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Energy and Distance based Data Aggregation in Underwater Wireless Acoustic Sensor Networks

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Abstract: The process of data aggregation will ease the primary constraints of Underwater Wireless Acoustic Sensor Networks (UWASNs) such as limited bandwidth, node energy and latency. In this paper, we propose a scheme for data aggregation and routing using static and mobile agents based on multiple leaf structure. The main component of a leaf structure are midrib, veins and petiole (leaf stalk). The proposed scheme functions as follows. (1) Formation of multiple leaf structures and selecting the local and master center nodes on it by means of mobile agent based on the factors such as residual energy, Euclidean distance, vein angle, midrib angle and connectivity. (2) Identifying the local center nodes on either side of veins and connecting it to the master center node by means of mobile agent. (3) The aggregation processes at local centers by taking into account of nodes along the veins and carry it to the master center and deliver the aggregated data to the sink node through super master node by means of mobile agent. The proposed scheme is simulated in different UWASN scenarios. The parameters of performance analyzed are local and master center selection time, aggregation energy, energy consumption and lifespan of the network. We saw that our proposed scheme does better than the existing aggregation scheme.

Index Terms: UWASN, data aggregation, multiple agent, routing.

I. INTRODUCTION

The Underwater Wireless Acoustic Sensor Networks (UWASNs) are seizing the attention of the researchers due to its advancements. The numerous applications of UWASN such as monitoring the environment, pollution and habitat, marine data collection, detection of oil leakages, prevention of disaster etc., requires huge number of sensors which are networked for its better performance and greater accuracy [1-3]. Nevertheless due to unique features of underwater environment such as less bandwidth, long propagation delay, attenuation, limited energy etc., researches find tough to work in UWASN [4]. Each UWASN comprises of small sensor nodes, Autonomous Underwater Vehicles (AUVs) and Gateway nodes which have the potentiality to sense, compute and communicate among each other or to the external sink node using wireless channel. Acoustic frequency ($1.5X10^3$m/s) is means of communications in underwater environment. Underwater sensors have partial memory and energy to store, process and communicate the data. To embark upon many significant concerns in UWASNs such as consumption of energy, redundancy in data transmission and increase in bandwidth and latency various techniques of data gathering, fusion and aggregation are inculcated. Thorough research is under progress to increase the life span of the network which sequentially depends on the energy of sensor nodes. The lifespan of the network depends on the factors such as architecture of the network, aggregation scheme and routing [5]. The sensor nodes in UWASN are deployed randomly to collection the information from different aquatic mediums such as rivers, lakes etc., and delivers to the sink node. Many UWASN protocols [6-7] are used to monitor such aquatic mediums. But these protocols do not fit in for the large aquatic mediums such as oceans and seas. To trounce such situations, data aggregation techniques are used along with routing protocols to transmit the aggregated data to the sink node. The main purpose of data aggregation techniques are to minimize the redundant data, energy consumption and delay. Data aggregation is defined as the process that accumulates the data to minimize the transmission of redundant data and transmit the aggregated data to the Base Station (BS) moreover employing temporal or spatial aggregation methods. We have employed multiple leaf structures in the scheme for the process of data aggregation and routing. The multiple leaf structures is created by sink node for collecting the data inside the network using aggregation technique to increase the scalability of the network. The proposed scheme has the following advantages. 1) Each leaf structure covers all the nodes in UWASN. 2) The selection of local and master aggregation nodes are performed along the veins and midrib of each leaf structure. 3) The super master node at the junction provides has less deviation from its neighboring nodes with higher connectivity and proficient use of residual energy. The arrangement of rest of the paper is in subsequent ways. Section 2 briefs on the related works carried out in data aggregation and routing. Section 3 discusses briefly about our proposed multiple leaf structures for data aggregation. This section also briefs about local and master center aggregation. Section 4 explains about performance evaluation where in, it highlights on the simulation parameters and analysis of the results. Finally, Section 5 concludes the paper with few future enhancements.

II. RELATED WORKS

A survey on data aggregation in underwater wireless sensor networks discussing various techniques of data aggregation highlighting their benefits and limitations are in the study [8]. The performances of various clustering schemes are compared and measured in terms of delay, consumption of energy and packet drop with and without aggregation.

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The authors in [9] have discussed about energy efficient data aggregation arrangements built on the concepts of distributed compressed sensing for cluster based underwater acoustic networks to reduce the cost and increase the lifetime of the network. The authors in [10] have discussed about the arrangements grounded on secure agent routing that increases the quality of service. They worked on identifying the wormhole flexible secure neighbors to direct the data through secure path. The authors in [11] have discussed about energy efficient compressed data aggregation scheme for three dimensional underwater acoustic sensor networks to reduce the consumption of total energy. They have employed the concept of data sampling for the randomly selected nodes and these nodes transfer the data to cluster heads.

