Chapter 1

Introductory Chapter: Next Generation of Broadband Networks as Core for the Future Internet Societies

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Additional information is available at the end of the chapter

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1. Introduction: evolution of the needs for "broadband"

The Internet traffic is an ongoing explosive increasing from year to year, so that the annual global IP traffic surpassed the zettabytes threshold in 2016. Furthermore, it is predicted that the overall IP traffic will grow at a compound annual growth rate (CAGR) of 24% from 2016 to 2021 [1]. Different factors are alimenting this growth, such as the increasing number of connected devices from different types, as illustrated by **Figure 1**. This continuous growth has a big impact on different level of networking, such as the wide area network, metro (metropolitan) network, access networks and the home (in-house/in-home) networks. Along the evolution of telecom networks, the access networks were always the "weak point" of the infrastructure and therefore referred to as "the bottleneck". Consequently, one of the first challenges in the era of Internet is the realisation of high-speed "broadband access networks". Basically, the concept and the term "Broadband Communications Networks" refers to any type of networks/access technologies used by Internet Service Providers (ISP) to provide a broadband Internet access for a multimedia content delivery/distribution according to technical considerations and requirements such as guaranteed Quality of Service (QoS). So many technologies were/are developed to support Broadband Communications in different connection forms such as Dial-up, Digital Subscriber Line (DSL), Optical fibre, cable, Broadband over Powerline, Mobile and wireless Internet access and satellite Internet. There are also quite a few other broadband options available for the Internet connection. Both wired and wireless broadband solutions exist, but none is universally considered optimal for all use cases and products configuration. In fact, the quantification of the meaning of "broadband access" in Mbps is evolving with the time depending on user-experiences in using or consuming the offered data services. With the apparition of the notion "broadband" access, systems had to guarantee at least a capacity of 2 Mbps. This was achieved in a first stage through the successful rollout of Asymmetric Digital

Subscriber Line (ADSL). With the increasing data traffic, the fastest version of DSL, Very high bit rate DSL—VDSL, has partially fulfilled the requirements of intensive data traffic by offering 25 Mbps, but it is limited by the weak coverage of its signal transmission, which does not go over 300 m. Currently, it is expected that the speed of broadband access will merely double by 2021, so that the global fixed broadband speed will reach 53 Mbps, up from 27.5 Mbps in 2016 [1].

The classical paradigm requiring the high speed for downlink connection, which was the reason for the success of ADSL, is not valid anymore for the current broadband access networks. For the cloud services, the end-users also need high-speed uplink to be able to upload their data to the cloud server(s). Furthermore, services and businesses based on big data are nourished by huge data volumes, which are collected in different forms (video, location information, sensing information, software logs, etc.). These two aspects concern both wired as well wireless network access.

The realisation of broadband for downlink and uplink can always be achieved by using optical fibres in the access domain guaranteeing very high speeds. However, it remains in most case economically unfeasible/unprofitable. Thus, the deployment of fibre in access networks, either as fibre-to-the-home (FTTH) or through fibre-to-the-building (FTTB) remains low and extremely different from one country to another, even in the industrial western countries. For example, according to most recent statistics from FTTH Council Europe, fibre access penetration in France does not go over 14.9% of households (with 3% through FTTH and remaining 11.9% through FTTB); while in Germany, this rate reaches 2.3% of households (with 1% FTTH plus 1.3% using FTTB) [2].

Beside the high speeds, the mobility is the second major key requirements of today's society, which makes from the "Broadband Mobile Internet" the headache for mobile operators. The age of Mobile Internet has started with the Universal Mobile Telecommunications System (UMTS), i.e. the third generation of mobile communications—3G. However, this start did not reach the expected success. Among the main causes for this start failure, two facts can be cited:

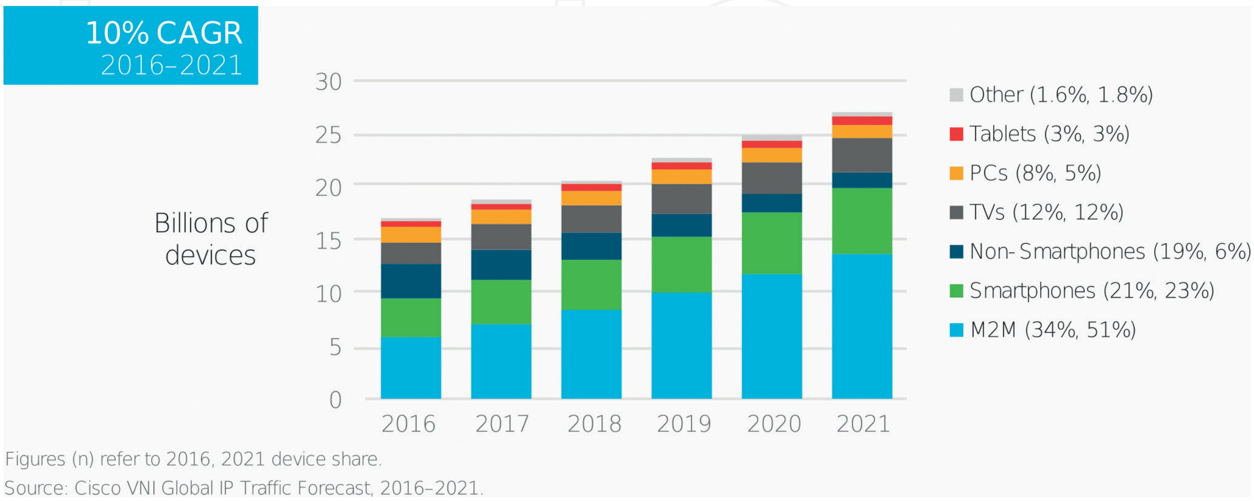

Figure 1. Global devices and connections [1].

Technically, UMTS was designed to offer up to 2 Mbps for the end-users; however, in the field only about 300 kbps were possible. From the economical aspect, the fees of spectrum licences have reached some astronomical levels that bring strong imbalance in the business model.

The failed targets of 3G were partially corrected through the new versions of UMTS, like the High-Speed packet Access (HSAP or 3G+, some references use 3.5G). However, the real breakthrough of mobile broadband has been brought by the fourth generation of mobile technology based on 3GPP Long Term Evolution (LTE) that allows capacities up to 300 Mbps. This speed increased significantly with the extension to LTE-Advanced and LTE-Advanced Pro (referred to as 4.5G). With the successful rollout of 4G around the world (except in some developing countries), the mobile broadband data traffic grew 70% between Q1 2016 and Q1 2017 and a further stronger increase in number of mobile/wireless connected device at their generated traffic is foreseen for the next years [3].

Mobile communications are experiencing a major revolution catalysed by the change in the way our today's society creates, shares and consumes information. While the preparation for massive deployment of 5G by 2020 is still ongoing, researchers are already talking about the "Beyond 5G" (B5G) mobile communications era. It is widely agreed that B5G network should achieve greater system capacity (<1000 times) in terms of data rate (terabits per second) and user density (the Internet-of-things and nano-things) [4]. Accordingly, three ways are considered to realise several orders of increase in throughput gain: the extreme densification of infrastructure, large quantities of new bandwidth and a large number of antennas, allowing a throughput gain in the spatial dimension.

2. Changing applications landscape

The telecommunications operators, especially the mobile services providers, have experienced one of the main mutation in the telecom markets, as the voice-dominated services are no longer making the main revenue for their business. In fact, in the period between 2006 and 2008 the operators' revenues were data dominated. At that period, the data traffic started its exponential growth, while the price stagnated accompanied with the economic recession. To balance their business model, operators started to converge their infrastructure to all-over-IP services, by the elimination of the circuit-switched infrastructure, which requires high OPEX and a wasting resources/bandwidth per excellence [5]. This was triggered by the adoption of 3GPP LTE as fourth generation mobile technology that transmits the voice service over IP packets (VoIP). The rollout of 4G has solved the main challenges that were facing the operators, but in the after-4G era, new challenges and requirements must be met such as more bandwidth, shorter latency and ultra-high reliable (UHR) communications. This is resulting either from new services/businesses or caused by a change in user or societal behaviour. As major pillars in new services or applications, we can cite the video, smart cities, big data and Mobile Big data (MBD), Internet-of-things (IoT), Car-to-X communications or Internet-of-vehicles (IoV), etc.

According to the mobile traffic analysis by application, the increased viewing of video on mobile devices, embedded video and emerging video formats will extremely drive data consumption; as stated in the recent Mobility Report [3]. As stated in this report, mobile video traffic is forecast to grow by around 50% annually through 2023 to account for 75% of all mobile data traffic. Social networking is also expected to grow—increasing by 34% annually over the next 6 years. However, its relative share of traffic will decline from 12% in 2017 to around 8% in 2023, as a result of the stronger growth of video traffic. The position of video in mobile data consumption is illustrated in **Figure 2**. Furthermore, streaming videos are available in different resolutions to increase the user experience and satisfaction by using more high-resolution videos, which will certainly affect data traffic consumption to a high degree. Accordingly, watching HD video (1080p) rather than video at a standard resolution (480p) typically increases the data traffic volume by around 4 times. An emerging trend with increased streaming of immersive video formats, such as 360-degree video, would also impact data traffic consumption. For example, a YouTube 360° video consumes 4–5 times as much bandwidth as a normal YouTube video at the same resolution [3]. In addition, the emergence of new applications and changes in consumer behaviour can shift the forecast relative traffic volumes.

