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Managing Congestion in High-Density Networks using Triple Designated Path Routing Algorithm



Abstract - Wireless sensor networks (WSNs) provide adaptable and effective solutions for various industrial applications, particularly downstream oil and gas pipelines. Given the extensive spread of pipelines in this sector, wide communication coverage is necessary, which requires nodes to be arranged in a grid pattern. Initial performance evaluations using reactive (AODV) and proactive (OLSR) routing protocols identified several issues as the network size increased. These issues, primarily due to higher loads, include packet loss, decreased throughput, energy waste, and un-equal distribution of network resources, all leading to network congestion. A novel routing algorithm known as the Ad hoc On-Demand Distance Vector Dual Triple Grid (AODVDTG) has been developed to tackle these issues. This algorithm aims to improve routing stability by minimizing the number of control packets and facilitating smoother packet transmission. It achieves this by categorizing traffic into two distinct paths: triple and dual interleaving, based on the x and y-axis coordinates. Substantial enhancements in network performance were observed when comparing the proposed AODVDTG algorithm with established routing protocols such as AODV and OLSR.

Keywords: Routing Algorithm, WSN, OLSR, AODV, Grid Network, Oil and gas.

1. INTRODUCTION TO WSN IN OIL AND GAS INDUSTRY

The oil and gas industry are in three main stages, as shown in Figure 1. First, the upstream sector uses non-invasive surveys and advanced drilling techniques to extract resources [1]. Once extracted, these re-sources are moved to the midstream sector via methods like barges, trucks, or pipelines [2]. The midstream sector handles the storage and transfer of crude or hydrocarbon materials to the downstream sector. The feedstock undergoes processing and refining in the downstream sector before being marketed. Within re-fineries, smaller pipelines or trucks are used to move materials. This integrated process ensures the effective extraction, transportation, and use of oil and gas resources, playing a crucial role in the global energy supply chain [3].

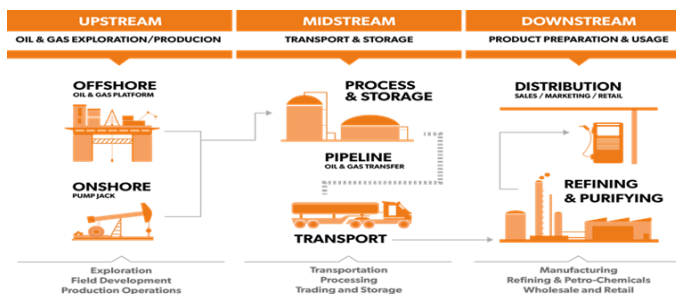


Figure 1: The division within the oil and gas industry[4]

For many years, Wireless Sensor Networks (WSNs) have been effectively meeting the needs of various modern applications like avalanche detection, agricultural threat

monitoring, home automation, healthcare tracking, and pipeline condition monitoring. Their popularity is due to their flexibility, simplicity, and cost-effectiveness. WSNs are particularly valuable in the oil and gas industry for collecting data from hard-to-reach or remote locations. They are used to monitor both above-ground and underwater pipelines, employing various sensors to detect issues inside or outside the pipelines. For underwater detection, WSNs use acoustic communication instead of radio frequency (RF) communication, as RF is ineffective under-water due to high-frequency wave absorption[5].

The growing demand for wireless sensor networks (WSNs) and rapid technological progress bring new challenges for researchers. A key problem in dense networks is performance degradation, which involves packet loss, reduced data transmission rates, and increased routing overhead[6]. Network congestion makes these issues worse, highlighting the importance of solving routing problems. To tackle these challenges, various routing protocols have been developed at the routing or network layer of WSNs to improve network performance[7], as shown in Figure 2.

