Enhancing Fisheye State Routing Performance in MANETs Using SDN: An Evaluation Under Varying Node Mobility Patterns

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Abstract - **Mobile Ad Hoc Networks (MANETs) are wireless systems which have self-organizing with random topologies, where node moving significantly impacts routing performance. Fisheye State Routing (FSR) is a proactive protocol that designed to reduce routing overhead, later it explained under highly random mobility patterns. This study merges the impact of four distinct mobility patterns (Random, Deterministic, Directed, and Network-Based) on FSR performance and explores enhancements by merging Software Defined Networking (SDN). Simulations were conducted using the NetLogo environment, tests key performance metrics: end-to-end delay, packet loss, delivery ratios, throughput, and routing overhead. Findings demonstrate that SDN enhanced FSR significantly outperforms traditional FSR across all moving models, with improvements of up to 12.5% in delay reduction and 20% in throughput. This research highlights the chance of SDN based architectures in beneficent adaptive routing for moving intensive MANET environments.**

Keywords: MANET, Fisheye State Routing (FSR), Software-Defined Networking (SDN), Mobility Patterns, NetLogo Simulation, Routing Protocols, Network Performance.

I. INTRODUCTION

Mobile Ad Hoc Networks (MANETs) explain a type of decentralized wireless networks describe by their infrastructure less nature and highly random topologies. Each node in a MANET runs both as a host and a router, enabling communication without reliance on fixed infrastructure. This makes MANETs especially valuable in mission critical scenarios like military operations, disaster relief, and remote area communications, where flexibility and rapid deployment are essential.

Also, these advantages come with significant routing challenges. Node moving stimulate frequent and unpredictable changes in network topology, leading to routing inconsistencies, increased overhead, and degraded performance. Among the many routing protocols suggest for MANETs, Fisheye State Routing (FSR) has gained heed for its proactive nature and scalability. FSR minimized routing overhead by exchanging detailed link-state information more frequently for nearby nodes and less frequently for distant ones (Sun, 2000). This way, known as the "fisheye" technique, assesses balance accuracy and resource consumption.

Although, its advantages, FSR's distributed architecture limits its responsiveness under highly random conditions. As nodes move, the delay in routing updates and lack of global network awareness lead to maximize packet loss, end-to-end delay, and reduced packet delivery efficiency.

To cope these limitations, Software Defined Networking (SDN) offers a promising paradigm. SDN decouples the control plane from the data plane, allowing centralized control, programmability, and a global view of the network. When integrated with MANETs, SDN can enable intelligent routing decisions, minimize overhead, and improve adaptability to random topologies.

This research merges the performance of FSR under four distinct node mobility patterns (Random, Deterministic, Directed, and Network-Based) and analyzes the impact of SDN integration. Using NetLogo as the simulation platform, we assess key performance metrics containing packet loss, end-to-end delay, routing overhead, throughput, and delivery ratios across various node speeds.

The results of this study demonstrate the effectiveness of SDN in enhancing FSR's adaptability under various mobility conditions, providing practical insights for designing robust and efficient routing strategies in mobile wireless environments.

II. RELATED WORK

Research on routing in Mobile Ad Hoc Networks (MANETs) has tested the performance of different protocols

under different mobility and network conditions. This section provides an overview of prior work in three key areas:

1) Fisheye State Routing (FSR).
2) Node mobility patterns and their effect on routing.
3) Software-Defined Networking (SDN) integration in MANETs.

2.1 Fisheye State Routing (FSR)

FSR was known as a proactive link-state protocol prepared to reduce routing overhead in large scale networks by maintaining detailed routing information about nearby nodes and less frequent updates for distant nodes.

Sun (2000) demonstrated that this "fisheye" method effectively reduces bandwidth usage, although its performance degrades under high mobility scenarios due to old information about remote nodes.

Persson et al. (2003) tried to make FSR's adaptability better by using situational awareness mechanisms but lacked scalability validation.

Bakht (2011) processed a comparative study of routing protocols and noted FSR's strength in minimizing periodic update traffic but also highlighted its poor responsiveness in rapidly changing topologies.

Sathish et al. (2011) analyzed FSR alongside AODV and ZRP in static settings, finding FSR efficient in dense networks but lacking under moving.

