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# DUAL DESIGNATED PATH ROUTING ALGORITHM FOR CONGESTION CONTROL IN HIGH-DENSITY NETWORK

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## ABSTRACT

Wireless sensor networks (WSNs) offer promising and flexible solutions in a wide range of industrial applications, particularly in the oil and gas downstream pipeline. Such an application requires wide communication coverage due to the large dissemination of pipelines in the downstream sector and to fit this requirement, the nodes have to be arranged in a grid formation. Performance evaluation has been carried out using reactive (e.g., AODV) and proactive (e.g., OLSR) routing protocol during the early of the study. Several issues have been discovered as the network size increases, mainly due to the increased loads, which occupy the queue and congest the network traffic. These issues include packet loss, throughput degradation, energy wastage, and poor fair share of network resources. The OEG reactive routing algorithm is proposed to lessen the routing instabilities by reducing the control packets and promoting smoother packets flow through the traffic division into odd-path and even-path with the consideration of x and y-axis. The proposed routing algorithm was then compared to AODV and OLSR routing algorithm in terms of network performance. The proposed routing algorithm has shown notable improvements on the delivery ratio (28.4% more), throughput (13.6 kbps more), fairness index (0.02 more), passive nodes' presence (37.9% less), and energy consumption (0.76 J less) when solely compared to AODV on the highest network density.

**Keywords:** *Routing Algorithm, Wireless Sensor Network, WSN, Oil and Gas, Grid, Pipeline*

## 1. INTRODUCTION

In oil and gas industry, the exploration of raw materials takes place in the upstream sector, followed by the extracting process in the underground and underwater area as shown in Figure 1. The raw materials are discovered and extracted using the surveying method (non-intrusive) and the advanced oil-drilling method (intrusive) [1]. These materials are then sent to the downstream sectors through the midstream sector, either via barge, truck, or pipeline. The midstream sector also involves storing crude or hydrocarbon material [2]. In the downstream sector, the transported feedstock materials are processed, refined, and marketed. However, a small scale pipeline network or truck is used to move the material between the processing plants in the refinery area.

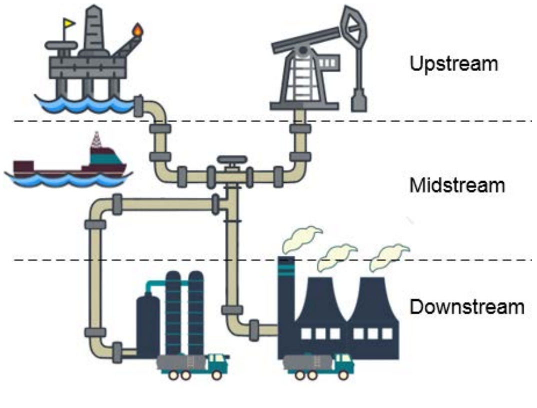

*Figure 1: The divisions in oil and gas industry*

As compared to truck or barge transportation, pipeline transportation offers cheaper and more feasible way of transporting materials [3]. However, there are some expected issues to arise, such as corrosion, unstable pressure, leakage, and sabotage. Due to the harsh materials stream, these issues could lead to explosion and oil spillage, which causes the reduction of fish stock and loss of farmable land [4]. According to The Star, on June 11, 2014, at the hills of Lawas, Sarawak, Malaysia, an explosion happened due to the pipeline leakage along a section of Petronas Sabah-Sarawak pipeline. Fortunately, the residents were 9 km away from the incident area [5, 6]. Such an incident indicates that proper remote and continuous pipeline integrity monitoring is essential to ensure the efficiency and safety of the pipelines.

In the past few decades, WSN has been introduced to occupy the industrial demand in various applications, such as landslide detection, agricultural threat detection, home automation, health care monitoring, and pipeline condition monitoring, owing to its high flexibility, simple, and cheap solution [7, 8, 9]. Besides, WSN also complements the oil and gas pipeline needs in collecting the data in inaccessible or remote areas [10].WSN is used in both above-ground and underwater pipeline monitoring using various types of sensors to detect the anomaly inside or outside the pipeline. Implemented WSNs for underwater detection uses acoustic communication since radio frequencies (RF) communication is not suitable for the underwater environment due to the high-frequency wave absorption [11].

There are several types of sensor networks apart from WSN, such as mobile ad-hoc network (MANET), vehicular ad-hoc network (VANET), and wireless mesh network (WMN). Static sensor networks are the ones other than MANET or VANET. The focused environment area in this paper is the oil and gas refinery pipeline (downstream). As illustrated in Figure 2, two types of pipeline distributions are used in the industry; the linear type, which is used in the midstream sector, and the spread-out type, which is used in the downstream sector.

*Figure 1: Two types of pipelines distribution*

As shown in Figure 3, due to the large dissemination of the pipeline area in the refinery station, static nodes arrangement with grid topology is chosen to fit the coverage requirement. In addition to that, this paper also covers the IEEE 802.11 accordance wireless standard with the contribution on the network layer (routing layer) of the Open Systems Interconnection (OSI) model [12]. The objective of the study is

- to investigate the impact of the network size on the network performance
- to develop a routing algorithm to increase network performance when the network size is varied.

During the early of the study, various performance issues using the existing routing protocols have been discovered and will be discussed in the later section. The contributions of this paper consist of

- presenting the problems faced in a grid network as the size increases
- presenting a novel routing algorithm that implements reactive odd-even routing technique to reduce the strain in the traffic due to the packets congestion by (a) splitting the traffic and (b) reducing the number of broadcast packets.

