AUV-Based Efficient Data Collection Scheme for Underwater Linear Sensor Networks

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ABSTRACT

The research on underwater wireless sensor networks (UWSNs) has grown considerably in recent years where the main focus remains to develop a reliable communication protocol to overcome its challenges between various underwater sensing devices. The main purpose of UWSNs is to provide a low cost and an unmanned data collection system for a range of applications such as offshore exploration, pollution monitoring, oil and gas pipeline monitoring, surveillance, etc. One of the common types of UWSNs is linear sensor network (LSN), which specially targets monitoring the underwater oil and gas pipelines. Under this application, in most of the previously proposed works, networks are deployed without considering the heterogeneity and capacity of the various sensor nodes. This negligence leads to the problem of inefficient data delivery from the sensor nodes deployed on the pipeline to the surface sinks. In addition, the existing path planning algorithms do not consider the network coverage of heterogeneous sensor nodes.

KEYWORDS

AUV Deployment and Path Planning, Efficient Data Collection, Heterogeneous Sensor Nodes, Linear Sensor Network, Underwater Pipeline Monitoring

I. INTRODUCTION

Offshore production accounts about 30% of global oil production, and 27% of global gas production, while these figures have remained stable during the last two decades (Planete-Energies, n.d.). Most importantly, the mentioned percentages are expected to remain steady despite the rapid onshore development of unconventional methods such as Shale oil and gas, and oil sands. Currently, offshore oil and gas reserves are considered a critical component to stabilize the world's energy supply while the deep-offshore productions are further expanding and currently it accounts to 6% of global production which was just 3% in 2008 (Planete-Energies, n.d.). However, special

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and sophisticated instrument is required to monitor the production and processing points, further a network of underwater pipelines is used to bring these resources onshore.

The structure of these offshore rigs and connecting pipelines is very complex and spread over the very large areas. Many oil companies with offshore operations always face the problem of leakages in pipelines connecting the offshore wellhead platforms to the land production facilities. Because, these pipelines are operated at high pressures, any failure can cause severe damage to human health and property as well as create environmental implications. For example, a spill of about 267,000 gallons of oil in the tundra of Alaska's North Slope went undetected for five days in March 2006 (New York Times, 2006). Such leakages and explosion incidents due to high pressures occur often in Gulf of Mexeco. In first major incident, in March 1980, it faced 140 million gallons spill, further even worst situation was occurred in 2010 when not only 210 million gallons spills occurred but also it led to deaths and injuries of more than two dozen workers. Fixing such underwater leakages and network faults may take a very long time during which the pipelines will be fully or partially out of operation. Moreover, in the event of any such incident, not only the clean-up process is very expensive, but it poses major environmental hazards. Having a reliable monitoring and control system for these infrastructures can significantly help in inspecting and saving them.

Although we cannot ignore the intentional threats like terrorism but non-intentional threats like human mistake and natural disasters are of more concerns for underwater pipeline monitoring. For example, during another incident, several underwater pipelines in the Gulf of Mexico were damaged by hurricanes in 2005 (Pipeline Guerrillas, 2007). Resulting to these reasons, environmental regulations are constantly changing and becoming stricter day by day. In 2008, The Office of the Comptroller of the Currency (OCC) approved a set of rules regarding the management of surface waste from oil and gas operations that force companies to haul highly contaminated soil and water to permanent disposal sites rather than spread it back over the land after closing a well. The OCC also approved stricter penalties to enforce industry compliance where the companies must develop new methods to follow these regulations, and to reduce accidents and emissions without impacting production.

A well-developed wireless sensors network on the pipeline facility can help to tackle the aforementioned issues. The sensors can be used for a range of applications like taking measurements inside or outside the pipelines. Inside measurements can be pressure, flow, and temperature measurements. While, examples of outside measurements are pipeline area monitoring, pipeline protection cameras, pipeline fire detection, and pipeline liquid leakages. Operation and maintenance of these subsea pipelines are extremely complex due to the severe conditions of the underwater harsh environment. Detailed monitoring makes it possible to fine tune operations and disclose early abnormal situations in order to maintain the production capacity by avoiding a major abruption or damage. Leaks and ruptures due to an aging and fast decaying pipeline system infrastructure cost millions of dollars a year. A well deployed network of wireless sensors can offer continuous, automatic monitoring systems that can provide early detection and warning of defects, such as corrosion and leaks, before they reach the magnitude of a major disaster.

Underwater sensor networks (USNs) have many applications, among these a subarea known as the Underwater Linear Sensor Network (UW-LSN), which involves monitoring the linear structures such as the underwater pipeline network. In the underwater environment, maintaining the pipelines health is a critical task, because it requires an active and regular monitoring process (Forrest, 1994). Traditionally, this monitoring is conducted through physical supervision which is very expensive due

Figure 1. Wireless Sensors for Underwater Pipeline Monitoring
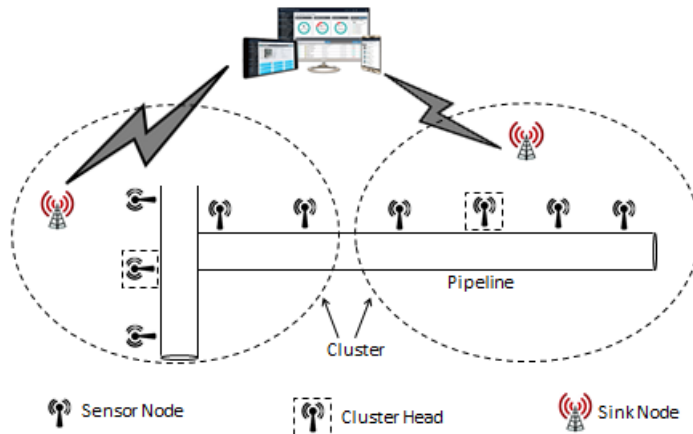
to high cost of technicians, tools, or robot systems, especially in an inaccessible and hard underwater environment. Fig. 1 depict the illustration of the underwater pipeline monitoring using wireless sensors

Considering the importance of LSN for offshore pipeline monitoring, this paper presents an AUV based hybrid linear sensor network data collection scheme. Under this scheme, sensor Nodes (SNs) are fitted in a pipeline field to check different issues regarding the pipeline and its surroundings while these sensors are supposed to fitted on a place that is out of the human reach and left unattended (Ali et al., 2015). Further, these sensors are connected with neighbor sensors where the acoustic communication is used to communicate and share data with each other. The installation of a fixed communication structure in a remote field to gather data from the sensors is prohibitive or impractical because of random topology and high cost of fixed installations. Therefore, in such situations, ad-hoc sensor networks in combination with AUV layered approach found to be beneficial in collecting the data from underwater surroundings.

