A Friendly Introduction to the Requirements and Supporting Technologies for 5G Cellular Networks

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Abstract: This article pretends to provide an easy-to-understand overview of the requirements and the technologies envisioned to support 5G cellular systems. Some meaningful statistics regarding the way traffic behaved during the year 2015 and a forecast up to year 2020 are presented. This allows a better understanding of the requirements for 5G that are currently being outlined and the applications that will be enabled. Given the orientation of this paper, two general aspects have been considered: a) How to increase and reach the required capacity of 5G systems by combining more spectrum, more cells and enhancing spectral efficiency by dealing with interference; and, b) The main aspects of the overall architecture of 5G systems, including discussions of the access network, backhaul and core. For each case several technologies that are under enhancements and optimization and others that are just being researched and still are in their initial steps are introduced and discussed.

Palabras clave: 5G, Cellular Systems, Massive MIMO, CoMP, SDN, NFV, HetNet, Self-Organizing Networks.

Una Introducción Sencilla a los Requerimientos y Tecnologías de Soporte de las Redes Celulares de 5G

Resumen: Este artículo pretende dar una visión fácil de entender sobre los requisitos y las tecnologías que se prevé brindarán soporte a los sistemas celulares de 5G. Se presentan algunas estadísticas de importancia relacionadas a la forma en la que el tráfico se comportó durante el año 2015 y el pronóstico hasta el año 2020. Esto permite una mejor comprensión de los requisitos para sistemas 5G que se están delineando actualmente y las aplicaciones que se podrán especificar. Dada la orientación de este trabajo, se han considerado dos aspectos generales: a) Cómo aumentar y alcanzar la capacidad de los sistemas 5G combinando más espectro, más celdas y mejorando la eficiencia espectral disminuyendo la interferencia; y, b) Los aspectos principales de la arquitectura de los sistemas 5G, incluyendo discusiones sobre la red de acceso, *backhaul* y el *core* de la red. Para cada caso, se presentan y discuten algunas tecnologías que están siendo mejoradas y optimizadas y otras que están siendo investigadas y que aún están en sus etapas iniciales.

Keywords: 5G, Sistemas Celulares, MIMO Masivo, CoMP, SDN, NFV, HetNet, Self-Organizing Networks.

1. INTRODUCTION

What the ITU (International Telecommunication Union) considers the requirements that a cellular system should comply to be consider a true 4G system were finally approved in January 2012 (Chen and Zhao, 2014). Research on 5G mobile wireless networks, including the technologies and architectures that will support them, started way before 2012. This research has been mainly driven by the wireless mobile Internet and the evolution of smart devices. Currently, there is a general agreement that 5G networks will start deployment by 2020 (IMT-2020, 2014).

It must be stated that currently there is no a 5G standard, only reference requirements are being established. It is expected that 5G will be integrated under the umbrella of the International Mobile Telecommunication (IMT) family that is being developed within the ITU´s framework.

In regard to 5G supporting technologies, it is worth noting that several of today´s technologies are expected to be at an advanced stage of maturity before 5G deployments. Besides, there are new technologies in their early stages of development that should be closely monitored along the evolution path toward 5G.

The increment in the number of devices and application´s requirements will determine the specifications for the future 5G systems. Many applications will be made available on mobile devices and across multiple kinds of devices. Tens of billions of smart devices will use their embedded communication capabilities and integrated sensors.

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Not every device or service will require very high data rates. Supporting a large number of Machine-to-MacFhine (M2M) communications in 5G will demand satisfying the following: a) Supporting a massive number of low-rate devices; b) Sustaining a minimal data rate in virtually all circumstances; and, c) Supporting very-low-latency data transfers (Boccardi, 2014).

The set of requirements and challenges of future 5G networks should include: higher-peak data rates, increased number of devices, higher traffic volume, reduced latency, enhanced indoor coverage, low energy consumption, increased traffic asymmetry, high reliability and so on.

These demanding requirements are all oriented to enable a fully mobile and connected society and can be satisfied by a combination of the following ingredients: a) Additional spectrum; b) Higher spectral efficiency; and, c) A higher density of cells. The final product will be a set of standards comprising the results of a vast amount of research related to existing and novel technologies over a time span of several years.

According to the whitepaper from NGMN (2015), using current values as a reference, generic targets for 5G systems have been proposed to offer: higher data rates (>10x on average, >100x at cell edge), lower latency (>10x improvement), higher connection density (>100x improvement) and higher traffic demand (> 1000x increase).

In some cases, very specific values have been outlined for 5G networks: support connections for at least 100 billion devices and 10 Gbps for each user with extremely low latency for good response times (Huawei, 2013).

