Clustered chain founded on ant colony optimization energy efficient routing scheme for under-water wireless sensor networks

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ABSTRACT

One challenge in under-water wireless sensor networks (UWSN) is to find ways to improve the life duration of networks, since it is difficult to replace or recharge batteries in sensors by the solar energy. Thus, designing an energy-efficient protocol remains as a critical task. Many cluster-based routing protocols have been suggested with the goal of reducing overall energy consumption through data aggregation and balancing energy through cluster-head rotation. However, the majority of current protocols are concerned with load balancing within each cluster. In this paper we propose a clustered chain-based energy efficient routing algorithm called CCRA that can combine fuzzy c-means (FCM) and ant colony optimization (ACO) create and manage the data transmission in the network. Our analysis and results of simulations show a better energy management in the network.

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1. INTRODUCTION

An Ocean on Earth is one of the main traditional divisions of the World Ocean, which occupies seventy percent of the planet's superficial and is the world's highest and most diverse biome. Researchers and scientists are drawn to this environment for a variety of reasons, including the fact that under-water events have a significant impact on terrestrial life. As a result, thorough surveillance of under-water activity is needed. Under-water wireless sensor networks (UWSN) have evolved as a useful method for discovering and exploiting this rugged world in recent years. Sensors and autonomous underwater vehicles (AUVs) are utilized in various numbers in this network to conduct collective tasks across a defined region. As an independent network, sensors are self-organized and can respond to sea environment characteristics. Sensor nodes transfer data to sinks after the sensing phase. It can transmit the data through intermediate nodes or AUVs. In the media used for transmission of data, under-water sensor networks differ significantly. Acoustic, gravitational, and light waves are also part of the physical layer. According to a comparison analysis conducted on [1], acoustic signals perform best in water environments because they can fly further due to their lower frequency range (10 KHz-1 MHz) than radio waves. Because of the high-speed of 1500 m/s, delays created by acoustic signals are significant in data transfer. UWSN have a variety of possible uses, like the networks for ocean sampling, deep-sea studies, catastrophe prevention, seismic monitoring, aided navigation [2]. The most features of These networks are characterized by scalability, mobility, and selforganization [3]. Because of the following inherent properties of the Under-water conditions, these characteristics face significant problems as opposed to terrestrial wireless sensor networks: i) The required bandwidth is extremely restricted, ii) The underwater channel is severely impaired by multi-path and fading, iii) The latency of underwater radiofrequency (RF) networks are five orders of magnitude higher than that of terrestrial RF networks, and it is highly complex, and vi) Because of the under-water channel's extreme characteristics, high bit error rates and transient lack of communication (shadow zones) can occur. Energy conservation is a critical problem in UWSN since sensor nodes are powered by batteries, which are difficult to replace or recharge in aquatic environments [2]. However, according to the node's limited energy, creating paths between nodes and distributing the collected data to the sink necessitate an energy-aware. UWSN routing protocols are hard to develop in general, and the aquatic environment makes it more difficult. Underwater networks may use acoustic waves as a communication medium [4]. The majority of sensors on the earth are static, whereas under-water sensor (US) entities could move with the flow of water. This means that a new routing strategy for UWSN should be implemented. Consequently, taking energy in consideration when designing a protocol is primordial such that battery capacity is used effectively to maximize the lifespan of both nodes and networks. We suggest an implementation of energy-aware algorithm designed for aquatic surveillance applications. Our proposition is based on chains and clusters as two main technics. The network is created by means of Fuzzy c-Means methods, which are used to generate cluster structure to decrease the distance between sensor nodes. The data transmission processes use a chain-based method that employs the ant colony optimization (ACO) algorithm. There are several reasons why the ACO algorithm is an excellent option for UWSN routing. The ACO algorithm has proved its ability to react quickly to changes in the network. The remainder of this article will be based on the following sections: Previous research on energy-efficient routing in WSN and UWSN are summarized in section 2. Section 3 contains a thorough description of our strategy. The simulation results of the proposed algorithm are presented in section 4, as well as their success in comparison to the MH-FEER, VBF, and REBAR protocols. The paper comes to a close with section 5, which addresses upcoming projects.