The works given in [12], [13] have discussed about cluster based data aggregation scheme. This scheme adopts cluster formation, identification of cluster heads and transmission of data to the sink node in UWASN. The authors in [14] have proposed a scheme built on agents for data aggregation and routing processes. The scheme was grounded on fish bone structure of wireless sensor nodes mainly to decrease the consumption of energy sequentially to enhance the lifetime of the network. Formation of the fish bone structure is by means of static and mobile agents and data aggregation is performed at three levels. Similarly, the authors in [15] have proposed a scheme built on agents for data aggregation and routing processes. They have built a wheel structure of wireless sensor nodes concentrating on decreasing the consumption of energy which in turn enhances the lifetime of the network. The authors in [16] have proposed a mobile agents based scalable and load balanced scheme to solve the bloated state problem in wireless sensor network. The authors in [17] have proposed a totally opportunistic routing algorithm for UWASN to avoid horizontal transmissions, void nodes, and reduce the delay in order to increase the throughput and energy efficiency. The authors in [18] have proposed an energy efficient data gathering scheme in UWASN where in it has mobile sink node and courier nodes. These nodes gather the data at specific stops to decrease the overall energy consumption in the network. The authors in [19] have proposed an efficient reliable AUV aided routing protocol for data delivery using shortest path algorithm in UWASNs. This protocol helps in limiting the number of connected nodes with gateways to avoid overloading. This aids to decrease the consumption of energy and enhance the lifespan of the network. The authors in [20] have suggested a data aggregation scheme built on the distance parameter for periodic sensor networks. The approach explains about two phases where the initial one searches for the similarities of measures by each node and the next phase utilizes distance based functions to identify the similarity among the set of nodes. The key goal in their approach is to minimize the redundant data conveyed from sensors and cluster heads in the cluster based network. Similarly the authors in [21] have suggested an efficient data aggregation scheme for periodic sensor networks. They have proposed three data aggregation schemes for CH level which is after local aggregation at sensor level to remove the redundant data generated by connected nodes. The work given in [22] have discussed about developing a new clustering scheme based on spatial similarity among the reading of the node assuming that the data are sent periodically to their cluster heads by sensor nodes. They have proposed a two tier data aggregation scheme to remove the redundant data. The works given in [23] have proposed a high efficient dynamic data aggregation scheme based on clustering and routing algorithms. The filtering efficiency is improved by adjusting the message list dynamically without delay.

A. *Our contributions*

The proposed multiple leaf structures for data aggregation and routing in UWASN is explained as follows. It uses static and mobile agents along with sensor nodes to form multiple leaf structures. Sensor nodes placed on the left and right side of the veins and on the midrib are involved in the process of aggregation and routing. Local and master Aggregator are optimally selected, provide the identification of the sensor nodes with respect to connectivity, distance between neighboring sensor nodes and optimum utilization of residual energy. There are two kinds of software agencies suggested in the scheme. 1) At the Sink called Underwater Sink Node Agency. 2) At each sensor node called Underwater Sensor Node Agency. The software agency at sink and each sensor node comprises of many agents and knowledge base. The following are the footsteps involved in the operation of the scheme. (1) Initially a mobile agent is triggered at Underwater Sink Node Agency which is termed as Master Aggregator Selection Agent (MASA) at an angle of 0◦ to 180◦ with a given reference provided in UWASN. (2) The leaf structure is constructed by MASA using master nodes on it considering residual energy, Euclidean distance, midrib angle and connectivity. (3) During the formation of leaf structure, MASA records identification of all master center sensor nodes along the 180◦ of the midrib. (4) At every master center node a mobile agent is triggered by Sensor node agency which is termed as Local Aggregator Selection Agent (LASA) at leaflet angle completed with the veins to identify all the local center nodes. (5) At the local center level a mobile aggregation agent visits every local center, collects and aggregates the data. Every local center node transmits the gathered data to its master center node along the midrib. (6) At the master center level a mobile aggregation agent is triggered by last master center node visits every master center node across the midrib, collects and aggregates the data. The aggregated data is delivered by each master center node to the sink node through super master node. The performance effectiveness of the proposed scheme is simulated in several UWASN set-ups and evaluating the factors like selection time of master center and local center nodes, lifetime of the network and consumed aggregation energy.The following ways brief about how our contributions in the proposed work varies with existing work. (1) Modeling of UWASN for aggregating and routing the data using multiple leaf structure. (2) Selection of master and local center nodes using static and mobile agents considering residual energy, connectivity, Euclidean distance, leaflet angle and midrib angle.