The remaining section of the paper is structured as follows. Section II discusses the review of related works in data collection techniques for pipeline monitoring process using sensor networks. Section III describes the data collection model for underwater linear sensor networks. Further, section IV presents the results and their analysis. While, section V pointed out some research issues and future research directions. Finally, section VI concludes the research study.

## II. RELATED WORK IN UNDERWATER PIPELINE MONITORING DATA COLLECTION

Several studies have been suggested in solving communication issues among the underwater sensing and communication devices (Abbas et al., 2018; Ayaz et al., 2011). UWSN communication is based on acoustic channels, which always needs to consider the main issues of acoustic signals, including (a) propagation delay of five orders of magnitude than the radio frequency; (b) continuous movement of the water affects acoustic signal and resulted to higher bit error rates; and (c) reduction of signal strength observed higher in underwater communication. All of these issues badly affect the efficiency of underwater acoustic communication. This section explains the some of the existing UWSN and UW-LSN deployment and data collection frameworks that play key roles in the development of pipelines monitoring network. The related literature presented in this section is divided into three categories including, A) the chain-based data collection, B) Multi-Level and Multi-Hop Based Data Collection Scheme and C) Autonomous Unmanned Vehicle (AUV)-based data collection.

A.   Chain-Based Data Collection Approach

All the sensor nodes in this type of data collection are connected to each other in a straight path like a chain which is depicted in Figure 2. It is not important that all nodes must maintain the routing table from source to endpoint as only directly connected neighbor node's information would be maintained. This type of technique is safer, and attackers can find it difficult to know the relations between nodes simply by seeing the entire network. Also, it will be difficult for attackers to follow the packets and find the link details and movement of communication in multiple sessions. These attackers might want to get information regarding the pipeline location or kind of resources in it.

In chain-Based underwater data collection all nodes are connected in linear direction therefore there is a high level of reliability risk if these nodes are connected through a wire such as if any of the nodes stops working, all the connected nodes will be out of service. It is also possible to decrease

Figure 2. Chain Based Deployment Model
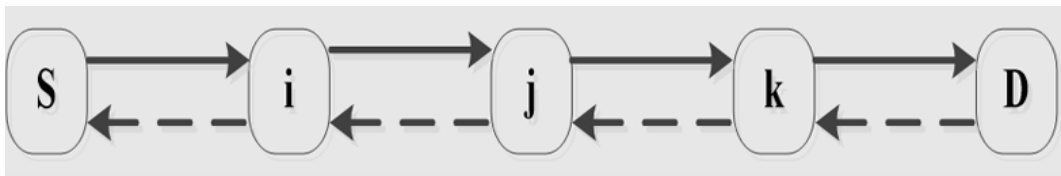
the risk by making the floatable-mobile chain like in (Abbas, 2017; BenSaleh et al., 2013). Further, the higher delay might be experienced due to the traversal of hop-by-hop data Forwarding.

B.   Multi-Level and Multi-Hop Based Data Collection Scheme

In this category the non-centralized data collection approaches are included. Linear sensor network consists mainly of the thin, thick, and very thick types of deployment schemes, depending on how the sensor nodes are deployed, either in one line or in multiple lines. In (Abbas et al., 2016), the method considers scalability in the distribution of heterogeneous nodes. The unequal-capacity nodes are spread based on their different capacity of transmission coverage. The nodes with higher capacity are utilized as a relaying node and dissemination node, while the smaller capacity nodes are used as the basic sensing nodes. In their proposed deployment method, the sensor node spacing might not be effective because of nodes with lower residual energy, which cannot transmit to a longer distance. Considering the deployment methods, the employed distribution strategies still encounter a significant amount of data error and propagation delay due to deployment spacing and un-evaluated homogeneous node. A proper node distribution in order to attain scalability is required. The multi-hop routing approach is expensive when used for the long-range LSN because it may utilize more energy and decrease the lifetime of the entire network.

C.   *Autonomous Dynamic Robotic Based Data Collection Schemes*

In this category, the autonomous unmanned vehicle-based data collection approaches are involved. Autonomous systems are unique in their functionality and they need a path for the movement of autonomous devices/robots. In (Kim et al., 2010) sensor-based Pipeline Autonomous Monitoring and Maintenance System (SPAMMS) has mentioned, which has a robot agent-based sensing technology for the monitoring of linear structures like pipelines. SPAMMS uses RFID technique for the deployment

of mobile sensors and autonomous robots. The mobile sensors are deployed in very important locations of the pipelines and the inspection can be scheduled and performed based on demand. When a mobile sensor is deployed in a pipeline and starts to function, it can move with the fluid flowing inside the pipeline. The fixed sensors convey event position details to mobile sensors for tracking of the damaged location in the pipeline. After the analysis of events reports, a robot agent travels inside the pipelines to perform a detailed examination and maintenance of the reported incidents such as damage, leakage, or corrosion of the pipeline. In addition, in (Jawhar et al., 2014), a framework for employing unmanned aerial vehicles for data gathering in linear wireless sensor network is suggested.

