Conclusion and Future Topics

This edited book has provided an overview of new enabling technologies for fiber-wireless (Fi-Wi) convergence in support of 5G mobile transport networks.

In the first part, to introduce the reader to the larger societal and economical ecosystem where transition to 5G is happening, Chap. 1 describes the current market and deployment status for broadband services. A similar, yet more technical, background on the current and evolutionary technical trends of LTE and LTE-A is provided in Chap. 2 that serves also as comprehensive technical introduction to relevant concepts for 5G wireless access. Chapter 3 elaborates on the main topic of the book, i.e., the role of fiber-wireless (Fi-Wi) convergence in support of 5G mobile transport networks, introducing the main technical issues motivating this book.

In Parts II, III, and IV, Fi-Wi technologies have been discussed at the three major network levels involved in the path toward convergence: system level, network architecture level, and network management level.

In Part II, devoted to system-level technologies, the basic principles and current standardization of the various analog-to-digital radio-over-fiber techniques currently available have been overviewed. These are instrumental to the understanding of the 5G transport network architectures described in Part III. As the backhaul/fronthaul of mobile traffic will not necessarily happen over optical fiber media, other competing wireless technologies in the field of millimeter wave have been also described.

In Part III, devoted to network architecture technologies, the concept of C-RAN is comprehensively overviewed under different viewpoints and by introducing a state-of-the-art picture of the level of advancement of important technologies at the network architecture level (NGPON, WDM-PON, BBU Hotelling, “No More Cell”). Chapter 8 shows how A-RoF, combined within an advanced PON architecture, can be used to build a scalable access network architecture. Chapter 9 overviews PON access architectures for building mobile backhauls, which will scale to the increased capacity requirements of future next-generation wireless broadband access network (NG-WBAN) technologies, and also includes the design of a fully distributed PON-based access architecture. Chapter 10 shows how the deployment of BBU hotels over a WDM access/aggregation network can be
optimized. Finally, Chap. 11 elaborates on the novel concept of “No More Cell” and how Fi-Wi convergence is a key enabler for it.

In Part IV, the next-generation point-of-presence architecture is initially described in Chap. 12, introducing the concept of a flexible platform that combines aggregation of fixed and mobile access traffic, IP edge routing, and the ability to host additional network functions and services, benefiting greatly from network functions virtualization (NVF) and software-defined networking (SDN) concepts. Subsequently, Chap. 13 describes the cooperative multipoint system that utilizes a base station (BS) cooperation technique to enhance the received signal quality, decrease the received interference, as well as improve the channel capacity of cell-edge users in the network.

The role of SDN is also extensively covered in two distinct Chaps. 7 and 14. While Chap. 7 focuses more on how SDN can cope with raising system-level challenges of convergence, Chap. 14 considers management aspects of SDN related to the support of cloud and mobile cloud computing services.

An overview of future topics in Fiber-Wireless (Fi-Wi) convergence

In the quickly evolving landscape of 5G research, several projects worldwide are currently contributing to the 5G transition. As an example, in Europe, the EU 5G infrastructure public–private partnership (5G-PPP) has been established with the aim of fostering the European ICT industry [3].

Clearly, 5G research is quickly evolving, and it was not possible to cover in this book the latest trends that have emerged in the last months prior to publication. We provide in the following a quick overview of some emerging topics that we consider particularly relevant to our book.

Impact of traffic dynamics and machine-to-machine (M2M) services. The growth in mobile traffic will not be homogenous, with busy-hour Internet traffic expected to grow more rapidly than average Internet traffic. The uptake of M2M services will, in addition, result in locally and over time varying characteristics of the mobile traffic. Thus, not only the future 5G mobile transport infrastructure will have to support a fast-growing overall mobile data volume and a significantly increased number of connected mobile devices at significantly improved energy- and cost-efficiencies, but it also will have to provide the capability to flexibly adapt to dynamically fluctuating traffic demands (over time, location, and characteristics) and a broad range of potentially new service requirements of future service portfolios. The wider use of M2M communications requires wider geographic coverage, with implications for the network architecture.

Mobile edge computing (MEC). MEC is a new technology which is currently being standardized by ETSI. MEC promotes the insertion of cloud computing capabilities at the edge of the mobile network, within the radio access network (RAN), in close proximity to mobile subscribers. The aim is to reduce latency, ensure highly efficient network operation and service delivery, and offer an improved user experience. MEC represents a key technology and architectural concept to enable the evolution to 5G, as it helps advance the transformation of the mobile network toward a programmable platform, by contributing to satisfy the
demanding requirements of 5G in terms of expected throughput, latency, scalability, and reconfigurability. 

**Midhaul/x-haul.** As seen in Chap. 10, in traditional CRAN implementations, the BBU-hoteling technique consists in geographically separating the BBU from its RRH, which remains located at the cell site, and consolidating BBUs into a common BBU hotel. In the first deployments of BBU-hoteling technique, the RRHs only perform basic layer 1 functions (i.e., digital-to-analog/analog-to-digital conversion (DAC/ADC) of the baseband signals, frequency up-/down-conversion, power amplification, and some signal measurements), but such configuration requires very high volumes of traffic, the so-called fronthaul traffic, to be exchanged between BBUs and RRHs through, e.g., the CPRI interface (see Chap. 5).

