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Implementation of A Delay-Tolerant Routing Protocol in the Network Simulator NS-3

Sumith, Vikaas Karthik K, Sandhya S

Abstract: ***This paper explores the implementation of the Epidemic Routing Protocol using the NS-3 simulator, with a focus on its application in intermittently connected networks, such as Mobile Ad Hoc Networks (MANETs). The Epidemic Protocol maximizes message delivery by flooding the network with multiple copies, ensuring reliability even in sparse or highly mobile environments. Through NS-3 simulations, the study examines the protocol's performance, considering factors such as network size, node mobility, and message Time-To-Live (TTL). The simulation, which models an ad-hoc wireless network using IEEE 802.11b, demonstrates that the protocol achieves a 100% packet delivery ratio with minimal latency. Tools like NetAnim provide detailed insights into node interactions and message dissemination, highlighting the protocol's effectiveness in maintaining communication under challenging conditions. The paper concludes that while the Epidemic Protocol is resource-intensive, it is highly effective for scenarios where traditional routing methods fail, offering a reliable solution for dynamic and partitioned networks.***

Index Terms: ***Epidemic Protocol, Delay-Tolerant Routing Protocol (DTRP), Mobile Adhoc Networks (MANETs), NetAnim, NS3.***

I. INTRODUCTION

In MANETs, nodes are free to move and self-organise, resulting in a highly dynamic and unpredictable network topology. Traditional MANET routing protocols assume that the network is dense enough to be fully connected, ensuring a path between every node. However, in many scenarios, such as disaster relief operations and military deployments, the network may be sparse, leading to frequent partitions. These networks, where a contemporaneous end-to-end path may not exist, belong to the category of Delay/Disruption-Tolerant Networks (DTNs) [1][2][3]. Epidemic Routing is a fundamental DTN routing protocol designed to maximize message delivery probability in such challenging environments. It works by continuously replicating and propagating messages across the network, leveraging node mobility to deliver messages to their intended destinations over time.

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*Correspondence Author(s)
Sumith, Department of Computer Science and Engineering, R V College of Engineering, Bangalore (Karnataka), India. E-mail: sumithmpchawan100@gmail.com
Vikaas Karthik K*, Department of Computer Science and Engineering, R V College of Engineering, Bangalore (Karnataka), India. E-mail: vikaaskarthik.k@gmail.com
Dr. Sandhya S, Department of Computer Science and Engineering, R V College of Engineering, Bangalore (Karnataka), India. E-mail: sandhya.sampangi@rvce.edu.in

The protocol's simplicity and robustness make it a valuable candidate for applications that require high delivery success rates in highly dynamic andpartitioned networks.

II. ARCHITECTURE OF DTN

In the DTN architecture, a bundle layer facilitates the connection between the application and transport layers of the network, as depicted in Figure 1. This architecture employs a store–carry–forward mechanism, where messages are stored in intermediate nodes for extended periods while being transmitted to their destination [4]. The Bundle Protocol ensures reliable data transmission by enabling message retransmission through intermediate nodes. It accommodates intermittent connectivity by incorporating a buffer at each node, allowing for data storage and transfer even in unpredictable conditions. This protocol supports various connectivity methods, including scheduled, predicted, and opportunistic connections, and is designed to operate effectively in heterogeneous environments

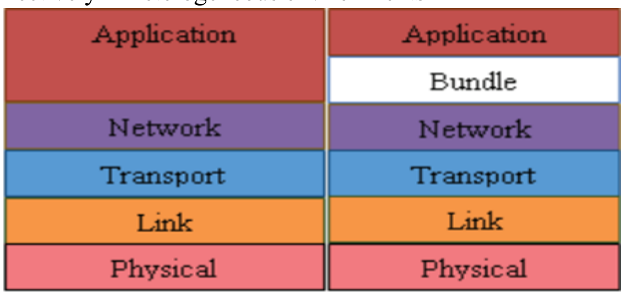

Fig. 1: Comparison Between TCP/IP and DTN Layers

III. RELATED WORK

An improvement to the traditional Epidemic Routing Protocol is proposed by introducing energy level and buffer size constraints. These enhancements aim to reduce network congestion, increase message delivery ratio, and minimize dropped messages by ensuring that only nodes with sufficient battery life and buffer space participate in data transmission. The modifications lead to a more efficient and reliable routing process within Delay Tolerant Networks [5][6]. The paper examines how epidemic routing performs in dense delay-tolerant networks DTNs. It highlights a phase transition in the probability of successful delivery based on node density, introduces fluid approximations using Ordinary Differential Equations (ODEs) to evaluate this behaviour, and validates them through simulations, offering insights into optimizing routing strategies in non-sparse networks [7].