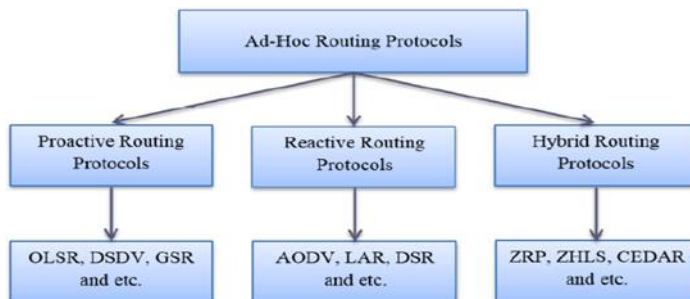


Figure 2: The network layer with three routing protocols[8]

Proactive routing protocols, like OLSR and DSDV, maintain pre-established routing paths, reducing delays but increasing resource use due to frequent updates[8], [9]. Reactive protocols, such as AODV, DSR, and LAR, create routes only when needed, minimizing overhead and potentially causing delays[5]. Hybrid protocols, like Zone Routing Protocol (ZRP)[10], Core-Extraction Distributed Ad-hoc Routing Algorithm CEDAR[11] and Zone-Based Hierarchical Link State Routing Protocol (ZHLS)[12] blend both approaches to balance delay reduction and resource efficiency, adapting to different network conditions.

This paper addresses network performance challenges as the size of the network changes. It also proposes an optimized routing algorithm specifically for monitoring the condition of oil and gas pipelines. The focus is on improving network performance at the network layer of the OSI model, following the IEEE 802.11 standard for refinery pipeline monitoring[13]. The nodes are spread out to simulate real-life deployment in a refinery pipeline, ensuring full communication coverage. The key contributions of this paper are: providing initial insights into network performance using a grid node arrangement, a setup not previously studied under the IEEE 802.11 standard, and detailing the technique used in the proposed algorithm based on the findings from initial insights into network performance using a grid node arrangement.

2. CHALLENGES AND OPTIMISATIONS STRATEGIES FOR HIGH DENSITY NETWORKS

Many applications employ a similar data transmission approach, utilizing a multi-hop technique to relay information from the sender node to the receiver node [14]. However, as the network size increases, several challenges are likely to emerge, including communication reliability, network scalability, energy consumption, and network robustness[1]. Communication reliability refers to the ability of the destination node to receive all data from each source node within a specified timeframe[15]. A scalable network maintains its performance despite variations in network load. Additionally, robustness refers to the network's ability to withstand malicious attacks, interferences, or node failures. In high-risk applications, such as pipeline condition monitoring, every piece of collected data is crucial for analysis, modelling, and prediction. These data are essential for understanding how the pipeline changes over time due to factors such as environmental conditions, stream pressure, and weather[16].

In oil and gas pipeline condition monitoring, a data-driven application, minimizing packet loss is crucial. As the number of nodes increases, the volume of packets also rises, leading to potential traffic congestion due to packet accumulation[17]. When the queue reaches its capacity, additional packets are dropped because there is no space left for them to be enqueued. This results in packet loss and a reduction in network throughput, as fewer packets are successfully received by the destination per second.

Saturated traffic is also exacerbated by the excessive generation of broadcast packets during route discovery, which leads to the queue being predominantly filled with broadcast packets rather than data packets[18]. This phenomenon is referred to as resource wastage, which can result in a severe fairness issue. In this state, some nodes consume more resources while others consume less, with certain nodes—referred to as passive nodes—not getting the opportunity to utilize any resources at all. Consequently, these nodes are unable to transmit their packets.

Congestion can also result in increased energy consumption by the nodes due to the high volume of packet processing and constant listening. This issue may lead to node failure as the power components become depleted. In high-risk applications, replacing these power components can be both challenging and dangerous[19], [20]. Therefore, a more refined and customized solution is necessary, especially for oil and gas pipeline applications, to address these challenges.

