Home Edge Computing (HEC): Design of a New Edge Computing Technology for Achieving Ultra-Low Latency

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Abstract. Edge computing systems (Cloudlet, Fog Computing, Multi-access Edge Computing) provide numerous benefits to information technology: reduced latency, improved bandwidth, battery lifetime, etc. Despite all the benefits, edge computing systems have several issues that could significantly reduce the performance of certain applications. Indeed, current edge computing technologies do not assure ultra-low latency for real-time applications and they encounter overloading issues for data processing. To solve the aforementioned issues, we propose Home Edge Computing (HEC): a new three-tier edge computing architecture that provides data storage and processing in close proximity to the users. The term "Home" in Home Edge Computing does not restrain our work to the homes of the users, we take into account other places where the users could connect to the Internet such as: companies, shopping malls, hospitals, etc. Our three-tier architecture is composed of a Home Server, an Edge Server and a Central Cloud which we also find in traditional edge computing architectures. The Home Server is located within the vicinities of the users which allow the achievement of ultra-low latency for applications that could be processed by the said server; this also help reduce the amount of data that could be treated in the Edge Server and the Central Cloud. We demonstrate the validity of our architecture by leveraging the EdgeCloudSim simulation platform. The results of the simulation show that our proposal can, in fact, help achieve ultra-low latency and reduce overloading issues.

Keywords: Home Edge Computing (HEC) · Edge computing systems
Ultra-low latency · Hierarchical architecture · Micro-cells · Three layers

1 Introduction

The main objective of current Edge Computing architectures (Cloudlet, Fog Computing, Multi-access Edge Computing) is to set up a distributed platform for integrating cloud technology into telecommunication networks in order to solve the problems

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encountered by cloud computing in relation to the emergence of new types of services. But with the advent of the Internet of Things (IoT) [1], hence the increase of the number connected devices that require more real-time processing, current Edge Computing technologies are failing to achieve their goal due to the degradation of the quality of the signal and data overloading at the edge computing level. For instance, if we consider the latest Edge Computing technology, Multi-access Edge Computing (MEC), the above-mentioned issues result in a poor connectivity between the mobile and the base station. This will make the computing capacity at the MEC level significantly reduced along with the performance of the network resulting on technical issues on the user equipment: an increase in power consumption to access the base station which consequently causes a reduction in the life of the batteries. To remedy these problems, a system for stabilizing wireless communication is essential. In addition, the increase in the workload at the system level of the peripheral computing leads to an increase in the service time in the data centers and also a delay in the transmission of the requests in the network which do not meet the requirements of new types of real-time applications. This delay is due to the overload of the communication network where requests from mobile devices converge towards edge computing.

To solve the aforementioned issues, we propose a new concept called Home Edge Computing (HEC), a three-tier edge computing architecture that provides data storage and processing in close proximity to the users. HEC is an extension of MEC, we add another layer of "local data center", namely the Home Server. The latter is located near the user (house, office, company, etc.) but is managed by the Internet Service Provider (ISP). The idea is to implement a miniature cloud in the access point or connection box that a user receives when he/she subscribes to an ISP. In addition to being transparent to the user, we do not need additional infrastructure for the implementation of HEC because this new architecture is based on already existing tools and infrastructures. As a result, requests that are constrained by latency can be processed locally and no longer need to be transferred to the MEC level or the central cloud. We believe that our proposal will contribute to the rapid emergence of 5G by allowing the technologies that are depicted in Fig. 1 to be processed with their required latency and bandwidth. HEC can also help improve the signal strength with the installation of micro-cells at the Home Server level. In order to validate our proposal, we run a simulation by using EdgeCloudSim which is simulation platform for edge computing technologies [16]. The results show that, indeed, Home Edge Computing is better for applications that are latency-sensitive.

The remainder of the paper is structured as follows: we survey the different Edge Cloud technologies in Sect. 2. In Sect. 3, we explain in detail our proposal before validating it through simulation in Sect. 4. Section 5 concludes the paper with a summary and probable future works.