The world knows currently a strong urbanisation of today's societies, where more people are living in cities than in rural areas. This generates a pressure on different resources, which are always available or generated in limited volumes and/or capacity, such as energy, water, road, spaces, transport means, hospitals, etc. Therefore, the decision-makers developed roadmaps for building smart cities, with the goal of an optimal generation and utilisation/consumption of these resources. The roadmaps differ from one country to another, but they all agree that the Information and Communications Technologies (ICTs) platforms will constitute the core of these smart cities. In some visions, smart cities consists in developing different smart domains, such as smart grid, smart parking, smart building/homes, smart education,

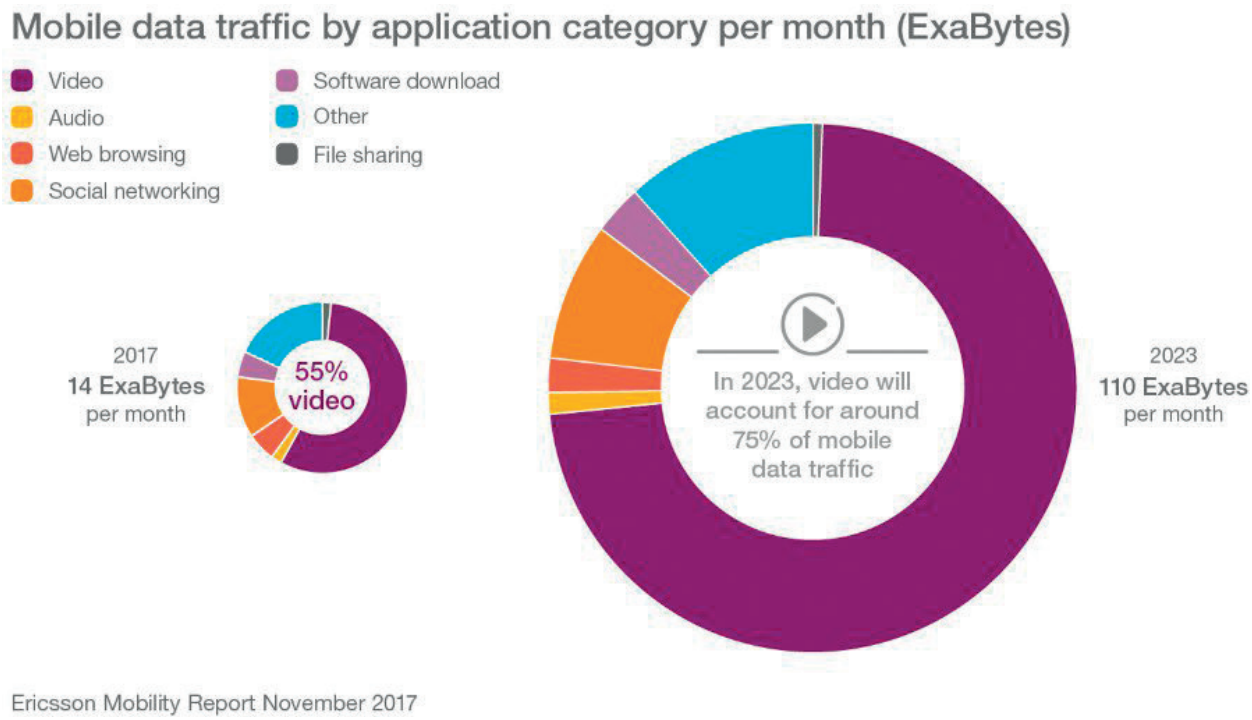

Figure 2. Increasing dominance of video content in mobile data [3].

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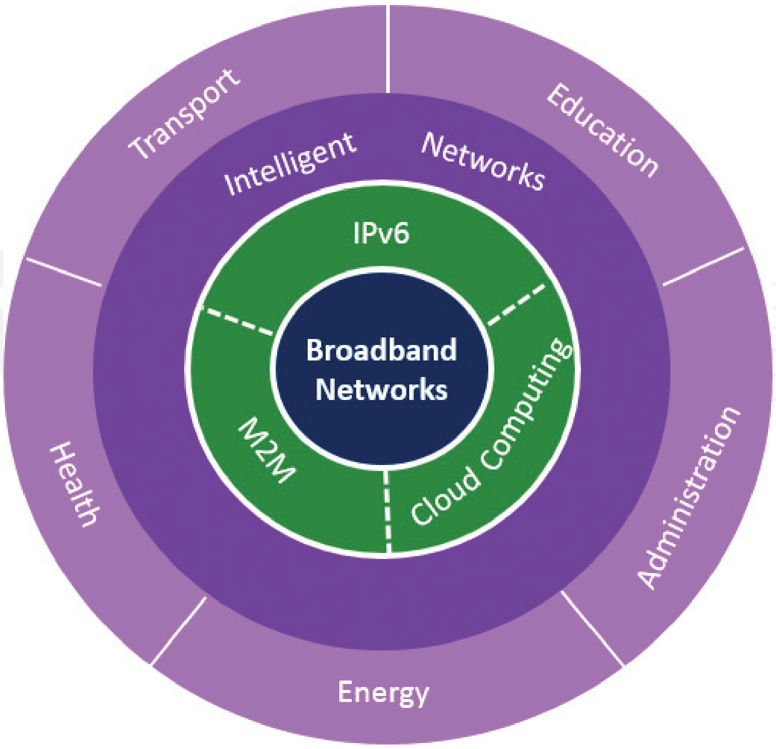