In the proposed work of Heredia (2009), a multi-UAVs framework was presented. This method increased the dependability of Unmanned Aerial Vehicle (UAV) sensor Fault Detection and Identification (FDI). In addition, the Differential Global Positioning System (DGPS) and inertial sensors are used for sensor FDI in each UAV. Furthermore, an extraordinary position estimation algorithm, which boosts individual UAV FDI system is used. Additional estimations are obtained using images received from two different UAVs while in an active state. However, the accuracy and noise level of the estimation depends on factors such as dynamic re-planning of the paths for different UAVs that obtain a better estimation in a situation where the faults caused by the errors in absolute position estimation cannot be detected using local FDI in the UAVs. In addition, the two main UAVs are discussed, and different data collection scenarios are highlighted. The Fig. 3 represents the AUV based data collection illustration in underwater. The system consists of four types of nodes, which includes sensor nodes (SNs), relay nodes (RNs), UAVs, and sinks. A UAV moves back and Forth along the linear network and transports the data that is collected by the RNs to the sinks located at both ends of the LSN. This network architecture is known as a UAV based LSNs (ULSNs). Using this

Figure 3. AUV based Data Collection
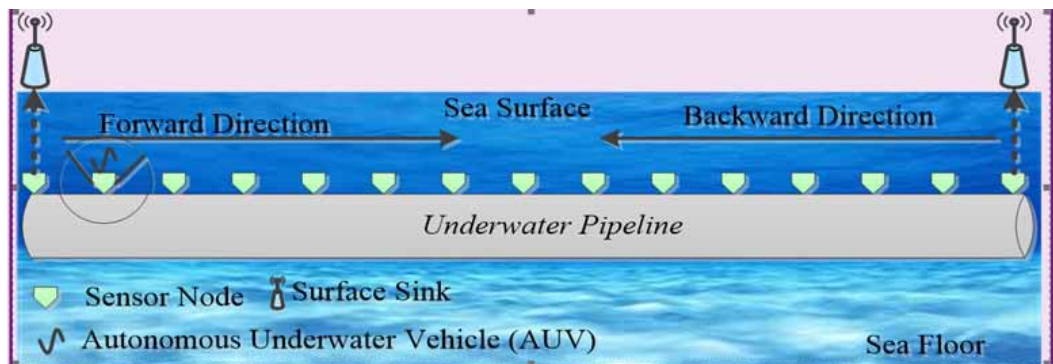
approach, the node energy consumption can be reduced because of the significant reduction in the transmission ranges of the SN and RN nodes and the use of a one-hop transmission to communicate the data from the RNs to the UAV.

Along these routing procedures, many researchers have utilized the UAVs, and this has resolved the problem of optimal pipeline monitoring using multiple mobile nodes. A mathematical model is provided in Ondráček et al., (2014), which captures the properties of the problem, including the environmental sensitivity and the path planning constraints of UAVs. In addition, two algorithms are designed to enhance the inherent scalability limits of this problem. The researchers were able to find an optimal solution for a large-scale real-world monitoring problem and provide a promising solution to UAVs path planning in such scenarios.

III. AUV BASED DATA COLLECTION SCHEME FOR UNDERWATER LSN

Considering the background and discussed issues in literature, this section presents a model to monitor the long-distance pipelines. The proposed model utilizes the heterogeneous sensors and an AUV as an agent of data collection purposes. The deployment concept classifies the sensors into discrete types considering their respective signal coverage. In addition, the classification also considers the operations, which leads to the attainment of an optimal number of sensor nodes in the deployment of large size networks. Then, an underwater vehicle, which is autonomous in nature, has been configured. The AUV employs sinusoidal movement because straight path navigation is often displaced when there is high water current. Further, the data collection procedure based on routing is considered for effective data packet forwarding. Fig. 4 depicts the concept for the linear sensor node deployment model.

The first type among the deployed hetrogenous sensor nodes are Basic Sensor Node (BSNs) which are hybrid in nature and carried limited storage capacity while they are needed to cover short ranges. The Data Relay Node (DRNs) are placed in between the BSNs and Data Dissemination Node (DDNs) which collect the data from BSN and transport to DDN. The DDN is used to cover long-range and has more storage capacity and it transfers all the data which is collected from DRN to the AUV when comes in within its range.

The sinusoidal path is employed by AUV because it can cover the signal coverage for both i.e., the data dissemination sensor node and the sink at the surface of the sea

Figure 4. Data Collection Network Model
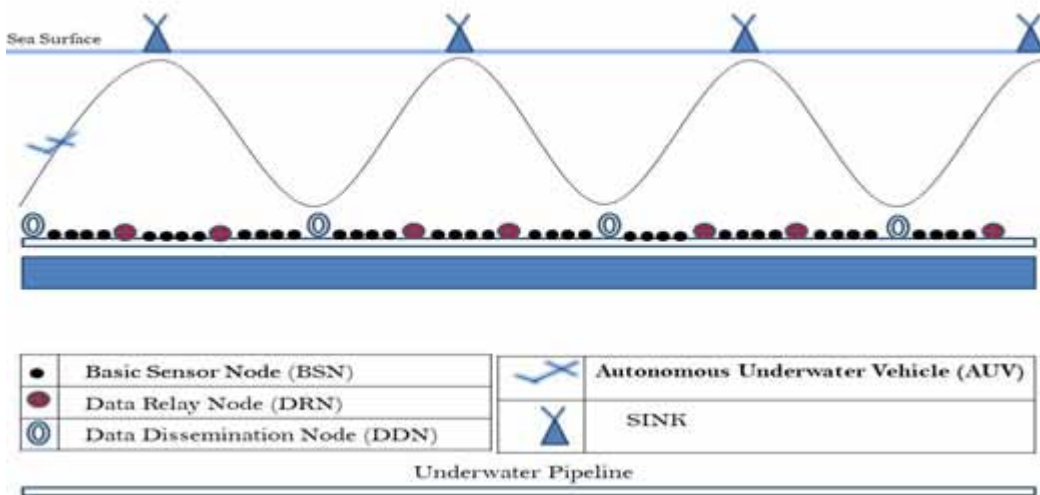
A. Deployment of Heterogeneous Types of Nodes

Fig. 5 (flowchart) explains the mechanism about the nodes, AUV and sinks deployment for the proposed network model. In the flowchart for AUV and sensor deployment, the deployment nodes are arranged according to the pipe length with node configuration based on the network coverage of the sensor nodes. Then the AUV sinusoidal path is estimated considering the positions of the heterogeneous sensor nodes. Afterwards, the receive signal of next node is estimated before sending

the data packet. Therefore, each node send data to the suitable node which further forward to the AUV and then to the sink node.

