Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/15167
DOI URL: http://dx.doi.org/10.21474/IJAR01/15167

RESEARCH ARTICLE

ARTIFICIAL INTELLIGENCE - BASED MULTIOPATH TRANSMISSION MODEL FOR WSN ENERGY EFFICIENCY

Shan-E-Fatima[1] and Dr. Monika Tripathi[2]

1. Research Scholar, Shri Krishna University, Chatarpur (M.P).
2. Professor, Shri Krishna University, Chatarpur (M.P).

Manuscript Info

Manuscript History
Received: 06 June 2022
Final Accepted: 10 July 2022
Published: August 2022

Key words:-
Artificial Intelligence, Transmission Models, WSN, Energy Efficiency

Abstract

This paper presents a network-coding-based transmission strategy called alternative multipath to boost the transmission reliability and energy efficiency of wireless sensor networks (AMNC). Encoded data packets are transmitted to the sink through alternative multipath from the cluster head. MATLAB 7.0 simulates WSN's energy utilization and reliability. Simulation findings show AMNC outperforms parallel multipath based on network coding. The two techniques show this. A well-defined discussion of the research subject, specific technologies, strengths and weaknesses, scopes, and problem formulation is required for any study. The ocean covers approximately two-thirds of the earth's surface, therefore it's hard for any economy to avoid it (i.e., country). The ocean serves as a main method of transportation, supports international trade, and is crucial for defense. In recent years, it has come to light how crucial ocean or water-routes are for enabling rapid and cost-effective transportation for the expansion of businesses. In order to realize transcontinental commercial practices and discover the true meaning of socioeconomic globalization, the role that oceanic waterways have played has been essential. On the other hand, maintaining efficient real-time environmental or auditory conditioning (also known as condition awareness) is required in order to make optimum mobility possible. Because of its exceptionally high dynamic network topology, an audio channel experiences a significant amount of network deviation; as a result, it calls for a communication paradigm that is more effective in order to support the aforementioned application environment.

Introduction:-

After looking into the matter, one might discover that water covers about 70 percent of the surface of the world. Over the course of the most recent few years, a variety of initiatives have been undertaken to investigate the potential for various kinds of enterprises, transportation, military objectives, entertainment establishments, and other kinds of establishments in the undersea environment. Additionally, a variety of activities such as petroleum exploration and mining, amongst others, have spurred academics and enterprises to investigate more within the ocean, which demands highly complex equipments, sensors communication, and other such things [1]. It is interesting to note that under maritime conditions, positioning a sensor node in a fixed place or position is very

Corresponding Author:- Shan-E-Fatima
Address:- Research Scholar, Shri Krishna University, Chatarpur (M.P).

challenging and very close to being impossible. On the other hand, the overall network architecture, which in turn influences the performance of the network, is influenced by a variety of local circumstances. Some of these factors include temperature, salinity, gravity, wave propagation, and higher wavelength disturbances. In actual reality, sensor nodes from a UWSN are placed in a specific location in order to collect information of interest.

The information that has been detected is subsequently sent to one or more surfaces sinks so that it may be correctly interpreted. Experts or expert systems will take appropriate actions based on the interpreted data, with the accomplishment of the job serving as the ultimate goal. Because of the challenging environment of the underwater channels, the hardware for the underwater nodes is more expensive than that of the terrestrial nodes, and they also need a comparatively high transmit power. Due to the fact that these nodes are notoriously prone to link outages or failures, they are fitted with limited battery power, which often results in the death of the node [2]. As a consequence, it results in the breakdown of the network or the loss of data, both of which may have potentially disastrous outcomes. Acoustic channels are used for communication in UWSNs rather than the more traditional radio channels. Acoustic channels are often impacted by a variety of factors, including multipath, path loss, Doppler loss, or the spread and noise components.

Architecture OfUWSN Communication System

The effectiveness of a routing protocol's ability to save energy and provide quality of service is heavily dependent on the topology of its underlying network. The primary objective of an energy-efficient network design is to make it possible for the network to have a longer lifespan. This is something that can be accomplished by reducing the total amount of energy that is used by linked sensor nodes. In addition to this, the significance of an effective routing protocol cannot be discounted in order to accomplish the same goal. Therefore, improving the UWSN routing protocol is unavoidable if one want to realize energy efficiency and quality of service in their communications [3] **(See Fig no-1)**.Taking it into consideration as a motivation, the goal of this research activity or the thesis is to push forward the development of an unique and resilient acoustic channel model as well as an energy efficient and QoS-centric UWSN routing protocol [04]. When considering the mobility of acoustic sensor nodes, the UWSN may be broken down into two main categories: 2) Mobile UWSNs, in addition to 1) Static UWSNs.

