DEVELOPMENT OF A WIRELESS MESH NETWORK ROUTING ALGORITHM FOR OIL AND GAS PIPELINE NETWORKS

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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
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DECLARATION

I declare that this thesis entitled "Development of A Wireless Mesh Network Routing Algorithm for Oil and Gas Pipeline Networks" 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 candidature of any other degree.

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Date	:	15/6/2021

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 : Dr. Siva Kumar Subramaniam

Date : 30/7/2021

DEDICATION

I dedicate this thesis to my parents, Suraini Buyadi and Azman Jaffar.

ABSTRACT

In the past decades, wireless sensor networks (WSNs) progressed with more advanced and sophisticated wireless technologies and sensors, predominantly for high-risk applications such as oil and gas pipelines remote monitoring. In the refinery area of oil and gas, a large scale of multi-points of sensing is required due to the wide distribution of pipeline network. WSN accommodates the collection of the gathered sensory data to the sink station with quality of service proportional to the network density. A larger amount of data are generated into the traffic as more number of sensor nodes introduced in the network. Since oil and gas pipeline monitoring application requires continuous data gathering, every sensor node will have to continuously transmit its data to the destination node. Consequently, the network will be experiencing bottleneck and performance degradation state due to the accumulation factor of the packets in the queue. Apart from that, due to different data rate area, the network resources have been utilised by the nodes without fairly manner, where the nodes closer to the destination point consume more resources and energy as compared to the nodes further from the sink point. The purpose of this research is to develop an enhanced routing algorithm suitable for oil and gas pipeline application in the refinery area. The second purpose of this research is to analyse the performance of the developed algorithm. A reactive routing algorithm, known as Odd-Even for Grid (OEG), has been developed for grid multi-hop topology to ensure the network is applicable for an application that requires wide coverage area, such as oil and gas refinery pipeline integrity monitoring. OEG algorithm implements load balancing features to lessen the contention of the packets in the traffic by separating the traffic into odd and even traffic. With the exception of the sink point, a node with even/odd-numbered address will only communicate with the rest of the respective nodes with even/odd-numbered address. By using OEG algorithm, the amount of broadcast packets also can be reduced. In accordance with IEEE 802.11, the tested and observed results in different simulation environment have shown an improved overall network performance in terms of packet delivery ratio (1–60%), throughput (1–19kbps), passive nodes (1-48%), fairness index (0.04-0.19), and energy consumption (0.01-1.48J). The improvement on packet delivery ratio using OEG algorithm has satisfied the benchmark of packet delivery ratio used by the other researchers for industrial applications. Hence, as compared to AODV and OLSR, OEG algorithm can suit better for continuous sensing application such as oil and gas pipeline monitoring. The research has highlighted the incompetency of the deliverable of the fairness index as the lacking point of OEG algorithm.