The Next Generation Mobile Networks Alliance (NGMN, 2015) proposes the following roadmap to 5G:

a. Detailed requirements ready by the end of 2015
b. Initial system design in 2017
c. Trials start in 2018
d. Standards ready by the end of 2018
e. Commercial system ready in 2020

Some argue that 5G should be more than just an evolution of 4G, that emerging technologies will cause a “disruption” requiring a rethinking of even long-term-accepted cellular principles (Chen and Zhao, 2014); for example, using millimeter wave wireless communications for 5G.

This article is written with an easy-to-understand orientation and addresses the overall structure of 5G systems. Firstly, it focuses on the problem of how to increase the capacity of the future 5G systems by combining the three fundamental aspects: available spectrum, number of cells and enhancing spectral efficiency. Secondly, the paper presents some guidelines regarding the possible architecture of 5G for supporting the new requirements; this is accomplished by discussing with the main components of cellular systems: the access network, backhaul and core network. The paper should be useful as an introduction and overview for those with a basic understanding of previous cellular systems and a starting point for those with deeper knowledge.

The remaining of the paper is organized as follows: Section 2 outlines some applications that will be enabled in future 5G systems. Sections 3 presents some statistics for the mobile data traffic for the year 2015 and forecasts for the 2015-2020 time span. Section 4 explains strategies for increasing the capacity of the system by combining more spectrum, more cells and enhancing spectral efficiency by dealing with interference; concepts such as HetNets, CoMP and Massive MIMO are introduced. Section 5 presents fundamental aspects of the architecture of 5G system; discussions of the access network, backhaul and core are included. Finally, conclusions are outlined in Section 6.

2. ENVISIONED APPLICATIONS

The whitepaper issued by NGMN (2015), when stipulating application requirements, presents eight use-case families:

a. Broadband access in dense areas: Pervasive video, smart office, HD Video/Photo sharing in stadium/open-Air gatherings.

b. Broadband access everywhere: 50+ Mbps everywhere, ultra-low cost networks.

c. Higher user mobility: High speed trains, remote computing, 3D connectivity.

d. Massive Internet of Things (IoT): Smart wearables (clothes), sensor networks, mobile video surveillance.

e. Extreme real-Time communications: tactile Internet (humans will wirelessly control real and virtual objects).

f. Lifeline Communication: natural disasters.

g. Ultra-reliable communications: Automated traffic control and driving, collaborative robots, eHealth, public safety.

h. Broadcast-like services: News and information, local and regional broadcast-like services.

Figure 1 illustrates some of the use cases and applications.

3. MOBILE DATA TRAFFIC STATISTICS AND FORECAST

In order to understand some of the presented requirements for 5G, it is important to take a look at how traffic has evolved and what some of the forecast for the coming years are.

Figure 1. Overall vision of the applications that will be supported by 5G systems (IMT-2020, 2014).

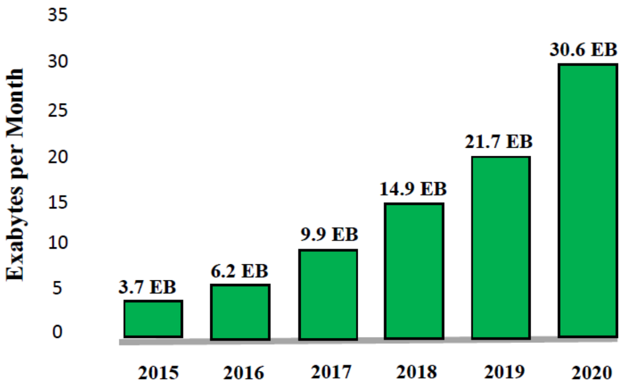

Figure 2. Forecast for the mobile data from 2015 to 2020 (Cisco, 2016).

3.1 Global data about the year 2015

Some relevant information for this article, taken from (Cisco, 2016), is included next

a. Global mobile data traffic reached 3.7 exabytes per month at the end of 2015, up from 2.1 exabytes per month at the end of 2014. A traffic growth of 74 % in 2015 (Figure 2).

b. Mobile video traffic exceeded 50 % of total mobile data traffic by the end of 2012 and accounted for 55 % by the end of 2015.

c. Global mobile devices and connections in 2015 grew to 7.9 billion, up from 7.3 billion in 2014. Smartphones accounted for most of that growth.

d. Average smartphone usage grew 43 percent in 2015. The average amount of traffic per smartphone in 2015 was 929 MB per month, up from 648 MB per month in 2014.

e. Globally, there were nearly 97 million wearable devices (a sub-segment of M2M) in 2015 generating 15 petabytes of monthly traffic.