2 Overview of Edge Computing Systems

The set of terms Internet of Things (IoT) was first introduced by Kelvin Aston in a presentation he made at Procter & Gamble (P & G) in 1999 [2]. Gubbi et al. discussed the evolution of wireless technology from Bluetooth to IoT via RFID in parallel with

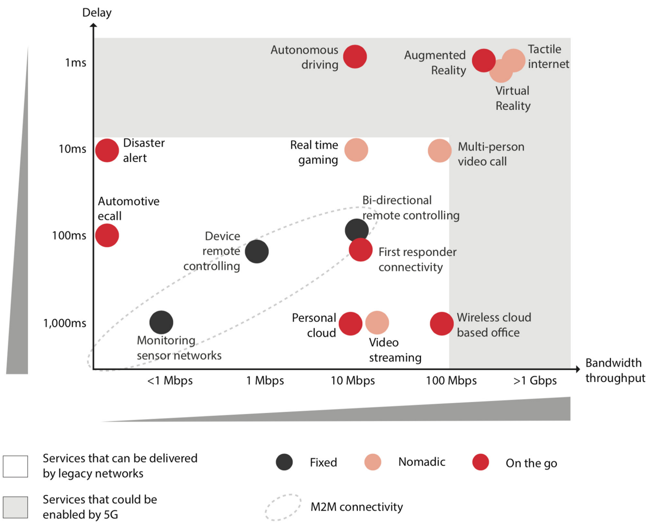

Fig. 1. Bandwidth of latency requirements of potential 5G use cases **Source:** GSMA Intelligence

application domains. They also talked about the achievements and challenges related to IoT in cloud computing technology [2, 3]. In 2019, the majority of data on the Internet will be generated by IoT devices [4] and will be processed at the edge of the network [5]. According to Cisco, by 2020, more than 50 billion objects will be interconnected around the world [6, 21]. As a result, certain types of applications will impose a low latency; others, according to their confidentiality, for example, would need to be processed locally. This is not in sync with the services that cloud computing can offer. Thus, with the many solutions that the edge computing system can offer, players in this area will focus on Edge technologies to address the various problems related to cloud computing technology. In this section, we present a summary of the different architectures of Edge computing systems, their advantages, their limitations and the need for a new Edge computing architecture.

2.1 Concept of Edge Computing Systems

Edge computing systems are introducing new ways to manipulate computing and storage resources. Industry and academia present proposals on the architecture of mobile Edge systems.

Cloudlet. With the advancement of the cloud system and the convergence of new services, mobile users need more resources and accessibility in their environment. As a result, Cloudlet was implemented (Fig. 2(a)). A Cloudlet is a virtualized architecture that spans between mobile devices and a remote cloud, which allows the storage and processing of certain types of data of mobile users without going to the remote cloud. The main goal is to be able to reduce the response time in order to meet the needs of some latency-sensitive applications [13]. Note that the Cloudlet has the advantage of