3. BACKGROUND STUDY

Proactive routing protocols are generally more resource-intensive compared to reactive ones because they frequently update the routing table, which leads to a significant increase in routing overhead and control packets[21]. For instance, protocols like Optimized Link State Routing (OLSR) regularly refresh routing tables with information such as the destination, next hop, and hop count. While this frequent broadcasting of control packets ensures faster data transmission, it also increases overhead and can waste resources. As the number of nodes in the network grows, issues like reduced throughput, lower delivery rates, and higher energy consumption become more prominent, affecting overall network performance, especially in routing. Researchers have focused on improving the network

layer, which determines the path packets take from the source to the destination using routing protocols that can be proactive, reactive, or hybrid[22], [23].

Responsive conventions, similar to Impromptu On-request Distance Vector (AODV), make courses just while required, saving assets by staying away from steady control parcel flooding; however, they may also expand latency[5]. The modified the ZigBee Routing Protocol (ZBR) and created a new protocol called Neighbour Perception ZBR (NP-ZBR) which showed better transmission delay and average node count results while maintaining similar end-to-end delay, transmission rate, and throughput as ZBR[24]. These changes in NP-ZBR aimed to reduce resource usage and congestion, leading to better hop count and transmission delay, ultimately making the NP-ZBR protocol more efficient and effective.

As detailed in reference[25], researchers conducted a recent study focusing on the routing overhead in reactive routing protocols within Wireless Multi-hop Networks (WMhNs). The study used specific routing overhead monitoring techniques and applied them to three distinct routing protocols: Dynamic Source Routing (DSR), Adhoc On-Demand Distance Vector (AODV), and Dynamic MANET On-Demand (DYMO). Implementing these monitoring techniques led to significant improvements in the overall network performance.

Researchers[26] performed an in-depth analysis of the AODV, DSDV, and FIXRT protocols in a linear network topology, using packet sizes of 32 and 128 bytes and following IEEE 802.11 standards. They found that the FIXRT protocol provided a notable 30% improvement in overall network performance. They also introduced a new routing method, OE-LSRP, which showed significant performance enhancements under the same standards and topology. The study tackled key industry challenges such as energy consumption, security, reliability, robustness, and scalability in Wireless Sensor Networks (WSNs). The results indicate that linear topology WSNs, when paired with certain protocols and routing methods, can achieve better performance, particularly in the oil and gas industry.

Researchers[27] highlight that the Double Interleaving Routing Algorithm, or AODVEO, is effective in enhancing the performance of oil and gas pipeline networks by reducing congestion and increasing efficiency. AODVEO improves network traffic management by splitting routes into Even and Odd traffic, which significantly cuts down routing overhead. When an odd or even node sends a Route Request (RREQ) to neighbouring nodes, only compatible nodes respond, and this process continues until the RREQ reaches its destination. The destination node then sends a Route Reply (RREP) back to the source, allowing the data to travel along the established route. The AODVEO protocol has proven to be highly reliable and efficient, significantly boosting the performance of wireless sensor networks with a linear topology.

In [28], the researcher examines Delay Tolerant Networking (DTN) routing and its two main strategies: Replication and Forwarding. The Replication approach, which is similar to flooding, involves creating multiple copies of a message to boost its chances of reaching the destination. Protocols like Epidemic and Spray and Wait use this method. On the other hand, the Forwarding approach focuses on choosing relay nodes strategically to enhance message delivery chances, particularly in resource-limited environments. Protocols such as Prophet and MaxProp employ this strategy. Both approaches help tackle DTN challenges

like intermittent connectivity, uneven traffic flow, high error rates, and variable delivery times.

The researchers [29] conduct a comparative analysis of various hybrid firefly algorithms for spectrum allocation (viewed as a discrete optimization problem) and power allocation (treated as a continuous optimization problem) in a TV White Space (TVWS) network. The algorithms evaluated include hybrid firefly approaches, genetic algorithms (GA), particle swarm optimization (PSO), and a combination of GA and PSO. Using simulation results obtained through Matlab, the study assesses the performance of these algorithms in terms of spectrum and power allocation. The goal is to identify the most efficient hybrid firefly algorithm for each optimization problem within TVWS networks, addressing their unique challenges.