3.2 Forecast for Mobile Data Traffic for 2015 to 2020 (Cisco, 2016)

a. Overall mobile data traffic is expected to grow to 30.6 exabytes per month by 2020, nearly an eightfold increase over 2015. Mobile data traffic will grow at a CAGR (Compound Annual Growth Rate) of 53 % from 2015 to 2020 (Figure 2).

b. By 2020 there will be nearly 1.5 mobile devices per capita. There will be 11.6 billion mobile-connected devices by 2020, including M2M modules.

c. By 2020 there will be nearly 1.5 mobile devices per capita. There will be 11.6 billion mobile-connected devices by 2020, including M2M modules.

d. The average mobile network connection speed (2.0 Mbps in 2015) will reach nearly 6.5 Mbps by 2020.

e. 75 % of the world's mobile data traffic will be video by 2020. This could emphasize the asymmetry of the ratio of downlink to uplink traffic to 10:1 by 2020.

4. INCREASING WIRELESS CAPACITY

4.1 Dealing with the need of more spectrum

Availability of new spectrum will enable increases in data rate and capacity. However, since spectrum is scarce at microwave frequencies, big chunks of new spectrum will be likely available only in higher frequency bands (e.g., millimeter waves frequencies - mmWaves) ranging from 3 to 300 GHz (Boccardi, 2014). At frequencies above 6 GHz, it would be possible to have very wide bandwidth channels (e.g., 500 to 1000 MHz of contiguous spectrum) to support very high data rates and short-range mobile connectivity.
At these frequencies, it is expected to have propagation restrictions, particularly when penetrating into buildings from the outside. On the other hand, due to very small wavelengths, a large number of tiny antennas (MIMO) can be used for mmWaves. Research on mmWave for cellular will need to incorporate in its analysis sensitivity to blockages, antenna arrays and more complex channel models.

The ITU World Radiocommunication Conference 2015 (WRC-15) was held on November 2015. WRC-15 identified frequency bands for mobile broadband services in the L-band (1427-1518 MHz) and in the lower part of the C-band (3.4 - 3.6 GHz). WRC-15 achieved agreement on some additional portions in other bands that were also allocated to mobile broadband services in order to be used in regions where there was no interference with other services. However, it is likely that beyond what was agreed at WRC-15, additional spectrum will be needed to deliver all the envisioned 5G services.

On the other end, spectrum below 1GHz is particularly useful for coverage, especially indoors and in rural areas. License-exempt spectrum should be exploited at lower frequencies as a complement to exclusively-licensed mobile spectrum. Clearly, this implies the coexistence of frequency bands with radically different propagation characteristics within the same system; this aspect must be considered when using carrier aggregation.

Carrier aggregation, as defined for LTE-A, is expected to have high penetration by 2020, but smarter carrier aggregation schemes will be needed to benefit from any spare frequencies, considering that some fragments of bandwidth may be located in quite disparate frequency bands. Kishiyama et al. (2013) propose the concept of a phantom cell where the data and control planes are separated; the control information is sent by high-power nodes at microwave frequencies, whereas the payload data is sent by low-power nodes at mmWave frequencies.

Given the scarce spectrum and the possibility of carrier aggregation, it is clear that methodologies for improving spectrum usage are required. Cognitive Radio (CR) is an innovative software defined radio technique considered to be one of the promising technologies to improve the utilization of the congested RF spectrum (Mitola, 2000).

A CR network must be aware of the state of the surrounding radio environment and regulate its own transmission based on that state. In interference-free CR networks, CR users may be allowed to borrow spectrum only when licensed users do not use it (Wang et al., 2014). CR´s promise for more flexibility in spectrum usage can be better seized when applied to small cells as in indoors environments.

In order to exploit cognitive radio, more frequency spectrum should be made available for small cells, such is the case when the FCC has considered implementing shared use of the 3550–3650 MHz band; this would be done, even though this band apparently cannot be cleared of incumbents in a reasonable/predictable timeframe. Formally, this strategy for licensed spectrum sharing is known as Licensed or Authorized Shared Access (LSA or ASA) (Bhushan et al., 2014).

4.2 Dealing with HetNets and higher density cells

Heterogeneous Networks (HetNets) involve a mix of radio technologies and cell types that should work together in a seamlessly fashion. Low power nodes can be microcells, picocells, home cells (for femtocells), relays, and distributed antenna systems (DAS).

Although the macrocell will continue to be the fundamental provider of coverage in 5G, small cells will be widely deployed either indoors or outdoors as a complement to macrocells.