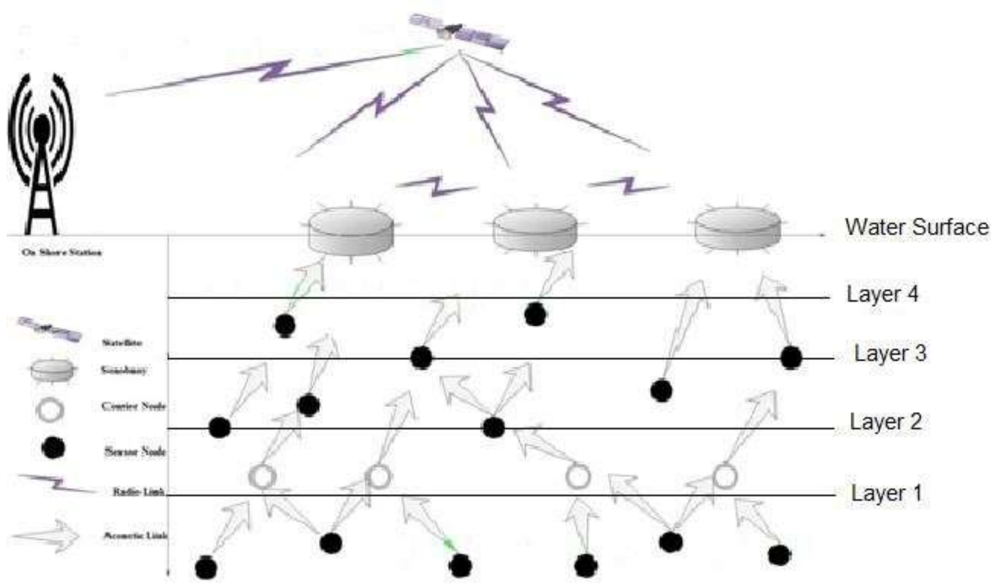

Fig. no 1:- Underwater WSN architecture.

Protocol Stack for Underwater Acoustic Channels

Energy efficiency should be ensured in each of the functional components that comprise the UWSN network, including both the hardware and the software. This will allow the lifespan of the UWSN network to be extended. Enabling sensor nodes with the capacity to generate their own power is one of the primary strategies that may be used in order to improve the energy efficiency of UWSN. It is possible to do this by investigating mechanical or chemical methods such as the flow of current. It has been determined that Li-Ion batteries are an appropriate choice for UWSN because to their high density, extended lifespan, and stability in a wide range of environmental conditions [05]. In point of fact, the most notable advantages of the Li-ion technology are its cheap cost, low discretion rate, flexible design that can be tailored to the requirements of the application, and readable battery status. In most cases, the sensor node receives its power from three alkaline cells. Together, these cells are capable of producing 27Wh of power, which is enough to support continuous operation for four days. Some investigations have also shown that a sensor node equipped with Li-ion batteries that are armored with seven 2 amp/hour batteries may be able to run continuously for even two weeks [06].

Literature Survey

An energy Efficient and Balanced Energy Consumption Cluster based Routing Protocol (EBECRP) for UWSNs was suggested by **Majid et al.** The authors' goal in developing their suggested solution was to evade the use of depth-based routing wherever possible by balancing the load on each node using mobile sinks. In addition to this, they used a clustering model in order to reduce the amount of multi-hoping, which leads to an increase in energy consumption. The selected CHs collect data from one hope neighbor nodes in order to reduce the amount of global communication that occurs and increase the amount of communication that occurs locally. An underwater opportunistic routing-based medium access control protocol called UWOR MAC was suggested by **Chen et al.** by concurrently taking into consideration the features of UWSNs and the notion of opportunistic routing. In particular, in order to enhance the channel usage, they built an Event Relationship Graph (ERG), which assisted in assessing the successful chance of many packets being delivered simultaneously. The optimum relay selection model was presented by **Wang et al**.in order to reduce energy use and ensure quality of service across MIMO-based UWA cooperative WSNs. When modelling the UAW channel, they used the finite-state Markov chain modelling technique. In addition, in order to carry out the process of relay selection, they added gain factors such as MIMO multiplexing-gain and diversity-gain in addition to the residual relay energy. The authors achieved the best possible relay selection by using the Linear Programming **techniXu et al.** presented a brand new Layered Multipath Power Control (LMPC) system with the goal of lowering the noise component in deep water. This would increase energy consumption, as well as enhance the dependability and robustness of communication in USNs. The goal is to decrease the amount of energy that is used while also ensuring that the extra environmental criteria are fulfilled. After proving that this optimization problem is an NP-complete problem and resolving the critical problems facing LMPC, which included the establishment of an energy-efficient tree and the management of energy sharing, the next step was to create a heuristic algorithm in order to arrive at a possible solution to the optimization problem.

In **Hu et al.'s** paper, they suggested a reinforcement learning-based energy-efficient routing protocol. In this paper, the authors focused on tackling the routing problem that occurs in UWSNs. Their technique presupposes that other MAC protocols are in use and aims to increase the lifespan of networks by making the remaining energy of sensor nodes more evenly distributed. The residual energy of each node, in addition to the energy sharing among a collection of nodes, is factored in throughout the routing method to compute the reward function that helps in choosing the adequate forwarders for packets. This helps to ensure that the routing method is as efficient as possible. EEEDBR is an extended enhanced energy efficient depth based routing protocol that was suggested by **Khizar et al**. for use in UWSNs.