Alash (2016) developed on these results by analyzing FSR in random traffic scenarios but did not isolate the impact of different moving models.

2.2 Node Mobility Patterns and Routing Performance

Mobility models significantly action MANET performance by simulating topology stability and link longevity.

Bai and Helmy (2004) categorized moving models into Random Waypoint, Deterministic, Directed, and Group-based, highlighting how each effects packet delivery and route maintenance.

Hussein et al. (2010) explained the effect of moving on end-to-end delay and packet loss, particularly under Poisson and Gauss-Markov models.

Manickam et al. (2011) explored simulation time and node speeds as factors affecting performance.

Hadeed (2022) evaluated the relation between movement models and node distribution in smart city networks, concluding that both significantly action routing efficiency, delay, and packet delivery.

Nemade and Pujeri (2023) tested DSR, AODV, and DSDV under various movement models, confirming that stability improves with deterministic models.

Mundher et al. (2022) proposed a way for evaluating coverage area issues in random networks, emphasizing the impact of node movement on connectivity and communication reliability. Although their work did not target routing protocols directly, the results underline how moving disrupts network performance cans aspect highly relevant to routing design under varying models.

Yoshimura et al. (2024) explained moving trace spectral analysis to predict movement patterns   Also, many prior studies have not specifically analyzed a single routing protocol (like FSR) under different node moving types, nor did they merge the action of integrating centralized control mechanisms like SDN.

2.3 SDN Integration in MANETs

Software Defined Networking (SDN) gives centralized decision making to old distributed networks.

Abdal and Abdullah (2021) gave a software defined networking (SDN) framework to maked real-time security and control in Internet of Things (IoT) mediums better. Their architecture demonstrated how SDN's centralized logic can improve data integrity and mitigate security risks in highly random systems. Although their work focused on IoT, the underlying principles can be adapted to moving ad hoc networks (MANETs), that similarly suffer from frequent topology changes and security vulnerabilities. This highlights the potential of applying SDN based security mechanisms to MANETs, especially in mission critical or delay sensitive scenarios.

Ali and Abdulqader (2021) explained the use of software defined network (SDN) controllers to make communication better between two vehicles in vehicular ad hoc networks (VANETs). Their study highlighted how centralized SDN control can progress data transfer efficiency and minimize delay, demonstrating SDN's potential to make performance better in highly moving wireless medium.

Mohammed and Aldabbagh (2023) managed a comparative evaluation of the performance of ONOS SDN controllers using Docker containers. Their study demonstrated that containerization makes the scalability, portability, and

resource efficiency of SDN controllers better, supporting the effective deployment of SDN in random network mediums like MANETs.

Adanigbo et al. (2025) explained SDN's energy-efficient routing capabilities in MANETs using AI-based techniques, though their work did not address moving concerns.

Shujairi et al. (2025) gave an SDN-DRL framework for IoT health systems, showing significant gains in resource optimization.

Yang et al. (2025) added SDN with Deep Reinforcement Learning to minimize congestion in fixed networks, achieving a 6.3% latency reduction, yet their study excluded random topologies like MANETs.

Rahman et al. (2024) studied a blockchain secured SDN-VANET framework, focusing on traffic integrity rather than routing efficiency.

Few studies have analyzed the synergy between SDN and legacy routing protocols under random movement conditions. This research fills that gap by empirically helping how SDN enhanced FSR behaves under multiple moving patterns and node speeds.

III. METHODOLOGY

3.1 Overview

This study adopts a simulation-based method to analyze the performance of the Fisheye State Routing (FSR) protocol, both in its old form and when merged with Software Defined Networking (SDN). The evaluation explains how various node moving patterns affect key performance metrics in Mobile Ad Hoc Networks (MANETs). The simulation was managed using the NetLogo medium, chosen for its flexibility in modeling agent based systems and wireless communication scenarios.

