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Performance Enhancement of Oil pipeline Monitoring for a Simulated Underwater Wireless Sensor Network

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Abstract

In the last two decades, underwater acoustic sensor networks have begun to be used for commercial and non-commercial purposes. In this paper, the focus will be on improving the monitoring performance system of oil pipelines. Linear wireless sensor networks are a model of underwater applications for which many solutions have been developed through several research studies in previous years for data collection research. In underwater environments, there are certain inherent limitations, like large propagation delays, high error rate, limited bandwidth capacity, and communication with short-range. Many deployment algorithms and routing algorithms have been used in this field. In this work a new hierarchical network model proposed with improvement to Smart Redirect or Jump algorithm (SRJ). This improved algorithm is used in an underwater linear wireless sensor network for data transfer to reduce the complexity in routing algorithm for relay nodes which boost delay in communication. This work is implemented using OMNeT++ and MATLAB based on their integration. The results obtained based on throughput, energy consumption, and end to the end delay.

Keywords: Underwater Wireless Sensor Network (UWSN), Improved Smart Redirect or Jump Algorithm (ISRJ), Oil Pipeline Monitoring.

تحسين أداء مراقبة الانابيب النفطية بأستخدام شبكات المستشعرات اللاسلكية تحت الماء

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الخلاصة:

في العقدين الأخيرين ، بدأت شبكات الاستشعار الصوتية تحت الماء تستخدم للأغراض التجارية وغير التجارية. في هذه الورقة ، سيتم التركيز على تحسين نظام مراقبة الأداء لأنابيب النفط. شبكات الاستشعار اللاسلكية الخطية هي نموذج للتطبيقات تحت الماء التي تم تطوير العديد من الحلول لها من خلال العديد من الدراسات البحثية في السنوات السابقة لأبحاث جمع البيانات. في البيئات المغمورة بالمياه ، هناك بعض القيود المتأصلة ، مثل تأخر الانتشار الكبير ، ومعدل الخطأ العالي ، وقدرة النطاق الترددي المحدودة ، والتواصل مع المدى القصير. تم استخدام العديد من خوارزميات النشر وخوارزميات التوجيه في هذا المجال. في هذا العمل ، تم اقتراح نموذج شبكة هرمي جديد مع تحسين الخوارزمية الذكية لأعادة التوجيه أو القفز(SRJ). يتم استخدام هذه الخوارزمية المحسنة في شبكة استشعار لاسلكية خطية تحت الماء لنقل البيانات و لتقليل التعقيد في خوارزمية التوجيه. يتم تنفيذ هذا العمل باستخدام OMNeT ++ و MATLAB اعتمادا على تكاملها. النتائج التي تم الحصول عليها على أساس الإنتاجية ، واستهلاك الطاقة ، وتأخير الشبكة

1. Introduction

The continuous progress in communications and integrated systems has led to significant development in the field of industrial tasks and greater control. The great scientific advances in information and communication technology, the improvement of microelectromechanical systems, industrial intelligence, and process control have improved all areas of industrial practices related to oil processing. Underwater acoustic wireless sensor networks (UAWSN) are used in different applications such as data collection, coastal monitoring, earthquake forecasting, oil pipeline monitoring, and pollution detection. The nature of difficult underwater environments imposes various constraints, most notably high bit error, propagation delay, low bandwidth, and short-range communications [1]. All of these limitations reduce the performance and lifetime of sensor nodes, therefore require the deployment of nodes in different ways. Deployment strategies play an important role in the success of underwater sensor networks because they need safeguards to address key objectives such as improving network life and full connectivity. Besides, deployment strategies should address the key factors associated with the node or network, such as delay, throughput, packet reception rate, transmission and reception capacity, and energy consumption. The linear nature of oil pipelines requires the establishment of a linear sensor network along the pipeline for monitoring. Underwater linear networks characterized by limited routing protocols due to the linear nature of the network thus, the simple algorithm is required to reduce the energy consumption due to the harsh environment. The Advantages of the SRJ algorithm are through combining the jumping and redirect strategies, SRJ algorithm provides the ability to overcome failure nodes. This algorithm depends on the number of hops to determine the direction of packets and thus reduces the energy needed to send packets. There are disadvantages in this algorithm, including the dynamic range of transmission, the complexity of the routing table for relay nodes, and the jumping of failure nodes, which is expensive in this environment [2]. This work proposes a new hierarchical network model by adding a new layer of nodes in the network model with improvements to the SRJ algorithm to increase the reliability of wireless sensor networks in an underwater environment. Fig (1) shows some of the deployment schemes for an underwater linear sensor network.