PEMBANGUNAN ALGORITMA PENGHALAAN BAGI SATU RANGKAIAN JEJARING WAYARLES UNTUK RANGKAIAN TALIAN PAIP MINYAK DAN GAS

ABSTRAK

Pada dekad-dekad sebelum ini, rangkaian sensor wayarles (WSNs) telah maju dengan adanya teknologi wayarles dan sensor yang terkini dan canggih, terutamanya untuk aplikasi-aplikasi yang berisiko tinggi seperti pemantauan jauh talian paip minyak dan gas. Didalam perkarangan loji penapis minyak dan gas, titik pengesanan berganda yang berskala besar amatlah diperlukan kerana taburan rangkaian talian paip yang luas. WSN memudahkan pengumpulan data sensor yang telah diperolehi ke stesen destinasi dengan kualiti servis yang berkadar kepada ketumpatan rangkain. Lebih banyak bilangan data yang dijana di dalam trafik disebabkan bilangan nod sensor yang diletakkan di dalam rangkaian juga lebih banyak. Oleh kerana aplikasi pemantauan talian paip minyak dan gas memerlukan pengumpulan data yang berterusan, setiap nod sensor hendaklah menghantar data secara berterusan kepada nod destinasi. Akibatnya, rangkaian tersebut akan mengalami kejejalan dan degradasi prestasi kerana faktor pengumpulan paket di dalam baris-gilir. Selain itu, disebabkan kawasan yang berbeza kadar data, sumber rangkaian telah digunakan secara tidak sekata dan tidak adil, dimana nod yang lebih dekat dengan nod destinasi menggunakan lebih banyak sumber dan juga tenaga jika dibandingkan dengan nod yang jauh dari nod destinasi. Tujuan kajian ini adalah untuk membangunkan sebuah algorithma yang tertingkat sesuai untuk talian paip minyak dan gas di perkarangan loji penapis. Tujuan kedua kajian ini adalah untuk menganalisa prestasi algorithma penghalaan yang telah dibangunkan. Sebuah algorithma penghalaan dikenali sebagai Ganjil-Genap untuk Grid (OEG) telah dibangunkan untuk topologi grid multi-loncatan untuk memastikan rangkaian dapat digunakan untuk aplikasi yang memerlukan liputan kawasan yang luas, seperti pemantauan keutuhan talian paip di penapisan minyak dan gas. Algorithma OEG mengimplementasikan ciri-ciri pengimbangan beban untuk mengurangkan persaingan paket-paket di dalam trafik dengan memisahkan trafik kepada trafik ganjil dan trafik genap. Tanpa mengambil kira nod destinasi, nod yang beralamat nombor genap/ganjil hanya akan berkomunikasi dengan nod-nod selebihnya berdasarkan alamat mereka yang bernombor genap/ganjil. Dengan menggunakan algorithma OEG, jumlah paket siaran juga telah dapat dikurangkan. Berdasarkan IEEE 802.11, keputusan kajian yang telah diuji dan diperhati menggunakan pelbagai persekitaran simulasi telah menunjukkan peningkatan prestasi rangkaian dari segi nisbah penghantaran paket (1-60%), truput (1-19kbps), nod pasif (1-48%), indeks kesaksamaan (0.04-0.19), dan penggunaan tenaaga (0.01-1.48J). Pembaikan terhadap nisbah penghantran paket menggunakan algorithma OEG telah mencapai penanda aras nisbah penghantran paket yang telah digunakan oleh pengkaji-pengkaji yang lepas untuk aplikasi industri. Oleh itu, jika dibandingkan dengan AODV dan OLSR, algorithma OEG lebih sesuai digunakan untuk aplikasi pengesanan yang berterusan seperti pemantauan talian paip minyak dan gas. Kajian ini telah menegaskan bahawa kebolehcapaian indeks kesaksamaan yang tidak cekap sebagai salah satu kekurangan algorihma OEG.

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LIST OF SYMBOLS AND ABBREVIATIONS

AODV	-	Ad-hoc On-demand Distance Vector
ASRJ	-	Adaptive Smart Redirect and Jump Algorithm
AUV	-	autonomous underwater vehicle
BER	-	bit-error rate
BRP	-	Bordercast Resolution Protocol
BSN	-	basic sensor node
CBR	-	constant bit rate
CRC	-	cyclic redundancy check
CSRO	-	Communication and Sensing Range Optimization
DI-LSR	-	Dual Interleaving Linear Static Routing
DRN	-	data relay node
DSDV	-	Destination Sequenced Distance Vector
DSR	-	Dynamic Source Routing
EEN	-	energy equivalent node
ENS_OR	-	Energy Saving via Opportunistic Routing
ERAODV	-	Enhanced Reverse AODV
GHz	-	Gigahertz
GPS	-	Global Positioning System
ha	-	hectare
HTTP	-	Hypertext Transfer Protocol
IARP	-	Intra-zone Routing Protocol
IEEE	-	Institute of Electrical and Electronics Engineers
IERP	-	Inter-zone Routing Protocol
ifQlen	-	interface queue length
IP	-	Internet Protocol
ISP	-	Internet Service Provider
kbps	-	kilobits per second
km	-	kilometre
LEACH	-	Low Energy Adaptive Clustering Hierarchy
LR-WPAN	-	low-rate wireless personal area network

m	-	meter
MAC	-	medium access control
MAG	-	Medium Access Guarantee
MAHRP	-	Memetic Algorithm Based Hybrid Routing Protocol
MAN	-	metropolitan area network
Mbps	-	Megabits per second
MHz	-	Megahertz
MPR	-	multi-point relay
mW	-	milliwatts
NBH	-	number of hops
NBP	-	number of packets
NRA	-	Node Rank Algorithm
NR-LEACH	-	Node Ranked–LEACH
NS2.35	-	Network Simulator 2.35
OCC	-	Office of the Comptroller of the Currency
OEG	-	Odd-Even for Grid
OLSR	-	Optimized Link State Routing Protocol
OP-AODV	-	Optimised AODV
OSI	-	Open Systems Interconnection
PAN	-	personal area network
RREP	-	route reply
RREQ	-	route request
SEECH	-	Scalable Energy Efficient Clustering Hierarchy
SH	-	Self-adjust Hybrid
SMTP	-	Simple Mail Transfer Protocol
SRJ	-	Smart Redirect and Jump Algorithm
TC	-	topology control
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
WPAN	-	wireless personal area network
WSN	-	wireless sensor network
ZRP	-	Zone Routing Protocol

LIST OF PUBLICATIONS

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Azman, A. S., Lee, M. Y., Subramaniam, S. K., and Feroz, F. S., 2021. Dual Designated Path Routing Algorithm for Congestion Control in High Density Network. *Journal of Theoretical and Applied Information Technology, 99(7)*, pp. 1608-1620. (Scopus Indexed, Q3)