The deployment of heterogeneous types of nodes is based on AUV path planning. The sensor nodes deployment is completed in three steps. In the first step the deployment of all the heterogeneous sensor nodes is carried out by using the formula in equation 1.

For i = 1 **to** N

$$x \neg i * d_m \text{ ----------------------------} \tag{1}$$

where i is the number of sensor nodes and dm is the distance between each node.

In the second step, types of nodes (BSN, DRN, DDN, SINK) and their ranges are explained about the communication by using octet rule.

$For\ every\ 100m\ deploy\ BSN$
$If\ the\ distance\ is\ certain$
$Else\ for\ 500m\ deploy\ DRN$
$\quad Else\ for\ 2500m\ deploy\ DDN$
End
Total number of Sinks = 5
Total number of BSN Nodes = 100
Total number of DRN Nodes = 20 Repeated after 4 BSN
Total number of DDN Nodes = 6 Repeated after 4 DRN
These parameters are assumed during the testing of the proposed algorithm.

The objective function of heterogeneous node distribution is presented in Fig. 6 based on AUV motion is to minimize the delay incurred while maximizing the network size which is a critical factor for UWSN environments.

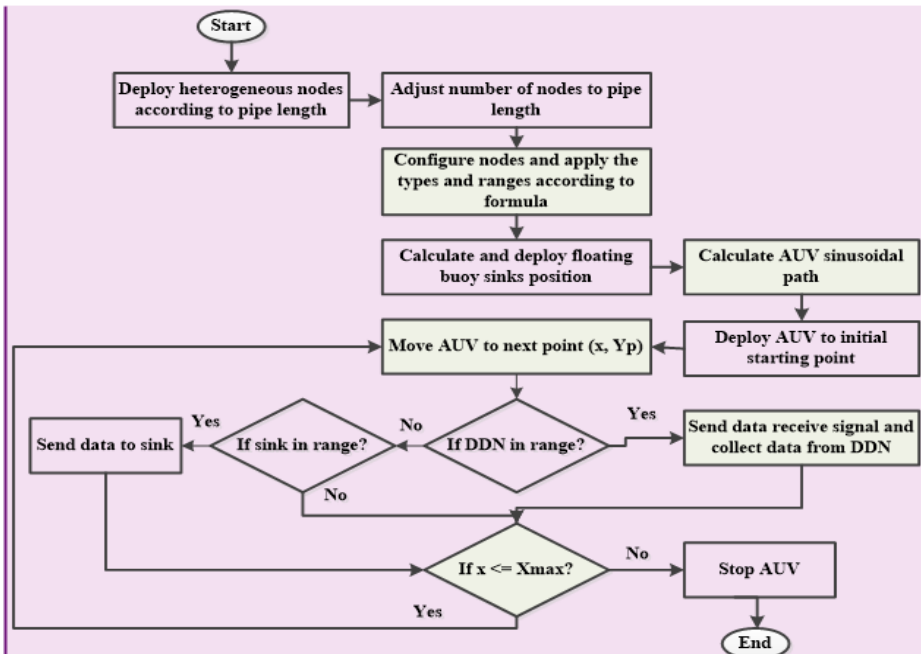Figure 5. Heterogeneous Nodes, AUV and Sinks Deployment Model

Figure 6. Types of the Nodes

In the third step calculate SINK location by using the formula in equation 2.
Where
For the 1ˢᵗ SINK:

$$(D(1+1)x + D(1)x)/2$$

$$(D2x+D1x)/2\text{--------------------} \tag{2}$$

For example, the distance between first sink should be 750m if the distance between two DDN is 500m.

B. Data Collection Scheme

After the node deployment phase, the data collection is done in two steps.

i.   Data collection between basic sensor nodes
ii. Data collection between AUV and DDN.
   i.   Data collection between basic sensor nodes.

To complete this, every node has two different types of IDs. One is Node ID and the second is Hop ID. Hop ID is the path followed by Node ID to reach its destination. This process is explained and summarized in Fig. 7.

Figure 7. Addresses of the different types of nodes
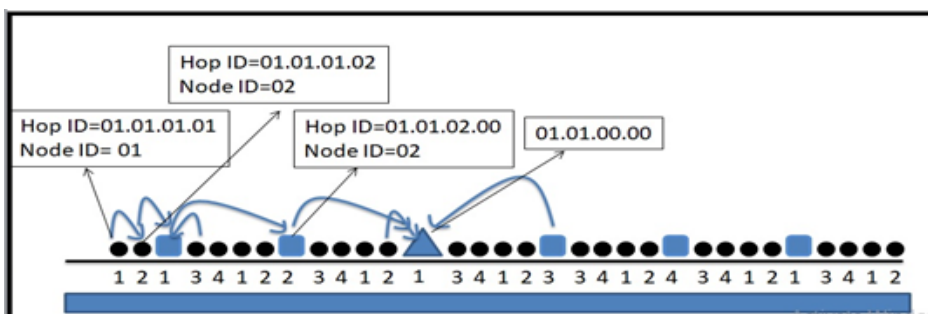
As represented in Fig. 8, in the first step the data packet is generated or received by BSN. In step 2, BSN checks this packet to see if it already exists in its cache or not. If yes, then BSN drops the packet and if no, then the packet is saved. In step 3, the existing data in BSN will be forwarded to the next node towards the node which is near to the DRN. The DRN will follow similar procedure and continues to forward the packet until it gets to the DDN. The DDN receives data packets from both sides of the BSN nodes within its signal coverage. The BSN forwards packets to the closest DDN based on the signal quality between them. In step 4, the DDN, will update the packet details and then forward to AUV, which hovers above DDN. If AUV already hovered above that specific DDN, then it would forward the received packet to the next DDN in the direction of the AUV.