A comparison of the performance and design of Epidemic Routing (ER) and Named Data Networking (NDN) in DTNs is presented [8][9]. It highlights that while ER adapts traditional IP for intermittent connectivity, NDN's inherent data-centric design offers superior efficiency, built-in security, and robustness in DTN environments. The paper provides a comparative and empirical analysis of routing protocols for DTNs, focusing on improving data delivery ratio and reducing delays [10]. DTN routing protocols are categorized into four types: encounter-based, time-based, infrastructure-based, and hybrid. The paper also empirically evaluates protocols such as Epidemic, PROPHET, and Spray and Wait using performance metrics like delivery probability, overhead, and message drop rate. A novel routing protocol for DTNs based on the Catalan series is proposed by improving the Binary Spray and Wait protocol [11]. Simulations reveal that the Catalan protocol achieves higher delivery ratios, reduced overhead, and faster convergence than traditional protocols, particularly in environments with intermittent connectivity, such as vehicular and pedestrian scenarios. The paper proposes a routing protocol for UAV-assisted Vehicular Delay Tolerant Networks (VDTNs) [12-20]. It introduces a new metric, persistent connection time, to enhance message forwarding by more accurately accounting for the capabilities of UAVs. Simulations demonstrate that the protocol improves message delivery reliability, reduces network overhead, and minimises delays compared to existing protocols. A comparative analysis of various opportunistic routing protocols in DTNs using the Adyton simulator. It evaluates protocols like EPIDEMIC, under different mobility models and buffer sizes, finding Simbetts to be generally superior. An optimization of the Spray and Wait (SW) routing protocol for DTNs. The optimization involves dividing the spraying phase into two parts, with each part spraying half the copies and adjusting the message lifetime [21][22][23]. Simulations on the ONE platform indicate that this method reduces the average transmission delay and node cache time, with a slight decrease in delivery rate. The discussion of essential characteristics of DTNs which are crucial in environments with poor connectivity. It reviews research challenges, routing protocols, and various applications across multiple domains, including space, disaster recovery, and IoT. The paper also highlights the importance of security, buffer management, and energy optimization in DTNs. The paper focuses on optimizing distribution paths for logistics vehicles in urban rail transportation using a Vehicle Routing Problem (VRP) model. It aims to enhance delivery efficiency by optimising vehicle routes, taking into account various constraints such as delivery time windows and vehicle capacity. The study utilises advanced algorithms to minimise total transportation costs and enhance logistics service quality. The paper proposes a P-Epidemic routing scheme to improve message delivery in DTNs [24-25]. By adjusting transmission probabilities based on node resources, such as buffer size, the method enhances delivery probability and reduces message overhead compared to traditional epidemic routing. The paper presents a systematic review of Opportunistic Networks, focusing on routing protocols in DTNs. It analyzes state-of-the-art routing approaches, highlights their challenges, and provides insights into security, performance factors, and simulation tools. The paper also identifies gaps and potential future directions in OppNet research, with applications in various fields like disaster recovery and mobile sensing. The paper examines the application in industrial settings, particularly for mobile robots. It models and tests DTNs in industrial settings, demonstrating their viability for various tasks with high latency tolerance. The study concludes that DTNs can enhance industrial communications, especially for autonomous robots, and identifies future research directions.

IV. EPIDEMIC ROUTING PROTOCOL

Epidemic Routing Protocol is designed to enable fast dissemination of messages across a network. In this protocol, the sender forwards the message to every neighbouring node, which then continues to propagate the message to their neighbours, resulting in a widespread distribution. This method ensures a high message delivery ratio, as it maximizes the chances that at least one copy of the message will reach the intended destination.

Figure 2 illustrates the message exchange process in Epidemic Routing. In this protocol, two nodes (A and B) within communication range regularly compare their stored messages. The arrows represent the exchange of messages: Node A sends message 1 to Node B, Node B sends message 2 to Node A, and Node A sends message 3 to Node B. This frequent exchange, governed by a cycle-time parameter, ensures optimal delivery rates but increases resource usage.

