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A Comparative Analysis of Clustered Hierarchical Protocols in Underwater Wireless Sensor Network

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Abstract: Under-water wireless sensor networks (UWSNs) are a new evolving innovation in which sensor nodes with restricted batteries are positioned in deep seawater. Different monitoring activities like strategic investigation, ocean climate observation, and resource exploration are achieved through these sensors' nodes. One of the vital issues in UWSN is to increase the lifetime of networks without increasing the hardware complexity, price, and size of the network. There are various challenges in underwater networks such as more propagation delay, inadequate battery power, less storage capacity, less robustness, and less energy conservation. Energy conservation is a real challenge that must be considered. Clustered routing protocols are utilized to cut down energy utilization in underwater sensor networks. LEACH protocol which is hierarchical in nature uses a clustering method for energy efficiency. The two methods; the use of a controller node in each cluster and data aggregation at that node is used in this protocol to save energy. Performance analysis of three clustered routing protocols; LEACH, E-LEACH, and, C-LEACH is performed in this paper using the NS2.35 simulator. These protocols are examined based on energy and communication-related parameters like remaining energy, nodes loss rate, number of alive and dead nodes, bitrate and bytes of data transmitted, packets transmitted and lost, etc. and results are presented systematically.

Keywords: *C-LEACH; Clustering Technique; E-LEACH; Energy Consumption; LEACH protocol; Under-water Wireless Sensor Networks.*

1. Introduction

Over the recent years, UWSNs have acquired an incredible deal of interest in the field of exploration. Water covers around 3/4 of the earth's surface. The vastness of ocean exploration. remained a challenge for humans. It is a very challenging task for the current technologies to be installed and deployed under the water. Nowadays there is an increasing requirement for underwater monitoring to search for underwater resources, catch technical data under the water, detection of disasters [1-2]**.** There is a specific requirement for underwater protocols and algorithms for monitoring and routing data due to harsh underwater environments [3- 4]. Protocols and algorithms used for ground-based sensor networks are not appropriate and dependable to be executed under the water because of different inadequacies as far as low bandwidth, the network's adaptability, high energy utilization, high transmission latency, and high density of water [5]. Underwater sensor networks are also considered useful for military operations. Various underwater vehicles are utilized for monitoring and data collection from deep seas [6]. Nodes in the sensor networks are static in ground-based networks while these are mobile in underwater environments, because of water events. Underwater wireless sensor nodes are bigger in size so they take more battery power and their substitution is not possible under the water [7].

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Underwater sensor networks are not quite the same as ground-based sensor networks because of the inherent qualities of the underwater environment [8]. These are:

- More propagation delay: Data transmission in the aquatic environment is about five times slower than transmission speed at the ground. So, this high propagation delay will damage the network's localization, and time synchronization also get affected.
- Mobile nodes: Sensor nodes move with the current of water (experimental results show that the oceanic water velocity is 3 to 6 km/h).
- High error rate: Various effects like noise, multipath of signals and Doppler effect cause high bit error rates in underwater sensor channels. These errors also result in temporary loss of connectivity.

1.1 Issues In Underwater Wireless Sensor Networks

1.1.1 Energy utilization

This is the primary issue in the sensor network because if the battery of the nodes drains out then the working of the network stopped [9]. With increasing time, the number of in-active nodes also increases which results in the shrinkage of the sensor network. In UWSNs, solar energy is not applicable and also battery replacement is also not possible under the water. There are various possible solutions to increase the battery lifetime as explained below [10]:

- Save energy using hardware and software solutions.
- By using mechanical devices to produce energy by itself.

- Using the best technique in battery for example using lithium-ion chemicals in batteries.
- Using sleep mode operation when nodes are in an inactive state**.**

Also, there is high attenuation in the underwater environment. The transmission power used by the transceivers in I underwater network is higher than the power needed in the terrestrial network [11].

Sensor nodes are in a mobile state under the water which results in the breakage of communication links. Also, in underwater networks, there is a high error bit rate. All these problems generate a situation of frequent data packet retransmission which results in the loss of a large amount of energy.

