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Multi-Access Edge Computing Deployments for 5G Networks

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ABSTRACT

The growth of the telecommunication industry is fast-paced with ground-breaking engineering achievements. Notwithstanding the technological advancement in the industry, it had continued to cope with the phenomenon of resource constraint in portable mobile telecommunication devices compared to fixed and tethered devices. Portable mobile handheld devices have very low computational, storage and energy carrying capacity occasioned by the needs to satisfy portability, very small form factor, ergonomics, style and trends. Solutions such as cloudlets, cyber foraging, mobile cloud computing (MCC), and more recently but most applicable, multi-access edge computing (MEC) have been proffered with different application methodologies including computational offloading, distributed computing, thin clients, middleware, mobile environment cloning as well as representational state transfer. There is a need to satisfy requirements of new and emerging use cases, especially the deployments of 5G coming up with applications such as virtual reality (VR), augmented reality (AR), intelligent transport systems (ITS), connected autonomous vehicle (CAV), smart hospitals, ultra high definition multi-feed live streaming, etc. The usage patterns of most of these different applications, though not always, is ephemeral and on-demand, except that the demand will be numerous, huge, asymmetric and highly latency-sensitive in terms of needs for computation, storage and analytics while at the fringe of the network where data are being generated and results being applied. In this research, we evaluated 5G end-to-end transport for vantage location of MEC server to achieve low user plane latency.

Keywords: 5G, control plane latency, functional decomposition, Multi-access edge computing, radio access network, resource constraint, user plane latency.

1 INTRODUCTION

There are several constraints on mobiles devices as well as other portable 5G user equipment (UE) devices. Computational resources, memory limitation, storage, network and energy carrying capacity are some of the constraints of cellular mobile communication UEs and these have a significant effect on the type of application software available and for how long battery can hold a charge to support such applications. The major constraints include computational power, charge holding time, storage and memory limitations, especially for complex processes [1]. Several latency critical services which need to be supported by 5G include: factory automation, intelligent transportation systems, robotics and telepresence, virtual reality (VR), augmented reality (AR), health care, serious gaming, smart grid, education and culture [2]. Moreso, the demand for high definition images and multi-feed super high definition quality live video streaming for mobile users is constantly being escalated over the recent decade. 5G is projected to provide services that will support communication, computing, control and content delivery (4C) [10] for high-intensity network traffic. There will be an enormous increase in the number of mobile devices, expectedly about 50 billion devices, but this number will be completely dwarfed by the exponential growth in the volume of data generated by powerful applications and feature-rich multimedia applications, and these will create hype for mobile data traffic and compute requirements [11]. The advent of so much anticipated 5G technologies, newly emerging mobile applications such as augmented reality (AR), virtual reality (VR)[32], face detection and identification surveillance, connected autonomous vehicles(CAV), intelligent transportation systems (ITS) and highway traffic management systems, ultra high definition multi-feed live streaming, etc. are anticipated to be among the most demanding applications over cellular wireless networks. In particular, the newly emerging mobile Augmented Reality and Virtual Reality (AR/VR) applications are anticipated to be among the most demanding applications over cellular wireless networks [12].

To resolve challenges posed by these constraints, the computational requirements of mobile applications were offloaded [22] to be processed on tethered external infrastructures with adequate resources. These external infrastructures are usually commercial off-the-shelf or customized standardized IT infrastructures configured to process and return results for applications. Different interventions have been proposed, including cyber foraging, cloudlet, mobile cloud computing (MCC) and multi-access edge computing (MEC).

