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Network Performance Optimization Using Odd and Even Dual Interleaving Routing Algorithm For Oil and Gas Pipeline Network

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ABSTRACT

The oil and gas industry is one of the world's largest conglomerates, involving the production of complicated and critical methods for refining. This indicates the high necessity for a secure and reliable system, such as the Wireless Sensor Network (WSN), which provides auspicious and flexible solutions for the industry. It is one of the most excellent and trendy solutions to the crisis existing within the oil and gas industry, especially in the midstream pipeline. In this application, the nodes were arranged in a linear architecture, to cover a long distance of the pipe. The factors causing the degradation of the overall network performance with increasing density were also identified, due to the increment of the load causing clogging and inhabiting the packet queue. This subsequently led to packet loss, throughput unfairness, higher power consumption, and passive nodes' presence in the network. The proposed routing protocol (AODVEO) was also reactive based on the AODV reducing the instabilities by splitting the traffic into even and odd paths. Additionally, the performances of AODV and DSDV were used to benchmark the efficacy of the proposed routing protocol.

INTRODUCTION

The oil and gas sector is divided into three main parts, namely upstream, midstream, and downstream, which are required to obtain commercial products as shown in Figure. 1. The process often begins with industry discovery and field development in the upstream sector, where all crude oil exploration and extraction are carried out. Using trucks, tanker vessels, or pipelines, raw materials are transported to the next station through the midstream, which plays an active role in the storage of crude oil before transmission to the downstream. In this sector, the transported materials are then refined and commercialized. Various methods are also observed for the transportation of raw materials, such as truck or ship utilization. However, pipeline transportation is found to be a cost-effective and more pragmatic mode of transportation (Abbas et al., 2018; Muller, 2017). Despite being a popular transportation choice, issues such as leakage, corrosion, and sabotage still occurred, leading to the unexpected disasters responsible for the destruction of the economy, workers, and nature.

On January 10, 2018, The Star reported that Petronas, the only administrator of Malaysia's oil reserves and third-largest exporter of global liquefied natural gas after Qatar and Australia, confirmed a leakage at the Long Luping section of the Sabah-Sarawak pipeline in Lawas. This showed that the 600 km oil and gas facility connecting Kimanis (Sabah) to Bintulu (Northern Sarawak) had a leakage at 1.45 am, which led to a devastating explosion ("Gas leak at Petronas Sabah-Sarawak Pipeline in Lawas The Star Online," 2018). Another explosion was also reported on January 13, 2020, serving as the fourth occurrence to be recorded since June 11, 2014, along the same pipeline ("Another explosion along Sarawak-Sabah interstate gas pipeline _ The Star," 2020).

Figure 1. Overview of Upstream, Midstream, and Downstream.

On April 12, 2019, The Straits Time reported an explosion at Petronas oil and gas complex, where two local workers and more than ten houses in Kampung Lepau were badly injured and damaged, respectively ("Explosion at Petronas oil and gas complex in Johor injures two, damages houses, SE Asia News & Top Stories - The Straits Times," 2019). These reports proved that the remote pipeline integrity monitoring system was essential to avoid any unforeseen disaster.

Introduction to Wireless Sensor Network

Wireless Sensor Network(WSN) has recently prevailed in the mobile tracking of pipeline health, due to its usability and cost-effectiveness (Ali, S., Qaisar, S., Saeed, H., Khan, M., Naeem, M., & Anpalagan, 2015; Raza et al., 2018). This is a collection of sensors with the ability to sense, process, and communicate, subsequently forming a network for monitoring the physical world (W. Z. Khan, Aalsalem, Gharibi, & Arshad, 2017). It has also been implemented in both sensor-integrated ground and underwater pipelines, to detect any form of unwanted irregularities (Abbas, Bakar, Ayaz, Mohamed, & Tariq, 2017; Aldosari, Elfouly, Ammar, & Alsulami, 2020; Felemban, Shaikh, Qureshi, Sheikh, & Qaisar, 2015; Watt, Phillips, Campbell, Wells, & Hole, 2019). Furthermore, the network topology is one of the techniques used to differentiate several types of sensors, due to being a node placement architecture. This is divided into two main structures, namely linear and spread-out topologies. Based on covering hundreds/thousands of kilometres, the nodes of the midstream pipeline are often positioned in the linear topology ("Malaysia Oil and Gas Midstream Market | Growth, Trends, and Forecasts (2020 - 2025)," 2016). Subsequently, the classification of the networks is separated into a one-tier flat and multi-tier hierarchical topology, as shown in Figs. 2 and 3, respectively.