1.1.2. Propagation delay

The propagation delay factor primarily depends on the underwater environment and properties of the communication medium. Some factors like depth of water, salt density, and temperature result in a change in propagation speed [4]. This delay affects the functionality of the protocol by deactivating its working process in the network.

2. Literature Review

In [12] authors have applied the LEACH protocol in UWSNs to improve energy efficiency. The head node in the cluster is rotated randomly to distribute energy equally to all other nodes. This protocol uses a TDMA schedule for balancing the network's energy consumption. The authors also proposed a LEACH-based protocol that integrates a novel energy model for the transmission of data in UWSNs. The authors analyzed hypothetically the energy utilization in underwater networks since underwater sensor networks have limited battery power [9]. To achieve this purpose, the authors have analyzed two states of water: deep water and shallow water. The authors considered the circulation of sound waves in water to derive an overall expression of energy consumption in both scenarios. Various operational standards for direct data transmission like clustering and packet relaying are also proposed by the authors. After analyzing both cases it is concluded that the packet relaying technique is better in deep water while the clustering technique is best in shallow water scenarios. Two clustering routing protocols using the LEACH protocol in order to conserve energy in the network are proposed by authors in [13]. The first protocol proposed is S-LEACH in which ADV packets collision is avoided by the division of time into various slots. In case of no collision situation in the network, all nodes can make a successful cluster. The second proposed protocol is C-LEACH in which to conserve energy, a control head node gets added to the network's center. After simulating both proposed protocols authors analyzed that the performance of both protocols is preferable to LEACH protocol in the case of the preservation of energy.

In [14] authors proposed a novel clustering-based routing protocol that adapts the LEACH protocol in its functioning. Multi-hop data transmission is used in this protocol. The concept of two gateway nodes is added in this protocol for collection and reception and transmission of data. Simulation results have been performed taking four parameters into consideration: total energy utilization, number of alive and dead nodes, and first dead node of the network. Conclusion is made by the authors that lifetime of the network is better in case of proposed protocols than the LEACH protocol. A new procedure is designed that uses the shortest route for transferring the data from all nodes to the sink node [15] which results in less energy utilization. Furthermore, the authors compared various protocols for underwater sensor networks that use less energy, including LEACH, ERP2R, DBR, and EADA-RAT. The authors used only two parameters for the performance evaluation of these protocols and these are: end to end delay metric and energy usage factor. The efficacy of the ERP2R protocol is superior to the other three protocols in case of increasing the lifetime of the network. Based on energy factors, data, and geographic information, the authors classify underwater protocols into three distinct categories [16]. Protocols of the first category improve network lifetime by improving energy efficiency, the second category increases data transmission efficiency while protocols based on the third category are adaptable to the ever-changing characteristics of the underwater environment. Analysis of these protocols has been performed by taking these factors into account: Utilization of energy, delivery rate of packets, and end to end latency, and system cost.

3. Motivation and Contributions

This paper has worked to comparatively analyze clustering-based protocols in UWSNs. The Under-water sensor network is an innovative technology for research that consists of sensor nodes and has many usages like target detection under the water, monitoring of environmental elements under the water, and disaster prevention. But there are various limitations in communication under the water. Various factors such as the Doppler effect, and noise interference affect the link quality of sensor nodes. Data transmission rate, communication reliability, throughput, and energy consumption are also affected by that interference. So, routing data under the water is a very challenging task. Routing protocols assure about data transmission to a destination node in the sensor network. But there are various complexities in underwater networks one of them is insufficient battery power of sensor nodes. The sensor networks' protocols used in ground are not directly applicable in under-water sensor networks due to some peculiar features of UWSN for example high energy utilization, dynamic structure of network, and significant time delays in communication. Therefore, the protocols used for routing data under the water need to be able to construct communication links that are reliable and fully functional. These routing methods need to be adaptable to a variety of different crises that can occur in underwater environments, as well as flexible enough to accommodate dynamic geography changes.

In this paper performance metrics of three clustering-based protocols of under-water sensor networks are analyzed. This paper's contributions are summarized as follows:

A brief summary of LEACH, E-LEACH, and C-LEACH is presented. This overview comprises their primary features, advantages, and limitations.