A fundamental target to be complied in 5G systems is the increment in the coverage and data rates for indoors environments; in such a scenario, subscribers themselves may end up helping the deployment of home and office located radiobases. However, technical differences will show up between indoors and outdoors environments; indoors is a richer scattering environment with lower mobility when compared to outdoors. Besides, indoors environments generally imply shorter distances between base stations and terminals along with a higher line-of-sight probability.

NSC (Neighborhood Small Cell) is the term used for depicting small cells deployed mostly by end users (Bhushan et al., 2014). NSC deployments require no site acquisition and minimal RF planning, and they may use existing broadband backhaul (DSL/cable) for connecting the cells to the core network. For easy deployment based on plug-and-play, NSC uses the ideas behind SON (Self-Organizing Network).

Widespread technologies such as MIMO, normally used outdoors in cellular systems, will be also applied indoors; this means that its performance will be affected due to the distance between antenna elements. This distance will impact the mutual correlation between the radio-channel fading on signals on different antennas either in the base stations or the mobile stations. In the case of macro radiobases these distances are typically in the order of 10λ. For indoor environments, an adequate separation is in the order of 0.5λ; hence a high number of antennas could be used in the radiobases, allowing improving data rates and the capacity of the system.

Low mobility in small cells enables more accurate and up-to-date knowledge of the current conditions of the channel; this scenario also allows improvements at data rates and capacity. However, there are additional aspects that must be considered and research is needed to overcome the associated problems; just to mention two of them: receivers at the terminals will not be able to work without macro coverage all the time and legacy terminals will not be able to access new 5G systems.

4.3 Dealing with higher spectral efficiency and interference

5G systems should be able to handle interference derived from unplanned deployments, and even under such adverse scenarios, they should comply with what users expect. CoMP and Massive MIMO will be essential to improve the achievable SINR (Signal-to-Interference-plus-Noise Ratio) in the system; with adequate values of SINR, it will be possible to improve the overall spectral efficiency and to maintain QoS consistency.

CoMP (Coordinated MultiPoint)

CoMP is used to overcome inter-cell and inter-sector interference so it is possible to improve spectral efficiency and to get user data rates beyond what is possible by using only MIMO, especially at cell edges. This is accomplished by coordinating base stations (BS) for both transmission and reception.

3G and 4G technologies are using full frequency reuse which leads to interference between cells; by using sectorization, it is also possible to end up with sectors using the same spectrum resources. This interference may become significant, especially for those terminals at the edge between sectors (intra-site interference) and between cells (inter-site interference).

A BS handling multiple sectors may have some of its infrastructure distributed (e.g. DAS) and linked via fiber or a point-to-point wireless link. Sectors within a cell can cooperate in intra-site CoMP, whereas BS can cooperate in inter-site CoMP.

CoMP needs to exchange channel state information and/or scheduling decisions between BS; furthermore, tight time synchronization among BS is required and fast exchange of user data is needed to make the these data available at all collaborating BS with minimum delay. Control information is to be processed in an adaptive way for either decentralized or centralized cooperation.

Figure 3 shows a centralized version of CoMP. Each terminal is associated to a single BS as an anchor for coordination purposes. Terminals must perform channel estimations (H_{ij})

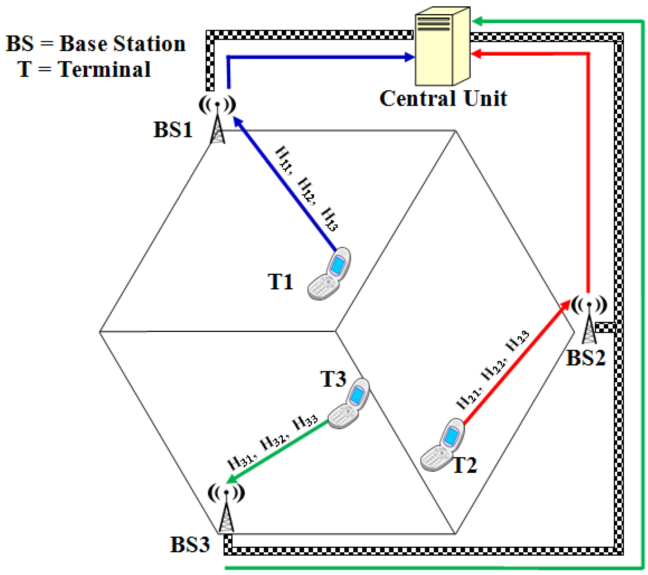

Figure 3. CoMP centralized architecture (Akyildiz et al., 2010).

and then feed this information back to its anchor BS. Once the information is gathered, each BS forwards it to the central unit that is in charge of deciding the scheduling and the transmission parameters; finally, this new calculated information is sent back to the entire set of participating BS (Akyildiz et al., 2010).

