Exploration of Linear Wireless Sensor Networks and Simulation Tools for Underwater Pipelines Monitoring Networks

Muhammad Zahid Abbas[1,2], Kamalrulnizam Abu Bakar[1], Muhammad Ayaz Arshad[3], Sadia Deep[4], Mohammad Hafiz Mohamed[1]
[1]Faculty of Computing, Universiti Teknologi Malaysia, Johor Bahru, Malaysia.
[2]COMSATS Institute of Information Technology, Vehari, Pakistan.
[3]SNCS Research Centre, University of Tabuk, Tabuk, KSA.
[4]Faculty of Science and Human Development, Univeriti Tun Hussein Onn Malaysia, Batu Pahat, Malaysia.
zahidmcs@gmail.com

***Abstract*—In the current technological age, Wireless Sensor Networks (WSNs) comprising of featured intelligent devices have become a dominant technology in the underwater environment. Being cost effective in nature, WSN consumes less energy for sensing and communication processes. Besides, WSNs also make use of minimum infrastructure in order to execute its common applications in pipeline monitoring, surveillance, and environment monitoring. While as far as Linear Wireless Sensor Network (LWSN) architecture is concerned, it requires special topology in which all sensors are placed in a linear form specifying and differentiating it from other WSNs. For underwater pipeline monitoring environment, there is no such complete 3D simulation tool to analyze different techniques so as to compare the visual results with the help of specific simulation parameters. The purpose of this study is therefore, to explore LWSN technology based on characteristics like pipeline monitoring issues, specification, and simulation tools. Moreover, various 3D environments like underwater, underground, above-ground LWSN properties and challenges are discussed. We have also compared the existing simulation tools with respect to different GUIs, and environments along with pipeline monitoring techniques being classified into different groups with respect to different kinds of simulation environments and evaluation methods. This investigation is expected to contribute towards advancements in network deployment for 3D underwater pipeline monitoring, and comprehensive 3D simulation tool development. It will prove helpful as well to the future researchers in visualizing and analyzing pipeline monitoring and simulation approaches.**

***Index Terms*—LWSN; Pipeline Monitoring; Simulation Tools; Underwater Environment.**

I. INTRODUCTION

This study introduces the deployment challenges and evaluation issues of Underwater Wireless Linear Sensor Network (UW-LSN) that always play a critical role in the development of underwater linear sensor network for pipelines monitoring. It is also going to review some of the UW-LSN simulation techniques with their pros and cons. A study of simulation tools in different domains of UWSN (Underwater Wireless Sensor Network), LSN (Linear Sensor Network), and UW-LSN is conducted as well with discussion about the similarities and differences. The study eventually concludes that although researchers have already started to explore the issue of underwater nodes deployment and testing in 3D underwater simulation environment but there are yet many research gaps to be explored.

Underwater wireless sensor networks are presently getting very popular in underwater ocean monitoring, survey and monitoring of the long underwater oil & gas pipelines [1]. UWSN has a greater scalability and flexibility as compared to the traditional WSN approaches. The recent research reveals that UWSN has opened many directions for future research. In spite of all this, there still exits many hardships and challenges for researchers to proceed further in UWSN like harsh underwater environment, propagation delay, dynamic topology, hardware limitations, and complicated application scenario [1, 2].

Moreover, the specific 3D simulation tool just for UWSN is very difficult to develop because of the underwater environment conditions and restrictions like communication challenges, continuous mobility and different deployment scenarios[3].Resultantly, terrestrial WSN simulation techniques do not prove effective for UWSN. It is therefore, essential to review the overall network architecture in order to find a suitable network design for the demanding applications like submarine communications and surveillance.

The principles of UWSN deployment architectures in different conditions and environments are explained by the authors of the study [4]. In this paper, classification of different simulation techniques is presented in terms of different environments, GUIs, and testing parameters, etc. Nodes deployment topology of the network play important role in designing the network architecture as each network topology and architectural approach has always a major contribution in network performance. A common UWSN deployment architecture is shown in Figure 1.

UWSN has a broad area of exploration in undersea environment and UW-LSN could be the most suitable for the monitoring of underwater oil and gas pipelines[6]. The unique property of the UW-LSN is that it deploys all the sensors in linear direction. The detailed description of UW-LSN and its main component is shown in the Figure 2.