A comparison is proposed among these protocols in order to examine the influence of these protocols on certain performance metrics, including residual network energy, number of packets transmitted, number of alive and deceased nodes, bit rate analysis, bytes transmitted, and packet loss rate.

4. Clustering Technique in Underwater Wireless Sensor Networks

Clustering is the division of sensor nodes into distinct, non-overlapping groups. Clustering is intended to generate energy efficiency in the network, as energy is a nonrenewable resource, particularly in underwater environments. Other objectives of clustering include increasing network throughput, balancing network traffic, and decreasing network data redundancy [17-18].

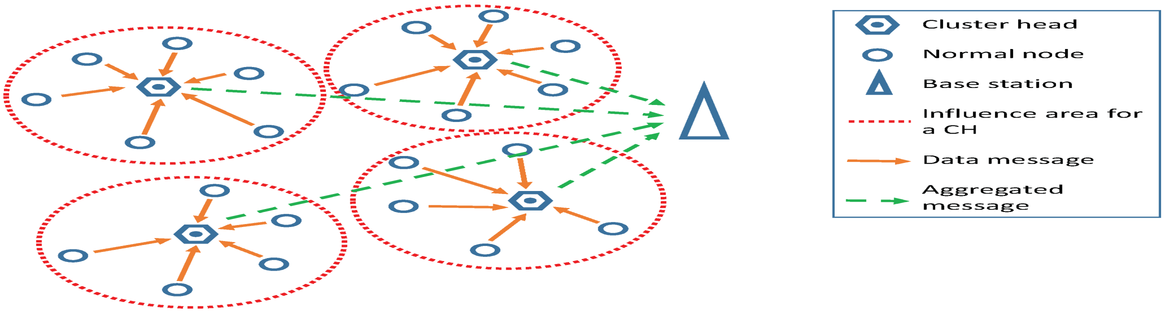

Fig 1. Clustering in UWSN.

4.1. Optimal clustering

According to this characteristic, the network should contain an optimal cluster density. By increasing clusters in the network; hops from one cluster head to the next will increases which results in high energy consumption. The average amount of energy used by each cluster head per round would rise if the number of clusters decreased. Both scenarios will result in an increase in total energy consumption. Therefore, sensor networks should contain the optimal number of clusters to establish network equilibrium. To balance the energy usage of sensor networks, researchers have proposed a variety of clustering routing schemes [19].

4.1.1. Clustering Hierarchical Routing Protocols

A. LEACH

Low-Energy Adaptive Clustering Hierarchy (LEACH) is a routing protocol in which energy is distributed equally throughout the network by using a random variation of head nodes in each cluster. The nodes group together to form clusters, with one node serving as the controller node of the cluster as a whole. Data from all cluster nodes is received by the cluster head node, which then adds it up and sends it to the base station node. [20].

This protocol works in multiple rounds, with each round consisting of two stages: in the first phase, the head node is selected, and in the second, data is transmitted to the sink node. In the initial phase, also known as the setup phase, the desired percentage value is considered for the election of the head node. A random value between 0 and 1 is chosen by each node, and it is then put up against the threshold value. This node is selected as the cluster head node for the current node if the number is below the threshold. The head node then broadcasts a message to other nodes in the cluster to inform them of its selection, and the remaining nodes select the head node that is closest to them. In the second stage, all cluster nodes send their data to the controller node, which sumps up all data and sends it to the sink node. In this protocol, Time Division Multiple Access is implemented. After data transmission, the nodes enter an inactive state [21].

Advantages:

Various advantages of LEACH protocols are:

- As a consequence of cluster heads aggregating the data from all sensor networks, network traffic is reduced across the entire network.
- Single hop routing is used in the network which helps in energy conservation.

- Location information of sensor nodes need not be known.
- No global knowledge of the network and no control information from the base station is required in this protocol.

