Energy Efficiency of Fog Computing and Networking Services in 5G Networks

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***Abstract*— Today many users with their smart mobile devices enjoy the benefits of broadband Internet services. This is primarily enabled by pushing computing, control, data storage and processing into the cloud. However, the cloud encounters growing limitations, such as reduced latency, high mobility, high scalability and real-time execution in order to meet the computing and intelligent networking demands for the next 5G mobile and wireless network. A new paradigm called Fog Computing and Networking, or briefly Fog has emerged to resolve these limits. Fog distributes computing, data processing, and networking services closer to the end users. It is an architecture where distributed edge and user devices collaborate with each other and with the clouds to carry out computing, control, networking, and data management tasks. Fog applied in 5G network can significantly improve network performance in terms of spectral and energy efficiency, enable direct device-to-device wireless communications, and support the growing trend of network function virtualization and separation of network control intelligence from radio network hardware. This paper evaluates the quality of cloud and fog computing and networking orchestrated services in 5G mobile and wireless network in terms of energy efficiency.**

Keywords—5G; Cloud Computing; Fog Computing; Fog Networking; FogRAN; Mobile Cloud Computing

I. INTRODUCTION

The rapid deployment of broadband mobile and wireless networks and the increasing popularity of smart mobile devices, resulted more and more users to enjoy the benefits of broadband Internet services [1]. This is primarily enabled with the high-performance computing power with the support of centralized mobile cloud computing platform [2], [3].

However, the cloud alone encounters many limits in order to meet the computing and intelligent networking demands for the next 5G mobile network [4], [5]. This includes reduced latency, high mobility, high scalability and real-time execution. Compared to existing 4G network, 5G network, which is expected to be deployed around 2020, should achieve system capacity growth by a factor of at least 1000 in terms of network traffic and connected devices, as well as an energy efficiency growth by a factor of at least 10 [6], [7]. In addition, 5G should provide high-speed video flows from 5G server to the 5G subscribers and massive Machine-to-Machine (M2M) communications [8].

Fortunately, Fog Computing and Networking, or simply Fog with its service orchestration mechanisms offers virtually unlimited dynamic resources for computation, storage and service provision, that can effectively cope with the requirements of the forthcoming services in 5G network. Fog Computing and Networking extends cloud computing to the edge of the network, and provides data, computing, storage, and application services to end-users that can be hosted at the network edge or even end devices such as set-top-boxes or access points [9]. The main features of Fog are its proximity to end-users, its dense geographical distribution, and its support for mobility [10].

Cloud and fog are inter-dependent because the coordination among devices in a Fog may rely on the Cloud [11]. They are also mutually beneficial. The fog would facilitate the creation of a hierarchical infrastructure, where the analysis of local information is performed locally with the fog computing and networking devices, and the coordination and global analytics are performed at the cloud computing centers [12]. The cloud services are usually deployed mostly at the edge of the network, but they can also be deployed at the IP/multiprotocol label switching (MPLS) backbones. The fog network is heterogeneous infrastructure that consists of high-speed links and wireless access technologies [13].

Fog applied in 5G network can significantly improve network performance in terms of spectral and energy efficiency, enable direct device-to-device wireless communications, and support the growing trend of network function virtualization and separation of network control intelligence from radio network hardware. 5G will use the benefits of the centralized cloud, cloud RANs and fog RANs and the distributed peer-to-peer mobile cloud that will create opportunities for companies to deploy many new real-time services that cannot be delivered over the existing mobile and wireless networks [14].

This paper evaluates the energy efficiency of Fog Computing and Networking services in 5G mobile and wireless network. It is organized as follows. Section II provides an overview of cloud and fog computing in 5G network architecture. Section III explains the model that is used for the evaluation of energy efficiency. Section IV evaluates the energy efficiency of fog computing and networking services in 5G network. Finally, Section V concludes the paper and provides future work directions.

II. CLOUD AND THE FOG COMPUTING IN 5G NETWORK

5G network would act as a nervous system of the digital society, economy, and everyday people’s life, where the cloud in 5G networks would be diffused among the client devices often with mobility too, i.e. the cloud would become a fog.

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More and more virtual network functionality will be executed in the fog, which would provide *mobiquitous* service to the users where smart devices, terminals, machines, smart things and robots would become innovative tools that produce and use applications, services and data [14].