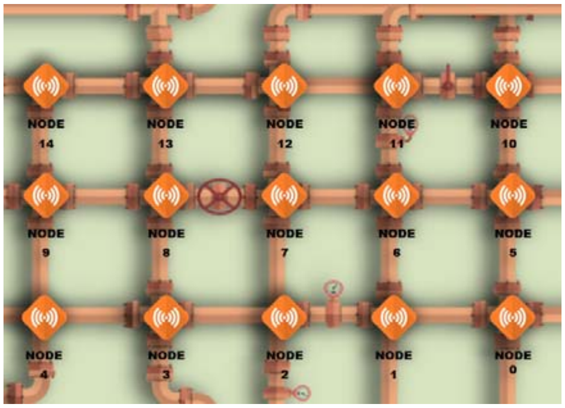

*Figure 3: Nodes deployment for pipelines monitoring*

## 2. PROBLEM STATEMENTS

Most of the applications would use the same data transmission technique, which is via multi-hop technique, from the sender node to the receiver node [13]. As the network size expands, some challenges that are often related to the (1) communication reliability, (2) network scalability, (3) energy consumption, and (4) robustness of the network are expected to arise. Reliable communication is when the destination node able to receive all the data from every single source node within a certain period. The scalable network is the network capable of conserving its performance when the network loads are varied. Apart from that, the robustness determines how resilient the network against malicious attacks, interferences, or nodes failure. In high-risk applications, such as pipeline condition monitoring, all of the collected data are important for the analysis, modelling, and prediction. These data also help to interpret the pipeline changes over time, such as corrosion or dent due to the surrounding environment, the pressure of the stream, and weather [14].

Since oil and gas pipeline condition monitoring is a data-driven application, it is important to keep the amount of packet loss as low as possible. As the number of nodes increase, the number of packets also increase. Hence, due to the packet accumulation factor, the traffic will get congested. Once the queue is fully occupied, the next packet will be dropped since there is no more room for it to enqueue. The network will experience packet loss and throughput degradation due to the decreased number of packets received by the destination per second.

The saturated traffic is also caused by the overproduced amount of broadcast packets during the route discovery. Hence, the queue is mainly filled with broadcast packets instead of data packets. This event is known as resources wastage which can cause a severe state of fairness. During this state, some nodes consume more resources and some nodes consume less. There are also nodes that will not stand the chance to consume the resources and these nodes are known as passive nodes. As a result, the nodes will not be able to transmit their packets.

Congestion also can cause the nodes to consume more energy due to the high amount of packet processing and listening. This issue can lead to node failure due to the depletion of the power component. In a high-risk application, the replacement of the power component can be challenging and dangerous. Hence, an improved and tailored solution, particularly in oil and gas pipeline applications, is required to overcome these issues.

## 3. BACKGROUND WORKS

Due to the wide distribution of the refinery oil and gas pipeline, the sensor nodes are configured in a grid formation to fit the nature of such distribution with the number of nodes on the x-axis times the number of nodes on the y-axis. During the early of the study, various performance issues have been discovered as the number of nodes increase. Throughput degradation, low delivery ratio, and high energy consumption are often related to the issues that influence the performance of the network on the network layer (routing). For these reasons, the network layer has been attracting researchers' attention in the past few years. The network layer is the high-level decision-making process in selecting the path for the packets to travel from the sensing point (source node) to the sink point (destination node) according to the specified forwarding mechanism used by the routing protocols. The types of routing protocols include proactive, reactive, and hybrid [15, 16].

Reactive routing protocols are known as on-demand routing protocols where the routing path dynamically changes and the routing discovery process (to establish the communication link between the sink node and the source node) is invoked only when needed [17, 18]. Since the information of the routing is not recorded, the flooding of the control packets due to the frequent update is reduced as well. Hence, such a technique allows more network resources to be conserved [19]. However, the route will require more time to be established and causing the latency to increase. Ad-hoc On-demand Distance Vector (AODV) routing protocol is included in the reactive routing protocols [20].

Proactive routing protocols, on the other hand, are known as table-driven routing protocols where the routing table is regularly updated to maintain an up to date routing details, such as the destination, next hop, current node, sequence number, and number of hops [21, 22]. The control packets are periodically advertised by the nodes in the network to their neighbours to update the routing information into the routing table. As compared to the reactive routing protocol, proactive routing protocol are more capable of sending the data in a timely manner. As a drawback, the network suffers from a high number of control packets, routing overheads, and any unnecessary packets due to the frequent updates while wasting the allocated network resources. Optimized Link State Routing (OLSR) is one of the examples of proactive routing protocols [23, 24].

Hybrid routing protocols are the incorporation of reactive and proactive routing protocols that utilise the benefits of both routing protocols. Zone routing protocol (ZRP) is included in the hybrid routing protocols that have been proposed to lessen the control packets and routing overhead produced from the proactive routing protocols. ZRP also reduces the latency resulted during the route discovery process from the reactive routing protocols [25]. In other words, ZRP monopolises the attributes of proactive and reactive routing protocols. However, ZRP will be not focused in this study since it is a cluster-based routing protocol, while AODV and OLSR is a flat routing protocol.

Undoubtedly, regardless of what type of routing protocol the network employs, the traffic becomes denser as the number of nodes increase. This issue happens due to the increasing number of (1) control packets and (2) data packets produced, which cause the traffic to congest. The control packets are required during the route discovery and route maintenance, while data packets are the actual data that was gathered and sent by the source nodes. For each node in the grid network, the traffic queue is limited by the interface queue length (*IfQlen*) as defined in Equation (1).

$$P_{total} = \left[ (DP_\alpha + CP_\alpha) + \sum_{\beta=\alpha+1}^{Nn} (DP_\beta + CP_\beta) \right] \le IfQlen \quad (1)$$

Where $Nn=N-1$, $N$ is the number of nodes in total and $P_{total}$ is the amount of bi-directional packets, which are bounded by the *IfQlen* limit. $DP_\alpha$ and $CP_\alpha$ is the total number of data packets and the total number of control packets respectively for the intermediate node $\alpha$. $DP_\beta$ and $CP_\beta$ is the total number of data packets and control packets respectively for the neighbouring node $\beta$, where $1 \le \beta \le Nn$. As the number of nodes increase, more control packets and data packets produced according to Equation (1). Hence, more performance issues were introduced in the network. Motivated by this observation, an Odd-Even for Grid (OEG) routing algorithm is proposed by considering the numbering (address) of the neighbouring nodes in the x-axis and y-axis of the intermediate node in the forward and reverse path.