Limitations:

- The information about the number of network cluster heads is not provided by this protocol.
- One of the main drawbacks is that when a cluster's head node declines for any reason then the cluster turns out to be useless since data assembled by head nodes will never reach a base station.
- There is a random division of clusters, which results in uneven distribution of clusters. Some clusters have a high number of nodes and some have a lesser number of nodes, in some clusters, the position of the head node is at the center of the cluster while in some clusters, the head node is near to edge of the clusters; this phenomenon increases the amount of energy used and performance of network degrades.

B. E-LEACH (Energy LEACH)

In this protocol, the preference for cluster leader nodes is decided by the remaining energy of all nodes of the network. Each cluster's head node is determined to be the node with the highest residual energy level [22].

In the first round, there is an equal chance for each sensor node in a cluster to be chosen as the head node. Due to the communication process in the first round, the energy level of each node is different from the second round. This protocol selects the head node the same as in the LEACH protocol; based on remaining energy. Cluster head node selection is improved in this protocol over the LEACH protocol which results in the conservation of energy and hence the lifespan of the network is increased [23].

Advantages:

- The network lifetime is extended because cluster head nodes are chosen depending on residual energy.
- Multi-hop data transmission is used in this which supports in energy conservation and enhancement of the lifespan of the network.

Limitation:

- Only residual energy factor is taken into account for cluster head node selection, that outcome in variable cluster sizes and load stability issues in the sensor network.

C. C- LEACH (Centralized -LEACH)

In this protocol, the base station performs important roles in a number of tasks, including selection of the head node, formation of a cluster, and the distribution of data across the network. In this protocol, the network's main nodes are dispersed among the sensor networks. This protocol's second phase, the constant phase, is executed at the base station, so network overhead is minimal. The setup phase is identical to the LEACH protocol. GPS is used by the base station node in order to obtain the network's nodes' positions. Energy is consistently distributed to all network elements. The base station then calculates the threshold energy of all sensor nodes; those with lower than threshold energy is excluded from the head node selection procedure for the current round. After identifying the network's head node, the base station transmits this information to all other nodes. If this ID matches any of the sensor nodes, then that node becomes a head node; otherwise, it operates as a regular node. The time division multiple access schedule is then sent by the cluster's head node to all of the cluster's nodes [22] [24-25].

Advantage:

- Compared to the LEACH protocol, it is an actual energy-efficient approach since Management of the whole process of head node selection, and data transmission is done by the base station.

Limitations:

- Every node requires GPS (Global Positioning System), which is costly and consumes more energy.
- Since this protocol is centralized, it is not scalable.

Table 1: Comparative analysis of LEACH, C-LEACH, and E-LEACH

Protocol/Comparison factors	LEACH	C-LEACH	E-LEACH
Clustering	Distributed	Centralized	Distributed
Overhead	High	Low	High
Scalability	Low	Low	Moderate
Energy Efficiency	Moderate	High	High
Location requirement	No	Yes	No
Load balance	No	Yes	No
Delay	Small	Small	High
Complexity	Low	Moderate	High

5. Performance Evaluation

Analyzing various aspects like energy consumption, number of packets transmitted, number of alive and dead nodes, bit rate, and packet loss rate is actually useful in each communication round in an underwater sensor network. Underwater sensor networks have larger nodes that require additional energy to complete the process. The network's total energy utilization comprises the energy used in data communication. To estimate the success of packet transfer from the source node to the destination node; bitrate, number of bytes transmitted, packets transmitted, and packet loss are useful performance metrics. Therefore, performance is estimated by measuring the remaining network energy, the number of packets transmitted, the number of alive and deceased nodes, and the transmitted bytes.

5 .1 Simulation Environment

Simulation is executed in NS 2.35 simulator. NS2 is simply a separate event-driven simulation device for reviewing the dynamic performance of sensor networks. NS2 simulator provides support for the simulation of all types of protocols of wired as well as wireless networks. This tool offers a modular stand for wired as well as wireless simulation supporting all network protocols, elements, and routing types [26- 27]. The parameters for simulating the three protocols; LEACH, C-LEACH, and E-LEACH are taken in the table shown below:

Table 2: Simulation Parameters

Parameters	Values
Network Area	1000x1000
Number of nodes	100
Protocols	LEACH, E-LEACH, C-LEACH
Initial energy	1J
MAC Protocol	802.15.4
Mobility	0 to 5 mtr/min
Energy Threshold	.2nj
Transmission energy	5nJ
Receiving Energy	5nJ

5.2 Simulation Results

a) Remaining energy analysis

Figure 2 depicts the remaining network energy. The graph represents the relationship between the remaining network energy and simulation time (in seconds). The graph depicts the amount of energy consumed in 100 seconds. Each node's initial energy is approximately 1J, and it continues to decrease with each round. The LEACH protocol's energy level terminates after 47 seconds. After 100 seconds, the remaining energy in the C-LEACH protocol is 17.31 joules and the remaining energy in the E-LEACH protocol is 71.57 joules. The conclusion of this analysis is that the E-LEACH protocol is best than LEACH and C-LEACH protocols.

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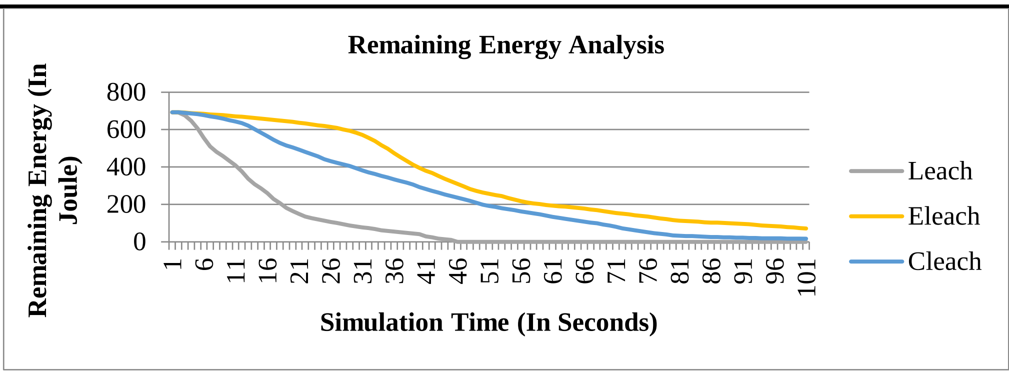

Fig 2: Remaining energy vs simulation time (in seconds)

b) Number of packets transmitted

Figure 3 shows how many packets are transmitted by the three protocols in 100 seconds. Protocol efficiency is measured by the number of packets sent each second. The graph shown below is plotted between number of packets transmitted versus time (in seconds). It can be clearly depicted that the number of packets sent by E-LEACH and C-LEACH are higher than LEACH protocol. So, it is concluded that E-LEACH and C-LEACH protocols have enhanced the network lifetime more than the LEACH protocol.

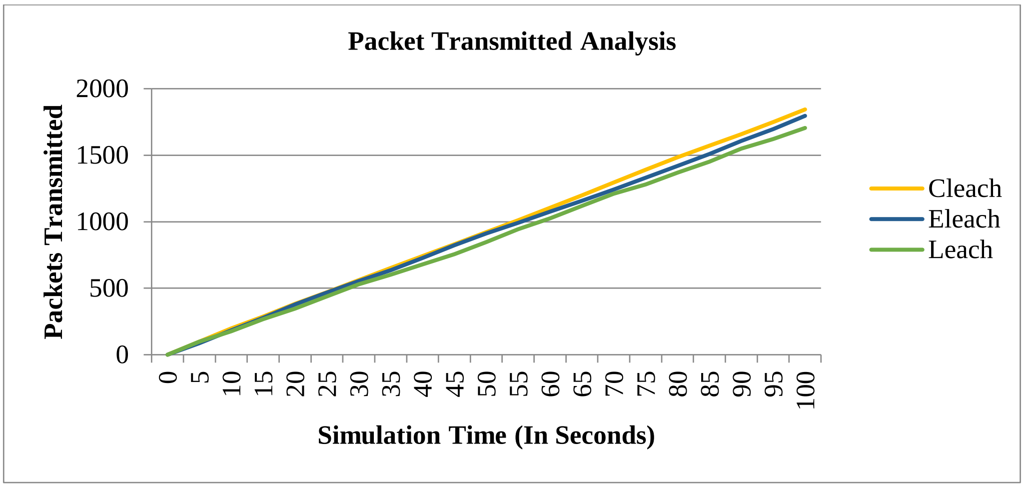

Fig 3: Number of packets transmitted vs. time (in seconds)

c) Packet loss analysis

The number of packets lost by three protocols in 100 seconds is shown is figure 4. It can be clearly represented that during transmission more packets are lost in the LEACH protocol than other two protocols.