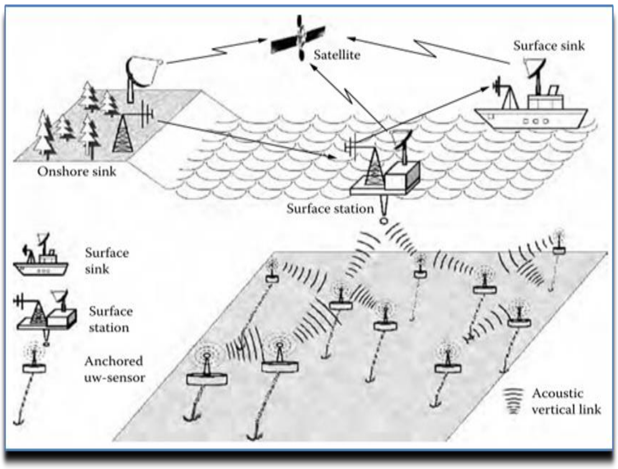

Figure 1: 3D UWSN General Architecture [5]

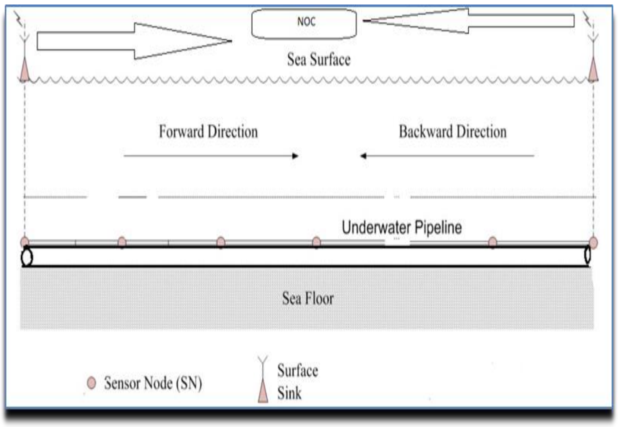

Figure 2: UW-LSN Generic Model [7]

The UW-LSN technique shown in Figure 2 contains different types of nodes:

Sensor Node (SN): These are basic sensing nodes that collect sensing data from underwater infrastructure such as pipelines. Each SN consists of limited amount of memory holding the sensing information for short period of time and then transferring the data to the next hop. The SNs are considered to be static and placed on the pipeline at regular intervals in a linear form covering the entire pipeline infrastructure.

Surface Sink: In underwater environment, most of the time sensing data is collected by basic sensor nodes and then transmitted to the Network Control Center (NCC) via surface sinks. These nodes normally float with the surface buoys and are distributed in such a way to cover length of the pipeline. These sinks nodes are normally equipped with both acoustic and RF antennas. The nodes collect information from the basic sensor nodes by acoustic channels and transfer that information to their NCC using the RF communication technology. Through using UW-LSN in the monitoring of long underwater pipeline, more sinks are placed at regular intervals; UW-LSN could also be divided into segments so that each segment could have their separate no of surface sinks.

II. Applications of LSN and UW-LSN

LSN used in an extensive range of linear structured applications including the followings:

A. Underwater Pipelines Monitoring

UW-LSN is being used for the monitoring of underwater oil and gas pipelines. The pipelines are mostly deployed in linear positions so using the LSN is more suitable option to control the flow and detect the leakage of pipeline [6, 8].

B. Railroad/Subway Monitoring

The LSN is used as well in monitoring, surveillance, and control of railroads and subways. Railway Infrastructures security and especially railways are major concern of many countries [9]. The deployment of sensors on critical components of the railed bridge and tracks is considered highly important. These sensors help to monitor the conditions of the railroad bridges and tracks to provide early detection of critical and dangerous cracks.

C. Powerlines Monitoring

Normally power lines are used to communicate their information back to the control center using the power line itself. In addition, installation of these sensors is done relatively quickly and without interrupting the service for the end customers. The linear sensor network has been helpful to monitor deep sea cables, such as long fiber optic cables.

D. Roads traffic control and vehicular networks

LSN deployed on road sides to monitor the motion of the vehicles along with the roads such as speed, accidents, and tracking [6]. Mobile vehicles can have regular communication with the fixed wireless nodes deployed on the road side; they trigger alert messages to drivers if there are any potential problems and traffic conditions ahead on the road. It also generates lifesaving warning to the car drivers to take control and to keep the sleepy drivers in active state.