A cloudlet is a trusted, resource-rich computer or cluster of computers that is well-connected to the Internet and is available for use by nearby mobile devices [3]**.** Cyber foraging dynamically augments the computing resources of mobile devices by opportunistically exploiting computing of tethered infrastructure in the surrounding environment [4], Cyber foraging provided the ability of infrastructure to seamlessly migrate computation from one node to another [5]**.** Cloud computing (CC) is the abstraction of computing resources e.g. processor, RAM, storage and network services from separate hardware units while presenting as a pool of reusable on-demand shared computing infrastructure that can be rapidly provisioned and released programmatically or manually with minimal management effort while creating cost benefits and flexibility. MCC is the integration of CC to serve cloud-based web apps over the Internet for smartphones, tablets, and other portable devices. Cloud computing in mobile cellular networks, like every other technology, has come with its fair share of challenges and solutions as cellular mobile communication technologies mature from 1G, 2G, 3G to 4G and looking forward to 5G. Ordinarily, cloud computing should provide enough resources for offloading [22] of computational demands. Despite all the potentials of cloud computing, it has failed in fulfilling latency requirements due to long response times, due, in turn, to the centralized cloud architecture model resulting into high signal propagation delay, affecting the end-user quality of experience (QoE) [1]. Other concerns presented by the use of cloud computing included security and privacy, addressing, interoperability, latency and bandwidth [6].

2 LITERATURE REVIEW

Prominent among the research efforts is the offloading of computation tasks based on the .NET framework to overcome the energy limitations of handhelds by leveraging nearby computing infrastructure, Mobile Assistance Using Infrastructure (MAUI) **[13]**. MAUI proposed a system that enabled energy-aware offload of mobile code to the connected infrastructure but could not support for multi-threaded applications but only applicable to Microsoft .NET Common Language Runtime (CLR) based applications. M. Satyanarayanan et al, 2009, proposed hybrid solution making mobile devices function as thin clients, all significant computation performed by VM in a nearby “cloudlet”, mobile devices gracefully degrade to a fallback mode whereby significant computation occurring at a distant cloud, or, in the worst case, solely its own resources **[3]**. Xinwen Zhang et al (2010) proposed a cloud computing model of a distributed framework that elastically extends application between mobile UE and the cloud [14]. In [15] CloneCloud proposed the seamless transformation of mobile device computation into a distributed execution on the mobile device and cloud virtual machine (VM). Kosta S. et al, 2012, proposed ThinkAir providing an efficient way to perform on-demand resource allocation and parallelism by dynamically creating, resuming, and destroying VMs in the cloud when needed supporting on-demand resource allocation critical to the management of asymmetric mobile users computational requirements[16]. Hyrax was proposed in [36], overlaying MapReduce[71] on a cluster of mobile phones to provide infrastructure for mobile computing. Exploring the now discontinued, Android Dalvik Virtual Machine, a distributed runtime environment aimed at offloading workload from smartphones, Code Offload by Migrating Execution Transparently (COMET) [37] was proposed. Likewise, Cloudlet Aided Cooperative Terminals Service Environment for Mobile Proximity Content Delivery (CACTSE) was proposed in [70] by leveraging cooperating terminals to provide mobile internet content delivery service at the edge of the network but this relied on resource-constrained mobile devices thereby challenging its scalability. A secure service-oriented mobile ad hoc networks (MANETs) communication framework named MobiCloud was proposed in [72] providing a platform for the cloned image of UE as a virtualized component.

To the best of my knowledge, every suggested solution has been geared toward edge computing. Edge computing is the technology that brings together IT and computing into radio access network (RAN), providing rapid computation while saving costs in terms of mobile device power consumption and a lot of data traffic between network edges and the core network. This paper explores the drawbacks of previous research works as well as limitations posed by pre 5G wireless technologies and seeks to demonstrate the importance of multi-access edge computing in meeting 5G enhance mobile broadband(eMBB) and ultra-reliable low latency communications (URLLC) specification of International Telecommunication Union (ITU) [7][8],[9].