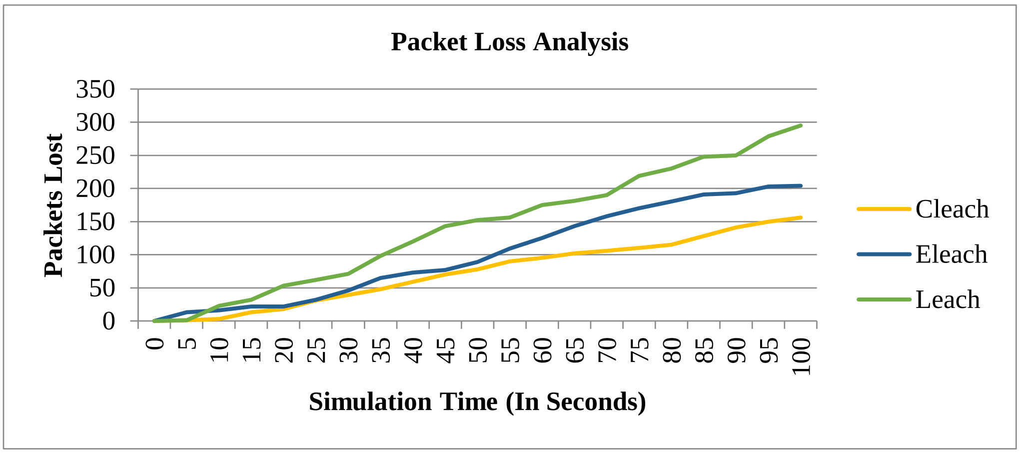

Fig 4: Packets lost vs time (in seconds)

d) Network Lifetime

In Figure 5 evaluation of three protocols is performed on the premise of network lifetime. The graph is plotted between the number of alive nodes in the network and time (in seconds). On the basis of the graph, it is observed that there are no alive nodes in the LEACH protocol after 46 seconds. From the figure it is concluded that E-LEACH and C-LEACH protocols have enhanced the network lifetime

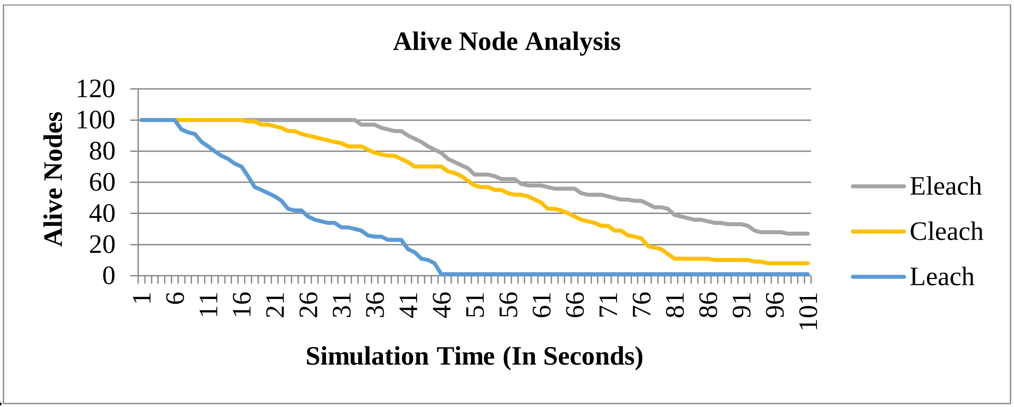

Fig 5: Alive nodes vs. time (in seconds)

e) Dead node analysis

Figure 6 signifies that on comparison of 1000*1000 m area of 100 nodes, it is concluded that all nodes in the LEACH protocol become dead after 46 seconds of time and in C-LEACH and E-LEACH protocols, 92 and 73 nodes become dead respectively after 100 seconds