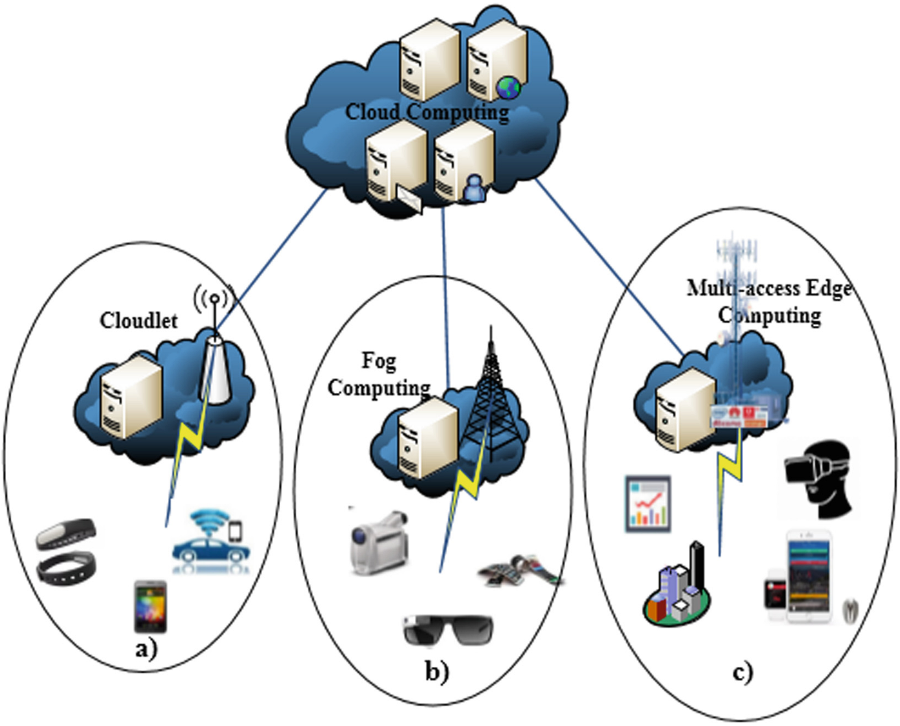

Fig. 2. Edge computing system architectures

being close to the user but does not have the same capabilities as those of the central or remote cloud. Thus its computing capacities are limited for certain services. In addition to its proximity to the users, Cloudlet also has the advantage of being exploited by mobile users who do not even have an internet connection.

Fog Computing. The second architecture of Edge Computing systems is Fog Computing (Fig. 2(b)). The latter extends the services of the central cloud by reducing the amount of data sent to the latter for processing and storage [7]. In addition, Fog Computing system may be integrated into the radio system in the operators' mobile networks [8]. Thus, Fog Computing has the advantages of exploiting storage functions, calculating, controlling, communications between users, depending on the type of requests [9].

Multi-access Edge Computing. The latest concept of Edge Computing systems is Multi-access Edge Computing (MEC). The latter, developed in 2014 by the European Telecommunications Standards Institute (ETSI), enables the provision of resources through cloud servers near users via the Radio Access Network (RAN) tickets [5, 10]. Thus, according to ETSI, MEC allows a considerable reduction of the latency and permits the operators to better locate the positions of the users. Moreover, unlike the aforementioned Edge Computing systems, MEC makes it possible to measure and improve network performance by setting up services (Software Defined Network

(SDN), Network Function Virtualization (NFV), etc.) [12]. Hence, the MEC system has several advantages: availability of the service, reliability, workload. It should be noted that the ultimate goal of MEC is to increase the bandwidth, dramatically reduce the latency and jitter, and provide quality of service (QoS) for mobile applications. MEC is fully integrated into the mobile networks and its servers are located at the base stations. The MEC ecosystem and the integration of MEC servers into the mobile network edge are illustrated in Fig. 2(c), where mobile devices are connected into the base station. The major disadvantage at the MEC level is when its platform is overloaded, there is a poor quality of service performance and an increased latency for real-time services.

2.2 Advantages and Limitations of Edge Computing Systems

Advantages of Edge Computing Systems. Edge computing systems have many advantages over traditional clouds, the most important of which are shown in Table 1.

Limitations of Edge Computing Systems. Despite all the benefits of Edge Computing, there are many drawbacks.

Overload. MEC system failure can occur when a MEC server is overloaded and/or broken. MEC can be overloaded by serving too many tasks, managing too many resources, performing data filtration, or from handling too many service requests [14], as a result, some types of traffic, even those that require minimal physical resources for processing and some that are latency-sensitive, will not be processed in time, which degrades the performance and eventually the quality of service (QoS).

Table 1. Comparison between cloud computing and edge computing systems

Items	CC	MCC	Edge systems
Latency/Jitter	High	High	Low (depends on the rate of use)
Distance to the user	High	High	Low
Deployment	Core network	Core network	Network edge
User devices	Any users	Any users	Mobile users
Storage capacity	Ample	Ample	Limited
Geo-distribution	Internet	Internet	RAN
Architecture	1-tier	1-tier	2-tier
Network access	Any	Any	Mobile
Scalability	Average	High	High
Computational power	Ample	Ample	Limited
Bandwidth saving	No	No	Yes
Battery life time	Limited	Limited	Ample
Utilization of context information	No	No	Yes

Poor signal quality in the macro cells in Edge Computing Systems. For the establishment of the MEC servers, it will first be necessary to make a survey taking into account two main factors the location of sites and areas of high density [14]. In these areas where the traffic is denser, we will have more MEC servers in the same cell (macro cell). On the other hand, this pertinent idea will not solve the problem because certain kind of services will not be satisfied with the performance because of the bad quality of the signal or even the congestion of the base station which is attached to the MEC in question if we take for example Smart Home (in which we have intelligent equipment) [11], it is desirable to bring the computer centers to end users in order to set up microcells in their geographical locations.