In a distributed approach (Figure 4), channel information (H_{ij}) the information collected by the terminals will be made available to each cooperating BS. Every BS will be running the same scheduler, so links between BS are no longer necessary. The nodes will produce the same output decisions and therefore the same transmission parameters are obtained and the same terminals are selected in the entire BS group.

For illustrating coordination schemes derived from processing shared channel estimation information, two alternatives are discussed:

a) Coordinated scheduling: it is a simple approach where user data are transmitted only from a single BS at a time (Figure 5); this BS can be dynamically selected, even though different BS may share control information;

b) Joint processing technique: this requires multiple BS to transmit user data to the terminal at the same time (Figure 6a) or a variation that uses a fast BS selection approach and only one of them transmits data at a time (Figure 6b).

There are several methods that can perform link adaptation based on predicted SINR values. Prediction is enabled by exchanging resource allocation information within a cluster of cooperating cells inserting moderate backhaul traffic. Other methods may require a much higher bit rate for information exchange.

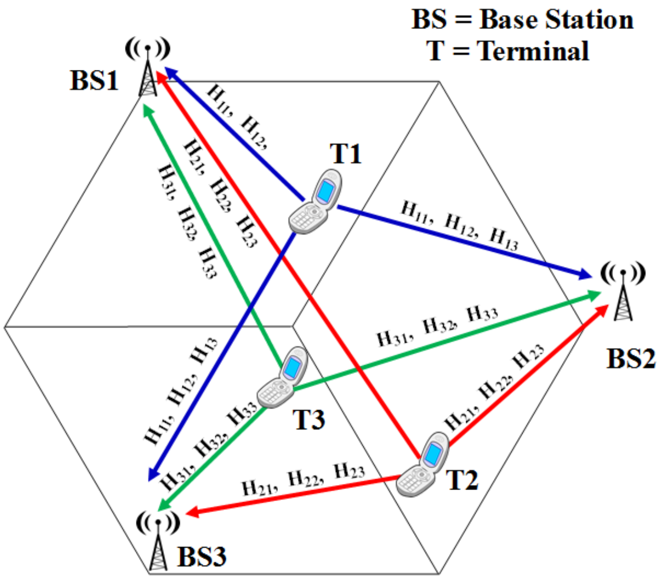

Figure 4. CoMP distributed architecture (Akyildiz et al., 2010).

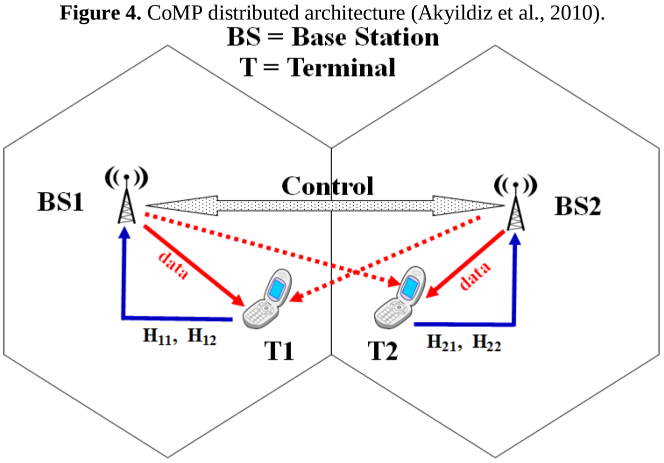

Figure 5. Coordinated scheduling approach (Akyildiz et al., 2010).

It must be noted that CoMP introduces overhead on the air interface and over the backhaul. In practice only a limited number of BS can cooperate in order to keep the overall overhead manageable. It is a new task to integrate a large number of small cells into CoMP, since small cells have specific characteristics (Andrews, 2013).

CoMP can be applied both in the uplink and downlink. The implementation of CoMP demands different requirements on the backhaul throughput and latency since inappropriate latency might provoke that exchanged channel information becomes outdated; additional requirements include: higher complexity, increased synchronization between cooperating BS located within a maximum distance, multi-cell channel estimation, more overhead. However, better solutions than current ones are needed for all of these aspects before CoMP can be integrated into next-generation mobile networks.

CoMP transmission and reception look like a promising set of techniques that need to be further investigated since they show great potential and are very promising but there are many issues that still remain open.