The cloud in 5G would appear in different forms: centralized cloud in 5G core, distributed cloud in 5G RAN (Cloud RAN and Fog RAN) and distributed peer-to-peer mobile cloud among the 5G smart end user devices. This is illustrated in Fig. 1.

The centralized cloud in the 5G core contains powerful high performance computing nodes that provide ubiquitous, pervasive, convenient, and on-demand network access to a shared pool of configurable computing resources such as networks, servers, storage, applications, and services that can be rapidly provisioned and released with minimal management effort or service provider interaction. The limited data processing and storage capabilities of the smart mobile devices are solved by moving both the data storage and data processing away from the smart mobile device to the cloud computing nodes. However, this requires high bandwidth and low latency.

One possible solution to this issue is to distribute the cloud in 5G RAN. The distributed cloud in 5G RAN may appear in two forms: Cloud RAN (CRAN) and FogRAN.

CRAN incorporates cloud computing into radio access networks (RANs) [15], [16]. However, the application storing and all radio signal processing functions are centralized at the cloud computing server in 5G core. However, billions of smart user devices need to transmit and exchange their data fast enough with the base band unit BBU pool, which requires high bandwidth and low latency.

To overcome this, heterogeneous cloud radio access networks (H-CRANs) have been proposed in which the user and control planes are decoupled [15], [17]. The centralized control function is shifted from the BBU pool in C-RANs to the high power nodes (HPNs) in H-CRANs. HPNs are also used to provide seamless coverage and execute the functions of control plane. The high speed data packet transmission in the user plane is enabled with the radio heads (RRHs). HPNs are connected to the BBU pool via the backhaul links for interference coordination.

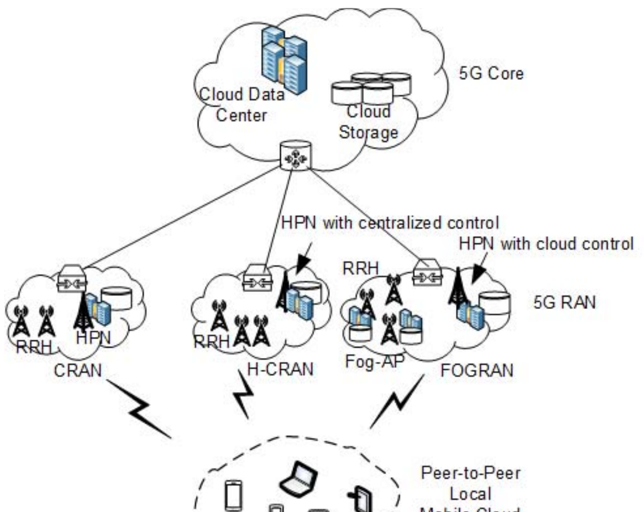

Fig. 1. 5G Network in a Cloud and Fog Computing Environment.

However, H-CRANs still have its own drawbacks. The data traffic data over the fronthaul between RRHs and the centralized BBU pool surges a lot of redundant information, which worsens the fronthaul constraints. In addition, H-CRANs do not take fully utilize the processing and storage capabilities in edge devices, such as RRHs and smart user devices, which is a promising approach to successfully alleviate the burden of the fronthaul and BBU pool. Finally, operators must deploy a huge number of fixed RRHs and HPNs in H-CRANs in order to meet the requirements of peak capacity, which makes a serious waste when the volume of delivery traffic is not sufficiently large.

To solve these issues, a novel radio access network architecture FogRAN is proposed [11], [15]. The main idea in the FogRAN is to take full advantages of local radio signal processing, cooperative radio resource management, and distributed storing capabilities in edge devices, which can decrease the heavy burden on front haul and avoid large-scale radio signal processing in the centralized baseband unit pool. The FogRAN consists of fog computing nodes that are located away from the main cloud data centers in 5G core, at the edge of the network. These fog computing nodes have dense geographical distribution. Therefore, they extend the cloud computing at the edge of the network, and provide very low and predictable latency, and high support of mobility. [9], [10], [18]. If the smart mobile device moves far away from the current servicing fog computing node, then the fog computing node will redirect the services and the application to a fog node that is now closer to the smart mobile device. Fog computing nodes also provide support of applications with awareness of device geographical location and device context. The fog computing nodes directly communicate with the mobile users through edge gateway and single-hop wireless connections using the off-the-shelf wireless interfaces, such as, LTE, WiFi, Bluetooth, etc. They independently provide pre-defined service applications to mobile users without assistances from cloud or Internet. In addition, the fog nodes are connected to the centralized cloud centers in order to leverage the rich functions and application tools of the cloud.

