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Enabling the Future: A Virtualized Approach to 5G and Edge Computing

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A B S T R A C T

This abstract examines the evolution of wireless communications technologies beyond 5G (B5G) and the emergence of 6G. It highlights their key role in powering the Internet of Things (IoT) and enabling edge computing. Built on shared resources, this system is exposed to various real-time application scenarios and uses simulated user equipment (UE) and operational Nextcloud instances. Performance metrics are analyzed and the system can automatically scale during high network traffic to ensure high availability. Key concepts include Radio Access Network (RAN), Edge Computing, User Equipment and Virtual Network Functions (VNF). This framework relies on shared resources and undergoes rigorous testing with real-time application scenarios, using simulated User Equipment (UE) and operational Nextcloud instances.

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INTRODUCTION

The text traces the evolution of mobile and wireless communication technologies from early analog cellular systems to the latest innovations in Beyond 5G (B5G) and the upcoming Sixth Generation (6G). These new technologies, including Holographic-Type Communication (HTC) and Extended Reality (ER), are expected to transform various aspects of human life.

The development of the new generation presents challenges, especially ensuring compatibility with the existing infrastructure and controlling the costs associated with infrastructure modifications. To address these challenges, the concept of virtualization is introduced. Virtualized network infrastructure offers advantages such as multi-tenancy, compatibility with different vendors, reduced costs and simplified experimentation for scientific communities. Virtualization is presented as a solution to improve network infrastructure by introducing flexibility and intelligence through a virtual environment. This virtualized network infrastructure offers benefits such as multi-tenancy, vendor compatibility, cost reduction and simplified experimentation. The integration of virtualization into 5G, B5G and 6G network concepts is discussed, especially through Network Functions Virtualization (NFV). Ongoing research is exploring the optimization of NFV and its potential combination with artificial intelligence (AI) and machine learning (ML) tools to improve network management. This integrated approach can improve the flexibility and efficiency of service modularity. In addition, the text proposes to extend this concept to merge SDN and physical layer security (PhySec) for better network security.

This work focuses on demonstrating the benefits of virtualization by implementing 5G and MEC (Mobile Edge Computing) on different virtual machines hosted on the same physical hardware resources. The performance of these hosted machines is analyzed in real-time to assess the effectiveness of virtualization. Edge computing, a significant area of research, is highlighted as a key enabling factor for virtualization services. To illustrate the concept, the authors implement the Free5GC mobile core networks and the Nextcloud edge server, which demonstrates the concept of virtualization at the edge.

The thesis is structured as follows: Part I provides an overview of 5G and edge computing, discussing how edge computing and virtualization bring radio access networks (RANs) closer to end users. Part II explains the design structure and components, both physical and virtual. Part III analyzes the performance of virtual machines by monitoring CPU utilization and network traffic during real-time applications. Section IV concludes the paper with propositions and suggestions for future research.

LITERATURE REVIEW

The fifth generation (5G) of wireless communication has introduced revolutionary applications such as Augmented Reality (AR), Virtual Reality (VR) and Tactile Internet. It was built on three main objectives:

a) **Enhanced Mobile Broad-Band (eMBB):** Providing reliable, high-speed broadband access over wide coverage areas.

b) **Ultra-Reliable Low Latency Communication (URLLC):** Enables end-to-end communication with latency of less than 5 milliseconds, ensuring highly reliable real-time connections.
c) **Massive Machine Type Communication (MMTC):** Supporting the wireless connectivity of a large number of devices to cater to the growing number of mobile users.

To meet the growing demands of a rapidly expanding mobile user base, stringent quality of service (QoS) requirements, and the diverse nature of future wireless communication environments, 5G incorporates several key technologies. These included mm-wave communications, small cells, and massive mMIMO (Multiple Input Multiple Output) systems. These technologies have been instrumental in meeting the challenges presented by the evolving wireless environment

This review discusses Edge Computing as a distributed computing paradigm adopted to meet the growing demands of 5G applications. Edge computing extends cloud computing by bringing the cloud closer to end users, improving capabilities and addressing constraints such as latency and security. Key features of edge computing include dense geographic distribution, mobility support, location awareness, context, and heterogeneity. These features increase its compatibility with 5G and its ability to meet application requirements.

Three different edge computing models are presented:
a) **Cloudlets:** The goal is to enable computationally intensive tasks by bringing cloud resources closer to end users, offering high-speed access and low latency.
b) **Fog Computing:** Fog computing enables real-time applications to run at the edge of the network through small access points called Fog Computing Nodes (FCNs) located between the cloud and end users.
c) **Mobile Edge Computing (MEC):** The distributed nature of MEC reduces computational and storage overhead between end users and the core network, resulting in lower latency and higher quality of service. MEC enables real-time applications such as content sharing, traffic management and E-health services.

METHODOLOGY

In this proposed work, a 5G system was built to coexist with an edge server, both sharing the same hardware resources (as shown in Figure 1). The 5G system was exposed to fluctuating usage levels generated by simulated user equipment (UE). At the same time, an edge server was deployed using a Kubernetes cluster, providing a high-performance Nextcloud application capable of real-time operation and potentially supporting multiple users.