E. Boarder Monitoring

National borders of the countries are used for different kinds of illegal activities such as smuggling of goods (drugs), unauthorized border crossings by civilian or military vehicles or persons, or any other kind of activities. In order to establish network for monitoring borders, different deployment strategies are used; LSN is deployed and as well as unmanned aerial vehicles are used to monitor the border [6].

F. Disaster predictions

LSN is used to measure the seismic actions of the coastal areas and inside the sea bed. It also generates tsunami warnings to the NOC (Network Operation Center).

G. Undersea Intelligence

Linearly deployed underwater sensors and AUV (Autonomous Underwater Vehicles) work for the intrusion detection, surveillance, and reconnaissance of the undersea environment. In reconnaissance, many kinds of AUV, acoustic and optical sensors are used to conduct a survey of the underwater environment providing help in detection of mines.

H. Navigation of Undersea Environment

Linearly deployed underwater sensors are used to locate risk on the seabed, to trace dangerous rocks in shallow and deep waters, and to do bathymetry profiling.

III. Pipelines Infrastructure Monitoring Methods and Technologies

The followings are commonly used pipelines monitoring technologies.

A. Physical Patrolling Technique

This is a traditional way of monitoring on the ground structures like pipelines and such kind of inspection remain possible by physical movement of the security persons who keep regular visits of the pipelines detecting the damaged position of the pipelines and thus inform the operation center preventing further damage. In real world example, Nigerian government has appointed a patrolling team of community leaders, Police and local security companies to do inspection of the pipelines. If the pipelines happen to be too long then this team also uses planes for frequent aerial supervision of the critical sections of the pipelines [4]. Although this kind of monitoring helps to make secure public or private resources but there still exists many records of damage of oil and gas pipelines.

B. Robots/ Sensors based Pipeline Infrastructure Monitoring

The static, robots, or mobile sensors are normally used to design monitoring networks and they are good enough to detect the faults in pipeline structure and update the status to the network operation center. There are multiple types of sensors deployment architectures for the monitoring of pipelines like wired networks, wireless networks, hybrid networks, or integration of wired and wireless networks [10].

C. Wired Sensor Network Architecture

Wired networks are mostly made by copper or fiber optic wires and normally used for the calculation of flow, pressure, temperature, vibration, humidity etc. These cables are used for two purposes such as data communication and power circulation to the different parts of the pipeline monitoring system. Wired sensor networks are easier to be installed but they are not much reliable for monitoring practices. They get easily damaged by cutting the wires. The common solution to increase reliability of wired networks could be made by dividing the whole network into multiple individual parts so that damage of the cut can become limited to that part.

D. Pipeline SCADA (Supervisory Control and Data Acquisition)

The SCADA monitoring system architectures is mainly based on centralized management system for data collection and control. This system deploys a large number of remote terminal units at different positions to check the pressure, temperature and flow of oil or gas in the pipeline. SCADA systems are basically designed to keep an eye on the security status of the entire pipeline and trigger maintenance actions for technical staff of the pipelines monitoring system [11]. SCADA system has a major challenge to implement fool proof security for pipeline monitoring. The main weakness of the typical SCADA systems is its static architecture that may minimize the limits of the system. Secondly the SCADA systems are rigid in design making them inflexible to adapt to new the applications.

E. Wireless Sensor Networks

Wireless networks have special features that are not available in other networks; like these are infrastructure less and flexible to deploy in different kind of environments. Similarly, it also works on the distributed, dynamic topology, independent and specific tasks based applications. A wireless sensor network is designed through a set of connected wireless sensor nodes and date flow on wireless communication channels. Each wireless sensor node participates in basic sensing and it collects data at different positions and the environments. Each node establish link with its neighbor nodes or NOC by using of communication protocol. These types of networks are common in practice for environment monitoring applications, home security, industrial process monitoring, health care applications and pipelines monitoring [12-14].

IV. Specific Issues Of The Pipelines Monitoring

There are many open issues which could lead to new areas of research in the field of wireless sensor networks in general and LWSN (Linear Wireless Sensor Networks) in special [15]. The main challenges and issues to design a LWSN are discussed in this section with their brief details.