The EEEDBR decides which forwarding node to use depending on which one has the most residual energy and the shortest distance to the sink. In EEEDBR, the network lifespan is enhanced by placing idle nodes in the medium depth zone. This is done because sensor nodes expire sooner in the low or medium depth region owing to the greater relaying of data packets that they are required to do in those regions. Depth and Energy Aware Cooperative Routing Protocol for UWSNs was described by **Pervaiz et al.** as an energy-efficient cooperative routing protocol with adjustable Depth threshold (Dth) (DEAC). When executing cooperative routing, DEAC takes use of the broadcast nature of the sensor nodes. A source node's optimized value of Dth is chosen, and then that value is altered in proportion to the number of living nodes immediately next to that source node. A prospective destination node is chosen from the nodes located outside of Dth, and a potential relay node is chosen from the nodes located inside D^{th}. The depth, the amount of leftover energy and the quality of the connection between the sensor nodes all play a role in the decision-making process for the destination and the relay. A data packet may be sent from a source node to its destination node in one of two ways: either directly from the source node to the destination node or indirectly via a relay node. At the destination, the Maximum Ratio Combining Technique is used to combine two data packets that have been received from the source node and the relay node (MRC). Khan et al. proposed an Energy Efficient, Interference and Route Aware (EEIRA) protocol for use in UWSNs. This protocol would combine direct and relay forwarding mechanisms in order to send packets from their source to their destination in a manner that is energy efficient, aware of interference, and route aware.

The process of relaying entails selecting the most effective relay from among a group of possible relay nodes. The criteria for the best relay is met by a relay node that meets both the requirements of having the shortest distance between the source and the destination as well as the fewest number of neighbor nodes. When the most reliable relay is located outside of the broadcast range of the source node, direct transmission is utilised instead. The network is broken up into three distinct zones that are named for their separate locations: the destination zone, the relay zone, and the source zone. The relay zone has the most space, giving users the largest number of options from which to choose the most suitable relay among the relay nodes found there. The property may be sensed by nodes in any of the three zones, and those nodes can then communicate the data to the sink. The nodes at the destination send the data on to the sink immediately.

Research Methodology:-

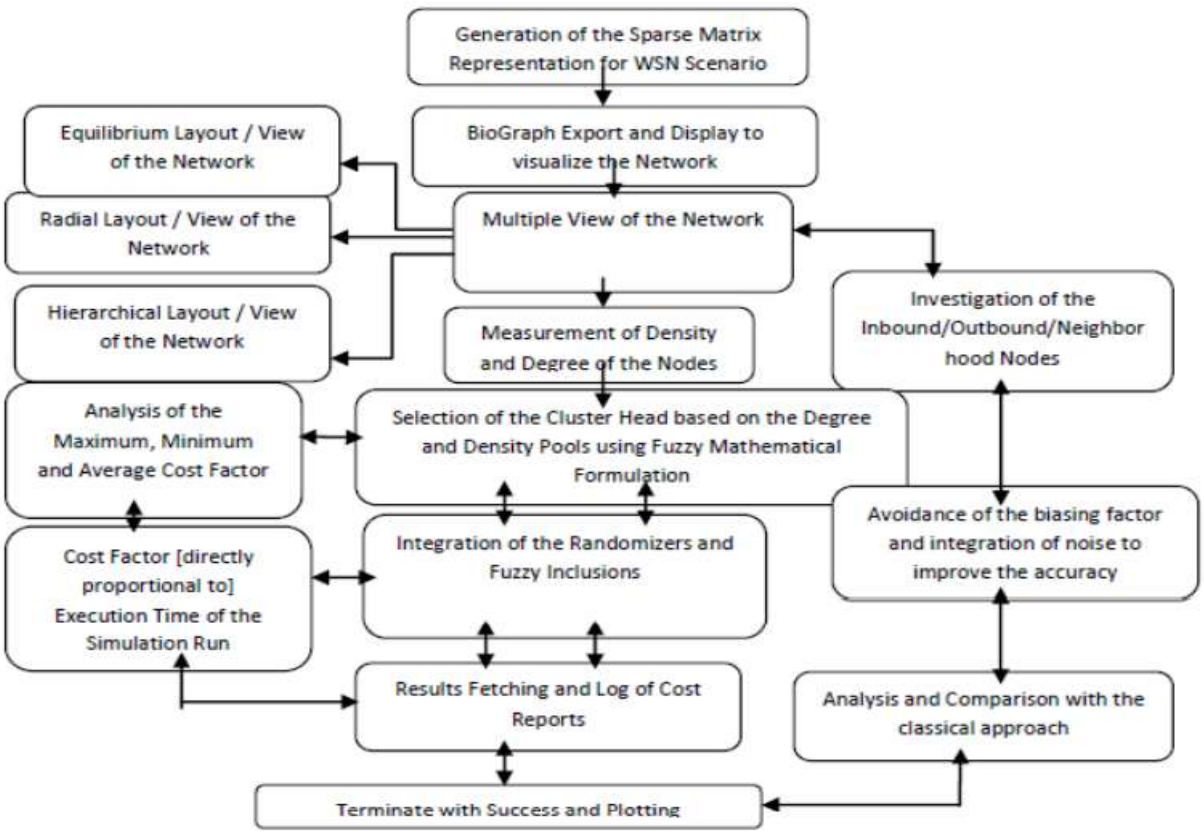

Fig no2:- Flow diagram of proposed research work.