2. STATE OF THE ART

Due to many characteristics that distinguish UWSNs from terrestrial sensor networks, such as complex topology caused by permanent node mobility and sparse deployments, routing is extremely difficult. As a result of these considerations, ground-based sensor network routing protocols are normally inapplicable to this type of network. Many WSN research studies in [5] have focused on the creation protocols that take in consideration the optimization of the energy consumption to extend the network's lifetime. Clustering is used in WSNs because it has proven to be an effective approach for providing better data aggregation and eliminating the longest distance because connectivity absorbs the most energy during network service. LEACH [6] is a known energy-aware protocol based on clustering with the permanent data distribution, and without mobility. LEACH nodes organize themselves into small clusters, and in each cluster one node is operating as cluster head. LEACH involves a random rotation of the cluster-head based on the energy available in the nodes, this rotation balances the energy consumption in the network nodes.

Chain is an other technic used by routing protocols in wireless sensor network (WSN); PEGASIS [7] is the most famous protocol in this group. Using a greedy algorithm, PEGASIS forms a chain that includes all network nodes. Nodes take turns becoming the leader of each round and relay the collected data to the sink. This method decreases the energy consumption, but the transfer delay is longer. In [8] and [9] A vector from a sender to a destination specifies the transmission, which is based in a pipe routing [8]. To solve the disadvantages of the above, a vector for node forwarder is suggested (hop-by-hop vectors) [9]. Jornet *et al.* [10] suggest focused beam routing (FBR), it is a cross layer solution in which power management closely couples physical layer functionalities, medium access control and the routing protocol. Jinming *et al.* [11] present an algorithm to alance the energy “reliable and energy balanced routing algorithm (REBAR)”. The data propagation range is set by an adaptative mechanism, also it forecast a bypass of routing voids in the network. the sphere energy depletion model is used to analyze the energy usage of entities in UWSN. In [12] Domingo and Prior suggest a GPS-free routing system for underwater applications characterized by non-time-critical and long-term, they propose clustering sensors with a distributed algorithm. The protocol starts with the creation of the clusters and determination of the cluster head, this later is based on residual energy. After that, the routing to the sink operation is based on multi-hop routing via other cluster-heads. The cost metric is introduced as a parameter to extend the lifetime of UWSN in [13]. Uichin *et al.* [14] resolve the problems of UWSN by proposing Hydro Cast, where the process of routing calculation is based on hydraulic pressure. Other energy-aware routing protocols link state based routing (LSB) [15] and round based clustering (RBC) [16]. For the protocol proposed in [17] improved adaptive mobility of courier nodes in threshold-optimized depth-based-routing (iAMCTD) the authors propose to improve the network performance by reducing the packet drop ratio by means of its formulated forwarding functions (FFs). Souiki *et al.* [18] suggest an energy efficient routing algorithm based on multi-hop fuzzy (MH-FEER). MH-FEER is a fuzzy-based energy-aware protocol to create clusters based on the fuzzy c-means method.

The nodes group themselves into clusters of unequal size at random, for each cluster there is a designated node as the cluster-head. The other nodes send data to nearest cluster head in a one hop; the designated cluster-head collects the nodes (members of the network), treat data with aggregation functions (min, max, sum..) to send the result to the sink. The data can be routed to the uw-sink through many cluster-heads with the minimum of hops.

MH-FEER incorporates cluster-head rotation among the sensors to avoid rapid draining of the batteries of network nodes (sensors). Mukhtiar *et al.* suggest Reliable multi-path energy efficient routing protocol for under-water wireless sensor network (RMEER) in [19], this protocol focus on creating an energy-optimized route between network nodes and extending their battery life. To achieve energy efficiency, the developers of [20] employ stochastic hill climbing, spatial routing, and the mobile sink technique, in which a sink creates a routing with stochastic hill climbing based on data obtained from cluster heads and sink movement. Fuzzy c-means (FCM) algorithm is used by Pramod and Chaturvedi [21] to build networks, and the network's performance is determined by the energy consumption (residual, critical residual status). Uniform, Poisson, and Gaussian models are used to calculate the energy.

3. OUR PROPRSED WORK

Different methods are merged in our contribution to address the issue of energy exhaustion in the area of UWSNs. We suggest an algorithm in which we first use the FCM algorithm to produce a predetermined number of clusters. Second, the local and the global chain is created by the ACO algorithm.

