# A new approach for a better recovery of cluster head nodes in underwater sensor networks

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***Abstract*— Energy efficiency is an important issue during the design and the overall performance evaluation of an UWSN system. Clustering sensor nodes have proven to be an effective method to improve the load balancing and scalability of the network while minimizing the system's overall energy consumption. In this paper, a new clustering algorithm is proposed to provide an improved cluster system against cluster-head failures. This study suggests that system CH failures could be further minimized when simultaneously a CH (primary CH) and a vice/backup CH are selected. Thus, when a primary CH fails due to an irreparable fault, a backup CH will take its place and it will operates as a head node. This study proposes two major procedures in order this to be accomplished, the detection failure and the recovery procedures. The first one initially detects any failures that occurred in the network and then reports this information to the relevant nodes to initiate recovery. The recovery procedure actually decides who and when will trigger the recovery function according to the origin of the CH node failure which can be either the energy depletion of the CH's battery or a software/hardware malfunction. The simulation results clearly indicate that there is an improvement in terms of network lifetime expectancy and energy consumption.**

***Keywords— underwater sensor networks; clustering; failure detection; failure recovery, energy efficiency***

## I. Introduction

It is common knowledge that underwater environments are places where communication media require overcoming barriers like the physical forces applied to them as well as the unpredictable underwater conditions that exist [1],[2]. Under such circumstances, a high probability of node failure is expected in underwater environments when compared to terrestrial networks [3]. Energy efficiency is an important issue during the design and the overall performance evaluation of an UWSN system [4]. However, conceiving/designing an underwater sensor network environment is not an easy task. Efforts have to be directed towards saving resources to maintain the stability of the system. To date, studies, more or less, are focusing on cluster algorithms in order to solve efficiency problems and such preserve sensor energy life expectancy [1]-[4]. Within this framework of debate this study suggests a new approach to solve both the problems that nodes face in hazardous underwater environments and to ensure the stability of the network. Clustering sensor nodes have proven to be an effective method to improve network's load balancing and scalability while minimizing the system's overall energy consumption [5], [6]. Recent studies suggest assigning both a primary and a backup cluster head so that the system recovers in case of a cluster-head failure [7]-[9]. In this paper, a new clustering algorithm is proposed to provide an improved cluster system against cluster-head failures. The new approach consists of an algorithm that when the clustering procedure starts and a primary cluster head is chosen, creates a failure detection and recovery cluster head selection scheme. In the following sections a detailed explanation/proof is provided to show how this cluster algorithm assigns the cluster-head and backup based on a number of selection criteria.

The structure of this paper is organized as follows. Section 2 presents the related work and the network architecture. In Section 3, the proposed algorithm with the detection and recovery procedures are described and analysed. In Section 4, the performance evaluation of the proposed scheme is presented. Finally, Section 5 concludes this paper.

## II. Related Work and Network Architecture

### A. Related work analysis

Clustering issues and algorithms have been widely investigated in the context of terrestrial WSNs [10]-[13] and UWSNs [2]-[6]. However, the event of cluster-head failures that leads to network connectivity problems has not been well addressed, in particular, for underwater sensor networks. A classic solution to this problem is to activate periodically the clustering process [10]-[11]. However, using the clustering process frequently will be expensive in terms of network resources due to the messages exchanged for cluster formation. The fact that the sensor nodes in a failed cluster can only be recovered until the next re-clustering is performed, will affect the timeliness and reliability level for the data exchanged between them and the cluster heads. This will result to a more energy intensive and unreliable system [14]. In the paragraphs that follow a summary of the current state of the art in head node failure schemes are presented with a short analysis of their strategies.

Hong Min et al [7], present a checkpointing scheme which stores the state of the head node and repairs the failure of it very efficient and quickly. During the head node selection phase this scheme selects additional backup nodes with similar sate to the head node in terms of the residual energy and operation capabilities. All gathered information sent by the cluster nodes to the head node is also saved in backup nodes. The backup nodes also periodically monitor the state of the head node. If the head node has a software or hardware problem, one of the closest backup nodes replaces it and serves as a new head node.

