DEVELOPMENT OF AODV BASED STATIC MULTI-HOP LINEAR ROUTING ALGORITHM USING 802.11 WIRELESS SENSOR NETWORK FOR OIL AND GAS PIPELINE

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MASTER OF SCIENCE IN ELECTRONIC ENGINEERING

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A thesis submitted
in fulfillment of the requirements for the degree of
Master of Science in Electronic Engineering

Faculty of Electronic and Computer Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

DECLARATION

I declare that this thesis entitled "Development Of AODV Based Static Multi-hop Linear Routing Algorithm Using 802.11 Wireless Sensor Network for Oil And Gas Pipeline" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature :

Name :

Date :

APPROVAL

I hereby declare that I have read this thesis, and in my opinion, this thesis is sufficient in terms of scope and quality for the award of the degree of Master of Science in Electronic Engineering.

Signature :

Supervisor Name :

Date :

DEDICATION

This thesis is dedicated to my parent who unconditionally supports and prays for my success, to my supervisors Dr Siva Kumar Subramaniam and Dr Farah Shahnaz Feroz who have been guiding me from the beginning of this journey as well as Jacqueline, Amierul and Azizul for the assistance and encouragement.

ABSTRACT

In recent years, the growing requirement for a static multi-hop wireless sensor network (WSN) has dominated remote supervision of the integrity of oil and gas pipelines. In the pipeline network, the sensing points are linked via wireless nodes connecting inspection points remotely to a centralised monitoring station. The introduction of the WSN to the pipeline network has critical factors leading to the deterioration of the overall network performance corresponding to the density of the network. In the selected application, the midstream of the oil and gas industry, the nodes must be arranged in a linear architecture to cover the length of the pipe. Such geographically diverse network configuration has a major effect on the disintegration of network stability, throughput unfairness, higher latency and energy usage from improper exploitation of network resources due to competitive data transmission, resulting in data snowballing effect on the destination node. Node starvation is also a factor that seriously affects the network performance of a large scale WSN multi-hop linear network. Unbalanced allocation of network resources between source nodes leads to the starvation of the node, which is a comparatively intensified factor overproduced data packets and source node distance from the destination node. Energy improvement in a static multi-hop linear topology is also linked to the lifetime of the network and is essential to the heterogeneous energy consumption nodes in the network. To decipher the mentioned problems, this thesis highlighted the challenges faced during the deployment of WSN in a large-scale network. The objective of this research is to develop a reliable AODV based multi-hop linear routing algorithm in accordance with IEEE 802.11 and to analyse the network performance implementing the proposed technique. This thesis highlighted two proposed routing algorithms namely Ad-hoc On-Demand Distance Vector Even, and Odd (AODVEO) and Ad-hoc On-Demand Distance Vector Triple Interleaving (AODVTRI) benched marked with commercial routing protocols Ad-hoc On-Demand Distance Vector (AODV) as well as Distance Sequence Distance Vector (DSDV). In AODVEO, the load of the traffic is reduced by splitting the traffic into two different routes (1) even-path and (2) odd-path with the consideration of x-axis. On the other hand, in AODVTRI, the traffic is divided into three different routes (1) alpha path, (2) beta path, and (3) charlie path with consideration of x-axis. Results showed that when the proposed technique is compared to the existing routing protocols in different simulation environments in conjunction with IEEE 802.11 standard, AODVEO showed improved network reliability (delivery ratio) as high as 19% and 15% in comparison to AODV and DSDV. In contrast, AODVTRI presented up to 26% and 22% of improvement when compared to AODV and DSDV, respectively. In terms of capacity (throughput) as well as energy, AODVEO showed up to 9 kbps more with 0.038J less energy consumption per packet and up to 13kbps more with 0.095J less energy consumption per packet when compared to AODV and DSDV. AODVTRI, on the other hand, showed up to 18 kbps more throughput with 0.082J less energy per packet when compared to AODV and up to 22kbps more with 0.140J less energy consumption per packet when compared to DSDV.