Figure 8. Packet forwarding between different types of nodes
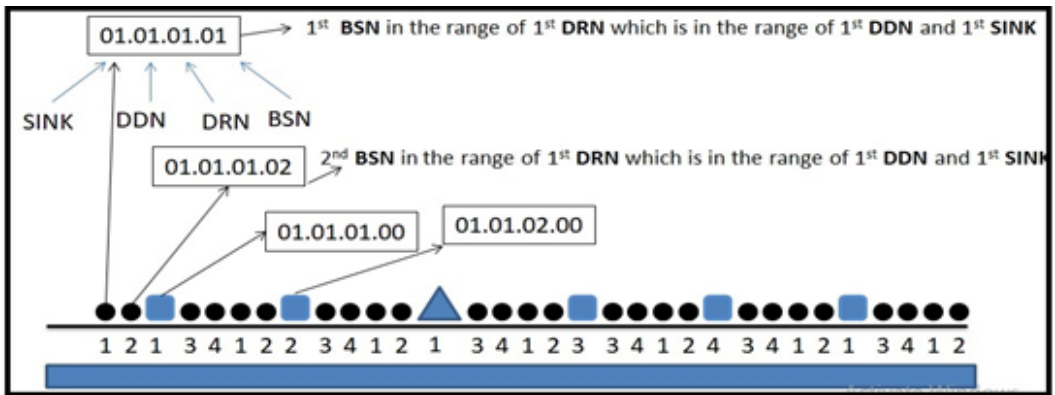
ii. Data Collection between AUV and DDN

The sinusoidal wave plays important role in many fields because it has the property to maintain its wave shape at the same frequency, arbitrary phase and magnitude that would become much supportive in data collection. In water, it is difficult to move in straight because of water current. The AUV hovered across the pipeline in a sinusoidal form, collecting data only from the DDNs. This data is transmitted to the sink nodes at the sea surface. The AUV motion is calculated using the following formula in Eq. (3)

Where R_D is the communication range between DDN and AUV. T_o is the threshold value and d_p is the distance between two DDN as shown in Fig. 9.

Figure 9. Variables used in AUV path planning and data collection

The two devices are able to transfer the data before the AUV moves out of the range of the DDN. This is illustrated in Fig.9 and Fig 10. The related parameters are R_c, R_D, h, α, T_o, and L, as expressed in figure 10. The passing time of an AUV within the range of DDN is sated as tfp.

Figure 10. (a) Singewave angle For AUV movement

Figure 10. (b) Singewave angle For Auv movement

Regarding the DDN and AUV communication, following procedure is applied which relates the various parameters that are involved when AUV is within the range of DDN and surface sink, while the two devices are able to exchange the data which is illustrated in figure 10(a)

Output: All data packets generated by BSNs have been delivered to the SINKs by using AUV. Fig. 11 depicts this procedure of data collection and forwarding algorithm as flowchart which consists of two main parts; coordination between heterogeneous nodes and AUV data collection from DDNs. In heterogeneous nodes if the packet is received by BSN, it will verify if the source is DRN or BSN, if it is from BSN then it will drop its own packet, otherwise forward to next BSN which is closer to DRN and DDN. If the packet is received by DRN, then it will verify the source; if the source is itself, then it will drop the packet; otherwise forward it accordingly. If the DRN is closer to DDN, then the packet will be directly sent to the DDN. Otherwise, it will send to the next DRN that is closer to DDN. The same procedure is continued until packets are collected from the entire pipeline. In AUV data collection the AUV starts movement across the network coverage area of all the DDNs that are situated on the pipeline and collects all the data from them and then move towards the sink node at the water surface.