S.Kumar and R. Sethi [8], propose a cluster head selection algorithm based on the condition of energy, distance and the maximum connectivity level between the nodes. When a cluster head is selected according to the minimum distance and maximum energy criteria, a vice cluster head is also selected. This alternate head is activated only when the cluster head dies, maintaining in this way the communication in the network.

Murugaraja S.K et al. [9], propose a clustering protocol that attempts to select a primary cluster head and a backup cluster head for each cluster member during clustering so that the constructed cluster network can overcome any cluster-head failure. Every cluster member has the capability to detect the failure of its cluster head by checking the heartbeats periodically sent by the cluster head. Therefore, when a cluster-head failure occurred, the cluster members of the failed cluster group can quickly switch over to the backup cluster head. In this way the cluster nodes recover their connectivity to the data sink without waiting for the next re-clustering to be executed.

To summarize, the existing algorithms present some issues that need to be further analyzed. For instance, the problem with Hong Min et al, algorithm is the excessive use of resources due to the simultaneous and continuous use of storage from both the primary and the backup CH node. The second algorithm proposed by S. Kumar and R. Sethi assumes an intermediate CH availability if the distance between the backup CH and the BS is more than the optimum transmission range. Finally the last algorithm suggested by Murugaraja et al. fails to clearly state which node will trigger the recovery process.

### B. *Network architecture*

An underwater network is typically made up of many autonomous and individual sensor nodes that perform data collection operations as well as store and forwarding operations to route the data that has been collected to a central node. The main challenges of deploying such a network are the cost, the computational power, the memory, the communication range and most of all the limited battery resources of each individual sensor node [15].

Grouping sensor nodes into clusters has been used by researchers in order to extend the lifetime of an underwater sensor network. Many clustering algorithms have been proposed in the literature for UWSNs in the past few years [16]-[20]. These techniques vary depending on the sensor network deployment, the network architecture, the characteristics of the sensor and the master sensor node (cluster head) and the network operation model.

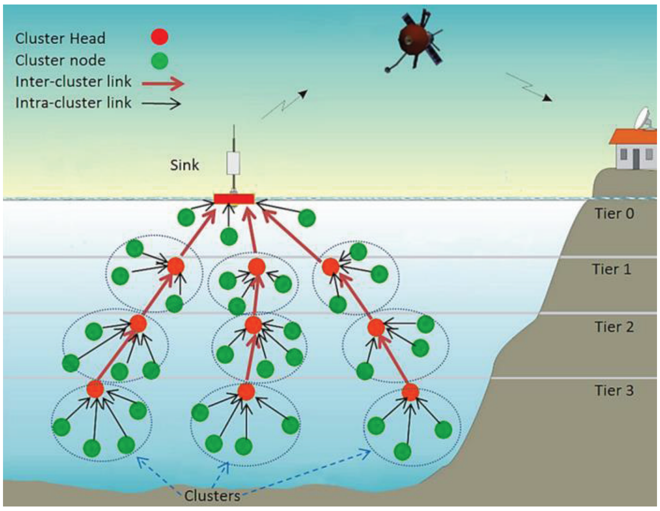


Fig. 1. Topology structure.

A typical cluster based network consists of a sink (base station) and certain sensor nodes that are grouped into clusters. In the structure, each cluster has a head, which are known as head-cluster or cluster head (CH). A CH may be elected by the sensors in a cluster or pre-assigned by the network designer. A CH may also be just one of the sensors or a node that is richer in resources. The CH is assumed to be reachable to all sensors in its cluster and it can broadcast messages to all sensors in this cluster. Sensor nodes perform two main functions: sensing and relaying. The sensing component is responsible for probing its environment to track an object or event. The collected data are then relayed to the sink through CHs in each level (tiers) [21]. The topology of such a system is shown in fig. 1.

In our case the cluster algorithm described in [22] has been used for forming the network and the cluster groups. According to this algorithm the clustering procedure follows the steps below:

1. Firstly the nodes are deployed inside the space randomly.
2. When the deployment is finished each node sends a control packet seeking for a CH. The look up area is the sphere around the node with radii equal to the maximum transmission distance R.
3. First the sink and afterwards each CH according to the clustering algorithm sends back an ACK accepting these nodes to become members of the cluster.
4. When the clustering procedure is finished and each node belongs to a cluster team, the communication process of sending and receiving data begins. This time the node does not use the maximum transmission distance R but the exact distance.
5. Every node gathers data from the environment and after a specific time or when the buffer is full, sends this data to the CH of its team.