Figure (1): Deployment schemes for underwater linear sensor networks.

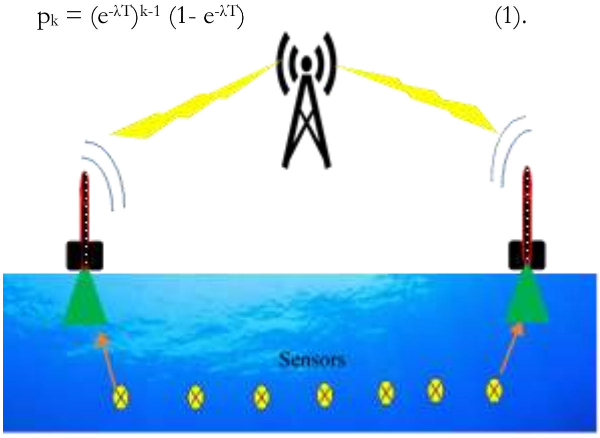
2. Background and related work

In previous years, Numerous research studies were conducted on non-linear sensor networks [8], [9], [10]and on linear sensor networks[11], [12], [13]. in [5], Provides a comprehensive analysis of the integration of wiring with radio and acoustic signals to establish a reliable network, meet underwater challenges, compare network connectivity, network power supply continuity, and physical network security. The jumping or redirect protocol (SRJ) is proposed and compared with the previous methods to increase the reliability of the underwater sensor network. In [14], The enhanced algorithm for the deployment of a linear underwater wireless sensor network (EULWSND) is presented for improved durability in the collection of underwater linear sensor data deployment strategies were discussed and compared with the proposed strategy taking into consideration the linearity of the underwater pipeline and the heterogeneity of sensor nodes.

3. Underwater wireless sensor network

Communications between underwater nodes are limited as a result of the harsh environment, and due to the factors of this environment, the nodes suffer from failure which leads to the interruption of parts of the network or the whole network, especially if these nodes are close to the sink as shown in fig (2). For each node over the oil pipeline, the supposed failure rate is equal to (λ) [3], forwarding time for all nodes is (T) and (k) represents a packet size, therefore, in this case, the probability of failure is:

$$p_k = (e^{-\lambda T})^{k-1} (1- e^{-\lambda T}) \quad (1).$$



Figure(2): Underwater linear wireless sensor network.

The energy consumption (E_{tx}) between two nodes in underwater for data transmission is determined by Equation (2):

$$E_{tx}=S \times T_{tx} \times K, S=2\pi \times H \times I \quad (2).$$

I: The intensity of the acoustic signal.
S: The transmission power (dBm).
H: The depth of water.
T_{tx}: Transmission time.

Based on equations (1) and (2) the probability of failure can be calculated. The probability of failure for the nodes close to the sink increase due to the traffic load, therefore, increasing the energy consumption depending on the factors mentioned.

4. Energy consumption and end-to-end delay

The process of energy consumption of the UASNs depends on the placement of these UASNs and trade-off with the end to end delay. For the nodes system, a sufficient number of underwater nodes should be deployed to fully cover the oil pipeline because these nodes are connected by acoustic waves and all these nodes are subject to the same environmental standards [4]. The source signal level (SSL) which calculated during send packet from the source node to the gateway can be represented by equation (3):

$$SSL = ANL + SNR + TL - DI \quad (3).$$

Where:
ANL: ambient noise level.
SNR: signal-to-noise ratio.
TL: transmission loss.
DI: directivity index.
The transmission loss can be calculated by equation (4):

$$TL = 10\log d + ACd\ 10^{3} + TA \quad (4).$$

Where
d: the distance between the sender and receiver.
AC: the absorption coefficient.
TA: the transmission anomaly.

For the transmission power TP can be represented by equation (6):

$$SIT = 10^{ssl/10} \times 0.67 \times 10^{-18} \quad (5).$$

$$TP = 2\pi \times d \times h \times SIT \quad (6).$$

Where

SIT**:** The intensity of an underwater signal.

h: The water depth in m.

