	*High*	*Medium*	*High*	*Medium*	*Low*
6	*Medium*	*Low*	*Medium*	*Low*	*Medium*
7	*Medium*	*Low*	*Low*	*Low*	*Medium*
8	*Medium*	*High*	*High*	*High*	*High*
9	*Medium*	*Medium*	*Medium*	*High*	*Medium*
10	*Low*	*Low*	*Low*	*Medium*	*Medium*
11	*Low*	*High*	*High*	*Medium*	Low
…	…	…	…	…	…
81	*Low*	*Low*	*Low*	*Low*	*Medium*

So, we updated ANFIS by two tunable parameters. They are node mobility and transmission rate. The Gaussian membership functions are selected because they are represented by two parameters: mean and variance. This membership function employs the minimum number of modifiable parameters. However, the number of modifiable parameters affected by type and number of membership function. For each CH, the node mobility factor (Mi) is defined as follows:

$$M_i = \sum_{i=1}^{n} (SC - SO)/S \tag{9}$$

Where (SC) is the sensor node, (SO) is the sensor node origin field and (S) is the mobility speed. Node transmission rate (TRi) is defined by the data rate for source-to-destination data transmission.

c) AUVs Movement Pattern Identification

In order to improve the performance of UWASN, AUVs movement is computed based on the previous position of AUV at time t-1. Unscented kalman filter (UKF) [11] is proposed for identifying AUVs movement pattern at time t. It is a combination of unscented transformation (UT) and standard Kalman filter. It can solve the nonlinear system predicting and measured values by sampling data points which need to compute. The UT uses a set of appropriate weighting discrete sampling points for representing mean and co variance of system state. AUVs move an elliptical trajectory. More specifically, AUV trajectory is formulated by an equation of ellipse.

$$(x - x_i)^2 / a^2 + (y - y_i)^2 / b^2 = 1 \quad (10)$$

Where a, b, xi and yi are real numbers. Additionally, θ is used to represent the angle of rotation. Assume that AUV movement pattern in ellipse centered at (0,0) and (θ=0)and the position (x,y) of AUV at time t (xt ,yt) is obtained by using following equation.

$$\frac{x_t^2}{a^2} + \frac{y_t^2}{b^2} - 1 - \quad (11)$$

$$\sqrt{(x_t - x_{t-1})^2 + (y_t - y_{t-1})^2} + \Delta t * S = \theta$$

where (xt−1,=yt−1), Δt and (p) are the previous positions of the AUV at time t-1 , (this can be more depending on the number of counts one would want to use) mobility trace and the average speed of AUV respectively.

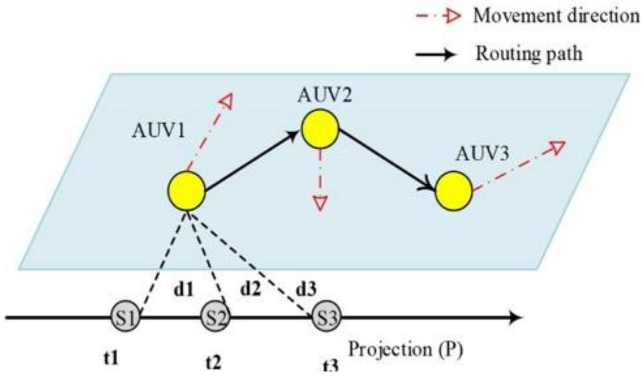

Figure 2: AUV Movement Pattern in Route Identification

4. Simulation Results and Discussions

This section is described as follows: simulation setup, performance metrics and results and analysis. We verified and analyzed the performance of MAEARP under NS-3 simulation (version 3.26) using C++ coding language.