## 4. DUAL DESIGNATED PATH ROUTING TECHNIQUE

The OEG routing algorithm is included in the reactive-type routing algorithm. The OEG algorithm considers the shortest and freshest route possible as the route of choice. In the conventional routing algorithm, during the discovery of the forward path, the packets are routed according to (1) the freshness of the route using the sequence number determination and (2) the distance of the path using hop count [26, 27]. In OEG routing algorithm, the criteria in choosing the route are based on (3) odd or even number determination for the nodes with the consideration of x and y-axis. The odd-numbered nodes belong to the odd traffic, while the even-numbered nodes belong to the even traffic. Figure 4 shows the developed algorithm to illustrate the third criterion that is used in the proposed OEG routing algorithm.

During the forward route, the route request (RREQ) packets are broadcasted by the source nodes over the network according to the sources' address, either odd or even-numbered, to establish the route with the respective destination node. If the source is odd, the RREQ will drop by at the odd-numbered neighbouring node and vice versa. The neighbouring node will accept and forward the RREQ if the RREQ meets the odd-even criterion (valid in both x and y-axis). Once the RREQ packet arrives at the destination, the RREQ is dropped and the route reply (RREP) packet is generated by the destination node to be sent to the respective RREQ source according to odd-even criterion (creating the reverse route). The actual route is considered established once the RREP packet arrives at the source. Further, the data packet is generated and relayed to the destination node using the established route.

Figure 5 illustrates the demonstration of an odd-numbered (On) source (N13) discovering a path to the destination (ND), assuming the distance between the nodes is *d* and the communication range for each node is *2.5d*. The RREQ packet is broadcasted to the neighbouring node N12 and N11 in the forward direction of the x-axis (route 1). Since the neighbouring node N12 is an even-numbered node, the RREQ is not allowed to be forwarded in the next hop and is dropped instead. As for N11, since it is an odd-numbered node, the RREQ is accepted and forwarded in the next hop. This process happens until the RREQ reaches ND. As soon as ND receives the RREQ, a packet interchange occurs by dropping the RREQ and sending the RREP to the source in the reverse direction (route 2). Throughout this process, the neighbouring node for the next hop is chosen based on the source by considering the odd-even criterion. The route used in the reverse direction might differ from the route in the forward direction, while the route used for the data packet (route 3) to travel is the same as route 1.

### 4.1 Packets Accumulation

Odd-even criterion has brought to the splitting of the network traffic (odd and even traffic) and reduced the packet queue in the traffic. The total packet accumulated in the even traffic can be described as in Equation (2).

$$PE_n = \left[(DPe_{2\alpha} + CPe_{2\alpha}) + \sum_{\beta=\alpha+1}^{n_1} (DPe_{2\beta} + CPe_{2\beta})\right] \leq IfQlenE_n \tag{2}$$

where

$$n_1 = \begin{cases} \frac{Nn}{2}, \ if\ Nn\ is\ even \\ \frac{Nn-1}{2}, \ else\ if\ Nn\ is\ odd \end{cases} \tag{3}$$

*Nn* can be referred as in the previous section and $PE_n$ is the total packets present in the even traffic queue and bounded by the even traffic queue limit, $IfQlenE_n$. $DPe_{2\alpha}$ is the total number of data packets and $CPe_{2\alpha}$ is the total number of control packets at node *2α*. $DPe_{2\beta}$ is the total number of data packets and $CPe_{2\beta}$ is the total number of control packets at the even neighbouring nodes *2β*, where $1 \leq \beta \leq n_1$. On the other hand, the total packets accumulated in the odd traffic can be described as in Equation (4).

$$PO_n = \left[(DPo_{2\alpha+1} + CPo_{2\alpha+1}) + \Sigma_{\beta=\alpha+1}^{n_2}(DPo_{2\beta+1} + CPo_{2\beta+1})\right] \leq IfQlenO_n \tag{4}$$

where

$$n_2 = Nn - n_1 - 1 \tag{5}$$

$PO_n$ represents the total packets present in the odd traffic queue and bounded by the odd traffic queue limit, $IfQlenO_n$. $CPo_{2\alpha+1}$ is the total number of control packets and $DPo_{2\alpha+1}$ is the total number of data packets at node *2α+1*. $DPo_{2\beta+1}$ and $CPo_{2\beta+1}$ is the total number of data packets and the total number of control packets respectively at the odd neighbouring nodes *2β+1*, where $1 \leq \beta \leq n_2$. The total packets in the whole network are as defined in Equation (6).

$$P_{total} = PE_n + PO_n \leq IfQlen \tag{6}$$

$P_{total}$ is the total packets accumulated in both odd ($PO_n$) and even ($PE_n$) traffic in the network with the consideration of *IfQlen* limit. Assuming the *IfQlen* is set to 50, any data after the 50th packet will be dropped from the network. Since all packets use the dedicated path to travel from the sources to the destination, less packet queue and congestion would result in the network traffic.

### 4.2 Number of Broadcast Packet Forwarding

In a common case, when there is no available route, a source node will have to initiate a forward route discovery by broadcasting the RREQ packet to all its $n_{forward}$ neighbouring nodes. The neighbouring node that can provide the freshest and shortest path to the destination node is chosen as the next RREQ forwarder. The total number of times the RREQ packet is being relayed from node to node can be illustrated as in Figure 2.

