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Evolution of Mobile Networks towards the Cloud

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Abstract: The paradigm of cloud computing has emerged as a promising solution. It transparently provides computing, storage and communication resources, offered as an "elastic" pay-per-use service. This article analyses the evolution of Radio Access Networks (RANs), highlighting how current challenges and requirements for these networks as well as the available technology solutions drive the evolution of these networks towards the cloud. The Cloud-RAN architecture emerges as a solution that takes advantage of the characteristics of the cloud, adapting computation, radio and network resources in an elastic way, depending on the needs. This architecture is expected to reduce up to 15% of mobile operators' acquisition costs and 50% of operating costs. The creation of an infrastructure is 3 times faster and will save up to 71% of energy compared to a traditional system.

Keywords: network; mobile communication; cloud.

Resumo: *O paradigma da computação na cloud tem emergido como uma solução promissora. Disponibiliza de forma transparente recursos de computação, de armazenamento e de comunicação, oferecidos como um serviço "elástico", onda apenas pagamos pelo que usamos. O presente artigo analisa a evolução em curso das redes de acesso móvel (RAN), evidenciando como os desafios e requisitos atuais para estas redes assim como as soluções tecnológicas disponíveis potencializam o desenvolvimento e implementação de redes móveis baseadas na cloud. A arquitetura Cloud-RAN surge como uma solução que tira partido das características da cloud, adaptando os recursos computacionais, rádio e de rede de forma elástica, dependendo das necessidades. Espera-se que esta arquitetura reduza aos operadores móveis até 15% dos custos de aquisição e 50% dos custos operacionais. A criação duma infraestrutura é 3 vezes mais rápida e economizará até 71% de energia, em comparação com um sistema tradicional.*

Palavras-chave: *redes; comunicações móveis sem fios; cloud.*

I. Introdução

The spread and intensification of use of mobile communication services, ranging from voice and SMS, to web access and video-streaming, has been growing very fast. Several systems have emerged over successive generations to respond. The evolution of mobile radio access network (RAN) systems - from GSM and UMTS to LTE and 5G to Wi-Fi - aims to meet the ever-growing and diversified demand for mobile services, facing ever-increasing challenges [1], [2]. Mobile-generated traffic has large spatial and temporal heterogeneities, requiring dynamic, resource-sharing, and energy-efficient heterogeneous networks [3].

In telecommunication networks, traditional equipment developed specifically for a given functionality is not extensible. When it is necessary to introduce some technological innovation, this requires the partial or even total replacement of equipment, resulting in great costs for operators. However, counter-reactively, in the IT domain, software-based and virtualization-based solutions have been widely adopted, allowing generic equipment to be given very specific functionality that was previously only possible with purpose-built hardware. Even more disruptively, cloud computing has allowed it to migrate features, applications, and services - once locally supported by equipment on enterprise premises - to the cloud. This computing paradigm has established itself as a promising solution for providing high efficiency in utilizing computing, storage and networking resources offered as a service. These resources may be elastically increased or decreased depending on needs and on a pay-per-use basis.

Taking into account the requirements of mobile communication systems, and integrating various concepts of available technology solutions, comes Cloud-RAN. It is an architecture where software-based base stations are instantiated and assembled into data centres, fibre-connected to small radio units with antennas that efficiently provide mobile phone coverage. Cloud-RAN takes advantage of all cloud features by adapting allocated resources (computational, radio and network) in an elastic and efficient manner depending on demand.

The massification of software-based solutions, virtualization and cloud concepts has allowed mobile networks to evolve to become increasingly efficient. This article provides an overview of the paradigms that have emerged around mobile networks that have evolved them into the cloud.

This article is structured as follows. Section 2 presents new paradigms of mobile networks. Virtualization and cloud concepts are discussed in Section 3, and Section 4 describes the innovative cloud-based mobile network architecture. Finally, Section 5 presents conclusions.

II. New Paradigms of Mobile Networks

A. Heterogeneous Networks

Heterogeneous mobile networks (called HetNets) bring together a variety of radio transmission Base Station (BS) formats, transmission systems and solutions, as illustrated in Figure 1. They pose challenges in coordinating a wide range of technologies and technologies. approaches.

