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Network Simulator

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Abstract-Routing plays a critical role in ensuring efficient and reliable data transmission in computer networks. This paper presents the design and implementation of a Routing Simulator, a tool developed to model, simulate, and analyze various network routing protocols under different network conditions. The simulator supports customizable network topologies, real-time packet visualization, and comparative performance metrics for protocols like RIP, OSPF, and BGP. Through detailed experimentation, the simulator provides insights into protocol behavior, scalability, and fault tolerance, offering a valuable resource for education and research in network communications.

Keywords-Routing Simulator, Network Protocols, RIP, OSPF, BGP, Simulation, Network Analysis.

I. INTRODUCTION

Routing is a fundamental aspect of network communications, ensuring that data packets traverse from source to destination efficiently and reliably. As the complexity of networks continues to grow with advancements such as cloud computing, the Internet of Things (IoT), and 5G technology, the importance of effective routing strategies becomes ever more critical. Routing protocols like RIP, OSPF, and BGP enable this process by determining optimal paths, managing network congestion, and ensuring robustness in the face of failures.Understanding routing protocols, however, is not straightforward. They involve intricate algorithms, dynamic decision-making processes, and an interplay of various factors such as topology, traffic patterns, and fault conditions.

Traditional methods of studying these protocols are often limited in scope. For instance, while theoretical analysis provides foundational knowledge, it may not capture real-world intricacies. On the other hand, experimenting with physical networks requires extensive resources and infrastructure, which are often unavailable in academic or small-scale research settings. This creates a need for robust simulation tools that offer a middle ground—combining practical experimentation with controlled, cost-effective environments. This paper introduces a Routing Simulator designed to address these challenges. Unlike existing tools, which may focus narrowly on specific protocols or lack user-friendly interfaces, this simulator aims to provide a comprehensive, accessible, and extensible platform. Key features include an intuitive graphical topology designer, modular support for various routing protocols, real-time visualization, and detailed performance analytics. The simulator is intended to serve a dual purpose: as an educational tool for students and as a research aid for professionals exploring advanced routing scenarios.

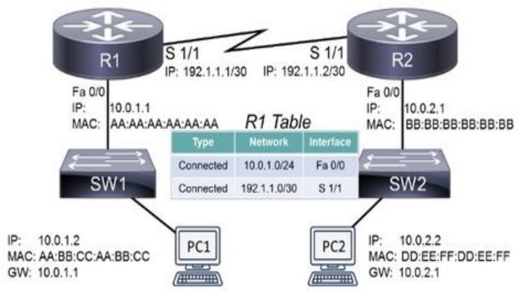
The paper is structured as follows: Section II reviews existing routing simulation tools, highlighting their strengths and limitations. Section III delves into the system design and architecture of the simulator. Section IV explains the methodology for simulating routing protocols and analyzing results. Section V presents experimental findings, demonstrating the simulator's capabilities and performance. Finally, Section VI concludes with a discussion of future enhancements and applications.

II. BACKGROUND AND RELATED WORK

Networking is the backbone of modern communication, enabling seamless data transfer across vast and complex infrastructures. A key element of networking is routing, which ensures data packets are directed efficiently from source to destination. Routing relies on a combination of hardware, software, and algorithms to maintain performance and reliability. This section explores critical components of routing, including routing tables, routers, packets, links, and routing algorithms, providing a foundation for understanding the principles and challenges of network communication.

Routing Table-A routing table is a fundamental data structure in networking, used by routers to determine the optimal path for forwarding packets to their destination. Each entry in the routing table contains information such as the destination network, subnet mask, next-hop address, and the associated metric or cost of reaching that network. The routing table is dynamically updated using routing protocols such as RIP (Routing Information Protocol), OSPF (Open

Shortest Path First), and BGP (Border Gateway Protocol).