The end-to-end delay (EED) in UASN can be calculated by equation (7):

$$EED = N\,(t_{prop(i,\, i+1)} + t_{pkt}) \quad (7).$$

Where $t_{prop(i,\, i+1)}$ represent propagation time between sensor nodes i and $i+1$ in underwater, t_{pkt} represent time to transmit a data packet, and N is the number of hops.

5. Smart Redirect or Jump Algorithm (SRJ)

A hierarchical network model of the linear structure sensor network consists of three types of heterogeneous nodes, each node has a task represented by data collection, routing, and dissemination for transmitting packets. Fig (3) shows heterogeneous nodes in multilayer, represent the relationship among these nodes.

- Basic Sensing Nodes (BSNs):

This node is deployed along the oil pipeline to detect the corroding and leakage that occurs in the pipeline. These sensors send data to the relay node in the next layer of the network structure.

- Data Relay Nodes (DRNs):

The role of these nodes is to collect data from the (BSNs) then select the shortest route and forward data to the DDN to reduce the energy consumption.

- Data Dissemination Nodes (DDNs):

These nodes collect data and direct to the sink which sends this data to Network Control Center (NCC), therefore this node has a higher communication capability. Based on DDNs deployment, it possible to divided linear networks into multi segments.

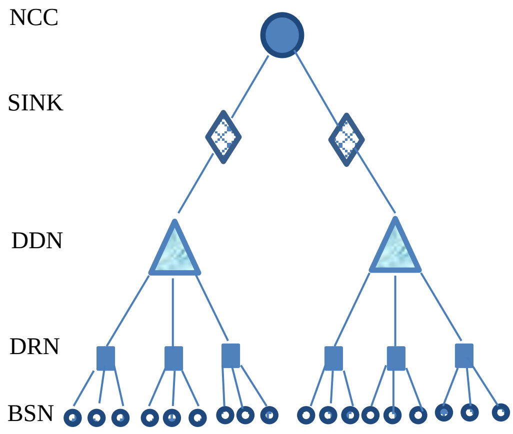
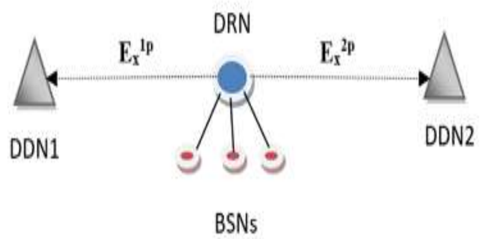


Figure (3): multilayer nodes for the Smart Redirect or Jump Algorithm (SRJ).

6. Messages Relaying by (DRN)

Relay nodes forward data based on (jump or redirect strategies) therefore, each node has a primary parent (DDN1) and secondary parent (DDN2). BSNs send a packet to the relay node (DRN) where this node forward data to its neighbor in the default direction. If the neighbor node is not active, the jump strategy is used to reach the other nodes. If the jump strategy not succeeds, in this case, the redirect strategy is used. Each relay node contains the information of the neighboring nodes and the operational status of each node. The direction of sending packets depends on the energy-consumption (Ex) in both directions [4]. If Ex1p < Ex2p, the packet direction is towards to the primary parent (DDN1), by contrast, the direction of the packet will be towards the secondary parent(DDN2).Figure (4) represents the direction of the packet based on energy-consumption. The energy-consuming in both directions based on the number of hops in each direction thus, each node must calculate the energy consumed to choose the shorter route, therefore, increase packets that are delivered to the parent node.

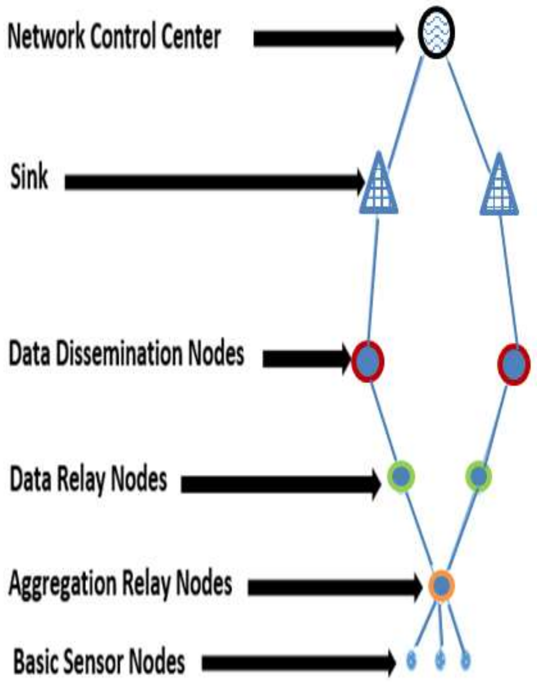


Figure(4): Packets direction based on the number of hops

7. Proposed methodology

Underwater networks depend on the way of nodes deployment to ensure communication between them.

