5G Networks: Advancement and Challenges

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***Abstract*—Nowadays, mobile networks are an indispensable part of everyday life. Although the advent of 5G is imminent, given that the 2020 is approaching, there are still a lot of addressable questions. It becomes of great significance that the Advancements and Challenges of the 5th generation of mobile networks are presented. The Strong points and the Weak parts should be indicated so that they will be treated. In this paper, a review of the current foundational stones of the 5G networks is completed. The state of all different technologies is noted.**

***Index Terms*—5G, survey, mobile networks, SWOT analysis**

I. Introduction

It is a well-known fact that the 5G mobile networks are of great importance, since they have been discussed extensively. These networks will play an important role both for the scientific community and the everyday life in the next decade (2020-2030) at an international level. There is a worldwide race for 5G, which is currently won by China, that is prepared for the advent of the new technology.

5G mobile networks will be able to offer a wide range of technologies and services at unbelievably high speeds with lower latency. These technologies and services will support existing devices, such as smartphones, computers, tablets, new "smart" devices and Machine-to-Machine (M2M) communications and the Internet of Things (IoT). Substantial technologies are going to star in the future networks, such as Software Defined Networking (SDN), Network Function Virtualization (NFV), Cloud Computing, Massive Multiple Input Multiple Output (Massive MIMO), Cognitive Radio (CR), Ultra-dense deployments.

The main challenges concern higher data rates, ultra-low latency, high reliability, security and higher capacity than the current 4G ones. 5G will reach 1000 times the systems' capacity, 10 times the spectral efficiency, the energy efficiency and data rates and 25 times the average cell rate compared to what today's network provide.

In this paper, the main technologies that are going to star into the next generation of mobile networks authors are reviewed. The most vital parts and the most discouraging drawbacks are considered, the issues that need to be solved and the needs of the 5G networks are pinpointed. The current state of each key enabler is presented and several ideas for future investigation are listed.

The remaining part of this paper is structured as follows: In Section II, the most important points of 5G, namely the requirements, needs, advantages, disadvantages and current state and projects are analyzed. In Section III, the key 5G enablers that are the technologies that will meet the 5G goals. In Section IV, the main technologies are contrasted. In Section V, the main conclusions are summarized and future research activity in the field is proposed.

II. 5G

In this section, the most important issues, concerning 5G milestones, requirements, needs, advantages and challenges are presented.

A. Requirements

Requirements concerning the 5G mobile communication networks are:

- **High data rates:** 5G networks should support data rates around 10 Gbps.
- **Low latency:** The latency should be around 1 millisecond.
- **More intense security:** Connected devices lead to hazards for the network.
- **Low energy consumption:** of both network and devices.
- **Augmented scalability**
- **High reliability:** is critical in many 5G applications and services.

B. Needs

In contrast to previous generations of cellular networks, it is expected that the fifth generation will significantly improve the performance, allowing businesses to exploit a wide range of applications, services and possibilities, such as smartwatches, wearables, autonomous vehicles and Internet of Things (IoT).

- **Entertainment** (e.g., multiplayer gaming, real-time streaming, mobile social media, cloud gaming, in-car entertainment, etc.)
- **Virtual Reality (VR) and Augmented Reality (AR):** a person interacts with the environment in real-time, by using wearables.

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- **Self-driving cars:** The 5G brings services and opportunities.
- **Smart cities:** The creation of a new digital ecosystem will benefit the citizens, as cities will function efficiently and sustainably.

C. Advantages & Disadvantages

It is widely known that people use the mobile networks on a daily basis, since the amount of the devices that use them are augmented. Some of the major benefits are:

- effectiveness and efficiency,
- more bandwidth,
- data rates of 10 Gbps or higher can be achieved, which will support more than 60,000 connections,
- the improved 5G network architecture leads to smoother handoffs.

There are some drawbacks concerning the usage of the 5th generation of mobile technology:

- security and privacy issues yet to be solved,
- less coverage distance,
- worries about possible health and safety problems.