2.3 The Need to Propose a New Edge Computing Architecture

Through the limitations of the aforementioned traditional Edge Computing systems and according to the needs of new services such as augmented reality, virtual reality and tactile Internet, the architecture of edge computing system has a critical need to be improved for it to be in phase with these advances. In other words, the requirements of these new applications in terms of proximity, latency and bandwidth cannot be achieved by the current Edge Computing systems. As shown in Fig. 1, the aforementioned services require latencies that are between 1 ms and 10 ms and bandwidths that are between 100 Mbps and 1 Gbps. Thus, with the architecture of the current systems of edge computing, this is practically impossible. First, the distance between the user equipment and the base station means that the RTT typically exceeds this latency. In addition, the signal deteriorates as the user equipment moves away from the antenna. This will have consequences on the transmission power of the requests and possibly the bandwidth.

To be able to solve all these problems of Edge computing systems, we propose a new architecture with three levels, called Home Edge Computing (HEC). This new architecture will allow these new services to have a local data center, called Home Server, in which some latency-sensitive requests can be processed. In addition, microcells will be integrated into these data centers in order to significantly improve the signal strength and possibly the bandwidth.

3 Home Edge Computing (HEC)

The objective of MEC was to provide Mobile Cloud Computing (MCC) with solutions to the problems that it could not solve such as mobility, response time (for certain types of traffic), proximity, resource optimization, etc. Despite the implementation of MEC in mobile networks, latency is still a major problem, especially if the peripheral system is at its maximum use. In other words, during peak hours (when the traffic has reached its maximum utilization level), there is a congestion at the servers that are found at the edge of the network (it is logical because the resources on the edges of the network are relatively limited). This causes a degradation of the network performance and possibly an increase in response time (latency), even for some requests that require minimum resource for their execution. This situation does not fit the real-time applications:

augmented reality, virtual reality, tactile internet. This will pose a real problem in the future because, according to Cisco, the number of connected objects in the global network continues to increase (the number will triple at the end of 2019, from 15 to 50 billion). In addition, with the establishment of micro-cells at the level of homes, the quality of the signal will be relatively efficient vis-à-vis the macro cells at the level of MEC because the signal on the latter may be very low on some mobiles depending on the distance with the antenna. This will provide a stable signal of good quality allowing fast processing of queries and can save energy. Hence the establishment of a micro-cell at the telecommunication network level is in line with the objectives of the 5G technology which aims to optimize the frequency and the bandwidth; possibly to be able to manage the new generation of intelligent equipment by considerably reducing the latency and also to be able to locally manage certain sensitive data which should not be transmitted all the time to the outside. To overcome these shortcomings, we propose a new architecture called Home Edge Computing (HEC). Our architecture will lighten the work of Multi-access Edge Computing based on certain types of requests by treating them locally.

3.1 What Is Home Edge Computing?

Home Edge Computing (HEC) is a new technique for having a storage and data processing device near the users (Home Server); it also allows us to set up a micro-cell at the user to reduce the workload at the base station located in the MEC and improve system performance. The HEC architecture comprises three levels of cloud (local cloud or Home Server, edge cloud, and central cloud). The term "Home" in Home Edge Computing does not restrain our work to the homes of the users, we take into account other places where the users could connect to the Internet such as: companies, shopping malls, hospitals, etc. Thus, HEC is a new architecture of the edge computing system that is more in proximity to the users compared to Cloudlet, Fog Computing and Multi-access Edge Computing. HEC is a concept proposed to solve the latency problem still present in MEC for certain types of applications that have very high needs in term of resources and have to be processed with relatively reduced delays. With this concept, we will no longer need to go to the MEC or the central cloud for some queries that do not require a lot of computing resources for their processing. One could take the example of smart homes and possibly health care. However, thanks to the synchronization with the edge computing and that of the central cloud, in case of unavailability of the resources on the Home Server, the latter will automatically launch a request, in a hierarchical way, to these two systems which potentially possess resources for satisfying the computational needs of the task.

