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Enhancing 5G Networks with Edge Computing: An Overview Study

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Abstract. This paper explores the synergies between Multi-access Edge Computing (MEC) and 5G technology, including their methodologies, characteristics, and architectures. MEC is a new computing model proposed within the framework of the rapid development of IoT, AI, and big data, aiming to bring cloud capabilities closer to the network edge. Its role is to reduce the distance between the data source and processing resources. Local data processing by edge servers reduces traffic volume and increases bandwidth, thus providing high data throughput and paving the way for 5G applications. Combining edge computing with other technologies such as SDN, NFV, NS, Massive MIMO, and NOMA enhances data management and quality of service, supporting highly interactive applications.

Keyword : edge computing, 5G, SDN, NFV, NS, Massive MIMO, and NOMA.

1 Introduction

With the rapid development of IoT, the number of smart devices connected to the Internet increased from 17.1 billion in 2016 to 50 billion in 2020. This increase leads to a considerable growth in the amount of data. Storing, processing, and analyzing all this data in real-time in traditional cloud computing centers is nearly impossible and causes problems such as:bandwidth overload, slow response times, low security and insufficient protection, excessive energy consumption and limited processing and computing capacities.

Edge computing has emerged to address these limitations; it offers: i) Low latency; from 80ms in cloud centers to less than 1ms by minimizing communication and propagation delays, ii) MEC collects and processes data generated by UEs based on their geographical location, iii) Context awareness: Edge computing can use the context-awareness feature of mobile devices to make better offloading decisions. It also allows the service provider to use this information to offer the user a better quality of experience (QoE), iv) Heterogeneity: The heterogeneity of the edge computing paradigm in various aspects, from end devices to edge servers and networks, ensures its compatibility with 5G and its ability to meet application requirements.

Multi-access Edge Computing (MEC) enables the delivery of 5G network services such as URLLC (Ultra-Reliable and Low-Latency Communications) for applications requiring real-time communications (autonomous cars, tactile internet, telemedicine and Vehicle-to-Everything (V2X) services etc.), eMBB (Enhanced Mobile Broadband) aimed at providing much faster mobile data rates (high-definition video streaming, online gaming), and mMTC (Massive Machine Type Communications) for the massive connectivity of IoT devices and sensors to collect, exchange, and analyze data. By providing computing and storage resources close to user equipment, MEC enhances network responsiveness and efficiency, thus meeting the stringent requirements of 5G.

2 5G Evolution and Architecture

2.1 5G evolution

The development of the 5G network is driven by the need to meet the growing demand for emerging technologies such as virtual/augmented reality, HD video streaming, and edge computing. It is based on a software infrastructure such as Network Functions Virtualization (NFV), Software-Defined Networking (SDN), and Network Slicing (NS). As well as new methodologies such as Massive MIMO and mmWave.

5G will offer an increased download speed of up to 10 gigabits/second, compared to the 100 megabits per second allowed by the 4G service. The 5G network is expected to have latency 10 times lower, 100 times greater efficiency and capacity, and 100 times higher traffic than the current 4G network.

2.2 5G architecture

The 5G system adopts a service-based architecture (SBA) by integrating network slicing and virtualization techniques across different domains. This enables the provision of a variety of services on the network while meeting the diverse requirements of users. Its architecture con-

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sists of three main components: the core network (CN), the radio access network (RAN), and the user equipment (UE). The core network is divided into a control plane (CP) and a user plane (UP), with different network functions (NF). Each function has a specific responsibility in the communication process [1]. As illustrated in Figure 1.

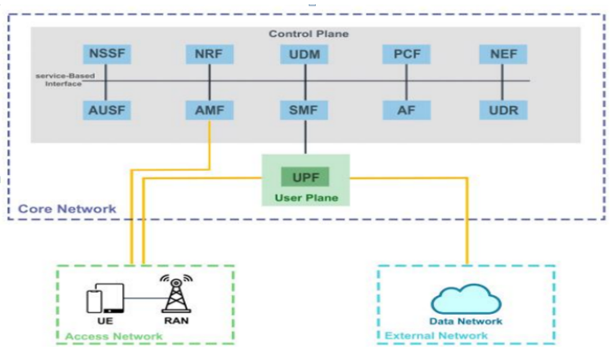

Figure 1: 5G architecture.

3 Edge computing

Researchers have different definitions of edge computing: Shi et al. introduced the emergence of the concept of edge computing as follows: ”Edge computing is a new computing model performed at the edge of the network. Downstream data from edge computing represents cloud services, upstream data represents the Internet of Things, and the edge in edge computing refers to arbitrary computing and network resources between the data source and the path to the cloud data center.” Satyanarayanan describes edge computing as follows: ”Edge computing is a new computing model that deploys computing and storage resources (such as cloudlets, micro data centers, or fog nodes, etc.) at the edge of the network, closer to mobile devices or sensors.” [2]. And in [3]Edge computing enables the collection, analysis, computation, and intelligent processing of data at every edge of the IoT network. This implies that data can be filtered, processed, and utilized near the devices or data sources where they are generated.