The capabilities of cloud and fog computing and networking can be spread even to the smart user devices, such as such as smartphones, IoT devices, sensors, etc. The devices form a local so called distributed peer-to-peer mobile cloud, where each device shares the resources with other devices in the same local cloud [19]. One of the devices is selected as Local Cloud Resource Scheduler, that performs management on the resource requests and allocates tasks to the devices in the local cloud or Fog Data Center if necessary. The decision about the selection of the Local Cloud Resource Scheduler is done according to the connectivity to the local network, CPU performance battery life time, etc.

The locally distributed peer-to-peer mobile cloud has its own strong capacities such as storage space, computational power, online time, and bandwidth. The peers have strong capacities such as storage space, computational power, online time, and bandwidth. The workload of the application is managed in a distributed fashion without any point of centralization. The lack of centralization provides scalability, while exploitation of user resources reduces the service cost. P2P architectures have ability to adapt to network failures and dynamically changing network topology with a transient population of nodes/devices, while ensuring acceptable connectivity and performance. Thus, P2P systems exhibit a high degree of self-organization and fault tolerance.

III. Energy Efficiency Model

One way to explore the performances of cloud fog computing services is through the energy efficiency, which measures how many joules are used for a single bit. Energy efficiency *EE* is defined as the ratio of the consumed power per user in a cell, *P* and the average user throughput in a cell, *T*:

$$EE = \frac{P}{T}\left[\frac{\text{[Joule/s/cell]}}{\text{[bit/s/cell]}}\right] \tag{1}$$

i.e.

$$EE = \frac{P}{T}\left[\frac{\text{Joule}}{\text{bit}}\right] \tag{2}$$

Throughput is the quantity of data that can pass from source to destination in a specific time. The user throughput is calculated as a ratio of the peak data rate *R* of the particular RAN, and the number of smart user devices *N*:

$$T = \frac{R}{N}\left[\frac{\text{bit}}{\text{s}}\right] \tag{3}$$

The user power consumption *P* can be expressed through the user throughput *T* with the following linear relation [20]:

$$P = \alpha T + \beta \left[\frac{\text{Joule}}{\text{s}}\right] \tag{4}$$

i.e.

$$P = \alpha T + \beta \text{ [W]} \tag{4}$$

where α and β are data transfer power coefficients specific for each RAN, given in Table I [20]. It is assumed that 5G is 100 times more efficient than 4G.

TABLE I. DATA TRANSFER POWER COEFFICIENTS FOR 3G, 4G AND 5G RAN

RAN	*α [mW/Mbps]*	*β [mW]*
3G	122.12	817.88
4G	51.97	1288.04
5G	6.5	11475.97

IV. Analysis of the Results

In order to evaluate the energy efficiency, the following simulation scenario is used. There is a single region in which are located a group of smart user devices, which are simultaneously served by 3G, 4G and 5G RAN network. Each RAN is connected to ten clouds. First five clouds are in the same region with the RANs, and the other 5 clouds are in a different region with the RANs. The smart user devices are assumed to have equal capabilities and to be simultaneously served by the RANs and the clouds.

Each smart user device may simultaneously receive data from the locally distributed peer-to-peer mobile cloud devices, from one or simultaneously several FOGRANs, or from one or several cloud computing centers. For simplicity it is assumed the size of the packets to be constant and each user receives data from one or several FOGRANs through all cloud computing centers.

Due to the distance and the type of RAN different modulation coding schemes are used. Therefore, different data rates are provided to the smart user devices. The modulation coding scheme and the correspondent peak data rates for each RAN are given in Table II [6 – 8].

The energy efficiency results are given in Fig. 2 and 3. Fig. 2 depicts the energy efficiency for different RANs as a function of the number of the users, while Fig. 3 gives the energy efficiency for different RANs as a function of the distance between the smart user device and the serving RANs. It can be noticed that as the number of smart user devices increases, or if the smart user device is more distant from the serving RAN more energy is required. In both cases 5G RAN provides better efficiency in terms of energy than 3G and 4G RANs, especially for large number of smart user devices and greater distance. This is because the peak data rate in 5G is much higher than 3G and 4G RAN. In addition, 5G has much lower latency than 3G and 4G.