PEMBANGUNAN ALGORITMA PENGHALAAN LELURUS BERBILANG HOP STATIK BERDASARKAN AODV MENGGUNAKAN RANGKAIAN PENDERIA WAYARLES 802.11 UNTUK SALURAN PAIP MINYAK DAN GAS

ABSTRAK

Sejak kebelakangan ini, permintaan yang meningkat untuk rangkaian sensor tanpa wayar multi-hop statik telah mendominasi pemantauan jarak jauh terhadap intergriti saluran paip minyak dan gas. Dalam rangkaian saluran paip, titik sensor dihubung menggunakan nod tanpa wayar yang menghubungkan titik yang diukur dari jarak jauh ke stesen pemantauan berpusat. Pengenalan WSN pada jaringan paip mempunyai faktor kritikal yang menyebabkan kemerosotan prestasi keseluruhan rangkaian seiring dengan kepadatan rangkaian. Dalam aplikasi terpilih iaitu aliran tengah industri minyak dan gas, nod mesti disusun dalam linier untuk meliputi jarak yang jauh. Geografi senibina rangkaian yang unik ini mempunyai kesan besar terhadap ketidakstabilan rangkaian, ketidakadilan daya pemprosesan, latensi dan penggunaan tenaga yang tinggi disebabkan penggunaan sumber rangkaian yang tidak tepat kerana penghantaraan data yang kompetitif yang mengakibatkan kesan bola salji data pada nod destinasi. Kelaparan nod adalah faktor lain yang secara serius mempengaruhi prestasi rangkaian dalam WSN linear multi-hop skala besar. Peruntukan sumber rangkaian yang tidak seimbang antara nod menyebabkan kebuluran nod, yang merupakan faktor yang meningkat kerana penghasilan paket data dan jarak nod sumber dari nod destinasi. Pengoptimuman tenaga dalam topologi linear multi-hop juga dikaitkan dengan jangka hayat rangkaian dan penting bagi penggunaan tenaga berbeza di nod dalam rangkaian. Untuk menguraikan faktor-faktor ini, tesis ini telah mengetengahkan cabaran yang dihadapi semasa penyebaran WSN dalam rangkaian berskala. Objektif penyelidikan ini adalah untuk membina algoritma peralihan linear multi-hop berasaskan AODV dengan piawaian IEEE 802.11 dan menganalisasi perstasi rangkaian yang menggunakan teknik yang dicadangkan.Tesis ini mengusulkan dua algoritma penghalaan iaitu Ad-hoc On-Demand Distance Vector Even dan Odd (AODVEO) dan Ad-hoc On-Demand Distance Vector Triple Interleaving (AODVTRI) yang ditanda aras dengan routing komersial Ad-hoc On-Demand Distance Vector (AODV) serta Disnatnce Sequence Disntacne Vector (DSDV). Beban lalu lintas di AODVEO dikurangkan dengan membahagikan lalu lintas kepada dua laluan yang berbeza (1) laluan genap, dan (2) laluan ganjil dengan pertimbangan paksi-x. Sebaliknya, lalu lintas di AODVTRI dibahagikan kepada tiga laluan iaitu (1) laluan alfa, (2) laluan beta, dan (3) laluan charlie dengan pertimbangan paksi-x. Apabila teknik yang dicadangkan dibandingkan dengan protokol komersial dalam persekitaran simulasi yang berbeza seiring dengan piawaian IEEE 802.11, AODVEO menunjukkan peningkatan kebolehpercayaan rangkaian (nisbah penghantaran) sehingga 19% dan 15% berbanding AODV dan DSDV. Sebaliknya, AODVTRI menunjukkan peningkatan sebanyak 26% dan 22% jika dibandingkan dengan AODV dan DSDV. Dari segi kapasiti (throughput) dan juga tenaga, AODVEO menunjukkan 9kbps lebih dengan 0.036J kurang penggunaan tenaga setiap paket dan 13kbps lebih dengan 0.095J kurang penggunaan tenaga setiap paket jika dibandingkan dengan AODV dan DSDV. AODVTRI pula menunjukkan throughput sehingga 18kbps lebih banyak dengan 0.082J kurang tenaga per paket jika dibandingkan dengan AODV dan 22kbps lebih dengan pengurangan penggunaan tenaga setiap paket sebanyak 0.140J jika dibandingkan degnan DSDV.

