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Performance Analysis of Proactive Routing Algorithm for a Multi-Hop Pipeline Network

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Abstract
Safety and reliability are the main challenges for the oil and gas industry, especially in pipeline monitoring. An example of a recent accidents is the 2022 Lawas gas pipeline explosion, which raised more attention toward keeping advanced monitoring and control. These incidents create great importance for using WSN in real-time monitoring within industrial processes that present hazardous conditions. However, congestion, latency, and existing routing protocols' inefficiencies afflict these, hence limiting the effectiveness of WSNs in pipeline monitoring. It proposes the DSDVTRI protocol, an enhancement of the DSDV routing protocol, as a means by which these challenges could be improved through a mechanism of triple interleaving. The DSDVTRI protocol splits network traffic into three distinct paths which are α (alpha), β (beta), and δ (delta) significantly reducing congestion by distributing the load evenly. Unlike traditional routing protocols that use a single path, this approach enhances throughput, delivery ratio, and fairness index, especially in multi-hop linear networks commonly used in pipeline monitoring systems. Besides that, the DSDVTRI protocol reduces latency and maximises general energy efficiency, responding to the fault tolerance challenge regarding WSN deployments in large-scale applications. From the simulation and comparative analysis of AODV and DSDV, the DSDVTRI protocol performs better across the key metrics, thus making it a reliable solution for ensuring pipeline systems' safety and operational efficiency in the oil and gas industry.
Keywords: AODV, DSDV, Routing Protocol, Pipeline

Background Story of Oil and Gas

One of the largest and most important industries in the world is that associated with oil and gas. The activities dealing with the extraction, refining, and transportation of petroleum products are potentially difficult. The integrity and efficiency of these operations are important because they can result in massive economic losses and environmental destruction. Therefore, there should be a reliable and robust surveillance system for these industrial assets [Natesan et al., 2022; Sebastin Suresh et al., 2022]. WSNs have been found to be an ideal solution for most of the problems plaguing the oil and gas industry. These networks are endowed with the capabilities for sensing, processing, and communicating data and hence suitable for monitoring and controlling industrial processes. In this regard, WSNs in pipeline monitoring have become more visible, particularly to provide real-time information about the state of pipeline infrastructure. Recently, Internet of Things (IoT) technology has been incorporated into WSNs for increased monitoring capabilities. IoT-based systems make use of intelligent devices in the effective monitoring of pipelines, as opposed to traditional wired systems [Almheiri et al., 2020; Aba et al., 2021].The efficiency of WSNs heavily depends on routing protocols that manage energy consumption, especially in controlling how often and how long a node transmits data. Traditional routing protocols did not adequately address the needs of pipeline monitoring, such as ensuring high reliability, low energy consumption, and scalability. Proactive routing protocols like DSDV and reactive protocols like AODV each have strengths and limitations, performing effectively under different network conditions based on these critical requirements.[Raghavendra et al ., 2020].

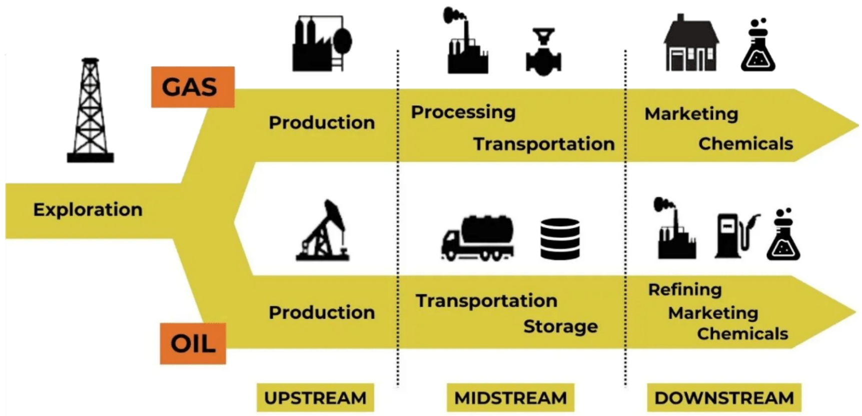

Figure 1: shows the outline of Oil and Gas industry

The roles of the upstream, midstream and downstream with respectively clearly defined functions are illustrated in figure 1. Since the risks in the upstream industry are influenced by external factors, this has the effect of having it with a comparatively higher risk profile as opposed to midstream sectors, hence more volatile. Midstream operations, transportation, and storage act as shocks that absorb most of the fluctuations between the upstream and downstream; hence, it is at a reduced risk in terms of interruption in supply chains. References: Ewing et al., 2024; Hussain et al., 2023. Downstream, however, marketing and distribution of such petroleum products as petroleum depend highly on oil price stability, product quality, and governance issues like corruption. These elements can effectively affect the question of whether revenues from this sector are sustainable or vulnerable to variation [Efuntade et al., 2022]. In addition to ensuring competent administration, studies have highlighted the importance of comprehending the complexities within the upstream, midstream, and downstream sectors. This understanding is essential for maintaining operational efficiency and mitigating risks in supply chain disruptions. Creating a complexity matrix for mining, midstream, and upstream would be one such tactic. Improving project management and operational efficiency could help overcome the challenges faced by these interconnected industries [Odhiambo et al., 2024].The performance evaluation of these routing protocols, DSDV and AODV, with a multi-hop linear topology designed for pipeline monitoring, is the focus of this paper. Ns-3 is used as a simulator in the study, following the IEEE 802.11 standards in providing empirical evidence on the efficacy of these protocols in delivery ratio, energy consumption, and network stability [Campanile et al., 2020].

