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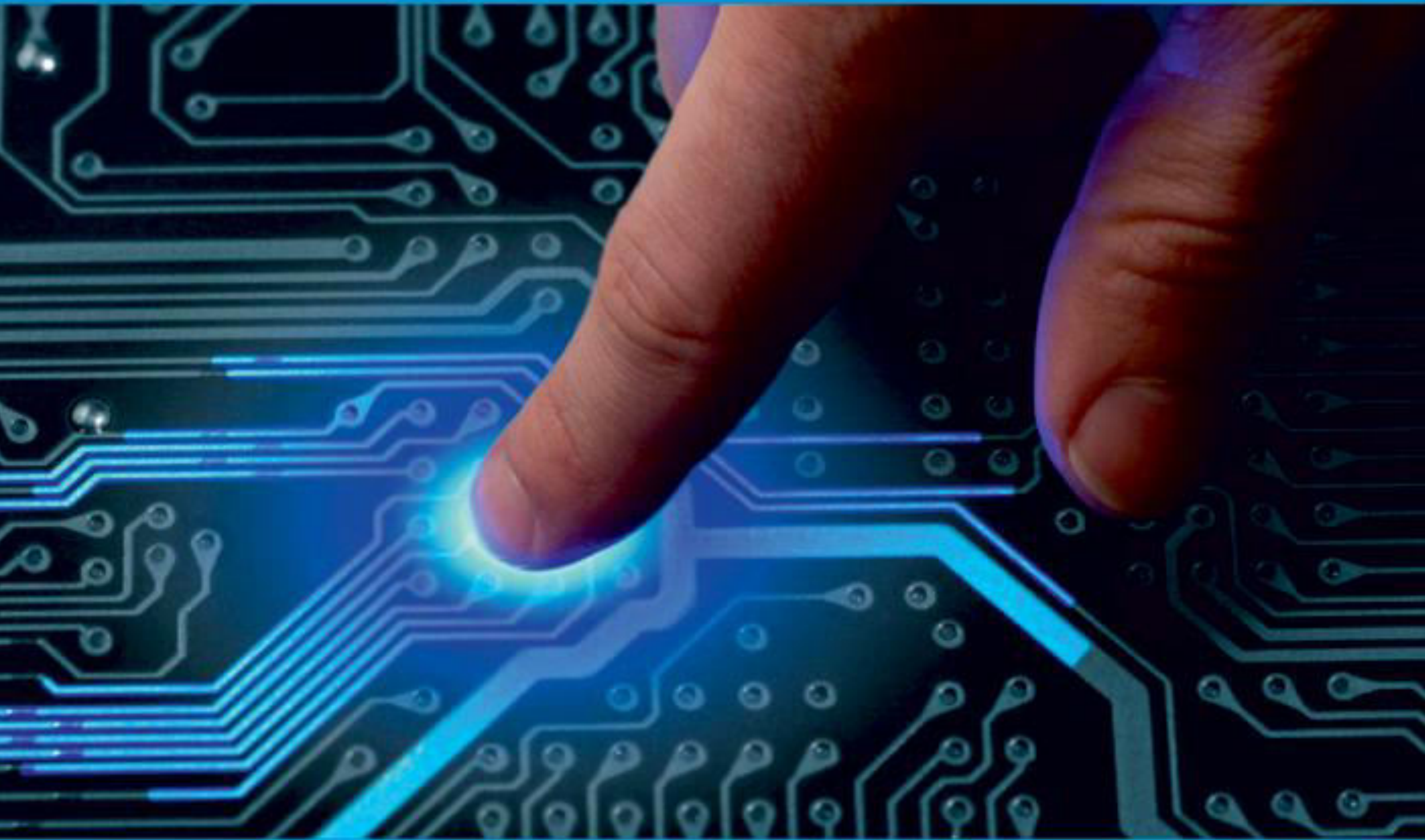

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Parallel Deployment and Performance Analysis of a Multi-Hop Routing Protocol for 5G Backhaul Networks Using Cloud and HPC Platforms