HetNets use multiple radio access technologies, from GSM and UMTS systems to LTE and 5G, through WiFi. Various cell sizes support traffic growth. Macro cells offer great coverage and capacity. Peak cells (200 meters, 30-100 users) extend the boundaries of macro cells, maximize service coverage and increase capacity. Femtocells (10-50 m, 4-16 users) increase throughput in indoor areas. Instead of a terminal connecting to the strongest signal BS, it connects to the BS capable of providing the highest throughput. Different BSs are used for downlink and uplink. The same frequencies can be used between different layers, which can cause interference, requiring the use of advanced interference prevention techniques.

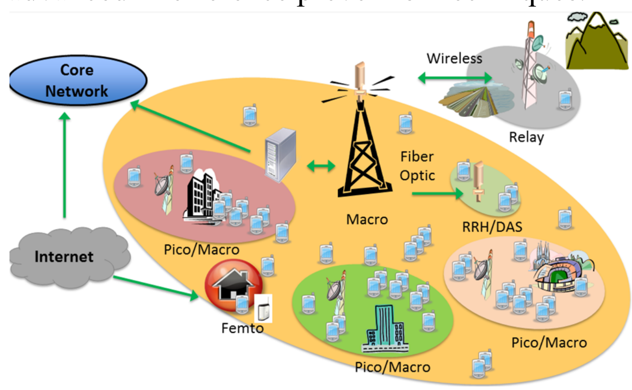

Figure 1. Heterogeneous network (extracted from [4]).

They are a solution for areas with high user density, or to solve localized interference problems. They reuse spectrum and collaborate effectively with other radio technologies. They also use wireless intermediate networks, repeaters and multi-hop communications.

B. Resource Sharing

- RAN sharing is an agreement between operators, transparent to users, to share network infrastructure and resources. Prevents duplication of networks and reduces necessary investments. There are several types of sharing:
- Geographic sharing, consisting of a standard roaming agreement. It is the national version of international roaming, where one operator's customers use another operator's infrastructure.
- Passive sharing, where infrastructure is shared (site, tower, antenna, generator,

transmission line). It is common in 2G and 3G, and has many benefits in terms of CAPEX acquisition costs.

- Active sharing, where RAN and spectrum are shared. It requires operational agreements, and brings major benefits in terms of CAPEX and OPEX operating costs. Spectrum can be shared in two ways, whether there is dedicated spectrum per operator or sharing spectrum between two operators.

C. Using Wi-Fi Networks

Wi-Fi networks are wireless local area networks, specified by the IEEE 802.11 standard, commonly used by laptops. It is a technology used in a complementary way to cellular networks. They are open and operate in frequency bands that are free to use, as opposed to RANs for which band licensing is extremely expensive, but each operator has a dedicated set of bands.

Due to the overhead of mobile networks, and thanks to the communication capabilities of mobile terminals that support Wi-Fi, it is possible to use complementary network technologies to deliver originally segmented data to cellular networks. This paradigm is called Wi-Fi offloading, which reduces the amount of data sent to cellular networks (UMTS, LTE), freeing up capacity for other users. It is also used in situations where reception is poor, allowing the user to connect through wired services with better connectivity. This also allows data cost control, which is usually free via Wi-Fi, and bandwidth availability is higher. The rules that trigger the mobile download action can be set by the user or the operator.

D. Energy Efficiency

Future mobile telecommunications systems should contribute to reductions in ICT energy consumption and greenhouse gas emissions, while allowing for massive increases in utilization rates and data. In fact, among mobile, fixed networks, mobile phones, TV and modems, mobile networks account for 50% of CO_2 emissions.

Achieving greater energy efficiency requires network-level task management [5]. On the one hand, the cellular structure must have optimized cell radii so as not to waste energy, using a mix of sizes, hierarchies and systems (2G, 3G and 4G), and integrating the use of repeaters. Management algorithms must adjust coverage and manage capacity by coordinating the various systems available and using sleep modes for traffic-free BSs, allowing them to shut down. In terms of radio resource management, cooperative scheduling, interference coordination, and joint allocation of power and resources should be used. Disruptive approaches such as multi-hop transmissions, ad-hoc networks, mobile-to-terminal transmission, and cooperative multipoint architectures should be adopted.