In [30], Mobile Adhoc Networks (MANETs) using the Adhoc On-Demand Distance Vector (AODV) protocol are vulnerable to attacks such as blackhole, wormhole, and selfish node attacks. These threats disrupt routing, leading to dropped or misdirected packets. The study, using NS2 simulation, reveals the significant impact of these attacks on network performance, showing increased packet loss and issues with selfish nodes. It also identifies an optimal packet size for maximum throughput, helping to determine the most suitable packet size for the network. Overall, the research emphasizes the need for robust security measures in MANETs to mitigate these specific attacks and enhance overall network resilience.

A recent study[31] introduces a new routing protocol called AODV Even and Odd (AODVEO). This protocol tackles network congestion by splitting the route into two separate traffic segments: Even and Odd. By dividing the traffic this way, AODVEO significantly improves performance metrics such as de-livery ratio, fairness index, and throughput. It also reduces energy consumption and the number of inactive nodes in the network. Overall, AODVEO effectively eases network congestion, enhances performance and efficiency, and addresses issues related to energy use and inactive nodes.

4. ROUTING TECHNIQUE FOR TRIPLE DESIGNATED PATH

The AODV Dual-Triple grid (AODVDTG) routing algorithm splits the network into two types of traffic. Typically, routes are chosen based on how recent they are and the shortest distance to the destination. However, the AODVDTG algorithm selects routes based on the IP addresses of the nodes, considering both the x and y coordinates of the network. Total nodes in the path are divided by 3 and 2 to determine the triple traffic or dual traffic.

In the route discovery process moving forward, the source node sends route request (RREQ) packets to its neighbouring nodes based on the triple-dual determination, as illustrated in Figure 2. If the source node dividable by 3, only neighbouring nodes with triple interval will receive the RREQ packets. Similarly, if the source node not dividable by 3, only neighbouring nodes with dual interval will receive the RREQ packets. This triple-dual determination is applied at each step as the RREQ is forwarded between nodes. When the RREQ packets reach the destination node, the destination sends a route reply (RREP) packet back to the source. The nodes that forward the RREP packets follow the same triple-dual pattern but in reverse order. Once the RREP reaches the source, the data packet can be transmitted to the destination using the established route.

Algorithm: RREQ and RREP forwarding

```

1  if packet type = RREQ then
2  while node ≠ destination do
3  if source%3=0 then
4  if node %3=0 then forward RREQ
5  else if source%3=1 and source%2 =0 then
6  if node %3=1 and node %2=0 then forward RREQ
7  else if source %2=1 then
8  if node %2=1 then forward RREQ
9  end
10
11 else if packet type=RREP then
12 while node ≠ destination do
13 if source%3=0 then
14 if node %3=0 then forward RREP
15 else if source%3=1 and source%2 =0 then
16 if node %3=1 and node %2=0 then forward RREP
17 else if source %2=1 then
18 if node %2=1 then forward RREP
19 end
20
21 switch node
22 case 'destination' then update forward routing table
23 case 'source' then update reverse routing table

```

Figure 3: AODVDTG routing algorithm

By using AODVDTG routing algorithm, the packet accumulation and packet contention can be reduced since the traffic has been divided into 3 as shown in figure 4. The distance between nodes is represented as d . In real life situation, this feature can be seen in roadway traffic where a three-lane roadway offer a lower chance of congestion occurrence as compared to a one- lane roadway.