(3) Efficient elimination of redundant data through four levels of aggregation process. (4) Validating and improving the performance of the proposed scheme with performance parameters such as aggregation energy, aggregation time and life time of the network.

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III. MULTIPLE LEAF STRUCTURE BASED DATA AGGREGATION

This section highlights on the topics such as scheme for aggregation, network environment, describing the different agencies used for the process of data aggregation and identification of master and local centers.

A. Network environment

The underwater wireless sensor network for data gathering, aggregation and routing schemes encompasses numerous heterogeneous sensor nodes, Gateway nodes and a Sink node. Following are the assumptions made with respect to sensor nodes which are distributed geographically in an assumed area. They are static in nature, have same energy and capable to reform the transmission power. But the super master node compared to other nodes has more energy and is able to reconfigure the transmission power. These wireless sensor nodes sense the data periodically and transmit the data to the sink node. To have unbeaten communication between the sensor nodes, all these nodes are set with processor and transceiver. Every sensor node in the network comprises of a stage with agents having the security features to manage to have unbeaten communication among the agents.

B. Prelude

The key terms used in the process of data aggregation scheme are explained in this section.

Leaf structure: It consists several nodes on left and right veins located on either side of the midrib and a super master node.

Super master node: It is in-between node situated at the junction of multiple leaf structures through petioles.

Master center node: It is in-between node situated at the midrib of leaf structure.

Local center node: It is in-between node situated along the veins of the leaf. The procedure of local aggregation which is done along the either side of the midrib removes the duplicate data out of the collected data from neighboring sensor nodes.

Number of neighboring sensor nodes: All the active sensor nodes which are available in the communication range from the total count of neighboring nodes.

Midrib angle: It is the angle at which master center node is placed with reference to directional axis from super master node.

Leaflet angle: The angle between the veins on the midrib with reference to midrib axis.

C. Proposed Agency

This section explains about a set of static, mobile agents and the agencies used in the identification of master and local centers. The usage of few notations in the explanation of the scheme are specified in Table 1.

1) Underwater Sink Node Agency:

The Underwater Sink Node Agency residing at sink node comprises of Underwater Sink Monitoring Agent (UWSMA), Master Aggregator Selection Agent (MASA) and Underwater Sink Knowledge Base (UWSKB) for communication among agents. The apparatuses of the sink node agency and their connections are shown in Fig. 1.

TABLE 1 NOTATIONS

Descriptions	Symbols
Set of UW-sensor nodes	$sn_1, sn_2, sn_3, \ldots, sn_m$
Communication range of UW-sensor node	R
Neighbor node count	N_c
Number of leaf structures	N_{fbs}
Weight factor of Local/Master center selection	W_l/W_f
Threshold distance of Local/Master center	D_{lth}/D_{pth}
Degree of neighbor nodes	D_{nth}
Midrib angle	θ_b
Residual energy of each node	E_{Rt}
Initial/Utilized energy of each node	E_i/E_u
Euclidean distance between nodes l&m	E_d,m
Probability of occurrence of redundant data	PR_{da}
Redundant data set	R_{da}
Probability of aggregated data	P_{Ag}
Data aggregation time at Local/Master centers	La_{agtime}/Ma_{gtime}
Total aggregation time	To_{agtime}
Total number of leaf structures	La_{total}
Time required to aggregate from leaf	T_f

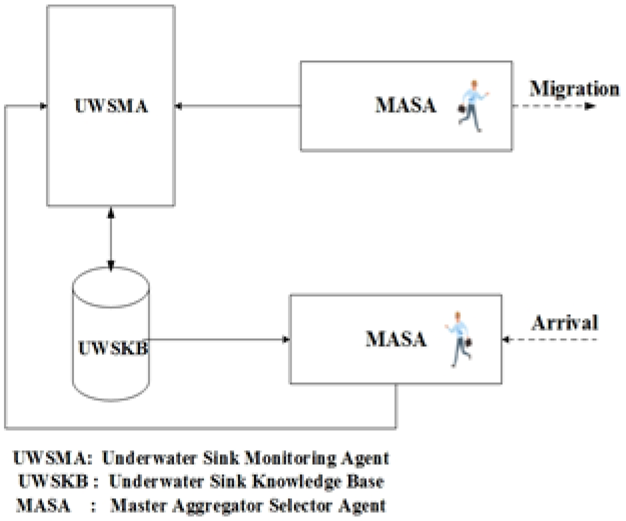

Fig. 1.Underwater Sink Node Agency

Underwater Sink Monitoring Agent (UWSMA): The monitoring and maintenance of neighboring nodes information is performed by a static agent located in sink node called UWSMA. The user runs the application to trigger the agent at the data collecting centers. UWSMA performs the following functions.

