EERCM: Energy Efficient and Reliable Communication Model for achieving QoS in Underwater Sensor Networks

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Abstract

Pervasive Underwater sensor networks (UWSNs) establish the communication in underwater for various applications such as natural exploration, surveillance, resource management etc. The Energy and Reliability are the prime factors to achieve effective communication through acoustic channel of these networks. Many researches attempted to improve these two factors through various methods in UWSNS. This paper proposes a communication model called EERCM that utilizes the advantage of Enhanced Network Coding based Energy Efficient and Reliable Multi-path routing to improve reliability and energy efficiency in UWSN. This model reduces the energy consumption of acoustic nodes to achieve Energy efficiency by adopting the hop-by-hop transmission method to form multi-path and each node maintains the paths information for local nodes to the next hop node without establishment of end-to-end paths and the neighbor nodes are diverged into groups during the hop node election and then the sensed information is sent to the next hop node that hop to lesser sink node. This redundant information provides reliable communication. This model is implemented and its performances are evaluated.

Keywords: Underwater sensor networks, EERCM, Multipath communication, Energy efficiency communication, Reliable Communication, Adaptive modem

1. Introduction

One third of the earth is covered by water. The underwater communication is necessary for various applications such as monitoring, surveillance, scheduling, underwater environment control, commercial exploitation, scientific exploration, attack protection and prevention etc. The self-organizing network of Mobile UWSNs supports these applications [1]. It uses acoustic communications, since radio does not work well in underwater environments due to low bandwidth, large latency and high error rate; underwater acoustic channels bring much defiance to the protocol design. Furthermore, the best parts of underwater nodes are mobile due to water currents [2, 3]. The major issues to be considered while implementing the UWSN are Energy efficiency, Memory capacity, Reliability, Data synchronization, Redundancy, Data security, Corrosion of sensors so on [4, 5, 6].

The recent development of underwater network systems moves one next step forward with respect to existing small-scale Underwater Acoustic Networks (UANs). UANs are associations of nodes that collect data using remote telemetry or assuming point-to-point

communications. This under water acoustic network differs from the underwater sensor networks in scalability, self-organization and localization [7].

1.1. Challenge in UWSN

The radio wave band frequency is restricted due to absorption in under water. The bandwidth of underwater acoustic channels working over several kilometers is about several tens of kbps, whereas short-range systems over several tens of meters can reach at hundreds of kbps. The path loss, noise, multipath, and Doppler spread affect the underwater acoustic communication channels. All these factors generate high bit-error and propagation delay.

1.1.1 Energy efficiency in UWSN: The major difficulty in deploying UWSN is energy efficiency because in case of terrestrial sensor networks battery failure can be identified easily and replaced easily but in case of underwater sensor networks frequent replacement of battery is tedious, hence the battery lifetime should be maintained for long period. In each sensor node for longtime communication the battery life should be maintained similar to the other nodes so that the sensor node will equally participated in the network. In our work we concentrate more on energy efficiency in acoustic sensor node because in order to inform the base station that the node is alive it has to frequently send the beacon signals to the surface base station but it will reduce the battery life of the sensor node. Hence, new energy harvesting methods need to be introduced to improve energy efficiency [5, 8, 9, 10].

1.1.2 Reliability and data security: Another two major issues are reliability and scalability of sensor nodes. A reliable network should be scalable network. Each network of sensor nodes should be capable of providing equal performance to all sensors which are present or going to be added in the network which is firmly known as scalability and also equal performance in sensor nodes will surely provide reliable data communication. Both reliability and scalability depend upon the performance of the routing protocol which is used in the network for routing purpose so that equal preference to each node in a network will improve the reliability and scalability of the network. Data security is another major issue. Data integrity is the most important phenomena in all types of communication. Some effective cryptographic schemes need to be employed to improve the data security [6, 11, 12, 13].

2. Related works

In recent research, various applications and challenges in underwater sensor networks are addressed.

