Problems of implementing 5 G networks in transport systems

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Abstract
This article provides an overview of the challenges to transport networks introduced by 5G and provides a first analysis of the key challenges to 5G transport in terms of capacity, flexibility and costs. Different use cases are discussed as well as technology options and control plane concepts. The three main transport challenges are identified: huge aggregated traffic volumes, on-demand provisioning of very high capacity in specific geographical locations, need for fast reconfigurability of the transport resources.

Keywords
Wireless access, transport systems, virtualization, 5G generation networks

1. Introduction

In the coming era of the massive 5G Internet of Things (mloT), we are expected to have 1000 devices connected to each person, and these devices will be components of the «5G operating system» for our smart cities, smart homes, smart transportation, smart healthcare, and more.

5G networks are expected to serve about 7 trillion diverse connected sites. Compared to the previous generation of mobile communications, the 5G infrastructure we are building now should reach luggage, people decided to apply them in practice this scale while still delivering the following metrics:

- 1000 times faster wireless zone throughput and more versatile service options;
- creation of a secure, reliable Internet with "zero perceived" downtime for the provision of services;
- 100 times higher user data transfer rate;
- 10x the battery life for massive IoT devices;
- 5 times decrease in end-to-end delay;
- Diverse requirements such as higher speeds for enhanced mobile broadband (eMBB), ultra-reliable and low-cost communications (URLLC), and higher density and long battery life for machine-type mass communications (mMTC) [2].

Based on the challenges for wireless access the main transport challenges are defined. Possible solutions addressing these challenges are also presented and discussed. We find that the transport infrastructure for future 5G deployment needs to both accommodate high traffic volumes over specific geographical areas and provide transport resources in a flexible manner. This quality will be indispensable for operational purposes but also to limit as much as possible deployment costs without

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compromising the quality of experience of the various provisioned services.

In order to understand the 5G transport challenges one must understand how 5G may evolve the radio access segment. Among the various initiatives that are looking into 5G, the EU project METIS defines 5G in terms of scenarios which the next generation wireless access networks will have to support. A total of five future scenarios have been defined, namely amazingly fast, great service in a crowd, ubiquitous things communicating, super real time and reliable connections, and best experience follows you. Each of these scenarios introduces a challenge. Three of these challenges are more traditional in the sense that they are related to continued enhancement of user experience and supporting increasing traffic volumes and mobility. Two emerging challenges, very low latency and very low energy, cost and massive number of devices, are associated with the application of wireless communications to new areas. Future applications may be associated with one or several of these scenarios imposing different challenges to the network. In METIS twelve specific test cases were defined and mapped onto the five scenarios. The selected test cases essentially sample the space of future applications. Once technical enablers that fulfill the requirements for these test cases are defined, it is expected that other applications subject to the same fundamental challenges, will successfully be supported. As a consequence, defining technical enablers for the 5G test cases means also defining technical solutions to the 5G challenges.

Today, 4G offers consumer data rates in megabytes order, latency in milliseconds order and device density for approximately 2000 connected devices per square kilometre worldwide, which has supported the introduction of Internet of Things (IoT). Despite such capabilities and due to an exponential increase of the demand and the new mobile telecommunication innovations, 4G would be replaced with the next generation (5G) by the start of the next decade, as stated in [3].

The 5G era will bring network and service capabilities not previously available. It will ensure continuity, higher data rate, lower latency, massive simultaneous connections and ubiquity of network across the world even in challenging situations for current 4G such as high mobility and in very dense or sparsely populated areas. In addition, 5G will be a key enabler for a real IoT, providing a platform to connect a massive number of sensors and actuators with stringent energy efficiency and transmission constraints [4].

A 5G transport network can be divided in two different segments, i.e., small cell transport and metro (aggregation). The small cell transport segment aggregates the traffic to (from the wireless small cells towards the metro) aggregation segment. Different solutions in terms of technology (optics, wireless) and topology (tree, ring, mesh) are possible [5] depending on the specific wireless access scenario. The metro (aggregation) segment, on the other hand, connects different site types (macro and/or small cells) among themselves and to the core network, the latter via the service edge (service node for the interconnection among different network domains). For the metro (aggregation) segment one promising solution is represented by a dense-wavelength-division multiplexing (DWDM) - centric network [6]. In such a network, packet aggregation takes place at the edges of the network (at the small/macro cells sites and at the service edge), while at the center (between access and metro rings) switching is done completely in the optical domain thanks to active optical elements such as wavelength selective switches (WSSs) and reconfigurable optical add-drop multiplexers (ROADMs) [7]. It has already been demonstrated that DWDM-centric solutions have the potential to offer high capacity (in the order of tens to hundreds of Gbps) and lower energy consumption than their packet-centric counterparts (with packet aggregation at the center of the network) [8]. For this reason the DWDM-centric metro/aggregation concept may represent a good candidate for future 5G transport networks. For the dedicated small cell transport segment it is not possible to define a single best candidate technology because of the variety of the small cell deployments which are test-case dependent. The main options can be categorized in copper, fiber and wireless-based technologies [9]. Wireless based solutions are attractive where cost of deploying wired transport infrastructure is prohibitively high. Copper-based options are able to offer rates in the order of a few Gbps over relatively short distances and therefore can be preferred in the areas where there is a large installed base of copper that can be reused. Optical transmission technologies are able to provide high data rates over long distances in an energy-efficient way. Fiber-based solutions are seen as a good and long term candidate for 5G small cells transport networks [10]. The table is organized in terms of: transport services that can be supported and technology maturity.

