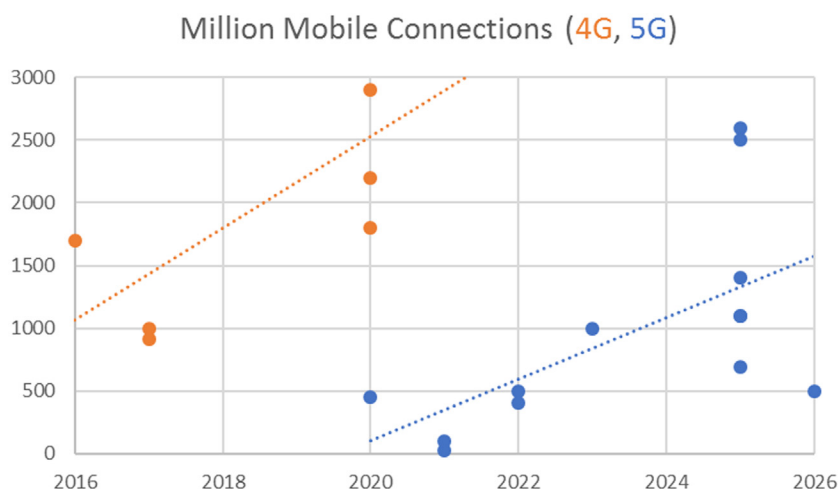




# Preface

Across the IoT, Autonomous Driving (ADAS), edge compute, and service provider ecosystem, 5G is understood to not “just” be about enabling a faster data connection to the end-user device. 5G evolves both existing technologies (radio access and home networks) while laying the foundation for new applications across consumer and industrial automation with the self-driving car being a prime example.

Even though 5G is very much hyped since 2016, infrastructure rollout has only started in 2019, with subscriber devices having become available in volume starting 2020. At the same time, 4G/LTE standards will continue to evolve and add more subscribers.



4G and 5G (projected) subscriber growth (multiple public sources, indicated with data points).

During 2G, 3G, and 4G network rollouts, wireless service providers and their system vendors built networks that, although providing predictable and high performance, are often characterized by their complexity, inflexibility, and associated high barrier to entrance.

Like the wireline network transformation when migrating from circuit-switched to packet-switched (PS) networks in the early 2000s, the wireless network is migrating from this proprietary nature to a true open-standards approach that allows “out-of-the-box” thinking and disruptive solutions in physical implementation and deployment. Consider, for example, the cost and execution requirements imposed by new operators like Reliance Jio in India, DISH in the United States, and Rakuten in Japan, needing to support fast ramp-up (quick provisioning), or the Facebook Terragraph project, bringing high-speed connectivity at a fraction of fiber deployment cost through the use of an unlicensed 60 GHz spectrum.

The rapid evolution of 5G standards combined with aggressive deployment schedules and cost targets drives a push for Radio Access Network (RAN) implementations on standard hardware and software platforms. This trend started with 4G networks where upper layer stacks are implemented on general purpose (GPP) compute platforms and the Linux operating system (OS) and is increasing with 5G deployments. Examples include the trend to Ethernet for fronthaul replacing quasistandards such as CPRI as well as rigorous standardization efforts in 3GPP to define standard APIs between different components.

Because of this trend, system vendors are moving increasingly aggressively toward Software Defined Radio (SDR) platforms where most, if not all, of the RAN MAC and PHY layers are implemented in a true software environment on the Linux OS. The expectation is that although the implementation efficiency may not match that of custom hardware and firmware, this is offset by cost and flexibility provided by SDR platforms through the use of GPP multicore devices and broad software enablement. On-chip integration of high-speed (25–100 Gbps) Ethernet hardware reduces the need for custom I/O solutions and allows for reuse of data center switch/routing solutions for fronthaul.

The trend for SDR even extends to the remote radio head/radio unit (RU). Very large compute requirements make it impossible for programmable cores (DSPs) to implement digital front end (DFE) functions as opposed to ASIC implementation. Optimized vector DSPs allow for a software-friendly and flexible deployment, while new chip-level partitioning, with on-chip data converter integration, modern memory interfaces, multi-chip integration, and other innovative techniques, enable the cost reduction required for massive MIMO deployment.