6. Every CH communicates only to each other and forwards the aggregated data to the sink which is the master CH.

## III. CLUSTER ALGORITHM

### *A. Problem statement*

In the event of a cluster head failure, it is important to provide an efficient mechanism to recover the connectivity of all affected cluster members. This can be accomplished by firstly finding the cause of this failure and then designing an improved recover algorithm. In this cluster based network two cases of CH node failure have to be taken into account:

a. Failure due to energy depletion of the CH's battery and

b. Failure due to software or hardware malfunctions such as communication device fault.

One solution of this problem is during the selection of the CH (primary CH), a vice/backup CH [8], [9] will also be selected. When a primary CH encounters an energy or software/hardware problem, a backup CH will take its place and it will operates as a head node. However, while designing such a system two major issues must be addressed. The first case is the failure of the backup CH before the primary while the second issue is a communication link establishment failure between the backup CH and a CH of an upper tier cluster group (see fig. 2).

In addition, a major topic that must be also examined is the method that captures and reports CH failures. A mechanism has to be designed to initially detect energy depletion or software/hardware failures in the network and then report this information to the relevant nodes to initiate recovery. Identification of a faulty CH node can be achieved by following two different approaches. In the first one each cluster member can independently detect the failure of its cluster head by periodically checking the messages sent by the CH [9]. On the contrary in the second one only the backup nodes can periodically monitor the state of the head node [7].

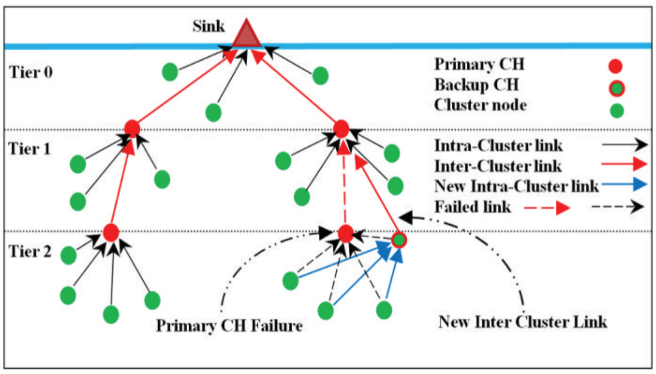


Fig. 2. Cluster head failure.

### *B. New algorithm description*

The new cluster algorithm has four major tasks:

a. The cluster formation and selection of the cluster heads (primary CHs).

b. The selection of the backup cluster heads (backup CHs).

c. The detection of the failure

d. The activation of the recovery procedure.

The cluster formation and selection of the cluster heads follow the approach described in section 2(B) above. The selection of the backup CH that follows is made only by the primary CH. The criteria for making this choice are the sensor's energy status and the distance between the primary and the backup CH. The steps of this operation are as follows:

1. CH sends a message asking info (energy level)

2. Sensor members send info to CH

3. CH compares the levels

4. CH chooses the sensor with the highest energy level and the smaller distance from it, as a backup CH.

The detection failure and the recovery are two new procedures been added, optimizing the cluster algorithm in the case of CH failure. The first one initially detects any energy depletion or software/hardware failures in the network and then reports this information to the relevant nodes to initiate recovery. When this happens, a backup CH will take the place of the primary head maintaining in this way the connectivity with the other cluster members.

### *C. Failure detection*

When the selection of the backup CH is finished, a private communication link is established between the primary and the backup CH. Both of them exchange messages stating their status (energy level and operation state). In this way the backup node periodically detects the state of the head node and vice versa. If the head node has a critical problem, the backup node will replace the failed head node and serves as a new CH node. On the other hand, in the case of a backup node failure the primary will choose a new one so that the constructed cluster hierarchy will continue to tolerate cluster-head failures.