Data Collection Algorithm:

```
Data collection process triggered by basic pipeline sensors BSNs
Process:
BSN generate packet(p)
if the packet p exists in the cache, then
                            discard(p)
else
                         forward(p)
          if the packet forwarded successfully then
                           update(p) and cache(p)
          else
                        discard(p)
Case 1: BSN Forward(p)
                if BSN Next_Node DRN/DDN then
                            Deliver(p)
                            Update (p)
                else
                            Deliver(p) next BSN
              Repeat deliver(p) unless Next_Node DRN/DDN
Case 2: DRN Forward(p)
                if   DRN Next_Node DDN then
                            Deliver(p)
                            Update (p)
                else
                            Deliver(p) Next_Node DRN
              Repeat deliver(p) unless Next_Node DDN
Case 3: DDN Forward(p)
                if   DDN Next_Node AUV then
                            Deliver(p)
                            Update (p)
                else
                            keep the packet in buffer(p)
```

```
                                    Wait till next visit of AUV
Case 4: AUV Forward(p)
                 if    AUV Next_Node SINK then
                                Deliver(p)
                                Update (p)
                 else
                                keep the packet in buffer(p)
                                Wait till next SINK
```
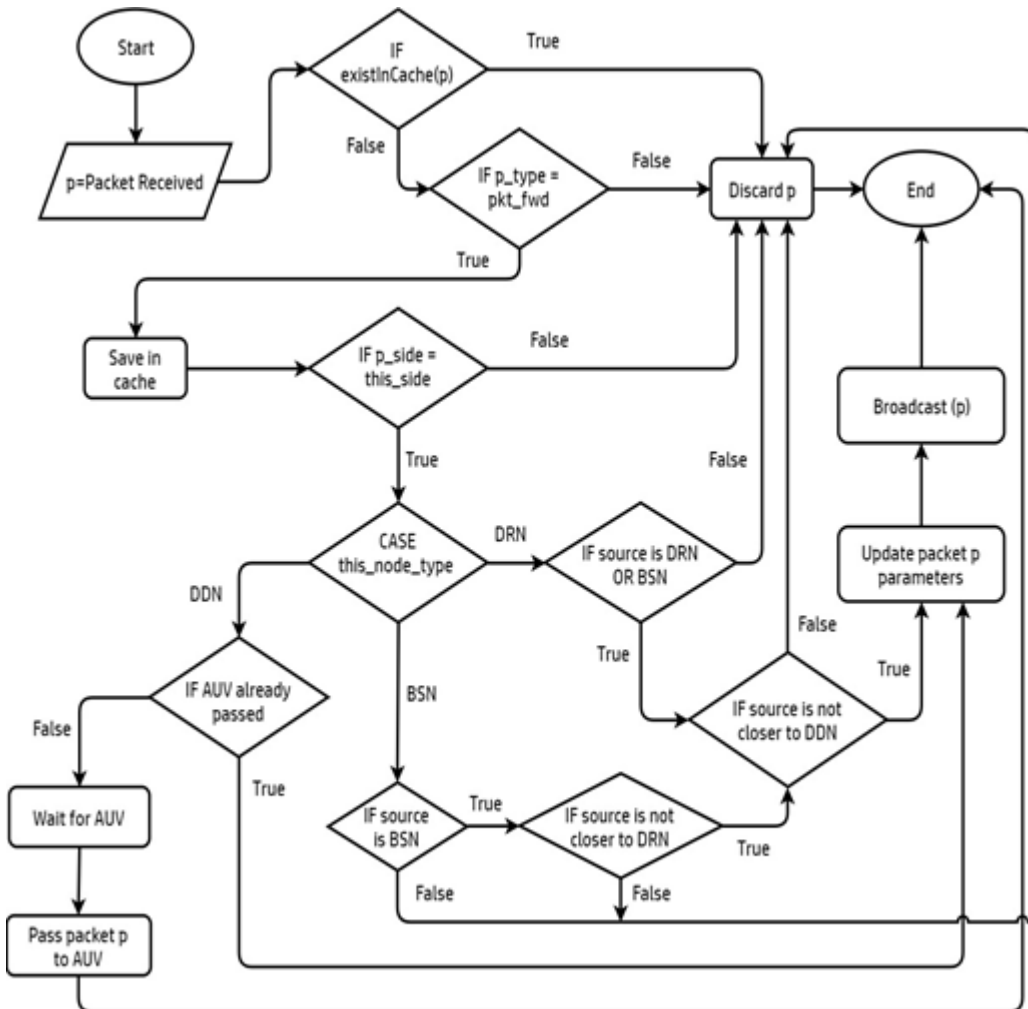
Figure 11. Flowchart of Data Collection and Forwarding Algorithm

IV. PERFORMANCE EVALUATION AND RESULTS ANALYSIS

The performance of the proposed scheme is evaluated against Dynamic Addressing-based Routing Protocol for Pipeline Monitoring (DARP-PM) Mohamed et al., (2013) and Autonomous Underwater Vehicle-based Linear Sensor Network (ALSN) Lai et al., (2012). The considered parameters in terms

of performance evaluation include Packet Delivery Ratio (PDR) and End-to-End Delay (E2ED), traffic load. The simulation was performed using the AQUA-SIM and its environment settings are presented in Table 1. The following are the detailed description and statistical formulation of the two evaluation parameters are considered.

Table 1: Simulation Setup

Parameters	Values
MAC	Underwater MAC
Transport Layer Protocol	UDP
Antenna	Omni-Directional
AUV speed	26Km/h-37Km/h
Channel Bandwidth	25Khz
Number of Sinks	5
Number of Nodes	20-180
Network Dimention	12600m
Pipeline deployment depth	500m
Sinks Location	Middle of two DDN
Types of nodes	BSN,DRN,DDN,SINK
Range of nodes	100,250,400,500m
Maximum pipeline length	12600m
Hello packet size	12byte
Hello message timeout	5sec
Simulation time	1000sec

Packet Delivery Ratio:

It is the ratio between a number of data packets generated at the pipeline-base nodes and the number of data packets are delivered to the sink node destination. The statistical formula is used to calculate the Packet Delivery Ratio (PDR) in terms of percentage can be expressed as follows in Eq 5.

$$PDR\% = \left\{ \left(\sum_{i=1}^{n} \frac{PS}{PR} \right) \Big/ N \right\} * 100 \qquad \text{----------------------} \tag{5}$$

Where PS denotes the number of data packets sent from the pipeline-base node in ith simulation run and PR represents the number of data packets which are received at the sink node in *ith* simulation run.

Delay:

The average time is taken for a data packet to be delivered from pipeline-base nodes to the destination sink nodes.

$$\sum_{S}^{D} A_{vg}\left(t\right) \text{----------------------}$$ (6)

The Eq 6 provide the details about $A_{vg}\left(t\right)$ which is the average time for the total data packet taken after collected from pipeline-base nodes to destination sink node as (S®D). The data collection scheme evaluation is carried out based on the simulation setup and its environment described in simulation setup.

Packet delivery ratio under different traffic loads:

The behavior of AUV-Based EDC for UWLSN, DARP-PM and ALSN schemes are analyzed in the harsh underwater environment for pipeline monitoring using heterogeneous sensors. The aim of employing PDR as an evaluation metrics is to assess and show the performance improvements of AUV-Based EDC for UWLSN compared to other baseline protocols while handling longer pipeline size for the collection of sensor data and different traffic loads.