(1) It calculates weight factor and Euclidean dis- tance of neighboring nodes and also updates information on aggregation in UWSKB. (2) It creates MASA based on the requirement to gather the data from UW-sensor nodes. (3) It selects the Master center based on the distance. (4) It maintains the threshold values D_{pth} and D_{lth}.

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Master Aggregator Selection Agent (MASA):
UWSMA triggers a mobile agent built on weight factor and Euclidean distance between neighboring nodes called MASA. The selection of master centers on the midrib of the leaflet structure is performed by MASA. The master center is updated with the information such as midrib angle, leaflet angle by MASA. It fixes the master centers on the midrib and provides the node identification (id) for all the traversed master centers till the last one in the leaflet structure.

Underwater Sink Knowledge Base (UWSKB):
UWSMA and MASA reads and updates the knowledge base with respect to the nodes linking to the sink such as: identification of the node, residual energy, neighboring count, strength of signal, geographical location and indices, threshold of midrib angle and leaflet angle, previously aggregated data, threshold data and reception time.

2) Underwater Sensor Node Agency:
The Underwater Sensor Node Agency residing at every sensor node comprises of Underwater Node Monitoring Agent (UWNMA), Local Aggregator Selection Agent (LASA), Local and Master Aggregation agent (LAA and MAA respectively) and Underwater Node Knowledge Base (UWNKB) for communication among agents. The apparatuses of the agency and their connections are shown in Fig. 2.

Underwater Node Monitoring Agent (UWNMA):
The information on data monitoring obtainable are data related to temperature, depth, salinity, strength of the signal, residual energy, transmission range, etc., is performed by the static agent located in every node of the UWASN is called UWNMA.

It also updates the aggregation information in UWNKB. The process of aggregation is updated by regularly by UWNMA, by comparing previously sensed data with present data of the each node. If there is a change in drift value between the two data, then the node is made to contribute for the process of aggregation. The status of the residual energy of each node is updated to the nearest node by UWNMA. UWNMA also updates UWSKB with each nodes' node id, position and its weight factor

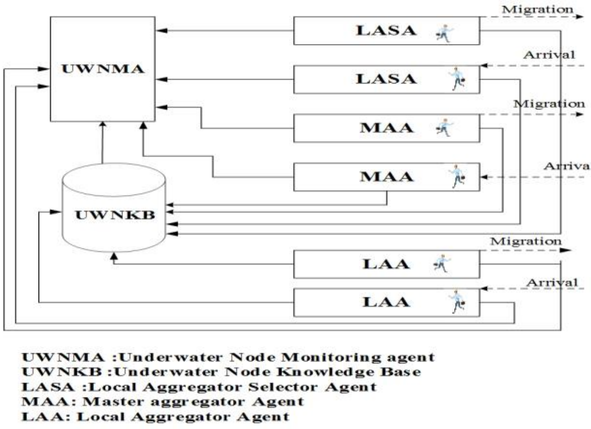

Fig. 2. Underwater Sensor Node Agency

Local Aggregator Selection Agent (LASA):
It is mobile agent residing in each node triggered by UWNMA. Since LASA gets weight factor and Euclidean distance of nearby nodes, it is accountable for electing the local center node. It gets leaf angle from UWNKB and directs it to immediate next neighbor nodes. It fixes the local centers on left and right sides of the ribs and provides the node identification (id) for all the traversed local centers till the last one in the vein of each leaf structure.

Local Aggregation Agent (LAA):
Each time when LASA instigates the process of aggregation, a mobile agent called LAA is triggered by UWNMA of the last local center. The path information of local center and aggregated data locally are updated from UWNKB to LAA. After obtaining these data from each local center, LAA continues with aggregation process, then it travels to immediate next local center along the vein to continue its journey to reach the master center at the midrib of the leaf structure. At each vein on either sides of the midrib, in order to aggregate the data, LAAs are activated in the last local centers. Lastly the aggregated data is delivered to the matching master center on the midrib.

Master Aggregation Agent (MAA)
Each time when MASA commences the aggregation process, a mobile agent is triggered by UWNMA of the final master center called MAA. MAA gets the path information of the master center and locally aggregated data along the midrib from the UWNKB and travel to immediate next master center alongside of the midrib on the way to the super master node. The aggregation process is initiated at each visited master center by MAA and prolong

its ride until it reaches the sink node through super master node.