### *D. Recovery procedure*

The responsibility of this procedure is to decide who (primary, backup, simple node) and when the recovery function will be activated. According to the new algorithm the recovery procedure takes into account the two cases of CH failure and therefore, the recovery function can be triggered by:

a. the cluster head in the case of energy depletion,

b. the backup cluster head in the case of software or hardware malfunction.

In addition, every cluster member has the ability to trigger the recovery function if the communication link to the CH has been cut off. Therefore, no data will be lost due to the capability of the sensor members to send the data to the backup instead of the primary CH.

The operation of the recovery procedure is summarized in table 1.

TABLE I. RECOVERY PROCEDURE

| Energy depletion | Software/hardware malfunction |
|---|---|
| 1. Primary CH triggers the recovery function when energy limit has critical value<br>2. Sensor members have the ability to follow the recovery scheme (send data to backup CH instead of the primary) if the communication link to the primary CH has been interrupted. | 1. Backup CH triggers the recovery function when the primary CH stops communicate with it.<br>2. Sensor members have the ability to follow the recovery scheme (send data to backup CH instead of the primary) if the communication link to the primary CH has been interrupted. |

## *E. Connectivity issues*

As already stated above once a backup CH is selected to replace a failed CH then there is a great possibility to be located outside the maximum transmission range from the next CH. In that case the communication link between the two CH will not be established and therefore, data will be lost. For example in fig. 3, the distance between the backup CH (cluster 2 –s4) and the CH of an upper tier cluster group (cluster 1) is longer than the maximum transmission distance.

The steps that lead to an efficient solution are as follows:

1. The backup CH (cluster 2-s4) sends info without receiving a reply ACK (new distance>max distance)
2. The backup CH sends a special packet (Control Packet) asking the closest sensor (cluster 1- s4) to change its status
   - This sensor is a member of an upper tier cluster group (cluster 1- see fig. 3)
3. The sensor changes its status to a CH (bridge CH) and connects to the backup CH.

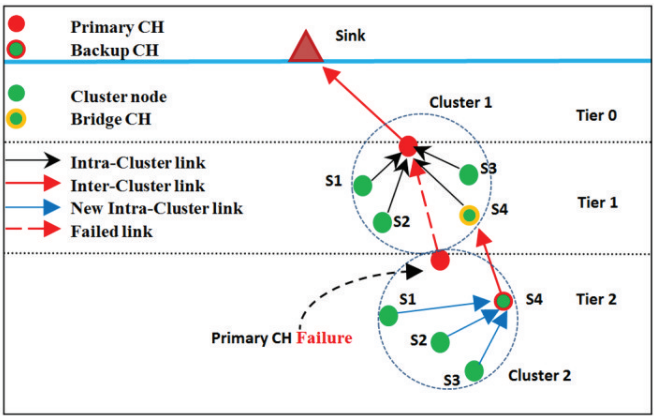


Fig. 3. Bridge CH.

# IV. PERFORMANCE EVALUATION

The main objective of the proposed algorithm is to optimize the energy conservation in the network while ensuring the connectivity of the network. To evaluate the algorithm a simulation study was carried out with the UWSN simulator USNET [22] developed in Builder C++. Initially the simulation configuration consists of 50 underwater sensor nodes while during the evaluation study the number of network's sensors increased from 50 to 150 with a unit step of 10 nodes.

Table 2 summarizes the simulation parameters. During the simulation process one of the cluster heads is designated at random to be the faulty node. Results obtained are compared with the cluster with single CH with respect to performance metrics like energy consumption and network operational lifetime.

TABLE II. SIMULATION PARAMETERS.

| Parameters | Values |
|---|---|
| Field size | 1000m x1000m x 500m (depth) |
| Number of Sensors | 50 to 150 nodes |
| Frequency range | 20 KHz |
| Data packet size | 500 bytes |
| Control packet size | 24 bytes |
| Initial energy | 2 Joules |

## *A. Energy consumption and Network Operational Lifetime*

The simulation calculates the network life time in terms of alive sensor nodes over the time period. As shown in fig.4 the proposed clustering algorithm achieves better network life time as compared to the single CH protocol. The results clearly show that the life expectancy of the network using the suggested algorithm is substantially prolonged. For 50 nodes the life expectancy for the cluster without backup CH is between 1510 and 1610 seconds while for the cluster with a backup CH the life expectancy of the nodes exceeds 1900 seconds. This difference is maintained throughout the simulation run as shown in fig. 4.