Thus, several reasons pushed us to create this concept, among which:

- The considerable reduction of the latency (ultra-low latency) for the requests coming from the users equipment and to be able to delegate certain tasks of the MEC server towards the Home Server for the reasons mentioned in [15].
- The installation, at the customer vantage point (office, hospital, company, house, etc.), of a new device relating to the Cloud (Home Server) and a micro-cell that

would alleviate the load of the MEC (and also the eNB) and would be able to satisfy the users in terms performance and processing of certain applications according to their needs in terms of bandwidth and/or latency.

3.2 HEC Architecture

The architecture for Home Edge Computing is depicted in Fig. 3. It is composed of three levels: Home Server, Edge Server and Central Cloud. In the environment of the HEC (home, office, hospital, etc.), all equipment will be wired or wirelessly connected to the local cloud. The Home Server serves, at the same time, as a gateway for this equipment outside the local network because it will be installed and managed by the Internet service provider. Thanks to the proximity of the HEC, the latency-sensitive queries will be rapidly processed. Moreover, for its connection to the rest of the network, we will have to use the system FTTx (Fiber To The x{Home, Office, etc.}) because it has an ultra-low latency and its flow can reach up to 1Gbps, which will correspond to our objective as shown in Fig. 1. Thus, for its operation (Fig. 4), if a request leaves the user's equipment, it is loaded in the box provided by the Internet provider. The Home Server inside the box will handle the customer's request. On this Home server, if the request cannot be processed, the system will hierarchically transfer the request to the cloud (Edge Server or Cloud Central). In addition to lightening the load of the MEC, HEC allows having micro-cells which can also help process latency-sensitive applications. With the Home Edge Computing (HEC) architecture, we can see that the only difference with MEC is the Home Server hosted by the customer. The Home Server has to be tiny, non-cumbersome and transparent to the customer. It must be able to fit within the box that the customer received from the internet service provider i.e. it has to be a mini computer e.g. Raspberry Pi.

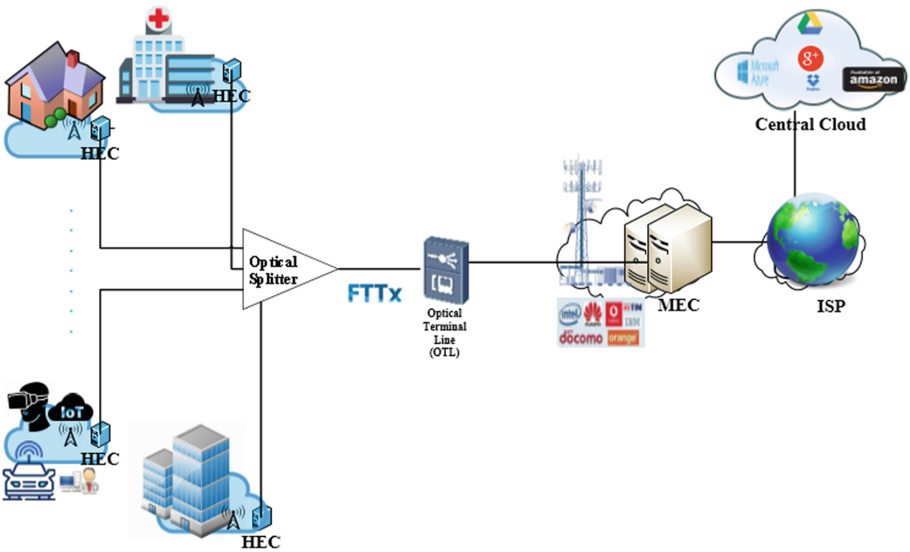

Fig. 3. Home Edge Computing architecture (HEC)

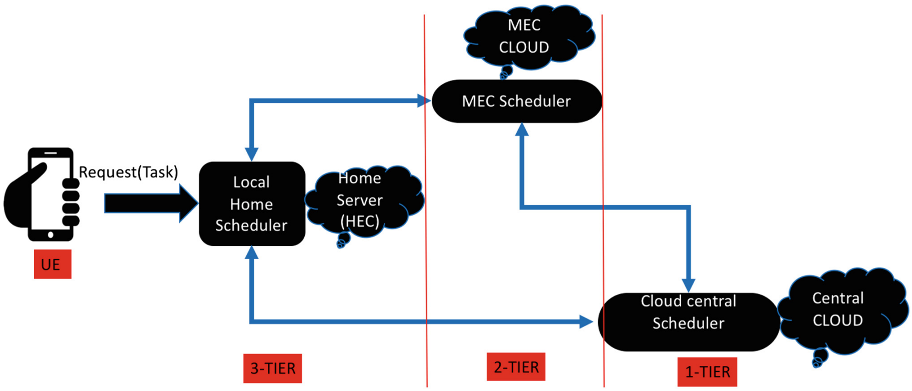

Fig. 4. Processing model in Home Edge Computing (HEC)