a) Experimental Setup

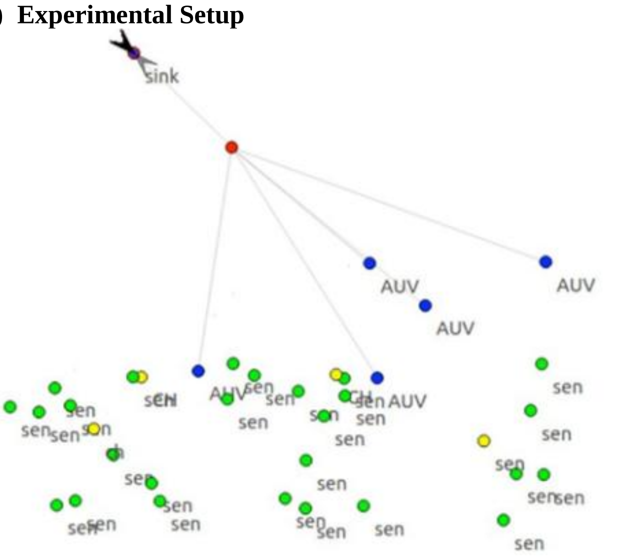

Figure 3: Simulation Environment

As shown in figure.3 we deploy nodes in a simulation area of 5000m x 5000m The AUV movement pattern is elliptical trajectory and it broadcasts hello message for every 5 seconds.

b) Results and Discussion

In this section we discuss the performance metrics for the proposed vs. previous schemes evaluation and also conduct simulations to compare the MAEARP with the previous Routing Protocols.

1) *Performance Metrics: Here we describe the definition of all the performance metrics for the proposed MAEARP evaluation. The definitions are as follows:*

- *Packet delivery ratio (**PDR**): It is defined as the ratio of the number of delivered packets from the source to the destination. It can be formulated as:*
  PDR = Packets Receive / Packets Sent (12)
- Energy consumption: The energy consumption is important metricthatdirectlyrelatedtotheprobabilityofsuccessratefor network. It is estimated as the consumed energy that sending one-byte data. It is computed as follows: Energy consumption of transmittingdata:

ET x (k,d) =(Eelecxk)+ (ampx k x d2) , d >1

Therefore, the power consumption of data transmissionbetween two sensors is proportional to the square of their distance. Energy consumption of receiving data: ERx (k) = Eelec * k

Total consumed energy of each cluster = ΣERx + ΣETx= Total consumed energy of data receiving + total consumed energy of data transmitting.

2) Comparative Analysis: Performance of our proposed MAEARP can be evaluated and compared with a number of previous schemes and number of quantitative metrics those defined in previous section. We have compared with AAEERP [5], DRA-MAC [6], DGS-AUV [7], DDGP-AUV [8], and ASR [9], and it's *describes the limitations of the previous works.*

Table 2: Describes the limitations of the previous works

	Achievement	*Limitations*
EAVARP	*It support for dynamic topology environment*	• *Data collection scheme was poor under a harsh un-derwater environment*
AAEERP	*Increases packet delivery ratio and outperforms un-der harsh oceanic condi-tion*	• *High energyConsumption* • *Single AUV doesnot fit for large scale UWASN*
DRA-MAC	*Ocean depth and angle in-formation overheard from the neighboring nodes*	• *High delay for Packettransmission* • *Data temporary loss may occurdue to collision problem*
DGS-AUV	*High variations in the AUV mobility parameters reduce the inter-AUV synchroniza-tion frequency*	• *Number offailures of AUVis high* • *Movement of the n*
DDGP-AUV	*Reduces the transmission power and latency to gather data at sink*	• *High energy consumption* • *It doesnot suitable forlarge scale UWASN*
ASR	*Determined secure neigh-bors for data transmission. This will improve the sys-tem efficiency*	• *High delay for secure packet transmission* • *High complexityin key dis-tribution*

c) **Impact on packet delivery ratio:** PDR illustrates the amount of delivered data packets from the source node to the destinationnode.