Problem Formulation

The explosion of a pipeline may lead to huge losses in business and human lives, thereby creating hindrances to the oil and gas business. An example is the 2022 gas pipeline explosion near Lawas, which killed one person and left two others injured. These incidents are simply proof that efficient monitoring and control systems have a big part to do with the safety and reliability of the industrial process. Basically, these incidents just depict how efficient monitoring and control systems are necessary to bring about safety and reliability in industrial processes [Rajeshwari & Devi, 2022].

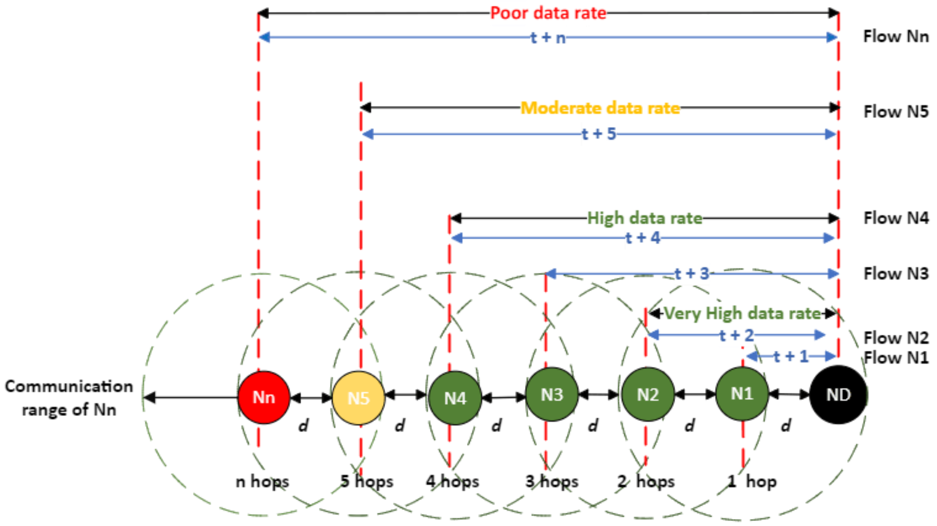

Figure 2 : Effect on data travel rate in multi-hop linear topology

The multi-hop linear topology in figure 2 was created to demonstrate how the data packet travel time factor affects fairness in a conventional multi-hop linear architecture. The diagram depicts three different data travel rates: poor, moderate, and high. These rates change based on how far a data packet must travel, with poor rates observed at nodes further away from the destination (Nn) and higher rates closer to the desti-nation node (ND). The labeled flows (Flow N1 – Flow Nn) represent how data is transferred between nodes in the multi-hop topology, showing how different nodes experience varying rates at the same time interval . At time t+1, the data rate for the multi-hop linear topology begins to show uneven transmission across source nodes due to the structure of the network. The time period indicates the reasonable data rate for nodes that are further away from the source. The typical characteristic in multi-hop linear topology brings about unequal data transmission rates across source nodes over a certain network configuration in this setup. [Liu et al., 2023]. When the impact becomes more pronounced at time t+2, the network will experience serious source node hunger, especially for nodes far off from the last node. This is a critical problem in any multi-hop linear WSN that results in in the direction of lost data packets and network resource waste.With these challenges in view, pipeline monitoring systems have integrated Advanced Routing Protocols in WSNs. Recent research efforts have focused on strengthening protocols to handle packet losses more ef-fectively, improving delivery ratios, and reducing latency, which are essential parameters for real-time monitoring in hazardous environments (Vaibhav et al., 2022).

However, the existing solutions face several challenges. For instance, large-scale WSN deployment has always been fault-tolerant while maintaining energy efficiency [Rajeshwari & Devi, 2022]. Furthermore, challenges in load balancing distribution in fault-tolerant systems to avoid failure remain [Mohapatra & Rath, 2021] . Even with these various routing protocols that have been developed for WSNs, there is still much to address as far as high latency, packet loss, and wasteful multi-path data communication are concerned. Such issues are very crucial in pipeline monitoring systems, whereby great demand for real-time data accuracy exists. Thus, optimization of the routing protocol still remains a necessity for reliable communication, minimization of delays, and reduction of packet losses in various applications where WSNs are to be used for pipeline monitoring. This requires better approaches for most of the solutions that are in place to improve the reliability and efficiency of WSNs used in pipeline monitoring (Sharad et al., 2022).

Previous Research and Study using IEEE 802.11 and IEEE 802.15.4 standards

Table 2
Shows the Related Work Using Iee 802.11 And Ieee 802.15.4 Standard

Title	**Application**	**Wireless Technology**	**Research Gap**
Linear Packet Network Coding to Enhance Reliability and Resiliency of Next Generation Wireless Networks with Topological Redundancies[Nikopour et al., 2023]	LPNC for emerging mission critical IoT applications and services.LPNC for Wi-Fi networks in A-MPDU scenario	IEEE 802.11	LPNC implementation is complex due to the need drawback faced such as complexity in implenmentation,dependence on sufficient packet reception,challenges in high-frequency bands,latency concerns and limited applicability in wireless network.
IEEE 802.11 Wireless sensor network for hazard monitoring and mitigation [Silvani et al., 2022]	Monitoring and mitigating natural hazards.Analogue measurements during natural hazards	IEEE 802.11	The proposed wireless sensor network for hazard monitoring faces several drawbacks, including a limited scope of testing, measurement