Intelligent management of network resources must be done using a fast timescale to match traffic patterns and service demands. On the other hand, the proportionality of the load should be evaluated. energy consumption, where energy consumption and resource utilization should match the traffic load, including zero power at zero load, ideally. Finally, the energy efficiency of the system should be improved by optimizing bandwidth and power allocation, as well as the number of antennas and active carrier frequencies.

III. Virtualization and Cloud

A. RAN Virtualization

Virtualization can be considered as the process of dividing a resource into multiple, non-transparent competitors. The trend of network role virtualization (NFV) is driven by the need for mobile operators to accommodate rapid traffic growth. Network expansion is constrained by the combination of limited spectrum and limited available funding. Operators are under intense pressure to offer more services at a lower cost (minimize their costs per bit). On the one hand, subscribers require faster access but want to avoid higher monthly contracts. There are several concepts of virtualization.

One way is the virtualization of BSs, where they virtualize radio components of BSs. There are several views, some consisting of centralizing resources, others distributing them, others using software running on General Purpose Processors (GPP). There are several proofs of concept, some based on a Cloud-RAN implementation (China Mobile, Alcatel-Lucent and Intel), others based on a Virtual-RAN implementation on an LTE network (Nokia, Intel).

The concept of virtualization can equally be applied to radio resources. Virtualization of wireless networks is considered to be a technology in which the physical network infrastructure and its radio resources are abstracted and divided into virtual network resources. These can then be shared between various parties, maintaining isolation beyond the other features. A virtual resource manager manages the physical resources and ensures that the different service agreements are respected, allowing multiple Mobile Virtual Network Operators (MVNOs) to share the same infrastructure.

B. Software Based Networks

The concept associated with Software-Based Networks (SDNs) can be extended to RAN (SD-RAN). It aims to create a flexible access network to meet the needs of different services and mobility. It enables logically centralized control of access networks and pool processing and coordination across the SD-RAN network architecture. Resource allocation is on-demand, as needed, scalable and dynamic. This results in lower operating expenses, and faster system deployment, upgrade and maintenance. Reduced processing on end nodes allows for cheaper, less energy deployments. It is a very similar concept to Cloud-RAN presented below.

C. Cloud Computing

At the same time, the cloud computing paradigm [6] has emerged as a promising solution for providing high efficiency in the utilization of computing, storage and networking resources offered as a service that can be scaled up or down depending on needs. and according to the pay-per-use principle.

Cloud computing is based on a set of principles such as on-demand and self-service, resource pooling (shared infrastructure), wide access network, fast elasticity, allowing end users to easily grow or decrease their provisioning. of cloud computing resources based on performance metrics, and measured service, paying only for what is used. The cloud computing paradigm can be extended to communication networks, leading to more efficient exploitation of resources. GPP Data Centers (DCs) can be located in central offices, supporting software-based network components. This allows its deployment and management to be done "as a service".

IV. Cloud RAN

A. Architecture

From the combination of several of the identified paradigms comes Cloud-RAN, a radio access network where mobile phone providing BSs are software-based and instantiated on some data centres, fibre-connected to small radio units providing mobile phone coverage [7]. Cloud-RAN takes advantage of all cloud features by adapting allocated resources - computational, radio and network - in an elastic and efficient manner, depending on demand.

Cloud-RAN is a centralized, collaborative radio RAN system based on real-time cloud computing [8]. There are several architectural proposals for Cloud-RAN [8], [9], as well as projects that address this topic [10], [11]. Many operators, such as China Mobile [12], are already conducting trials with centralized architectures to provide fast and dense RAN deployments. Cloud-RAN makes the RAN more flexible and efficient, where an BS is divided into two parts: a Remote Radio Head (RRH), and a Base Band Unit (BBU) connected via a fibre optic transport network [13] as illustrated in Figure 2.