A. Energy Management for Linear Topology Wireless Sensor Network

Energy management is always considered as one of the main challenge for WSN. The wireless sensor nodes are most small in size and having limited battery. It is not easy to replace or recharge these batteries so it requires the energy management to maximize the network lifetime. This issue should be considered while designing of LWSN long life communication network. Energy efficient communication protocol can play major role to stabilize the network as the linear topology is a distinctive way of wireless communications. Normally sensor nodes are limited in directional transmission along the linear path of sensor node distributions. The special protocols are needed to design LWSN that intelligently schedule the status of sensor nodes to save the energy and maximize the network life.

B. Communication Challenges

The designing of LWSN communication protocol is another major challenge for the long distance linear structures. The reason behind the requirement of LWSN communication protocol is that the two-dimensional communication protocols and multidimensional communication protocols do their route discovery and maintenance by using different strategies such as flooding and develop complete path between source and destination nodes. On the other hand, LWSN communication protocols do not require the costly process of flooding for route discovery as network topology is already known. For the communication of LWSN an addressing scheme is easily used in order to discover the routes and maintain communication between the nodes. Moreover, route maintenance in LWSN communication protocol is done automatically at the intermediate nodes by detecting the failure node address and by redirecting the traffic towards active nodes. It is better to use static addressing scheme that use to assign the nodes addresses just once at the time of network initialization.

C. Localization Challenges

The information about exact or relative position of the sensor nodes is essential for WSN communication protocols. This information is used efficiently for application specific tasks. For the networking communication functions like in monitoring systems, it is highly required to know about the event and occurring position. Localization [26] or position estimation in sensor networks has been always helpful for the applications such as object tracking, communication, coverage management and collaborative signal processing. There are various kinds of location schemes but they are mainly based on the direct and indirect approaches using absolute and relative addresses of nodes for the localization

D. Simulation tools and 3D visual results production challenges

The availability of 3D underwater simulation tool and testing of results is a critical issue. Most of the researchers use to customize the available tools according to their requirement but that cannot be used for general underwater applications. It is highly required to develop a specific underwater simulation tool that could provide support for testing of different parameters such as temperature, depth salinity, communication between nodes in different underwater environments like on water surface, shallow water, deep sea or at sea bed.

V. Comparison of Simulation Tools for Pipeline's Monitoring Evaluation Methods

There are different kinds of existing simulation tools for pipelines monitoring listed and compared in Table 1. This table shows that most of the researchers evaluate their research by hardware test beds in labs because proper 3D simulation tools are missing in this field.

It shows that most of pipelines are deployed in 3D environments like above ground, underground or in underwater but still it is hard to find a general 3D simulation tool for testing of these techniques.

On the hand, if we look at GUI support then it is clear that there are only few techniques that have this interface for evaluation of their monitoring process.

These available GUIs are mostly designed for testing the communication between sensors but they don't have 3D environment visualization support. In case of underwater applications environment setting being dynamic in nature, also play a major role in testing monitoring. Most of the researchers customize available 3D simulation tools for their specific application. It is highly required to design a general 3D simulation tool which could prove supportive as well for the benchmarking. Due to missing of general purpose 3D simulation tools, expensive evaluation solutions are commonly in use like lab test beds. These solutions are not feasible for underwater pipeline monitoring due to harsh and dark underwater environment.

It is shown in previous discussions that most of the research is being conducted on the ground pipeline monitoring, underground sewerage pipe monitoring while underwater pipelines monitoring still needs attention of the researchers. According to the Table 1, most of the existing pipelines monitoring techniques are deployed in 3D environments while the available simulation tools are mostly designed for 2D environment.

Most of the available tools do not have GUI support for network designing and visualization of 3D results and they are customized to fulfill the requirement of the specific application. The general 3D simulation tool with 3D visualization results is still missing to help researchers for evaluation of their results. The above diagrams present the classification of monitoring techniques according to the different kinds of simulation environments, GUI support, simulation tool customization and real lab test.

Table 1
Comparison of Pipelines Monitoring Simulation Tools and Evaluation Methods