$$P_t = \left[(P_{3\alpha}) + \sum_{\beta=\alpha+2}^{n_1} (P_{3\beta}) \right] \leq Q_t \quad (1)$$

$$n_1 = \begin{cases} \frac{N_n}{3}, & \text{if } N_n \text{ is dividable by 3} \\ \frac{N_n-2}{3}, & \text{if } N_n \text{ is not dividable by 3} \end{cases} \quad (2)$$

$$P_d = \left[(P_{2\alpha}) + \sum_{\beta=\alpha+1}^{n_2} (P_{2\beta}) \right] \leq Q_d \quad (3)$$

$$n_2 = \begin{cases} \frac{N_n}{2}, & \text{if } N_n \text{ is dividable by 2} \\ \frac{N_n-1}{2}, & \text{if } N_n \text{ is not dividable by 2} \end{cases} \quad (4)$$

$$n_2 = N_n - n_1 - 1 \quad (5)$$

$$P_s = \left[(P_{2\alpha+1}) + \sum_{\beta=\alpha+1}^{n_3} (P_{2\beta+1}) \right] \leq Q_s \tag{6}$$

$$n_3 = n_2 - 1 \text{ or } n_3 = N_n - n_1 - 2 \tag{7}$$

$$P_T = P_t + P_d + P_s \leq Q \tag{8}$$

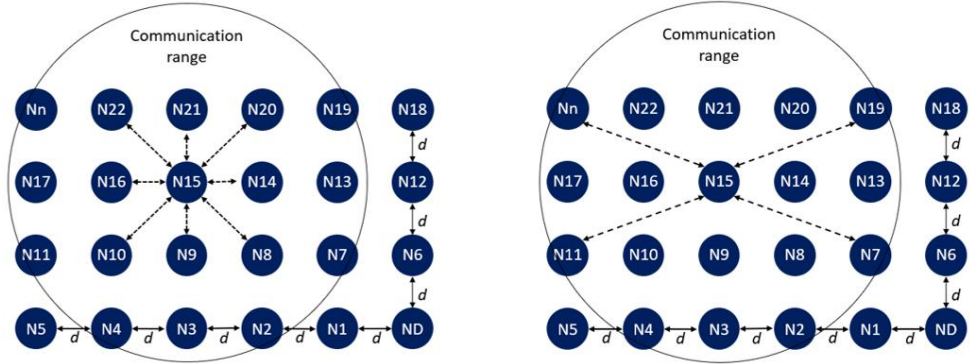


Figure 4: Broadcasting in conventional routing (left) and AODVDTG routing (right)

P_t , P_d and P_s is the total number of packets in triple, dual and single interleaving traffic respectively. $P_{3\alpha}$, $P_{2\alpha}$ and $P_{2\alpha+1}$ is the total number of packets (control and data packets) at the intermediate node with triple, dual and single interleaving address respectively. $P_{3\beta}$, $P_{2\beta}$ and $P_{2\beta+1}$ is the total number of packets (control and data packets) at the rest of the nodes with triple, dual and single interleaving address respectively. Q_t , Q_d and Q_s is the interface queue limit for triple, dual and single interleaving traffic respectively. The total number of packets for the whole network is P_T .

The AODVDTG algorithm reduces the number of broadcast packets by cutting the RREQ forwarding more than half, as shown in Figure 4. This reduction is crucial for optimizing queue space and conserving network resources. Additionally, with the traffic divided, only less than 50% of the network's nodes act as possible forwarders for each type of traffic.

5. SIMULATION SETUP

In the oil and gas industry, pipeline distribution can be categorized into two types: linear and spread-out. This paper emphasizes the spread-out distribution, which is why a grid node arrangement is employed. Simulating the network is crucial to identify any deficiencies within it, utilizing a specified environment, in this case, a grid topology with a varying number of nodes. Table 1 outlines the parameters and routing protocols used in the simulation conducted with Network Simulator 2 (NS2).

The resulting performance metrics, including delivery ratio, throughput, passive nodes, routing over-head, and fairness index, were recorded to demonstrate the behaviour of the simulated network. Additionally, statements from several research papers were referenced to support the rationale behind each presented result.