2.1 Multipath FEC Approach

The major difficulties in under water sensor networks are energy consumption, path loss, propagation delay and high bit error rates. To overcome this, a Multiple-path FEC approach (M-FEC) based on Hamming Coding was proposed for improving reliability and energy efficiency in USNs in [14]. It uses multicast and hydro cast routing protocols for under water communication. The Hamming coding techniques are used to enhance our protocol [15] to secure the data and also the mechanism for designing energy efficient and adaptive acoustic modem is discussed in [14, 16]. By combining these two ideas we designed and analyzed a novel communication framework for underwater sensor networks [17, 18]. However, low probability of nodes affects reliable number of multiple paths that consume more energy. Hop by hop retransmission is not allowed and acoustic channels will become weak due to multipath.

2.2 Optimization of Energy Efficient Transmission

Due to the singular channel characteristics underwater communication is a challenging one. Various protocols used in terrestrial environment are not suitable for the underwater environment [19]. The UWSN is provided with energy limited nodes that can't afford much energy because of small batteries and the power supply in UWSN cannot be replenished

The issue of energy efficient transmission is analyzed and discussed clearly in [20], by using new optimized theory called Karush-Kuhn-Tucker conditions (KKT conditions). It is an approximate solution for attaining better performance metrics such as better reliability in data communication and less communication delay. The energy consumption mainly depends upon the reliability and communication delay [20].

2.3 Energy-Efficient Routing Protocol

For the operation of energy limited sensor nodes MAC protocol designing is tedious. A scalable and long lasting MAC protocol is designed in [21] by modifying protocols like ALOHA, MACAW and MACA. This protocol saves more energy than the other existing protocols (it wastes only 3%) [21]. For future underwater sensor networks MAC protocol is the best base protocol to deploy the sensor nodes. Other routing protocols like delay insensitive and delay sensitive protocols are also combined with our routing protocol [22]. Reactive protocols are not suitable for underwater acoustic sensor networks. For delay sensitive and delay insensitive applications distributed routing algorithms were introduced in [22] and many routing protocols such as SBRB, FSBRB and DBRB were proposed by researchers as seen in [23].

2.4 Buffer Less Core Network

Scaled core networks are used to cater the rapidly growing internet traffic [24]. Using optical networks large amount of data is transmitted efficiently [25] with the speed range of terabits-per-second. This core network is used to transmit and store data in under water too. A brief study about the FEC approach is discussed in [10]. In this approach, short lived TCP and long lived TCP are relatively mixed together. This enables buffer less core networks. The core networks require high maintenance cost and they are less reliable [26].

2.5 Adaptive Modulation

In the acoustic sensor node, modem is responsible for data transmission and data reception, generally modem modulates and demodulates the signals which are transmitted and received respectively. Adaptive modem is used to maintain efficient network topology [27].

Adaptive modem is capable of modulating and demodulating with all kinds of modulation and demodulation schemes such as ASK, GMSK, MSK, PSK, QPSK, FSK, QFSK. Adaptive modulation includes symbol synchronization, equalization, and normalization. This adaptive modem feature enhances the network architecture for under water communication [28, 29].

2.6 Pressure Routing

Pressure routing protocols are introduced to enhance the speed of the routing protocol. Normalized and advanced routing techniques were used in [30] Hydro cast, a

hydraulic pressure based cast routing protocols that work based on the measured pressure level to cast data to the base station [31, 32] A novel routing mechanism is introduced in [30] which reduces greedy routing technology and also normalizes the network topology which make acoustic nodes to accept the pressure factors in deep sea [30].

2.7 Major Issues in UWSN:

The radio wave band frequency is restricted in under water due to absorption. The bandwidth of underwater acoustic channels working over several kilometers is about several tens of kbps, whereas short-range systems over several tens of meters can reach the speed of hundreds of kbps. The path loss, noise, multipath, and Doppler spread affect the underwater acoustic communication channels. All these factors generate significant bit-error and propagation delay [33].