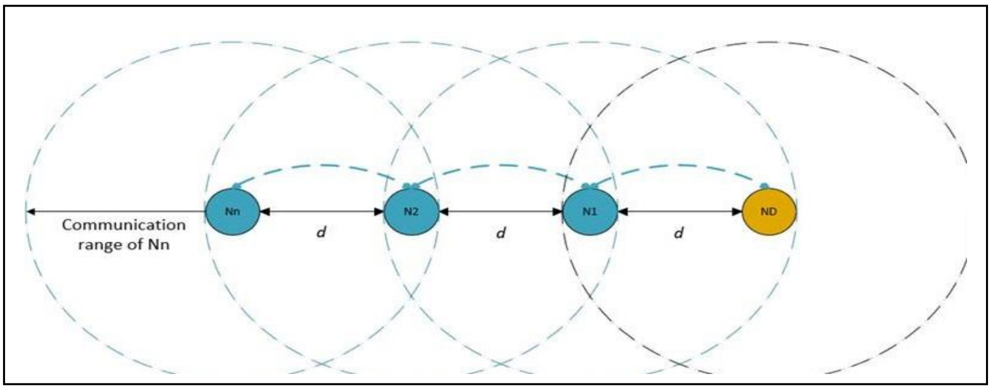

Figure 2. Flat one-tier topology.

Hierarchical topology often involves the communication of a cluster head and the nodes, with the generated information being forwarded to a higher level, as shown in Figure 3.

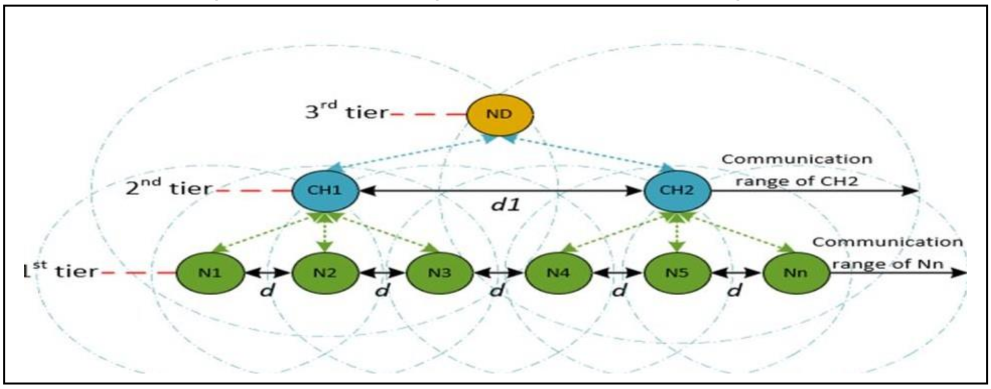

Figure 3. Hierarchical topology.

Wireless standards also significantly affect network efficiency or result, depending on the utilized application. In a real linear topology scale, the two criteria with implementational capabilities are as follows, (1) the IEEE 802.11, which contains the individual modules used to communicate with the wireless transmission serving a stationary or mobile terminal collection (S. M. Khan, Nilavalan, & Sallama, 2015), and (2) the IEEE 802.15.04, which is known as a low-rate private area wireless network. Based on this condition, the IEEE 802.11 was selected due to the tremendous data rate, compared to the IEEE 802.15.04. A brief comparison is subsequently displayed in Table 1.

Challenges and Limitations of Conventional Routing Protocols

Based on the preliminary stage of the study, several analyses were carried out on the existing conventional protocols, to identify their challenges and limitations. In this condition, multi-hop was used as the data transmission technique, where the sender node transferred the information to the receiver (Yao, Cao, Vasilakos, & Member, 2014). However, some problems were observed as the number of nodes increased, such as (1) energy consumption, (2) communication reliability, (3) network scalability, (4) robustness, and (5) security. According to A. Khan et al. (2019), the lifetime of a network was a crucial factor affecting restricted power supply in linear WSN topology, where a massive amount of energy was needed for data transmission in a large-scale system. Although the idea of preparing backup power was applicable, it was still unsuitable in underground or underwater nodes. In the oil and gas field, a secure contact network is highly needed, as the nodes are expected to obtain and transmit the data or signal to the destination when an anomaly is observed. This needs to be carried out within a specified amount of time, as failure often leads to a catastrophic accident. Subsequently, these data were crucial for monitoring the pipeline’s health, to avoid extra costs.