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Gracious, the Most Merciful

All praise to Allah SWT and His grace for the accomplishment of this thesis. I thank and praise my Creator, my Sustainer, for all the opportunities, trials and helps that have been showered on me during the completion of this thesis. I have learned and grow a lot during this process, not only academically but also in my personality.

First and foremost, I would like to take this opportunity to express my sincere gratitude to my main supervisor, Dr. Siva Kumar Subramaniam, Universiti Teknikal Malaysia Melaka (UTeM), for his guidance, support, and inspiration. His positive and warm encouragement that keeps me motivated to complete my study will not be forgotten. I would like to offer my gratitude to my co-supervisor, Dr. Farah Shahnaz Feroz, Universiti Teknikal Malaysia Melaka (UTeM), who supported my journey throughout my study. I offer my special thanks to Mr. Mazran Esro, Universiti Teknikal Malaysia Melaka (UTeM), for all help and encouragement I have got from him. I would like to extend my gratitude to Universiti Teknikal Malaysia Melaka (UTeM) for the provision of the research platform.

Last but not least, my deepest gratitude to my parents, Ikhwan Lee and Masdzalinda, for their unfailing encouragement and prayers for my success. Also, to my siblings, Mohamad Elmy Lee and Nor Alissa Lee, for the creative suggestion and ideas that help me to complete this thesis. I would like to convey my appreciation to my partner and friends, Jacqueline, Amierul, and Azizul, for the assistance, encouragement, and inspiration throughout the completion of this thesis.

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LIST OF SYMBOLS AND ABBREVIATIONS

ABR	-	Associativity-Based Routing
ACK	-	Acknowledgement
ACO	-	Ant Colony Optimization
AnTHocMMP	-	AntHoc Max-Min-Path
AODV	-	Ad-hoc On-demand Distance Vector
AODVEO	-	Ad-hoc On-demand Distance Vector Even and Odd
AODVTRI	-	Ad-hoc On-demand Distance Vector Triple Interleaving
APMD	-	Adaptive Persistent M Data Packet
BRP	-	Bordercast Resolution Protocol
BQ	-	Broadcast Query
CARP	-	Channel-Aware Routing Protocol
CDG	-	Compressive Data Gathering
CP	-	Control Packet
DNS	-	Domain Name System
DP	-	Data Packet
DSDV	-	Distance Sequence Distance Vector
EECSR	-	Energy-Efficient Compressive Sensing-Based Clustering Routing
FIFO	-	First-In-First-Out
GHz	-	GigaHertz
HTTP	-	Hypertext Transfer Protocol
IARP	-	Intra-zone Routing Protocol
ID	-	Identification
IEEE	-	Institutes of Electrical and Electronics Engineers
IERP	-	Inter-zone Routing Protocol
IP	-	Internet Protocol
ISO	-	International Organization for Standardisation
J	-	Joule
km	-	Kilometre
LAN	-	Local Area Network

LEACH	-	Low Energy Adaptive Clustering Hierarchy
LNG	-	Liquefied Natural Gas
LQ	-	Local Query
LR-WPAN	-	Low-rate Wireless Personal Area network
LWSN	-	Linear Wireless Sensor Network
MANET	-	Mobile Ad-hoc Network
Mbps	-	Megabit per second
MHZ	-	MegaHertz
MPR	-	Multi-point Relays
mW	-	mili Watt
ND	-	Destination node
NIS	-	Network Information Service
NS	-	Network Simulator
OLSR	-	Optimized Link State Routing Protocol
OSI	-	Open Systems Interconnection
PAN	-	Persoanal Area Network
PDORP	-	PEGASIS-DSR Optimized Routing Protocol
RD	-	Route Delete
RF	-	Radio Frequency
RN	-	Route Notification
RREP	-	Route Reply
RRER	-	Route Error
RSSI	-	Received Signal Strength Indicator
RREQ	-	Route Request
SMTP	-	Simple Mail Transfer Protocol
SPT	-	Shortest Path Tree
t	-	Time
TC	-	Topology Control
TCL	-	Tool Command Language
TCP	-	Transmission Control Protocol
TTL	-	Time To Live