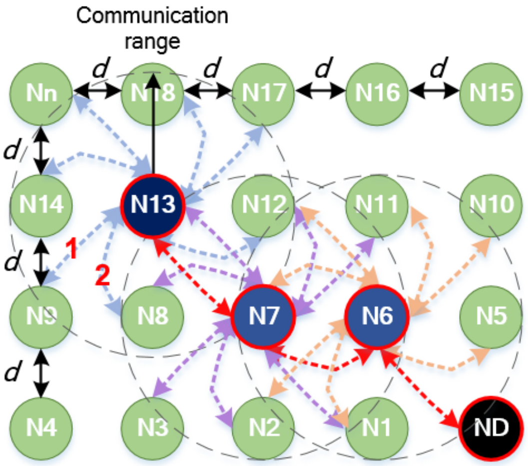

*Figure 2: Number of times of RREQ forwarding in conventional routing*

Note that the source node (N13) transmits the RREQ packet two times in a quadrant of the communication range. Thus, in total, N13 transmits the RREQ packet 8 times, which is equivalent to the number of the one-hop neighbouring nodes of N13. The total number of possible RREQ forwarders can be denoted as $m_{forwarder}$ as shown in Equation (7).

$$A_{forwarder} = \{N1, N2, N3, \ldots Nn\}$$

$$m_{forwarder} = n(A_{forwarder}) \tag{7}$$

$$N_{RREQ} = n_{forward} \times m_{forwarder} = \Sigma_{m=1}^{m_{forwarder}} n_{forward} \tag{8}$$

Where $N_{RREQ}$ is the total number of RREQ forwarding and $A_{forwarder}$ is a set of possible forwarders in one round of route discovery. Hence, the $N_{RREQ}$ for the round in Figure 2 is 24. If the communication range of each node is wider, a larger $N_{RREQ}$ would be accumulated and more exhausted the network resources would be. In distinction to the conventional routing, OEG algorithm offers a better load-balancing mechanism to distribute the RREQ packets in the network by separating the traffic into two.

The number of times of RREQ forwarding using OEG routing algorithm during the route discovery can be seen in Figure 3. The $n_{forward}$ for odd-numbered source node N13 is half of the $n_{forward}$ in the conventional routing.

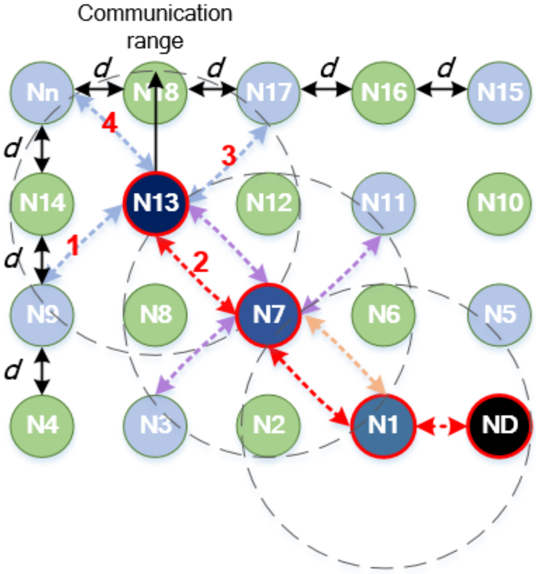

*Figure 3: Number of times of RREQ forwarding in OEG algorithm*

Due to the traffic splitting, the number of possible forwarders in each traffic for OEG algorithm is assumed to be as half as the number of possible forwarders in the conventional routing. Now both odd and even traffic will have the same number of possible forwarders as shown in Equation (9).

$$m_{O\_forwarder} = m_{E\_forwarder} = \frac{m_{forwarder}}{2} \qquad (9)$$

Since the $n_{forward}$ is halved, the total number of RREQ forwarding in one round of route discovery for both odd ($N_{O\_RREQ}$) and even ($N_{E\_RREQ}$) traffic can be denoted as in Equation (10).

$$N_{O_{RREQ}} = N_{E_{RREQ}} = \frac{n_{forward}}{2} \times \frac{m_{forwarder}}{2}$$
$$= \sum_{m=1}^{\frac{m_{forwarder}}{2}} \frac{n_{forward}}{2} = \sum_{m=1}^{m_{forwarder}} \frac{n_{forward}}{4}$$
$$= \sum_{m=1}^{m_{O}forwarder} \frac{n_{forward}}{2} = \sum_{m=1}^{m_{E\_forwarder}} \frac{n_{forward}}{2} \qquad (10)$$

In a conclusion, OEG routing algorithm offers a considerably lesser number of RREQ forwarding as compared to the conventional multi-hop routing algorithm, such as AODV. The traffic splitting feature reduces the strain and contention in the traffic by providing more opportunities for the packets to enqueue during the high traffic. Hence, apart from the energy consumption, the number of packet loss and packet processing time also can be reduced.

### 4.3 Number of Unicast Packet Forwarding

The destination relays the RREP packet in the reverse direction once the RREQ packet reached the destination. In general, the path utilised during this period of reverse routing is the same as the forward routing. Since the RREP packet is unicast in nature, the impact of the optimisation of RREP packet towards the traffic is minor. However, during the high traffic, this optimisation could contribute to a better traffic stream. As shown in Figure 4, it can be observed that the number of RREP forwarding in the reverse routing is less than the number of RREQ forwarding in the forward routing.

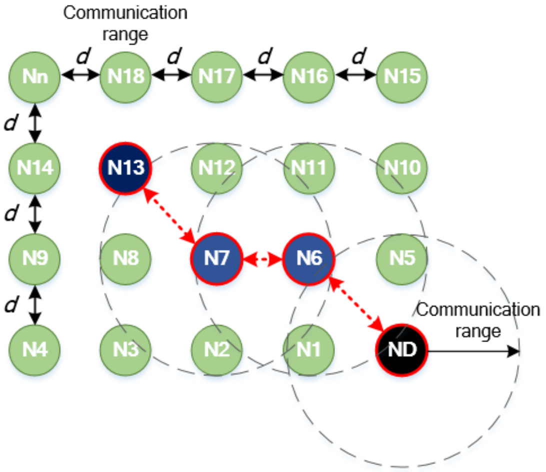

*Figure 4: Unicasting of RREP packet in conventional routing*

During this period, the destination node (ND) is considered as the RREP source. It can be seen that the number of possible RREP forwarders in the reverse routing is equivalent to the $m_{forwarder}$ in the forward routing. Hence, the number of possible RREP forwarders can be simply denoted as $m_{forwarder}$. Since RREP is unicast in nature, $n_{forward}$ can be denoted as 1 as concluded in Equation (11).

$$\begin{aligned} N_{RREP} &= n_{forward} \times m_{forwarder} \\ &= 1 \times m_{forwarder} = m_{forwarder} \end{aligned} \tag{11}$$

Where $N_{RREP}$ is the total number of RREP forwarding in one round of reverse routing.