Table 1. Comparison of IEEE 802.11 and IEEE802.15

Parameter	Wifi	ZigBee	WirelessHart	Z-Wave
IEEE standard	802.11a/b/g/n/ac	802.15.04	802.15.04	802.15.04
Operational frequency	5GHz(A,ac)/2.4GHz(b,g)/2.4GHz-5GHz(n)	2.4GHz	2.4GHz	2.4GHz
Nodes per master	2007	>65000	500	232
Range	100meters(a,b,g)/250meters(n)	1600 meters	250 meters	100 meters
Date rate	11Mbps(b)/54Mbps(a,g)/450Mbps(a,c)600Mbps(n)	250Kbps	250Kbps	250Kbps
Battery Life/Cost	Days-weeks/High	Months-years/Low	Months-years/Low	Months-years/Low

The scalability of a network often leads to the achievement of a stable performance without being affected by the nodes. This explains that when the network expands, the number of nodes being deployed is increased. In this condition, more data and traffic are then generated and created, respectively. However, the network and its performance become overcrowded and degraded. This confirms that the scalability of the system is affected by the following, (1) network capacity, (2) queue threshold, and (3) range of source node to the destination. Based on robustness and security, the flexibility level of the network is determined by the management of massive data, intrusion, or malicious attack volumes, respectively. Since the nodes are implemented to decrease human interference, unauthorized personnel are likely to attack the system towards the obstruction of data collection, by triggering a false alarm or manipulating the packets (W. Z. Khan, Hossain, Aalsalem, Saad, & Atiquzzaman, 2016). Additionally, a routing protocol is deemed decent based on the adaptability and delivery of optimum performance within the network.

Related Work

At the beginning of the studies, several performance issues were mostly observed due to the increasing number of nodes. In this condition, the deprivation of delivery ratio, throughput, and the high energy consumption are reflected in the network layer (routing layer) performances. This revealed that many experts were attracted to routing, to improve the overall network performance. It. is also known as a high-level decision-making mechanism, where information is transferred from the source to destination nodes through an inter-network containing one or more transitional structures (Radhakrishnan et al., 2016). Moreover, the efficiency of routing protocols is typically calculated from the link reliability perspective among the nodes, disconnection, and restoration of connections, which is an essential operation where approximately all data packets are likely to be missed. In this case, the three most popular protocols are reactive, proactive, and hybrid systems. The reactive routing protocols use an on-demand approach for discovering paths (Kaur & Singh Kahlon, 2014), indicating that the routes are dynamically changing based on the present network conditions (Mohammed, 2019). When the network's status is not continuously monitored or updated, the flooded messages and route tables are minimized (Goswami S, Joardar S, Das C B, Kar S, 2017). However, the path discovery process is found to continuously occur, causing more time to establish the connection, which leads to increased end-to-end delay. The Ad-hoc On-Demand Distance Vector (AODV) is also an example of a reactive routing protocol, which uses RREQ (route request), RREP (route reply), and RRER (route error) for route management (Govindasamy & Punniakody, 2018; Xin & Yang, 2015). In this condition, RREQ and RREP are used as broadcast and acknowledgement packets, respectively. Meanwhile, RERR is transferred to the source node during the link interruption. The verifies the systematic restart of the route detection process when some data are still observed for transmission (Govindasamy & Punniakody, 2018).