D. Current state

There is no doubt that the 5G mobile communication technology will open a new dimension to our lives and will significantly alter our life-style. This is why many companies have started many tests of the fifth generation wireless technology. Funding will allow the country to become a major player in the development of 5G technology, as India aims to be the leader in 5G technology in Asia.

Vodafone performed the first UK trials in April 2018 using mid-band spectrum and China Telecom's initial 5G build-out in 2018 will use mid-band spectrum as well. Last but not least, the world first service of 5G was in South Korea, as the South Korean telecoms deployed it all at once on the first day of December in 2018.

Worldwide 5G commercial launch is expected in 2020, as much work remains in upgrading the current mobile infrastructure, in order to be able to accommodate 5G technologies, whereas many companies are pushing for launching 5G by 2019.

In 2019 and 2020 it is expected that several Spectrum and Band Arrangements will happen. The Radio Framework and the IMT-2020 Radio Specifications will be presented. And finally, an updated plan will be set for future network enhancement.

III. Technologies

In this section, the technologies that will contribute to the development of 5G are summarized. In Figure 1, the basic 5G key enablers are presented.

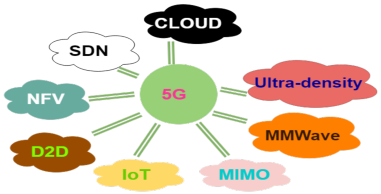

Fig. 1. The most substantial 5G key enabling technologies.

Fig. 2. An Ultra-Dense deployment architectural scheme.

A. Ultra-density

The Ultra-dense structure in the Figure 2 consists of different small cells (picocells, femtocells) that re-use bandwidth. Ultra-dense deployments offer the following benefits to end-users:

- **Higher throughput as well as lower round-trip time.**
- **Improved indoor coverage.**
- **Closed user group access.**

5G has substantial requirements, such as: 50 times more capacity, peak data rates exceeding 10Gbit/s and ultra-low latency below 1msec.

B. Software Defined Networking (SDN)

SDN splits the control and the data plane. There is the application plane, upon which a large amount of applications run. These planes are interconnected and interact with one another. The control plane is the smart part of the network and performs all the orchestration. A basic SDN architecture is presented in Figure 3. The open issues of SDN are [1]:

- **Controlling:**
  - Standardization of the control interfaces
  - Measures to avoid performance degradation
- **Reliability:**
  - Seamless connectivity/connection recovery
  - Security requirements in EPC and RAN

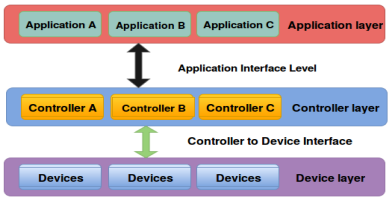

Fig. 3. A SDN deployment architectural scheme. [1]

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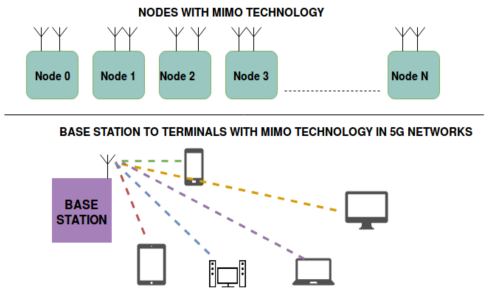

Fig. 4. A MIMO deployment architectural scheme.

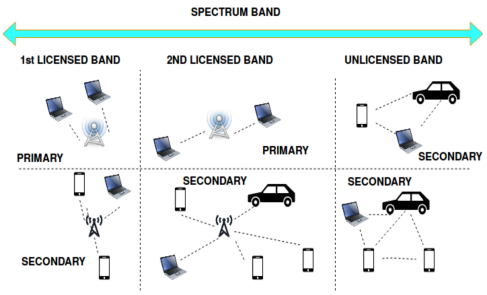

Fig. 5. A CR deployment architectural scheme.