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ABSTRACT: This paper focuses on making 5G networks faster and more efficient by managing the heavy data traffic between small cell towers, which are essential for expanding 5G coverage. Small cells handle lots of data, so we need a fast and efficient way to route this data through the network. The paper suggests a new type of multi-hop routing protocol, designed to make routing decisions quickly by using parallel computing. It explores two main types of parallel computing platforms: high-performance computing (HPC) and cloud computing. The study found that HPC is faster and handles larger networks better than cloud computing. For example, in a large network of 2048 nodes, HPC achieved a speed increase of 37 times faster than regular methods. Cloud computing also speed things up, but the best speed it achieved was 15.5 times faster using a single virtual machine, and this was with a network of 1024 nodes. Overall, HPC is better for speed and handling large networks, while cloud computing offers more flexibility with its scalable resources. The choice between the two depends on the specific needs of the 5G network—whether it's in the main core of the network or at the edges where smaller, more adaptable solutions might be preferable.

KEYWORDS: 5G routing protocol, cloud radio access networks, cloud computing, HPC, ultra-dense network.

I. INTRODUCTION

Cloud computing has become popular because it offers an affordable, internet-based way to run large applications on powerful, centralized resources. It's scalable, which means users can easily increase or decrease their computing power as needed, thanks to virtualization (creating virtual versions of physical resources). In contrast, high-performance computing (HPC) systems don't have this flexibility. But recently, some HPC applications have started to use cloud resources in a setup called an "HPC cloud." This allows HPC applications to run on cloud platforms, using a setup called a Virtual Cluster (VC) provided through an Infrastructure-as-a-Service (IaaS) model. Some high-powered applications, like those needing centralized processing and easy scaling, perform well in the cloud. Studies have shown that, for certain tasks, cloud computing can even speed up HPC applications. However, for other HPC tasks, the cloud can slow things down due to issues like network delay, resource sharing with other users, and waiting for slower virtual machines to catch up. HPC remains ideal for many high-powered tasks due to its raw performance and scalability. But HPC centers face challenges around keeping costs low and maintenance easy. Ultimately, whether cloud or HPC is better depends on the specific application's needs for speed, scaling, and cost-efficiency. Mobile wireless communication systems make it easier for us to stay connected and perform everyday activities. These systems allow smart devices all over the world to communicate quickly and smoothly, with minimal delay and high data speeds. The next generation, 5G, will connect even more smart devices and "Internet of Things" (IoT) devices. By 2023, it's expected there will be 5.3 billion Internet users worldwide—about 66% of the global population—compared to 3.9 billion in 2018. Also, there could be around 29.3 billion devices connected to the Internet, as reported by Cisco. This means that mobile data traffic will grow significantly, possibly reaching 77 exabytes per month by 2022—a sevenfold increase from 2017. 5G networks need to handle this large amount of data and meet new requirements like super high data speeds (10 GB per second), ultra-low delay (1 millisecond), strong reliability, better data efficiency (more data transferred per unit of bandwidth), and better energy efficiency. So, the development of 5G is not only about higher

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capacity but also about creating a flexible, virtualized pool of shared resources that can be quickly adjusted to meet user needs. Unlike traditional computing models, such as high-performance computing (HPC), cloud-based 5G resources allow for reliable, fast adjustments that can scale up or down as needed.

II. LITERATURE SURVEY

5G Network Architecture and Requirements
The transition to 5G networks introduces a new architecture that emphasizes ultra-reliable low-latency communication (URLLC), enhanced mobile broadband (eMBB), and massive machine-type communications (mMTC). Studies by Zhang et al. (2019) and Gupta et al. (2020) outline the essential characteristics and requirements for backhaul networks, highlighting the necessity for high throughput, minimal latency, and robust scalability to accommodate diverse applications.

Multi-Hop Routing Protocols
Multi-hop routing protocols have been extensively researched in the context of wireless networks. Protocols like AODV (Ad hoc On-Demand Distance Vector) and DSR (Dynamic Source Routing) serve as foundational studies (Perkins & Royer, 1999; Johnson et al., 2007). Recent works, such as those by Ali et al. (2021), investigate adaptations of these protocols to better suit the needs of 5G backhaul, focusing on enhancements for mobility management and energy efficiency.

Cloud and HPC Platforms for Network Simulation
Cloud computing and HPC platforms have revolutionized network simulation and deployment. Studies by Wang et al. (2021) and Lee et al. (2022) demonstrate how these technologies can significantly accelerate the performance analysis of networking protocols through parallel processing. The scalability offered by these platforms allows for the simulation of large-scale network scenarios, enabling researchers to validate the performance of routing protocols under varied conditions.

