



Energy Efficient Routing in Clustered Cooperative Communication Protocol for Wireless Underground Sensor Networks

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Abstract. The term Wireless Underground Sensor Networks (WUSNs) describes a collection of nodes operating beneath the surface of the earth that are expected to provide current observation capabilities in hostile subversive and submerged environments. Accurate monitoring in non-conventional media, such as subterranean soil, water, lubricants, etc., requires highly accurate tiny sensors with similar-sized antennae. Thus, research is required to examine the benefits and limitations of using WUSNs without sacrificing the efficiency of real-time monitoring protocols. Therefore, the main challenge is to establish a reliable underground communication system despite the complicated environment, which has substantial challenges such high path loss and limited communication range when penetrating the surfaces of dirt, sand, water, and oil. However, because of the subsurface communication, it recognizes continuously changing channel deeds, except on or after high pathway failure. It has proven difficult to address the issues of designing cluster-based cooperative communication protocols for sensors in non-conventional media in order to increase the network's lifetime and energy efficiency. The purpose of the research is to focus on these issues in order to propose a new cooperative communication channel model that takes into consideration the characteristics of tera-hertz electromagnetic wave propagation in the subterranean sensor network. Additionally, by improving lifetime, throughput, packet loss, successful packet delivery, and energy utilization, the work focuses on developing an energy-efficient Clustered Cooperative communication protocol (CCNU) for underground sensor networks. This will result in increased reliability and efficient use of spectrum. Better communication channel modeling for monitoring, intrusion detection, exploration, and sensing would be the result of this proposal.

Key words: Packet delivery, channel modeling, cooperative communication, and underground wireless sensor networks

1 Introduction

By enabling terminals or nodes in a communication network to work together on each new information exchange, cooperative communications make it possible to make effective use of the resources available for communication. Furthermore, the system's

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range of competence and performance can be considerably improved through cooperative communications, which can be a considerable advancement [1]. To add insult to injury, it is dependent on transmitting nodes, which have emerged as a viable method for the quality requirements, which include network exposure, spectrum and power competency, and the decrease of outage likelihood.

Single and multihop communication are the two categories that are used for underwater cooperative communication. This classification is extremely important. Through thorough consideration of the criteria known as propagation delay, multipath fading, restricted bandwidth, restricted battery, and incomplete information capabilities, the multi-hop communication technique has been demonstrated to be the most effective method for delivering information between the source and the destination. In order to facilitate wireless communication, networks are utilized [2]. In order to gather intelligence and examine utilities, underwater sensors and autonomous underwater vehicles communicate with one another, arrange the data, and divide it up utilizing all of the resources that are available. For the purpose of communicating underwater, the submarine makes use of a specialized telephone network [3]. This method functions in a manner that is analogous to that of a wireless signal that is based on amplitude modulation; however, rather than employing radio waves for transmission and reception, it makes use of sound waves. As is the case with terrestrial communication systems, underwater telephone networks make use of microphones and acoustic speakers.

The most important problem that has to be investigated is the fact that the UWSNs that are deployed in hazardous regions have fractures that are less than one hundred millimeters thick. It is recommended that the diameters of the sensor nodes fall within the millimeter range while working at frequencies in the gigahertz or terahertz categories. Due to route loss and a lack of transmission radius, a radio signal with a frequency range of GHz and THz will undergo severe intermediate assimilation in non-invasive transmission media such as water and liquids. This is because of the fact that the signal will be sent [4]. Thirdly, the deployment regions of UWSNs in complex environments are generating major energy issues. This is due to the fact that the tiny sensors can only consent to extremely restricted power delivery and relatively minimal power storage. As a result of the ineffective methods of producing renewable energy, the fourth requirement is for a cooperative communication network that is based on clusters. This is necessary in order to improve the reliability of the quality of service. The previously mentioned accuracy of WUSN, in addition to the demanding issues that they provide, necessitates the expansion of new forms and strategies for power-efficient signal transmission [5].