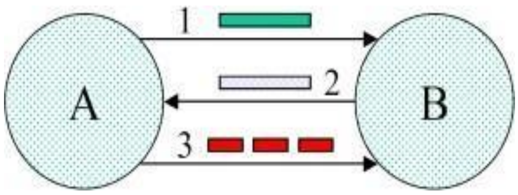

Fig. 2: Message Advertisement (1), Request (2), and Message Transmission (3) in the Message Exchange Process in Epidemic Routing

A. Transmission Process

Figure 3: Flowchart describing a cautious approach to message dissemination in Epidemic Routing. Unlike the pure flooding mechanism, this process incorporates checks on the receiving node's buffer space and energy levels before forwarding messages.

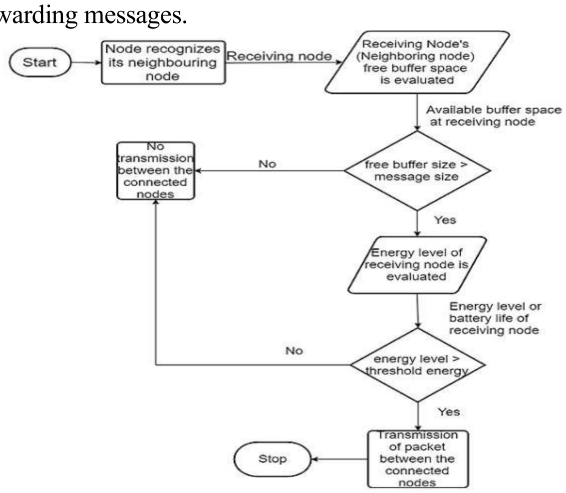

Fig. 3: Flow Chart for Message

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This approach helps mitigate the potential downsides of Epidemic Routing, such as buffer overflow, energy depletion, and unnecessary traffic, by ensuring that only capable nodes participate in message forwarding. • It adds efficiency to the basic Epidemic Protocol by selectively forwarding messages, which can be particularly beneficial in energy-constrained or resource-limited networks.

V. NS-3 SIMULATION OVERVIEW

This NS-3 simulation script models a simple ad-hoc wireless network using the IEEE 802.11b standard, with five nodes deployed in a grid layout. The script sets up the nodes to communicate using UDP (User Datagram Protocol), simulating traffic generation and reception with applications designed to mimic an epidemic routing protocol. The simulation incorporates mobility, where nodes can move randomly, and utilises tools such as PCAP for packet tracing and NetAnim for visualisation.

A. Simulation Setup

This section on the laboratory simulation set is as follows:

- Node Creation: The simulation begins by creating five nodes, each representing a device in the network. These nodes are arranged in a grid pattern, with each node initially placed at specific coordinates using the GridPositionAllocator.
- Wi-Fi Configuration: The Wi-Fi network is configured using the IEEE 802.11b standard, which operates at 2.4 GHz and supports data rates of up to 11 Mbps. The YansWifiChannelHelper and YansWifiPhyHelper are used to set up the wireless channel and physical layer, respectively. The AdhocWifiMac ensures that the nodes communicate in ad-hoc mode, which is suitable for decentralized network setups without a central access point.
- Mobility Model: The RandomWaypointMobilityModel is applied to simulate node movement. Nodes move randomly within the simulation area, pausing occasionally before changing direction and speed. This mobility model is standard in simulations of mobile ad hoc networks (MANETs), where devices can move freely.
- Internet Stack and IP Assignment: Each node is equipped with the Internet stack, allowing it to communicate using IP addresses. The IPv4AddressHelper assigns IP addresses to each node's network interface, ensuring unique addressing for proper communication.
- Traffic Simulation: The On-Off Application generates UDP traffic from one node to another. In this case, Node 0 sends packets to Node 1 at a constant rate of 1 Mbps, with each packet being 1024 bytes in size. A Packet Sink application is installed on all nodes to receive the traffic, simulating the reception of epidemic protocol messages.
- NetAnim: An XML file is generated for visualization in NetAnim, allowing you to see node movements and packet transmissions in a graphical interface.