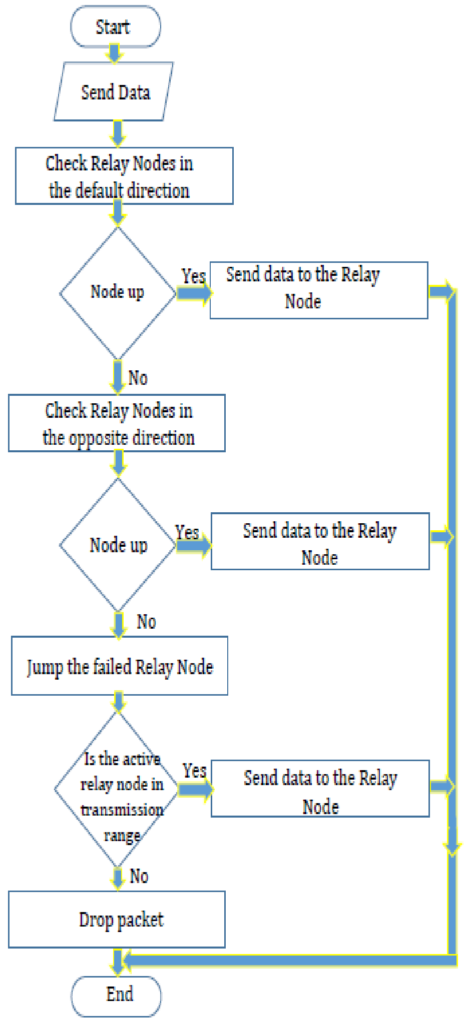
In the proposed approach, add a node associated with the sensors that were associated with the relay nodes in the previous structure. This node collects data and sends it to the relay nodes depending on the status of these nodes and not on the number of hops in both directions. This node is called Aggregation Relay Node (ARN) and it does not transmit other data, as in relay nodes, but only data from the associated sensors. The new hierarchical network model is shown in Fig (5).



Figure(5): Hierarchical representation of the new network model.

The new structure is based on the proposed algorithm applied in (ARN). This algorithm called improved SRJ algorithm (ISRJ) which relies on the transmission of packets to the active node within the transmission range in the default direction. If a node fails, the packets are sent to the active node within the transmission range in the opposite direction. In case of failure to reach both directions, the transmission range is increased to reach the relay node. If there is no relay node is reached, in this case, the packets are dropped. The routing of data received from the sensors by the ARN node reduces overwork on relay nodes and thus, saves the energy consumed with an acceptable end-to-end delay. If the relay node fails, it does not affect the entire network, but only on the sensors associated with it, unlike the old case where the failure of the relay node affects the entire network where the sensors associated with the node are lost and the transmission range for adjacent nodes exceeds the failed node.

In the new hierarchical network model, the failure of the relay node does not necessarily mean that the sensors are out of service because the (ARN) node is connected to other relay nodes in both directions. Also, the sensors do not need to search for a new node to connect to the data transfer as it is in the old structure in case of failure of the relay node and thus save energy consumed. Besides, adding ARN nodes reduces the overhead communication on relay nodes. Fig(6) represents the improved SRJ algorithm implemented in (ARN) node.



Figure(6): Improvement SRJ algorithm for ARNs

Depending on the state of the relay nodes on both sides of the ARN node, the packets are routed and the change of direction is prioritized before the jumping process to reduce the energy consumed

8. Simulation scenarios and result

In this section, the proposed network model is simulated with the proposed algorithm to monitor the oil pipeline using two software tools Omnit++ and Matlab. The programming in the OMNeT++ simulator is dependent on the C/C++ language and NED (NEtwork Description). Network and link layers are protocol layers simulated using Omnet ++. The third protocol layer is the physical layer which is simulated as a Matlab function Integrated into Omnet++. The physical layer can be simulated as a modulator, a channel, and a demodulator [5]. Table -1- represent the simulation parameters.