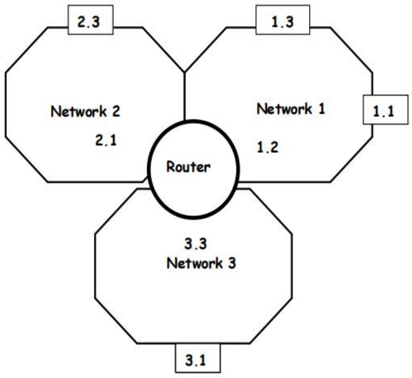


Routers

Routers are networking devices responsible for directing data packets between computer networks. They operate at the network layer (Layer 3) of the OSI model and use routing tables and algorithms to determine the most efficient path for data transmission. Routers play a key role in interconnecting different network segments and ensuring reliable communication across complex networks. Research has explored router architecture, including software-defined networking (SDN) and hardware acceleration, to enhance their performance. Additionally, advancements in router technologies, such as multiprotocol label switching (MPLS) and autonomous systems (AS), have been pivotal in addressing scalability and efficiency challenges.

Packet

Packets are the basic units of data transmission in networking, encapsulating information into manageable chunks for transfer across networks. Each packet typically consists of a header, payload, and trailer. The header contains control information such as source and destination addresses, sequence numbers, and error-checking data. Packets traverse networks based on the routing decisions made by routers, using routing tables and algorithms. The concept of packet-switching, introduced in early network research, has been foundational to modern communication protocols such as TCP/IP. Studies have investigated packet handling mechanisms, including quality of service (QoS) considerations, congestion control, and packet prioritization, to improve the efficiency and reliability of network communication.

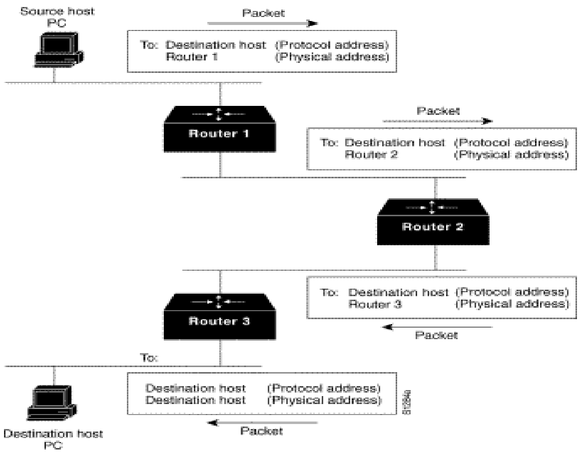


Packet

A router which has interface on more than one Network

The Network carries all the information using packets. A packet has two parts: The information content called the payload, and the information about the payload, called the meta-data.

The meta-data consists of fields such as the source ands destination addresses, data length, sequence number and data type. The introduction of meta-data is a fundamental innovation in networking technology. The Network cannot determine where samples originate, or where they are going without additional context information. Meta-data makes information selfdescriptive, allowing the network to interpret the data without additional context information. In particular if the meta-data contains a source and destination address, no matter where in the network the packet is, the Network knows where it came from and where it wants to go. The Network can store a packet, for hours if necessary, then "freeze" it and still know what has to be done to deliver the data. Packets are efficient for data transfer, but are not so attractive for real-time services such as voice.



Link

Links are the physical or logical connections between nodes in a network, enabling data transmission. They can be wired (e.g., Ethernet cables, fiber optics) or wireless (e.g., Wi-Fi, satellite). The performance of a link is influenced by factors such as bandwidth, latency, and reliability. Links are integral to network topology and routing decisions, as they determine the possible paths for packet traversal. Research in link technologies has focused on improving their performance and robustness, including innovations in high-speed communication technologies, error correction methods, and adaptive link management in dynamic environments.