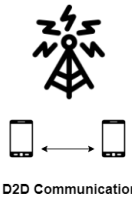

Fig. 6. A D2D architectural scheme.

– Equilibrium among performance, security and flexibility.

C. Network Function Virtualization (NFV)

NFV enables substituting hardware with software. Software or network functions are introduced into the network by using NFVs. These open issues are [1]:

- **Controlling:**
  - Seamless control and provisioning
  - Creation of network granularity policies
- **Reliability:**
  - Seamless and high quality connectivity
  - Virtualization of terminal points
- **Scalability:**
  - Carrier-grade scalability and robustness
  - Openness and interoperability

D. Multiple Input Multiple Output (MIMO)

One of the key 5G technologies is MIMO. This wireless technology includes a number of transceivers and receivers of the signal. Depending on the number of existing antennas, this technology is called MIMO or Massive MIMO. Figure 4 indicates how MIMO technology functions. This technology includes many advantages:

- **Augmented data rates & spectrum efficiency**
- **Quality of Service (QoS)**
- **Greener technology:** Lower energy consumption to the sender's side.

But its most substantial drawbacks are: **More Hardware & Complex software**

E. Cognitive Radio (CR)

On these networks, there are users, who have priority and access the licensed spectrum. There are also other users that perform real-time network status checks whether the licensed spectrum is being used or not. They use the unauthorized spectrum or the licensed spectrum if it is free. Figure 5 depicts the interaction with the network. The CR technology includes several fundamental benefits:

- **Re-usage of available resources**
- **Combination Technology**
- **Tax-free usage of spectrum zones** [2]
- **High-efficient networks** [3]
- **The sub-usage of the frequency zones**

The most important problems are listed below:

- **Need for multi-spectrum antennas**
- **Bigger safety gaps**

F. Device-to-Device (D2D)

Device-to-Device (D2D) is the communication between two mobile users without the Base Stations (BS) or the core network. Figure 6 presents the D2D architectural concept.

- **Basic Characteristics:**
  - **Trusted devices:** D2D allocate closed access to trusted devices in accordance to a list. [4]
  - **Modes:** There are a lot of different modes: Silent, Non-orthogonal Sharing, Orthogonal Sharing, Cellular. [5]
- **Advantages:**
  - **Gains:** D2D offer proximity, reuse, hop and paring gain. [5]
  - **Enables spectral reuse** [5] [6]
  - **Lower interference**
  - **Improvement of the energy consumption and throughput** [6]
  - **Combination with Wi-Fi direct:** Reduces power and delays.
  - **Short distance communication:** allow high spatial reuse.
- **Disadvantages:**
  - **User activity:** Is difficult or even impossible to be controlled.

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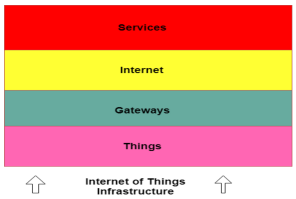

Fig. 7. An IoT abstract architectural scheme.

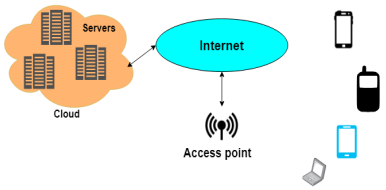

Fig. 8. A basic mobile cloud architectural scheme.

  - **Device Power consumption** [5]
  - **Interference Management** [5] [7]
  - **Co-existence with overlay networks** [5]
  - **Limited Penetration Capability** [8]

G. Internet of Things (IoT)

An IoT architecture varies enough per application. Several efforts of standardizing the infrastructure and the protocols are made. Figure 7 presents the basic IoT architectural concept. IoT is a technology that offers several fundamental benefits in terms of smart cities, e-health, smart homes, etc.

- **Health applications**
- **Specific set EU Guidelines**
- **Smart home applications**
- **Smart cities**
- **Challenges**:
  - **Privacy, Identity Management, Security and Access Control, Standardization and Interoperability, Data deluge**
  - **Security challenges:** Privacy concerns, Regulations and Policy, Violations and Criticism.