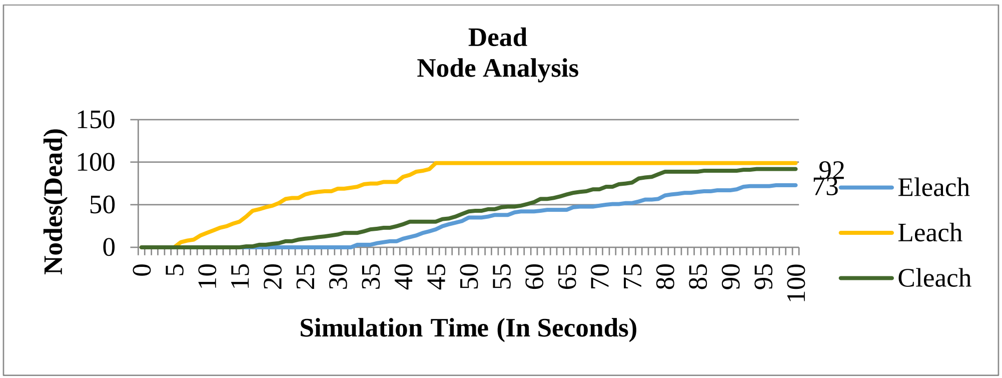

Fig 6: Dead nodes vs time (in seconds)

f) Bytes transmission analysis

Figure 7 shows the comparison analysis of LEACH, E-LEACH, and C-LEACH protocols on the basis of bytes transmitted to the base station node in 100 seconds of time. From the graph it is concluded that both versions of LEACH protocols are better than LEACH.

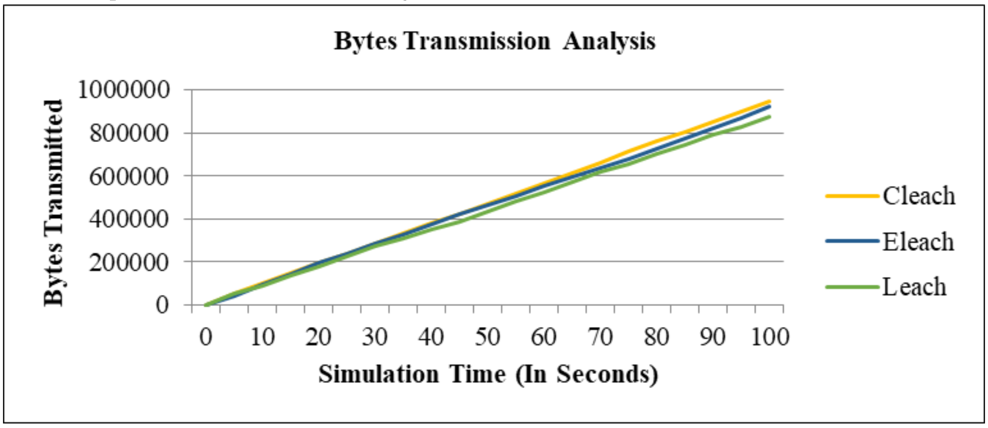

Fig 7: Number of bytes transmitted vs time (in seconds)

6. Conclusion

As a result of the ocean's vital role in human existence, underwater reflection is now a topic of discussion. Three clustering routing methods for underwater wireless networks are examined in this paper. These three protocols are comparatively analyzed on the basis of various energy-related and communication-related parameters like remaining energy of nodes, the total number of packets transmitted, lost packets during transmission, the number of alive and dead nodes, number of bytes used during transmission. After simulation, it is concluded that versions of LEACH i.e., E-LEACH and, C-LEACH are better in the case of network lifetime. C-LEACH is superior to LEACH and E-LEACH in certain aspects, including packets that are transmitted from sensor nodes to the base station, the number of packets that are lost during data transmission, and the transmitted bytes. In contrast to the LEACH protocol, the efficacy of E-LEACH and C-LEACH is therefore commendable.

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