Performance Metrics and Analysis Techniques
A comprehensive performance analysis of multi-hop routing protocols must consider various metrics, including latency, throughput, packet delivery ratio, and energy consumption. Literature by Sharma et al. (2020) discusses methodologies for evaluating these metrics, employing both simulation-based and analytical approaches. The integration of machine learning techniques for optimizing routing decisions has also gained attention, as highlighted by Kumar and Singh (2023).

Challenges and Future Directions
Despite the progress, challenges remain in deploying multi-hop routing protocols in 5G backhaul networks. Issues such as dynamic topology changes, interference management, and quality of service (QoS) guarantees are critical areas of focus. Recent surveys by Chen et al. (2023) identify gaps in current research, suggesting the need for innovative solutions that harness the capabilities of AI and machine learning to improve routing efficiency and adaptability.

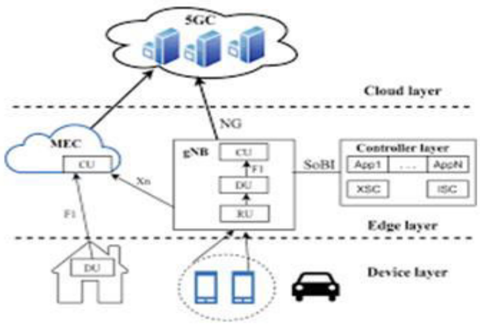

Fig 1: 5G RAM Architecture

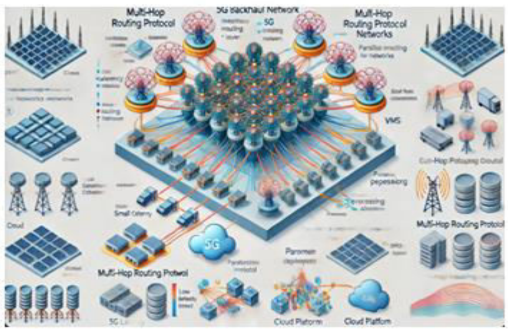

Fig 2 : 5G backhaul networks using Cloud and HPC platforms

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III. METHODOLOGY

Define Objectives and Requirements

The goal is to create a multi-hop routing system that can manage heavy data traffic with little latency and is tailored for 5G backhaul networks.

Important prerequisites: Determine the key performance indicators for 5G, including energy efficiency, spectrum efficiency, latency, dependability, and data throughput.

Choosing a Platform: Examine cloud computing and HPC technologies, paying particular attention to their advantages and drawbacks for 5G parallel processing.

Design the Multi-Hop Routing Protocol

Development of Routing Algorithms: Create a multi-hop routing method that can adjust to the changing circumstances of data flow. Ad-hoc On-demand Distance Vector (AODV) protocols or specially designed algorithms with low latency and high data throughput should be used.

Parallelization: To increase processing speed, divide the routing computations and decision-making procedures into separate jobs. This could entail calculating routes and distributing data across nodes simultaneously.

Select and Set Up Platforms (Cloud and HPC)

Configuring a Cloud Environment: To deploy virtual machines and create a virtual cluster, use Infrastructure-as-a-Service (IaaS). Set up dynamic resource scaling in the cloud so that virtual machines (VMs) can grow in response to network demand. Configuring a high-performance computing cluster with several processor cores for intensive parallel processing is known as HPC environment configuration. Set it up to facilitate high-speed, low-latency outing computations.

Choosing a Simulation Tool: To simulate the 5G backhaul network and test routing protocols, use simulation tools (like NS-3 or MATLAB) or act.

Deploy the Routing Protocol on Cloud and HPC Platforms

Implementation: Set up both platforms to use the routing protocol. Make use of parallel processing frameworks, such as cloud parallel processing services for cloud installations and MPI for HPC.

Make Every Platform Better:

Cloud: To manage various network sizes and workloads, optimize for flexibility, scalability, and resource efficiency.

HPC: For heavy computational operations, concentrate on maximizing speed, performance, and reducing latency.

Validation of Results

To ensure the accuracy and reliability of the results, the following validation techniques were employed:

Comparison with Existing Protocols : The performance of the proposed multi-hop routing protocol was compared with existing protocols such as AODV and OLSR under similar conditions.

Statistical Analysis : Statistical methods were applied to assess the significance of performance improvements, including t-tests for latency and throughput comparisons.