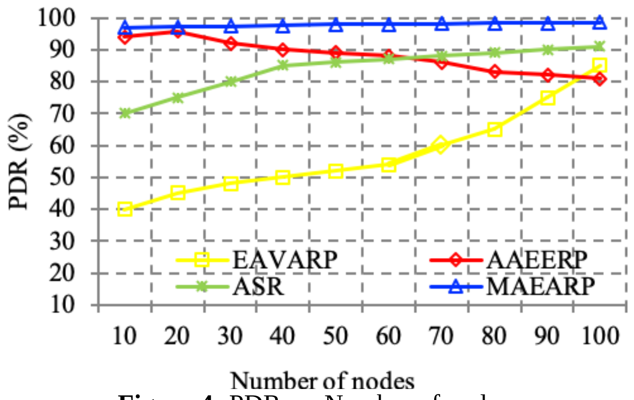

Figure 4: PDR vs. Number of nodes

Figure 4 shows the PDR for proposed work vs. previous schemes including EAVARP [12], AAEERP [5], and ASR [9]. From the graph, it can be seen our proposed MAEARP achieves high PDR (98%) even when the number of nodes increases. The reason is that the MAEARP takes into account node speed and valid distance between cluster head and AUV. In EAVARP, data collection is rigid in harsh ocean environment. In AAEERP, the PDR is 95.7% when numbers of nodes are 18 and 88% when number of nodes are 64. AAEERP increases the packet delivery ratio because of the variable communication time, but the number of nodes limited since it leads to congestion problem.

d) **Impact on energy consumption:** Increase in network dimension caused increase in energy consumption. All the previous schemes are effort to deliver packets with less amount of time. Due to traffic generated from the non-legitimate nodes, the energy consumption increases with increasing number of nodes.

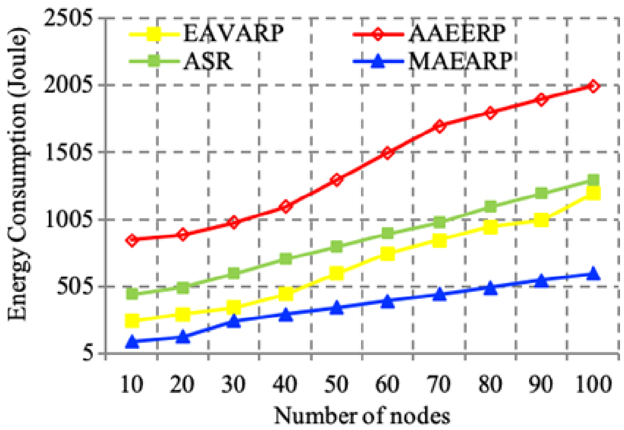

Figure 5: Energy consumption vs Number of nodes

Figure 5 illustrates the relationship between the energy consumption with respect to number of node sates.

The optimum route computed from the source to the final destination which is derived using ANFIS classifier and dynamic TDMA MAC protocol. The ANFIS is a FIS implemented in the framework of an adaptive fuzzy neural network, and isa very powerful approach for building complex and nonlinear relationship between a set of input and output data [13], [14]. It combines the explicit knowledge representation of FIS with the learning power of artificial neural networks "ANNs". Usually, the transformation of human knowledge into a fuzzy system (in the form of rules and membership functions) does not give exactly the target response. So, the optimum valuesofthe FIS parameters should be found. The main objective of the ANFIS is to determine the optimum values of the equivalent FIS parameters by applying a learning algorithm using input- output data sets. The parameter optimization is done in such a way that the error between the target and the actual output isminimized.

5. Conclusion and Future work

In this study, the performance of the proposed MAEARP routing protocol was simulated using NS3, represented by varying the VoIP codecs, node speeds, numbers of nodes, and numbers of calls. Two performance metrics were measured, PDR and energy consumption. The two scenarios hypothetically occurred on a flat plot with a2 area of 5000 x 5000 m. An advantage of MAEARP it classifies nodes to several clusters. Simulation results showed that the proposed MAEARPC is superior in terms of PDR and energy consumption. This result achieved the best QoS for routing protocols in a realistic environment where other routing protocols models were considered. Many issues can be considered in the adoption of the MAEARP routing protocol, among which are energy efficiency and secure communication. In the future, we planned to implement our proposed scheme in 3D space.

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