Fig. 12 describes the evaluation of AUV-Based EDC for UWLSN in terms of PDR based on different loads in relation to time. Based on the several rounds of simulations, it is observed that AUV-BASED EDC for UWLSN performs well at different network traffic loads such as 1, 2, or 3 packets/sec. It is depicted in Fig. 12 that when traffic load is less, then packet delivery increased. That is, when the network traffic load increased up to three packets/sec then packet delivery ratio decreased but still remained better than the compared schemes. The main reason behind this is the network load and the data collection mechanism.

Figure 12. Traffic Load Evaluation based on PDR
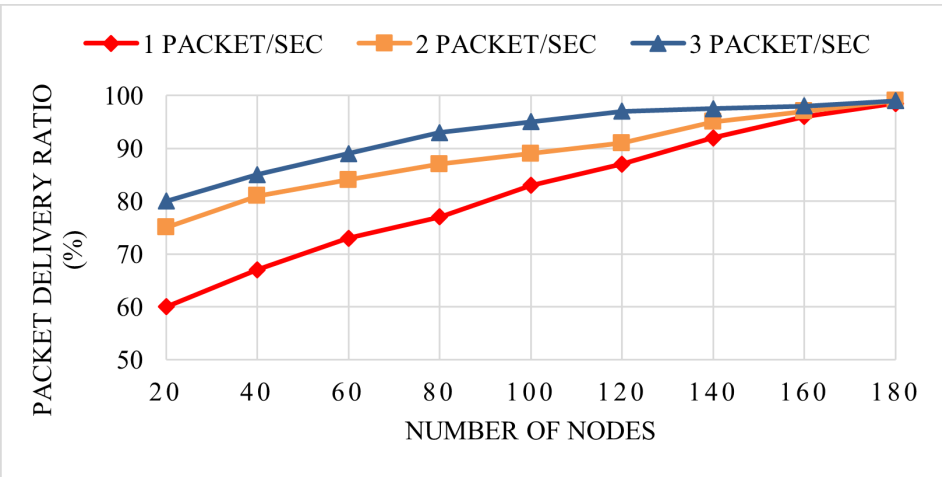
Packet delivery ratio as compare to other schemes:

It is shown in Fig. 13 that AUV-Based EDC for UWLSN has higher packet delivery ratio in the comparison to DARP-PM and ALSN. This happens due to usage of AUV and multiple sinks where sinusoidal path helps to deliver data efficiently to the closest floating buoy sink. In DARP-PM and ALSN, Courier Nodes (CNs) collect the data and forward until the data reaches the sink since very few numbers of sinks are deployed.

Figure 13. Packet Delivery Ratio based on different Traffic Load of EDC
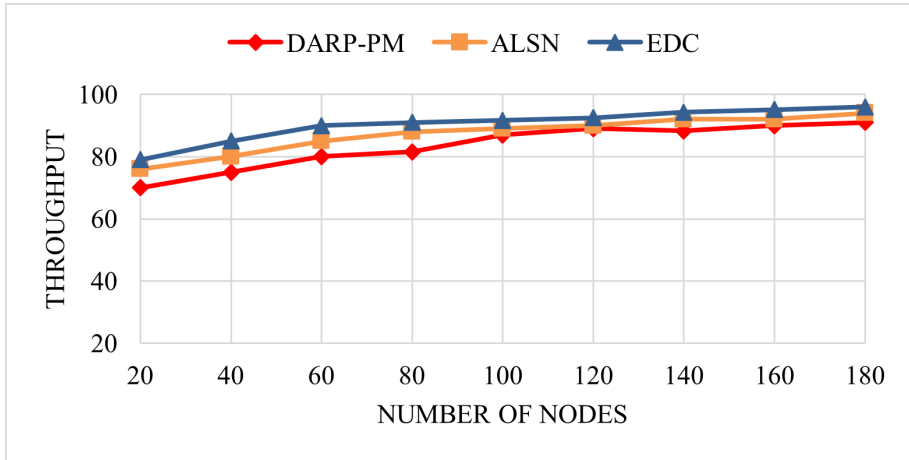
End-to-End Delay under different traffic loads:

AUV-Based EDC for UWLSN's E2ED performance is evaluated based on the different network traffic loads as mentioned earlier. It is shown in Fig. 14 that different traffic loads leave a major impact on E2ED. As the network load is lesser then the E2ED becomes small otherwise E2ED becomes higher at higher traffic load of 3 packets/sec. Delay is common in underwater acoustic communication, which is almost 5 times slower than Radio Frequency (RF), so traffic load has higher impact on delay. If the traffic load increases, ultimately the E2ED increases.

Figure 14. End-to-End Delay Evaluation based on Traffic Load
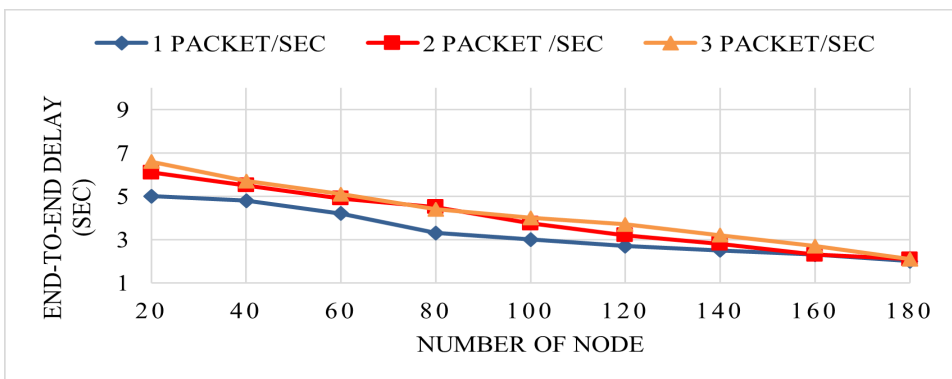
End to End delay as compare to other schemes:

The performance of AUV-Based EDC for UWLSN in terms of E2ED is benchmarked against with two existing protocols named as DARP-PM and ALSN (three times). It is shown in Fig. 15 that AUV-Based EDC For UWLSN produces smaller E2ED as compared to DARP-PM and ALSN. The unique property of AUV-Based EDC for UWLSN is usage of AUV with sinusoidal path planning that helps to collect the data efficiently and deliver directly to the floating buoy sinks with the minor delays. In DARP-PM and ALSN, Courier Nodes (CNs) and AUV used to collect data from basic sensors nodes but cannot forward data directly to the sink because the mode of their sinks deployment does not support direct data collection.