H. Mobile Cloud

The mobile cloud consists of: Terminal, Local Cloudlet and the Remote Cloudlet. Virtualization is a service approach that is widely used in Cloud [9]. Figure 8 depicts the basic mobile cloud architecture.

- **Characteristics:** Fairness, pricing approach and utilization period.
- **Types of Cloud:** Remote, Local or Hybrid [10].
- **Services:** Infrastructure as a Service, Platform as a Service and Software as a Service
- **Applications:** Individual, Group, Community, Opportunistic and Participatory Sensing.
- **Advantages:**
  - **Pay as you go**
  - **Data Storage**
  - **Reduction of Development time** [9]
- **Disadvantages/Open Issues:**
  - **Adoption of the operators:** offer cloud services to their clientele.
  - **Data security:** is debated and required by users.
  - **Cloud RAN problems:** Limited capacity, Insufficient and low utilization. [10]
  - **Base Band Unit (BBU) problems:** The BBU is low- compatible, inefficient and inelastic. [10]

I. Milimeter Wave (MMWave)

MMWave (30-300GHz) rends the under-utilized and unused bands of spectrum usable and connects more users.

- **Basic Characteristics:**
  - mmWave channel and beamforming technologies,
  - The 28 and 38 GHz will be the used bands,
  - 40 GHz is going to be the most possible one
  - The effective cell radius is 220m. [11]
- **Advantages:**
  - **More effective algorithms**
  - **MMWave communications promise to offer gigabit per second data rates**
  - **Digital Beamforming usage**
- **Open Issues:**
  - **Propagation losses**
  - **Delays:** Due to incumbent users that must be removed from the spectrum when it's licensed.
  - **Difficulty in the estimation accuracy** [12]
  - **E-band challenges:** Increased phase noise, limited amplifier gain, need for transmission line modeling of circuit components etc. [13]

IV. Compare & Contrast

In this section, the main technologies should be compared. A Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis is a technique that helps indicating how several facts deriving from external or internal factors could be either helpful or harmful to achieve a goal or promote a product. Strengths and Opportunities are both helpful deriving from internal and external factors respectively. Weaknesses and Threats are both harmful and derive from internal and external factors respectively.

In the following section, a SWOT analysis Table I lists the Strengths, Weaknesses, Opportunities and Threats that are pinpointed concerning the 5th generation of mobile networks and its adoption.

Table II includes the evaluation of the 5G key enablers. The technologies are compared in terms of the following features:

- **Cost:** Although, most technologies reduce the costs, several of them include augmented Operational Expenditures (OPEX) costs. MIMO induce larger OPEX since

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TABLE I. SWOT ANALYSIS OF 5G ENABLERS.

	Helpful	Harmful
Internal origin	1) **Better usage of Bandwidth (BW) (mmWave, Ultra-density, CR)** 2) **Network control & Management (CR, SDN)** 3) **Cost reduction (NFV)** 4) **Serve more users (MIMO, Ultra-density, SDN)**	1) **Interference (mmWave, Ultra-density, MIMO)** 2) **Need for Standardization (NFV, SDN, MIMO, CR, IoT)** 3) **Network attacks (SDN, IoT, D2D)** 4) **Need for marketing so that users adopt them (D2D, IoT, Ultra-dense)**
External origin	1) **5G implementation** 2) **More users imply more needs** 3) **Augmentation of data streams** 4) **Social media usage** 5) **Novelty**	1) **Augments expenditures (Ultra-dense, MIMO)** 2) **Create insecurity to users (D2D, IoT)** 3) **Difficulty to spread widely (SDN, NFV, D2D)**

an augmented number of antennas is needed, while in MMWave the BW used is more expensive.