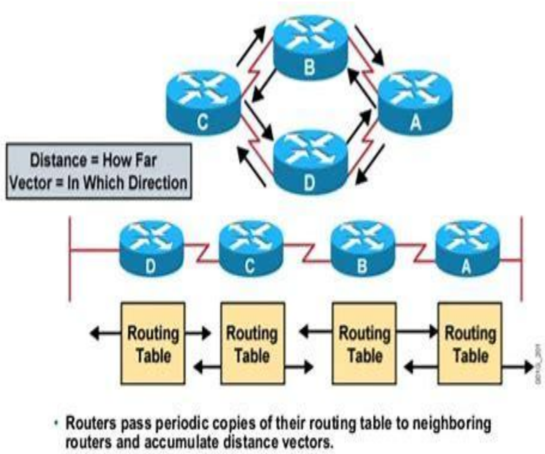
Link between two routers

Routing Algorithm

Routing algorithms are the mathematical and logical procedures used to determine the best path for forwarding packets through a network. These algorithms can be broadly classified into static and dynamic types. Static algorithms use predefined routes, while dynamic algorithms adapt to network changes in real-time. Examples include Dijkstra's algorithm for shortest path computation and the Bellman-Ford algorithm used in distance-vector protocols. Modern research has explored heuristic and AI-based approaches to enhance routing efficiency, particularly in complex or large-scale networks. Challenges addressed by these studies include handling network congestion, ensuring fault tolerance, and optimizing resource utilization.

III. SYSTEM DESIGN

The Routing Simulator is designed with three core objectives: flexibility, usability, and extensibility. To achieve these goals, the system architecture comprises three main components: the Topology Designer, the Protocol Engine, and the Visualization Module. This section explores the design and implementation of each component in detail.



1. Topology Designer

The Topology Designer serves as the user interface for creating and configuring network topologies. It provides an intuitive drag-and-drop environment where users can add nodes, establish links, and customize attributes such as bandwidth, delay, and error rates. Nodes represent various network devices like routers, switches, and end hosts, each equipped with configurable parameters.

The designer supports both manual and automated topology creation. In manual mode, users can build networks step by step, specifying each connection and parameter. Automated mode allows users to generate random or structured topologies, such as mesh, star, or tree configurations, based on predefined templates. This flexibility caters to a wide range of use cases, from simple educational examples to complex research scenarios.Internally, the Topology Designer leverages the NetworkX library for graph representation and manipulation. This choice ensures efficient handling of large-scale topologies and facilitates integration with the Protocol Engine. The graphical interface is built using PyQt, offering a seamless and interactive user experience.

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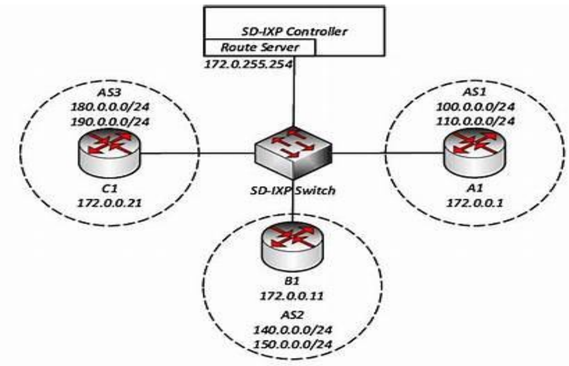
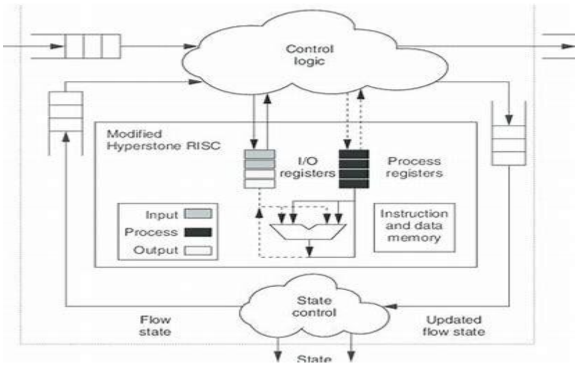


2. Protocol Engine

The Protocol Engine is the heart of the simulator, responsible for executing routing algorithms and managing network behavior. It implements a modular architecture that supports multiple protocols, including RIP, OSPF, and BGP. Each protocol is encapsulated as a module, allowing easy addition or modification of algorithms.