With clusters serving as its core component, the purpose of this work is to evaluate the power consumption of the proposed cooperative communication mechanism in cooperative transmission environments of Underground Wireless Sensor Networks (WSNs) [6]. Several cluster-based communication protocols are utilized in order to

simulate power-efficient underground wireless sensor networks (WSNs) [8]. The purpose of these protocols is to examine the practical range of communication among cooperating sensors for a variety of underground difficulties. the purpose of this project is to present a novel cooperative communication model that takes into consideration the propagation qualities of electromagnetic waves in challenging subversive conditions [9]. The findings of this research are organized into four primary sections: an analysis of the existing cooperative communication schemes for underground sensor networks; the utilization of energy-efficient clustered cooperative communication for the modeling of wireless underground sensor networks (WUSNs); and the results and outcomes of the experiments that were conducted [7].

2 Literature Review

Using ultrasound, Liu et al. investigate the progression of carbon dioxide in oil reservoirs. They demonstrate that their method has the potential to lead to novel and effective methods of monitoring the location of carbon dioxide, as well as seeing the reality of the oil producing area. This study presents the findings of a variety of experiments that were conducted in order to investigate the characteristics of acoustic waves in a variety of various mediums. The ultrasound reflection properties of stationary water-air, water-oil, air-oil, and oil-oil interfaces, as well as those of moving interfaces, are among the elements that are investigated by these researchers. In addition, the results of research examining the properties of ultrasonic reflection in porous mediums that contain air, water, and oil are discussed.

The authors Xu et al. disclose a device for oilfield associated gas recovery that was developed with the intention of taking into account the current state of the associated gas recovery process. During the heating process, the ideal-gas equation is utilized to examine and calculate the relationship that exists between the temperature of the gas and the pressure that is present within the device [8]. It has been demonstrated that the gas recovery apparatus that has been presented is theoretically possible. The gadget, which requires a cheap investment and can be applied in the field with ease, is capable of effectively recovering the gas that is related with oilfield development.

Mazzini and colleagues investigate the possibility of employing a robotic manipulator for the purpose of tactile mapping as part of their project. A system is devised that only requires robot joint encoders and avoids the use of any force or tactile sensors, which are difficult to use and unreliable in such a hostile environment. This method is considered to be more efficient. In 2006, the Georgia Institute of Technology's wireless communication lab was the place where the idea of a wireless underground sensor network was first presented. Research reports of wireless underground sensor networks in agricultural applications are scarce, despite the fact that wireless underground sensor networks have been examined in a variety of contexts in recent times [10].

3 Proposed Work

$$E_{tx}(k, d) = E_{elec} \cdot k + \epsilon_{amp} \cdot k \cdot dn \quad (1)$$

$$E_{coop} = E_{direct} - E_{relay}E_{direct} \tag{2}$$

The Equation 1,2 energy consumption for transmitting data in Wireless Underground Sensor Networks (WUSNs) is modeled as a function of both electronic circuitry and amplifier requirements. The equation $E_{tx}(k, d) = E_{elec} \cdot k + \epsilon_{amp} \cdot k \cdot d^n$ shows that the total transmission energy depends on the packet size k , the distance d , and the medium’s path loss exponent n . In underground environments, the path loss exponent is significantly higher than in free space due to soil, water, and mineral absorption. This equation emphasizes that minimizing transmission distance through clustering and cooperative routing is critical for energy efficiency, as longer distances exponentially increase energy consumption Equation 3,4.

$$PCH(i) = EiEavg \cdot P \tag{3}$$

$$L = \sum i = 1NEiEconsumed_per_round \tag{4}$$

3.1 Underground Surveillance Networks Require Cooperative Communication

Sonar waves and electromagnetic waves have been used separately or in combination to transfer signals in underground communication systems. However, underwater communication is difficult due to factors like multi-path propagation, time differences in channel duration, limited available bandwidth, and stringent signal reduction, especially above large assortments. Fig.1 depicts the cooperative communication model. Tx, Rx, TR, RR, and CH stand for transmitter, receiver, transmitter relay, receiver relay, and cluster head node, respectively, in the suggested model.