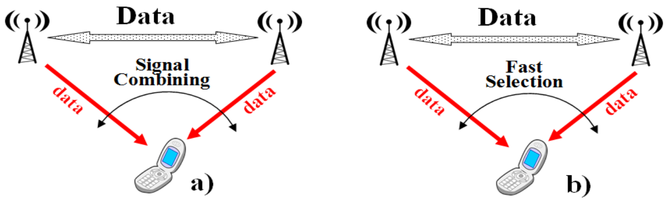

Figure 6. Joint processing techniques: a) joint transmission b) dynamic cell selection (Akyildiz et al., 2010).

Massive MIMO

Massive MIMO or Large-Scale MIMO is a form of multiuser MIMO that uses a much larger number of antennas per site to multiplex messages simultaneously for several autonomous devices on each time-frequency resource. As a complement to MIMO, it is possible to focus the radiated energy toward intended directions using narrow beamforming in order to minimize intra and inter-cell interference, pushing the systems closer to a noise limited environment.

Channel-State information (CSI) plays a key role in a multiuser MIMO system so both forward and reverse link channel information must be gathered. It has been found (Marzetta, 2010) that even with a very noisy channel estimate, more antennas in the BS provide a positive contribution; in the extreme case of assuming an infinite number of antennas, the effects of fast fading and uncorrelated noise vanish. Besides, it is always possible to recover from a low SNR by adding a sufficient number of antennas.

Having a large number of antennas also requires more pilots for channel estimation and this means fewer resources for user data; at the same time, these higher number of pilots impacts spectral efficiency. For dealing with this situation, orthogonal pilot sequences are reused; this is known as *pilot contamination.* So, for example, when a BS is obtaining the CSI associated to its own terminals, it can inadvertently learn about the CSI of terminals in other cells, those which share the same pilot sequence. The pilot signals received by a BS are contaminated by pilots transmitted by terminals in other cells. So, research is underway to overcome this critical problem and to look for new schemes for efficient acquisition of CSI, even under user motion (Marzetta, 2010).

Massive MIMO is well suited for higher frequency bands since a large number of antenna elements can be placed within practical form factors. Increasing the number of antennas brings along higher complexity and costs so this option should be deploy gradually and it is still a subject of research. New designs will be needed to make practical antenna form factors for massive MIMO at lower carrier frequencies.

Dealing with increased asymmetry

The increased asymmetry suggested by increased video traffic, makes explicit the well-known lack of flexibility of FDD since it has more difficulties dealing with asymmetry issues. Asymmetrical FDD carrier aggregation (CA) has been considered as a solution. CA is part of LTE-A and it allows

