Draft Version

Network performance optimization using Odd and Even routing algorithm

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***Abstract* - The revolution on static wireless sensor network (WSN) had gained popularity in remote monitoring especially in oil and gas pipeline integrity. The use of WSN in oil and gas pipelines facilitates real time data transmission from sensors to the monitoring station located miles away. WSN for pipeline network are critical performance driven communication mechanism due to its unique linear geographical set up. The network performance of linear topology is compromised proportionally to the number of nodes. Such a drawback results in poor delivery ratio, throughput, latency and fairness due to its snowball effect towards the destination node. In this paper, we proposed a novel routing method, Odd-Even Linear Static Routing Path (OE-LSRP) to achieve significant improvements in overall network performance in TCP traffic. Various simulation experiments are tested with OE-LSRP in accordance to IEEE 802.11standard to achieve results in making it feasible for the pipeline network.**

***Index Terms* - Linear topology, pipeline network, static routing, TCP performance, static wireless sensor network**

I. INTRODUCTION

The key features of wireless sensor network (WSN) increased its popularity on monitoring oil and gas pipelines integrity. WSN is considered as a communication backbone for the oil and gas industry to relay real time information for the remote monitoring operations. Pipelines are used as a cost effective and safer transportation medium [1] which is still vulnerable to physical damage or dangerous accidents [1, 2]. Many studies has indicated that pipeline transportation has a history of failures but when it's all compared with railroad transportation the percentage is just a small fraction of accidents reported [1].

Accidents in oil leaks from pipeline results in anomalies in temperature readings below the pipeline, whereas a rupture gas pipeline produces a temperature drop above the pipeline. Continues temperature and pressure monitoring of oil and gas pipeline helps to discover leaks or rupture proactively which enables faster respond to the impending accidents [3, 4].

The most important features of WSN in monitoring oil and gas pipeline integrity will be reliability, durability and scalability. The overall network performance is critical for the sustainability of the network in the long run. The unique geographical linear structure of the WSN on pipelines, creates limitations on overall network performance [5, 6]. The accumulation of data from each independent nodes as shown in (1) has to share the same path to transfer the data towards the destination nodes.

$$NTP = \sum_{i=0}^{n}(DP_i + CP_i) \leq IfQ \qquad (1)$$

Where NTP is the total packets for *n* number of nodes, DP_i is the total data packets, CP_i is the total control packets at node *i* and *IfQ* is queue size in network.

In a real life set-up, all nodes are considered as source which is likely to send its respective data to the destination simultaneously. In such a scenario, there are higher chances of data packet accumulation on a certain node in the network as shown in (1) which will build up and results into a bottleneck. In accordance to IEEE 802.11 standard, there are a number of crucial factors which makes the linear topology least popular compared to the other known topologies [7, 8]. Some of the crucial factors in WSN is the transmission range, carrier sensing range, queue size, transmission power, battery lifetime and bandwidth. The factors could be manipulated by overwriting or with improved routing algorithm to enhance its existing performance [9].

II. RELATED WORKS

Oil and gas pipelines are fixed infrastructures which are stretched over longer distance from one point to the other which could be hundreds of miles away. In general, the communication between two destination nodes takes place through intermediate nodes which are arranged in series as shown in Fig. 1. Because of the structure, such networks are faced with unique issues.

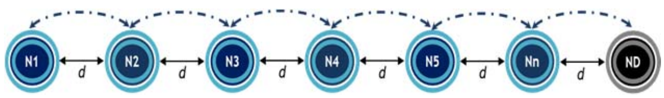

Fig. 1: A typical single hop linear topology with Nn number of source nodes and ND as destination node evenly distributed in *d* within the communication range.

In pipeline networks all nodes are statically located to establish a chain of communicating thru all available nodes in the network. Pipeline network consists of a series of static nodes where each node is designed to perform as host or/and as a router. A node in a specific location which wants to transmit a data packet first needs to discover or set the route to the destination node using route discovering protocols. The two most common methods in route discovery are reactive routing protocol (on demand) and proactive routing protocol (table-driven) [10, 11].