Therefore, edge computing is a computing paradigm aimed at providing services and performing computations at the edge of the network and the data source. It involves transferring network, computing, and storage capabilities from the cloud to the network edge.

3.1 Edge computing architecture

Edge computing architecture represents a distributed network that extends cloud capabilities to the edge by integrating edge nodes. These edge nodes connect end devices to the cloud, enabling enhanced computational power and storage closer to the data source. The architecture consists of three layers [4], as illustrated in Figure 2.

The terminal layer encompasses mobile terminals as well as IoT devices such as sensors, smartphones, smart cars, and cameras. These devices are primarily dedicated to data collection, which they then transmit to the upper layer for processing or storage [5].

The edge layer, or boundary, gathers edge nodes scattered between terminals and the cloud, including BS, RAN, routers, switches, and gateways. This layer includes several key components:

Edge nodes: a generic term referring to any device at the network edge, including edge devices, edge servers, or edge gateways, where edge computing tasks can be performed.

Analytics module: software used to analyze data at the edge and generate real-time insights.

Applications: software programs running on edge nodes, used to process data and provide real-time insights.

Orchestration module: software used to manage and deploy applications at the edge, optimizing the performance of edge computing systems.

Security module: edge security software used to protect devices and data from cyber-attacks.

The cloud layer consists of high-performance servers and storage devices, also capable of performing the analysis tasks that the edge layer cannot handle.

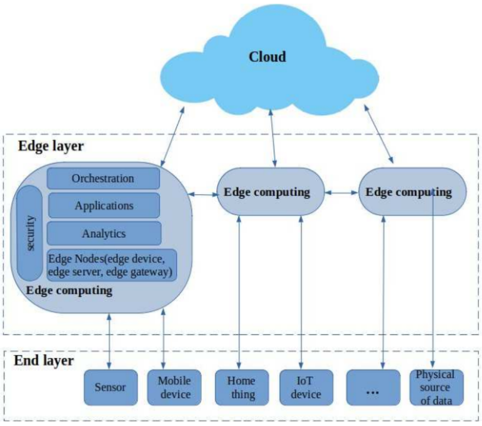

Figure 2: Edge computing architecture

4 Edge Computing in 5G: Solutions and Integration

4.1 Categories of Edge Computing in 5G

In this section, we present various architectures that have been proposed to optimize the deployment and utilization of resources in edge computing and 5G. These architectures are based either on the MEC (Multi-access Edge Computing) category or on hybrid approaches, which involve the participation of all network levels for resource provision and the execution of computing processes.

[6] Proposes the ”Energy Efficient Computation Offloading” (EECO) architecture to minimize energy consumption in executing computational tasks and in the communication process. This architecture is organized into three main steps: 1) Classify the UEs based on their energy consumption for computation and file transmission, as well as the transmission delay between mobile UEs and the MEC. Type 1 UEs use the MEC as a computation server. Type 2 UEs perform the computation by themselves. Type 3 UEs

have the choice to perform the computation either on the MEC or by themselves. 2) Assign priorities to different UEs based on their energy levels and 3) Allocate channels to different users based on their priorities, thus reducing the number of UEs competing for channels.

[7] Proposes the D2D architecture for 5G mobile edge computing to share computational and communication resources among nodes. The key objective is to achieve energy-efficient collaborative task executions at the network edge for mobile users. UEs use the graph matching algorithm, which represents nodes and links in a graph with three main steps: Node removal in Step 1, where nodes without tasks are removed; Node replication in Step 2, where a new replicated node is added to the node with a task to execute; and Matching in Step 3. A task node executes a task locally if its own replica can handle it, and offloads the task to another node if the latter can process it.

[8] proposes an integrated fiber-wireless (FiWi) access architecture aimed at enhancing MEC services and using Ethernet as a means to transfer traffic from the radio access network (RAN) to the core network for broadband access. This architecture leverages dynamic access functions to Radio Access Technologies (RATs) and 5G Device-to-Device (D2D) communication.

[9] proposes Software Defined Vehicle Networks (5G SDVN) by combining the SDN (Software Defined Network) function for efficient VNG (Vehicle Network Gateway) management and integrating MEC to introduce a programmable, flexible, and controllable architecture for 5G-SDVN. The central idea of this architecture is to separate the entire network into a control plane, which allows the MEC to obtain a comprehensive understanding of the network states to make optimal decisions with a lower response time. The social plane abstracts the communication between the VNGs, while the data plane is intended for the effective transmission of data.

[10] proposes a real-time collaborative architecture to manage heterogeneous resources such as different storage and computing capacities at the network edge. This architecture uses a hybrid platform where tasks are distributed and offloaded between the Cloud, MEC, and mobile terminals: mobile terminals handle tasks that require less processing and computing capacity, the MEC server deals with latency-sensitive tasks, while the Cloud handles non-latency-sensitive tasks. Additionally, it leverages the 5G RAT function.