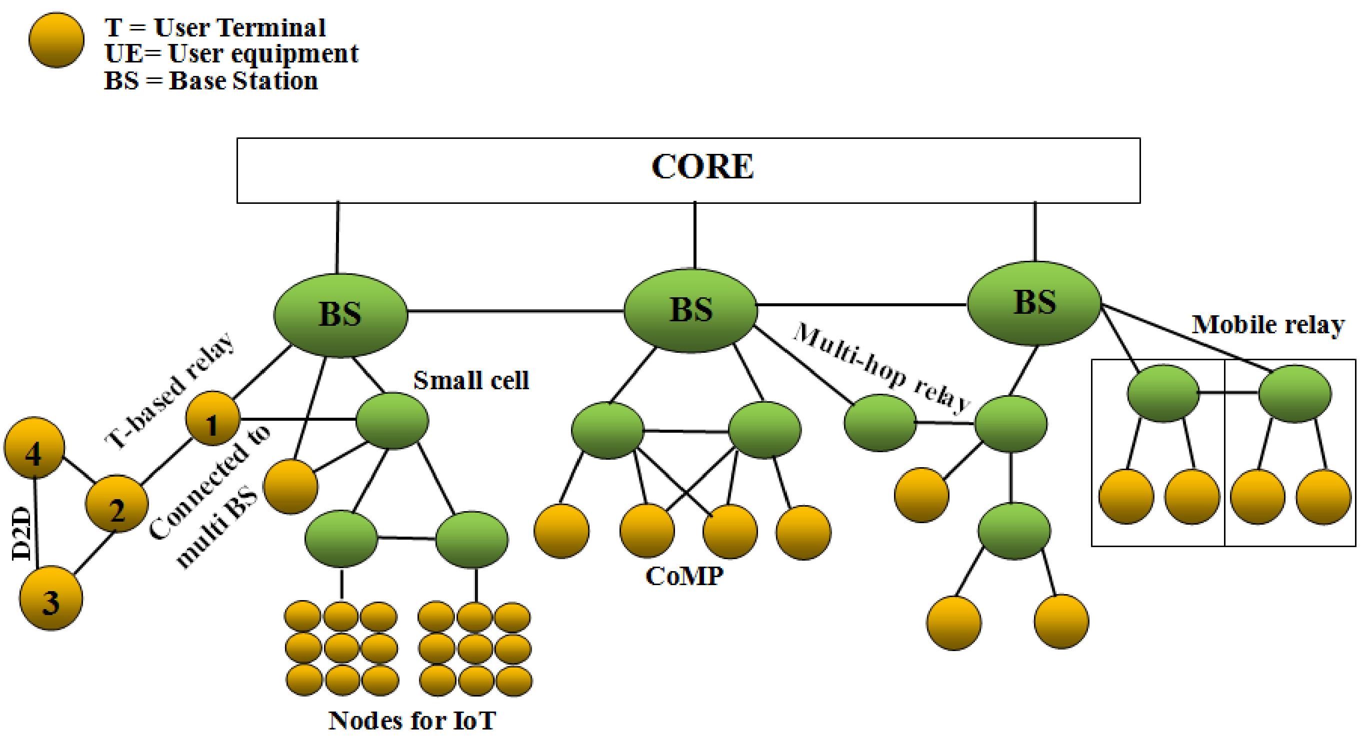

Figure 7. Access network for 5G systems (Chen and Zhao, 2014).

combining up to five channels, each of 20MHz. To overcome FDD´s limitations the idea is to aggregate more bands in the downlink than in the uplink. For sure, TDD is also to be considered as an option due to its flexibility and the fact that it also can support CA.

5. ARCHITECTURE

5.1 Dealing with the access network

5G will operate in a highly heterogeneous environment characterized by the existence of multiple types of access technologies. As part of these alternatives, novel ways of communications are foreseen, such as D2D (Device-to-Device). D2D communication allows nearby devices to establish local links in an ad-hoc fashion, so that traffic flows directly between them instead of going through BS (IMT-2020, 2014). D2D communication reduces latency and power consumption, increases data rates, and creates proximity-based services such as proximate multiplayer gaming.

D2D also enables the possibility that a terminal device becomes an intermediary for another nearby device in order to reach a BS; this is referred to as D2D relay for traffic offloading. Of course there is a set of new problems to solve such as the discovery process of candidate relays, opportunistic relay selection, interference management, minimization of relay power consumption and protocol development. Research is underway (Sadiq et al., 2013).

There is a gamut of options regarding radio access technologies (RAT) to be used in 5G. One possibility is a new single unified RAT that could be optimized and configured for different frequencies and use cases. The positive aspect of this alternative is that considering a long term span, operators will not have to manage multiple access networks although an initial migration phase to the new RAT must be planned. On the contrary, supporting multiple RAT, with potentially different air interfaces, could complement each other, acting as a single unit (NGMN, 2015).

To provide access-agnostic network functions, other RAT may be considered, including Wi-Fi, the fixed network and the evolution of current 4G alternatives. The latter will provide backward compatibility for devices that cannot utilize the new RAT, facilitating the migration toward 5G.
As an alternative to be considered within the present discussion is the concept of Cloud Radio Access Networks (C-RAN) (China Mobile, 2011) which adopts a centralized architecture that allows carrier aggregation between macro and small cell carriers. So it is possible to have connectivity and mobility within the macro cell coverage and achieve higher throughput and capacity in small cells called “add-ons”. This advanced C-RAN architecture handles CA and handoffs within centralized baseband units (BBU) at BS, drastically reducing signaling traffic to the core network (DoCOMO, 2014).

New communications schemes such as M2M and D2D will enable different kinds of connections: terminal to terminal, small cell to small cell, small cell to BS, relay node to BS, relay node to relay node. Multi-hop connections and mobile relays will also be possible (Figure7). As shown in Figure 7, relaying could dynamically change the topology of cellular systems and could also help decreasing power consumption. A multi-hop structure can efficiently support access of M2M terminals. A UE-based mode can construct new M2M services by letting UE be a core access node in Internet of Things (IoT) networks (Chen and Zhao, 2014). End-to-end latency is critical to enable new real-time applications such as safety and augmented and virtual reality. To this end, innovations in air interface, hardware, protocol stack, backbone, and backhaul as well as network architecture can all help to meet this challenge.

5.2 Dealing with the backhaul and the core

As previously mentioned, for end-user deployments and spatial network densification, SON techniques will allow reducing or even eliminating the burden of RF planning. The 3GPP standards already offer a framework for self-organizing networks (SON) to support automatic configuration and optimization of the network but extensive research is still needed for the envisioned 5G systems.