3.1. FCM clustering

We propose the fuzzy c-means clustering algorithm [22] to create clusters, it describes the probability of clustering using membership. FCM, on the other hand, is a local optimization algorithm that is extremely sensitive to initialization and quickly falls into the local minimum value.

The finite vectors x_i (i = 1, 2, , n) are divided into c ($1 < c < n$) classes, and the clustering center of eachclass is solved to make membership minimum as the non-similarity index. The objective function is defined as (1):

$$J_m = \sum_{i=1}^{c} \sum_{j=1}^{n} U_{ij}^{m} \quad (1)$$

where U_{ij} denotes group membership, *ci* denotes the clustering center; d_{ij} denotes the special distance from vector c_i to x_j. , the weighted index is represented by m. The following are the algorithm steps:

1. The matrix U memberships are initialized with the formula:

$$\sum_{i=1}^{c} U_{ij}^{m} = 1 \ , \ \forall j = 1,..,n \quad (2)$$

2. The next formula is used for the clustering center:

$$c_j = \frac{\sum_{i=1}^{n} U_{ij}^{m} \cdot x_i}{\sum_{i=1}^{n} U_{ij}^{m}} \quad (3)$$

3. The objective function is calculated by the formula (1). The algorithm is terminated if the objective function is less than a certain threshold, or if the relative value function's last alter value is less than a certain threshold.
4. The matrix is updated using the following formula and repeat the step2.

$$U_{ij} = \frac{1}{\sum_{k=1}^{c} (\frac{d_{ij}}{d_{kj}})^{\frac{2}{m-1}}} \quad (4)$$

3.2. Algorithm for ant colony optimization

M. Dorigo's ant colony optimization (ACO) [23] is proposed to resolve difficult problems of combinatorial optimization. The pheromone trail laying and following actions of real ants, where the pheromones is the main communication mechanism, is the source of inspiration for ACO. This algorithm is used to solve a wide range of problems like vehicle routing, and scheduling [24]. In our proposition, the ACO is used to create a local chain for clusters. The concept is inspired by the traveling salesman problem (TSP) [25], in which the ACO creates the shortest open chain in clusters. Each ant is initially assigned to a node randomly. Ants use a probabilistic decision rule to choose which node to visit during the development of a feasible solution. When an ant k constructs a partial solution in node I the probability of going to the next sensor (node) neighbor to node i is calculated by the formula:

$$p_{ij}^{k}(t) = \begin{cases} \frac{\tau_{ij}(t)^{\alpha}.\eta_{ij}^{\beta}}{\sum_{l \epsilon J_i^k} \tau_{ij}(t)^{\alpha}.\eta_{ij}^{\beta}} & \text{i}f\ j\epsilon J_i^k\ 0\ \ otherwise \end{cases} \tag{5}$$

where J_{ik} is the list of potential moves for an ant k when it is on a node i, η_{ij} is the visibility which is proportional to the reciprocal of the interval between two nodes i and ($1/d_{ij}$) and $\tau_{ij}(t)$ is the intensity of the runway at a given iteration t. The algorithm is adjusted by two key parameters: α and β, which determine the relative intensity and visibility of an edge. After the tour nodes have been finished, an ant k deposits a quantity of pheromone on each edge of the path:

$$\Delta\tau_{ij}^{k}(t) = \{ \frac{Q}{L^k(t)} \quad if\ (i,j)\epsilon T^k(t), 0\ \ otherwise \tag{6}$$

At iteration t the performed by ant k is represented by $T^k(t)$, $L^k(t)$ the length of the path and a Q parameter configuration. The pheromone left by ants in previous iterations disappears:

$$\rho\Delta\tau_{ij}^{k} \tag{7}$$

After each iteration, there are two sums of pheromones, evaporated and laid.

$$\tau_{ij}(t+1) = (1-\rho).\tau_{ij}(t) + \sum_{k=1}^{m} \Delta\tau_{ij}^{k} \tag{8}$$

where: m represents the number of ants, ρ represents the adjustment parameter. We eliminate from each chain the longest path after the accomplishment of all tours.