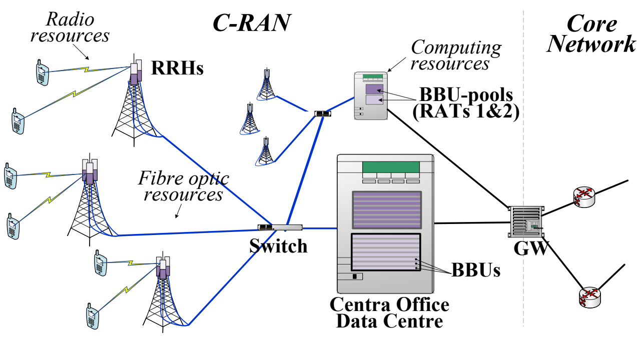

Figure 2. Cloud -RAN architecture (extracted from [3]).

The RRH is the physical radio part of BS, consisting of the antenna and a small radio unit responsible for radio functions. BBU aggregates the baseband functions of an BS as well as those of control and management. A BBU is software based, and can be any radio access technology (RAT). A BBU can be instantiated on one or more virtual machines (VM) on a DC. Multiple BBUs, from the same or different technologies, can be grouped into one DC, forming a BBU-pool. This division of BS allows you to have cheap and small RRHs on sites with almost no infrastructure, with all digital processing resiliently supported by cloud-based GPPs.

Expected impact achieves up to 15% CAPEX and 50% OPEX savings compared to distributed BS 3G, fast system storage saving up to 1/3 of the time and saving up to 71% energy compared to a traditional RAN system [7] Still, BBUs currently run on dedicated hardware platforms. RANaaS extends Cloud-RAN by leveraging GPP platforms, virtualization, and the cloud paradigm to enable on-demand, elastic resource allocation for BBUs. Figure 3 presents a motivating scenario showing how Cloud-RAN is scalable on demand.

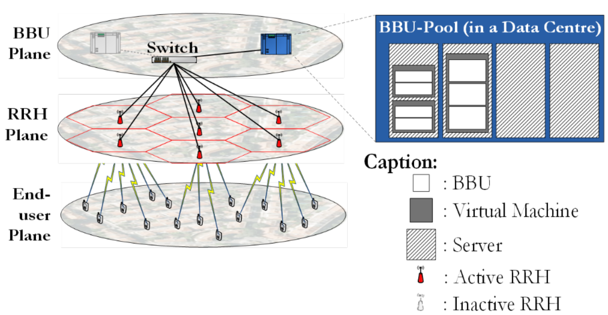

Figure 3. Application of the Cloud-RAN scenario (extracted from [3]).

With few users, 3 RRH-BBU pairs cover the service area and provide the requested capacity. As the number of users increases, more RRHs are activated and the associated BBUs instantiated in the BBU-Pool to provide the requested capacity. With a highly loaded network, some BBUs should be dynamically instantiated on a different DC, as the processing resources required exceed the capacity of the BBU-Pool.

Cloud-RAN uses new technologies in several steps:

- Distributed RRH and centralized BBU architecture.
- Advanced multipoint transmission / reception technology.
- SDR with multi-standard support.
- GPP virtualization technology.
- Efficient resource management in the face of variations in traffic offered throughout the day.

Cloud-RAN improves and simplifies rapid network construction and deployment, changing the cost structure of mobile operators. It also allows you to easily upgrade your network. To expand network coverage or split a cell to improve capacity, simply install new RRHs and connect them to the BBU-pool. Cloud-RAN breaks the static link between RRHs and BBUs; each RRH does not belong to any specific physical BBU. Radio signals to and from a given RRH can be processed by any BBU, which is part of the processing capacity allocated in the BBU-pool, thanks to real-time virtualization technology.

If network load increases, operators only have to upgrade BBU-pool hardware to accommodate increased processing capacity. This is a fully centralized solution, combined with an open platform and GPP, which allows you to upgrade from the standard via software only. It will provide a much more efficient, competitive and profitable infrastructure in the dynamic market environment.