According to proactive routing protocols (table-driven protocols), the update of the table was regularly carried out, with information such as the hop, sequence numbers, hop figure, and destination, being made permanent by occasionally transmitting control messages between all network nodes (Hamid & El Mokhtar, 2016; Pandey, Raina, & Rao, 2015). These have a more rapid route establishment, subsequently verifying consistent path availability. Since the routes are continuously updated, the will delay is outrightly minimized, with network traffic being more constant (Mohammed, 2019). On the downside, the network is flooded with routing information (control packets and routing overhead), as congestion is observed due to the frequent table updates consuming all the systematic resources. Moreover, the DSDV (Destination Sequence Distance Vector) is an example of a proactive routing protocol, where each node is needed to transfer a sequence number that is periodically increased and transmitted to all neighbouring structures with other updates (Chavan, Kurule, & Dere, 2016; Singh & Verma, 2015). The hybrid routing protocol is a combination of proactive and reactive systems, due to their utilization advantages. This obtains correct path information to determine the optimum direction of the target node, by updating routing information when needed. It is also generally known as the combination of DSDV and Link State Routing (LSR), optimized for rapid integration with lower power and memory consumption. Therefore, network traffic should be denser regarding the number of nodes, irrespective of the routing protocol selected for implementation. This relationship occurred due to the increment of both control and data packets congesting the traffic of the system. All the nodes were also considered as sources in real-life deployment, with data being simultaneously transmitted. From each node, the sum of transmitted data is shown in Equation. (1).

$$NP=(CP_i+DP_i)+\sum_{j=i+1}(CP_j+DP_j)\leq IfQlen \quad (1)$$

Where,

$$x = n - 1 \quad (2)$$

Where NP = the total packets of the network constricted by the IfQ length limit, n = the number of nodes, CP_i and DP_i = the sum of control and data packets for node i, respectively, with the condition $1 \leq i \leq x$, as well as CP_j and DP_j = the control and data packets for the adjacent nodes j, respectively. Based on Eq. (1), the generated total packets increased with higher overall node quantities, leading to several network performance issues. This led to the proposition of the Ad hoc On-Demand Distance Vector Even and Odd (AODVEO) routing protocol.

Ad Hoc On-Demand Distance Vector Even And Odd (AODVEO)

The AODVEO routing algorithm was mostly developed based on the AODV system. This was not in line with the conventional AODV algorithm, which determines its path by selecting the shortest and freshest route (van Glabbeek, Höfner, Portmann, & Tan, 2016). The AODVEO system also establishes its path based on Even and Odd paths, as shown in Fig. 4. Furthermore, it is designed to deliver improved results regarding the overall network performance for linear topology, compared to the conventional routing algorithm. Different from the standard practice, AODVEO also separates the route into Even and Odd traffic (Figure. 4), for the reduction of congestion. When an odd/even node transfers the RREQ to its surroundings, only the compatible systems are eligible for acceptance and continuous transmission. This process is then prolonged until the RREQ is dropped when arriving at its destination node. Once dropped, the destination node transmits RREP in a reverse direction, where collection at the source structure leads to the transmission of the data packet through the established route.

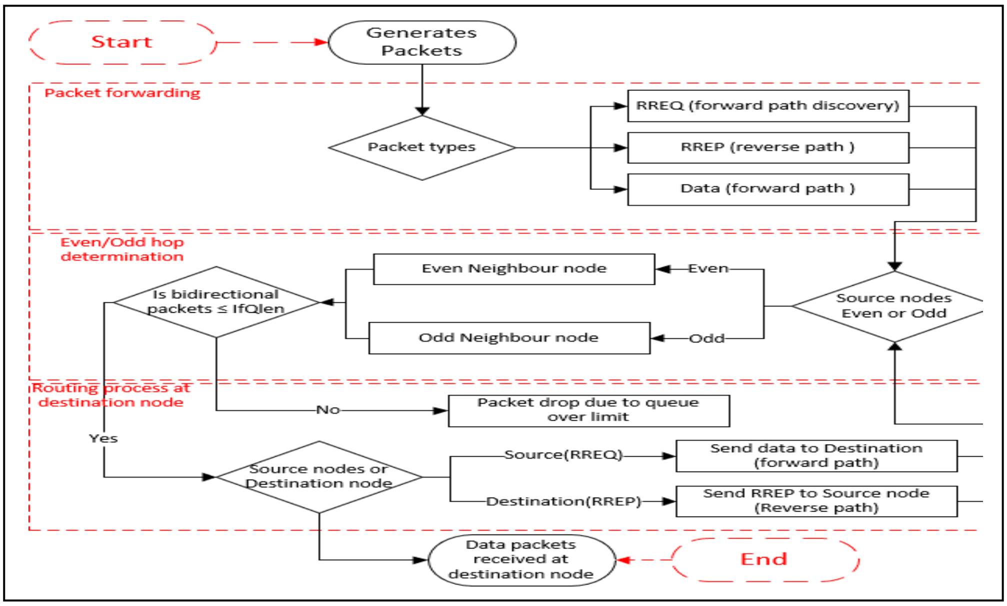

Figure 4. AODVEO routing algorithm

Figure 5 shows the forward transmission of the RREQ packet to the neighbouring nodes, E2 and O2, through the odd-numbered source (On). Since E2 is an even-numbered node, the transmitted packet was rejected and dropped. Meanwhile, the packet was acknowledged in O2 and transmitted to the subsequent hop, due to the oddness of the node. This process was continuously conducted until RREQ reached ND, with the packet interchange procedure subsequently carried out by discarding RREQ and forwarding RREP in the opposite direction to the source.