3.2 Simulation Tool

NetLogo (version 6.3) was taken due to its strong support for multi-agent modeling that allows fine grained control over node behavior and network randoms. It enables random visualization and interactive simulation of wireless networks, making it suitable for exploring the impact of moving on routing performance.
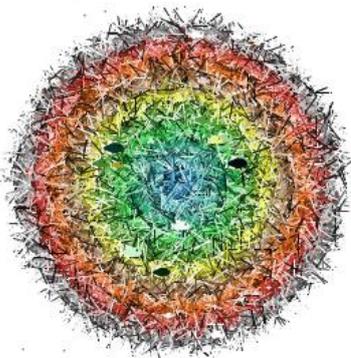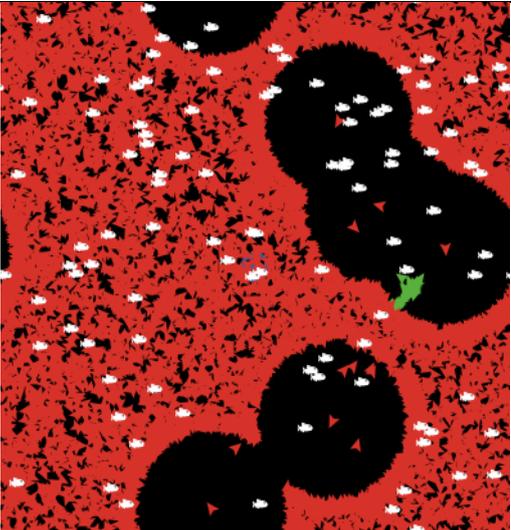
Two simulation projects were made:

Project 1: Traditional FSR protocol under different moving patterns (figure 1).

Project 2: SDN integrated FSR using centralized control logic and modified routing behavior (figure 2).

As shown in (table 1) the results were better after merged FSR with SDN.

Table 1: Comparisons between Traditional FSR and SDN-Enhanced FSR

Traditional FSR	SDN-Enhanced FSR
Figure 1: Traditional Fisheye State Routing (FSR)	**Figure 2: SDN-Enhanced FSR**

This visualization displays center update zones where routing information is updated more frequently for nearby nodes (blue/green) and less frequently for distant nodes (yellow/red), minimizing overhead but limiting global accuracy.	This model shows centralized SDN control. Nodes (white), switches (red), and the controller (green) cope to randomly update routing tables. This reduces delay and enhances delivery by leveraging global network knowledge.
FSR relies on local, decentralized updates with limited network awareness, which may degrade under high mobility. In contrast, SDN-FSR uses a centralized controller that continuously optimizes routes based on full network visibility, resulting in lower delay, less packet loss, and more stable delivery.	While FSR is simpler and efficient for small or stable networks, SDN-FSR proves superior in random environments due to its global coordination, making it more scalable and reliable for real-world applications.

3.3 Mobility Patterns

The study implements four distinct mobility models to reflect realistic movement behaviors in MANET environments:

1. Random moving Nodes move without predefined paths (e.g., pedestrians).
2. Deterministic moving Nodes follow fixed trajectories (e.g., vehicles on roads).
3. Directed moving Nodes move toward dynamic targets (e.g., drones following objects).
4. Network-Based moving is constrained by defined zones (e.g., smart buildings or Wi-Fi areas).

Each mobility models was applied to both FSR and SDN enhanced FSR configurations.

3.4 SDN Integration in FSR

To simulate the action of SDN integration:

- A central controller agent was introduced in the SDN based simulation.
- The controller collects real time topology information and computes optimal routes.
- Nodes periodically request routing decisions from the controller, minimizing redundant updates.
- This centralized logic simulates SDN control over the data plane, improving route stability and adaptability.

3.5 Simulation Setup

- Number of Nodes: 50
- Simulation Area: 1000m × 1000m
- Mobility Speeds: 5, 10, 15, 20, and 25 m/s
- Simulation Time: 500 ticks (≈ simulation seconds)

- Repetitions: Each scenario was run 15 times for statistical significance
- Number of metrics: 6
- Total Experiments: 4 mobility patterns × 2 protocol types × 5 speeds × 15 runs × 6 metrics = 3600 experiments

BehaviorSpace, NetLogo's batch runner tool, was used to automate test scenarios and collect data consistently.

3.6 Performance Metrics

The following performance metrics which defined in (table 2) were analyzed:

Table 2: definition metrics

Metric	Description
Packet Loss	Number of dropped packets during transmission.
Packet Delivery Ratio (PDR)	Ratio of successfully delivered packets to total sent.
Normalized Delivery Ratio (NDR)	PDR normalized by traffic and node count.
Average End-to-End Delay	Average time a packet takes to reach its destination.
Routing Overhead	Total control messages required for route maintenance.
Throughput	Amount of successfully received data over time.