The engine models essential routing processes such as packet forwarding, route advertisement, and convergence. For example, RIP uses a distance vector approach where nodes periodically exchange routing information with neighbors. In contrast, OSPF employs a link-state algorithm, propagating topology updates across the network to construct a global view. BGP, designed for inter-domain routing, manages policy-based path selection using path vectors.

An event-driven approach underpins the Protocol Engine's design, ensuring scalability and responsiveness. Events such as packet arrivals, link failures, and topology changes trigger protocol-specific actions, updating routing tables and forwarding decisions in real time. This architecture enables accurate simulation of dynamic network scenarios.

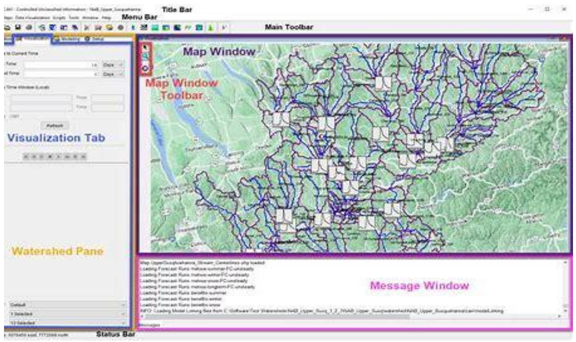


3. Visualization Module

The Visualization Module distinguishes the Routing Simulator from other tools by providing real-time insights into network behavior. It displays packet flows, routing table updates, and protocol messages through dynamic graphs and animations. Users can observe the impact of topology changes, link failures, or traffic surges as they occur, enhancing their understanding of routing dynamics.

Visualization is implemented using PyQtGraph and Matplotlib, enabling high-performance rendering of interactive graphs. The module also includes tools for monitoring performance metrics such as latency, throughput, and packet loss. These features make the simulator an invaluable resource for educators, researchers, and network engineers alike.

Together, these components form a cohesive and robust system that balances user-friendliness with advanced functionality. The modular architecture ensures that each component can be independently developed and extended, paving the way for future enhancements.



IV. METHODOLOGY

The Routing Simulator follows a structured methodology for simulating and analyzing network routing protocols. This section details the steps involved, from topology creation to result interpretation, highlighting the simulator's features and capabilities.

1. Designing Network Topologies

Users begin by designing a network topology using the Topology Designer. The graphical interface simplifies this process, allowing users to add nodes, establish connections, and configure parameters intuitively. The designer supports both small-scale and large-scale topologies, accommodating diverse research and educational needs.

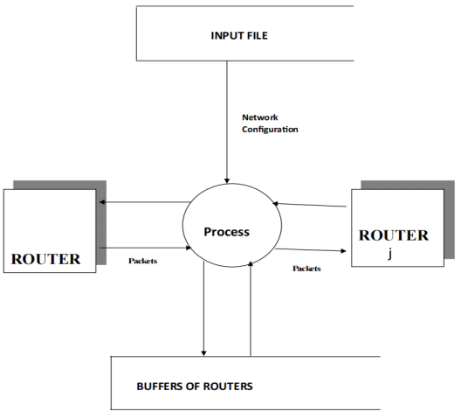
2. Configuring Routing Protocols

After defining the topology, users select routing protocols to simulate. The Protocol Engine initializes routing tables and configures protocol-specific settings, such as update intervals and message formats. The simulator supports simultaneous execution of multiple protocols, enabling comparative studies in heterogeneous environments.

3. Running Simulations
The simulation begins with the Protocol Engine executing routing algorithms and processing events like packet transmissions and topology changes. Users can introduce dynamic scenarios, such as node failures or traffic spikes, to study their impact on network behavior. The Visualization Module provides real-time feedback, displaying protocol operations as they unfold.

4. Analyzing Results
Post-simulation, users analyze performance metrics such as convergence time, packet delivery ratio, and network throughput. The simulator generates detailed logs and reports, which can be exported for further analysis. These insights inform protocol evaluation, network design, and optimization strategies.