Underwater Node Knowledge Base (UWNBB):
UWNMA and LASA reads and updates the knowledge base about the nodes connected to the each sensor node such as:

identification of the node, residual energy, neighboring count, strength of signal, geographical location and indices, threshold of leaflet angle, previously aggregated data, threshold data and reception time.

D. Master and Local center selection process

Initially master center selection process begins wherein UWNMA of neighbor nodes determine the node weight W_f based on the neighbor count N_c *and* residual energy at time t $E_{R(t)}$. The angle between the master center and neighbor UW-sensor node is computed by Equation 1.

$$\theta_p(i) = tan^{-1}\frac{(y_l - y_m)}{(x_l - x_m)} \qquad (1)$$

Where (x_l, y_l) and (x_m, y_m) are node l and node m locations.

The residual energy E_{R_t} of each UW-sensor node in the network is given by Equation 2.

$$E_{R_t} = |E_i - E_u| \qquad (2)$$

Where the initial energy and utilized energy of the node is depicted as E_i and E_u respectively.

The Euclidean distance between a UW-sensor node l to its neighbor node m is given by Equation 3.

$$E_{d\,l,m} = \sqrt{|x_l - x_m|^2 + |y_l - y_m|^2} \quad (3)$$

UWSNA of sink node center instigates the process of selecting a master center by sending the inquiry messages among neighbor nodes in the network. UWNMA of neighbor nodes determine the node weight Wf constructed on the neighbor count Nc and residual energy at time t ER(t). As a reply message, UWNMA of neighbors' nodes compute their Wf and send location of the node along with Wf to UWSMA as given in Equation 4.

$$W_f = K(E_{R_t} * N_c) \quad (4)$$

Where K is a constant ranges between 0 and 1.

In the process of master center selection, the UW-sensor nodes placed at angle θ_p are measured. The threshold distance of UW-sensor nodes is represented as D_{pth}. If $E_{d\ l,m)} > D_{pth}$, then the UW-sensor node can participate in the process of selecting the master center. The UW-sensor node with highest W_f , is elected as master center amongst competitive neighboring nodes by UWSMA. If none of the competitor is found based on the threshold condition ($E_{d\ l,m)} > D_{pth}$), then the D_{pth} is incremented or decremented to identify other competitors by UWSMA. The first master center is selected from the competitor nodes along the midrib. Since then, MASA is triggered by UWSMA to identify the remaining master centers till it touches the final master center in a network. To identify the pathway to link all the master centers in the network, the node id's of every master center is transported by MASA.

Similarly in the selection of local centers the neighboring nodes of master centers determine the node weight W_l based on N_c, $\theta_p(i)$, residual energy $E_{R(t)}$ and the Euclidean distance between neighbor nodes and master center as in equations (4), (1) and (2) respectively. Neighboring nodes located on the ribs at an angle of 45° to 60° and 135° to 150° *on* the either side of the midrib are mentioned to be the nodes placed at leaflet angle. If the consideration of the angles is taken apart from these angles then there will be a chance of overlapping coverage area. Built on leaflet angle and Euclidean distance and neighbor node count $N_{c.}$ UWNMA of master center selects the local center. The node weight W_l of local center is computed as specified in Eq. 5.

$$W_l = K(E_{R_t} * N_c) \quad (5)$$

Where K is a constant ranges between 0 and 1.

The local center selection process is carried out by considering the nodes located at leaflet angle. The threshold distance of nodes is represented as D_{lth}. If $E_d\ l, m> D_{lth}$, then the node can participate in the process of selecting the local center. The node with maximum W_l, is elected as local center amongst competitive neighboring nodes by UWNMA. If none of the competitor is set up based on the threshold condition ($E_d l,m\ > D_{lth}$), then the D_{lth} is incremented or decremented to identify other competitors for local centers by UWNMA. Since then, LASA is triggered by UWNMA to identify the remaining local centers till it touches the final local center in a network. To identify the pathway to link all the local centers in the network, the node id's of every local center is transported by LASA.

As the value of $E_{dl,m}$ varies, the threshold values D_{pth} and D_{lth} are maintained by UWSMA in the following ways. To begin with, a threshold parameter T_i is fixed by UWSMA to get few master/local centers. If the centers are not found for this value of x, then UWSMA increments T_i as ($T_i + \delta$). If the centers are not found for incremented value of threshold then UWSMA continue incrementing the threshold value as (T_i+$B\delta$), where $B = 2^p$, and jp^j is an integer. The probability of obtaining centers is better by considering 2^p than by incrementing the threshold values like ($T_i + \delta$), ($T_i + 2\delta$), ($T_i + 3\delta$), and so on. When the master center selects the initial local center, LASA is triggered by UWNMA of master center to recognize the left over local centers alongside the vein till it covers all the local centers in a network. To identify the pathway to link all the local centers in the network, the node ids of every local center is transported by LASA and constructed in the form of leaflet structure as shown in fig. 3.