Benefits. Home edge computing has many advantages:

- Ultra-low latency for applications that could be treated by the Home Server.
- Reduction of the workload on the Edge Server (MEC).
- Considerable improvement of the signal strength thanks to the installation of micro-cells at each HEC.
- A hierarchical resource allocation system.
- Hierarchical resource allocation: We have what is called the hierarchical aspect at the level of the cloud in general. Thus, any flow from the user (UE, tablet, IoT, laptop, …) will pass the first level i.e. the Home Edge Computing (HEC) will be loaded. If HEC cannot process the request, it will be transferred to the MEC or the Central Cloud. This allows the MEC to have fewer spots (scheduling) and tasks to process.

3.3 Use Cases

In this subsection, we will focus on some of the most specific use cases that experience the need for ultra-low latency for proper operation. As shown in Fig. 1, with respect to our goal and that of 5G technology, we will take the examples of augmented reality, tactile internet and virtual reality. From this fact, we will prove that our proposed solution is more adequate than MEC in terms of latency-sensitive applications.

Augmented Reality. According to Azuma et al. [19], augmented reality can be defined as a system that combines real and computer-generated information in a real-world environment, interactively, in real-time, and aligns virtual objects with physical objects. It is a world in which everything is virtual. In other words, it is closely related to virtual reality. From this fact, the interconnection between the human being and this world can be done by a simple vision, by touch but also by movements. This new concept of HEC will allow the interaction with the real world and that of technology. Moreover, if we talk about this interaction, we think about real-time because nothing can interact with reality without being in phase with it. We can take the example of Daydream View and Google glasses.

Tactile Internet. The term tactile internet was first invented by Prof. Gerhard Fettweis [18]. The tactile internet environment can be considered as a chain environment that includes the touch of the human being (operator) until the task is executed by the robot (remote operator). The architecture of the tactile internet can be divided into three parts, namely the master domain (or of the human), the network domain and the slave domain. Note that communication between the master and the slave is possible thanks to what is called haptic communication, which establishes a link between the human being and the robot through the network domain.

Virtual Reality. The virtual reality system can be defined as the ocular interaction, in real time, between the eye of the human being in general and a 3D representation of the virtual world by the computer according to certain types of software. But this interaction can also involve touch, smell, sound, etc. Thus, to be able to reach this quasi-real concept (approximately <= 1 ms for latency), it is necessary to set up a data center very close to the device in question in order to overcome the constraints with regard to network latency and the local processing of these requests from the virtual reality system. Thus, HEC will be better than MEC to meet this challenge as needed in terms of time.

4 Experimental Validation

The main objective of this section is to show the effectiveness of the new HEC compared to MEC. For this, we use the EdgeCloudSim simulator [16] as a simulation environment. This allows us to measure the network latency, the service and the processing time between MEC and HEC.

4.1 EdgeCloudSim

Developed by Sonmez et al. [16], EdgeCloudSim leverages CloudSim [17] to meet the needs of Edge Cloud system specialists. With the CloudSim platform, the specific needs of researchers in the field of mobile edge cloud could not be met. One could even say that EdgeCloudSim is an extension of CloudSim. Because, in addition to having the features of CloudSim, EdgeCloudSim allows offloading tasks to the edge computing. Thus, depending on the needs, different modules are implemented in this environment, namely a mobility module, a load generator module, an edge orchestrator module, a network module and a main management module of the simulation [16]. Note that all these features are based on the CloudSim platform which provides the modules for data centers. In this simulation we focus on the network and data center modules as they relate best to HEC. We need two types of data centers, MEC and HEC. We do not need the Central Cloud in our simulation, because it showed its limits with respect to MEC. So, in a recursive way, we show that HEC has better latency than MEC.