The graph shown in Figure 1 shows that the transport solutions used in modern networks, in terms of their throughput, correspond to the level of development of transmission technologies at the end of the 80s. last century.

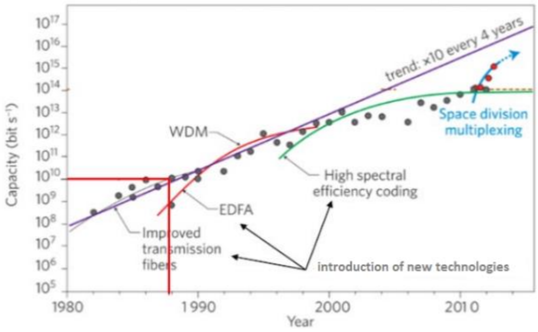

Figure 1. Growth of channel capacity of transport networks.

For some test cases, like the open air festival, optical based small cell transport may not be preferable, due to high deployment costs. In these cases, wireless-based solutions may represent a better alternative, mainly because they are usually easier, faster, and cheaper to deploy. Modern wireless transport technologies are able to provide very high capacities over short and medium distances, thanks to the introduction of new transmission paradigms, such as MIMO, and the opening of new spectrum ranges.

The use of dynamic resource sharing and NFV puts requirements on the control plane. A software-defined networking (SDN) [11] based control plane with programmable control of network resources and end-to-end orchestration could provide a framework for such a scenario. It could enable dynamic optimization of the use of transport network resources and provide a framework for interaction with other controllers [12]. On the other hand, the design and implementation of such a complex control plane introduces several challenges. A main challenge is the definition of an orchestration entity able to keep track of the availability of different type of resources and perform end-to-end optimization. A centralized orchestration entity leads also to scalability issues, which could be addressed through the adoption of a multilayer control architecture and resources abstraction models. Different multi-layer SDN-based control architectures are possible depending on how the controllers of different segments are expected to interact. The dedicated small cells transport controller manages the resources in the dedicated small cells transport network and provides the overall transport controller with an abstract and simplified view of this network segment. The overall transport controller is in charge of managing all the transport resources and providing connectivity services to the other controllers. The controllers interact via the orchestrator, which possesses an abstract and simplified view of all the resources and performs end-to-end provisioning and optimization.

Long-term economic prospects show that prosperity among urbanites will also grow, and therefore the demand for public and individual transport will increase.

Consequently, car ownership is likely to continue its rapid rise. China alone gained an additional 17 million new cars in 2014, taking ownership to a record 154 million. As an obvious consequence, road traffic congestion can be expected to become more intricate, further exacerbating already high negative environmental, social and economic impacts.

Information and communications technology can mitigate these impacts. Applications of information and communications technology in the transport sector, have led to the development of so-called “intelligent transport systems” (ITS). ITS improve traffic efficiency and safety, with positive outcomes for sustainable development. Though driven initially mostly by the more advanced countries (United States, Japan, and some European countries), ITS are increasingly being used by developing countries, which are confronted with urgent needs to improve traffic in rapidly growing cities. ITS are also becoming increasingly tailored to the specific needs of developing countries, and recent evolutions in information and communications technology such as the analytical power offered by open and big data further raise the prospects for ITS to be designed within developing countries in response to their specific needs.

Even though 5G technologies have not yet hit the market, there is a great expectation of all the possible applications that will arise thanks to their qualities, in many cases improving the services presented by the previous networks but in other cases bringing new and more innovative services never seen before.