	through wireless sensor network		uncertainties, network latency issues, challenges with user mobility, dependence on existing technologies, and complexity in implementation, particularly in dynamic or remote environments.
Linear system design with application in wireless sensor networks[Gao et al., 2022]	Wireless sensor networks Linear system design	IEEE 802.11	Linear system design in wireless sensor networks faces drawbacks such as limited applicability to non-linear systems, assumptions in modeling that may not hold in real-world scenarios, lack of experimental validation, scalability challenges in larger networks, insufficient attention to energy efficiency, and complexity in implementation which may hinder widespread adoption.
TDMA-based scheduling for multi-hop wireless sensor networks with 3-egress gateway linear topology[Nguyen et al., 2021]	TDMA-based scheduling for multi-hop wireless sensor networks.Packet transmission scheduling on 3-egress gateway linear topology	IEEE 802.11	Existing scheduling schemes cannot maximize successful packet delivery probability.Focus on Y-shaped topology with 3-egress gateway linear topology.
Finite State Machine of the MQTT-SN Protocol for its Operation Over IEEE 802.15.4 in Linear Topologies[Cajamarca et al., 2024]	Implementation of MQTT-SN protocol in linear topologies.Development of finite state machine (FSM) for MQTT-SN protocol	IEEE 802.15.4	Minimizing processes at node side for large-scale linear structures.Validating MQTT-SN protocol deployment in linear topologies using WSNs.
Network Coding in TDMA-based Scheduling for Fluctuating Linear Wireless Sensor Networks[Nguyen et al., 2024]	Facility monitoring Localized event surveillance	IEEE 802.15.4	High link loss challenges successful delivery probability.Fluctuating packet generation may exceed downstream link capacity.

Efficient Cluster Tree Topology Operation and Routing for IEEE 802.15.4-Based Smart Grid Networks[Kim et al., 2023]	Smart grid monitoring applications.QoS provision for smart grid applications	IEEE 802.15.4	Lack of comparison with other existing protocols.Limited discussion on scalability challenges in smart grid networks.
Linear Packet Network Coding to Enhance Reliability and Resiliency of Next Generation Wireless Networks with Topological Redundancies[Gao et al., 2022]	LPNC for emerging mission critical IoT applications and services.LPNC for Wi-Fi networks in A-MPDU scenario	IEEE 802.15.4	Challenges in implementing LPNC in various wireless network scenarios.Evaluation of LPNC resiliency against link blockage in high frequency bands
Reliability of linear WSNs: A complementary overview and analysis of impact of cascaded failures on network lifetime[Carsancakli et al., 2022]	Linear Wireless Sensor Networks (LWSNs) Deployment scenarios necessitating sensor nodes over a line topology	IEEE 802.15.4	Impact of coordinated vs. random node failures on NL.Severe decrease in NL due to coordinated node failures.

Methodology and Algorithm Elaboration

The equation 1.0 represents the total number of packets, *NP* which is the total number of packets in network where, $N = n-1$. CP_i is the sum of the control packets while DP_i is the sum of data packets for node *i* with condition $1 \leq i \leq x$. CP_j and DP_j represents the sum of control packets and data packets for adjacent node *j* respectively with the restriction of $1 \leq j \leq x$. As shown in Equation 1.0, when the total number of nodes increases the total packets generated also increases. As a result, the traffic in the network becomes congested, and issues related to the network performance arise. Hence, this paper proposed Ad-hoc Destination-Sequenced Distance-Vector Triple Interleaving (DSDVTRI) routing protocol to increase the performance of the network.

Ad-hoc

$$NP = (CP_i + DP_i) + \Sigma_{j=i+1}^{y} (CP_j + DP_j) \leq If\ Qlen_{Dn} \quad (\mathbf{1.0})$$

Destination-Sequenced Distance-Vector Triple Interleaving (DSDVTRI)

The DSDVTRI routing protocol, based on DSDV, integrates a triple interleaving mechanism that distinguishes it from the original protocol by distributing network traffic across three distinct paths: α(alpha)-path, β(beta)-path, and δ(delta)-path. Unlike DSDV, which typically uses a single path for routing, DSDVTRI's approach reduces the load on any single route, thereby minimizing congestion. This distribution of traffic enhances overall network performance, particularly in terms of throughput and delivery ratio, by effectively managing and balancing the traffic load across multiple path.

$$NP\alpha = (CP\alpha_i + DP\alpha_i) + \Sigma_{j=i+1}^{y} (CP\alpha_j + DP\alpha_j) \leq IfQlen_{Dn} \quad \textbf{(2.0)}$$

NPα in equation 2.0 is the sum of network packets for α-traffic queues for *y* number of nodes. $CP\alpha_i$ represents the overall control packets, while $DP\alpha_i$ represents the overall data packets for node *i* where $1 \leq i \leq x$. $CP\alpha_j$ and $DP\alpha_j$ are the control packets and data packets for neighbouring nodes *j* with $1 \leq j \leq x$ condition. The *NPα* must be smaller or equal to *IfQlen* for the *α* traffic.

y is determined as :

$$y = \begin{cases} \frac{x}{3}, if\ x\ is\ divisible\ by\ 3 & \textbf{(3.0)} \\ \frac{x+1}{3}, \quad if\ x+1\ \ is\ divisible\ by\ 3 & \textbf{(3.1)} \\ \frac{x+2}{3}, \quad if\ x+2\ is\ divisible\ by\ 3 & \textbf{(3.2)} \end{cases}$$

As stated in equation (3.0,3.1,3.2) , *y* is the total number of nodes involved in α-traffic, where *x* is the total number of nodes in the network (excluding the destination node).

$$NP_{\beta} = (CP_{\beta i} + DP_{\beta i}) + \Sigma_{j=i+1}^{y} (CP_{\beta j} + DP_{\beta j}) \leq IfQlen_{Dn} \quad \textbf{(4.0)}$$