In comparison to the conventional routing, Figure 5 demonstrates the accumulation of number of times of RREP forwarding using OEG routing algorithm during the reverse routing. The $n_{forward}$ remains as 1.

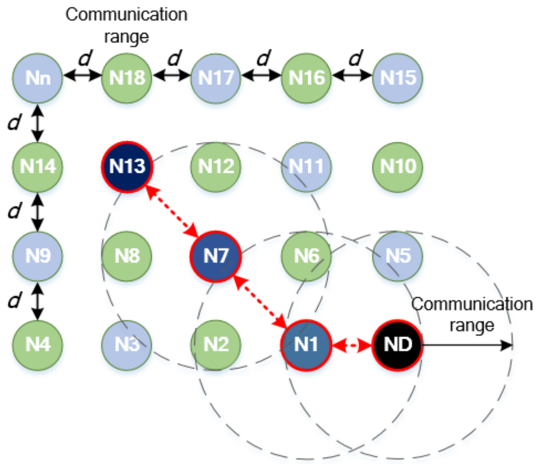

*Figure 5: Unicasting of RREP packet in odd traffic*

The number of possible RREP forwarders are assumed to be halved due to the traffic splitting. Both traffics will have a similar amount of possible forwarders as mentioned in Equation (10). Thus, the total number of RREP forwarding in the reverse direction for both odd ($N_{O\ RREP}$) and even ($N_{E\ RREP}$) traffic can be denoted as in Equation (12).

$$\begin{aligned} N_{O_{RREP}} &= N_{E_{RREP}} = n_{forward} \times \frac{m_{forwarder}}{2} \\ &= 1 \times \frac{m_{forwarder}}{2} = \frac{m_{forwarder}}{2} \end{aligned} \tag{12}$$

Thus, it can be seen that the contribution of the RREP packet forwarding optimisation during the acknowledgement phase is minor. However, this optimisation can bring a significant improvement during saturated traffic.

### 4.4 Next Forwarder Probability

Probability indicates 0 as the unlikelihood for an event to happen and 1 as the certainty of the event to happen. In routing, the probability of the packet forwarding shows how fast the packets being relayed from one node to another node. Assuming the routing information has not yet been cached in the routing table in a particular round of route discovery, the source node or the current forwarder has to determine the next hop neighbouring nodes to forward the RREQ packet. The lower the number of neighbouring nodes within the communication range of the forwarder, the higher the probability of the packet forwarding, and the shorter the time it takes for the forwarder to decide the next forwarder. The probability of choosing the next RREQ packet forwarder in the conventional routing can be denoted as in Equation (13).

$$P_{forwarder} = \left(\frac{1}{n_{forward}}\right) \tag{13}$$

$$P_{forwarder\_total} = \left(\frac{1}{n_{forward}}\right)^{m_{forwarder}} \tag{14}$$

Where $P_{forwarder}$ is the probability and $P_{forwarder\_total}$ is the total probability in choosing the next RREQ packet forwarder, with the consideration of $n_{forward}$. In OEG routing algorithm, the total probability in choosing the next RREQ packet forwarder in either even ($P_{E\_forwarder}$) or odd ($P_{O\_forwarder}$) traffic can be represented as in Equation (15).

$$\begin{aligned} P_{O_{forwarder}} &= P_{E_{forwarder}} \\ &= \frac{1}{n_{forward}/2} = \frac{2}{n_{forward}} \end{aligned} \tag{15}$$

$$\begin{aligned} P_{O_{forwarder_{total}}} &= P_{E_{forwarder_{total}}} \\ &= \left(\frac{2}{n_{forward}}\right)^{m_{OE\_forwarder}} \end{aligned} \tag{16}$$

$P_{E\_forwarder\_total}$ and $P_{O\_forwarder\_total}$ is the accumulated probability in choosing the next RREQ packet forwarder for even and odd traffic respectively. Since the value of $m_{OE\_forwarder}$ is as half as the $m_{forwarder}$ in the conventional routing, it can be concluded that OEG routing algorithm demonstrates a greater probability in determining the next RREQ packet forwarder. Thus, the splitting of traffic in OEG routing algorithm can help the nodes to quickly select the next RREQ forwarder. As for the reverse route, the probability of choosing the next RREP packet forwarder is always 1.

To investigate the impact of the traffic optimisation of OEG routing algorithm towards the overall network performance, a number of simulations have been conducted using OEG, AODV and OLSR routing algorithm under various network environments.

## 5. SIMULATION SETUP

The machine used during this study is equipped with Intel Xeon 3.2 GHz, 8 GB of memory, and 1.5 TB of storage. The average time required to complete one set of results for each routing algorithm is two weeks and four days. The simulation has been carried out using AODV (reactive), OLSR (proactive), and OEG (reactive) using Network Simulator 2.35 (NS2.35). The results were then averaged from the five best out of seven randomly generated scenarios to achieve a detailed performance evaluation with 500 seconds of simulation time. The distance between each node, *d* is 50 meters to imitate the actual deployment of nodes in most of the pipeline applications and each node covers 125 meters (*2.5d*) of communication range since most of the IEEE802.11 devices are equipped with this characteristic. The transport agent used is Transmission Control Protocol (TCP). The nodes are arranged according to the non-cluster grid with the node formation of 6 by 4, 8 by 6, 10 by 8, 12 by 10, 14 by 12, 16 by 14, 18 by 16, and 20 by 18. The implemented packet size is 128 bytes with a transmission rate of 1 packet per 2 seconds. The queue length is set to the default value (50) since most of the commercial brands, such as TP-Link and Cisco use this value as the optimum value for their IEEE802.11 devices. Increasing this value leads to heavier traffic and higher latency, while decreasing it leads to more packets drop due to the reduced space for the packets to enqueue. The parameters used during the simulation are as shown in Table 1.