UWSN	-	Underwater Wireless Sensor Network
VANET	-	Vehicular Ad-hoc Network
Wi-Fi	-	Wireless Fidelity
WLAN	-	Wireless Local Area Network
WMN	-	Wireless Mesh Network
WSN	-	Wireless Sensor Network
ZRP	-	Zone Routing Protocol

LIST OF PUBLICATIONS

Journal with Impact Factor

N/A

Indexed Journal

Lee, M.Y., Azman, A. S., Subramaniam,S. K., and Feroz, F.S., 2022. Network Performance Optimisation Using Triple Interleaving Routing Algorithm for Oil and Gas Pipeline Network. *International Journal of Communication Network and Distributed System ,2022.* (Scopus Indexed, Q3)

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N/A

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CHAPTER 1

INTRODUCTION

1.1 Background

The oil and gas industry is known as one of the world's largest conglomerates involving complicated and critical crude oil refining methods. The oil and gas pipeline is a well-known and cost-effective means of transportation worldwide for the distribution of various liquefied or gas supplies such as raw or refined oil products and gas. In a large scale implementation, pipeline transportation is an interdependent networking system that transfers millions of liquefied supplies every day around the world (Ali *et al.* 2015, Green and Jackson 2015a). The pipeline is one of the leading transportation modes for the oil and gas industry that could be laid both offshore and onshore. Pipeline transportation requires close monitoring as a failure in pipelines causes disruption of supply, loss of precious commodity, and not to mention irreversible environmental damage (Ali *et al.* 2015). However, pipelines are known to be one of the safest transportation media in the oil and gas sector (Green and Jackson 2015b, Strogen *et al.* 2016).

As demand for oil and gas exploration continues to rise, remote monitoring of pipelines using wireless sensor network (WSN) has gained popularity. Remote pipeline monitoring has become more prevalent due to the rapid enhancement of communication protocol technology, sensing capabilities, energy-efficient wireless devices, and lower implementation costs for broad applications. (Al-ghamdi *et al.* 2010, Carlsen and Asa 2010, Ali *et al.* 2015, Subramaniam, Khan, *et al.* 2017). WSN is a collection of sensors that can sense, process, and communicate, forming a network for monitoring the physical world (Khan *et al.* 2017). By implementing wireless sensor devices that reduce infrastructure costs by up to 80% compared to wired technologies, the oil and gas industry would be able to maximise their production. Since the pipelines are located in a remote area, accidents or unwanted tragedies are highly possible to occur. For example, on April 12, 2019, The Straits Time reported that two people were injured during the explosion at Petronas oil and gas complex in Kampung Lepau, Johor, Malaysia (Explosion at Petronas oil and gas complex in Johor injures two, damages houses, SE Asia News and Top Stories - The Straits Times 2019). These pipelines were also exposed to terrorist attacks (Bjerga and Aven 2016). Moreover, infrastructure defects such as cracking due to corrosion or external climate may reduce the pipeline's performance (Arun Sundaram *et al.* 2018). A secure and reliable system is highly needed to track, control, and manage the integrity of the pipeline remotely to minimise risk without affecting industrial production.

The oil and gas industry is divided into three major sectors, upstream, midstream, and downstream, as described in Figure 1.1. In the upstream sector, the exploration and extraction of raw materials that can be found either underground or underwater took place (Cordes *et al.* 2016). This sector is usually located in the middle of the ocean. There are three types of methods used to extract oil and gas: primary recovery, secondary recovery, and enhanced recovery. Primary recovery uses the underwater pressure to move fluids to the surface and uses artificial lifting techniques such as pumping to carry the materials to the surface.

On the other hand, secondary recovery is the most used recovery strategy where water is pumped back into the oil-bearing reservoir to get more oil out of the ground during the drilling process. Enhanced recovery is typically used to retrieve the leftover oil from the area. One solution is thermal recovery, where the steam is pumped into the reservoir, and the elevated pressure brings the products to the surface.