Equation 4 shows distribution network for *β*(beta)-path,followed by equation 6.0 where y is the total number of nodes involved in *β*-traffic, where x is the total number of nodes in the network (excluding destination node). NP_{β} in packets for *β*-traffic queues for *y* number of nodes. $CP_{\beta i}$ represents the overall control packets, while $DP_{\beta i}$ represents the overall data packets for node *i* where $1 \leq i \leq x$. $CP_{\beta j}$ and $DP_{\beta j}$ are the control packets and data packets for neighbouring nodes *j* with $1 \leq j \leq x$ condition. The NPβ must be smaller or equal to *IfQlen* for the β-traffic.

y is determined as :

$$y = \begin{cases} \frac{x}{3}, if\ x\ is\ divisible\ by\ 3 & \textbf{(5.0)} \\ \frac{x+1}{3}, \quad if\ x+1\ \ is\ divisible\ by\ 3 & \textbf{(5.1)} \\ \frac{x+2}{3}, \quad if\ x+2\ is\ divisible\ by\ 3 & \textbf{(5.2)} \end{cases}$$

As stated in equation (5.0,5.1,5.2), *y* is the total number of nodes involved in *β*-traffic, where *x* is the total number of nodes in the network (excluding the destination node).

$$NP_{\delta} = (CP_{\delta i} + DP_{\delta i}) + \Sigma_{j=i+1}^{y} (CP_{\delta j} + DP_{\delta j}) \leq IfQlen_{Dn} \quad \textbf{(6.0)}$$

Equation 6.0 shows distribution network for δ (beta)-path. NP_{δ} in Equation 6.0 is the sum of network packets for *β*-traffic queues for *y* number of nodes. $CP_{\delta i}$ represents the overall control packets, while $DP_{\delta i}$ represents the overall data packets for node *i* where $1 \leq i \leq x$. $CP_{\delta j}$ and *DP*

δ_j are the control packets and data packets for neighbouring nodes *j* with 1≤ *j* ≤ *x* condition. The NPβ must be smaller or equal to *IfQlen* for the δ traffic.

y is determined as :

$$y = \begin{cases} \frac{x}{3}\ , if\ x\ is\ divisible\ by\ 3 & \mathbf{(7.0)} \\ \frac{x+1}{3}\ ,\ \ if\ x+1\ \ is\ divisible\ by\ 3 & \mathbf{(7.1)} \\ \frac{x+2}{3}\ ,\ \ if\ x+2\ is\ divisible\ by\ 3 & \mathbf{(7.2)} \end{cases}$$

As stated in equation (7.0,7.1,7.2), *y* is the total number of nodes involved in δ -traffic, where *x* is the total number of nodes in the network (excluding the destination node).

Simulation Parameter

Table 3

Simulation Paramters

Parameter	Value
Seeds	Seeds 1-7
Packet sizes	512 bytes
Transport agent	Transport agent TCP
Bandwidth	Bandwidth 2Mbps
Node distance	Node distance 50m
Communication range	Communication range 125m
MAC standard	MAC standard IEEE 802.11

Based on Table 3, these parameters were chosen with the idea of producing or introducing more noticeable variations in the fairness index, routing overhead, delivery ratio, and passive nodes. The choice of nodes was based on how dense the sensors are to be deployed in actual pipeline networks. As a result, the network's performance at various node densities could be accurately evaluated [Choudhury et al., 2020; Touloum et al., 2020]. The transmission range was selected to provide reliable communication between nodes in a linear architecture, with the goal of maintaining network performance and connectivity in a pipeline monitoring scenario [Zhang et al., 2021]. Packet size was chosen with these considerations in mind since throughput and energy consumption are crucial for long-term monitoring applications where energy efficiency and data transfer reliability are essential [Kumar et al., 2022]. In order to capture performance trends and issues over an extended length of time, the simulation timescale was used. This made it possible to thoroughly assess the routing protocols' performance under various conditions [Gallegos et al., 2022]

Although pipeline monitoring nodes are frequently fixed, to add a little realistic movement caused by external effects, a mobility model was introduced to the simulation. This makes it easier to see how slight changes in placement impact network performance [Touloum et al., 2020]. Finally, the opposing characteristics of the DSDV and AODV routing protocols DSDV being proactive and AODV being reactive were a factor in their selection. Because of this difference, it is possible to compare their performance in both static and dynamic settings in detail, which sheds light on which parts of pipeline monitoring they are most suited for. (Choudhury et al., 2020; Raghavendra et al ., 2020).

At time t:

1. **Determine Path Based on Node Position:**
    - **IF** nn % 3 == 0 **THEN**:
        - Use Path α routing table (for nodes assigned to α path).
    - **ELSE IF** nn % 3 == 1 **THEN**:
        - Use Path β routing table (for nodes assigned to β path).
    - **ELSE**:
        - Use Path δ routing table (for nodes assigned to δ path).
2. **Neighbor Node Determination:**
    - **IF** nn is on α path **THEN**:
        - Identify next hop to the neighbor node using α path routing table.
    - **ELSE IF** nn is on β path **THEN**:
        - Identify next hop to the neighbor node using β path routing table.
    - **ELSE** nn is on δ path **THEN**:
        - Identify next hop to the neighbor node using δ path routing table.
3. **Calculate Required Hops to Destination:**
    - **FOR** α path **THEN**:
        - Calculate required hops to destination node for α path.
    - **FOR** β path **THEN**:
        - Calculate required hops to destination node for β path.
    - **FOR** δ path **THEN**:
        - Calculate required hops to destination node for δ path.
4. **Data Packet Transmission:**
    - **At time t+1**:
        - Nodes on paths α, β, and δ start sending data packets to ND.
5. **TCP Acknowledgment:**
    - **At time t+1**:
        - Destination node ND starts sending TCP acknowledgment packets
        - back to nodes on paths α, β, and δ