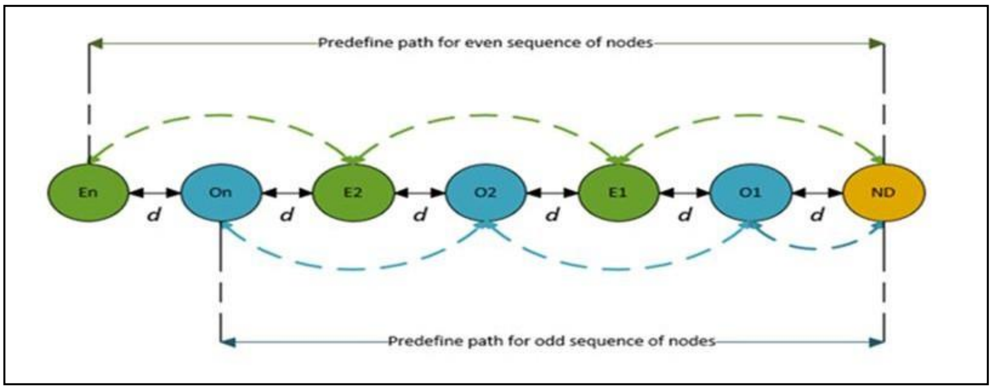

Figure 5. AODVEO Even and Odd path.

A queue limit is a simple mechanism for controlling the bidirectional packet movement within every network node. This is observed in the AODVEO system, although the dual-path (Even and Odd) approach lessens the routing overhead by half, subsequently ensuring better network traffic. In the system, the total packets accumulated for Even and Odd nodes are shown in Eqs. (3) and (4), respectively.

$$NPE=(CPE_i+DPE_i)+\sum_{j=i+1}^{x}(CPE_j+DPE_j)\leq IfQlen \quad (3)$$

NPE = the even packet queues for the x nodes in the network, CPE_i and DPE_i = the sum of overall control and data packets for node i, where $1 \leq i \leq x$, as well as CPE_j and DPE_j = the control and data packets for the neighbouring nodes j, where $i \leq j \leq N$.

$$NPO=(CPO_i+DPO_i)+\sum_{j=i+1}^{x}(CPO_j+DPO_j)\leq IfQlen \quad (4)$$

NPO = the odd packet queues for x nodes in the network, CPO_i and DPO_i = the sum of overall control and data packets for node i, with the restriction of 1≤ i ≤ x, as well as CPO_j and DPO_j = the control and data packets for the neighbouring nodes j, where i ≤ j ≤ x. Furthermore, the accepted data at the destination node is shown in Eq. (5), where the packages (data and control packets) arriving with a queue length more than IfQlen were oddly and evenly dropped from the network.

$$TNP = NPE + NPO \quad (5)$$

TNP = the packets accumulated in the network, as well as NPE and NPO = the total numbers of packets available in the even and odd traffics (Eqs. 3 and 4). In this condition, the limitation of IfQlen was found to bound the equations, with simulations carried out using the proposed AODVEO, AODV, and DSDV routing protocols. This was conducted in a specified environment and condition, to validate the results of splitting the traffic into two paths.

RESEARCH METHOD

The simulation was conducted using AODV, DSDV, and AODVEO, through the Network Simulator 2.35. In this condition, only the best five of the seven runs (seven seeds) were selected and averaged, with the spacing (d) and time (t) being 50 m and 500 s, respectively. Moreover, the transport agent and traffic type applied were the Transmission Control Protocol (TCP) and Constant Bit Rate (CBR), respectively. The size of the executed packet was also 512 bytes, with the transfer rate being two packets/secs, as shown in Table 2.

Table 2. Simulation parameters.