Figure 3. Broadband networks as core of future smart cities – German government's point of view [6].

e-administrations, etc. One of the visions is depicted in **Figure 3**, representing an early version of the smart cities from the German government's point of view, where broadband networks are the cornerstone in the ICT infrastructure [6]. A more complex and detailed recent version of this structure, which includes security and big data, can be found in [7].

3. Technologies to build the next generation of broadband networks

In spite of the above-cited challenges, the future mobile generation (5G) has found new emerging technologies to overcome all the boundaries, as explained in different chapters of this book. As key technologies of 5G, we can cite massive multiple-input multiple-output (massive-MIMO), network densification (or Ultra Network Densification), Cloud-based Radio Access Network (C-RAN), virtualisation, improved energy efficiency by energy-aware communication and energy harvesting, etc. However, mobile/wireless communications alone cannot be successful without the support from optical fibre, especially for the backhauling. This later is one of major parts of 5G as well as new spectrum parts, among others. The issues related to backhauling in 5G are discussed in Chapter 4 "5G Backhaul: Requirements, Challenges, and Emerging Technologies" and Chapter 5 "Radio Access Network Backhauling Using Power Line Communications", while spectrum issues are discussed in Chapter 3 "Spectrum usage for 5G mobile communication systems and electromagnetic compatibility with existent technologies".

One of the key success factors of next mobile broadband networks is the finding of new locations in the spectrum (Unlicensed, mmWave and THz). In a first step, operators have started to restructure their network to offload their traffic in the unlicensed bands. The 3GPP new technologies of Licenced Assisted Access (LAA) and LTE in unlicensed band (LTE-U) employ an unlicensed radio interface that operates over the 5 GHz unlicensed band to leverage the radio resources for operators' transmission [8, 9]. In a second step, to overcome the increase demand for wireless communication and scarcity of the spectrum bands, new land or parts of the spectrum are currently under exploration. Specifically, millimetre-wave (mmWave) communications systems (30–300 GHz) have been officially adopted in the fifth generation (5G) cellular systems, and several mmWave sub-bands have been allocated for licenced communications. However, the total consecutive available bandwidth for mmWave systems is still less than 10 GHz, which makes it difficult to go to the next step of the evolution and support data rates of the terabit per second. This pushes the researchers' community to explore the terahertz band (0.1–10 THz) communication, which is now envisioned as a key wireless technology to fulfil the future demands within 5G and beyond. Detailed discussion of this topic is given in Chapter 9 "Atmospheric attenuation of the terahertz wireless networks".

Optical fibre is forcing its way to go beyond the backhauling domain and FTTB, since so many countries have recognised the importance of high-speed broadband networks. The passive version of optical access network had a big part in lowering the deployment costs, besides the utilisation of software defined network (SN) technology. Discussion of the aspects related to "how to force the way for fibre" near to the end-user can be found in Part 2 of the book.

4. Conclusion

Broadband communication networks are currently a real need for today's society, and not more just a trend or luxury. In general, there is a lot of conferences and documentation in the literature about Broadband Communications Networks, but only few are interested in making it very transparent and accessible to others according to a broad perspective, cutting across wired/wireless technologies and Internet sectors. For example, what kind of Internet access do we need to have when moving to new Internet-driven applications of business and/or for specific computing contexts/smart environments? High Speed? Broadband? Wireless connection? Satellite? Optical Fibre? Mobile networks? What are the lessons we need to know about the practice in order to get fresh innovative ideas to speed up business operations and to improve every aspect of the human life? What are recent advances and notable emerging technologies, which will make us look beyond the horizon? Providing answers to these questions, based on the latest research and developments of the broadband communications technologies, is the focus of the following chapters.

With all this in mind, drawing on research experiences and lessons from over the globe, this book explores the latest research and developments of the broadband communications technologies associated with broadband communications network architectures in support of many emerging paradigms/applications of the global Internet from the traditional architecture to the incorporation of smart applications.

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