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CHAPTER 1

INTRODUCTION

1.1 Background

Operating on increasingly narrow margins and emphasised on maximising production from the existing resources, oil and gas industries are implementing wireless sensory devices that offer up to 80% fewer infrastructure costs as compared to wired solutions (Anonymous, 2018; Rao et al., 2012). As the demand and the exploration of oil and gas continue to rise, the implementation of wireless sensor networks (WSNs) constantly increasing for essential applications. Figure 1.1 summarise the expansion of their capabilities and productivity. Besides, environmental regulations are continuously amended and becoming stricter every year. In 2008, rather than releasing the residue back to the operational area, a set of rules has been amended by the Office of the Comptroller of the Currency (OCC) for compliance of oil and gas companies to haul the highly polluted water and soil to permanent wastage disposal areas (Akhondi et al., 2010). Due to the stricter penalties, oil and gas companies are urged to employ feasible solutions that best fit the enforcement of the new regulations while at the same time minimising the risk without affecting industrial production.

WSN progresses with more advanced sensors and various network architecture that offer modern generation solutions for linking assets in remote areas as well as facilitating the deeper exploration of hydrocarbons material in challenging environments (Ali and Choi, 2019). Further, transportation of crude materials requires critical infrastructure monitoring including the oil and gas pipeline to prevent the occurrence of unwanted tragedies that have a great impact on the economy and environment (Shukla and Karki, 2016). Being a critical element in materials transportation, these pipelines could easily be sabotaged and pose a serious threat from terrorist attacks (Henry and Henry, 2015), particularly in this period of 2020 Russia-Saudi Arabia oil price war. In addition, infrastructure defect including cracking, corrosions, or external environment could lead to pipeline failure (Sundaram et al., 2018). However, numerous studies have shown that the percentage of reported incidents due to pipeline failure are lower as compared to the other types of transportations. Pipeline transportation is also relatively safer, more reliable and cheaper as compared to the others.

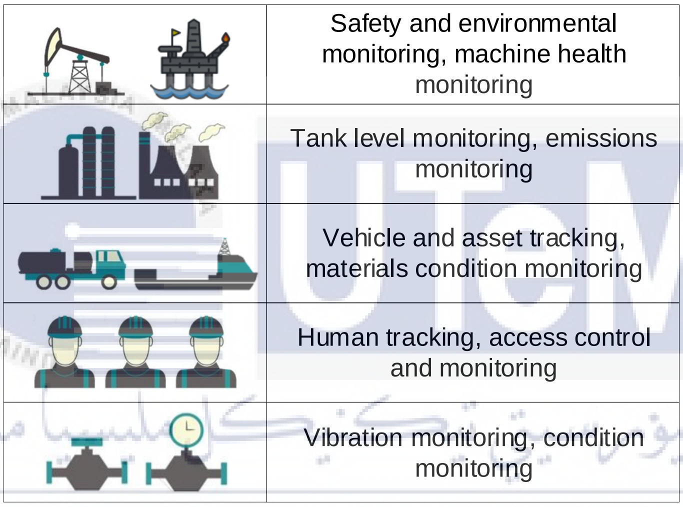

Figure 1.1: WSN applications in oil and gas industry

The oil and gas industry separates its process into three sectors, which is downstream, midstream, and upstream, as shown in Figure 1.2. The upstream sector includes all the processes involved in the exploration and extraction of hydrocarbon materials that can be found in the underground or underwater environment (Johnson et al., 2017; Shafiee et al., 2019). During this timeframe, sophisticated technologies, equipment, and techniques are used to draw the materials to the surface. Intrusive-type of upstream process involves drilling and seismic contractors, engineering firms, and service rig operators. Non-intrusive-type of the upstream process involves surveying experts, such as geologists, scientists, and geophysicists (Boul and Ajayan, 2020).

The raw materials will then undergo field processing and temporarily stored in refinery tanks, bulk terminals, and holding tanks (Gülen, 2016). However, as a part of the safety measures, material that poses extremely high pressure, such as natural gas, must be kept in the underground reservoirs (temporary storage). Apart from storing and processing, the midstream sector predominantly responsible for accommodating the transportation of the materials from upstream to downstream sector via barge, oil tanker, or pipeline (Eissa, 2020; White et al., 2019).

Once the oil and gas materials arrive at the downstream sector, they will be processed, refined, and converted into finished products before they can be commercialised (Azman et al., 2019). These products include gasoline, synthetic rubber, liquefied natural gas, heating oil, lubricants, plastics, pesticides, fertilisers, and antifreeze. As compared to the midstream sector, a smaller scale of transportation is used in this sector to move the materials between plants (Lee et al., 2019). Laboratory testing, including research and development, specification of International Organization for Standardization (ISO) standard, quality control, and laboratory outsourcing, is performed in this sector as well.