Parameters	**Value**
MAC	IEEE 802.111
Routing protocols	AODV, DSDV, AODVEO
Topology	Linear
Number of nodes	20,40,60,80,100,120,140,160,180,200
Packet size	512 bytes
Seed	1-20
Interface queue type	Drop tail
Packet queue length	50 packet
Propagation mode	Two ray ground
Simulation time	500 seconds

RESULTS AND DISCUSSION

Delivery Ratio

This is the correlation between the successfully obtained and total transferred packets, due to being an important performance measure for the reliability of a specific network. Since most implementations were data-critical in the oil and gas sector, all the lost information values were found to be highly enormous to the industry. In this condition, the lower delivery ratio indicated more network packet loss. Based on Fig. 6, the packet distribution ratio decreases with an increase in the network size, clarifying that the delivery ratios of AODV and AODVEO were almost identical at a smaller scale of 20-40 nodes, with DSDV being slightly higher. In the deployment of 80 nodes, the AODVEO routing protocol significantly surpassed AODV and DSDV by 15 and 11%, respectively. This revealed that the proposed protocol (AODVEO) was more efficient in preserving the packet transferred to the target node, compared to AODV and DSDV. Additionally, the packet queue was minimized by separating the traffic into two distinct routes, leading to the elimination and accomplishment of congestion and more data flow, respectively.

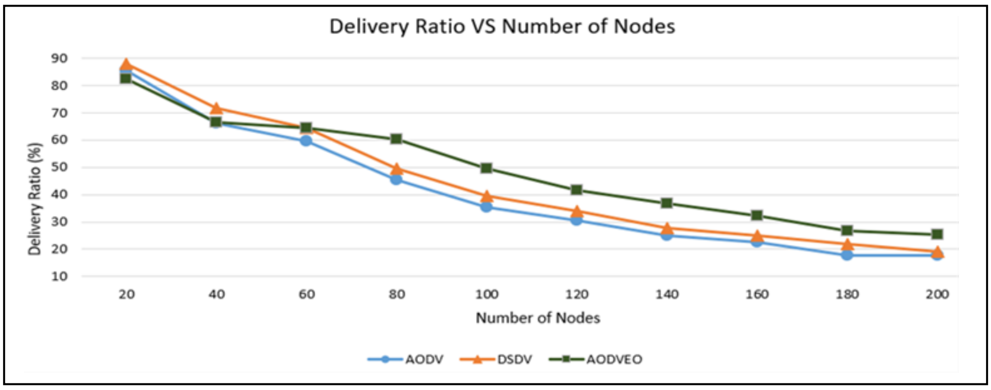

Figure 6. Delivery ratio (%) vs the number of nodes.

Throughput

This is defined by the rate of the received data (from the packet) transferred from the source to the destination nodes (kbps) within the network. Based on a consumer's perspective, throughput is more important when highly compared to the delivery ratio within the available resources, indicating a more significant system capacity. However, the delivery ratio is more critical from the designer's perspective, due to determining the problems causing low network throughput. In this report, AODVEO outperformed both AODV and DSDV from a small to large-scale network size of 20-200 nodes, regarding the analysis of throughput (Fig. 7). This showed that AODVEO highly delivered 8.82 and 12.17 kpbs at 20 and 200 nodes, respectively, compared to DSDV. In Fig. 6, the throughput trend was also a reflection of the packet delivery ratio (Fig. 5), where the source node attempted to re-transmit the data based on the loss of information. This led to a lower distribution of delivery ratio and successfully received data, with the throughput subsequently affected severely.

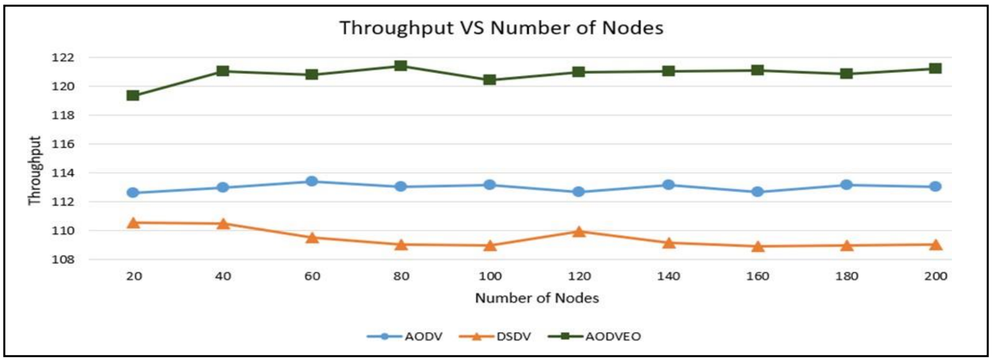

Figure 7. Throughput vs the number of nodes.