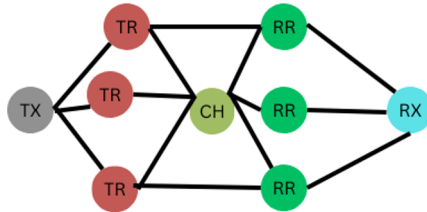


Fig. 1. Cooperative Communication Model

To maintain connectivity for the underwater environment, serial communication flows between TX-TR-CH-RR-RX nodes. Communication for a critical mechanism of an electronic infrastructure system, such as the sender node, communications medium, receiver node, and noise, is made possible by the very low frequency range of 3 to 30 kHz, which may pass through saltwater to almost no tens of meters. Because water has a higher permittivity and conductivity than air, it is more difficult to transmit and receive sound waves and digital information using analog and digital methods in subterranean environments. However, in terms of frequency, the high attenuation of plane waves differs from air. Furthermore, microwaves are a superior

choice because water does not conduct electricity effectively at subterranean frequencies, and radio waves cannot travel an excessive distance. However, for underwater frequencies, the above-ground reception needs to be completely protected from the nearby water. For the reasons listed above, the most important problem in the design of subterranean wireless cooperative communications systems is that spectral efficiency and association consistency must be used to overcome multipath fading and interference that occur in the underground environment. The cooperative mechanism in the suggested communication model refers to the process of sending data from the source node to the destination node via the TR, CH, and RR cooperative nodes. Because the nodes have been deputed serially, this model's specialization is ensuring reliability.

Channel Modelling for WUSNs Using Clustered Cooperative Communication and Energy Efficiency: A strategy for channel modelling based on clustered cooperative communication that uses less energy is suggested. Fig.2 depicts the entire WUSNs environment. Layers 1 and 2 are the two layers of this model. Each cluster head is connected to the others so that they can communicate with the target node via the communication medium. Before each cluster is connected to other clusters in the communication architecture, the nodes in each tier can convey the data they have collected to the cluster head. in a manner that ultimately directs the collected data from every cluster to the destination node. In order to make communication dependable, the communication model uses layers to favor the best cluster head. In the suggested architecture, the cluster head selection is important because it establishes strong communication between its nodes, giving it complete control over data transit.

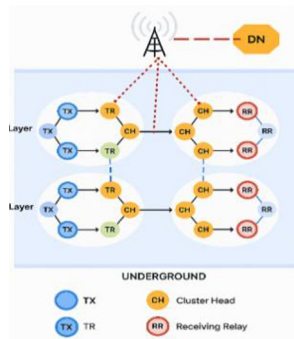


Fig. 2. Model for Cooperative Communication Underwater

For the purpose of employing the relay nodes in between the source and the destination in order to achieve effective and efficient communication, cooperative communication is supposed to be used in this underwater environment Fig.2. Within the framework of the suggested communication model, the Destination node is tasked

with the responsibility of receiving the data from its cluster heads in the order that the cooperative nodes set up in order to achieve the most efficient configuration. A superior selection of layers and a cluster head for monitoring the quality of links in order to guarantee that cooperative nodes data is of a high quality are the highlights of the model that has been proposed.

4 Results and Outcomes

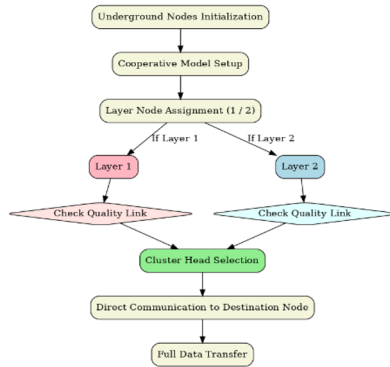


Fig. 3. Communication Flow for Wireless Underground Sensor Networks

This simulation of energy-efficient clustered cooperative communication is put through its paces with the help of the Channel Modeling protocol. In order to begin the simulation process, the first step is to create the simulation channel model for the WUSN program. The channel is anticipated to be capable of supporting a total of four clusters, each of which will be comprised of a cluster head and cluster nodes. The data that is collected by the nodes within each cluster and sent to the control node is collected from the underground range of the nodes. All of the cluster heads have been physically and logically connected to one another in order to ensure dependability and minimize delay spread. This has been done so that they are able to communicate with one another and quickly exchange relevant information for later transmission. The proposed communication path for the WUSN is depicted in Fig.3. Once the sensing process is complete, it is thought that the TxR is in charge of transmitting data, and the Rx is responsible for performing the reciprocal role of receiving data from the transmitter. It is possible that TxR will be able to relay the information that was transmitted by the transmitter, while RxR is responsible for the reception of data from the receiver no. The primary objective of this proposed cooperative communication surveillance model is to fulfill the functional characteristic of the Cluster Head, which is an important component in the process of connecting the layer to the control node. Additionally, if the information is sufficiently understandable, the cluster node has the