Table1: simulation parameters.

Parameters	Value
Pipeline length	1000 m
Type of nodes	BSN,ARN,DRN,DDN
Total Number of DDN	2 nodes
Total Number of DRN	10 nodes
Total Number of ARN	5 nodes
Total Number of BSN per ARN	4 nodes
Ranges of nodes	50,75,100, m
Bandwidth	20Khz
Packet size	64byte
Hello Packet	12 byte
Propagation model	Underwater propagation
Packet protocol	UDP
Number of Sinks	2
simulation time	1000s

The deployment scheme of the nodes to a 1,000-meter oil pipeline includes the deployment of sensors from the point 25 meters, and the sensors are deployed every 50 meters. For the DRN nodes, the deployment scheme starts from the point 50 meters and are deployed every 100 meters. ARN nodes are deployed starting from the point 100 meters and deployed every 200 meters. As for the DRN nodes, the deployment scheme for the DDN is at the point 0 meters and 1000 meters. The location of each node is determined by dividing the length of the oil pipe(L)by the total number of nodes (Nt) multiplying by the number (n).

$$L/(Nt*n) \qquad (8).$$

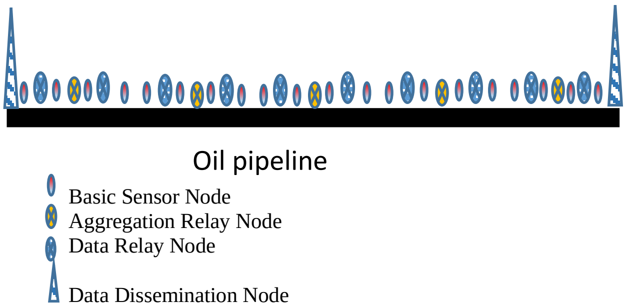


Figure (7): New hierarchical sensor network.

The results in this work are compared against the old hierarchical network model with (SRJ) algorithm. Figure (7) represents the four-level hierarchical sensor network that has adopted in this work.The heterogeneous nodes around the oil pipeline are distributed by estimating the transmission ranges of these nodes. BSN devices act as sensors that send their data to the ARN node, which in turn sends them to the relay node depending on the proposed algorithm. The relay nodes deliver the packets to the DDN nodes, which in turn send them to the sink that converts them to the network control center (NCC).

A- Throughput

The process of adding the ARN node leads to improve the performance of the network in terms of increasing the probability of the arrival of packets sent by the sensors. Also, the proposed model provides more productivity in case of relay nodes fail because ARN node will provide another path for the sensors towards the relay nodes. Fig (8) represent received throughput in different period's time.

B- Energy Consumption

The process of energy consumption of the UWSNs depends on the placement of the nodes and trade-off with the end to end delay. For the system of nodes, a sufficient number of underwater nodes should be deployed to fully cover the oil pipeline because these nodes are connected by acoustic waves and all these nodes are subject to the same environmental standards. In this experiment, better results were obtained after using the proposed new network hierarchy. In Fig (9), the new structure with the proposed ISRJ algorithm outperforms the old structure using the SRJ algorithm due to the increase in the number of nodes and the reduction of overwork on the relay nodes by deciding to route packets by the ARN node and thus reducing the memory used for storage. Besides, the ARN node increases the transmission range when there are no active relay nodes in both directions, extending network life and increasing reliability.

C- End-to-End Delay

The experience of the new hierarchy shows that end-to-end delays are acceptable compared to the SRJ algorithm. The ARNs that are added to the network increase the number of hops by one hop for the transmitted data because these nodes do not participate in the transmission of other data in the network. The number of jumps greatly affects the delay from source to destination, which should be a trade-off between energy consumption and delay from start to finish. In this work, the ARN node sends data to the relay node within its transmission range depending on the number of active relay nodes. The processes in the relay nodes are better because of the new structure with the proposed algorithm, which reduced the overwork on these nodes. The end-to-end delay average has been recorded depending on the number of active relay nodes in the network. For example, in case there are 7 or 8 active relay nodes the average end-to-end delay for SRJ strategy is 1.002s and 1.23s respectively while in ISRJ strategy is 0.944s and 1.2801s respectively. Fig (10) shows the end – to – end delay of the two compared strategies.