*Table 1: NS2.35 simulation parameters*

| Parameters | Value |
|---|---|
| Routing algorithm | AODV, OLSR, OEG |
| MAC | IEEE 802.11 |
| Number of nodes | 24, 48, 80, 120, 168, 224, 288, and 360 |
| Traffic type | CBR |
| Interface queue type | DropTail/PriQueue |
| Packet size | 128 bytes |
| Packet queue length | 50 |
| Simulation time | 500 seconds |
| Propagation model | Two ray ground |

## 6. RESULTS AND DISCUSSION

The OEG, AODV, and OLSR routing algorithm have been tested using the simulation environment stated in the previous section and evaluated using the following metrics:

### 6.1 Packet Delivery Ratio

Based on the user's perspective, throughput is more critical compared to the packet delivery ratio. However, from the network design perspective, the delivery ratio is more critical compared to throughput since it helps in recognising the issue that might contribute to poor throughput in the network. A lower packet delivery ratio indicates more packet loss in the network. The packet delivery ratio can be described as the correlation between the successfully received packets with the total sent packets. Since most of the applications in the oil and gas industry are data-driven applications, any missing data is highly impactful to the industry itself. As illustrated in Figure 10, the packet delivery ratio decreases as the network size increases. The proposed routing algorithm outperformed the AODV routing algorithm prominently after the deployment of 168 nodes (1% increase) onwards (28.4% increase with 360 nodes). This result indicates that the proposed routing algorithm is more capable of retaining the packet sent to the destination compared to AODV and OLSR. The proposed routing algorithm also shows a highly notable improvement at 120 nodes onwards when compared to the OLSR routing algorithm. With the splitting of the traffic into two, the packet queue in the network has eventually been reduced, particularly due to the reduction of the amount of broadcast packets. Hence, the congestion also has been reduced and more data flow has been achieved, particularly in the high-density network.

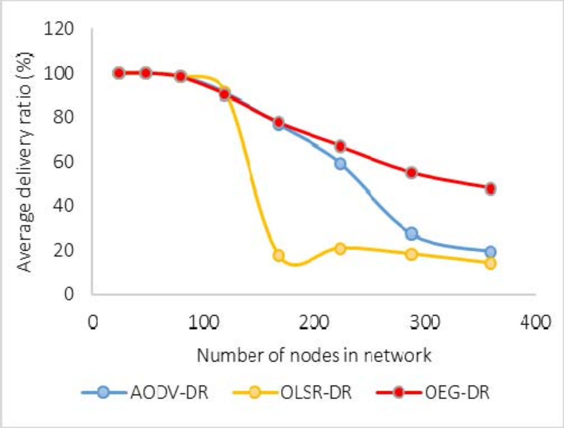

*Figure 10: Packet delivery ratio against number of nodes*

### 6.2 Throughput

Throughput can be defined as the rate of bytes (from the packets) received in kilobytes per second (kbps) unit. As illustrated in Figure 11, a comparable difference in throughput between the algorithms can be seen starting at 80 nodes deployment onwards. However, the proposed OEG algorithm shows a better network throughput compared to OLSR and AODV routing algorithm. When compared to AODV, the proposed routing algorithm is capable of delivering 1.2 kbps and 13.6 kbps more throughput at 80 and 360 nodes deployment respectively.

The trend of the throughput reflects the trend in Figure 10. Due to the packet loss, the amount of successfully arrived packets at the destination per second have reduced. Hence, the throughput as well has been badly affected.

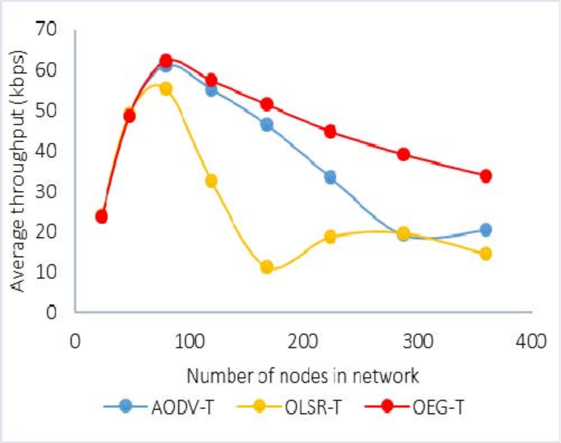

*Figure 11: Throughput against number of nodes*

### 6.3 End-to-end Delay

End-to-end delay can be defined as the amount of time accumulated for a packet to arrive at the destination. Apart from transmission delay, the packet may also experience propagation (throughout the medium), processing, and queueing delay [28]. In Figure 12, the end-to-end delay for OEG is the highest in the small-sized network. The trend of both end-to-end delay and throughput (Figure 11) is related to each other. It can be seen that the higher the throughput, the higher the time required for the packets to arrive at the destination. Due to the number of the arrived packets per second are higher, the queue is occupied much faster [29]. Hence, the packets have to stay in the queue much longer before they can be processed and forwarded in the next hop. This issue not only time-consuming but also energy-consuming.

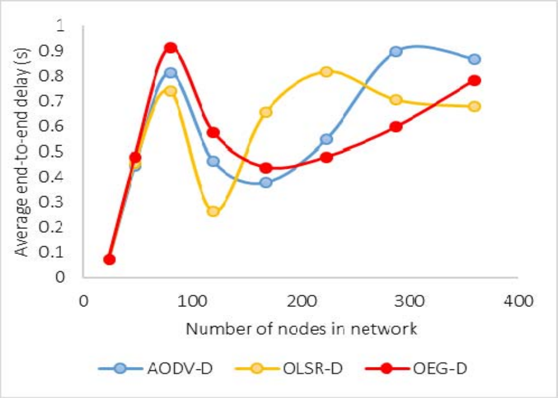

*Figure 12: End-to-end delay against number of nodes*

### 6.4 Energy Consumption

Energy consumption is calculated in Joule (J) to indicate the power usage in the network. Most of the time, the nodes closer to the destination deliver more packets as compared to the nodes that further from the destination. Such an event has led to uneven load distribution in the network [30]. In the area where packet contention is high, the queue can be easily congested and the incoming packet will be dropped due to the occupied space in the traffic. This issue has led to energy wastage due to (1) the packet regeneration, retransmission, and reforwarding. If this situation keeps repeating, a substantial amount of energy wastage in the network will occur.