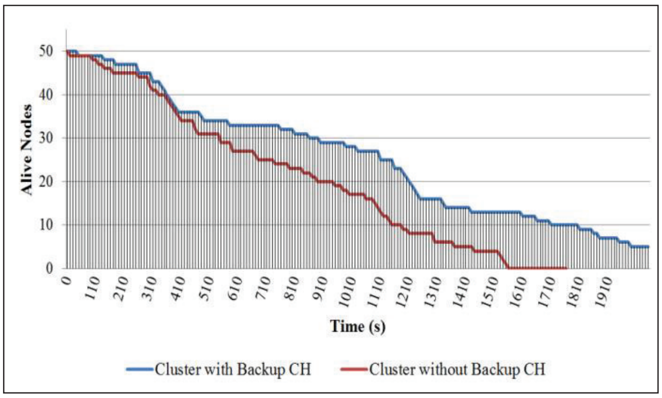


Fig. 4. Network lifetime

The simulation output in fig. 5 shows the energy consumption in relation to the number of nodes used in the system. The results also show a better performance when using the proposed clustering algorithm with the detection and recovery procedures. For example for 50 nodes the energy consumption is approximately 1.25 joules for the cluster without a CH backup compared to 0.25 joules for the cluster with a backup. This difference is maintained throughout the simulation run. Overall, the energy consumed for the proposed algorithm not only utilizes less energy but also it increases at a slower rate.

All the results indicate that the proposed algorithm performs better compared to the scheme without backup CH. This mainly achieved because of the use of the detection failure and the recovery procedures with the significant support of the CH-bridge solution. The accurate CH failure detection without interrupting the normal data transmissions, the quick trigger of the recovery function and the use of a CH bridge, effectively enhance network survivability and utilize the overall energy consumption of the system.

In the case of a scheme without a backup CH the activation of the recovery mechanism means the use of a re-clustering procedure within the failed cluster group. This operation consumes more energy as the sensors have to exchange messages to select the new cluster head. It is also affect the normal network operation and is time consuming. The sensor nodes within the failed cluster will stop sending the aggregate information from the environment to the cluster heads until the re-clustering procedure is completed.

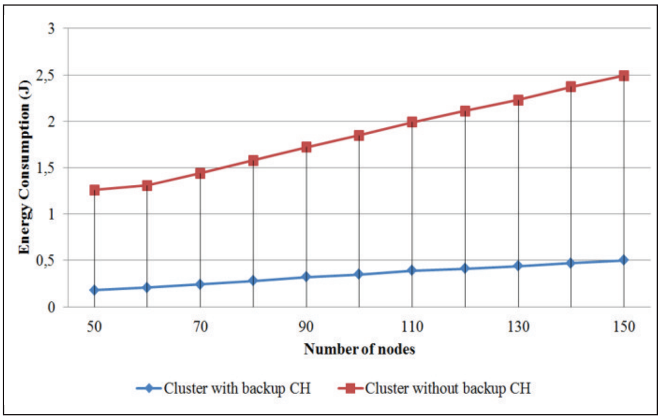


Fig. 5. Comparison of the energy consumption values.

## V. Conclusion

In this paper, an effective clustering mechanism has been proposed to provide a more efficient cluster structure against cluster-head failures in underwater sensor network. According to this cluster algorithm during the selection of the CH (primary CH), a backup CH will also be selected. When a primary CH encounters energy or software/hardware problem, a backup CH takes its place and operates as a head node maintaining in this way the connectivity with the other cluster members. This can be accomplished with the use of two major procedures; the detection failure and the recovery procedures. The first one initially detects any energy depletion or software/hardware failures in the network and then reports this information to the relevant nodes to initiate recovery. The recovery procedure actually decides who and when will trigger the recovery function. Through the simulation results, it is showed that the proposed algorithm is more energy efficient and it can effectively enhance network survivability capacity in the event of cluster-head failures, than the scheme with a single cluster head.

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