Large-Scale Deviations (Lsd) Caused due to Location Dynamism

In acoustic environment, there are many parameters that significantly influence the geometry and make it uncertain. Some of these parameters are the transceiver movement, variation in the surface height, bottom shape, etc., which make exact system geometry uncertain [07].

$$h_p = \bar{h}_p \frac{1}{\sqrt{\left(1+\frac{\Delta l_p}{l_p}\right)^k a_0^{\Delta l_p}}} \qquad \text{.....1}$$

$$\left(1+\frac{\Delta l_p}{l_p}\right)^k \approx 1 + k\frac{\Delta l_p}{l_p} \approx \left(1+\frac{k}{l_p}\right)^{\Delta l_p} \qquad \text{.....2}$$

To ensure positive gain, here performed the exponential approximation of (7.12) Page 136 and considering the location uncertainty path gain is considered as log-normally distributed. Thus, the CTF is obtained as

$$\xi_p = a_0 - 1 + \frac{k}{t_p}, \; with \;\; a_0 \approx 1$$ ….3

$$H(f) = \bar{H}_o(f) \sum_p h_p e^{-j2\pi f \tau_p}$$ …………..4

Characterization Of the Small Scale Acoustic Channel

As discussed above, the CTF can achieve only the large scale effect and is unable to retrieve any small-scale phenomena like scattering in acoustic medium. On the contrary, scattering plays a decisive role in signal strength over propagation **(See Fig no2)**. An acoustic signal with the frequency suffers scattering on wavy surfaces and the objects having dimension of the order of a few signal wavelengths equal to. For illustration, the wavelength associated with an acoustic frequency element of 15 kHz is 0.1m, and therefore the distance can be stated as "small." To develop a scattering model in an UWSN channel, it is needed to emphasize on a single path, say. In previous section, this path was designed by considering respective path gain and the propagation delay. However, in practice if scattering exists within acoustic medium, particularly towards path, it usually gets split into multiple micro-sized paths. Mathematically,

$$H(f) = \bar{H}_o(f) \sum_p \sum_i h_{p,i} \, e^{-j2\pi f \tau_{p,i}}$$ ……5

$$\gamma_p(f) = \frac{1}{h_p} \sum_{i \geq 0} h_{p,i} \, e^{-j2\pi f \delta \tau_{p,i}}$$

Thus, the eventual CTF can be derived as

$$H(f) = \bar{H}_o(f) \sum_p h_p \gamma_p(f) e^{-j2\pi f \tau_p}$$ …….6,7

Systematic Random Linear Network Coding (SRLNC)

SRLNC uses many optimization methodologies to improve UWSN multipath transmission. The proposed transmission model ensures delay-sensitive multipath transmission across UWSNs for dependable and secure mission-critical communication [08]. SRLNC introduced CVO optimization. This optimization linearizes data packets using Coefficient Vectors (CV). Linked sinks usually have the CV information to decode data. Coefficient Matrix stores all CVs (CM). Despite broadcasting CVs, the information that indicates row of the coefficient matrix (also known as the index position) is utilised to generate a particular linear combination that will also be communicated with coded data packets. CV and CM are combined to create coefficient information (CI). The intermediate node in the planned UWSN network decompresses CI and appends it before sending it to the next hop node on its route to the sink. Since the source node's initial CM isn't shared with other nodes, no intermediate node can decode the data. It enables continuous SRLNC connection in multipath UWSN.

The operation of SRLNC may be seen as having three stages:[09]
1) The processing that occurs at the source node,
2) The processing that occurs at the intermediate node, and
3) The processing that occurs at the sink node.

Dataset Description

In this experiment, three separate datasets were used to see how effectively traditional machine learning models and deep learning models modelled the underwater acoustic channel [10]. This evaluation was carried out in order to determine which kind of model was more accurate. The conclusions drawn from this analysis are shown down below. This is an explanation of the datasets, which are as follows: Data 1 was acquired using a test bed. To minimize disruption, the test bed was built from an existing water tank. The transmitter and receiver were set below the water level perpendicularly and horizontally apart. Data collection and production flowchart 1. First, a QPSK modulation block, which creates continuous signals, was used to handle digital message signals. A stronger cosine transmission filter was subsequently applied to the continuous signals. The acoustic transmitter then broadcast filtered-QPSK modulated continuous signals on the underwater channel. The sonar positioned immediately after the channel might pick up and record these continuous signals. Each data item is 60 seconds long and sampled at 1 million per second.

Models And Approach Used

UWSN Network Model

Using a 3D model of the UWSN to test an SRLNC-based routing algorithm. Similar sensor nodes are randomly dispersed. Each sink node has a radio frequency modern and an acoustic modern, knows its 3D position and associated node information via location services, and may utilize this knowledge in routing decisions. The proposed routing protocol uses SRLNC-based transmission to route nodes using geographic route information. Designating the node nearest to the sink as the data forwarding node enables straightforward transmission. This reduces data loss. Nodes utilize SRLNC. The sink decodes incoming N linearly independent encoded packets. The optimum forwarding node is estimated using a greedy forwarding model.

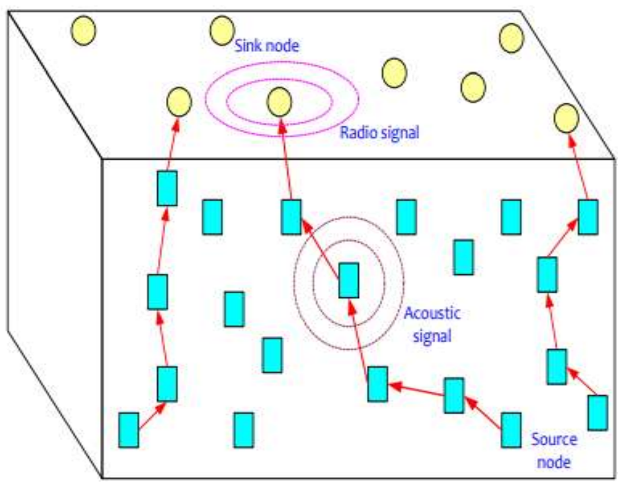

Fig no 3:- 3D Acoustic Network Structure.

