Next Generation 5G Wireless Networks: A Comprehensive Survey

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Abstract—This article summarizes a review of the evolutionary process towards 5G wireless networks. The most important problems that networks face today are highlighted, as well as the changes that will be introduced to keep pace with modern technologies but also the vision of the main operators interested in 5G. The objective is to shed light on the different visions that revolve around 5G networks: what are the main building blocks of 5G architectures? what are the main challenges and how to face them? Referenced readings note that it is only by meeting most requirements that 5G networks can provide perfect service, super reliable communication and massive connectivity. Therefore, the most demanding part of the 5G revolution is the design of a flexible system that respond to all the requirements and allow successful integration and management of various distinct technologies optimized for different use cases.

Index Terms—5G, RAN, mm-Wave, QoS, IoT, IoV, D2D, SDMA, LOS, NLOS, SDN, TDD, LTE, HetNets, MiMo, CoMP, BS.

1 Introduction

The generations of wireless communications 1G, 2G, 3G and 4G are part of a technological continuity: each new generation brings an evolution to the previous one. But with the increase in wireless data demand by the new set of applications (usually multimedia and cloud applications) and the rapid growth in the use of smart devices, a new load has been created on existing cellular networks. Thus, a new technological breakthrough was born. This new standard of mobile wireless technology aims to:

- Provide very high data debits (Gigabits per second);
- Lower latency;
- Increase the capacity of BS (base station);
- Improve QoS.

In this article, we will review the evolution of wireless technologies towards the fifth generation. First, we will list the problems and challenges of existing cellular networks, then we will summarize the vision and motivation behind 5G from several operators and suppliers; Next, we discuss the architectural changes required for this new technology, including the evolution of the radio network, next generation smart antennas but also the advantages of SDNs, cloud RANs and HetNets; Finally, we summarize all this in a conclusion including some research perspectives.

1.1 Existing technologies: Problems & Challenges

In recent years, the use of mobile cellular networks has taken a large place in our daily life, it increased by 70% in 2014 according to the Visual Networking Index (VNI) 2015 of Cisco, the same index predicts that cellular networks will have more than half of the devices connected as smart devices before the year 2019. This increase has also led to an exponential growth in multimedia traffic (since 2012, video traffic represent more than half of global mobile traffic).
In addition, the current LTE (Long Term Evolution) networks could not support all the new applications that floated on the surface: IoT (Internet of Things), IoV (Internet of Vehicles), eHealth and financial technologies. In addition, the introduction of new R&D activities, such as MIMO (Multiple-Input and Multiple-Output), small cells, CoMP (Coordinated Multipoint) transmission, HetNets (Heterogeneous Networks) and smart antennas have made it possible to start the deployment of 5G architecture. Another essential key towards the next gen 5G systems is the unexplored cellular spectrum, or what researchers call the mm-wave bandwidth, which can take wireless communications to the next level.

1.2 5G visions

The capacity of wireless communications depends on 2 main elements:

1) Spectral efficiency and bandwidth;
2) Cell sizes.

The latter are already present in small sizes and cannot be reduced, hence the key to improving said capacity lies in bandwidth, in particular, most of today's cellular networks use the sweet spot band or the beachfront spectrum (between 300 MHz and 3GHz) due to its reliable propagation characteristics over different radio environments. But with all the R&D results mentioned in the section above and the existence of a large part of the unused mm-Wave spectrum (3 to 300 GHz) and also the experiences of several fields (such as the Federal Communication Commission of the United States, radio astronomy and airport communications), the major researches in wireless technology have set up 8 requirements for 5G technology, that will fulfill its objectives (Capacity, Connectivity, Reliability and Latency):

1) Rates of 1 to 10 Gbps in real networks;
2) 1 ms round trip latency;
3) High bandwidth in the unit area;
4) Capability of connecting massive number machines including smart devices;
5) 99.999% perceived availability;
6) Almost 100% coverage for connectivity "anytime and anywhere";

7) Reduction in energy usage by almost 90%;
8) Reduction in power consumption by devices.

Based on these 8 requirements, different large industries and research organizations have started to collaborate to define their vision of 5G, and we list here some of these different visions of telecommunications providers and operators:

- Qualcomm (American multinational telecommunications Equipment Company) has started to develop a platform unifying 4G and 5G technologies in parallel with the aim of improving costs and energy efficiency while enabling a new range of services.
- METIS (Mobile Wireless Enablers for the Twenty-Twenty Information Society) and Horizon 2020 (The EU's largest research and innovation program), which is a project launched and funded by the EU, started from 2012 with the objective of:

  1) Exploring new paradigms and concepts of systems;
  2) Optimizing and standardizing this new technology;
  3) Implementing the 5G system in Europe.