3.3. A detailed description of the proposed algorithm (CCRA)

3.3.1. Clusters and chains formation phase

We consider the application scenario that N network nodes (sensors) are distributed arbitrarily into a 3-D field in a zone of $(M * M * M)m^3$. After being dispersed, the sink obtains critical global knowledge (position, energy) of all sensors by sharing information between the sink and sensor nodes. Sink then splits the sensing region into a set of clusters with unequal dimensions. The number of clusters c is determined by taking the square root of the total number of sensors. Using FCM algorithm, the sink computes cluster-heads and assigns network nodes to clusters.

After FCM forms the clusters, the lower chains are created using the ACO algorithm. Since all chain nodes have the same amount of resources, in each lower chain, the leader should be in the center at first. In the next iterations, nodes' residual energy is the main parameter to make leader node rotation. Figure 1 depicts a closed chain with a cluster and six linked nodes. The ant colony optimization algorithm, which is used in TSP, was used to generate this sequence. The shortest open chain is then obtained by removing the longest interval between two consecutive nodes. Figure 2 shows the removal of the line connecting nodes 1 and 6. One higher chain including c leaders and the sink will be constructed as well by the same way. The black lines in Figure 3 reflect the lower chain where each node is linked in a cluster, where the Figure 4 represent the link between the leader nodes and the sink.

3.3.2. Leader node selection phase

FCM develops the UWSN infrastructure, one higher chain and several lower chains. The method of selecting a leader is carried out at the cluster level. The leader will initially be at the core of the chain, in other rounds the node residual energy is the main parameter in selecting the cluster-head. To prevent the rapid draining of the batteries our proposed work envisage a leader rotation after each round, thus distributing energy consumption.

3.3.3. Data transmission

Sensors begin data collection and transmission operations after the establishment the higher chain, and lower chains also the selection of the cluster's heads. For data transfer, the same token passing method implemented in PEGASIS is used. Each end node in a chain begins by transmitting to the next node in created chain. The next node receives the data, merges it with its own, and transfers it to the next node. This is how data is sent from the farthest node in the chain to the leader. Following that, each leader in the higher chain uses the same method to forward the data to the sink. The theory of the CCRA algorithm is summed up in pseudo-code 1.

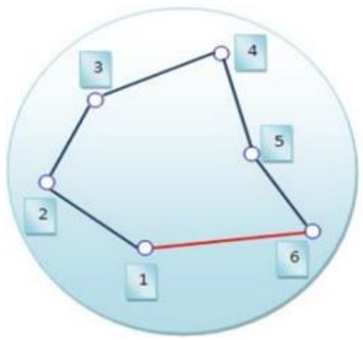

Figure 1. Formation of the closed chain

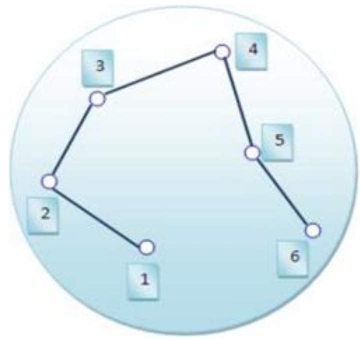

Figure 2. Formation of the open chain

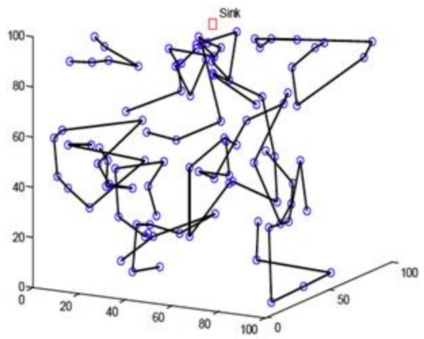

Figure 3. The lower chains formation

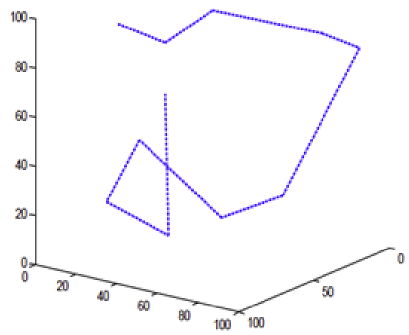

Figure 4. The global chain formation

4. SIMULATION AND RESULTS

4.1. Simulation settings

MATLAB was used to run the simulation studies. In a region of (100100100)m3, a dense sensor network with 100 nodes is being simulated. The network is considered homogenous, with an initial energy of 10J for each sensor node. At the coordinates (50, 50, 150) m we use a single sink to increase the number of hops. We presume that sensors' information (position, residual energy) are shared with the BS to be used at the beginning of each round.