Table 1: Simulation Parameters

Parameter	Value
Routing Protocol	AODV, DSDV, AODVDTG
Bandwidth	2Mbps
Transport agent	TCP
Topology	Grid with nodes formation of 6x4, 8x6, 10x8, 12x10, 14x12, 16x18 and 18x16
Packet size	512 bytes
Node distance	50 m
Number of nodes	24, 48, 80, 120, 168, 224, 288
Propogation model	Two ray ground
Simulation time	500 s

6. RESULTS AND DISCUSSIONS

As interpreted in Figure 5, the bundle conveyance proportion diminishes as the organization size grows. Nonetheless, the proposed steering calculation reliably beats the AODV directing calculation, exhibiting a significant expansion in execution after conveying 168 hubs. This recommends that the pro-posed calculation is more viable for conveying bundles to their planned objective than both AODV and OLSR. Besides, the proposed calculation shows critical improvement over OLSR, beginning from 120 hubs. Separating traffic into two unmistakable ways diminishes the bundle line inside the organization, especially by decreasing the number of transmission parcels. This mitigates clogs and further develops in-formation streams, especially in thickly populated networks[32].

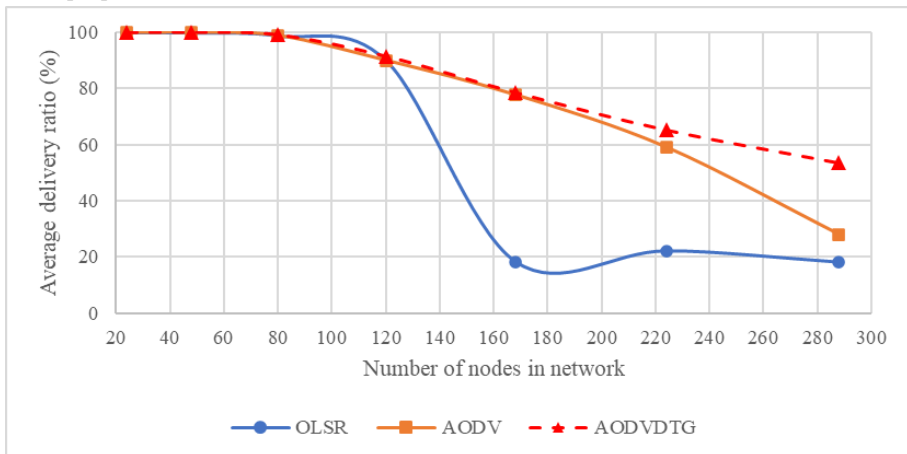


Figure 5: Delivery ratio against the number of nodes

Figure 6 uncovers a massive contrast in throughput among calculations from 80 hubs onwards. The proposed AODVDTG calculation outflanks both OLSR and AODV, accomplishing 22.92 kbps higher throughput at 80 hubs and 36.56 kbps higher at 288 hubs contrasted with AODV. This aligns with the pattern found in Figure 5, where bundle misfortune lessens the quantity of effectively gotten parcels each second, affecting throughput[33]. AODVDTG's adequacy originates from its effective directing methodology, which limits parcel misfortune and further develops information conveyance in organizations of enormous scope.