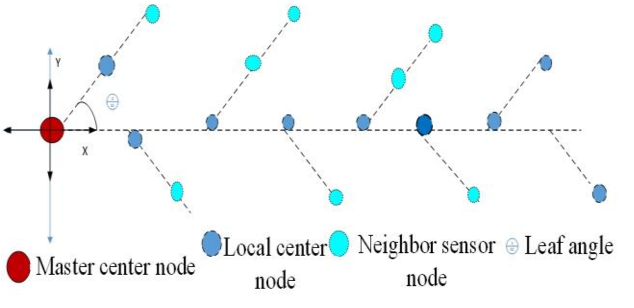

Fig. 3. Master/local center in a leaf

The data aggregation framework is as shown in fig. 4 which depicts sensors, sink, multiple leaf structure nodes for aggregation, mobile and static agents. The data from all the neighboring nodes are gathered and aggregated by all the local centers. The local centers' data is aggregated by LAA which is triggered by last local center and is delivered to the corresponding master center. Similarly the master center's data is aggregated by MAA which is triggered by last master center and is delivered to the super master which is connected directly to the sink. This super master also plays an important role in the aggregation mechanism. As a backup, the super master holds the copy of the aggregated data to be transmitted to the sink. Since the super master node placed at the arbitrary center of the network area, all the data from entire 360° directions covers all nodes in UWASN. In this way a flexible multiple leaflet structure can be designed for all architectures of UWASN.

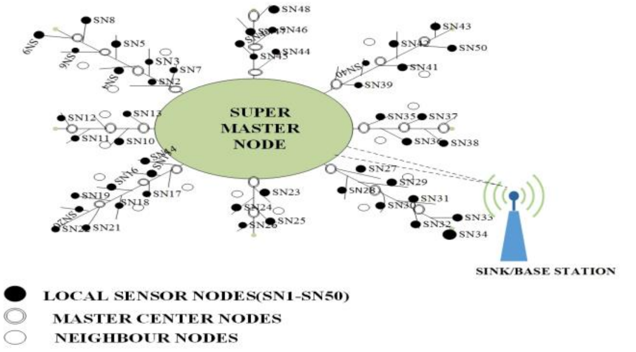

Fig. 4. Aggregation framework

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E. Aggregation mechanism

The process of aggregation is performed at four levels: Initially at node level, then at local and master center levels and finally at super master level. UWNMA in a node follows the mentioned steps. (1) Each individual node in the network has UWNMA which in a given time window uses statistical averaging of the data and store the average and variance.
(2) To have loss less aggregation, UWNMA of all local centers collects the data from neighboring nodes and apply union set theory where the redundant sets are eliminated and new set (S) is generated. (3) The data supplied by the local centers is collected by UWNMA of master center and applies union set theory to eliminate duplicate sets for loss less aggregation. UWNMA also plays a major role in node or link failure as follows. If the node/link fail due to which local/master center fails, then UWNMA initiates recovery mechanism. Every sensor node in the network is updated with weight factors of the neighbor nodes, at any time if the connection miscarries along the way then, UWNMA finds the node with maximum weight factor. As a substitution the node with maximum weight factor is selected as master/local center for the futile master/local center. The study of data aggregation is as follows. The data congregated at every node i is represented as $DG_i = DG1, DG2, DG3..., DGn$ *with* respect to time window $t1$ $tn = t1, t2, t3..., tn$, respectively. The redundant data in the data set DG_i is R_{da}. The probability of occurrence of redundant data $P_{R\,da}$ is given in Eq. 6.

$$P_{Rda} = R_{da}/DG_i \qquad (6)$$

Hence the probability of aggregated data beyond sensed data DG_i is specified in Eq. (7).

$$P_{Ag} = 1 - P_{Rda} \qquad (7)$$

The local aggregation time at the conforming local centers are represented as LAt1, LA_{t2}, LA_{t3} ...$LAtn$. Then the time for aggregation at each leaflet is given by Eq. 8.

$$La_{agtime} = \sum_{i=0}^{n} \alpha_i * LA_{n-i} \qquad (8)$$

Where the value of α is between 0.001 to 0.003; $\alpha_i < \alpha_{i+1}$; $i \leq n$.
Subsequent to the process of aggregation at the local center, the size of the aggregated data differs as it is forwarded from one to another local center. The data gathering is performed at each leaflet. As the data size increases, aggregation time process also increases. In turn to optimize the aggregation time for local aggregation, the threshold value of α are chosen as 0.001 to 0.003 seconds.
The data aggregation time at local centers is depicted as T_{leaf} and is given by eq. 9.