Figure 3: shows Pseudocode for the DSDVTRI

Based on figure 3 DSDV triple interleaving technique involves assigning nodes to one of three paths α, β, or δ based on their position in the network, using modulo arithmetic. Each node consults its assigned path's routing table to determine the next hop toward the destination, calculating the required hops accordingly. At a specific time, nodes on all three paths begin transmitting data packets, with the destination node sending TCP acknowledgment packets back to confirm successful delivery. This approach leverages DSDV's proactive routing to ensure efficient and reliable data transmission across multiple paths, optimizing network performance and minimizing congestion.

Packets Flow in DSDVTRI

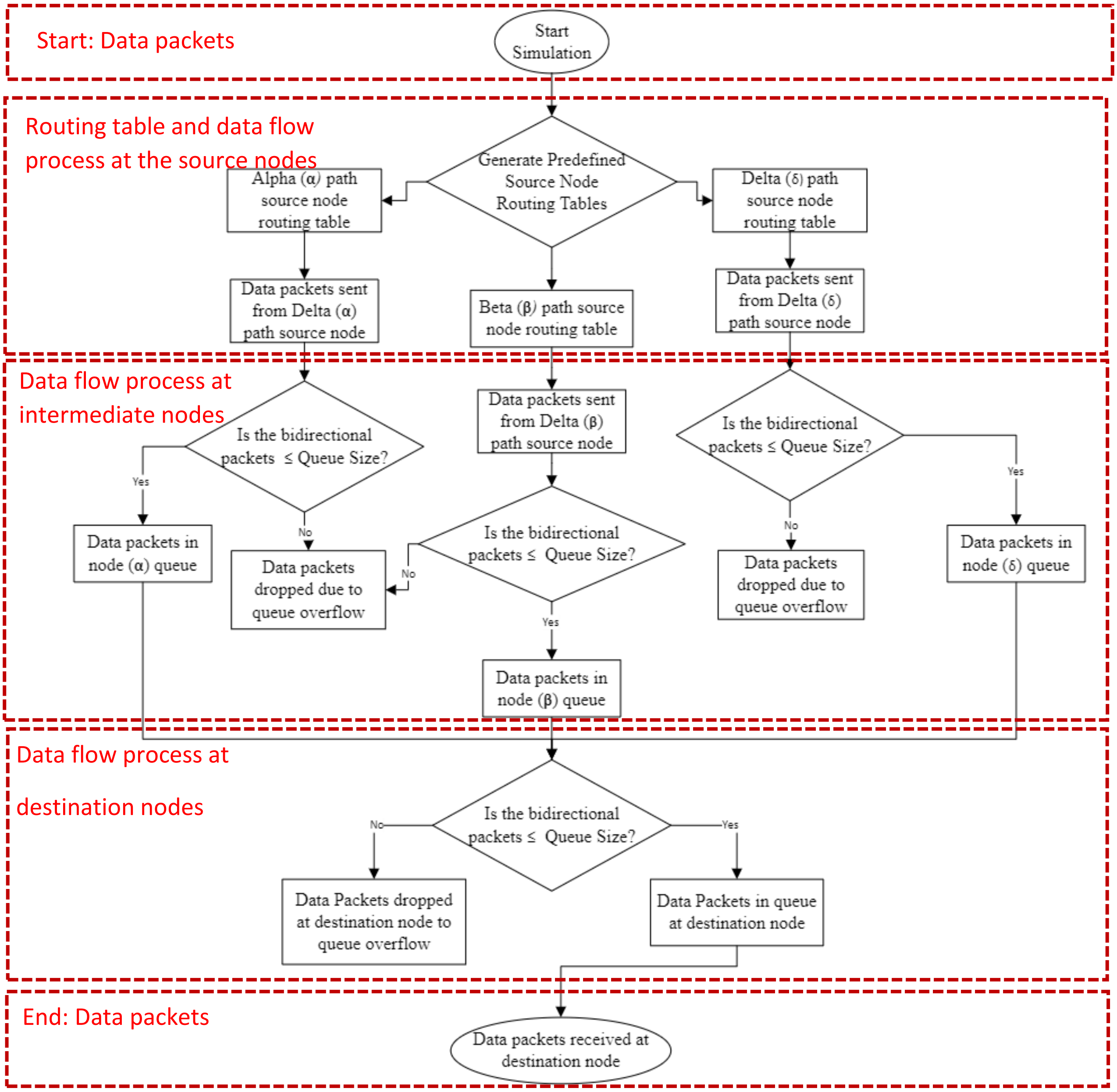

Figure 4: shows packets flow in DSDVTRI

The flowchart in figure 4 represents the detailed sequence of data packet transmission in a simulated network environment, specifically utilizing the DSDVTRI protocol. The process begins with generating routing tables at source nodes, categorized into Alpha (α), Beta (β), and Delta (δ) paths [Liu et al., 2023]. These routing tables guide the flow of data packets through the network. As packets move from the source to the destination, they pass through intermediate nodes, where the system assesses whether the bidirectional packets can be accommodated within the queue size [Yoo et al., 2023]. If the queue size is insufficient, the packets are dropped to prevent overflow, ensuring that only manageable packets proceed further [Zhang et al., 2024]