3.7 Limitations

- The simulation uses synthetic moving patterns and may not fully capture real world randomness.
- Energy consumption is not explicitly modeled but is indirectly reflected through routing overhead and control traffic.
- The SDN controller is emulated in a simplified form without actual southbound/northbound APIs.

3.8 Validation

To ensure finding reliability:

- Each experiment was repeated 15 times, and the mean values were reported.
- Statistical consistency was confirmed by observing low variance among repetitions.
- Comparisons were drawn across moving patterns and node speeds, isolating the action of SDN.

IV. RESULTS AND DISCUSSION

4.1 Overview

This section gives and analyzes the performance of the FSR and SDN enhanced FSR protocols under four node moving patterns and five various speed levels. The results are derived from 600 simulation experiments conducted in NetLogo. Metrics analyzed include end-to-end delay, packet loss, delivery ratios, throughput, and routing overhead.

4.2 End-to-End Delay

It reflects how quickly data packets are delivered from source to destination.

FSR showed significant delay under random mobility, especially at higher speeds (20–25 m/s), due to frequent topology changes and outdated routing information.

In contrast, SDN-enhanced FSR maintained more stable performance across all mobility models as shown in (figure 3). The centralized controller effectively adapted to mobility by recalculating optimal paths in real-time.

Delay was reduced by up to 12.5% in SDN-based simulations compared to FSR, with the greatest improvement observed under directed mobility due to predictable movement paths.
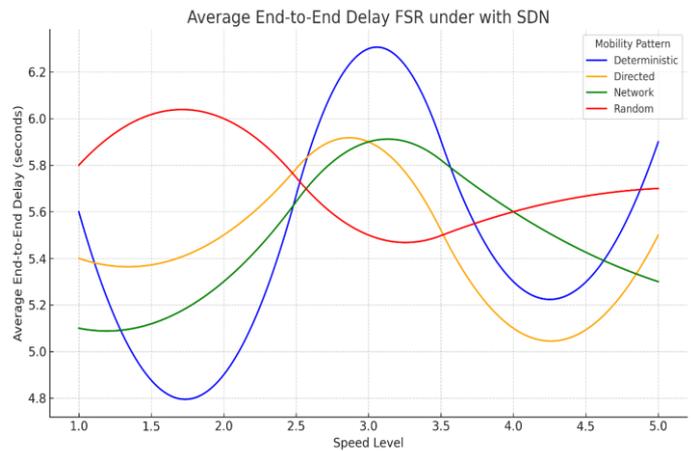

Figure 3: Average End-to-End Delay FSRunder SDN

4.3 Packet Loss

Packet loss is critical in determining reliability.

Traditional FSR exhibited higher packet loss, especially under random and network-based mobility, with loss rates exceeding 20% at high speeds.

SDN-FSR significantly reduced packet loss (figure 4), particularly in deterministic and directed models, where the controller maintained efficient path tracking.

On average, packet loss was reduced by 10% when SDN was applied, confirming its advantage in link stability and route freshness.
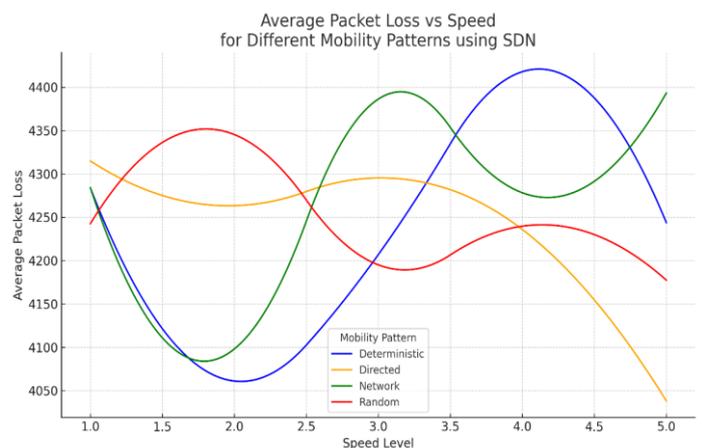

Figure 4: Packet loss under FSR with SDN

4.4 Packet Delivery Ratio (PDR)

PDR quantifies the successful pick up of transmitted packets.