Artificial Neural Network Approach

Electromechanical, static, or microprocessor-based distance relays attain accuracy. Various faults and network changes may affect its accuracy. These solutions may adjust dynamically to a system's operational settings at a quick pace. ANN's ability to learn and detect complex input/output mappings. Noisy patterns, which contain missing or unwanted portions, can recognise and categories patterns [11]. ANNs may address overreach and underreach issues in typical distance relay design. ANN uses voltages and currents as raw inputs, skipping the requirement to calculate phasors and other symmetrical components. Multi-layer perceptrons (MLP), recurrent neural networks, radial basis functions (RBF), probabilistic neural networks, etc. are utilised for defect classification and detection. Back propagation, orthogonal least square, extended kalman filter, etc. helped design them. ANNs may boost initial distance relay zone and system protection. Fault tolerance, lowest response time, and generalization capabilities are network performance considerations to consider. ANN improves many transmission line protection characteristics. Recurrent networks were examined to make the ANN sensitive to time-varying voltage and current waveforms. These networks allow hidden network units to observe their prior output, which shapes future behavior argue for Elman recurrent networks. These ANNs don't have well-defined operations, hence their findings aren't reliable.

Supervised clustering reduces the amount of iterations in multilayer feed forward network learning [12]. Constructed a neural network simulator to find the appropriate ANN structure for data training and hardware construction. It's here. No rule exists for how many hidden layers and neurons should be employed in each hidden layer, which is a significant flaw of ANNs. [13] Proposes a high-speed distance relaying technique based on RBFNN because it can recognise defects using outside-training-pattern data. It's unknown whether the ANN-based relay gives the ideal output to retain relay properties.

Result and Discussion:-

This research work's purpose is to assist the research efforts that are being made to merge the solutions that have been presented in order to offer an extra energy efficient routing method by means of the specialized system of creation that employs the least distance vector from the base station of each node. The research efforts are being made to assist the research work. The inclusion of a fuzzy-based mathematical formulation is brought to completion by the technique that has been presented. Reading the data from the wireless sensor nodes is where the Fuzzy Integrated Density and Energy Optimization Algorithm (FIDEOA) that has been suggested get started. The formation and initialization of the dynamic graphs of nodes is the next step that is carried out.

A measurement of the density of each node is performed based on the percentage of the number of connections among and to nearby nodes. This measurement is carried out with the addition of an arbitrary number to the density that has been measured for each node in order to avoid any kind of biassing. The next step in this process is determining whether or not the distribution of the Cluster Head should be based on the Threshold Value [14]. The Threshold Value is going to be compared to all of the nearby densities, and the element that matters will be the degree of dissimilarity between them that is the smallest. After that, the value that is most closely approaching the threshold will be used to determine the Cluster-Head. The simulation of the suggested systematic RLNC or SRLNC based UWSN routing protocol has shown greater performance in terms of increased PDR and throughput, low latency, and energy consumption. This was achieved via the use of both RLNC and SRLNC.

The performance with a dynamical and computationally efficient channel model demonstrates that the proposed SRLNC based UWSN routing scheme has the potential to be significant for those scenarios in which large scale fading (primarily due to node movement or dislocation) and small scale fading (due to scattering and small wavelength deviation) occur frequently [15]. These scenarios include situations in which small scale fading can be caused by small wavelength deviations. It is strengthened to be utilised for large scale UWSNs where QoS focused mission essential data transmission and energy efficient communication is necessary. The suggested routing protocol with iterative buffer flush based SRLNC is what strengthens it. In the near future, the improvement scopes could make it possible for the suggested channel model to improve the spatial correlation between the acoustic routes. Enriching SRLNC data compression as well as encoding and decoding is another avenue that may be investigated to increase FEC's overall productivity.

Characterization Of SRLNC Transmission Model

The effectiveness of the SRLNC algorithm for the efficient transmission of data over a multipath channel was evaluated in terms of throughput while varying payload (samples per generation), packet loss rate, throughput with variation in link loss, and the requirement for redundant packets, among other metrics. The Galois field of dimension 8 is used in the SRLNC method that has been suggested, which enables it to be both time and computation efficient. In most cases, increasing the number of redundant packets allows for more precise decoding at the receiver; however, this comes at the expense of increased computational overheads. Taking this into consideration, SRLNC was evaluated using both one and two redundant packets for each generation, and comparable results were found. At first, it was assumed that there would be just one redundant packet, and the size of the generation was set at 10. In order to evaluate SRLNC taking into account real UWSN where there is the potential for continual fluctuations in the link quality, throughput was investigatedby altering the link loss probability. The Gilbert Elliot Model is used so that the link loss pattern may be produced. The throughput of SRLNC was measured under several conditions of link failure probability (0.0025, 0.005, 0.0075, 0.01, 0.0125, and 0.015) provides an indication of the SRLNC algorithm's throughput **(See Fig no4)**. The data packet loss that occurs as a result of the constant increase in payload is shown in the findings suggest that throughput shifts depending on the payload **(See Fig no5)**, but SRLNC maintains a sufficient level of production displays the fluctuation in throughput in accordance with the change in the link loss pattern. Taking into consideration the real setting, where there is a correlation between increasing link loss and decreasing throughput, the outcome confirms this correlation.