$$T_{leaf} = La_{agtime} * La_{total} \qquad (9)$$

The master aggregation time at the corresponding master centers are represented as $M\,A_{t1}$, $M\,A_{t2}$, $M\,A_{t3}$ ...$M\,A_{tn}$. Then the total time to aggregate the data at master center is given by Eq. 10.

$$Ma_{agtime} = \sum_{i=0}^{m} \beta_i * MA_{n-i} \qquad (10)$$

Where the value of β is between 0.003 to 0.005; $\beta_i < \alpha_{i+1}$; $i \leq m$

In the multiple leaflet structure based data aggregation, the process of aggregation assumed to begin at the last master center. Subsequent to the process of aggregation at the master center, the size of the aggregated data differs as it is forwarded from one to another master center. The data gathering is performed at each master center. As the data size increases, aggregation time process also increases. In turn to optimize the aggregation time for master aggregation, the threshold value of β are chosen as 0.003 to 0.005 seconds. The total aggregation time is given by Eq. 11

$$To_{agtime} = Ma_{agtime} * T_{leaf} \qquad (11)$$

IV. PERFORMANCE EVALUATION

This section deliberates about performance parameters, simulation parameters and results. The proposed scheme is simulated for various network scenarios and compared with works given in [14] in terms of lifetime of network, time required to select local and master centers, aggregation time and energy.

A. Simulation parameters

We have considered the scenario for simulation which consists of heterogeneous underwater wireless static and mobile sensor nodes within the boundary of 600m by 600m with a varying depth of 100m to 500m. The number of nodes are varied from 50 to 200 and are placed deterministically for testing performance evaluation with transmission power between 2mW to 4mW. The data rate follows the Poisson process varied from 0.002 to 0.1 pkts/msec. The discrete event network simulator tool, NS-3 is used for simulation. Table 2 presents the parameters for simulation used for analyzing the proposed scheme.

B. Performance parameters

Following are the performance parameters assessed.
(1) **Selection time for Local/Master center**: The essential time to select the Local/Master centers respectively.
(2) **Aggregation energy**: The average energy consumed by all nodes, local and master centers for data aggregation.
(3) **Aggregation time**: The time possessed by all nodes, local and master centers to aggregate the data.
(4) **Network lifetime**: The number of rounds utilized to die the first node in the network.

TABLE II NOTATIONS

Parameters	**Symbols**	**Values**
Bandwidth	BW	400Hz
Communication Range of sensor nodes	R	400-600 mtrs
Leaf angle threshold	θ_{lth}	450 to 600
Initial energy of each node	Ei	5joules
Time constant at Local/Master center	α/β	1-3msec/3-5msec
Threshold distance at Local/Master center	D_{lth}/D_{pth}	400-500 mtrs/300-500mtrs
Incremental threshold communication range value	δ	10 mtrs
Size of sensor data at each node	S_d	512tes

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C. Result analysis

Fig.5 depicts the time required for selecting local centers with respect to number of nodes in the network. The selection time for Local centers increases as the number of nodes in the communication range increases which is due to LASA need to visit more number of nodes.

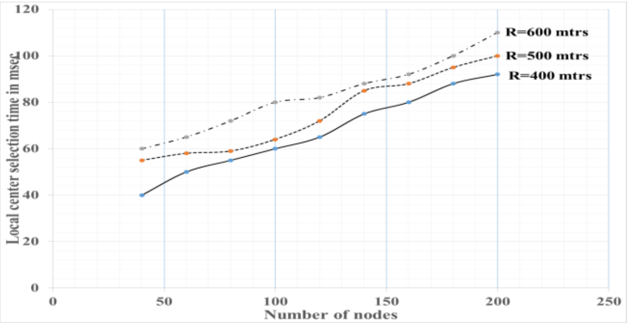

Fig. 5. Local center selection time Vs. Nodes

Fig.6 depicts the time required for selecting master centers with respect to number of nodes in the network. The selection time for master centers increases as the number of nodes in the communication range increases.