Technique	Signal/Channel Support	3D/2D Deployment	GUI Support	Customized / Generic	Evaluation Environment	OSI Layer Support	Remarks
SPAMMS [16]	RFID	3D	Yes	Customized	Lab test	Physical	Feasible only for on-ground pipelines
PIPENET [17]	Acoustic, WSN	3D	Yes (Spider 8 DAQ)	Customized	Lab test	Physical	Not feasible for underwater
SewerSnort [18]	GPS, WSN	3D	Yes (3D SewerSnort schematic)	Customized	Lab test	Physical	Not feasible for underwater
SRJ Algorithm [19]	Acoustic	2D	N/A	Generic	N/A	Routing	Requires extra computational work
KANTARO [20]	Laser Optical	3D	Yes (naSIR mechanism)	Customized	Lab Test	Physical	Not feasible for underwater environment
SCADA [21]	Wired, Wi-fi, GPS	3D	Yes (AquaMet)	Generic	Open Source / Commercial	Physical	Not feasible for underwater pipelines
SWATS [22]	Pressure and Acoustic	3D	Yes	Customized	Use SCADA as Testbed	MAC	Not feasible for underwater pipelines
Distributed Topology Discovery Algorithm [23]	All Signalling Methods	2D	N/A	Generic	N/A	Routing	Single sink architecture with higher delay
AUV Based [7]	Acoustic, WIMAX, GPS	2D	N/A	Customized	Performance Comparison	Routing	Feasible for interval based monitoring not for event based.
Post Disaster Road Monitoring algorithm [24]	WSN	2D	N/A	Customized	Nodes Location Assignment	Routing	Requires buffers of neighbour tables for routing
TriopusNet [25]	WSN	3D	N/A	Customized	Lab test+ Real Time Pipeline Test	Physical, Routing	Require many robots and expensive for underwater pipelines inspection

VI. CONCLUSION

This research study has presented a brief overview about the design structure of LWSN highlighting the issues of underwater environment sensor network evaluation. After having compared the existing simulation tools and setups, it concludes that more the 70% techniques have no any GUI support, only physical layer lab tests without acoustic communication while for large scale pipe monitoring, routing evaluation is highly important to be considered. Besides, Table 1 highlights that more the 50% techniques are deployed in 3D environment but due to lack of 3D general purpose simulation tool, the expensive way of testing is adopted in labs by using test beds. The paper finally concludes that a generic 3D simulation tool is highly required for the underwater pipeline monitoring networks evaluation.

ACKNOWLEDGMENT

This research was at conducted at Universiti Teknologi Malaysia (UTM). The authors greatly acknowledge the Research Management Center, UTM and Ministry of Higher Education (MOHE) Malaysia for financial support through Fundamental Research Grant Scheme (FRGS) Vot. No R.J130000.7828. 4F788.

REFERENCES

[1] I. F. Akyildiz, D. Pompili, and T. Melodia, "Challenges for efficient communication in underwater acoustic sensor networks," *ACM Sigbed Review,* vol. 1, pp. 3-8, 2004.

[2] M. Murad, A. A. Sheikh, M. A. Manzoor, E. Felemban, and S. Qaisar, "A Survey on Current Underwater Acoustic Sensor Network Applications," *International Journal of Computer Theory and Engineering,* vol. 7, p. 01, 2015.

[3] R. L. Thompson, N. Lesnikowski, B. Rush, E. E. Potrzebowski, and D. Richardson, "New 2D and 3D Acoustic Tools and Techniques for Underwater Metrology and Inspection," in *Offshore Technology Conference*, 2012.

[4] 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, pp. 23-33, 2007.

[5] D. Pompili and T. Melodia, "Three-dimensional routing in underwater acoustic sensor networks," in *Proceedings of the 2nd ACM international workshop on Performance evaluation of wireless ad hoc, sensor, and ubiquitous networks*, 2005, pp. 214-221.

[6] I. Jawhar, N. Mohamed, and D. P. Agrawal, "Linear wireless sensor networks: Classification and applications," *Journal of Network and Computer Applications,* vol. 34, pp. 1671-1682, 2011.

[7] I. Jawhar, N. Mohamed, J. Al-Jaroodi, and S. Zhang, "An efficient framework for autonomous underwater vehicle extended sensor networks for pipeline monitoring," in *Robotic and Sensors Environments (ROSE), 2013 IEEE International Symposium on,* 2013, pp. 124-129.

[8] M. Z. Abbas, K. A. Bakar, M. A. Arshad, M. Tayyab, and M. H. Mohamed, "Scalable Nodes Deployment Algorithm for the Monitoring of Underwater Pipeline," *TELKOMNIKA (Telecommunication Computing Electronics and Control),* vol. 14, 2016.

[9] M. Hartong, R. Goel, and D. Wijesekera, "Security and the US rail infrastructure," *International Journal of Critical Infrastructure Protection,* vol. 1, pp. 15-28, 2008.