Apart from that, the increasing distance between the sink node and the source node also contributes to the increasing number of hops of the packet and the amount of energy used. This issue can be visualised as in Figure 13; as the number of nodes increase, the energy consumption increases as well. OLSR shows the worst energy consumption in the network, while the proposed routing algorithm shows the best energy consumption prominently from 120 to 360 nodes deployment. When compared to AODV, the proposed routing algorithm utilises 0.01 J to 0.76 J less energy for 120 to 360 nodes deployment respectively. With the predefined traffic, the network able to reduce the enqueued packets, particularly at the destination area, and prevent the energy issue.

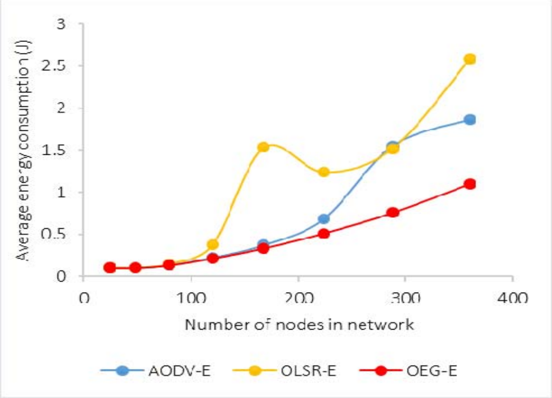

*Figure 13: Energy consumption against number of nodes*

## 6.5 Passive Node

A passive node is a node without a chance to transmit the packet over the network. The passive nodes present due to the wasted and unequally distributed network resources throughout the network. The number of passive nodes exists the fewest with the proposed routing algorithm as shown in Figure 14. At 360 nodes deployment, the number of passive nodes that exist in the network using the proposed routing algorithm are less than 40% of the deployed nodes, while the number of passive nodes that exists in the network for AODV and OLSR is more than 50% of the deployed nodes. Due to the congested traffic, some nodes will not be able to transmit their packets due to the excessive amount of unprocessed packets in the queue. Thus, these nodes are considered as passive nodes and often appear when the packet contention in the network is high.

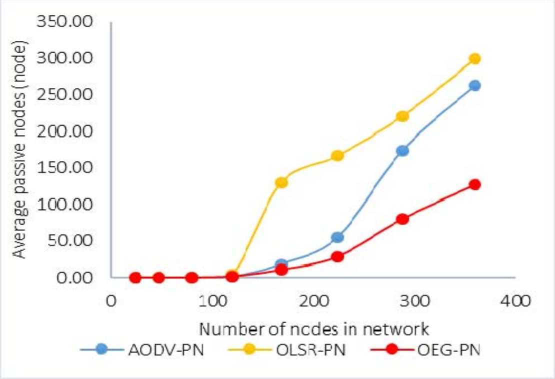

*Figure 14: Passive nodes against number of nodes*

## 6.6 Fairness Index

Fairness index determines how fair the resources are distributed among the nodes in the network. The closer the fairness index to 1, the better the distribution of the allocated resources over the network. Accomplishing an optimum network fairness index with a large number of nodes is a complicated job, particularly when designing a routing algorithm. The proposed routing algorithm outperforms AODV and OLSR starting from the 80 nodes deployment onwards as illustrated in Figure 15. Even with more throughput, the fairness index achieved by the proposed routing algorithm still below 0.5, which can be seen starting at the deployment of 168 nodes and getting worse as the network size increases. This issue shows that the fairness issue has been partially resolved since the allocated resources were still not equally distributed in the network. Generally, the nodes closer to the destination have higher traffic (consume more resources) due to the packet accumulation factor as compared to the nodes further from the destination (consume fewer resources). This event has caused an imbalance in resource utilisation where the nodes closer to the destination consumed more resources as compared to the nodes further from the destination.

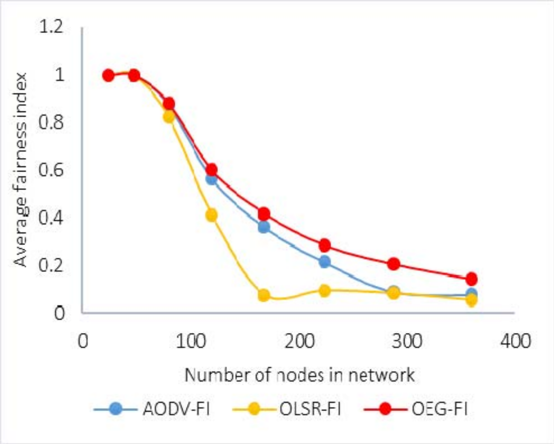

*Figure 15: Fairness index against number of nodes*

## 7. CONCLUSION

Most of the time, the raw materials are transported via pipelines since the transportation cost is less as compared to barge or truck transportation. Due to the harsh environment of the refinery area, continuous pipeline condition monitoring is highly essential to ensure the pipelines' integrity. Since the dissemination of the pipelines in the refinery is wide, network with grid nodes arrangement is the most feasible solution to fit the coverage requirement. During the early of the study, reactive (AODV) and proactive (OLSR) routing algorithm has been simulated to observe the behaviour of the network using the grid nodes arrangement. Numerous performance issues have stemmed out as the number of nodes increase, such as throughput degradation, packet loss, high energy consumption, severe network fairness, and the presence of passive nodes. These findings show that the first objective has been achieved.