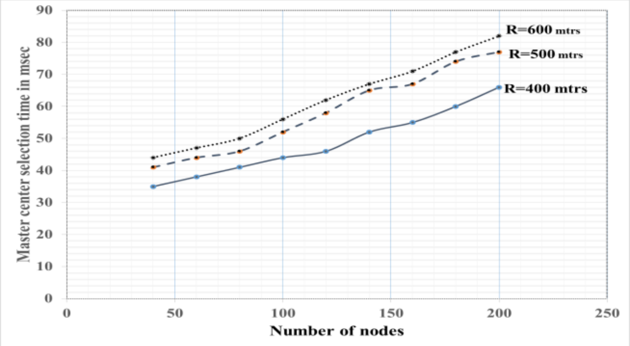

Fig. 6. Master center selection time Vs. Nodes

Fig.7 depicts the time required for data aggregation with respect to number of nodes in the network. From the above graphs, it is observed that number of nodes increases resulting in increase of communication range. As a result more redundant data is generated which in turn increases time for data aggregation in the network. In our proposed scheme, the process of aggregation is carried out by software agents which reduces the time for aggregation when compared to other aggregation schemes.

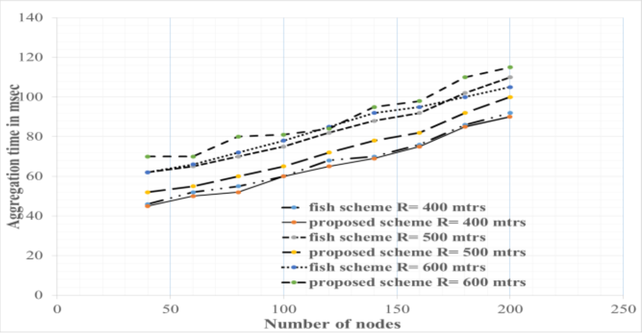

Fig. 7. Aggregation time Vs. Nodes

Fig.8 shows the consumption of energy for aggregation of data. In our proposed scheme the reliability in the aggregation process is realized by status of master and local centers in the network. The status of these centers are specific and fixed, as a result it performs better when compared other aggregation schemes to reduce the amount of data to be processed in the network. Hence the consumption of energy also reduces.

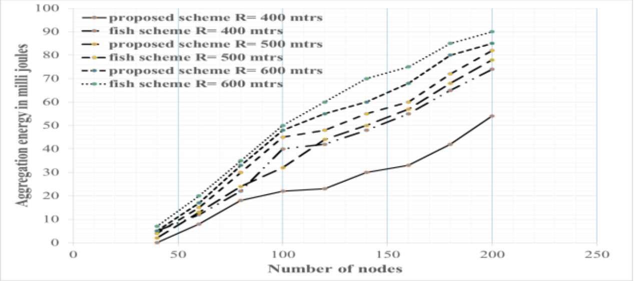

Fig. 8. Aggregation energy Vs. Nodes

Fig.9 depicts the relation between lifetime of network with number of nodes and various communication range. Increased communication range results in increased connectivity but using our proposed scheme the redundant data are eliminated which conserves the energy of the nodes. As a result the network lifetime is increased.

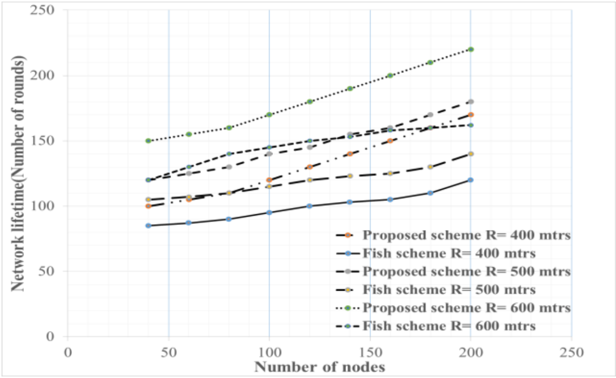

Fig. 9. Network lifetime Vs. Nodes

V. CONCLUSION

In this paper, we have presented a multiple leaf structure based data aggregation and routing in underwater acoustic sensor networks using agents. The proposed scheme works on four levels of aggregation: at node level, at master center level (along the midrib of leaf), at local center level (along the veins of the leaf) and at super master node. The static and mobile agents are used to form multiple leaflet structure with underwater nodes and sink node. These agents facilitate in selecting the local and master aggregation nodes along the multiple leaflet structure starting from last node in leaf up to sink node. Based on the factors like weight, residual energy of sensor nodes and Euclidean distance the aggregation nodes are selected. Simulation analysis shows that the proposed scheme compared with fish based structure aggregation scheme performs better with respect to aggregation energy, aggregation time and aggregation ratio. The forthcoming workings that can be well thought out for the suggested scheme are developing a cognitive agent based aggregation and routing, mobility of sensor nodes and sink node. Effective compressing techniques can be adopted to reduce the cost of the network.

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