"Edge computing is a distributed, open IT architecture that features decentralised processing power, enabling mobile computing and Internet of Things (IoT) technologies. In edge computing, data is processed by the device itself or by a local computer or server, rather than being transmitted to a data centre. " - Hewlett Packard [28]. Multi-access edge computing, formerly mobile edge computing, is defined by European Telecommunications Standard Institute (ETSI) as a platform that provides IT and cloud computing capabilities within the radio access network (RAN) in close proximity to mobile cellular and non-cellular subscribers - It is network functionality that offers connected compute and storage resources at the fringe of network providing dramatic improvement of mobile network UE experience through near wireline latency**[21]**

3 METHODOLOGY

We designed prototypes for MEC deployment scenarios for 5G network and evaluated the 5G network 3GPP and non-3GPP components specifications for us to be able to compare MEC application end to end transport latency in 5G deployment with 4G as well as deployments in previous mobile wireless technologies. This took into considerations; CUPS, lower layer splits and higher layer splits. The end-to-end transport latency has a significant effect on determining the value of the user plane (UP) latency which in combination with control plane latency determines the effective end-to-end latency.

The estimated UP latency values were compared with benchmark values of known low latency use case requirements [34]:

- Virtual Reality & Augmented Reality: **7-12ms**.
- Tactile Internet (e.g. Remote Surgery, Remote Diagnosis, Remote Sales): **< 10ms**.
- Vehicle-to-Vehicle (Co-operative Driving, Platooning, Collision Avoidance): **< 10ms**.
- Manufacturing & Robotic Control/Safety Systems: **1-10ms**.

3.1 TRANSPORT NETWORK

This paper focuses on 3GPP 5G service-based architecture (SBA) as presented in Figure 8.1 instead of the standard representation in reference point architecture as we bring MEC into the RAN, specifically at the packet layer convergence protocol (PDCP) layer. In SBA, 5G network functions interact directly if required [17] by employing RESTful API principle over hypertext transfer protocol version 2 (HTTP/2) [25] using JavaScript Object Notation (JSON) as a data format and OpenAPI as the interface definition language [26]. 3GPP 5G SBA core network functions (NF) interactions occur over a common computer platform (CCP) [34]. CCP, mostly represented as a data bus, can be fully distributed permitting localization of virtualized network functions (VNFs) in different parts of the network to manage different capabilities.

5G software entities of concern to this research work are the network exposure function (NEF) and network repository function (NRF). NEF allows access to shared data layer for MEC. It provides support for event exposure, packet flow description (PFD) s management, provisioning information for an external party which can be used for the UE in 5GS, device triggering, and negotiation about the transfer policies for the future background data transfer. Also, provide the ability to influence traffic routing [17]. The network repository function (NRF) offers discovery functions allowing for software entities in the control plane, for example, can identify others and connect directly whenever there is a need to interact.

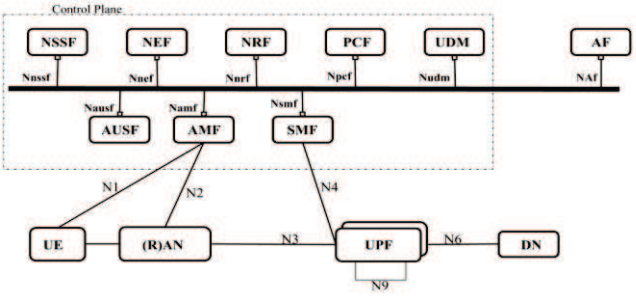


Figure 2.1: 3GPP 5G System Service-Based Architecture [17]

It provides support for register, deregister and update services to NF, NF services and consumers with notifications of newly registered NF along with its NF services. NRF provides capability which allows a particular NF service consumer to discover a set of NF instances with specific service or a target NF type. Also enables one NF service to discover a specific NF service [17] while the services available will be indexed via network exposure function (NEF) in the control plane (CP)

3.2 NG-RAN Decomposition

Considering the functional decomposition of NG-RAN achieved with Next-generation Node B Centralised Unit (gNB-CU) - gNB-Distributed Unit (gNB-DU) split connected together over F1 logical interface [19],[20]. F1 interface provides means for interconnecting a gNB-CU and a gNB-DU of a gNB within an NG-RAN, or for interconnecting a gNB-CU and a gNB-DU of an en-gNB within an E-UTRAN [35]. While F2(eCPRI/CPRI/NGFI) is non-3GPP specified interface[24][31][33] connects gNB-DU with active antenna unit(AAU), radio unit(RU) or remote radio unit(RRU) when deployed over distance, NG logical interface connect a set of gNBs interconnected via **Xn** logical interface within an NG-RAN to the 5G core network (5GC)[20]. **F1**, **F2** and **NG** interfaces constituting midhaul, fronthaul and backhaul networks, respectively [20].