V. DATA FLOW DIAGRAM



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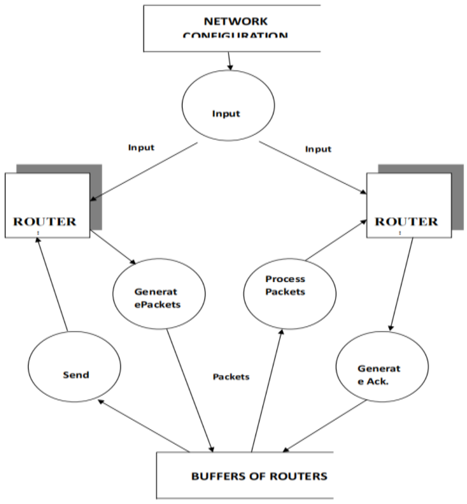

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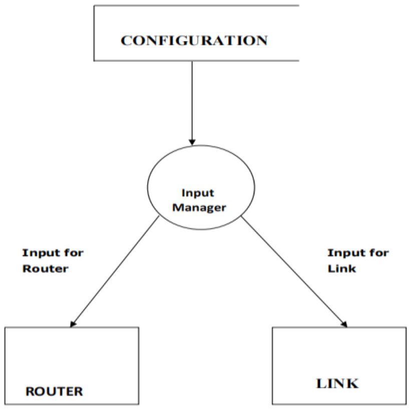

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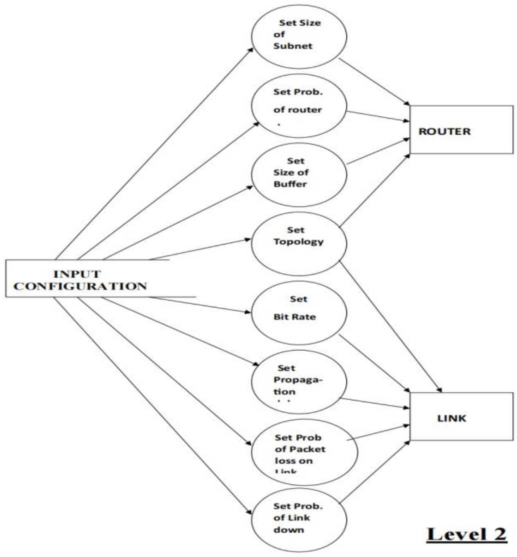

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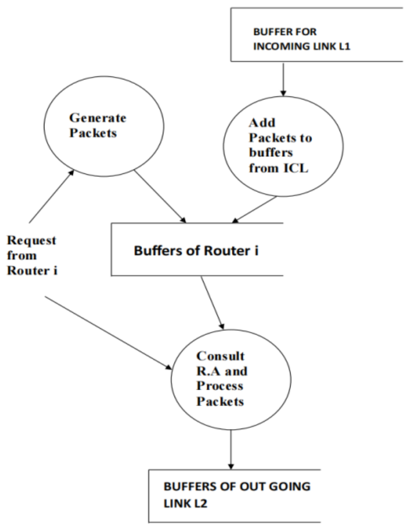

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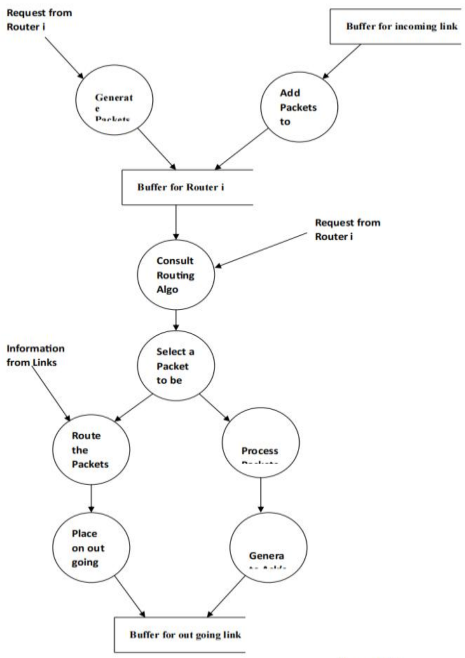