Also we assume that position is calculated by the angle of arrival (AoA) of the signal and the distance using the nodes' outfitted instruments. The use of this calculating technic is due to the wavelength of sound. Moreover, US nodes are habitually larger than land-based sensors, and they have room for such devices. There is no mobility model for UWSN in the aquatic environment, so we use therandom walk mobility model. After each round, all sensors adjust their coordinate location.

We assume that nodes calculate and send the environmental parameters to the receiver nodes in fixed periods. In addition, each sensor node will track target parameters using sensing mode, and the gathered information are sent to the cluster head and the uw-sink. The transmitting mode is used transmit data to the cluster head (to aggregate and send data to the uw-sink).

4.2. Energy model

In our proposition we use energy model suggested in [26] for under-water acoustic networks. This model states that to reach a power level P0 at a receiver at a distance d, the transmitter power $E_{TX}(d)$ must be:

$$E_{TX}(d) = P_0 . d^2. \tag{9}$$

where *α(f)* is a medium absorption coefficient calculated in dB/m and depends two parameters: salinity and the frequency spectrum, *α(f)* is calculated by the following equation:

$$\alpha(f) = 0.11 \,.\frac{10^{-3}.f^2}{1+f^2} + 0.44\,.\frac{10^{-3}.f^2}{4100+f^2} 2.75 \times 10^{-7} f^2 + 3 \times 10^{-3} \quad (10)$$

where f is the transmission carrier frequency in KHz. The receiving power is assumed to be one-third that of the transmitting power.

The transmission in the under-water environment is strongly influenced by the salinity of the water. To model this influence *Jinfang et al.* in [26] based on two parameters the salinity (p), the temperature (T) of water and the deep (H). The delay is obtained as (11):

$$D=1449.5+ 45.7T^2+0.23T^3+(1.333-0.216T^2)*(s-35)+16.3*H+.18H^2 \quad (11)$$

where H denotes the water depth. The residual energy of the sensor can be calculated by (12);

$$E_{resi}=E_{init}-(E_{rx}+E_{tx}) \quad (12)$$

4.3. The Aspects of energy efficiency and network lifespan

In the simulations, we test and compare the efficiency between our proposed algorithm (CCRA) and MH-FEER [18]. Total energy usage and network lifespan are two main efficiency indicators that are evaluated. We ran simulations to test and compare the performance of MH-FEER [18] adapted to aquatic characteristics with our proposed routing algorithm, and we evaluated two main performance metrics; the used energy and network lifespan

Algorithm 1. Pseudo-code of CCRA algorithm

```
Fix the number of clusters ;
it_max is the maximum number of rounds;
RE is the network remaining energy;
nc denotes the number of clusters ;
Xi, Yi and Zi denotes coordinates of node i;
d(i; j) denotes distance between nodes j and j + 1 in chain i ;
step 1: Custers formation ;
        • Apply FCM algorithm to form clusters;
        - Each cluster cl(i) contains a number of nodes;
        - Initially all nodes have the same amount of energy;
while it ≤ it_max or RE > 0 do
        step 2: Local chains formation ;
        for i ←1 to nc do
                Apply ACO algorithm as it is used in the TSP to form closed chain i;
                for i ←1 to length(cl(i)) - 1 do
                dmax← 0;
                d (i; j) ← √q(Xj − Xj + 1)² + (Yj − Yj + 1)²(Zj − Zj + 1)²;
                if dmax < d (i; j) then
                        dmax ← d (i; j)
                else
                        dmax
                end
        end
        Delete dmax in chain i to obtain open chain;
end
step 3: Leader nodes election ;
for i ←1 to nc do
        if it equal 1 then
                Initially, LN(i) is chosen in the middle of chain i;
        else
                LN(i) is chosen based on residual energy;
        end
end
step 4: Global chain formation ;
for i ←1 to nc + 1 do
        Apply ACO algorithm to form a single chain regrouping all LNs and the sink ;
end
step 5: Intra-chain transmission ;
step 6: Inter-chain transmission ;
end
```

As shown in Figure 5, the total energy needed increases as the number of rounds increases. The suggested CCRA algorithm is also more energy efficient, as seen in the graph and saves the overall amount of energy used in the network. This is because the chain solution eliminates further long-distance transmissions from nodes to CHs and from CHs to sinks in MH-FEER. Second, instead of receiving 10 messages, the chief would only receive two. (10 nodes per cluster in MH-FEER).