4.2 Simulation Parameters

In our simulation environment, we have to configure 3 types of home devices: the data center, the host and the virtual machine. The configuration of these devices depends on the type of home server we choose. Moreover, in the simulation platform, we have to define different parameters (Tables 2 and 3) and different use cases: virtual reality, augmented reality, tactile internet, gaming. As we show in Fig. 5, in our environment, we consider the two lowest levels: TWO_TIER and THREE_TIER. For the simulation, each scenario (TWO_TIER and THREE_TIER) must be repeated ten times. As a result, 100 new mobile devices are added after each repetition in order to see the evolution of the latency with respect to the WLAN and WAN network respectively at the HEC and MEC positions.

In addition, the majority of configuration parameters (Table 2) are collected from the Cisco Global Mobile Data Traffic Forecast Update [20]. These settings are WAN propagation delay, LAN Internet delay, and bandwidth (for LAN and WAN). The remaining values can be taken at these intervals according to the number of devices and iteration compared to the simulation. Finally, for the orchestration policy, we chose NEXT_FIT because we did not take into account the QoS aspect for this simulation.

Table 2. Default configuration properties

Parameters	Values
Min_num_Dev	[100–1000]
Max_num_Dev	[1000–10000]
Mob_num_Count	[100–1000]
WAN_Prop_Delay (sec)	0.005
LAN_Inter_Delay (sec)	0.1
WAN_Bandwidth (KB)	680
WLAN_Bandwidth (KB)	[1000–10000]
MIPS_For_Cloud	[1000–20000]
Orchestrator_Policies	NEXT_FIT
Simulation_Scenarios	THREE_TIER
	TWO_TIER

Finally, in Table 3, we took the configurations of the Raspberry Pi which will represent our HEC Server. This HEC will allow the hosting of Virtual Machines (VMs) according to requests from User Equipment (UE).

Legend. Min_num_Dev: minimum number of devices, Max_num_Dev: maximum number of devices, Mob_num_Count: mobile devices number count, WAN_-Prop_Delay: WAN propagation delay, LAN_Inter_Delay: LAN internal delay, MIPS_For_Cloud: million instruction per second for cloud.

Table 3. Home devices configuration

	Parameters	Characteristics	Values
Datacenter	Arch.	x86	N/A
	OS	LINUX	
	VM	XEN	
Host	Core	N/A	4
	MIPS		4000
	RAM		2000
	Storage		128000
Virtual machine	VMM	N/A	XEN
	Core		1
	MIPS		1000
	RAM		500
	Storage		10000

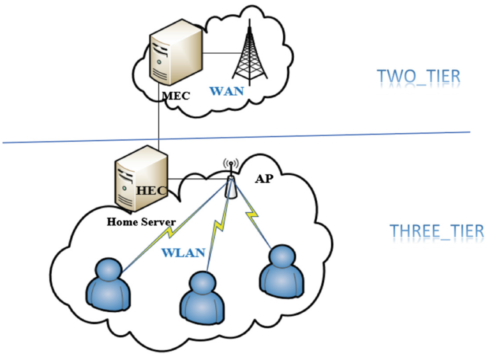

Fig. 5. Simulation architecture in EdgeCLoudSim platform

4.3 Results and Discussion

After the simulation, we could clearly see that it was possible to significantly reduce the latency in the network based on the distance between the two levels (TWO_TIER and THREE_TIER) but also according to the number of mobile devices. Thanks to our method and the help of our simulation platform, we were able to considerably reduce the transmission time of requests using HEC, i.e. the Home Server. Thus, the average delay, under the same conditions, went from 94.82% on the MEC to 5.17% at the HEC level (Fig. 6).

Moreover, as the response time does not depend solely on the network delay, we have also taken into account the service time and the processing time. According to Fig. 6, it was possible to significantly reduce the latency between the MEC and the HEC based on the requests launched by the mobile equipment.