In underwater acoustic networks, sensor localization is not desired because nodes are usually fixed. In mobile underwater sensor networks, localization is required because the majority of the sensors are mobile with the current. Detecting the locations of mobile sensors in aquatic environment or three dimensional environments is very tedious. However, the limited communication capabilities of acoustic channels and the need for improving the localization accuracy must be considered [34, 35].

4. Data Communication Model EERCM

EERCM is designed with braided model where each node of the main paths has one backup node. Due to the impact of using multiple hops in underwater wireless sensor networks, node-disjoint paths may be frequently long, and therefore use significantly more energy. In disjoint multipath, some nodes on main routing paths may be used for many times, which leads to more energy consumption. Braided multipath increases implicitly the number of paths. All the nodes on main paths may be used equally by turns, which leads to less energy consumption and makes overall network load balancing. In this protocol the clustering hierarchy technology is combined with distributed routing technology. Distributed under water routing protocols with MAC technology is used to build this routing protocol called EERCM.

4.1 Algorithm

% Finding Shortest path to reach the Sink node, Path setup & Data Transmission%

Step 1. $S_N \rightarrow$ Flood (Req.)   // Sending to all neighbors
                                          // S_N – Source Node
Step 2. $I_N \rightarrow$ Update (P_I)   // Updating path information
                                          // P_I – Path Information
                                          // I_N – Intermediate node
Step 3. $I_N \rightarrow$ Update (H_C)   // Updating hop count to identify shortest path
                                          // H_C – Hop count
Step 4. $C_H \rightarrow$ Record (H_C)   // Records the path information periodically
Step 5. Repeat (1,2,3)   // Until reach the destination node
Step 6. $S_K \rightarrow$ Reply(Rep.)   // Reply the Rep. packet
                                          // S_K – Sink node
Step 7. $S_N \rightarrow$ Collect(P_I)   // Collect the path information from the cluster header

Step 8. S_N → Compute (H_C, P_I)   // Compute the shortest path hop count
Step 9. S_N→ Generate(R_N)   // Generating the random number
                                  // R_N – Random number
Step 10. S_N→Encode(D,R_N)   // Encoded data ED
                                  // D– Data
Step 11. S_N→Send (I_N)   // Send
Step 12. I_N → Forwarded (I_N)   // Until reach the destination node
Step 13. D_N→ Receive (E_D)   // Receive the encoded data
                                  // D_N – Destination node
Step 14. D_N→ Decode (E_D,R_N)   // Decode the data D
                                  // E_D – Encoded data

4.2 Implementation strategy

The EERCM Communication provides reliable transmission in underwater wireless sensor network with enhanced energy consumption methodology, load balance and data redistribution strategy by the optimization techniques. The objective function is the total energy consumption for transmitting and receiving packets from the edge cluster to the sink. It uses a set of sub-optimal paths occasionally to increase the lifetime of the network. The paths were selected by using probability function, which mutually depends on the energy consumption of each routing path. The approach is concerned with Network survivability. This approach deals with the minimum energy path all the time will destroy the energy of nodes on that routing path. The whole network lifetime is increased by using one of the multiple paths with a certain probability. The protocol assumes that every node is addressable with a network coding-based addressing which includes the location (longitude and latitude) and the basic types of the nodes.