B. Cloud-RAN Implementation

There are several challenges in deploying a network based on the Cloud-RAN architecture. Fiber-optic resources linking BBU-pools and RRHs must meet very demanding latency requirements, dictating a maximum fiber length between BBU and RRH of 15 km [13] and high bitrate links (a tri-sector site with LTE, UMTS, and GSM may require rates of up to 20 Gbps [13]). Mapping RRHs to a BBU-pool is another challenge related to load balancing between BBUs or BBU-pools [14]. Thanks to the cloud concept, BBUs can be DC-based and their resources (processing, storage and connectivity) can be scaled according to the load range of the associated RRHs. However, using GPPs to run BBUs is challenging because there are very strict maximum delay requirements when processing radio frames. These will require not only a large amount of processing power, but also a real-time operating system. Such applications are not yet fully exploited in the cloud domain, and having GPU-specific BBU software is a rather complex challenge in terms of code and process optimization [14]. For load balancing between DCs, BBUs can be migrated from one DC to another, requiring evolved mechanisms to ensure that it is perfectly matched to attached end users. A key aspect is the quantification of the relationship between load and processing needs at BBU. In [15] an implementation of this architecture is made that allows to evaluate the advantages of Cloud-RAN when combined with the virtualization of radio resources. These results evidence the advantages of this architecture.

C. RAN as a Service

The Mobile Cloud Networking (MCN) project [16] extends the cloud computing paradigm to communication networks. MCN combines mobile networking with decentralized computing, smart storage, offered as a service: On-Demand, Elastic, and Pay-As-You-Go. MCN aims to offer on-demand, elastic RAN-as-a-Service (RANaaS), adaptable to load variations [17]. BBUs currently run on dedicated hardware platforms. RANaaS extends Cloud-RAN by leveraging GPP platforms, virtualization and the cloud paradigm, and leveraging shared computing, storage resources, and cloud infrastructure to enable on-demand, elastic resource allocation for BBUs. RANaaS allows you to simultaneously offer multiple tenants (MVNOs) features according to specific SLAs. This requires dedicated mechanisms for integrated management of virtual radio resources. This is supported by elastic on-demand resource allocation, enabled by resource usage detection and prediction mechanisms, to optimize the services offered. Thanks to the virtualization capabilities of software-based BBUs, these can be split into multiple instances per tenant, allowing for isolated management of associated resources. This solution provides a flexible way to instantiate, scale, and release RAN resources whenever needed.

The components of the RANaaS architecture can be instantiated into on-demand, resiliently scaled GPPs with shared resources (both radio and hardware) following the pay-per-use principle. It is proposed in [17] an architecture that supports this concept of RANaaS. The architecture's success lies in its modularity, well-defined functional elements, and clean separation between operational and control functions. Allows operators to upgrade their network and quickly deploy and adapt resources as needed. In addition, new players can easily enter the market by allowing a virtual network operator (MVNO) to provide connectivity to its users, only by paying for shared RAN facilities provided on-demand resiliently by radio resource providers, which have spectrum and manage your access. This will have a major impact on the development of new integrated and flexible RANaaS-based services.

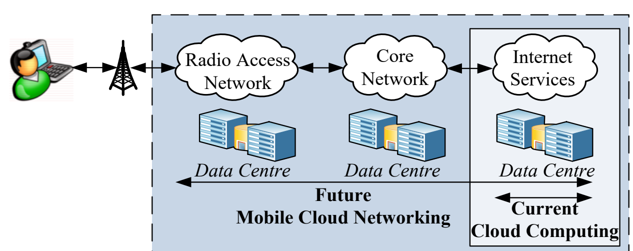

Figure 4. Mobile cloud networking vision (extracted from [17]).

V. Conclusion

The widespread use and intensification of the use of mobile communications services has been increasing. Several systems have emerged over successive generations to respond. However, these networks face management and planning challenges, both in terms of network densification and efficient capacity growth. New paradigms have emerged to meet these new requirements. Cloud-RAN stands out as a strong candidate capable of responding and integrating the various technological proposals. Brings RANs the advantages of cloud: resource sharing, elasticity, demand, and pay-as-you-go. Based on real-time virtualization technology, Cloud-RAN minimizes CAPEX and OPEX costs by pooling multiple resources in one DC. Enables fast, flexible, and optimized deployment of RANs, supporting pay-per-use models. They represent the next technological leap for the 5G.

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