- **Scalable:** Most technologies induce expendable characteristics, since it's very easy to add more network components or expand the network in a very easy way using less configuration. D2D and MIMO are not scalable since it's not easy to add more components (including ✓)
- **Efficiency:** Most technologies are very efficient and enhance the usage of resources in the network. (including ✓)
- **Coverage:** Most technologies cover the network offering more resources or reallocating the existing ones. (including ✓)
- **Capacity:** Most technologies offer augmented capacity. (including ✓)
- **Heterogeneous:** Some of the technologies (including ✓) cooperate well with others.
- **BW:** Some of the proposed models need more bandwidth to operate, while others are able to reallocate or better allocate the existing one. The Table II includes the: **reallocate**, which means that BW is reallocated, **need** means that more BW is needed for the network to operate properly, and the NFVs include **virtual** BW, because in these technologies the network resources are virtual, cheaper and efficient.
- **Cognitive:** Some of the technologies appear to be cognitive, namely they learn by the network's behavior and are exploiting data offering more resources in places needed. The **Statistics** are used in order to better allocate the resources. The Cognitive Secondary BSs have several capabilities and are able to check whether they can transmit to a bandwidth zone or not. **Cognitive SBSs**
- **Appeared:** The time frame in which a technology widely appeared in research.
- **Adoption:** The adoption level of each technology nowadays. **Little** means that is not widely adopted, while **Future** means that will be introduced in the future and **Large** means that it is already widely adopted in a large scale.
- **Standard:** For some technologies, standardization activities explain the solution's basic functionalities, while there are not standards for others (none). In Table II the standardization organizations are pinpointed.
- **Technology Readiness Level (TRL):** includes how "ready" is the technology to start functioning right now and follows a widely known technique, called TRL. It scales from 1 to 9 and the larger numbers mean that the technology is ready.
- **Reduced time:** Some of these solutions reduce the time needed (including ✓) in order to be introduced in the market.
- **Network management:** Some of the networking technologies are useful in order to manage the network (including ✓).
- **Interference:** The degradation of the signal happens to some technologies (including ✓).
- **Power:** The power consumption is augmented for some technologies and it induces several operational expenses (including ✓).

V. Conclusions & Future Work

Many different technologies, e.g., SDN, NFV, Cognitive Radio, MIMO, Massive MIMO, IoT, D2D, Cloud Computing, MMWave etc., are indispensable and therefore, are key enabling technologies for the 5th generation of mobile networks. These technologies have great advantages and

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TABLE II. EVALUATION OF THE BASIC 5G ENABLERS.

Factor \ Solution	SDN	CR	Cloud	Ultra-dense	MIMO	D2D	IoT	NFV	mmWave
Cost	Reduced	Reduced	Reduced	Reduced	Increased	Reduced	Reduced	Reduced	Increased
Scalable	✓	✓	✓	✓			✓	✓	✓
Efficiency	✓	✓	✓	✓	✓			✓	✓
Coverage	✓	✓				✓		✓	
Capacity	✓	✓	✓	✓	✓	✓		✓	✓
Heterogeneous	✓	✓	✓	✓		✓	✓	✓	✓
BW	reallocate	reallocate	reallocate	reallocate	need	need		virtual	reallocate
Cognitive	Statistics	Cognitive SBSs							
Appeared	2011	1999	1996	2007	1970	2008	2008	2012	2017
Adoption	Little	Future	Little	Little	Large	Little	Little	Little	Future
Standard	OpenFlow	IEEE	Many	3GPP	IEEE	IEEE	None	Many	IEEE
TRL	8	7	9	9	9	9	9	8	8
Reduced time	✓	✓	✓					✓	
Network management	✓	✓						✓	
Interference				✓	✓	✓		✓	✓
Power	✓	✓	✓		✓		✓	✓	✓

there are several open issues that need to be addressed. The MMWave and MIMO technologies appear to have augmented OPEX. The MIMO and D2D technologies need more BW to be reallocated. The power consumption of the IoT, D2D and MIMO should be reduced.

Therefore, several solutions and algorithms of the new technologies need to be introduced. What is more, the CAPEX of all the technologies should be limited so that providers adopt these technologies.

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