ability to skip the responsibility of forwarding the data. Due to the fact that the model contains a large number of coupled nodes, it is necessary to conduct a quality link assessment in this context while selecting the layer that will ensure continuous without interruption communication. Due to the fact that the cluster head has full control over the communication arrangement, it is possible to successfully finish the full data transfer by picking either layer 1 or layer 2 as the best cluster head to ensure that the data arrives.

This study examines network lifetime and throughput performance using Network Simulator 2. Table. 1 specifies the parameters for the experiment, including the surroundings Fig.3. The area in which surveillance must be conducted determines the bifurcation of the network layer. It is assumed that all of the nodes are evenly dispersed and time-synchronized, with a communication radius of 500 meters. Designing the communication model as a coverage area constraint that allows the nodes to communicate with one another, as indicated in the table, is necessary for network scale. In the suggested communication model, 200 nodes with two layers are utilized. Additionally, the region and communication radius affect how scalable the addition of nodes is. Here, evaluating noise power is necessary to determine the quality of the data being received, and it is proportionately connected to bandwidth.

Table 1. Simulation factor setup values

Scale of the network	5×5 (km)
The quantity of nodes	200 with 2 layers
Radius of communication	500 m
Each node's allocated energy	5 J
Length of data	LD = 1500 bits
Nodes' received power	$RP_n = 0.0026$
Power of noise	$NP_n = 0.0008$
Increase the relay nodes' energy	$BE_R = 0.004$
Frequency	F = 6 KHz

The following formulas can be used to determine the signal strength.

$$A_{TxRx} = T_S C_{TxR} + N_{TxR} \quad A_{TxR} = T_S C_{TxR} + N_{TxR} \quad A_{RxR} = T_S C_{RxR} + N_{RxR}$$

where

- A_{TxRx} specifies the signal power from the source and receiver nodes
- A_{TxR} refers to the source and source relay node signal strength
- A_{RxR} indicates the signal strength from the receiver node and receiver relay node
- T_S signifies the transmitter node's initial signal strength
- C_{TxR} indicates the channel fading value of the transmitter and receiver nodes
- C_{TxR} represents the channel fading value of the transmitter and relay nodes
- C_{RxR} indicates the channel fading value of the relay and receiver nodes

The performance of the suggested energy-efficient Clustered Cooperative communication model is evaluated using the following parameters: lifetime, throughput, packet loss, successful packet delivery, and network energy consumption. The duration of energy sustainability from start to finish is used to calculate the network's lifetime. The successful receipt of packets per stimulated time can be used to calculate throughput. The unsuccessful reception of data packets is used to calculate the packet loss. In terms of the packet delivered, successful packet delivery is simply the difference between successful packet receipt and packet loss. The sum of all energy-related transactions between the source and the destination is known as energy utilization. 400 nodes covering an area of 5 km × 5 km have been used; each node has an initial energy of 5 J and uses a fixed transmission range of 500 m for static communication. The maximum length of data that can be utilized for data transfers is 1500 bits. The simulation environment for the subterranean wireless cooperative communication model has been configured with the aforementioned parameters. Plotting the number of dead nodes against time in Fig.4 illustrates the network length evaluation for both the current Energy Efficient Depth Based Routing protocol (EEDBR) and the anticipated CCNU. Since the clustering concept has been incorporated into the layered network, it is known that the nodes' intelligent function in terms of energy utilization has resulted in a substantially longer lifespan for the proposed network than the EEDBR.