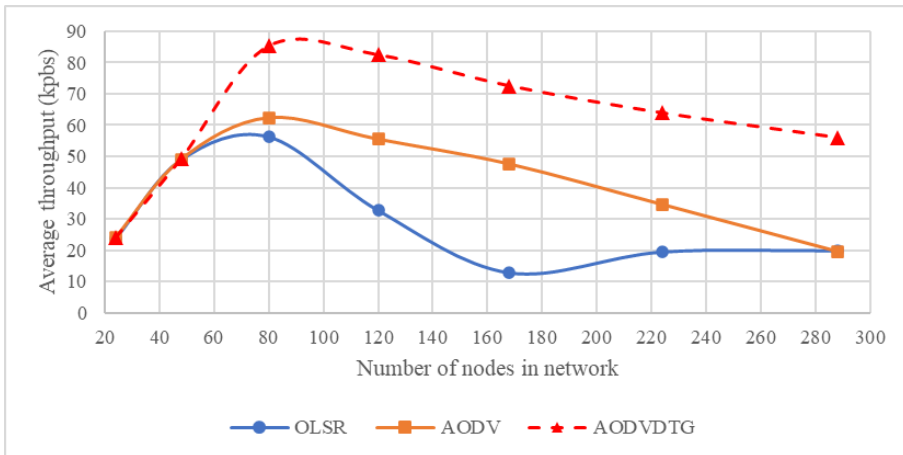


Figure 6: Throughput against the number of nodes

As per Figure 7, energy utilisation in a remote sensor network increases with the distance between sink and source hubs and the all-out number of hubs. This is because bundles must go through additional bounces, consuming more energy. OLSR has the most noteworthy energy utilisation among the tried calculations, while the proposed steering calculation shows the best energy effectiveness, particularly with 120 to 360 hubs. The calculation's upgraded proficiency is because of its viable administration of predefined traffic, which limits parcel lining close to the objective hub[34]. These decrease the line above and address energy-related issues like battery channels and abbreviated network life expectancy. The proposed steering calculation offers a promising answer for improving energy utilization in large-scale remote sensor organisations

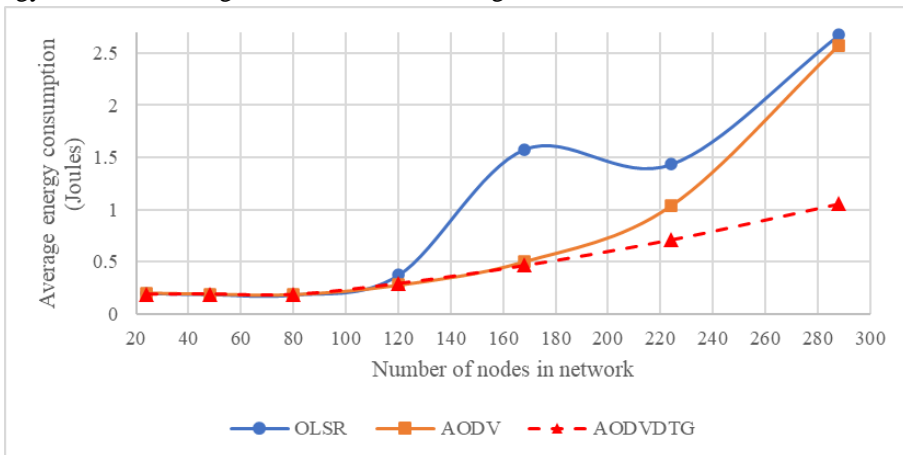


Figure 7: Energy consumption against the number of nodes

Figure 8 shows that the proposed steering calculation outperforms AODV and OLSR calculations regarding inactive hubs. With 288 hubs, the proposed calculation has less than 35% inactive hubs, while AODV and OLSR have more than 60%. This lower inactive hub count can be credited to the proposed calculation's viable blockage of the board. When a clog happens, a few hubs might become incapable of sending parcels because of line

overabundances and enter an uninvolved state, particularly under high bundle conflict. By proficiently directing traffic and diminishing blockage, the proposed calculation empowers hubs to process and communicate bundles all the more really, decreasing the probability of latent hubs and further developing in general organization execution and dependability. The proposed calculation's unrivalled administration of latent hubs features its true capacity as a viable answer for enormous-scope remote sensor organizations.