Figures 6 and 7 illustrate the simulation results, where the first node in the MH-FEER algorithm dies after 106 rounds, whereas the first node in the CCRA algorithm dies after 120 rounds. Furthermore, we notice that in the last node dies after 128 rounds in MH-FEER while the last node dies after 217 rounds in the proposed algorithm. Consequently, we can confirm that CCRA presents better results in term of energy efficiency and load balance compared to MHFEER. CCRA offers a longer lifespan than MH-FEER by more than 41.01%. Also, with CCRA the lifespan of the network is longer, and the quality is better.

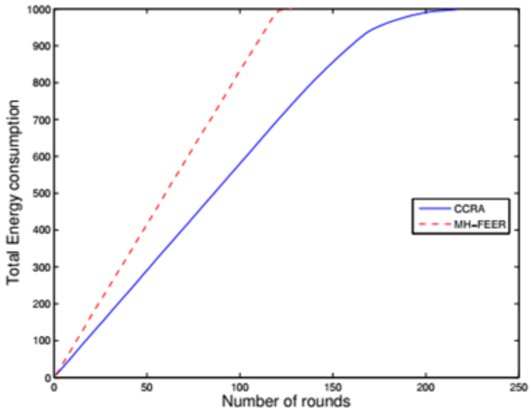

Figure 5. Total used energy vs number of rounds

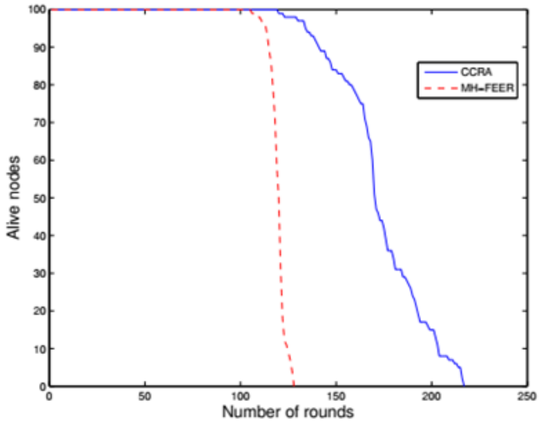

Figure 6. Alive nodes vs number of rounds

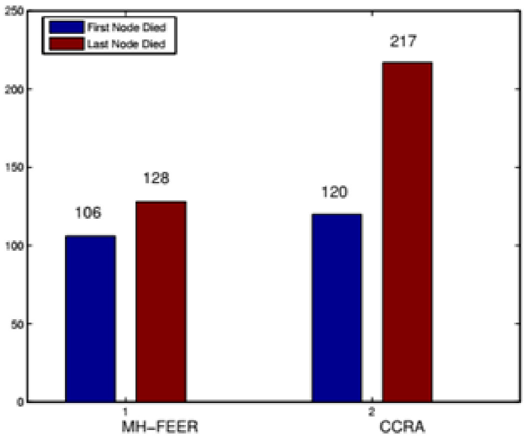

Figure 7. The first and last nodes died in the networks

4.4. Mobility impact

In this section of testing, we shall be comparing the CCRA algorithm under different mobility scenarios (low, high), static scenario and the MH-FEER [18] protocol.

- Static scenario: nodes are randomly deployed at a predefined position.
- Low mobility scenario (Low Mob Sce): node's speed (0–5 m/s)
- High mobility scenario (High Mob Sce): node's speed (5–20 m/s)

4.5. Comparison with VBF and REBAR protocols

Figure 8 shows the comparison of our proposed protocol with VBF [8] and REBAR [11] protocols in terms of alive sensor nodes. This comparison is done with the same simulation parameters used in [11]. As depicted in the previous figure, the first node in VBF, REBAR and CCRA depletes its energy after 40, 125 and 353 rounds respectively. We also observe that in 500 rounds, CCRA keeps more active nodes comparatively with VBF and REBAR. Thus, CCRA prolongs the network lifetime.