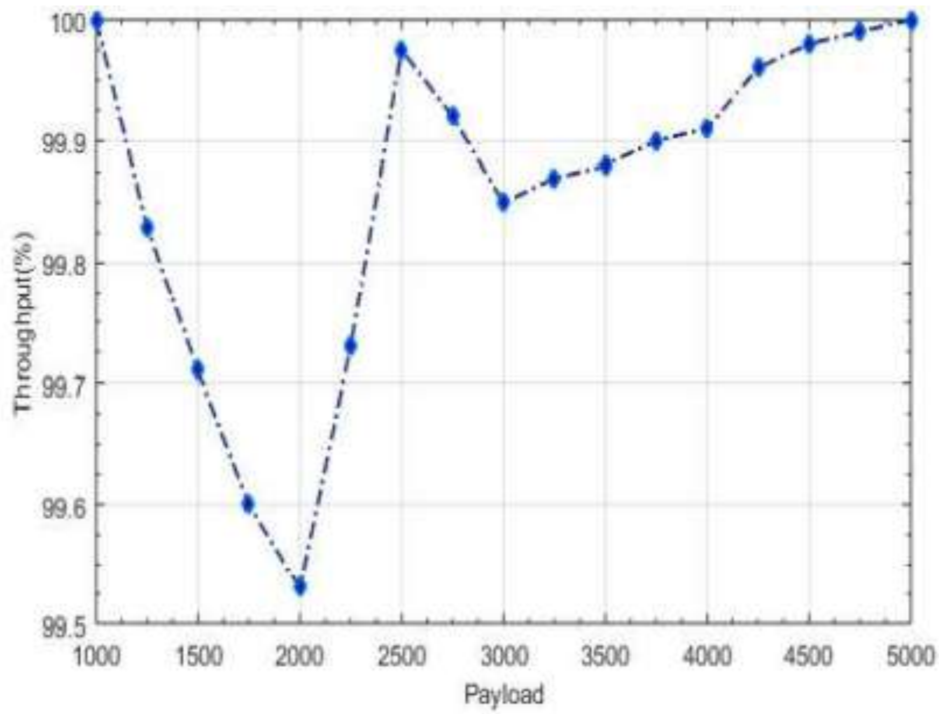

Fig no 4:- Effect of Payload on S-RLNC.

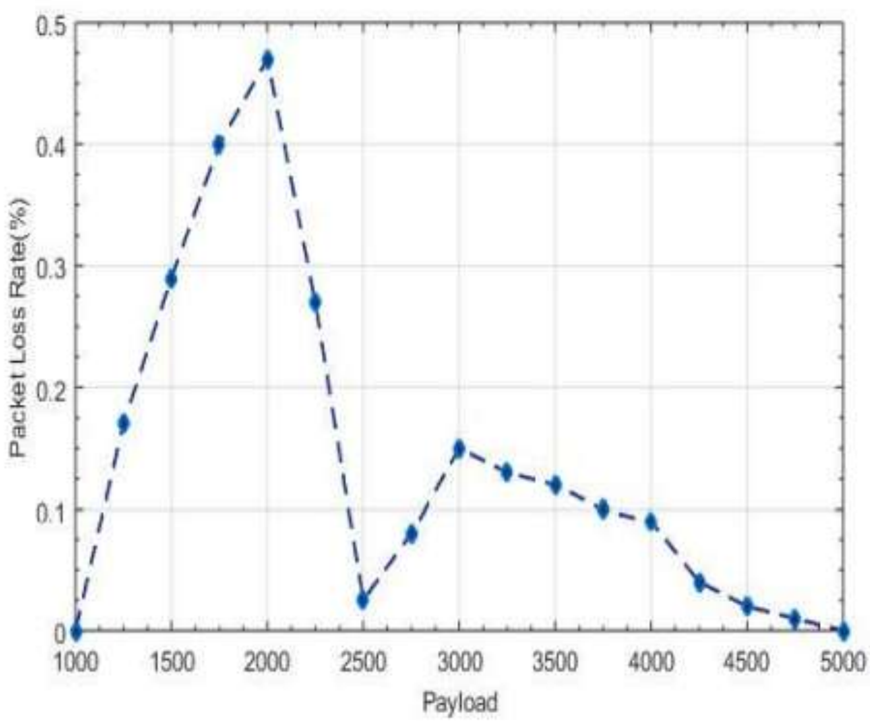

Fig no 5:- Effect of Payload on Data packet.

To enable optimal computationally efficient routing scheme over UWSNs, enriching FEC is vital. Maintaining minimum number of redundant packets to decode the data packets can be advantageous. It can reduce the computational overheads as well as unwanted bandwidth utilization. To estimate the minimum number of redundant packets per generation to have maximum data decoding at the receiver node, SRLNC **(See Fig no- 6,7)** is tested with

1 and 2 redundant packets per generation, where the proposed approach exhibited higher throughput with 2 redundant packets per generation.