Self-configuration might be enabled at first by using network listening and terminal feedback for neighbor-cell discovery that will later help with a coordinated selection of operational parameters among neighbors. Mobility management might be SON-optimized coping with more challenging handoff requirements. SON might even enable load balancing in the backhaul since the backhaul may be shared with other devices (e.g., WiFi Access Points). QoS may be maintained through dynamic load balancing based on backhaul bandwidth availability (Bhushan et al., 2014).

In general, the techniques and ingredients used to increase capacity are of no use unless it is complemented by improvements of the backhaul connecting a BS to the core network. The backhaul can be either wireless based or high-performance fiber based. A wireless backhaul could provide a viable solution, connecting the edge nodes (small cells) to aggregator nodes (called feeder links), and then to the gateway nodes (called aggregation links), which have fiber backhaul to the core network (Bhushan et al., 2014).

On the core side, technology advancements in recent years (e.g., SDN, NFV, big data) will change the way these networks are being constructed and managed.

The concept of NFV (Network Functions Virtualization) is based on the idea of using CPU virtualization and other cloud computing technologies to migrate network functions from dedicated hardware to virtual machines running on general purpose computers; NFV is still considered an emerging paradigm (4G Americas, 2014).

Software Defined Networking (SDN) is a new networking architecture that decouples the control and switching planes (Morillo et al., 2014).

The switches or white boxes are required to be extremely efficient at their task of switching and must reduce their intelligence to a minimum.

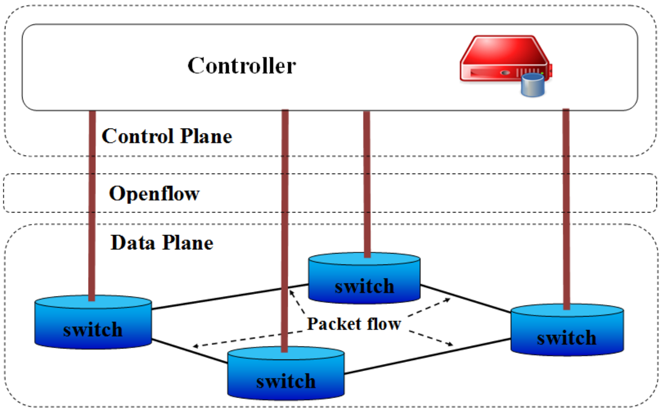

Figure 8. SDN architecture.

The intelligence of the control plane is derived to a server controller (Figure 8) that executes software modules that define the functionality of the switches and generate rules that must be installed in the switches. The controller communicates with the switches by means of a protocol (e.g. Openflow); in the switch side this protocol allows manipulating the flow table of the switch.

NFV and SDN are two independent architectural approaches that complement each other to deliver a complete virtualized solution, but NFV does not require SDN implementation to realize its benefits.

These changes in the architecture will enable the development of a highly flexible infrastructure that will allow operators the deployment and introduction of new services into the network at an increased pace of innovation. It will also be possible to render OPEX and CAPEX savings.

The 5G architecture could be implemented as a native SDN/NFV architecture pointing to virtualizing as many functions as possible, including functions related to devices from the mobile and fixed infrastructure, network functions, and management functions.

5.3 Dealing with security

Security is a fundamental requirement to be taken care of from the beginning of the conceptualization of 5G systems and the security architecture should be directed toward providing options beyond node-to-node and end-to-end security available in today's mobile systems. Since 5G will support a wide range of applications requiring diverse communication scenarios such as human-based and machine-based, these new systems will have to handle highly sensitive data that need to be protected against unauthorized access, use, modification, inspection, attack, etc.

6. CONCLUSIONS

It becomes evident, after all of the information presented, that 5G systems are currently in the phase of establishing requirements and that LTE-A will have a few years to evolve up to 2020 (according to what could be considered an initial roadmap). Important entities such as 3GPP, NGMN and ITU and companies such as DoCOMO, Huawei, and Cisco are actively participating and have recently emitted white papers that contribute to the aforementioned phase.

It is also important to notice that technologies previously included in several of the cellular generation standards have being improved and are mature and will actually be used in 5G systems with some modifications but it is also clear that it could be the case that some of the central ideas of past cellular systems might be reviewed and even discarded not only for dealing with interference, RF planning and capacity constraints but also in the structure of the core network. New technologies are also under development; CoMP, massive MIMO, SDN. NFV and the use of mmWave frequencies are all technologies that have to overcome challenges and constraints and require further research to look for a place in the future 5G standards.

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