E*h*nergy Consumption

Energy consumption is measured in Joule (J) and described as the overall network power utilized over the total received packet. This is because energy management is an essential wireless parameter in linear topology, with a communication connection discontinuity being created by a single node failure. Since more packets were being delivered, the power consumption closer to destination nodes was often higher, causing the congestion of the traffic line. However, the congestion is likely to drop when a package is produced by or crosses through the nodal area. In this condition, issues such as energy waste were generated due to packet regeneration and hopping. Based on Fig. 8, the energy expenditure is also increased with the elevating value of the nodes. This proved that the DSDV and AODVEO networks consumed the highest and lowest amount of available energy, respectively. Despite having higher throughput values, the AODVEO routing protocol still outperformed AODV and DSDV by 0.00398 and 0.00536 J, respectively, at a small network size of 20 nodes. Meanwhile, it used less energy of 0.0377 and 0.0953 J for AODV and DSDV at a larger network size of 200 nodes, respectively.

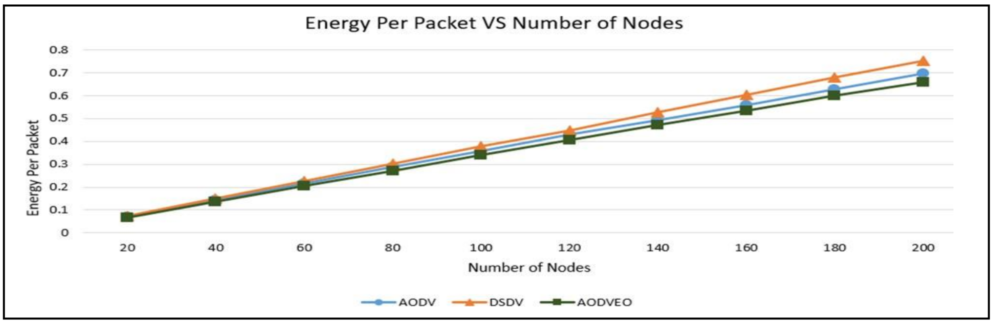

Figure 8. Energy consumption vs the number of nodes.

Passive Nodes

These nodes are unable to transmit data to the target network area, due to the unnecessary or unevenly allocated bandwidths within the system. They also occur mostly in high traffic networks with a constrained energy source. Moreover, the passive nodes cause a breakdown of communication, which affects the network's lifetime. Based on Fig. 9, the occurrence of these elements in AODVEO and DSDV is found at the deployment of 80 nodes, with subsequent observation confirmed at 60 for AODV. In a large-scale network of 200 nodes, the total number of these elements in AODVEO, AODV, and DSDV was 59.8, 72.6, and 68.9%, respectively. Although AODVEO had a higher value of throughput, its passive nodes were still lower than AODV and DSDV.

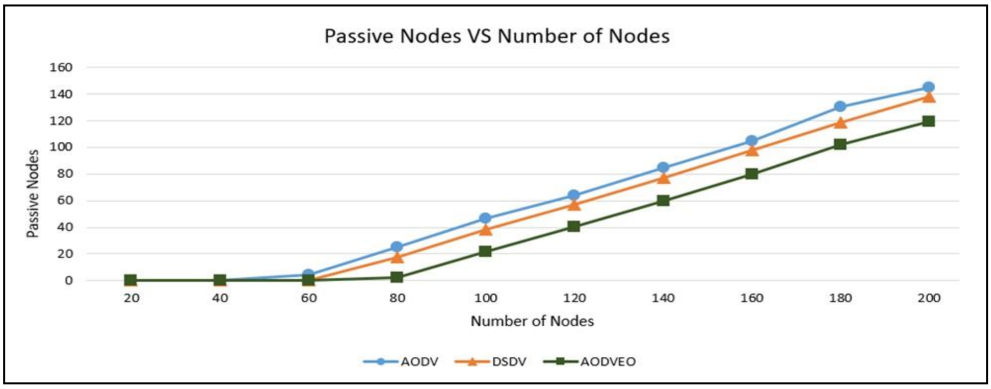

Figure 9. Passive nodes vs the number of nodes.