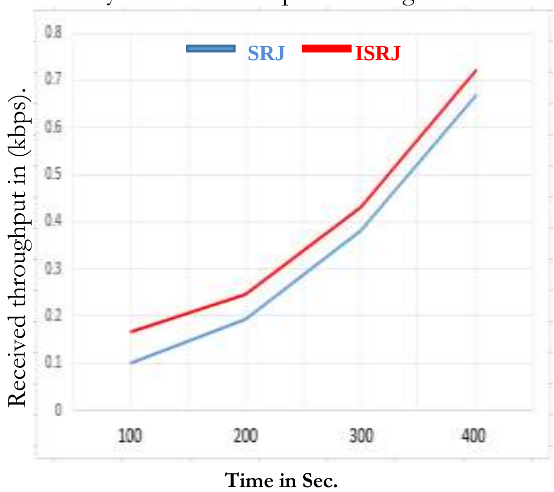
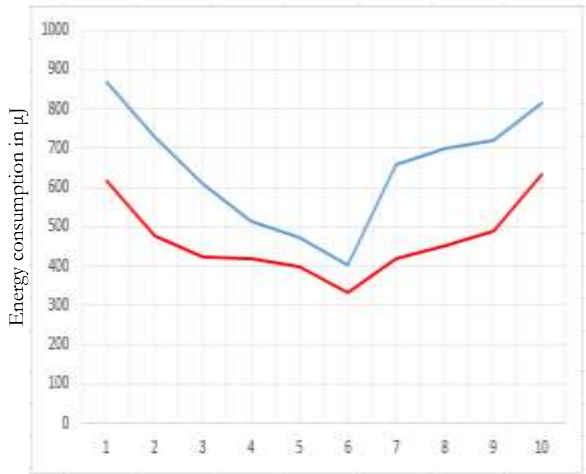
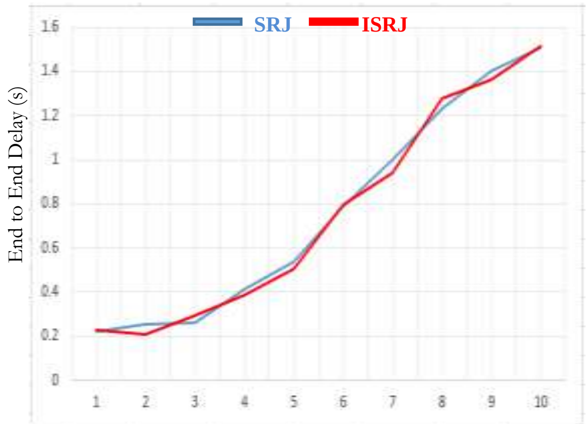


Figure (8): Received Throughput Results



DRN Number
Figure (9): Energy Consumption Results



Number of DRN

Figure (10): end – to – end delay

8. Conclusion

The process of monitoring the underwater oil pipelines receives wide attention due to the importance of these pipelines for the transfer of crude oil. Added nodes are used to collect data from the sensors and directed to the relay nodes and propose an algorithm based on the status of the nodes in both directions. The results show the superiority of the new network hierarchy. In the case of the first scenario, the received network throughput between the two strategies was compared based on different period's time. The ISRJ approach outperforms on average 17.4% in terms of packet delivery ratio over SRJ due to maintaining the number of sensor nodes in case any relay node fails in the proposed strategy as the nodes are directly connected to ARNs that provide greater network reliability. The end-to-end delay in the simulation scenario is acceptable when compared to the amount of energy consumed in the ISRJ strategy. Where it is noticed that the difference in end-to-end delay between two strategies is in milliseconds in the different cases depending on the number of relay nodes. Thus it is acceptable in a harsh underwater environment. The use of ARNs in the network led to reducing the energy consumed in the relay nodes, resulting in a longer lifetime of these nodes, thus increased network reliability. As the average energy consumption decreased by 20.3% in the network. The trade-off between end-to-end delay and energy consumption has shown that the network is not much affected by the end-to-end delay and the energy consumed in the ISRJ approach is lower than in SRJ.

9. References:

[1] M. Barbeau, S. Blouin, G. Cervera, J. Garcia-Alfaro, B. Hasannezhad, and E. Kranakis, "Simulation of Underwater Communications with Colored Noise Approximation and Mobility," p. 6.