The emerging concepts of the Internet of Things, Smart Cities, and Intelligent Transportation Systems are three of the main paradigms that will be promoted with the appearance of 5G technologies. At the moment it has been possible to reach a basic level of services based on IoT due to

the limitations of 4G technologies, but thanks to the possibilities of network availability anywhere, at any time with a higher data rate, we could finally have a real connectivity among a dense population of mobile devices.
The particular case of Intelligent Transport where vehicles are seen as intelligent mobile devices capable of connecting to the network to share information of their environment is a topic with a great impact within the intelligent planning of resources into a Smart City. In fact, for governments and modern economic development in general is vital to improve the transportation management system and promoting sustainability. The optimization of the transportation system will result in a reduction of the environmental impact and energy saving, as well as time and money.
Despite all the great advantages that show the coming of the 5G era and of the IoT, there are still problems to face in the technological field. There are also social and ethical problems related to the inclusion of new services that will not be easy for the population to assimilate, as it is the case of self-driving vehicles inside the city and possible undue access to personal information of the users due to the fact that all our data will be shared in the cloud. Such problems are related to security, but seen from the side of avoiding fatal accidents in one case and in the other hand seen as protection of private information.

2. Conclusion

This article provides an overview of the challenges to transport networks introduced by 5G and provides a first analysis of the key challenges to 5G transport in terms of capacity, flexibility and costs. Different use cases are discussed as well as technology options and control plane concepts. The three main transport challenges are identified:
- huge aggregated traffic volumes,
- on-demand provisioning of very high capacity in specific geographical locations,
- need for fast reconfigurability of the transport resources.

Two approaches for designing and dimensioning a future 5G transport network have been considered. One is based on over-provisioning of transport resources while the second is based on dynamic resource sharing and network function virtualization (NFV) aided by a software defined network (SDN)-based controller. These two approaches have been compared in two specific 5G test cases:
- virtual reality (VR) office,
- open air festival.

The analysis highlighted that the use of a common DWDM centric access metro network combined with a dedicated small cell transport can be an efficient choice for the future 5G transport. In addition, a SDN-based transport controller, able to efficiently perform dynamic resource sharing and NFV, helps in achieving high resource utilization and in reducing deployment costs. 5G mobile communications is seen as the enabler for the networked society where connectivity will be available anywhere and anytime to anyone and anything. The details of 5G are the subject to ongoing research and debate, mostly focused on understanding radio technologies that can enable the 5G vision.
Let's define a list of potential problems of the transport network for 5G and label each of them as serious, moderate, or minor (ranking in descending order according to the percentage).

1. Major challenge:
- meeting ultra-low latency requirements – 57%
- costs of extending wireline connectivity to new cell sites (densification)- 40%
- achieving RAN capacity requirements – 39%
- meeting timing and synchronization requirements – 36%
- costs of upgrading existing RANs – 35%
- network automation – 31%
- implementing network slicing in the transport network – 28%
- implementing cloud/virtualization of BBU functions – 21%
- compatibility of new and legacy protocols (i.e., MPLS/segment routing/EVPN) – 19%

2. Moderate challenge:
- meeting timing and synchronization requirements – 51%
- network automation – 51%
- implementing network slicing in the ransport network - 51%
- achieving RAN capacity requirements – 48%
- compatibility of new and legacy protocols (i.e., MPLS/segment routing/EVPN) – 44%
- implementing cloud/virtualization of BBU functions – 43%
- costs of extending wireline connectivity to new cell sites (densification) – 37%
- costs of upgrading existing RANs – 37%
- meeting ultra-low latency requirements – 33%

3. Minor challenge:
- compatibility of new and legacy protocols (i.e., MPLS/segment routing/EVPN) – 32%

- implementing cloud/virtualization of BBU functions – 29%
- costs of upgrading existing RANs – 23%
- costs of extending wireline connectivity to new cell sites (densification) – 17%
- implementing network slicing in the transport network – 16%
- meeting timing and synchronization requirements – 14%
- network automation -13%
- achieving RAN capacity requirements – 11%
- meeting ultra-low latency requirements – 9%.

Meeting ultra-low latency requirements has become a major challenge in the design of backhaul networks for 5G, and by a wide margin. Low latency needs can be met with dedicated high-speed optics, but costs quickly undermine economic viability. Packet technologies are more bandwidth efficient and less expensive, but guaranteeing latency is an issue. This is the transport network dilemma.

We note that 80 percent of backhaul delay is dependent on fiber distance, so reducing the distance between the core network and the user is the best way to reduce latency. The latency of devices in the transport network is important when congestion occurs. Thus, the cross-section of the network can be used to prevent overload and ensure low latency.

After low latency, expanding wired connections to new cell sites and meeting RAN bandwidth requirements came in second and third, cited as a major issue by 40% and 39% of respondents, respectively. These concerns are also consistent with anecdotal evidence and are directly linked to the cost issues associated with meeting performance / capacity requirements without disrupting the business model. Automation took the bottom half of the list. However, it is unclear if this is due to minimal automation issues or the fact that automation is not particularly relevant in the near future, since everything will focus primarily on building infrastructure.

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