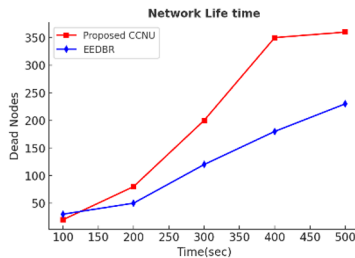


Fig. 4. Lifetime of the network

The plot of the energy use graph between the time and energy utilization for the proposed CCNU and the current EEDBR is displayed in Fig.4,5. The suggested protocol has an advantage over the current protocol, according to the energy use graph, since it successfully uses all available energy to improve the network's quality.

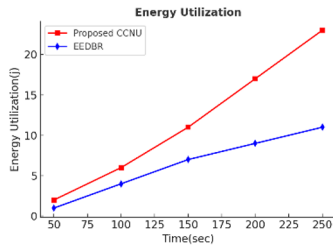


Fig. 5. Utilization of Energy

Time vs. packet received, as displayed in Fig.6, is used to calculate throughput. The suggested methodology has proven quite appealing since it improves throughput for various iterations without sacrificing latency.

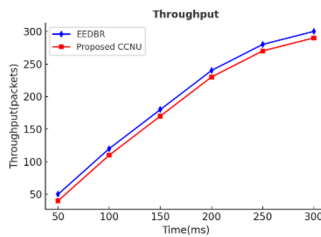


Fig. 6. Throughput

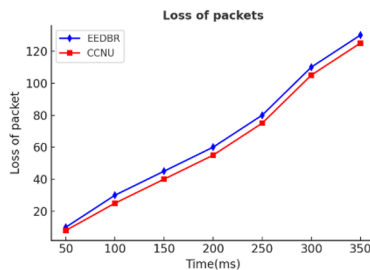


Fig. 7. Loss of Packet

Fig.7,8 compare the packet loss and successful packet delivery using time versus packet loss and time vs packet delivery ratio, respectively. The proposed CCNU's layered cum clustered architecture provides the necessary connectivity, which is the cause for the

successful packet delivery. The proposed CCNU's packet loss is completely unaffected by the transmitter-receiver transaction.

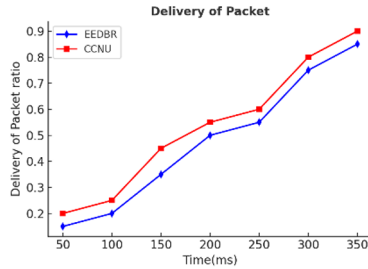


Fig. 8. Delivery of Packets

The following are the essential recommendations: The suggested study looked at WUSN's communication strategies for promoting orderly teamwork in challenging subterranean environments. The propagation properties of electromagnetic waves in the harsh underground environment are being made possible by this predicted model, which has been highly needed. To make the network dependable, it is also necessary to evaluate the potential communication lengths between nodes and performance in terms of lifetime, throughput, packet loss, successful packet delivery, and energy consumption for various subterranean hazardous conditions. However, elaborating on the fundamentals and limitations of employing electromagnetic waves with a short range for underground communication is crucial. In contrast to the current EEDBR Protocol, the proposal would allow for the effective and efficient use of WUSNs in conjunction with the cluster-based cooperative communication (CCNU) model in complex underground environments. This would be beneficial for applications such as monitoring, intrusion detection, exploration, and sense. The cluster head selection method of its layer in the suggested model satisfies the requirement of effective spectrum utilization by using the least amount of energy without sacrificing quality. The shortcomings of the current model, such as its unreliability due to its failure to take into account hostile environments and its failure to incorporate additional QoS criteria, have been addressed in the suggested model.

5 conclusion

In this paper, the Energy-efficient Clustered Cooperative Communication channel modelling for Wireless Underground Sensor Networks (WUSNs) was proposed. Simulation experiments have been conducted with the goal of focusing on these issues in order to propose a novel cooperative communication guiding model in subsurface sensor networks. Using lifetime, throughput, packet loss, successful packet delivery, and energy consumption, the energy-efficient Clustered Cooperative

communication protocol (CCNU) has also been used to provide improved dependability and more effective spectrum usage compared to the current EEDBR Protocol. The suggested work has led to the conclusion that the sensor network based on cluster cooperative communication offers better communication channel modelling for monitoring, investigating, and sensing in multi-hop environments. Future study will focus on developing a cooperative communication model for the communication network while taking energy efficiency into account as a critical tool in cluster-based hierarchical architecture.

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