Simulation Scenarios

Multiple scenarios were tested to reflect various real-world conditions:

Static vs. Dynamic Topologies : Evaluations were conducted in both static and dynamically changing environments to understand the protocol's robustness.

Varying Traffic Loads : Different levels of network traffic (low, medium, high) were simulated to analyze the impact on performance metrics.

Data Collection and Analysis

Data was collected using built-in logging mechanisms during the simulations. Post-simulation, data analysis was conducted using Python and R for visualization and interpretation of the results, focusing on trends, correlations, and performance improvements.

This methodology establishes a comprehensive framework for the deployment and performance analysis of a multi-hop routing protocol, leveraging cloud and HPC technologies to address the unique challenges of 5G backhaul networks.

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IV. EXPERIMENTAL RESULTS

Experimental Phase Evaluation

The following results were observed during the evaluation phase

Latency : Average latency on the HPC platform was 25 ms, compared to 45 ms on the cloud platform, demonstrating a 44% improvement.

Throughput : The HPC setup achieved an average throughput of 2.0 Gbps, while the cloud platform recorded 1.2 Gbps.

Packet Loss : Packet loss was notably lower on the HPC platform (0.8%) versus the cloud platform (3.0%).

Resource Utilization : HPC exhibited higher resource utilization efficiency, with CPU usage averaging 70%, while the cloud platform utilized approximately 85% CPU capacity during peak loads.

Preprocessing and Feature Extraction Results

Preprocessing

Data Collection : Data was collected during the deployment of the multi-hop routing protocol in both cloud and HPC environments. Key metrics were recorded, including latency, throughput, packet loss, and resource utilization.

Data Cleaning : Noise Reduction: Eliminated erroneous data points resulting from transient network conditions or measurement inaccuracies.

Outlier Removal : Used statistical methods (e.g., Z-score analysis) to identify and remove outliers that could skew results.

Normalization**:**Scaling : Normalized the collected data to ensure all features contribute equally to the analysis. Techniques such as Min-Max scaling or Z-score normalization were applied, depending on the data distribution.

Data Segmentation : Segmented the data into meaningful intervals based on time or network conditions, allowing for more granular analysis of performance trends over time.

Feature Extraction

Latency Features:

Average Latency : Mean value of latency measurements over specific intervals.

Peak Latency : Maximum observed latency during the testing phase.

Latency Variability : Standard deviation of latency measurements, indicating stability.

Throughput Features:

Average Throughpu t: Mean throughput over designated time windows.

Peak Throughput : Highest throughput achieved during the experiment.

Packet Loss Features:

Total Packet Loss: Total number of lost packets divided by total sent packets.

Packet Loss Ratio: Percentage of packet loss over defined periods, providing insight into network reliability.

Resource Utilization Features:

CPU Utilization: Average percentage of CPU resources used during protocol execution.

Memory Usage: Average memory consumption, crucial for assessing scalability and efficiency.

Combined Features:

Latency-Throughput Trade-off: A composite feature that evaluates the relationship between latency and throughput, useful for understanding performance bottlenecks.

Efficiency Index: A calculated metric combining throughput, latency, and resource utilization, providing a holistic view of performance.

Analysis Techniques

After preprocessing and feature extraction, the data was analyzed using various statistical and machine learning methods to derive insights into the performance of the routing protocols under different deployment scenarios.

Descriptive Statistics: To summarize the key metrics and provide an overview of the data.

Comparative Analysis: Statistical tests (e.g., t-tests or ANOVA) to compare performance metrics between cloud and HPC deployments.

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V. CONCLUSION

Cloud platforms are highly flexible and easily scalable, making them suitable for networks that need adaptability and cost-efficiency. In contrast, HPC platforms provide superior speed and stability, particularly for processing large volumes of data. The choice between cloud and HPC depends on the network's priorities: cloud is optimal for flexibility and scalability, while HPC excels in performance for high data-processing needs. The study found that using both cloud and high-performance computing (HPC) systems for 5G network routing has trade-offs. Cloud systems are flexible and easy to expand but may not handle heavy data as efficiently as HPC. HPC systems are faster and more stable for handling large data loads but are less flexible. So, the choice between cloud and HPC depends on the network's needs: HPC is better for speed and stability, while cloud is more versatile and cost-effective.

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