4.3 Simulation Results and Comparison

The NS-2 network simulator is used with the modifying   MAODV protocol to run the experiment in order to identify the performance of the communication model in terms of spreading threshold and location error is compared with prediction and without prediction parameters.
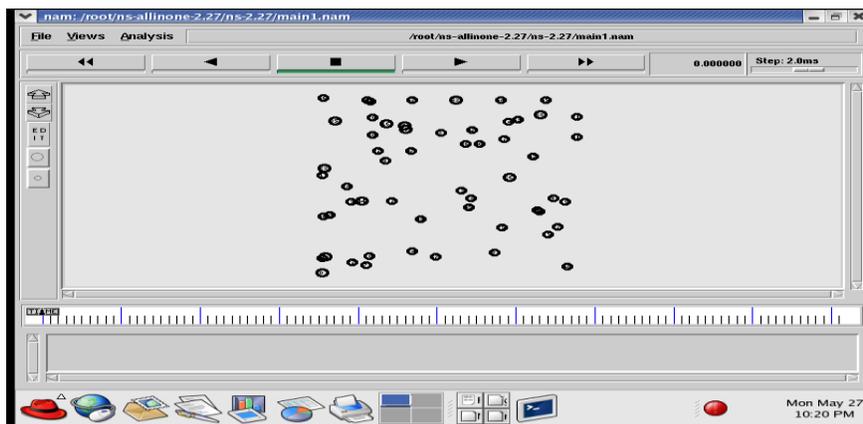

Figure 1. Initial Positions of the Nodes

It is observed that this communication model improves the packet delivery ratio, improves data transmission reliability and saves the energy consumption. The performance of reliability, redundancy and normalized energy consumption is analyzed. Figure 1 shows the initial position of the sensor nodes. The scenario where the source node initiates the detection process is shown in Figure 2. After detection the source node and the neighbor nodes were identified by the beaconing process as shown in Figure 3. Figure 4 shows the enhanced communication which is processed based on the Data Communication Model EERCM. Each every information is communicated with base station effectively as shown in Figure 5.
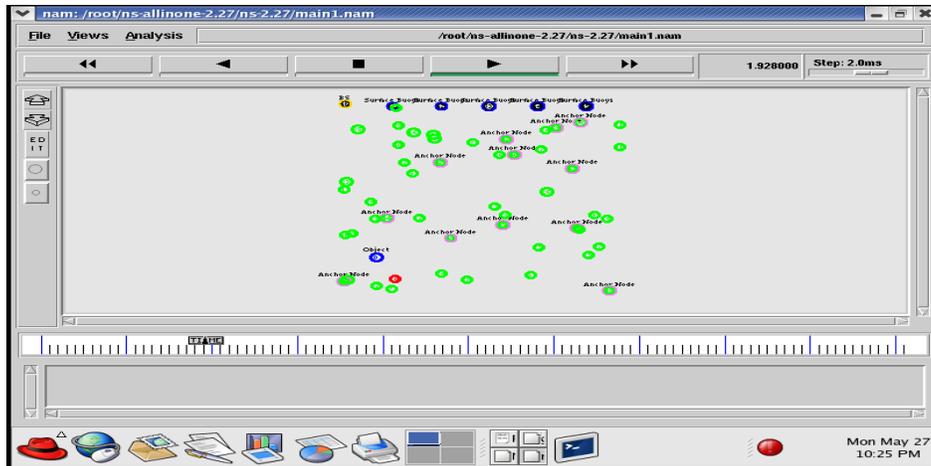