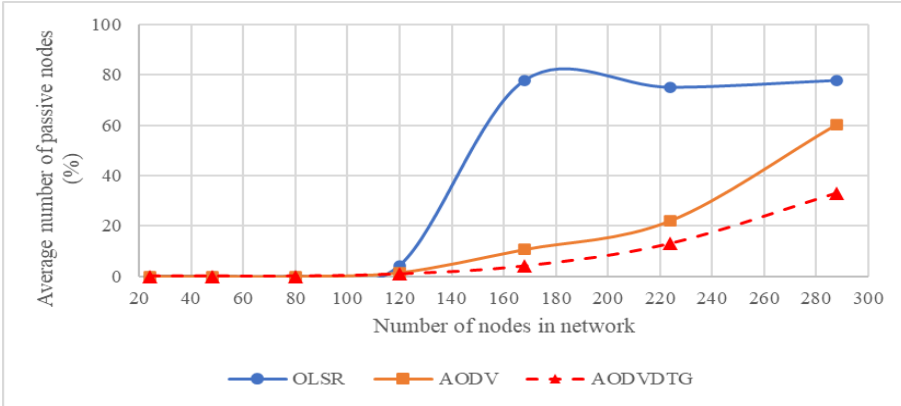


Figure 8: Passive nodes against the number of nodes

Figure 9 shows that the proposed steering calculation outflanks AODV and OLSR from 80 hubs onwards; however, it has a decency record beneath 0.5 from 168 hubs and diminishes as the organization's size develops. This demonstrates that while reasonableness has been somewhat tended to, assets are not equitably disseminated[25]. Hubs close to the objective commonly handle more traffic and consume more assets because of bundle gathering, while those farther away utilize fewer assets. This irregularity prompts lop-sided asset utilization, with objectives close to hubs utilizing a bigger portion of accessible assets[35]. Future exploration could investigate calculations that better disseminate traffic load and powerfully allot assets to develop reasonableness further. Procedures like burden adjusting and dynamic asset designation could guarantee even-handed admittance to assets for all hubs, no matter what their situation. Tending to these reasonableness issues can upgrade the organization's general exhibition and effectiveness.

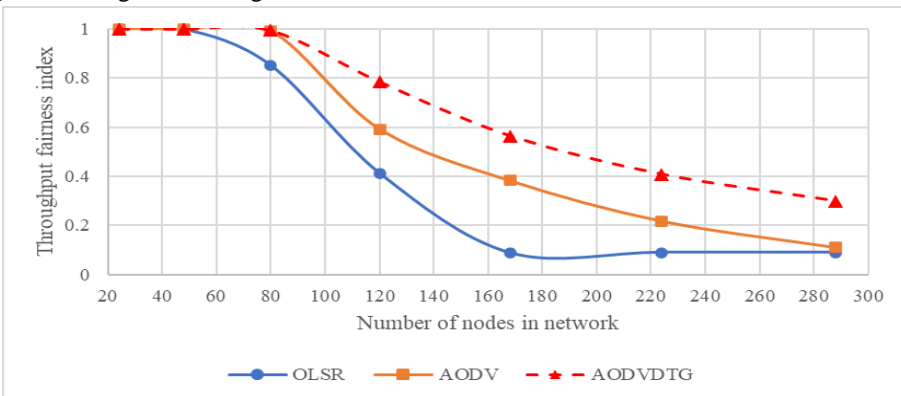


Figure 9: Fairness Index against the number of nodes

7. CONCLUSION

Observing pipeline trustworthiness is fundamental in processing plants with tremendous pipeline organizations because of testing working circumstances. A lattice hub arrangement is commonly utilized to cover enormous regions. Past examinations examining the presentation of AODV and OLSR steering calculations in this arrangement uncovered a few issues as the number of hubs expanded, including diminished throughput, bundle misfortune, higher energy utilization, reasonableness issues, and expanded dormant hubs. A receptive AODVDTG directing calculation was proposed to handle these difficulties. This calculation coordinates bundles along devoted ways, upgrading by and large organization execution. In organizations of enormous scope, the AODVDTG calculation beats AODV altogether. It further developed throughput, expanded the bundle conveyance proportion, diminished energy utilization, and diminished idle hubs. These results show that the review's goals were effectively met. Generally speaking, the AODVDTG directing calculation presents a promising answer for supporting pipeline observation's effectiveness and unwavering quality in processing plants. By really overseeing network assets and advancing parcel directing, this calculation can assist with guaranteeing the nonstop and safe activity of the basic foundation.

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