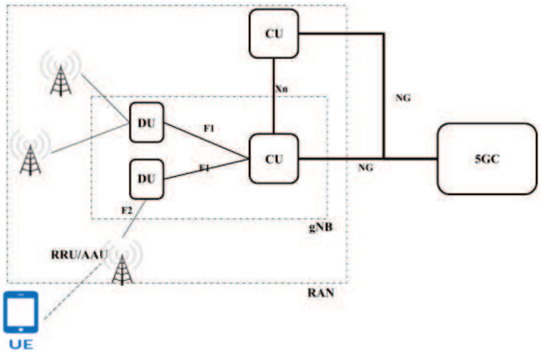


Figure 2.2: Functional Decomposition of NG RAN.

Considering eCPRI, this functional decomposition of RAN will permit the location of MEC server close to the CU sending and receiving UP packet data traffic over F1 and eCPRI providing high bandwidth capacity at very low latency capable of supporting eMBB and URLLC use cases [7], [8]. Decomposition of RAN permits distance separations between CU, DU and RRU/AAU [20] while allowing for C (cloud, cooperative and centralized) - RAN configurations [27], [28], [29] [30].

The functional decomposition of RAN may not be as simple as depicted in Figure 2.2 but it depends on the level of applicable split options as available in Figure 8.6 as this will determine the level of coordination capabilities that can be delivered by a C-RAN.

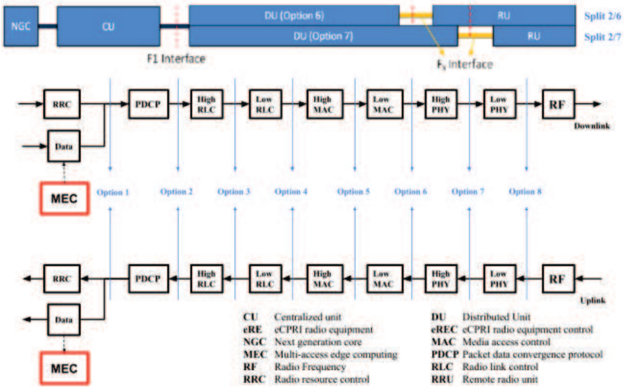
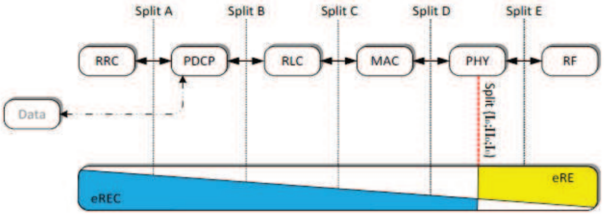


Figure 2.3(a): RAN protocol split [21], [23] with addition of MEC



2.3(b): eCPRI Functional decomposition on RAN layer level [24]

3.3 5G MEC Deployment Prototypes

Higher layer functional split (HLFS) option 2 for the midhaul [20], and lower layer functional split (LLFS) option 7 for fronthaul [24] were considered permitting four RAN deployment scenarios [20] and as a result four MEC deployment scenarios:

1. Independent RRU, DU and CU/MEC locations;
2. DU and CU/MEC co-located with distance separated RRU;
3. RRU and DU co-located with distance separated CU/MEC;
4. RRU, DU and CU/MEC integration within a single co-location.