  The project structure includes several suppliers (Alcatel, Ericsson, Nokia, Huawei, and NSN) with the help of the four main European operators: Deutsche Telekom, Orange, Telecom Italia, Telefonica and DOCOMO (telecommunications operator predominant in Japan).
- Nokia Future X vision has focused on defining a new spectrum, which will allow 5G systems to be flexible according to the different cell ranges, carrier frequencies and antenna technologies. They also focused on minimizing the need for long and costly post-deployment integration.

2 The new 5G architecture

The deployment of 5G technology with all the challenges that cellular networks face today will require a gradual transition from the current model, which is the BS (base station) centered paradigm to the user model. This new network architecture will transform the role of the end-user in wireless communications into a contributor to the transfer and delivery of content within networks. In this section, we will discuss some of the requirements of this new architecture.

2.1 Radio Network evolution, Advanced Air Interface and Smart Antennas

With the introduction of mm-wave frequencies, new rules will be defined for 5G cellular network structures. But with a highly reflective external environment, the propagation of these signals is very limited, so the new model will need a new conception of the arrangement of the nodes. To this end, Rappaport TS (founding director of NYU Wireless) and his group offer several models of site node mapping to help reduce the reflection of mm-waves, for instance:

1) High density deployments are required for areas requiring high data rates, such as metro stations and shopping centers.
2) Line-of-sight (LOS) propagation paths are preferred to non-line of sight (NLOS) ones.
3) The reflected and broadcast NLOS signals can be used when the LOS signals are completely blocked.

In addition, 5G networks must allow a wide range of devices, users and services to communicate with each other. Therefore, the interest of Farooq and his team for Samsung Electronics has been to find a way to integrate 5G with other cellular networks (4G, 3G). To this end, they proposed hybrid structures (millimeter waves integrated into 4G networks) as well as independent structures, which would allow the user to switch between the two networks for a better experience. These mixed structures can also be used to separate data and information controls so that the millimeter wave spectrum is used to provide data while system and control information is transmitted over 4G networks. On the other hand, millimeter wavebands offer a promising option for connecting small densely deployed Base Stations, they should use small antennas, which will allow a large number of antennas to be used unlike those used today, this will improve the direction of the waves to the desired direction while canceling all other directions (directional air interfaces). The following figure shows this change from omnidirectional to directional.

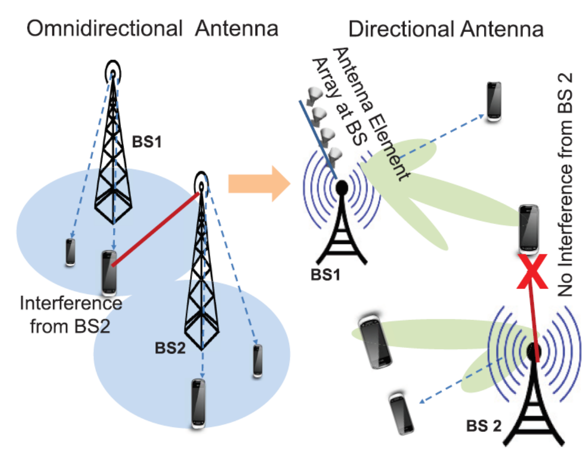

Fig. 1. Omnidirectional Antennas and Smart Beamforming Directional Antennas.

But for all of this, the high power consumption of many signal components can limit these benefits. Many solutions have been discussed in the article, such as the use of mixed structures which incorporate the formation of analog and digital beams or even the division of BS into several segments, which will lead to the relaxation of the material. However, this will pose new synchronization and transmission challenges.

In addition, using different sets of antennas for different ray forming techniques will provide effective performance, for example:

- Horn antennas at the end of the transmitter;
- Patch antennas at the end of the receiver;

- Special antenna networks in high-rise urban environments for the vertical direction of the beam.

These multibeam antennas should explore the SDMA (Spatial Division Multiple Access) capacities, which will result in an increase in the system capacity (reuse of the same frequencies) and in the transmission quality with beams directed towards the BS, this will serve different users in the same region. BS operating outside the limits of these narrowed beams will experience near zero interference from other BS operating with the same radio frequency. And it will help reduce one of the big problems in wireless communications: interference in the same channel. Therefore, an intelligent antenna design, optimized on directional gains, cost and complexity is very important for the development of 5G wireless communications. Hybrid beam forming systems will originate several directional links and will each consist of a number of antenna sub-arrays. These configurations are crucial for the direction of the beam. The following figure illustrates three different possibilities for organizing an antenna sub-network:

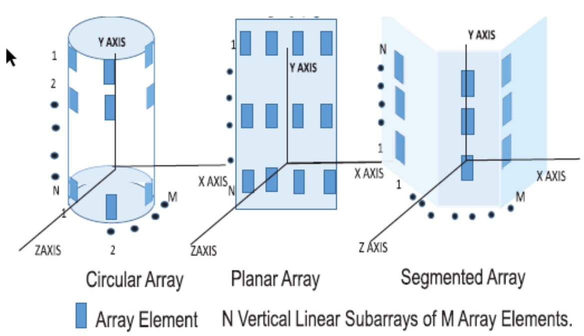

Fig. 2. Three Major Array Configurations for Smart Antennas.