Before moving the raw resources to the next sector, they will undergo field processing and be stored temporarily. Several processes will be done, including the separation of crude oil, natural gas, and water. After separation, the raw materials are stored in various storage containers, such as floating roof tanks, pressure tanks, and liquefied natural gas (LNG) tanks (Abdel-Aal *et al.* 2015). Besides processing and storage, it is mainly the responsibility of the midstream to transport materials from the upstream to the midstream sector through pipelines, ships or oil tankers.

Upon entering the downstream sector, the resource must be processed, stored and converted into finished products before being marketed. The commercialised commodity includes diesel fuel, gasoline, synthetic rubber, home heating oil, lubricants, kerosene and plastics. The developed product undergoes various evaluations, including the International Organization for Standardization (ISO) test before they are commercialised. The distribution mechanism utilised in midstream is typically on a smaller scale, primarily to transfer materials between storage and refinery plants.

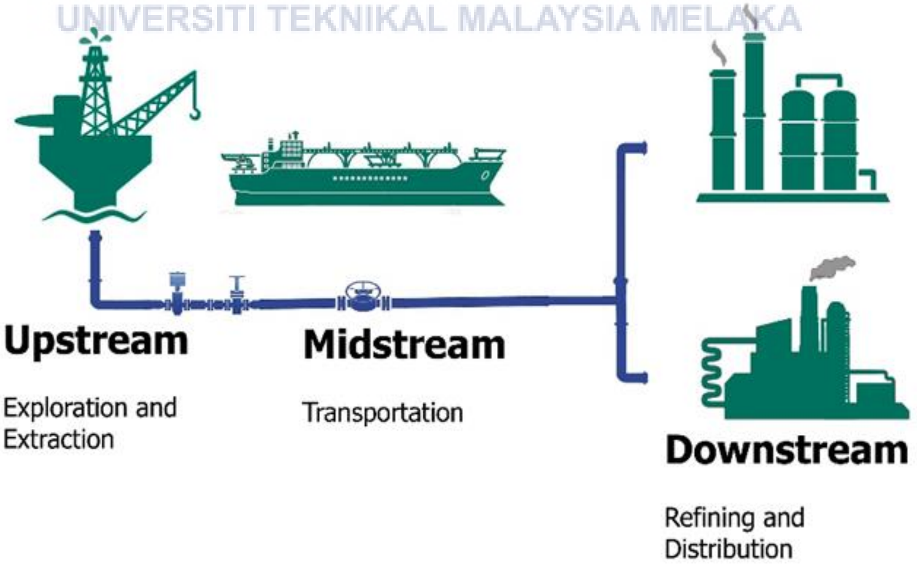

Figure 1.1 Upstream, Midstream and Downstream

While there are different types of transportation modes, such as trucks and oil tankers, which are more flexible in terms of the pathway, pipelines remain the most reliable and secure way of transporting valuable materials. Several reports have shown that pipeline failures do occur, but the number of recorded incidents is minimal compared to other forms of transport (Gilbert and Zalik 2019). Nonetheless, there are several factors, such as climate change, that can affect the proficiency of the pipeline. As a result, pipelines demand a dependable and consistent monitoring system to detect any irregularities so that the authorities can take precautions to avail themselves of any disastrous event.

Midstream sectors, typically situated between the upstream and downstream sectors, generally consist of a wide range of distances. According to Mordor Intelligence, pipeline capacity in Malaysia is around 5.2 billion cubic meters per year. In contrast, the length of the pipeline is roughly 2500 kilometres (Malaysia Oil and Gas Midstream Market Growth, Trends, and Forecasts (2020 - 2025) 2016). As a result, the transportation of the materials in midstream requires lengthy coverage of pipelines, as illustrated in Figure 1.2. Sensors nodes will be mounted at various points of the pipelines to ensure that the state of all the pipelines is covered and monitored. With the availability of the various type of sensors that can be integrated into the network, the safety, reliability, integrity, health and security of the pipeline can be significantly improved.