1. Physical Infrastructure

The experimental setup includes physical hardware with a host operating system and a virtualized infrastructure with specified characteristics detailed in Table I. The host machine accommodates this virtualized infrastructure using a host hypervisor. To achieve this virtualization, Oracle VirtualBox is installed on the host machine, which allows the deployment of a distributed system on multiple isolated virtual machines (VMs).

2. Virtual Infrastructure

In this experimental setup, two applications are running in a shared hosting environment using Oracle VirtualBox. The first application includes a 5G system implemented through the Free5GC open source project. It uses two virtual machines: one for the mobile core network and SIM registration and the other for the RAN and simulated UEs. This setting aims to assess the functionality of the 5G virtual network elements.

The second application creates an edge server using a Kubernetes cluster, making it easy to store data close to end users through Nextcloud's client-server software.

a) **Free 5GC:** This project focuses on the implementation of a standalone 5G core network and divides it into Control Plane (CP) and User Plane (UP) elements for flexible deployment of Network Functions (NF) through Network Functions Virtualization (NFV). MongoDB is used for data storage.

b) **Nextcloud:** This platform offers cloud file hosting services and is implemented using Minikube, a container management tool. Minikube will create a local Kubernetes cluster and allow an external client to access the Nextcloud server within the cluster. Automatic scaling of Nextcloud instances occurs when CPU resources exceed 80%.

Both applications serve as key components for testing and evaluating the functionality and performance of 5G and edge computing in a virtualized environment.

3. Hardware and virtualization setup

Start by configuring the physical hardware and host operating system. Make sure that the host computer has the necessary specifications to support virtualization. Install Oracle VirtualBox on the host computer that will be used to create and manage the virtualized environment.

4. Creating Virtual Machines (VMs)

Use Oracle VirtualBox to create the required virtual machines. In this case, two virtual machines are set up: one for the 5G system and the other for the edge server.

5. 5G System Configuration

Deploy the Free5GC project within the 5G VM. This project implements the basic components of a 5G network and divides it into a control plane (CP) and a user plane (UP). Configure basic network functions, including Subscriber Management Function (SMF) and User Plane Function (UPF). Also set MongoDB as the database to store the data.

6. Edge Server configuration

Deploy a Kubernetes cluster environment in the Edge Server VM. This cluster will be used to run Nextcloud, which offers file hosting services in the cloud. For this purpose, use Minikube, a container management tool. Minikube is preferred because it allows implementing a local Kubernetes cluster while providing the necessary Kubernetes features.

7. Data collection and analysis

Collect data on various performance metrics during the experiment, including latency, bandwidth, and resource utilization. Analyze data and evaluate the efficiency and functionality of the virtualized environment, 5G system and edge server.

8. Evaluation and future improvements

Evaluate the results of the experiment and identify areas for improvement. Consider the performance of both the 5G system and the edge server in meeting specified requirements and quality of service (QoS) objectives. Make suggestions for improvements and optimizations.

This methodology enables comprehensive testing and evaluation of the 5G system and border server in a virtualized environment with a focus on performance, scalability and efficiency. It provides a basis for assessing the practical applicability of these technologies in real-world scenarios and offers insights for future research and development.

RESEARCH RESULT AND DISCUSSION

In this work, a virtualized distributed system working with both 5G system and Edge computing infrastructure was implemented. Discussion and application of use cases are as follows:

A. 5G Virtualized System

- The 5G user equipment was subscribed through the web console of the 5G core component, which initialized various instances of the 5G core, RAN, and simulated UE.
- The first use case involved testing the UE's Internet connectivity by verifying network reachability using the ping command. During this operation, hardware resource metrics were monitored with an average data rate of 1 Mbps.
- The second use case focused on video streaming over a simulated UE. Resource usage metrics indicated that overall CPU usage remained below 15%, with a maximum network data rate of 550MB/s when streaming high-quality video.

B. Nextcloud

- Nextcloud was deployed as a service accessible via TCP/IP port 80. Load balancing was based on user traffic and hardware resource consumption.
- Under high load, the system could automatically scale and create new Nextcloud instances.
- As a test case scenario, Nextcloud instances were manually scaled with 3 additional replicas, with host CPU usage closely monitored. The duration for creation, initialization and load balancing for these 3 replicas was only 1 minute.
- Increased network utilization to balance the traffic load of the new replicas, with incoming connections allowed and monitored via the ingress object.
- The architecture implemented with Kubernetes enables high availability and scalability and ensures system performance. In the event of a sudden instance failure, Kubelet automatically detects the problem and restarts a new service, ensuring high availability.

These use case applications illustrate the effectiveness of a virtualized distributed system in managing both 5G and Edge computing workloads, highlighting its potential for scalability, high availability, and resource efficiency in real-time scenarios.

CONCLUSION

This system represents a significant step forward in 5G and edge computing and demonstrates the potential of a virtualized, distributed system to meet the evolving requirements of modern communications networks. Through the integration of 5G technology and edge computing, our experiments have demonstrated the effectiveness of this approach in achieving low latency, high performance, and efficient resource utilization. Use case applications for a virtualized 5G system and Nextcloud deployment illustrate the practicality of this concept in real-world scenarios. In addition, the automatic scaling and high availability achieved through Kubernetes underline the adaptability and robustness of the proposed architecture. As we move into an era driven by latency-sensitive data-intensive applications, the synergy between 5G and edge computing as presented in this work holds great promise for future network architectures and services and paves the way for a new network paradigm.

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