[2] G. Heredia, "Multi-Unmanned Aerial Vehicle (UAV) Cooperative Fault Detection Employing Differential Global Positioning (DGPS), Inertial and Vision Sensors," p. 15, 2009.

[3] Premalatha, J., and PM Joe Prathap. "A Survey on Underwater Wireless Sensor Networks: Progresses, Applications, and Challenges." MATEC Web of Conferences, Taiwan, May, 2016.

[4] Faheem et al., "QoSRP: A Cross-layer QoS Channel-Aware Routing Protocol for the Internet of Underwater Acoustic Sensor Networks," Sensors, vol. 19, no. 21, p. 4762, Nov. 2019, doi: 10.3390/s19214762.

[5] N. Mohamed, I. Jawhar, J. Al-Jaroodi, and L. Zhang, "Sensor Network Architectures for Monitoring Underwater Pipelines," Sensors, vol. 11, no. 11, pp. 10738–10764, Nov. 2011.

[6] E. F. Farid, A. A. Mahmoud, and A. M. Bahaa-Eldin, "Adaptive Smart Redirect and Jump Algorithm (ASRJ) for Wireless Sensor Networks," in 2015 Tenth International Conference on Computer Engineering & Systems (ICCES), Cairo, Egypt, 2015, pp. 247–252

[7] M. Z. Abbas, K. Abu Bakar, M. Ayaz Arshad, M. Tayyab, and M. H. Mohamed, "Scalable Nodes Deployment Algorithm for the Monitoring of Underwater Pipeline," TELKOMNIKA, vol. 14, no. 3, p. 1183, Sep. 2016.

[8] M. S. Choi, W. Yaqiong, K. T. Kim, S. J. Yong, and H. Y. Youn, "A New Polling Protocol with Efficient Cluster Creation for WSN," in 2010 IEEE/ACM Int'l Conference on Green Computing and Communications & Int'l Conference on Cyber, Physical and Social Computing, 2010, pp. 357–362.

[9] K. Almi'ani, A. Viglas, and L. Libman, "MobileElement Path Planning for Time-Constrained DataGathering in Wireless Sensor Networks," in 201024th IEEE International Conference on Advanced Information Networking and Applications, 2010, pp.

[10] P. N. E. S. Barbosa, N. M. White, and N. R. Harris,"Wireless Sensor Network for Localized Maritime Monitoring," in 22nd International Conference on Advanced Information Networking and Applications- Workshops (aina workshops 2008), 2008, pp. 681.

[11] M. Zimmerling, W. Dargie, and J. Reason,"Localized power-aware routing in linear wireless sensor networks," in CASEMANS, 2008.

[12] M. Zimmerling, "Energy-efficient routing in linear wireless sensor networks," in Mobile Adhoc and Sensor Systems, 2007.

[13] Z. Guo, H. Luo, F. Hong, and P. Zhou, "GRE: Graded Residual Energy Based Lifetime Prolonging

Algorithm for Pipeline Monitoring Sensor," in 2008 Ninth International Conference on Parallel and Comp, vol. 8, no. 3, Nov. 2018, Distributed Computing, Applications and Technologies, 2008, pp. 203–210.
[14] Z. Ahmed and K. Abu Bakar, "An Enhanced Underwater Linear Wireless Sensor Network Deployment Strategy for Data Collection," Int J Innov
[15] 686.843–850.G. Tuna and R. Das, "Trade-off Analysis of Underwater Acoustic Sensor Networks," p. 7, 2017. tdma-based sensor networks Proc. IEEE International Conference on Communications (Seoul, Korea) 5 pp.3278-84.
[16] Michailidis E T, Tuna G, Gezer G, Potirakis S M and Gulez K 2014 ANN-Based Control of a Multi-Boat Group for the Deployment of an Underwater Sensor Network International Journal of Distributed Sensor Networks 2014 786154.
[17] Stojanovic M and Preisig J 2009 Underwater acoustic communication channels: Propagation models and statistical characterization IEEE Communications Magazine 47(1) 84-9.
[18] Proakis J G 1995 Digital communications (3rd ed.) (New York: McGraw Hill).
[19] Urick R J 1983 Principles of Underwater Sound (Mcgraw-Hill).