The most well-known commercial reactive routing protocol is Ad hoc On-Demand Distance Vector (AODV) [10-14] operates on demand basis for searching a route. The sequence number of the destination is used to identify newest route to destination. In a linear topology if two nodes are within the communication range, the source node will route to its destination node with an option to bypass its intermediate node based on real time changes as shown in Fig. 2. Dynamic Source Routing (DSR) [10, 11, 14] is another on demand routing protocol is similar to AODV but navigate route between source node to destination node using its data packet. All nodes hold the accumulated route information's which will be used to route the data packets to the designated destination. DSR is not viable for long range linear communication due to high overhead.

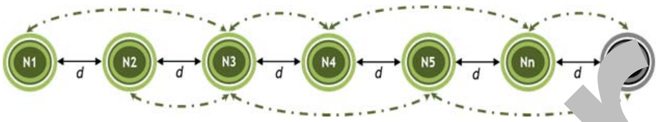

Fig. 2: A linear topology with Nn number of source nodes and ND as destination node evenly distributed in *d* within half the communication range.

Table-driven routing protocols have been a popular choice in various topologies except long range linear topology. The most known commercial, proactive routing protocol is destination-sequence distance-vector routing (DSDV) [11, 13, 14]. DSDV identify available route to destination node in the network which shows less delay for route set up process. The limitations of DSDV are that regular update is required for the routing table's entries based on real time changes on the network as shown in Fig. 2. Such a process consumes high battery power and a portion of the bandwidth even during idle state of the network. Optimized link-state routing (OLSR) [11, 15] is another commercial table-driven routing protocol is similar to DSDV but identify routes to destination nodes which is known and retained before data packets are send. Having the routes available to the destination nodes, the route discovery delay for finding a new route is zero. OLSR has issues with high value of routing overhead generated which is greater than a reactive protocol.

Fixed routing path (FRP) is an efficient routing protocol with suppressed routing messages where route is manually pre-calculated to an optimal shortest path [16, 17]. The concept of hierarchical or cluster encourages wireless multi-hop communication to a specific cluster to decrease number of data transmitted by data merging before sending it to the receiver [9]. The Power-Efficient Node Placement Scheme (PENPS) uses the concept of number of node optimization and distance to different path loss parameters for linear wireless sensor networks [18]. Hierarchical and concept of sectioning nodes into basic sensor nodes, data relay nodes and data dissemination nodes which are placed in linear with respective purpose for each node [19]. Wireless nodes with flat data collection algorithm response to impromptu data and forwards it to the neighbouring nodes with minimum buffered waiting time [20].

Generally the routing protocol performance is measured in terms of links stability between nodes, breaking and reconstruction of links is a crucial activity in a network where most data packets get lost. In a wireless network, all nodes generate broadcast messages in a timely interval to their neighbouring nodes within the communication range to ensure their presence and to retain the pre-established routes.

III. ODD-EVEN LINEAR STATIC ROUTING PATH (OE-LSRP)

Odd-Even Linear Static Routing Path (OE-LSRP) is designed to produce better results in terms of overall network performance for linear topology compared to the other available routing algorithms. OE-LSRP has a better performance and higher efficiency as the routes between all source nodes to the destination nodes are predefined based on Odd and Even path as shown in Fig. 3.

Fig. 3: A dual path linear topology with On/En number of source nodes and ND as destination node evenly distributed in *d* within half the communication range.

There are many optimization issues incorporated with node placement in a multi-hop linear topology especially on connectively between source and destination nodes. In order to minimize the node failures in OE-LSR, sensors are arranged in d distance within the maximum communication range of 2d in order to send and receive data as shown in Fig. 3.

In general, routing table is generated or updated based on available nodes within the communication range. In linear topology the routing table is generated or updated based on a chain sequence between the source nodes to the destination node in a single routing table which will be fully/partially stored in all nodes in the network. Unlike the standard practice, OE-LSRP predefines two sets of routing table which is based on the node sequence in the network not taking in account of the number of source nodes and destination node. The two routing tables are automatically generated from a series of "Odd" and "Even" numbered nodes forming two individual bidirectional path in the network. The nodes allocated in the

"Odd" or "Even" routing table will be able to send and receive data packets along with the control packets in the predefine route during the network active period without any possibilities of path crossing.