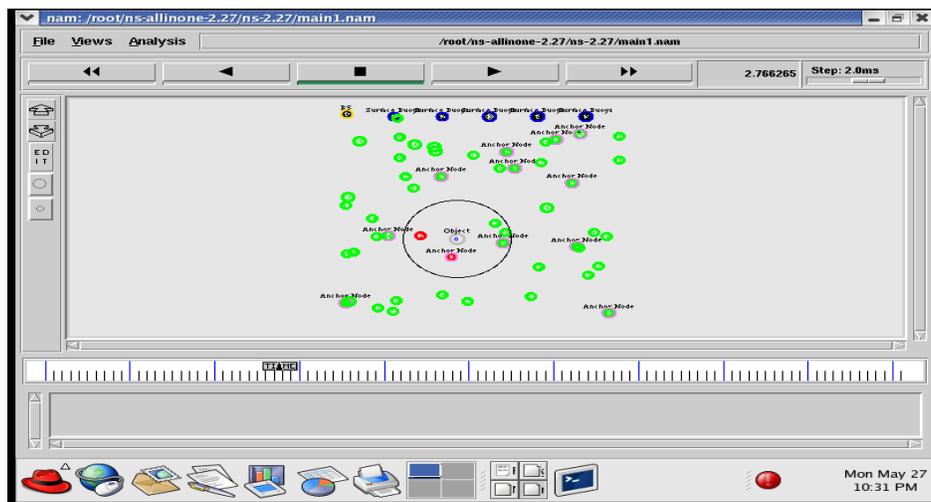**Figure 2. Source Node Initiate Detection**
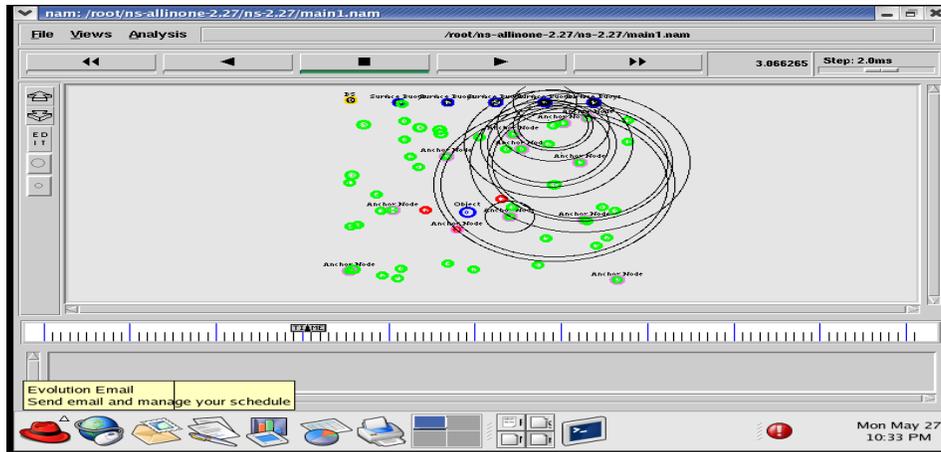

Figure 3. Beaconing Started
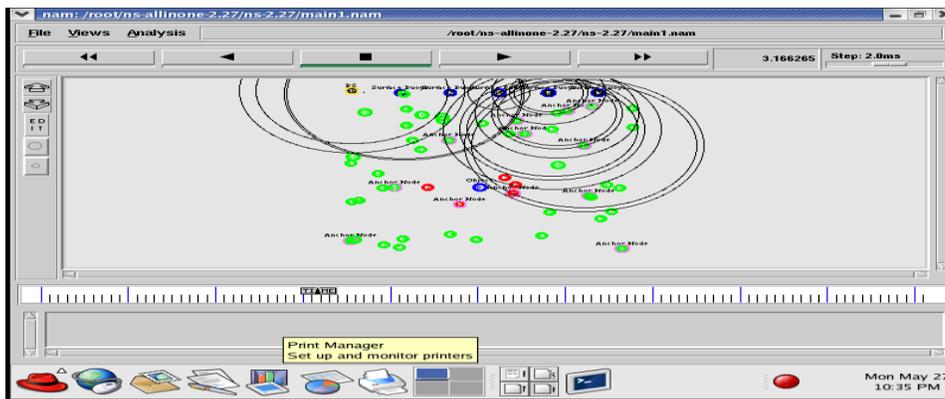
Figure 4. Protocol Implementation

Figure 5. Communicating With Base Station

5. Conclusions and Future Work

In this paper, EERCM model is implemented. The enhanced communication framework for effective communication in underwater sensor networks is analyzed and compared with the existing system. This communication model shows gradual improvement in both energy efficiency and reliability of the underwater sensor networks.

This model enhances the reliability of sensor network greatly and reduces the transmission path number. This protocol follows network coding rule for selecting the appropriate field space, so that the sink node can recover the original packets from the packets which have chaotic order or partial information loss. The advantage of proposed routing protocol is path reduction and network fault tolerance.