Hence, with the proposed reactive OEG routing algorithm, most of these issues could be resolved by distributing the packets through the dedicated path. When compared to AODV in the largest network configuration (360 nodes), OEG routing algorithm able to route the network to deliver 13.6 kbps more throughput, 28.4% more delivery ratio, 0.76J less energy consumption, and 37.9% fewer passive nodes presented even the end-to-end delay is higher. These results show that the second objective has been achieved.

The limitation of OEG routing algorithm is the slight improvement on the fairness index. The OEG algorithm also only able to operate according to the static IP of the nodes. Since OEG algorithm is a flat tier algorithm, it is suggested the future work to implement cluster-based architecture to further investigate its impact on the network performance. Suggested directions for future work also include the improvement of network fairness mainly for the large-sized network.

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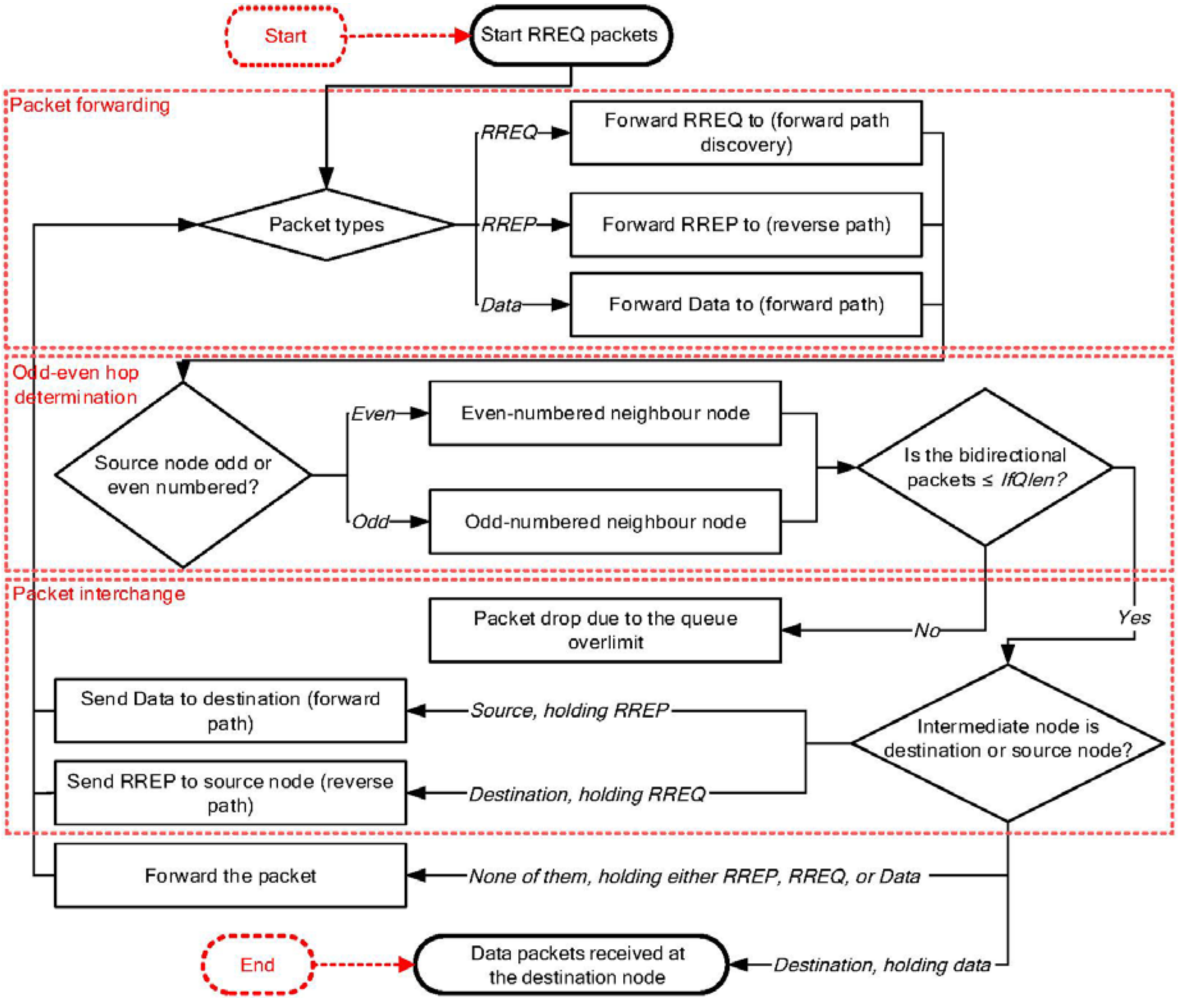

*Figure 6: OEG routing algorithm*

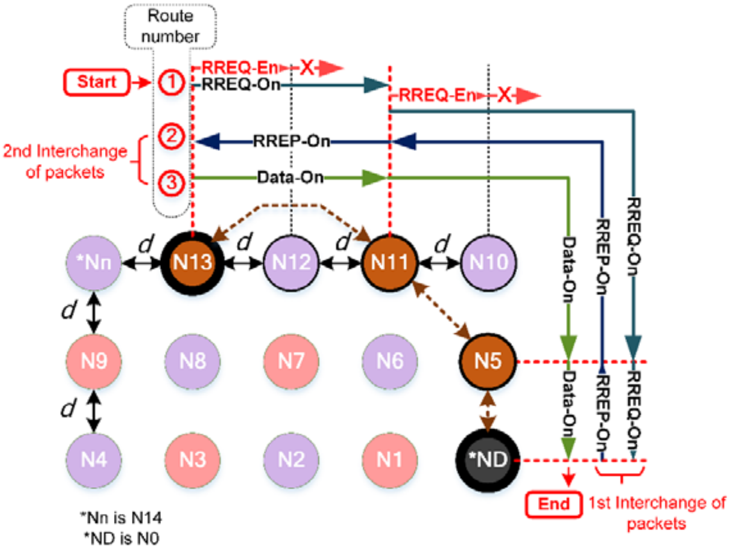

*Figure 7: OEG routing demonstration*