The dual path method reduces the routing overhead by half and allocates better proportion for the data packets compared to any conventional routing algorithm making it a good solution for pipeline network. The accumulation of data for Odd and Even nodes are as shown in (2) and (3) respectively to transfer the data towards the destination nodes.

$$\text{TPO} = \sum_{i=0}^{n} (DPO_i + CPO_i) \leq IfQ_O \quad (2)$$

Where TPO is the total packets for *n* number of nodes (Odd), DPO_i is the total data packets for *n* number of nodes (Odd), CPO_i is the total control packets for *n* number of nodes (Odd) and IfQ_O is the queue size for Odd numbered nodes in network.

$$\text{TPE} = \sum_{i=0}^{n} (DPE_i + CPE_i) \leq IfQ_E \quad (3)$$

Where TPE is the total packets for *n* number of nodes (Even), DPE_i is the total data packets for *n* number of nodes (Even), CPE_i is the total control packets for *n* number of nodes (Even) and IfQ_E of is the queue size for Even numbered nodes in network.

$$\text{NTP} = \text{TPO} + \text{TPE} \leq \text{IfQ} \quad (4)$$

Where NTP is the network total packets at destination for *n* number of nodes which could be Odd/Even and the value of TPO / TPE is from (3/4).

The other key aspect of OE-SLRP is the basic control packets required for static wireless nodes. The eliminated control packets are hello packets and routing packets where the location and path of the nodes in the network is permanently fixed. The crucial task of a node is to continuously sense link between neighbour nodes and to update the routing table by using the means of a timely routing messages. Unlike in static wireless nodes, no routing messages or routing table updates are required for a normal operation in an idle condition as it doesn't influence any changes in data transfer path. With limited control packets in OE-SLRP pushes more room to accommodate higher data packets enabling for higher data transfer rate. The proportion of data packets has significant hike compared to other available routing protocols in linear topology making OE-SLRP an idle solution for higher data rate.

IV. Performance Analysis and Evaluation

This section of the paper illustrates results on overall network performance for the proposed OE-SLRP by the means of Network Simulator 2 (version 2.35) [10, 21]. In all simulation set up, OE-SLRP is compared with one reactive routing algorithm which is AODV along with two proactive routing algorithm which is DSDV and FRP [16, 17] for performance comparison purposes. All described results are from an average value of five runs with different seed values over 200 second's simulation duration. The data packet start time for each source is generated using a custom random function with 20 sections of 10 seconds per section during the simulation time. The data packet start time are generated randomly from 0 sec – 2 sec in each section which will retain the active period of the source for 6 seconds per cycle.

All nodes named in the results are stationarily located for the full simulation duration with one destination node and the rest as source nodes. The predefined setting for the simulation is as tabulated in Table 1.

TABLE I
NS2 Simulation Parameters

Parameters	Value
Channel type	Wireless channel
Radio propagation model	TwoRayGround
MAC type	802.11
Interface queue type	DropTail/PriQueue
Simulation area	10 km × 10 km
Source nodes	19, 39, 59, 79, 99
Max packet in ifq	50 (packets)
Agent type	Transmission control protocol (TCP)
Traffic type	Constant bit rate (CBR)
RXThresh	100 meters
CSThresh	125 meters
Packet size	1024 bytes
Data rate	1 packet/sec
Simulation duration	200 sec

In all the presented results from Fig.5 to Fig. 9 there are 2 types of measurements: a network performance metric and number of node failures. The Y1 axis (left vertical axis) represents the network performance metric and the Y2 axis (right vertical axis) represents the number of node failures. The number of node failures is shown in Table 2:

TABLE 2
Number of Node Failures Based on Routing Protocols over Number of Nodes in Network

Number of nodes in network	Number of node failures based on routing protocols			
	AODV	DSDV	EVOD	FRP
20	0	0	0	0
40	0	9	0	0
60	0	29	0	0
80	5	49	0	0
100	12	69	0	1

In this simulation, OE-SLRP, AODV, DSDV and FRP are tested and evaluated on the following metrics:

A. Delivery ratio: In any wireless network one of the crucial parameters measured will be the delivery ratio which shows the success of the network in receiving packets over send packets [10, 13, 14] as described in (8).

$$\text{Avg. Delivery Ratio} = \frac{\sum_{i=0}^{n}\left(\frac{RP_i}{SP_i}\right)\times 100\%}{n} \quad (8)$$

Where RP_i is the total received packets for n number of nodes, SP_i is the total send packets for n number of nodes and n is the maximum number of nodes in network.