In future the sensor nodes can be deployed in under water environment with seabed experimental setup and the collected information can be converted into file packets and it can be stored in Hadoop file system in order to deploy the underwater sensor network in cloud architecture. Then the processed information will be updated automatically and distributed in cloud environment for adopting many pervasive applications such as surveillance system in navy field and climatic disaster monitoring system (TSUNAMI monitoring system).

References

[1] J. -H. Cui, *et al.*, "The challenges of building mobile underwater wireless networks for aquatic applications", Network, IEEE, vol. 20, no. 3, **(2006)**, pp. 12-18.

[2] I. F. Akyildiz, D. Pompili and T. Melodia, "Underwater acoustic sensor networks: research challenges", Ad hoc networks, vol. 3, no. 3, **(2005)**, pp. 257-279.

[3] E. M. Sozer, M. Stojanovic and J. G. Proakis, "Underwater acoustic networks", IEEE Journal of Oceanic Engineering, vol. 25, no. 1, **(2000)**, pp. 72-83.

[4] J. Lopez, R. Roman and C. Alcaraz, "Analysis of security threats, requirements, technologies and standards in wireless sensor networks", Foundations of Security Analysis and Design V. Springer Berlin Heidelberg, **(2009)**, pp. 289-338.

[5] E. J. Leavline and D. A. A. G. Singh, "MREHS: Implementaion of MPPT-based RF Energy Harvesting System for Electrical Appliances", Frontiers in Science, vol. 2, no. 6, **(2012)**, pp. 187-191.

[6] D. A. A. G. Singh and E. J. Leavline, "IATARPA: Implementation of anonymity threat avoidance routing protocol architecture for MANET", Third International Conference on Advanced Computing (ICoAC) 2011, IEEE, **(2011)**.

[7] J. -H. Cui, *et al.*, "Challenges: building scalable and distributed Underwater Wireless Sensor Networks (UWSNs) for aquatic applications", Channels, **(2005)**, pp. 1-17.

[8] A. Aziz, *et al.*, "A survey on distributed topology control techniques for extending the lifetime of battery powered wireless sensor networks", **(2011)**, pp. 1-24.

[9] J. Heo, J. Hong and Y. Cho, "EARQ: Energy aware routing for real-time and reliable communication in wireless industrial sensor networks", IEEE Transactions on Industrial Informatics, vol. 5, no. 1, **(2009)**, pp. 3-11.

[10] V. C. Gungor and G. P. Hancke, "Industrial wireless sensor networks: Challenges, design principles, and technical approaches", IEEE Transactions on Industrial Electronics, vol. 56, no. 10, **(2009)**, pp. 4258-4265.

[11] R. Rajagopalan and P. K. Varshney, "Data aggregation techniques in sensor networks: A survey", **(2006)**.

[12] J. N. Al-Karaki and A. E. Kamal, "Routing techniques in wireless sensor networks: a survey", Wireless Communications, IEEE, vol. 11, no. 6, **(2004)**, pp. 6-28.

[13] D. A. A. G. Singh and E. J. Leavline, "Data Mining In Network Security - Techniques & Tools: A Research Perspective", Journal of Theoretical and Applied Information Technology, vol. 57, **(2013)**.

[14] J. Xu, K. Li and G. Min, "Reliable and energy-efficient multipath communications in underwater sensor networks", IEEE Transactions on Parallel and Distributed Systems, vol. 23, no. 7, **(2012)**, pp. 1326-1335.

[15] "Network coding rules", http://www.nhcerm.com/, **(2011)**.

[16] M. Stojanovic, "Optimization of a data link protocol for an underwater acoustic channel", Oceans 2005-Europe, vol. 1, IEEE, **(2005)**.