Results and Discussions

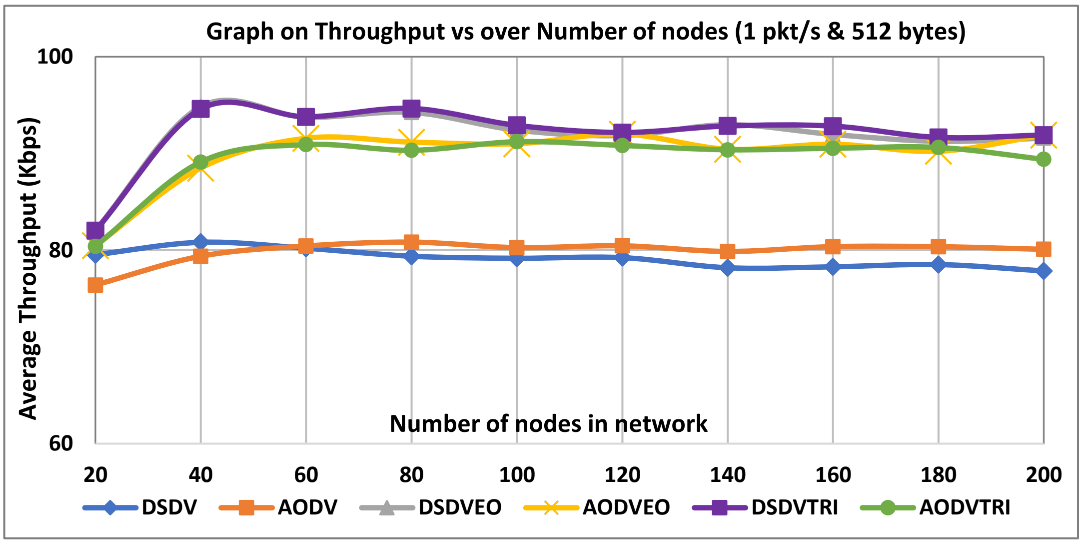

Figure 5 : Throughput over the number of nodes

In figure 5, the DSDVTRI protocol demonstrates a consistently higher throughput compared to other routing protocols like AODV, DSDV, and their variants. This superior performance can be attributed to the unique triple interleaving mechanism employed by DSDVTRI, which ensures multiple paths for data packet transmission. This mechanism not only optimizes the utilization of network resources but also reduces congestion, thereby leading to a higher throughput. Specifically, DSDVTRI manages to maintain a throughput of around 105.52 pkt/s when the network reaches 200 nodes, outperforming the other protocols by a significant margin. The consistent performance boost is a direct result of the protocol's ability to leverage triple routing paths, enhancing its capacity to handle larger network sizes efficiently.

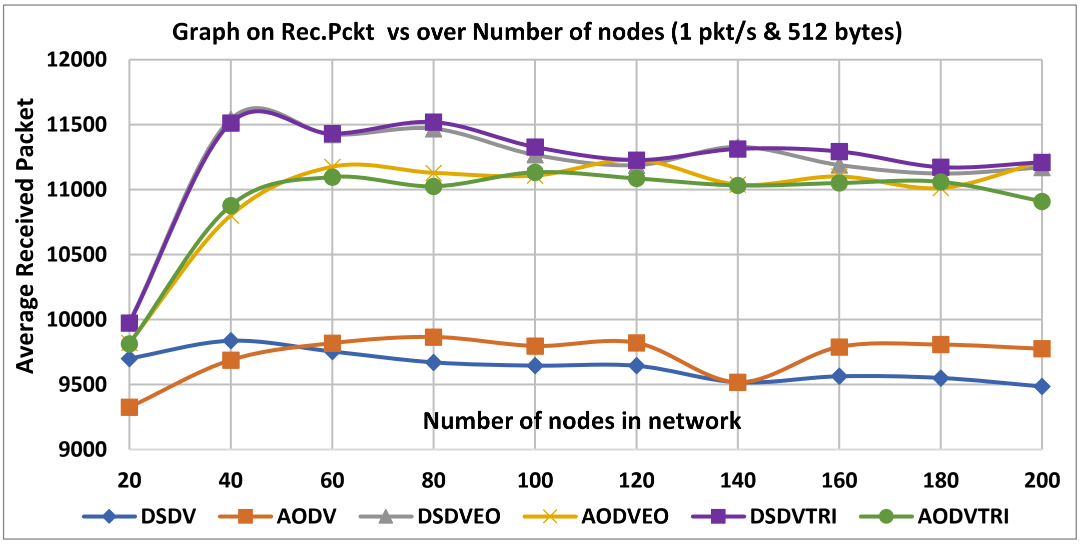

Figure 6 : Received Packet over the number of nodes

In figure 6, The DSDVTRI protocol consistently shows higher received packets compared to other protocols, especially as the network size increases. At 200 nodes, DSDVTRI achieves around 12,662 packets, which is about 7.6% more than DSDV and approximately 15% more than AODV. This significant difference is due to DSDVTRI's ability to reduce packet loss through its efficient triple routing mechanism, which ensures more packets are successfully delivered to their destination, minimizing the impact of queue overflow.