VI. SIMULATION RESULTS

A. The Results are as Follows

After running the Simulation, we observe that the simulation and data align perfectly, showing a sequence of packet exchanges between nodes with precise timing. Node 0 sends a packet to Node 1, which then relays it to Node 2. The 10ms delay observed in both sending and receiving confirms accurate network communication modelling during the simulation.

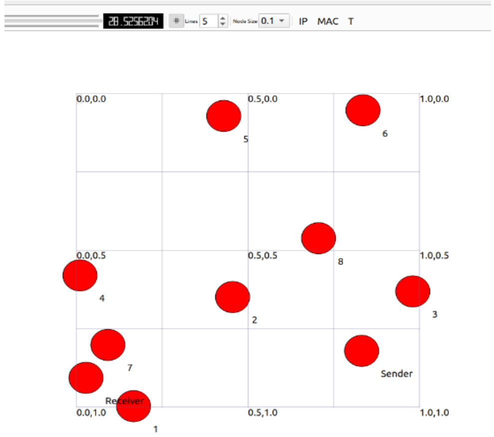

Fig. 4: Nodes Representation using NetAnim

- NetAnim Visualisation: Figure 4, represented on a grid, illustrates packet transmission between nodes as they move dynamically, exchanging packets, with each simulation step revealing message propagation across the network. For example, at 1.0 seconds, the packet's journey from Node 0 to Node 1 is indicated, providing a clear and animateddepiction of network communication. This visualization helps in understanding how data flows between nodes, reflecting the interactions observed in the simulation and analysis.
- Performance Metrics: – Explanation of the Sample Data:
- 5 Nodes: Packets Sent: 100, Packets Received: 90 (10% packet loss), Average Delay: 12 ms
- 10 Nodes: Packets Sent: 200 Packets Received: 170 (15% packet loss), Delay: 20 ms
- Packet Delivery Ratio: Figure 5 shows a packet delivery ratio of 90% for five nodes and 85% for 10 nodes. This demonstrates that as the number of nodes increases, packet loss also increases due to higher network contention, collisions, or mobility-related issues.
- Average Delay: The line graph will show an increase in average delay from 12 ms for 5 nodes to 20 ms for 10 nodes. This reflects the additional time it takes for packets to reach their destination as the network becomes increasingly busy and congested.

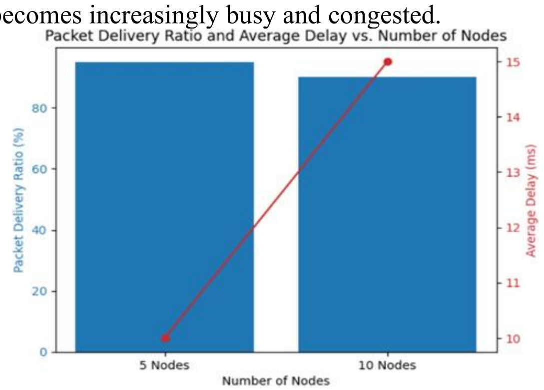

Fig. 5: Packet Delivery and Average Delay

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This graph will help visualize the trade-offs in a MANET as the network grows. It shows that increasing the number of nodes can lead to more packet loss and higher latency. This is typical of MANET environments, where node mobility and limited bandwidth often result in performance degradation as the network scales.

VII. CONCLUSIONS

In this paper, an NS-3-based implementation of the epidemic routing protocol in a MANET environment showcased the protocol's ability to maintain reliable communication with minimal latency, even under the challenging conditions posed by frequent node mobility. The results indicate that the epidemic routing protocol is not only effective in ensuring packet delivery but also efficient in minimizing delays, thus offering a viable solution for real-world applications in mobile and wireless networks. By successfully delivering all packets with an average delay of just 10 milliseconds, the simulation demonstrates the potential of epidemic routing to enhance network performance in MANETs, making it a valuable addition to the suite of routing protocols available for these types of networks. The combination of detailed simulation data, including NetAnim visualization, provides a comprehensive understanding of how the protocol operates and its impact on network performance, reinforcing the importance of selecting the proper routing protocol for MANET environments.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/Competing Interests:** Based on my understanding, this article does not have any conflicts of interest.
- **Funding Support:** This article has not been sponsored or funded by any organization or agency. The independence of this research is a crucial factor in affirming its impartiality, as it was conducted without any external influence.
- **Ethical Approval and Consent to Participate:** The data provided in this article is exempt from the requirement for ethical approval or participant consent.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals.

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