Fairness Index

This is the network-wide measure of resource equality allocation, where the closeness to 1 leads to a better outcome over the network. In linear WSN, network imbalances are an important factor with any protocol, as AODVEO outperformed AODV and DSDV by 0.06 and 0.05 at the deployment of 20 nodes, respectively (Fig. 10). Despite this, the fairness index for AODVEO was still below 0.5 at a 40 node deployment. This subsequently became worse with the continuous elevation of the nodes being deployed. Based on Fig. 10, the graphical numbers indicated that the issues surrounding network fairness were yet to be completely resolved since the resources allocated were far from being equally distributed.

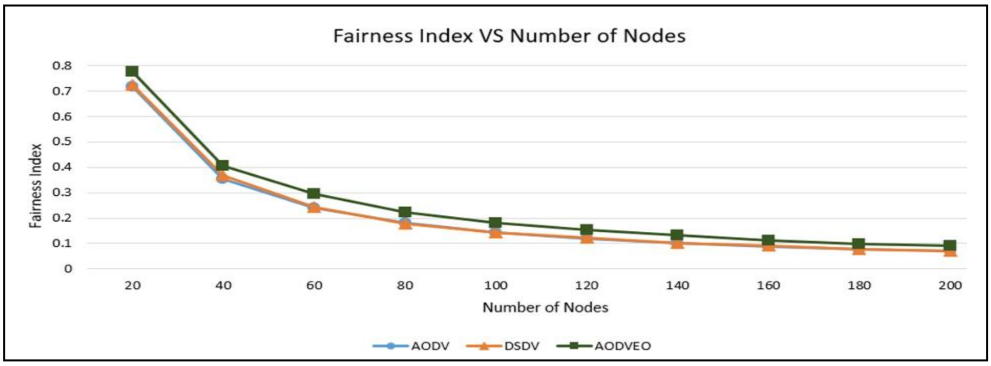

Figure 10. Fairness index vs the number of nodesCONCLUSION

The rice planting and harvesting process is at risk of falling into the level 4 category in terms of ergonomics. According to the RULA (Rapid Upper Limb Assessment) method analysis, the high category with recommendations for an investigation and change immediately. Gender, BMI, length of employment, and tenure have no bearing on MSD levels. The waist and the neck have a percentage of MSDs of 98 % and 95%, respectively. These were the body parts subjected to a high level of ergonomic risk. Traditional agriculture workers were advised to improve work procedures and tools before the situation worsened to reduce long-term risks.Several factors, including job demands, socio-cultural factors, workplace characteristics, and environmental factors, cause or exacerbate work-related disorders, according to WHO (1985). Otherwise, musculoskeletal problems such as awkward posture, prolonged standing, kneeling, slouching, and repetitive muscle activity occur in most cases of agricultural work due to the physical demands on the body. Fatigue, illness, and accidents will inevitably result from this posture. Workers' lack of knowledge of agricultural health and safety puts them in the most dangerous situations. This study included agricultural activities in the occupational group with the highest risk of musculoskeletal disorders (MSDs). When combined with tool design and related educational interventions, these ergonomic considerations effectively prevent MSD problems. The study's conclusion emphasizes the importance of ergonomic hand tool design as a form of intervention.

CONCLUSIONS

Many interrelated factors were found to affect the overall network performance in a pipeline network, as reactive and provocative routing protocols (AODV and DSDV) were simulated in the early analytical stages, with the system efficiency subsequently reviewed. This proved that numerous network performance issues were identified with a continuous increase in system size. Based on the results, the proposed reactive routing protocol, AODVEO, was found to be very reliable and efficient. This improved the overall network performance of a wireless sensor network with linear topology. In the most extensive configuration (200 nodes), AODVEO routed the network to produce more throughput and delivery ratio, as well as less energy and passive nodes at 8.19kbps, 7.546%, 0.03772J, and 12.8%, respectively. However, a negligible development of the fairness index was observed, where the IP (index point) was found to be below par (0.5). In Figure. 10, the reflected values also indicated that the resource was not yet distributed equally through the network. Therefore, more studies need to be conducted in refining the issues of fairness, especially for the large-scale network.

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