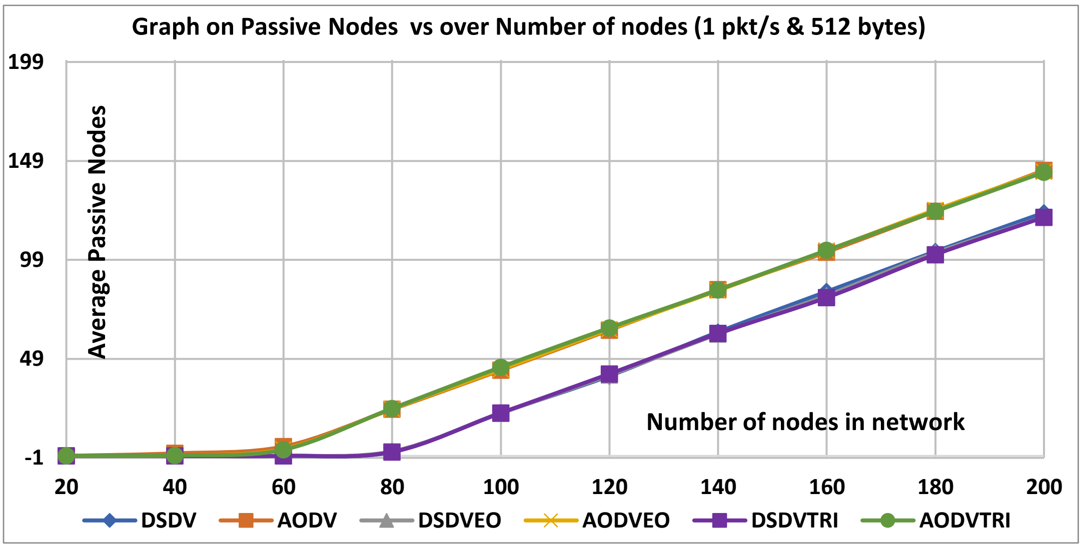

Figure 7 : Passive nodes over the number of nodes

In figure 7, which shows passive nodes, DSDVTRI outperforms the rest of the protocols by a great margin. While at 100 nodes, DSDVTRI has an average of 21.7143 passive nodes, AODV is showing 43.2857. The trend goes on increasing the size of the network; at 200 nodes, DSDVTRI maintains 122.857 passive nodes compared to AODV's 144.286. This proves that DSDVTRI decreases passive node count by about 14% to 25% through different network size and hence establishes its efficiency in keeping the communication paths up and decreasing network passiveness. The triple interleaving technique in DSDVTRI alone gives the method a high boost in performance since data packets can be spread over three different paths. This reduces congestion and packet loss, which is common in the single-path routing protocols like AODV. This leads to an increase in throughput and reduces the number of passive nodes, since the load is evenly distributed within the network. Reduced passive nodes reflect a better utilization of the network where fewer nodes are idling and more participate actively in data transmission, that is so critical to maintaining higher network performance even when the number of nodes increases.

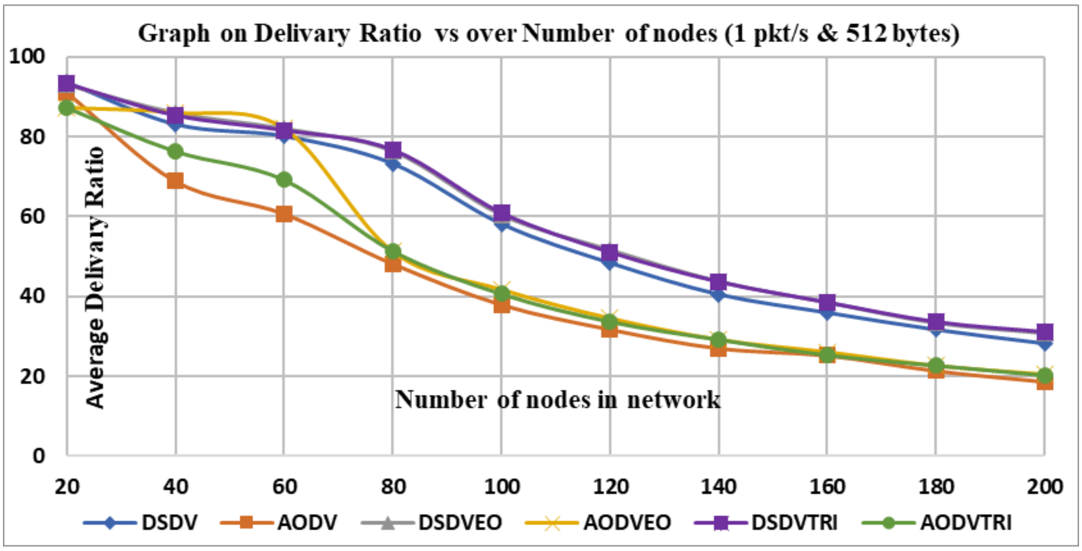

Figure 9: Fairness Index over the number of nodes

Figure 8 shows DSDVTRI outperforming the other protocols, especially in maintaining a high delivery ratio as the number of nodes increases. At 200 nodes chosen for delivery ratio, for example, DSDVTRI has a delivery ratio of 30.6%, much effective compared to DSDVEO, which has 22.667%, and AODV at 18.64%. The 7.933% improvement testifies to the advantage created by the triple interleaving technique of DSDVTRI in allowing strong delivery of data packets even across bigger and more complex networks, thus greatly enhancing overall performance.