As seen from the results, the least number of 20 nodes to the largest number of 100 nodes, OE-SLRP outperforms all the other routing protocol in terms of delivery ratio as shown in Fig. 5. One of the main reasons in achieving this result is based on the prefix odd and even routing path where generated packets are transferred to its next destination on principles explained in Section III of this paper.

The delivery ratio performance with OE-SLRP is 2% - 5% better than FRP and AODV. On the other hand, the performance of DSDV has plunged from 97% to 28% from the least number of 20 nodes to the largest number of 100 nodes which is due to the excessive control packets generated as explained in Section II.

The measured metrics of delivery ratio is in percentage (%) which only gives a raw understanding of the successfulness of packets received rather than the actual number of packets received which makes a significant difference in other wireless metrics. In the same principles, OE-SLRP has a significantly small difference in the delivery ratio over other routing protocols compared in Fig. 5 but further performance can be visualized in next discussed results.

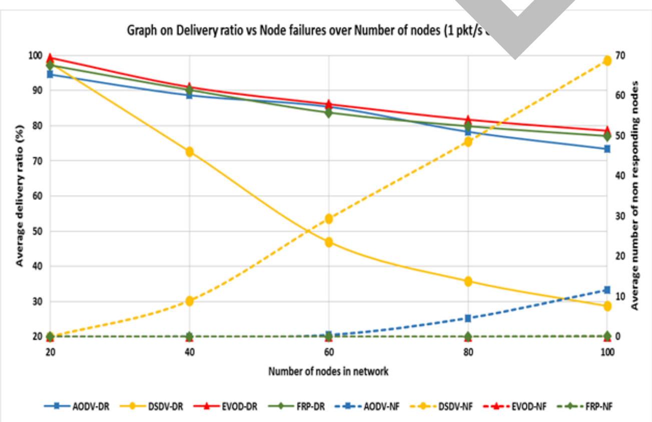

Fig. 5: Graph on delivery ratio (%) vs non responding nodes over number of nodes

B. Throughput: The other crucial parameter measured the throughput. The average throughput over all flows in the network [10, 22] is (9).

$$\text{Avg. Throughput} = \frac{\sum_{i=0}^{n}((\sum(Pkt\ size \times 8 \times RP_i))/(End\ t - Srt\ t)}{n} \quad (9)$$

Where *Pkt size* is as defined in the simulation parameter, RP_i is the total received packets for n number of nodes, $End\ t - Srt\ t$ is the Δ *Duration* for the entire simulation duration and n is the maximum number of nodes in network.

The capability to achieve higher throughput in a wireless network is always a desirable. The throughput measurement from the least number of 20 nodes to the largest number of 100 nodes, OE-SLRP outperforms AODV, DSDV and FRP as shown in Fig. 6. The main reason for higher throughput for OE-SLRP is its capability of transferring higher data in parallel using two the proposed prefix odd and even routing path.

Below 40 nodes, the difference in throughput is quite small yet there is a difference of 4 Kbps – 19 Kbps using OE-SLRP while there are significant differences of 20 Kbps – 40 Kbps for above 60 nodes between OE-SLRP and the other routing protocols used in the simulation as shown in Fig. 6. With the capacity to achieve higher throughput, OE-SLRP will be able to transfer large data within the network. Moreover, with a small difference in delivery ratio as shown in Fig. 5, the OE-SLRP has a significant impact in average throughput for the simulated scenario which makes it a more desirable choice of routing protocol for linear wireless network.