From Figure 9, it is clear that The CCRA protocol consumes significantly less energy than the MH-FEER protocol in all the given scenarios. We can also note that the total energy consumption of CCRA algorithm in the three scenarios at the beginning are close up but when the number of rounds increases beyond 115, it does slightly increase with the speed growth. In general, we can conclude from Figure 10 the CCRA algorithm is better than MH-FEER in term of alive nodes even in the three mobility scenarios. As seen in the graph, as the speed of the CCRA algorithm increases, the number of alive nodes decreases.

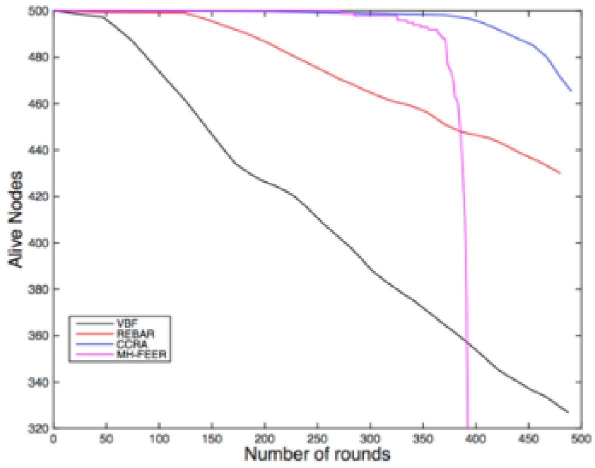

Figure 8. Alive nodes vs. number of rounds

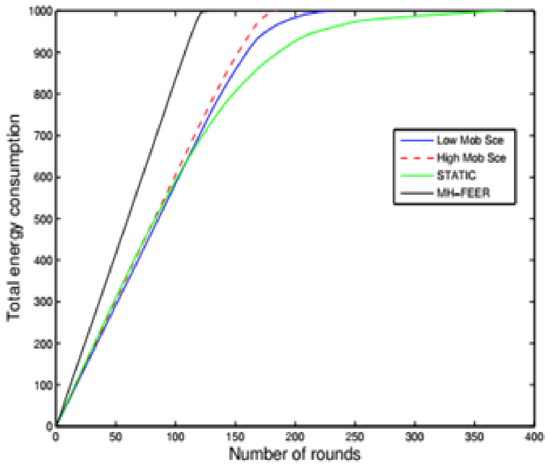

Figure 9. Total energy consumption vs. number of rounds under different mobility scenarios

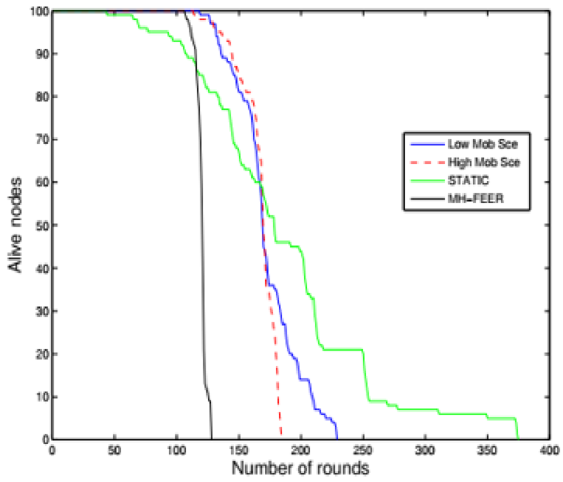

Figure 10. Alive nodes vs. number of rounds under different mobility dcenarios

5. CONCLUSION

In this article, we present CCRA, an energy efficient and a new load balancing routing algorithm for UWSN. CCRA is a synthesis of the principles of clustering and chaining. Several clusters of nodes are partitioned using the FCM method. The chain-based c performs data transfer by locating the shortest chain to the sink using an ACO algorithm. As shown in simulation results the CCRA is better in term of load balancing and energy efficiency than the MH-FEER, VBF, and REBAR protocols, improves network lifespan, and decreases energy usage. The suggested algorithm is not only energy efficient, but also extremely robust in a variety of mobility scenarios.

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