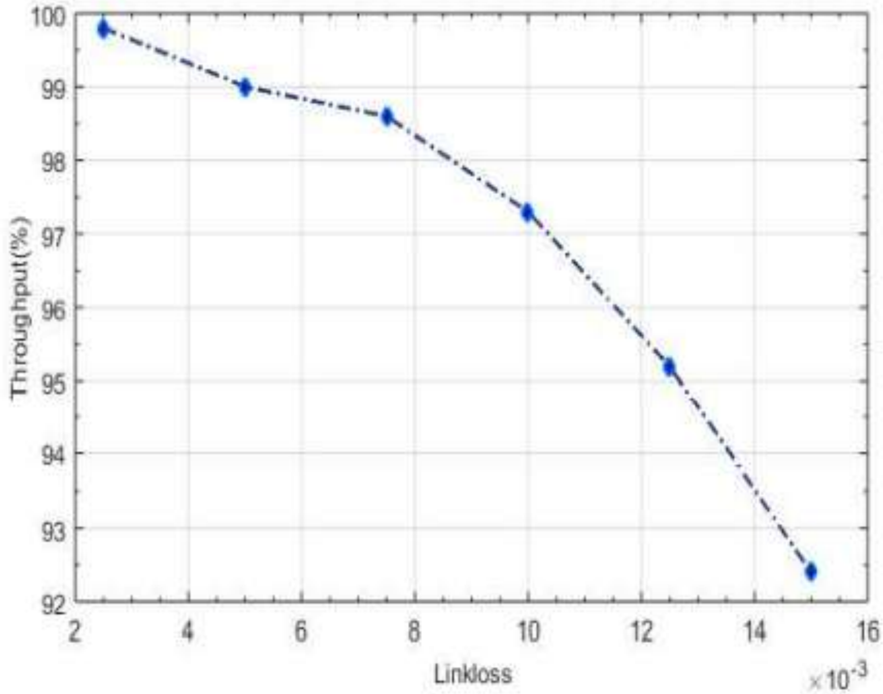

Fig no 6:- Links on S-RLNC.

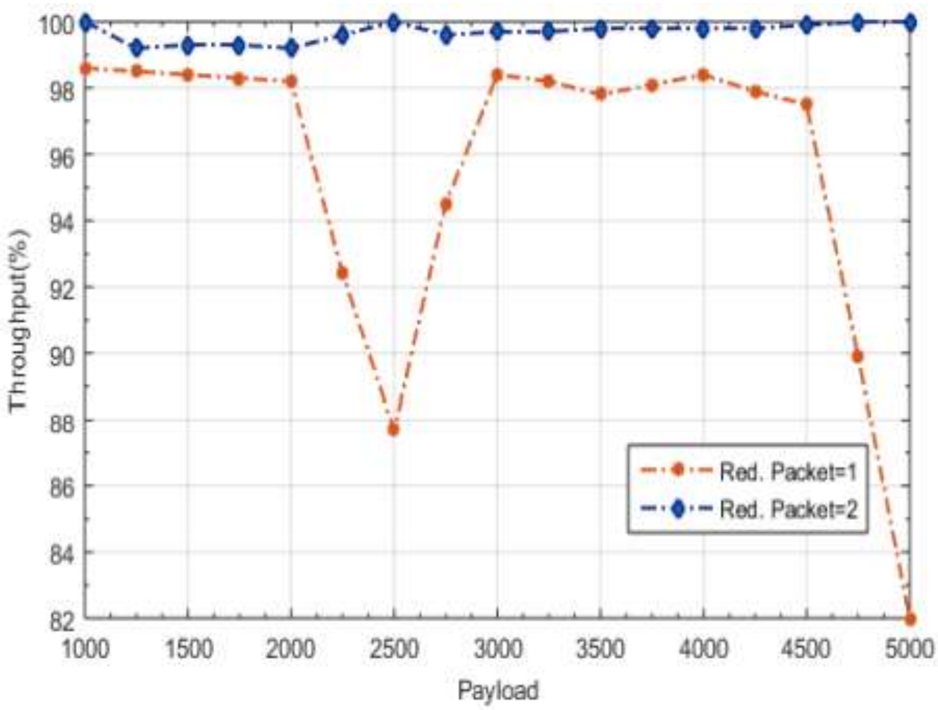

Fig no7:- No of packets on S-RLNC.

Table no1:- Accuracy Rate with Author Variation.

NOTEWORTHY CONTRIBUTIONS BY VARIOUS AUTHORS WITH ACCURACY RATE			
S.NO	**AUTHOR**	**PUBLISHED YEAR**	**ACCURACY RATE**

1.	V Poornachander	2022	**96.44%**
2.	Deepika Lokesh	2022	**94.69%**
3.	N.V. Uma Reddy	2022	**88.64%**
4.	Dinesh Anton	2022	**91.48%**
5.	Arun Kumar. K	2022	**95.78%**
6.	AC Sumathi	2022	**95.89%**
7.	Pedro Pinto	2022	**98.46%**
8.	Weidong Fang	2021	**98.46%**
9.	Chunsheng Zhu	2021	**84.48%**
10.	Zhang	2021	**70.98%**
11.	CS Reddy	2021	**72.78%**
12.	Dharmendra Chouhan	2021	**64.87%**
13.	Vinod Kumar	2020	**94.88%**
14.	Naga Raju	2020	**79.87%**
15.	Pasquale Pace	2019	**85.45%**

Conclusion and Future Scope:-

Because of the rapid increase in communication systems and the applications that are linked with them, academics and industry have been pressured to investigate and develop communication systems that are both more efficient and more resilient in order to satisfy important needs. The goal of academics and industry has always been to develop communication systems that are cheap in cost and energy consumption while also focusing on quality of service. As one looks about, one discovers that in the most recent few years, UWSN has emerged as one of the most dominant study areas to serve key acoustic communication goals. This can be determined by exploring around.