3.4 Latency

Latency varies from one MEC deployment scenario to another and might be difficult quantifying all the parameters due to differences in performance of equipment along the way, e.g. from DU to CU [31], and all the way to MEC, etc. However, we assumed 1-way latency range between 5 ~ 8ms between CU and DU, and in essence, 8ms network latency between CU and DU eases the co-location of the CU with the Serving Gateway and other application platforms [31], but in this case, with MEC

The total one-way user plane latency becomes:

$$T = T_{NR} + T_{DU} + T_{CU} + T_{Transport} \qquad (1)$$

Where:

- T_{NR} is the one-way packet propagation delay over new radio (NR) i.e delay between UE and DU, including packet processing time within the UE.
- T_{DU} is the one-way packet propagation delay between DU and CU, including processing delay within the DU.
- T_{CU} is the one-way packet propagation delay between CU and 5GC, including processing delay within the CU.
- $T_{Transport}$ is the one-way packet propagation between the 5GC and data network (DN). This might include propagation delay to the Internet if service requested by the UE is not within an operator network and has to be sourced from the Internet.

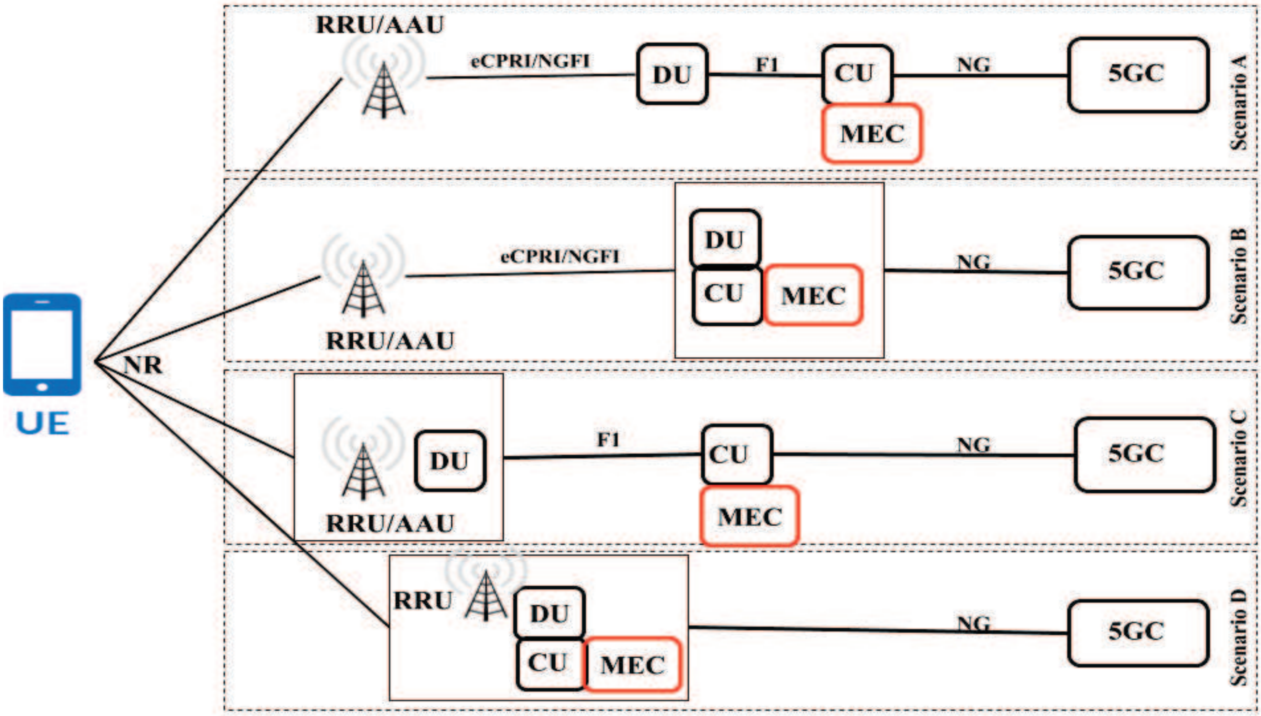


Figure 2.4:5G MEC deployment prototypes

Deployment of MEC in all the four scenarios in the proposed prototypes above provided the options for a direct connection between MEC and the CU. The total one-way UP latency became:

$$T = T_{NR} + T_{DU} + T_{CU} \qquad (2)$$

4 RESULTS AND DISCUSSION

This is a work in progress, our efforts to simulate 5G network transport latency to determine UP latency is being challenged by the fact that 5G next-generation (NG) core and RAN technologies are, to a large extent, still on white papers but enough specifications have been defined and written about it. Therefore, 3GPP and non-3GPP specifications were the major sources of our data for the evaluation of UP latency for our proposed MEC deployment.

TABLE I: 5G INTERFACES SPECIFICATIONS [20]

Network	**Reach distance**	**Latency (1-way)**	**Capacity requirements**
New radio(NR)		4 ms eMBB 2 ms URLLC	
Fronthaul(eCPRI)	1 ~ 20 km	< 100 μsec	10Gb/s-825Gb/s
Midhaul(F1)	20 ~ 40 km	1.5 ~10 msec	25Gb/s-800Gb/s
Backhaul(NG)	5-80km (Aggregation) 20~300km (Core)		CU: 10Gb/s-25Gb/s CN: 100+Gb/s

Evaluating (2) for eMBB for the proposed four deployment scenarios by applying 5G specification values in Table I:

$$T = T_{NR} + T_{DU} + T_{CU} \qquad (2)$$

4.1 Results

Scenario A

$T = 4000 + 100 + 1500\ \mu\text{sec}$
$= 5600\ \mu\text{sec}$
$= 5.6\ \text{ms}$

Or

$T = 4000 + 100 + 10000\ \mu\text{sec}$
$= 14100\ \mu\text{sec}$
$= 14.1\ \text{ms}$

Scenario B

$T = 4000 + 100\ \mu\text{sec}$
$= 4100\ \mu\text{sec}$
$= 4.1\ \text{ms}$

Scenario C

$T = 4000 + 1500\ \mu\text{sec}$
$= 5500\ \mu\text{sec}$
$= 5.5\ \text{ms}$

Or

$T = 4000 + 10000\ \mu\text{sec}$
$= 14000\ \mu\text{sec}$
$= 14\ \text{ms}$

Scenario D

$T = 4000\ \mu\text{sec}$
$= 4000\ \mu\text{sec}$
$= 4\ \text{ms}$

4.2 Discussion of results

Scenario A features dual functional splits in the RAN. The RRU/AAU at the cell site, DU at the aggregation site while CU and MEC deployed at the edge site. Every interface interconnecting all 5G functional spilt contributed to the UP latency, optimally this prototype deployment produced an estimated round trip time (RTT) value of **11.2ms**. Considering scenario B, this is a centralized RAN MEC deployment which employed only the lower layer functional split having DU, CU and MEC co-located at the edge site while RRU/AAU connected via eCPRI interface is deployed at a remote cell site. Optimally, the RTT is **8.2ms**. Scenario C features only 3GPP upper layer single functional split between DU deployed with RRU at the cell site and CU with MEC at the edge site with optimal RTT **11ms**. Scenario D is monolithic RAN. This setup is most applicable to 5G MEC deployment for femtocells with RRT of **8ms**. The RTT values from the mentioned prototype MEC deployment are all with the latency requirements for Virtual Reality & Augmented Reality of 7-12ms, Tactile Internet < 10ms, Vehicle-to-Vehicle < 10ms and Manufacturing & Robotic Control/Safety Systems: 1-10ms.

5 CONCLUSION

So far, several research efforts have been carried out to augment for the mobile wireless device computational power and energy carrying capacity deficiencies, but the ultimate solutions lie in the optimization of MEC capacities to cater for asymmetric UE applications by improving the latency figures. Co-locating MEC server close to gNB-CU assures low user plane latency to support emerging 5G applications

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