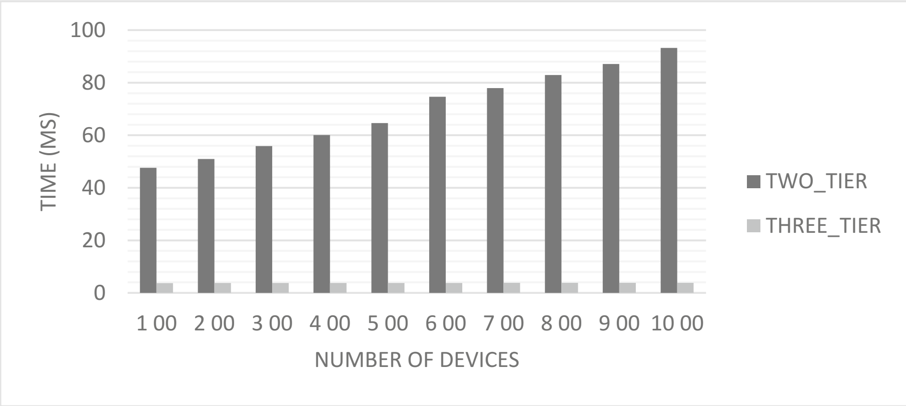

Fig. 6. Network delay

In Fig. 7, we have a visualization of the processing time and the service time of the two data centers: the home server and the edge server. In this figure, we add another y-axis in order to be able to integrate the network delay. Thus, after analysis of the information, we found that, on average, the service and the processing time of the HEC are higher than those of the MEC unlike the situation in Fig. 6. Unsurprisingly, this can easily be explained by the fact that the resources at the MEC level are more important than those of the Home Server according to the MIPS, the number of cores, the RAM, etc.

Our future goal is to find methods or techniques that will allow us to significantly reduce processing and service time.

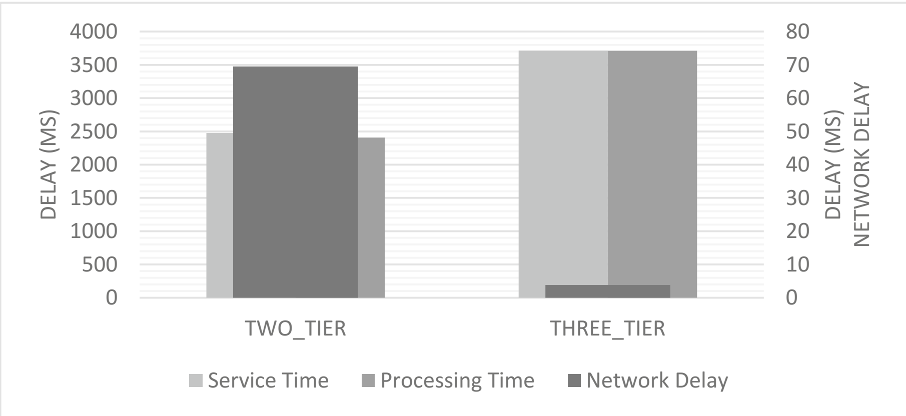

Fig. 7. Latency between HEC and MEC

To remedy these issues, we plan to work on:

- The establishment of a home server cluster that will allow us to distribute the load effectively.
- The implementation of a hierarchical resource allocation system.
- A quality of service policy for real-time services in Home Edge Computing.

5 Conclusion and Future Work

Cloud Computing has been a success in the Information Technology world. But with the advancement of new technologies and the need for mobility, cloud computing has grown rapidly to give birth to Mobile Cloud Computing (MCC). The latter encountered many issues due to constraints imposed by new services and applications. The issues lead to the implementation of the Edge Computing systems (Cloudlet, Fog Computing, Multi-access Edge Computing). With the advent of the IoT, real-time applications, augmented reality services, tactile internet, etc., Edge Computing technologies or the most recent one Multi-access Edge Computing (MEC) faces many difficulties namely the overload of its data centers especially in the peak hours which causes an increase in latency, a degradation of the performance of the applications related to the bad quality of the signal, etc. Hence, to remedy these problems, we proposed a new three-level architecture, called Home Edge Computing (HEC), whose main objective is to significantly reduce latency and to be able to improve the power of the signal by placing micro-cells at the level of each home server. Through simulation, we demonstrated the value of our proposal by reducing the transmission delay between MEC and HEC. For our future work we will focus on the implementation of techniques that will help solve the problems related to the limitation of resources on HEC and we will also focus on resource allocation algorithms in the said edge architecture.

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