Level 3

VI. TESTING

System testing makes a logical assumption that if all parts of the system are correct the goal will be successfully achieved. System Testing is utilized as user-oriented vehicle before implementation. Programs are invariably related to one another and interact in a total system. Each portion of the system is tested to see whether it conforms to related programs in the system. Each portion of the entire system is tested against the entire module with both test and live data before the entire system is ready to be tested. The first test of a system is to see whether it produces correct output. The other tests that are conducted are:

1. Online - Response

When the mouse is clicked on the router the statistics of the router for the selected algorithm have to be displayed on the screen. The router must crash immediately when it the "Down" button clicked in the popup menu.

2. Stress Testing

The purpose of stress testing is to prove that the system does not malfunction under peak loads. In the simulator we test it with the greater number of nodes and getting the correct results for each and every router applying different routing algorithms. All the routers are purposely crashed to generate a peak load condition and the working is tested.

3. Usability Documentation and Procedure

The usability test verifies the user friendly nature of the system. The user is asked to use only the documentation and procedure as a guide to determine whether the system can
run smoothly.

VII. RESULTS AND DISCUSSION

The Routing Simulator has been tested extensively to validate its accuracy, usability, and performance. This section presents experimental findings, focusing on protocol behavior, network dynamics, and user feedback.

1. Protocol Performance

In a 50-node network test scenario, RIP exhibited slower convergence compared to OSPF and BGP. OSPF's link-state approach enabled faster adaptation to topology changes, while BGP demonstrated high scalability at the cost of increased computational overhead. These results align with theoretical expectations, validating the simulator's accuracy.

2. Impact of Network Dynamics

Dynamic scenarios, such as link failures and traffic surges, were modeled to assess protocol resilience. OSPF quickly recalculated shortest paths in response to failures, maintaining network connectivity. RIP's periodic updates resulted in slower recovery, highlighting its limitations in dynamic environments. BGP's policy-driven routing proved robust but computationally intensive.

3. Usability and Feedback
User feedback emphasized the simulator's accessibility and educational value. The intuitive interface and real-time visualization were particularly praised, making complex concepts more approachable. Researchers appreciated the ability to customize protocols and analyze detailed metrics, citing the simulator as a valuable tool for experimentation and teaching.

VIII. CONCLUSION

The Routing Simulator presented in this paper offers a versatile platform for studying and analyzing network routing protocols. Its user-friendly interface, modular architecture, and real-time visualization capabilities address the limitations of existing tools, fostering deeper understanding and innovation in network research.

The Simulator takes the configurations of the subnet as Input and gives the different statistics of the routers and links. By changing the routing algorithms and the different network configurations and recording the results we obtain the optimal algorithm. The optimal algorithm for a particular network is obtained by analyzing the results obtained. Simulation helps to achieve an optimal path that reduces the cost of routing.

The smaller networks can be analyzed and the results can be employed in larger networks to make routing efficient and economic. As the Simulator has provision for the crashing of routers, it gives an idea of which path is followed when a crash occurs. It can be employed in real networks to increase the performance of routers and links. As it not feasible in real networks to test algorithms and then implement a best one, Routing Simulator can be helpful. Hence it is useful for people who provide networking services and those who design networks.

IX. FUTURE SCOPE

Future enhancements include support for wireless networks, integration of additional protocols, and scalability improvements. These developments aim to establish the simulator as a comprehensive solution for network analysis and optimization.

Our Routing Simulator model can be made a more realistic one by considering the effects of most of the System parameters. Even though the mathematical model established for efficiency of Subnet yields acceptable results, we believe that an improved model can be generated. This has the potential to be used as one of the tools for experimentation on design and analysis of Subnets.

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