TABLE II. MODULATION CODING SCHEME (MCS) AND PEAK DATA RATE (R) FOR 3G, 4G AND 5G

3G RAN		**4G RAN**		**5G RAN**	
MCS	***Peak Data Rate (Mbps)***	***MCS***	***Peak Data Rate (Mbps)***	***MCS***	***Peak Data Rate (Mbps)***
64 QAM / MIMO 4x4	672	64 QAM / MIMO 4x4	3900	256 QAM / MIMO 8x8	50000
64 QAM / MIMO 2x2	84	64 QAM / MIMO 2x2	1000	256 QAM / MIMO 4x4	40000
64 QAM / MIMO 1x4	42	64 QAM / MIMO 1x2	600	128 QAM / MIMO 8x8	30000
16 QAM / MIMO 4x4	21	64 QAM	450	128 QAM / MIMO 4x4	20000
16 QAM / 15 codes	14.4	16 QAM / MIMO 4x4	390	128 QAM	15000
16 QAM / 10 codes	7.2	16 QAM / MIMO 2x2	300	64 QAM / MIMO 8x8	10000
16 QAM 5 codes	3.6	16 QAM/	150	64 QAM / MIMO 4x4	5000
QPSK 5 codes	1.8	QPSK / MIMO 4x4	100	64 QAM /	2500
8PSK	0.72	QPSK / MIMO 2x2	50	16 QAM / MIMO 4x4	1500
4PSK	0.384	QPSK	10	16 QAM	1000

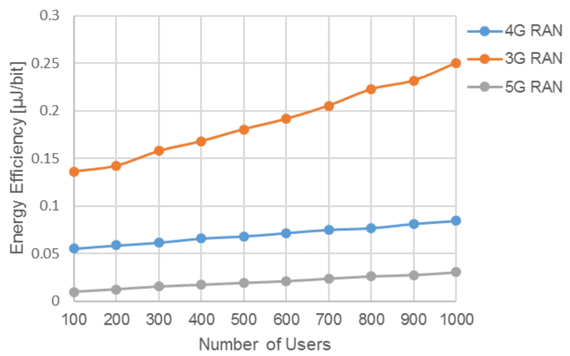

Fig. 2. Energy Efficiency as a Function of the Number of Smart User Devices.

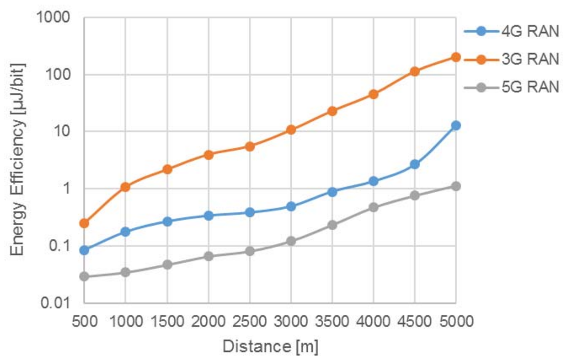

Fig. 3. Energy Efficiency as a Function of the Distance between Each RAN and the Smart User Device.

V. Conclusion

This paper evaluated the quality of Fog and Cloud Computing services in 5G mobile network in terms of energy efficiency. Firstly, it provided an overview of cloud and fog computing in 5G network. Then energy efficiency model was discussed. Finally, the quality of fog and cloud computing services in 5G was evaluated in terms of energy efficiency. The results clearly show that 5G will have a great benefit of implementing both cloud and fog computing environment in 5G, because cloud and fog orchestration mechanisms would effectively cope with the forthcoming services that require reduced latency, high mobility, high scalability and real-time execution.

The cloud in 5G networks will be diffused among the client devices, often with mobility too, i.e. the cloud will become fog. More and more virtual network functionality will be executed in a fog computing environment, and it will provide *mobiquitous* service to the users. This will enable new services paradigms such as Anything as as Service (AaaS), where devices, terminals, machines, and also smart things and robots will become innovative tools that will produce and use applications, services and data. This is particularly important for critical usage cases of IoT devices and Tactile Internet that requires 1 ms end-to-end latency, and big data analytics that requires real time processing with stringent time requirement that can only be carried out in the fog.

In the future every smart user device could be served by different RAN types. The choice of selecting the most suitable RAN, should be make primarily of the size of data files being transferred, throughput, latency, etc. The algorithm for such RAN selection will be our future work direction.

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