[10] N. Mohamed, I. Jawhar, J. Al-Jaroodi, and L. Zhang, "Sensor network architectures for monitoring underwater pipelines," *Sensors,* vol. 11, pp. 10738-10764, 2011.

[11] R. Gordon and J. Atkinson, "Clarke et al," *Practical modern SCADA protocols: DNP3,* vol. 60870, 1991.

[12] E. Fadel, V. Gungor, L. Nassef, N. Akkari, M. A. Maik, S. Almasri, *et al.*, "A Survey on Wireless Sensor Networks for Smart Grid," *Computer Communications,* 2015.

[13] A. Singh and T. Sharma, "A survey on area coverage in wireless sensor networks," in *Control, Instrumentation, Communication and Computational Technologies (ICCICCT), 2014 International Conference on*, 2014, pp. 829-836.

[14] A.-K. Tariq, A.-T. Ziyad, and A.-O. Abdullah, "Wireless sensor networks for leakage detection in underground pipelines: a survey paper," *Procedia Computer Science,* vol. 21, pp. 491-498, 2013.

[15] A. C. Azubogu, V. E. Idigo, S. U. Nnebe, and O. S. Oguejiofor, "Wireless Sensor Networks for Long Distance Pipeline Monitoring."

[16] J.-H. Kim, G. Sharma, N. Boudriga, and S. S. Iyengar, "SPAMMS: a sensor-based pipeline autonomous monitoring and maintenance system," in *Communication Systems and Networks (COMSNETS), 2010 Second International Conference on*, 2010, pp. 1-10.

[17] I. Stoianov, L. Nachman, S. Madden, T. Tokmouline, and M. Csail, "PIPENET: A wireless sensor network for pipeline monitoring," in *Information Processing in Sensor Networks, 2007. IPSN 2007. 6th International Symposium on*, 2007, pp. 264-273.

[18] J. Kim, J. S. Lim, J. Friedman, U. Lee, L. Vieira, D. Rosso, *et al.*, "SewerSnort: A drifting sensor for in-situ sewer gas monitoring," in *Sensor, Mesh and Ad Hoc Communications and Networks, 2009. SECON'09. 6th Annual IEEE Communications Society Conference on*, 2009, pp. 1-9.

[19] N. Mohamed, J. Al-Jaroodi, I. Jawhar, and S. Lazarova-Molnar, "Failure impact on coverage in linear wireless sensor networks," in *Performance Evaluation of Computer and Telecommunication Systems (SPECTS), 2013 International Symposium on*, 2013, pp. 188-195.

[20] A. A. Nassiraei, Y. Kawamura, A. Ahrary, Y. Mikuriya, and K. Ishii, "A New Approach to the Sewer Pipe Inspection: Fully Autonomous Mobile Robot" KANTARO"," in *IEEE Industrial Electronics, IECON 2006-32nd Annual Conference on*, 2006, pp. 4088-4093.

[21] B. Miller and D. Rowe, "A survey SCADA of and critical infrastructure incidents," in *Proceedings of the 1st Annual conference on Research in information technology*, 2012, pp. 51-56.

[22] S. Yoon, W. Ye, J. Heidemann, B. Littlefield, and C. Shahabi, "SWATS: Wireless sensor networks for steamflood and waterflood pipeline monitoring," *Network, IEEE,* vol. 25, pp. 50-56, 2011.

[23] I. Jawhar, N. Mohamed, and L. Zhang, "A distributed topology discovery algorithm for linear sensor networks," in *Communications in China (ICCC), 2012 1st IEEE International Conference on*, 2012, pp. 775-780.

[24] X. Sun, J. He, Y. Chen, S. Ma, and Z. Zhang, "A new routing algorithm for linear wireless sensor networks," in *Pervasive Computing and Applications (ICPCA), 2011 6th International Conference on*, 2011, pp. 497-501.

[25] T. T.-T. Lai, W.-J. Chen, K.-H. Li, P. Huang, and H.-H. Chu, "TriopusNet: automating wireless sensor network deployment and replacement in pipeline monitoring," in *Proceedings of the 11th international conference on Information Processing in Sensor Networks*, 2012, pp. 61-72.

[26] C. W. Chen and Y. Wang, "Chain-Type Wireless Sensor Network for Monitoring Long Range Infrastructures: Architecture and Protocols∗," *International Journal of Distributed Sensor Networks,* vol. 4, pp. 287-314, 2008.