[11] proposes an architecture that integrates three different components to dynamically compose services in real-time: (1) cloud servers where data is decomposed into a set of files called blocks, (2) MEC servers where these blocks are replicated for faster data access based on subscriber locations, and (3) smart IoT devices where these files are cached to support faster access to services.

[12] Proposes a four-layer architecture for urban traffic management:1) The Environment Sensing Layer, Collects traffic data via roadside infrastructure and onboard sensors. 2) The Communication Layer, Utilizes 5G networks for high-speed communication and increased flexibility through technologies like MIMO and cognitive radio. The D2D (device-to-device) technology is also used to provide positioning services and direct, flexible information exchange. 3)The MEC Server Layer, Places computing resources at the edge of end-users on 5G base stations, thereby improving real-time responsiveness for critical missions such as traffic light control and accident rescue. It includes the hosting infrastructure (hardware virtualization and vehicular communication resources), the application platform (infrastructure as a service and middleware), and applications deployed on independent VMs. 4)The Cloud Layer, Offers on-demand network access to a shared pool of resources, including processing power, storage, applications, and services.

4.2 Integrating MEC in 5G

Edge computing and 5G are two technologies with similar characteristics: both reduce latency for users and increase network bandwidth. We aim to understand how these two tools work together by providing local storage, local computing, local data analysis, and local decision-making. This combination meets the demands of 5G applications such as intelligent transportation systems, smart grids, serious gaming, robotics, and telepresence. This section presents some research related to the integration of edge computing into 5G.

[13] A discussion on the importance of integrating MEC with new 5G technologies and beyond to meet the growing demand for applications requiring real-time responses. Specifically, the integration of NOMA (Non-Orthogonal Multiple Access) into MEC to ensure massive connectivity in 5G networks, the integration of mmWave and massive MIMO into MEC for high data rates and low latency, the integration of MEC with EH (Energy Harvesting) and Wireless Power Transfer (WPT) to overcome the limitations of traditional systems (battery life, computing capacities, etc.), the integration of MEC with UAVs (drone communication) to enhance the communication capabilities of 5G networks, the integration of MEC with IoT devices, the integration of Machine Learning into MEC to optimize MEC mechanisms (intelligent decision-making and resource management), and also the integration of MEC with VM (Virtual Machine), SDN, and NFV.

[14] Focuses on the problem of MEC resource allocation for 5G networks, including computing, storage, and network resources, to meet the demands of various services and applications while considering constraints such as latency, bandwidth, and user mobility. It also discusses the methods used to address this problem: Mathematical optimization (Optimization solver, Ad-hoc algorithms, Lyapunov function, Game-theory based algorithms), Heuristic algorithms, Machine learning and Hybrid methods).

[15] Proposes a solution that integrates MEC with 5G and IoT to address the limitations of Mobile Cloud Computing (MCC), such as bandwidth overload, limited processing capabilities, and slow response times. By combining MEC with Time-Sensitive Networking (TSN), satellite communication, NOMA (Non-Orthogonal Multiple Access), Massive MIMO (Multiple-Input Multiple-Output),

mmWave (millimeter wave) technology, Energy Harvesting (EH) and/or Wireless Power Transfer (WPT), along with VM (Virtual Machine), SDN (Software-Defined Networking), NFV (Network Functions Virtualization), Network Slicing (NS), and AI technologies.

[16] Presents the advantages of integrating MEC into IoT in the 5G, such as traffic filtering, accelerated decision-making based on locally processed data, and improved scalability and longevity of IoT applications. This is achieved using NFV (Network Functions Virtualization), SDN (Software-Defined Networking), IC (Information-Centric Networking), and NS (Network Slicing).

Integrated Technologies	**Description**	**Advantages**
NOMA(Non-Orthogonal Multiple Access)	NOMA allows a group of users to share the same time-frequency resources.	Reduces transmission latency and increases bandwidth in 5G networks.
MIMO massif (Multiple-Input Multiple-Output	Use of a large number of antennas to improve capacity and spectral efficiency.	Interference management, real-time optimization, and reduction of the load on central data centers.
mmWave	Provide high frequencies for extremely fast data rates.	Edge computing reducing latency and improving the responsiveness of real-time applications.
TSN (Time-Sensitive Networking)	Supports the scheduled transmission of periodic data streams with strict real-time requirements	Enhance heterogeneous computing, storage, and edge-cloud collaboration capabilities, industrial systems, and autonomous vehicles.
SDN, NFV, NS(Network Slicing)/ VM(Virtual Machine)	Automation of network management tasks/Provide isolated environments	Reduced time and costs.

Table 1: Comparison of Integration Approaches of Edge Computing and 5G Technologies

Conclusion

The integration of Edge Computing with 5G functionalities represents a major technological advancement that transforms the way data is processed and services are delivered. By bringing computing capabilities closer to end users, this integration addresses the growing demands for ultra-low latency, high bandwidth, and intensive data processing. Therefore, this paper paves the way for multiple research areas, exploring how each of these functionalities can work with Edge Computing.

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