i) Circular
ii) Planar
iii) Segmented

Circular subarrays are better suited for wireless communications due to their improved coverage (curvature allowing wider beam orientation). Linear configurations have better directivity, but their scanning angle range is limited, while simple segmented configurations can also achieve the required level of directionality and range scanning. Generally, horn antennas have higher gains than all other antennas. A sub-array of horn antennas provides the high power required for the BS. Space, size and power are limitations of the mobile device. So the simplest patch antennas are good candidates for the devices.

2.2 SDN and CoMP

All the changes made with the new 5G model and the evolution of radio interfaces, highlight the need to use small cells and increase the number of antennas, but this will create new problems in their configuration and maintenance. With the Software Design Network (SDN), a new simplified solution is proposed, it consists in dividing control (configuration and management) and data planes, thus introducing speed and flexibility in 5G networks, but also increase of the user plane becomes independent of the control plane. The following figure shows the separation of user and control signals.

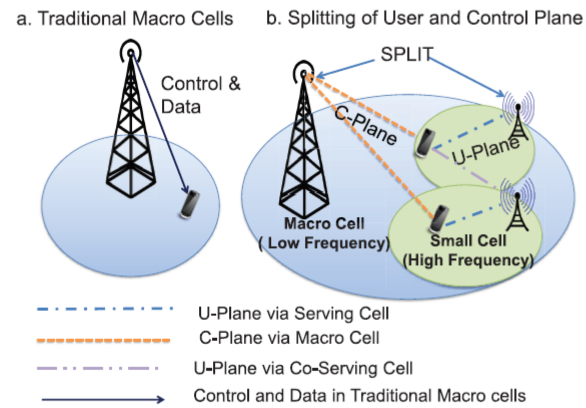

Fig. 3. Control Plane and User Plane Separation.

Multiple BS collaborations will be necessary to improve the data plan, and for that, the coordinated multipoint (CoMP) transmission is the solution suggested in the article, it allows several base stations to interfere collaboratively in the transfer and processing of user data.

2.3 Cloud RAN and HetNets

Cloud Radio Access Network and Heterogeneous Networks are mobile network architectures that could help meet the growing needs of end users. Cloud RAN is a centralized technology, based on cloud computing and virtualization for RAN, it allows large-scale deployment, collaborative radio support and virtualization capabilities in real time. It proposes to improve system architecture, mobility, coverage performance and energy efficiency thanks to its ability to easily manage all complex control processes. It also encourages the sharing of configurable resource pools which minimizes deployment and maintenance costs. Recent research has proposed SDN-based virtual networks with the cloud as the backbone. China Mobile strongly supports C-RAN as it defines new fundamentals for network construction, deployment and flexible network services for end users. Hetnets, on the other hand are networks made up of several types of mixed cells and different access technologies, for example: a typical HetNet uses a combination of legacy communications (GSM) and modern radio access communications such as LTE. The mixture of small, pico and femto cells with the already existing macro cells will lead to an improved and efficient frequency reuse. The following figure shows the concept of HetNets.

But with these architectures, the interference between the different types of cells will increase, the article refers to several interference management solutions, one of them is the reverse TDD (Time Division Duplex) protocol, this protocol makes reference to a duplex communication link where the uplink is separated from the downlink by the allocation of different time slots in the same frequency band. In reverse TDD, the BS mode is in a downlink while the small cells operate in an uplink and vice versa.

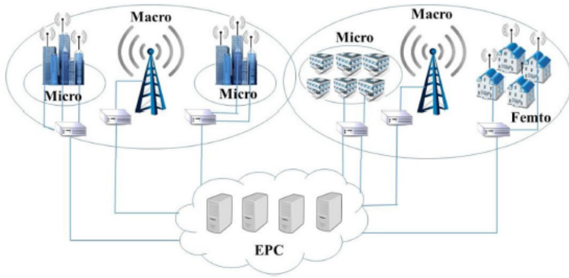

Fig. 4. Coordinating Cells in HetNet Architecture.

3 Conclusion

The proliferation of mobile multimedia services, and the new suite of smart devices and applications has led to an explosion in mobile data traffic. Therefore, communication systems are increasingly facing performance degradation and latency problems. Despite efforts in terms of scaling and developing the actual networks, operators can no longer handle this exponential increase while major keys towards the future such as the millimeter wave spectrum and cloud-based architectures are not integrated into the system. So here comes the time for the new generation of networks to cover the aforementioned problems and also to open a new horizon for the next generation.

Research perspectives

- Mac layer design changes for the 5G networks;
- The challenges facing design and cloud management for networks.

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