[17] D. Pompili, T. Melodia and I. F. Akyildiz, "A CDMA-based medium access control for underwater acoustic sensor networks", IEEE Transactions on Wireless Communications, vol. 8, no. 4, **(2009)**, pp. 1899-1909.

[18] "Underwater Simulation Module for Network Simulator 2", http://www.nbqadri.com/ns2/, **(2009)**.

[19] Z. Zhou, et al., "Efficient multipath communication for time-critical applications in underwater acoustic sensor networks", IEEE/ACM Transactions on Networking, vol. 19, no. 1, **(2011)**, pp. 28-41.

[20] H. Yang, *et al.*, "Optimization of energy efficient transmission in underwater sensor networks", Global Telecommunications Conference 2009, GLOBECOM 2009, IEEE, **(2009)**.

[21] V. Rodoplu and M. K. Park, "An energy-efficient MAC protocol for underwater wireless acoustic networks", OCEANS 2005, Proceedings of MTS/IEEE, IEEE, **(2005)**.

[22] D. Pompili, T. Melodia and I. F. Akyildiz, "Routing algorithms for delay-insensitive and delay-sensitive applications in underwater sensor networks", Proceedings of the 12th annual international conference on Mobile computing and networking, ACM, **(2006)**.

[23] D. Pompili and I. Akyildiz, "Overview of networking protocols for underwater wireless communications", Communications Magazine, IEEE, vol. 47, no. 1, **(2009)**, pp. 97-102.

[24] P. Rost and G. Fettweis, "On the transmission-computation-energy tradeoff in wireless and fixed networks", GLOBECOM Workshops (GC Wkshps) 2010 IEEE, **(2010)**.

[25] E. J. Leavline and D. A. A. G. Singh, "Hardware Implementation of LZMA Data Compression Algorithm", **(2013)**.

[26] A. Kuzmanovic and E. W. Knightly, "Low-rate TCP-targeted denial of service attacks: the shrew vs. the mice and elephants", Proceedings of the 2003 conference on Applications, technologies, architectures, and protocols for computer communications, ACM, **(2003)**.

[27] L. Wu, *et al.*, "Designing an adaptive acoustic modem for underwater sensor networks", Embedded Systems Letters, IEEE, vol. 4, no. 1, **(2012)**, pp. 1-4.

[28] M. K. Simon and M. -S. Alouini, "A unified approach to the performance analysis of digital communication over generalized fading channels", Proceedings of the IEEE, vol. 86, no. 9, **(1998)**, pp. 1860-1877.

[29] R. Ma and S. Cheng, "Hamming coding for multiple sources", IEEE International Symposium on Information Theory Proceedings (ISIT) 2010, IEEE, **(2010)**.

[30] U. Lee, *et al.*, "Pressure routing for underwater sensor networks", INFOCOM 2010 Proceedings IEEE, **(2010)**.

[31] R. Wattenhofer, *et al.*, "Distributed topology control for power efficient operation in multihop wireless ad hoc networks", INFOCOM 2001, Twentieth Annual Joint Conference of the IEEE Computer and Communications Societies, Proceedings IEEE, vol. 3, **(2001)**.

[32] K. Akkaya and M. Younis, "A survey on routing protocols for wireless sensor networks", Ad hoc networks, vol. 3, no. 3, **(2005)**, pp. 325-349.

[33] J. Partan, J. Kurose and B. N. Levine, "A survey of practical issues in underwater networks", ACM SIGMOBILE Mobile Computing and Communications Review, vol. 11, no. 4, **(2007)**, pp. 23-33.

[34] P. Casari and A. F. Harris, "Energy-efficient reliable broadcast in underwater acoustic networks", Proceedings of the second workshop on underwater networks, ACM, **(2007)**.

[35] L. Wang, Y. Yang and W. Zhao, "Network coding-based multipath routing for energy efficiency in wireless sensor networks", EURASIP Journal on Wireless Communications and Networking, vol. 2012, no. 1, **(2012)**, pp. 1-15.