In recent years, there has been an uptick in interest in UWSNs as a result of the relevance of their significance towards the acoustic communication purposes to meet public, scientific, strategic, or military, and industrial (i.e., transportation) objectives. UWSNs have been instrumental in the monitoring of the ocean's environment, the exploration of gas deposits, the warning of tsunamis, assisted navigation, distributed tactical surveillance, mine reconnaissance, the collection of oceanographic data, the monitoring of oil spills, the monitoring of real-time warships, and the prevention of disasters. Despite the fact that it will inevitably become a communication system, UWSN has remained a study topic that is relatively underdeveloped. The majority of the factors contributing to it are its complicated functional or operational qualities, related time-varying dynamism, and expensive nature. Although UWSNs are often thought of as being very similar to WSNs, traditional routing techniques developed for WSNs cannot be used to UWSNs.

Energy consumption, signaling overheads, acoustic signal speed, propagation latency, restricted bandwidth, disruptions created owing to waves, noise, changing delays, and a high error rate likelihood are the primary challenges posed by UWSNs. Because of the time-varying topology, the routing in UWSNs is complicated, which causes the network to experience an excessive amount of link loss and data drop. As a consequence, it causes a significant amount of data to be retransmitted, an increase in latency, a significant amount of energy fatigue, and a cumulative decline in quality of service. As a direct result, it reduces the effectiveness of UWSNs.

References:-

[1] I. F. Akyildiz, D. Pompili, T. Melodia, Underwater acoustic sensor networks: research challenges, Ad Hoc Networks, Vol 3, No 3, May 2005, pp 257-279.
[2] Xie Peng, J. Cui, L. Lao, VBF: vector-based forwarding protocol for underwater sensor networks. Networking technologies, services, and protocols; performance of computer and communication networks; mobile and wireless communications systems. Springer Berlin Heidelberg, 2006, pp 1216- 1221.
[3] H. Luo, Z. Guo, K. Wu, F. Hong, Y. Feng, Energy Balanced Strategies for Maximizing the Lifetime of Sparsely Deployed Underwater Acoustic Sensor Networks, Sensors, Vol 9, No 9, 2009, pp 6626-6651.
[4] J. Li, P. Mohapatra, Analytical modeling and mitigation techniques for the energy hole problem in sensor networks, Pervasive and Mobile Computing, Vol 3, No 3, June 2007, pp 233-254.
[5] X. Yang, K. G. Ong, W. R. Dreschel, K. Zeng, C. S. Mungle, C. A. Grimes, Design of a Wireless Sensor Network for Long-term, In-situ Monitoring of an Aqueous Environment, Sensors, Vol 2, 2002, pp 455–472.

[6] B. Zhang, G. S. Sukhatme, and A. A. REQUICHA, Adaptive Sampling for Marine Microorganism Monitoring, in IEEE/RSJ International Conference on Intelligent Robots and Systems, (Sendai, Japan), Sept 2004.
[7] N. Soreide, C. Woody, and S. Holt, Overview of Ocean Based Buoys and rifters: Present Applications and Future Needs, in International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology (IIPS), Jan 2004.
[8] E. Cayirci, H. Tezcan, Y. Dogan, and V. Coskun, Wireless Sensor Networks or Underwater Surveillance Systems, Ad Hoc Networks (Elsevier), Vol 4, No 4, 2006, pp. 431–446.
[9] A. Quazi and W. Konrad, Underwater Acoustic Communication, IEEE ommunications Magazine, Mar. 1982, pp. 24–29. Page 178
[10] M. Stojanovic, Acoustic (Underwater) Communications, in Encyclopedia of elecommunications (PROAKIS, J. G., ed.), John Wiley and Sons, 2003.
[11] J. Proakis, J. Rice, E. Sozer, and M. Stojanovic, Shallow Water Acoustic Networks, in Encyclopedia of Telecommunications (PROAKIS, J. G., ed.), John Wiley and Sons, 2003.
[12] J. Proakis, E. Sozer, J. Rice, and M. Stojanovic, Shallow Water Acoustic networks, IEEE Communications Magazine, 2001, pp 114–119.
[13] J. A. Catipovic, Performance limitations in underwater acoustic telemetry, Oceanic Engineering, IEEE Journal of, 1990, pp 205 - 216.
[14] M. Stojanovic, J. A. Catipovic, and J. G. Proakis, Phase-coherent digital communications for underwater acoustic channels, Oceanic Engineering, IEEE Journal of, 1994, pp 100 - 111.
[15] M. Stojanovic, Underwater acoustic communications: Design considerations on the physical layer, Wireless on Demand Network Systems and Services, WONS. Fifth Annual Conference on. Garmisch-Partenkirchen: IEEE, 2008, pp 1-10.