Figure 15. End-to-End Delay Performance Evaluation of Various Schemes using 3 Packets/Sec
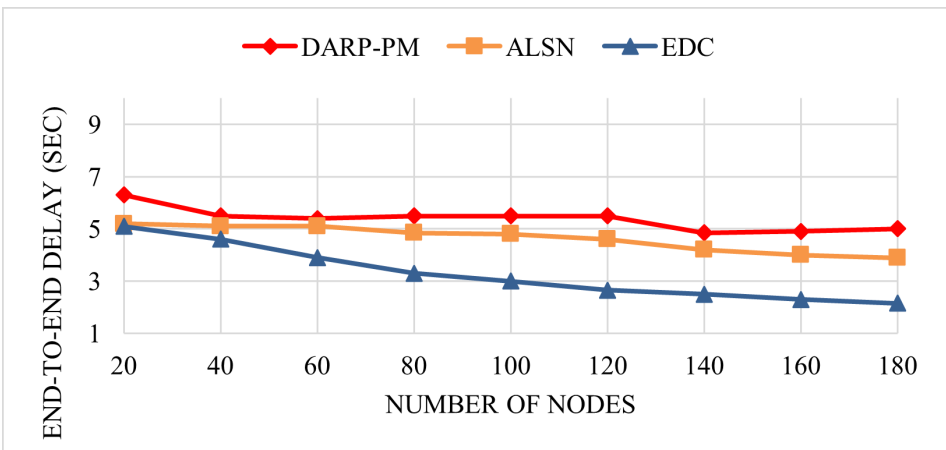
Analysis of Total Throughput:

The evaluation performance of the AUV-Based EDC with the MDD-CDA and SHND baseline schemes is carried-out considering the throughput. It is shown in Fig. 16 that AUV-Based EDC has higher throughput performance in comparison to MDD-CDA and SHND schemes. This happens due to the employment of the AUV with the efficient path planning where a sinusoidal path helps to deliver the data efficiently to the closest floating buoy sink. The efficient heterogeneous node deployment also assists in improving the efficient data packet delivery. In addition, the adapted opportunistic routing further assists in efficient data collection. In MDD-CDA, the AUV do not move in sinusoidal path format hence, the path planning in proposed scheme contribute to the efficiency of this work. In SHND, Courier Nodes (CNs) collects the data and forwards until the data reaches the sink since very few numbers of sinks are deployed, thus affect the performance of the scheme. The percentage of the performance improvement of the proposed scheme against MDD-CDA and SHND is 15.5% and 12.7% respectively.

Figure 16. Throughput Performance Evaluation of Various Schemes
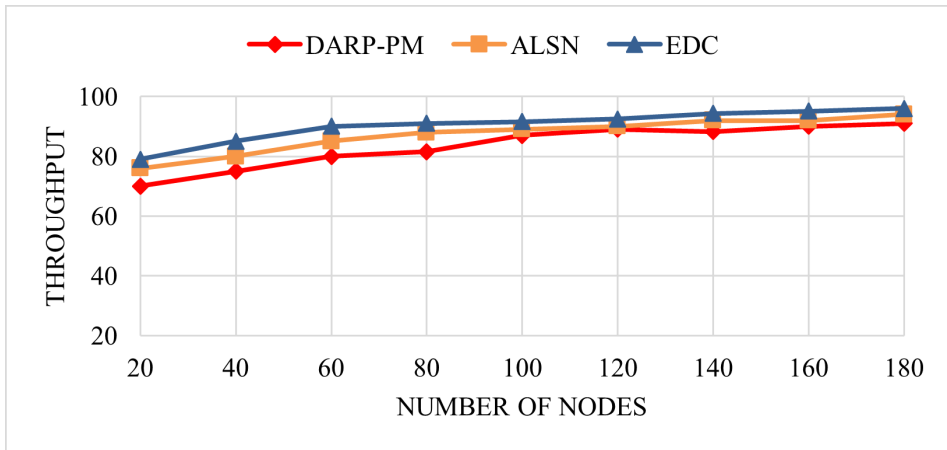
V. CONCLUSION

The developed AUV-Based EDC for UWLSN scheme is assessed when dealing with the issue of long-distance pipeline monitoring and heterogeneous sensors adoption. To evaluate the performance of proposed scheme for UWLSN, different traffic loads are tested based on packet delivery ratio and end to end delay. In addition, the AUV-Based EDC for UWLSN scheme was benchmarked against with the DARP-PM and ALSN schemes in terms of both of the mentioned parameters under underwater data collection scenario. The AUV-Based EDC for UWLSN scheme deals with the design of network architecture, the AUV path planning algorithm and the data collection algorithm. The simulation experiment results prove that the developed scheme performs better with higher traffic loads along different other scenarios. The found results show that presented scheme has better performance in terms of PDR with 8%-37% increase in packet delivery compared to both DARP-PM and ALSN scheme. In addition, our scheme outperforms the DARP-PM and ALSN scheme in terms of E2ED with about 9% - 25% decrease in delay. It is concluded that AUV-Based EDC for UWLSN scheme performs better and efficiently under most of the targeted scenarios.

CONFLICT OF INTEREST STATEMENT

The authors have no conflict of interest to proclaim for the publication of this paper.

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