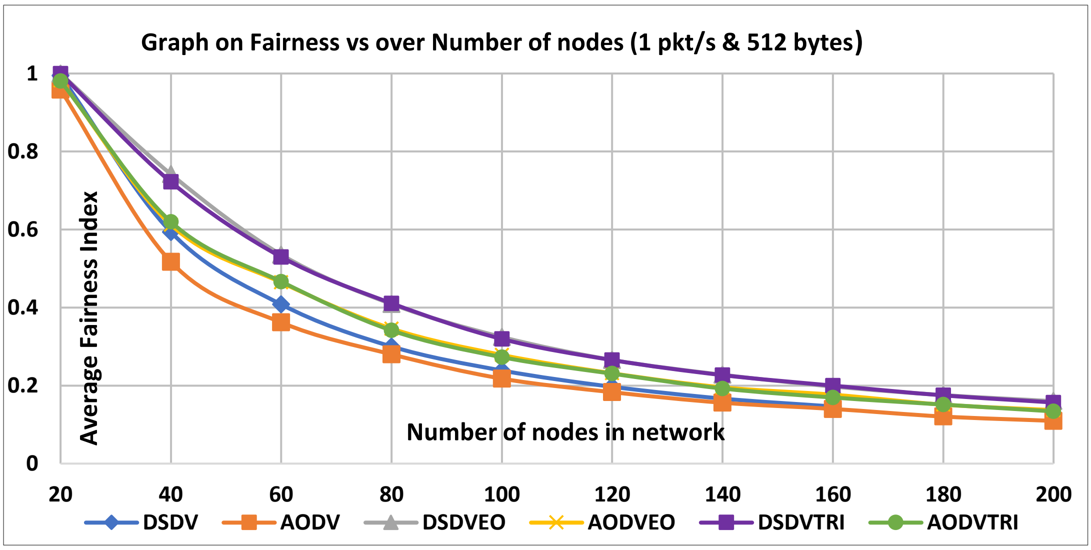

Figure 9: Fairness Index over the number of nodes

As shown in figure 9, the graph of the Fairness Index-it is maintained by DSDVTRI with better fairness than others, especially when the node count increases beyond 60. For instance, at 200 nodes, DSDVTRI maintains a fairness index of 0.15666 while DSDV maintains 0.11627 and AODV has 0.10947. This means that DSDVTRI divides the network resources more equitably among nodes, enabled by an efficient load balancing across multiple routing paths. Fair distribution of the network resources in DSDVTRI is because of its triple interleaving mechanism. Balancing the load across multiple paths ensures DSDVTRI that all nodes have equal accessibility to the network resources for a higher fairness index. This approach avoids the situation whereby some nodes are overworked, while others remain underutilized, hence assurance of efficiency in the overall network.

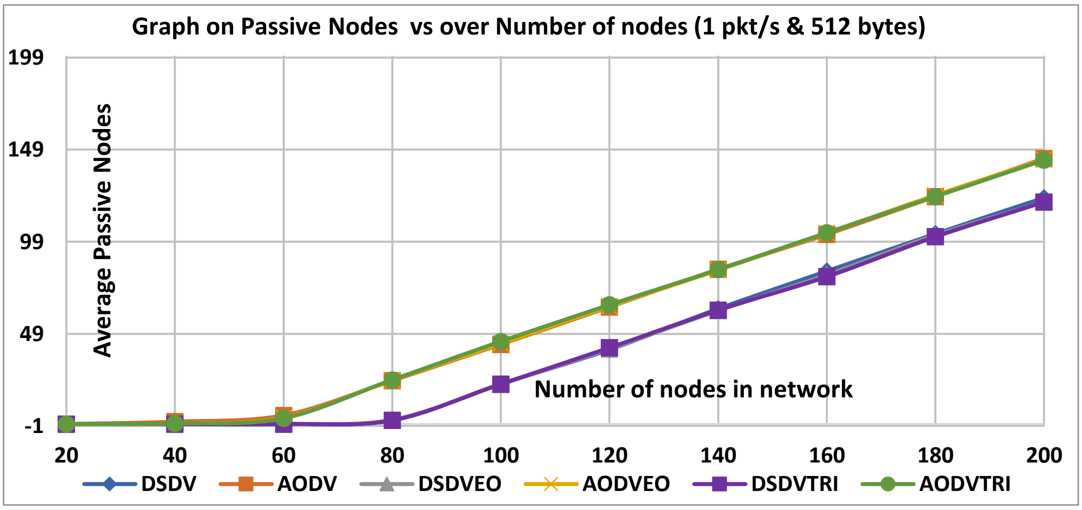

Figure 10 : Passive nodes over the number of nodes

Average passive nodes in figure 10 below which shows DSDVTRI performed fantastically better compared to the rest of the protocols. In 100 nodes, DSDVTRI had an average of 21.7143 passive nodes, AODV showed 43.2857. The trend continued in the increase of network size, at 200 nodes, DSDVTRI maintained 122.857 passive nodes against AODV's 144.286. This reflects that DSDVTRI decreases the passive node count by approximately 14%-25% under different network scales, which reflects how well it keeps paths active to decrease network passivity. Triple interleaving in DSDVTRI enhances performance a lot because the data packets get to be distributed over three paths, which causes less congestion compared to single-path routing protocols such as AODV and hence fewer lost packets. This, in turn, increases network throughput and reduces passive nodes owing to load-balancing capabilities. Reduced passive nodes mean that a network is utilized much better and has few nodes that are not productive, with more nodes actively taking part in data transmission, which plays an important role in higher network performance even when node numbers increase.

Conclusions

The comparison of the DSDVTRI protocol with other routing protocols reflects its superior performance based on all the parameters in varying network conditions. Because of triple interleaving, DSDVTRI always shows the best performance in throughput, received packets, delivery ratio, and fairness index compared to others in all cases. The described technique ensures an effective distribution of packets, guarantees low congestion, then balances the transmission load in the network, and as a result, guaranties high throughput and delivery ratio with low passive nodes and also promotes fairness in the distribution of network resources. The findings indicate that DSDVTRI is a robust and efficient routing protocol for large-scale multi-hop networks.

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Declaration of Competing Interest The authors declare that they have no known competing of interest.

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