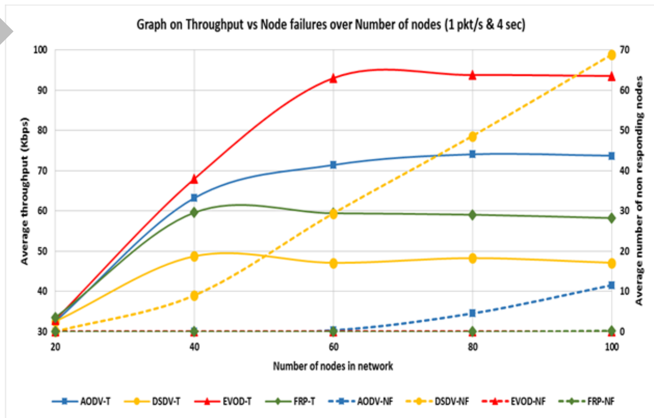

Fig. 6: Graph on throughput (Kbps) vs non responding nodes over number of nodes

C. End to end delay: The other crucial factor in wireless performance is end to end delay. End to end delay is the average value of total time take to transmit data over all the flows in the network [10, 13] as described in (10).

$$\text{Avg. Delay} = \frac{\sum_{i=0}^{n}((\sum(End\ t_i - Srt\ t_i)/\sum(RP_i))}{n} \quad (10)$$

Where *End* t_i – *Srt* t_i is the Δ *Duration*$_i$ for the respective duration for *n* number of nodes, RP_i is the total received packets for *n* number of nodes, and *n* is the maximum number of nodes in network.

Referring to all the previous results, OE-SLRP has proven to be the best routing protocol for producing higher delivery ratio and throughput but when it comes to delay, OE-SLRP is not that desirable because the readings shown in Fig. 7 indicated that OE-SLRP had taken 1 to 4 folds more in terms of duration compared to AODV and DSDV. The readings recorded for FRP is between 3 to 8 folds more in terms of duration compared to AODV and DSDV from the least number of 20 nodes to the largest number of 100 nodes.

In OE-SLRP, higher performance was achieved in delivery ratio and throughput which has an implication towards overall delay. The higher volume of data received which is measured in Throughput as shown in Fig. 6 using OE-SLRP will explain the reasons of higher end to end delay which reflected in Fig. 7. To control the end to end delay to a reasonable duration, steps could be taken to control the number of generated packets if it's applicable.

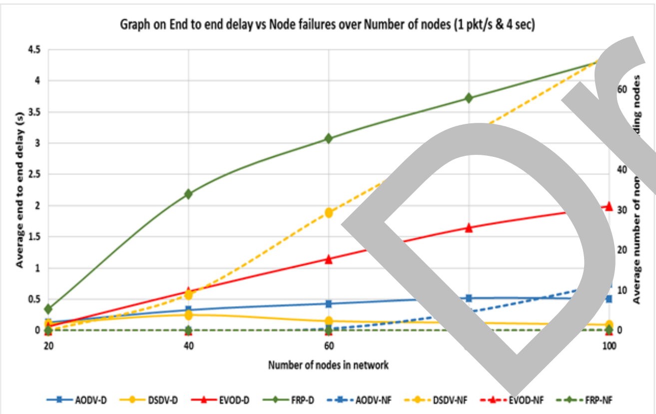

Fig. 7: Graph on end to end delay (ms) vs non responding nodes over number of nodes

D. Fairness index: In linear topology fairness or equality within the network is a crucial factor from the prospective of network stability. The scalar measurement of resources (data packets) allocation discrimination among all source nodes [22] is described in (11).

$$\text{Fairness index} = \frac{(\sum_{i=0}^{n} n_i)^2}{N \sum_{i=0}^{n} {n_i}^2} \quad (11)$$

Where n_i is the normalized throughput for *n* number of flows and for N is the number of nodes in network.

In any linear wireless network achieving the right balance of fairness is a challenging task of the routing protocols. In a small size linear network, fairness is hardly visible since the effects as mentioned in Section I of this paper. The result of fairness index has shown that OE-SLRP has a great amount of equality in the network compared to AODV, DSDV and FRP as shown in Fig. 8. The fairness in OE-SLRP is above 0.97 from 60 nodes and below where else FRP, AODV and DSDV started to plunged below OE-SLRP after 20 nodes. Even at 100 nodes, OE-SLRP manage to retain the fairness above 0.8 where else the other routing protocols recoded below 0.68.

All the fairness recorded in Fig. 8 is based on the higher throughput produced by OE-SLRP as shown in Fig. 6 which makes OE-SLRP a routing protocol which is capable not only handling high data rate but also retains its fairness among all nodes in network. One of the greatest advantages of using OE-SLRP is that there is no node failures as results tabulated in Table 2. When there are node failures [19] in network this will reflect the results in fairness index [22]. In some scenario with least number of node failures as for FRP, there will be a very bias data transfer management which is as shown in Fig. 9.