As of today, more efficient solutions are being investigated to reduce the amount of bandwidth to be exchanged between the RRH and the BBU. This is especially true if we consider future 5G deployment, where a large number of small cells are expected to be deployed, featuring high MIMO counts and large radio bandwidths. Therefore, different interface points (RAN splits), i.e., different functional separations between L1 and L2/L3 cell processing, are being investigated, in terms of potential cost/performance benefits and required capacity. These split points determine the separation of a cell site into two components, a central cell, where higher-layer cell functions are virtualized and consolidated for a set of cell sites, and remote cells, i.e., base stations. In contraposition to traditional fronthaul, the traffic transported between remote and centralized cell is also known as midhaul or x-haul. Some of these techniques are currently under standardization, e.g., in the IEEE 1914 workgroup, but research studies are needed to identify the most effective split point in the midhaul architecture. Even technical solutions enabling reconfigurability of the split point are currently being proposed, which could be used to select the split point according to the requested amount of traffic or to the specific coordination requirements of the cellular network.

**Energy efficiency.** 5G systems have to resolve the fundamental challenge of handling the anticipated dramatic growth in the number of terminal devices, the continuous growth of traffic (at a 50–60% CAGR), and heterogeneous network layouts, without causing a dramatic increase in the power consumption and management complexity within the network. Specifically, 5G communication systems need to support unprecedented requirements for the wireless access connection, targeting cell throughput capacities of $1000 \times$ current 4G technology and round-trip latency of about 1 msec. Since the perlink data rates will be increased by about $100 \times$, energy efficiency becomes a critical challenge of 5G systems, e.g., the joules per bit will need to fall by at least $100 \times$. Thus, 5G will have to be designed to be a sustainable and scalable technology.

Potential solutions to the energy efficiency issue include recourse allocation, network planning, renewable energy, and hardware architectures. Thus, this energy chase will eventually cover terminal devices, network elements, and the network as a whole, including data centers. Specifically, sophisticated resource allocation policies that optimize system energy efficiency and can be implemented in a centralized/distributed fashion are of paramount importance. Energy-efficient
network planning refers to techniques that minimize the number of base stations (BSs) for a coverage target and intelligent BS sleep mode mechanisms for energy savings. On the other hand, the integration of renewable energy sources on 5G networks is a promising solution for network sustainability and energy efficiency. This technology enables the exploitation of natural energy resources such as solar power, wind, and mechanical vibration, as well as energy harvesting from ambient and/or controlled electromagnetic radiation. Finally, energy efficiency requires the design of low-power consumption circuits such as power amplifiers and analog front ends in microwave and millimeter frequency ranges, DSP-enabled optical transceivers for access and backhaul networks, and ultra-low-power wireless sensors harvesting ambient energy (e.g., solar, thermal, vibration, and electromagnetic energy). Further, hardware architectures incorporating wireless power transfer technologies and having sleep mode capabilities (i.e., specific hardware components can be switched off for energy savings) present another exciting alternative to battery-less sensor operation for machine-to-machine (M2M) and device-to-device (D2D) communications.

**Advanced modulation format in the wireless side.** 5G will support diverse use of various waveforms for enhanced mobile broadband connection, wide area Internet of Things and high-reliability services. Current OFDM modulation developed for the 4G system is not capable of serving the rapidly increasing demands for data volume and types of user equipment. In order to accommodate new applications carried by 5G, system operation issues of DSP complexity, system latency, and battery life are drawing more attention for researchers. The design and optimization of next-generation physical layer waveforms is a hot topic in both academia and industry.

Several waveforms are actively investigated and developed as the candidates for 5G system. OFDM-based multicarrier modulations are preferable for a balance between performance and complexity, including GFDM (Generalized FDM), FBMC (filter bank multicarrier), UFMC (universal and filtered multicarrier), and other minor modification versions of OFDM.

FBMC is a multicarrier modulation with filter-shaped subcarriers, which significantly suppress the out of band leakage and relax the carrier frequency offset (CFO) synchronization requirement in receiver. However, its high DSP complexity and PAPR issue limit it to downlink applications. UFMC, on the other hand, is beneficial in uplink due to its comparably lower DSP complexity in the transmitter and supports asynchronous transmission that omits the time-advance process in multiuser environment. The uplink transmission can benefit from reduced latency and increased compatibility with burst-mode packet uploading. The above modulations are widely investigated in traditional bands below 6 GHz and also millimeter-wave bands beyond 30 GHz.

Recently, more modulations closer to OFDM are being proposed and studied. One example is the CP-OFDM (CP stands for cyclic prefix) with weight overlap and add (WOLA), which does not change the FFT/IFFT-based OFDM core. By applying simple weight overlap and add, different OFDM symbols are combined within the time-domain windowing, which improves the performance with
out-of-band (OOB) leakage. Another candidate, flexible CP-OFDM (FCP-OFDM), is designed to provide a flexible trade-off between multipath handling and OOB leakage suppression by splitting the cyclic prefix (CP) to CP and zero prefix (ZP) portion before feeding into shaping filter. These modulations emphasize more on the DSP complexity and power efficiency aspect of the system, while maintaining an acceptable performance in terms of OOB leakage, spectral efficiency, and asynchronous transmission.

Currently, there is no clear winner on the next-generation 5G modulation. Hence, we believe traditional OFDM modulation will be around a little bit longer even beyond 3GPP release 14 for conventional carrier frequency up to 6 GHz and release 15 for higher frequency up to 110 GHz.
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