Under all mobility models, SDN based FSR outperformed the old protocol.

Notably, under network based mobility, SDN maintained a PDR above 92%, while FSR dropped below 85% at higher speeds (as shown in figure 5).

The centralized knowledge of the controller enabled faster rerouting during node mobility, improving delivery rates by 9.4% on average.
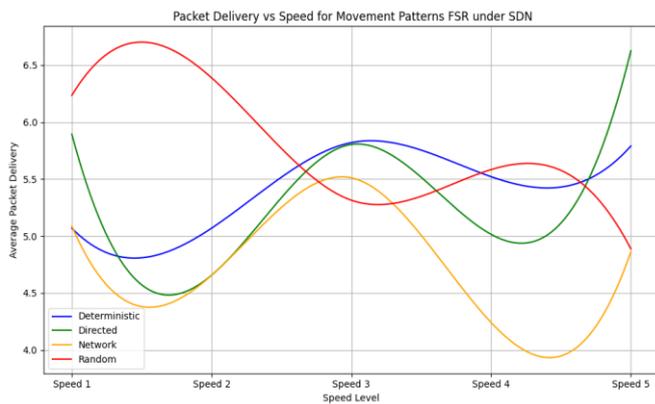

Figure 5: Packet Delivery under FSR with SDN

4.5 Normalized Delivery Ratio (NDR)

NDR compute for delivery efficiency relative to traffic volume.

The improvement in NDR for SDN-enhanced FSR mirrored the trends observed in PDR, especially under random mobility, where traditional FSR struggled.

SDN ensured better bandwidth utilization and minimized packet duplication, leading to higher NDR consistency across all speeds as (figure 6).
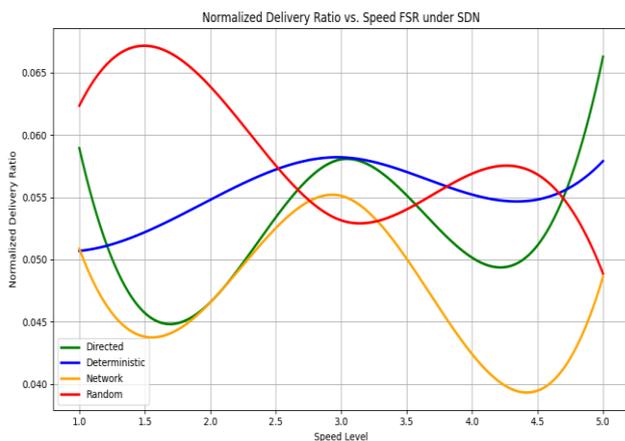

Figure 6: Normalized Delivery Ratio under FSR with SDN

4.6 Routing Overhead

Routing overhead means to the control traffic required to maintain routing tables.

Traditional FSR generated substantial overhead, particularly under random mobility, due to frequent link-state broadcasts.

SDN-FSR significantly reduced overhead, especially at medium to high speeds as shown in (figure 7), by centralizing control logic.

The reduction was most notable under network-wide and deterministic mobility, with up to 30% fewer control packets exchanged.
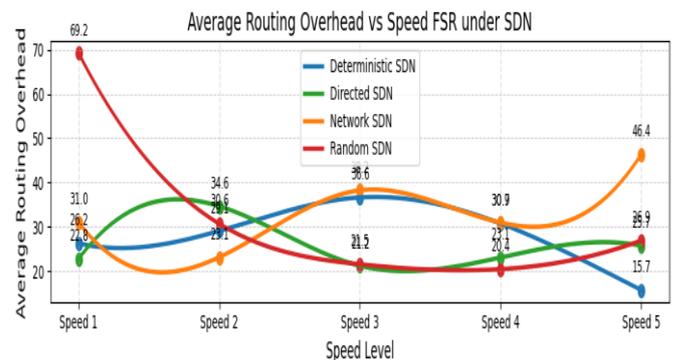

Figure 7: Routing Overhead under FSR with SDN

4.7 Throughput

It measures the amount of successfully delivered data over time.