The fairness index can be further improved by controlling the number of generated packets and the acknowledgment packets.

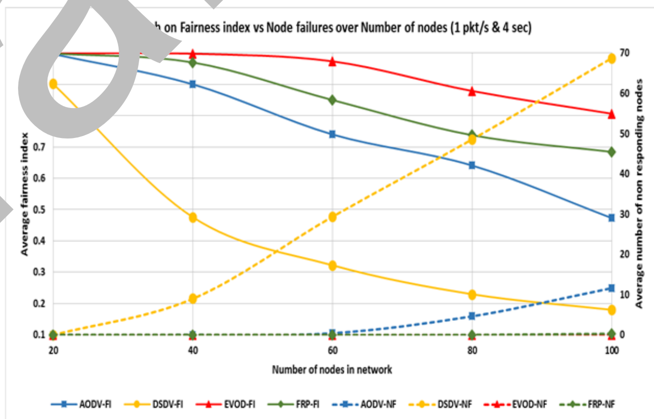

Fig. 8: Graph on fairness index vs non responding nodes over number of nodes

The other metric to visualise the fairness in a network is using the variation of received packets when a constant number of packets are sent (constant in most pipe networks). Variation of received packets in the measurement of maximum and minimum number of packets received from all source nodes as described in (12).

$$Pkt\ variation\ i = \frac{(Max\ pkt_i - Min\ pkt_i)}{Max\ pkt_i} \times 100\% \quad (12)$$

Where *Max* pkt_i is the maximum number of received packets recorded and *Min* pkt_i is the minimum number of received packets recorded for the respective *n* number of nodes in network.

Based on Fig. 9 the percentage of received packet variation for OE-SLRP is the lowest of all from the least number of 20 nodes to the largest number of 100 nodes compared to other routing protocols used in the simulation. For OE-SLRP the variation is very low for 40 nodes and below compared to AODV, DSDV and FRP which has a large range of variation. This indicates that the imbalance of data packets received in the network OE-SLRP is at a fair state compared to the other routing protocols. The imbalance of data packets received for 60 nodes and above is higher for OE-SLRP but still below the other routing protocols. The reason behind of the increased received packet variation for OE-SLRP is due to the high volume of data packets transmitted. The variation could be reduced by controlling the number of generated packets and the scheduling methods.

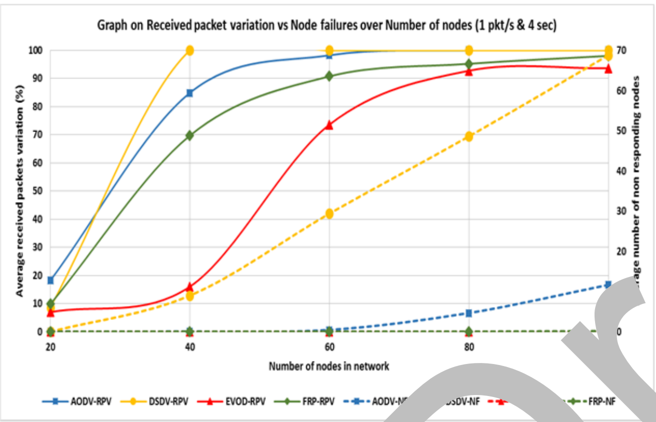

Fig. 9: Graph on received packet variation vs non responding nodes over number of nodes

IV. Conclusion

This paper has highlighted research conducted to optimise factors affecting the overall network performance on linear topology. Test simulations were performed to evaluate the proposed Odd-Even Linear Static Routing Path (OE-LSRP) which has demonstrated and achieve significant improvements in overall network performance in TCP traffic. OE-LSRP is a novel routing algorithm to improve reliability (delivery ratio), latency (end to end delay) and responsiveness (dealing with node failures) which had crucial implication towards the sustainability of the linear wireless network. These findings have functional implications especially in throughput, fairness issues and energy consumption at this state of research where detail analysis will be carried out next for further optimization of the proposed metric.

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