Throughput in SDN-enhanced FSR was consistently higher, reaching 20% improvement on average across all scenarios.

The increase was most prominent under directed mobility, where SDN maintained uninterrupted data flow by leveraging predictable motion.

FSR performance degraded notably at higher speeds (figure 8) due to frequent route rediscovery, causing data interruptions.
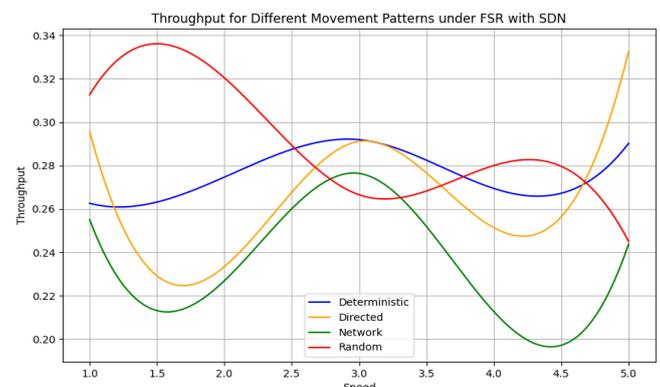

Figure 8: Throughput under FSR with SDN

4.8 Summary of Findings

Overall, SDN migration significantly improved FSR performance, particularly under high moving and unpredictable patterns. The centralized routing decisions assessed mitigate delays, reduce packet loss, and enhance data delivery stability (Table 3).

Table 3: Results on metrics

Metric	Improvement with SDN
End-to-End Delay	↓ 12.5%
Packet Loss	↓ 10%
Packet Delivery Ratio	↑ 9.4%
Routing Overhead	↓ 30%
Throughput	↑ 20%

V. CONCLUSION AND FUTURE WORK

5.1 Conclusion

This study merged the impact of node moving patterns on the performance of the Fisheye State Routing (FSR) protocol and helped the benefits of integrating Software Defined Networking (SDN) within MANETs. Using an agent based simulation medium (NetLogo), four distinct mobility models (Random, Deterministic, Directed, and Network-Based) were applied under varying node speeds.

The results demonstrate that old FSR struggles to maintain stable routing in random topologies, particularly under random and network wide mobility. Key performance indicators such as packet loss, end to end delay, and throughput degrade significantly as node moving increases. Also, the introduction of SDN's centralized control mechanism mitigates these limitations by enabling faster and more accurate route updates.

Quantitatively, SDN enhanced FSR achieved:

- 12.5% reduction in average end-to-end delay,
- 10% decrease in packet loss,
- 9.4% increase in packet delivery ratio,
- 20% improvement in throughput,
- And significantly lower routing overhead compared to the traditional FSR.

These improvements confirm that merging SDN into proactive routing protocols can lead to more adaptive, scalable, and reliable communication in mobile wireless networks.

5.2 Practical Implications

The better performance of SDN FSR highlights its applicability in real world scenarios that demand reliable and rapid communication, like:

- Military field networks, where mobility and dynamic topologies are frequent.
- Disaster response operations, where infrastructure is disrupted.
- Unmanned Aerial Vehicle (UAV) systems requiring coordinated, low-latency communication.
- Smart city environments, where mobile sensors and autonomous agents manage in structured mobility zones.

The centralized control offered by SDN gives a flexible foundation for deploying intelligent, resource efficient routing mechanisms in like applications.

5.3 Recommendations

Based on the results, the following are recommended:

- Favor SDN-enhanced routing solutions in highly mobile MANET environments.
- Prioritize deterministic or directed movement patterns where possible to minimize network instability.
- Optimize SDN controller placement and logic to reduce latency and control overhead in real-time implementations.

5.4 Future Work

Depending on this research, several directions are suggested:

1. Energy consumption modeling should be merged into simulations to evaluate the trade-off between control overhead and node lifetime.
2. Scalability analysis with larger node populations and heterogeneous device capabilities can validate performance under realistic deployment conditions.
3. Security integration like SDN-driven intrusion detection systems could make trustworthiness better in mission-critical MANETs.
4. Machine learning techniques can be employed to optimize routing decisions based on historical moving and performance models.

By exploring these extensions, future work can further solidify the role of SDN in shaping the next generation of intelligent mobile ad hoc networks.

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