AT&T, China Mobile, Deutsche Telekom, NTT DOCOMO, and Orange jointly announced the creation of the Open-RAN (O-RAN) Alliance in February 2018. Press releases say the O-RAN Alliance is a worldwide, carrier-led effort to drive new levels of openness in the RAN of next-generation wireless systems. But what does this mean? It means that three wireless networking industry trends are coming together into a “perfect storm” moment. First, networking products in the wireline space (switches, routers, and similar equipment) have moved from proprietary, hardware-centric implementations to a software-centric implementation that executes on general-purpose, Arm or x86 hardware. Second, the wireless infrastructure vendor landscape has consolidated dramatically. Consider Nokia, which has been consolidating Alcatel, Lucent, Nokia, Nortel, Siemens, and more companies. Wireless operators, who are the customers of these infrastructure vendors, see a potential for an oligopoly that implies reduced innovation and increased pricing and vendor dependency.

Lastly, there is a geopolitical aspect that worsens the competitive situation. There has been broad coverage on Huawei being banned as an infrastructure vendor, leading Huawei customers to reach out to find alternative paths to acquire equipment.

Given the promise of O-RAN to open up a whole new ecosystem of hardware and software vendors, there is obvious excitement in the industry around the concept of a software-centric ecosystem of vendors that can be mix-and-matched to implement a wireless network, especially if this allows the wireless network to be composed out of systems that are optimized to the task at hand—say rural, dense urban, industrial, or private networks.

At the same time, there is a lot of catching up to do. The institutionalized knowledge from the big wireless systems vendors takes a long time to catch up to, in systems, hardware, and software design. This book is a jump-start to engineers who are developing O-RAN hardware and software systems and provides a top-down approach to O-RAN systems design. We cover wireless and systems history as an introduction into why wireless systems look the way they do today, before introducing relevant O-RAN and 3GPP standards. The remainder of the book discusses hardware and software aspects of O-RAN system design, including dimensioning and performance targets. We include real-life examples of relevant elements of detailed hardware and software design where needed as a guide for developers. Lastly, we show a few practical examples of where O-RAN designs play in the market and how those examples map to hardware and software architectures.

The target audience includes hardware and software engineers as well as product managers and consumers of O-RAN products who are looking to understand better what O-RAN is.

This book is organized as follows:

Chapter 1, *Open Radio Access Network Overview*, gives an overview of the O-RAN standard and its origins and covers related topics like 5G and spectral availability for 5G deployment. This provides a background for a discussion on deployment options, which defines the hardware and software architecture.

Chapter 2, *System Components, Requirements, and Interfaces*, outlines the requirements and architecture of key system components such as the central unit (CU), distributed unit (DU) and RU.

Chapter 3, *Hardware System Dimensioning*, establishes key performance metrics such as front/backhaul throughputs, memory requirements, interconnect performance, as well as latency and other metrics.

Chapter 4, *Hardware Architecture Choices*, talks about the different hardware implementation options, from server-based designs to more embedded implementation options for CU/DU as well as options for RU system design. We discuss the pros and cons of each architecture approach.

Chapter 5, *System Software*, is like the hardware architecture choice but more software centric in nature. We cover OS components such as Linux and DPDK/bbdev as well as required software drivers.

Chapter 6, *User-Plane Application Components*, covers relevant details of the Physical and Layer 2 application stacks. We outline functions implemented by these stacks. This includes 3GPP defined functions such as PDCP, RLC/MAC, and PHY and implementation-specific parts such as Air Interface Scheduler, O-RAN eCPRI fronthaul, and DFE.

Chapter 7, *Wireless Scheduling and Quality of Service Optimization Techniques*, delves deeper into the most complex and differentiating piece of the User-Plane stack: the wireless scheduler algorithm. We explain commonly used algorithms for time and frequency domain scheduling and outline the potential structure of a scheduling algorithmic framework.

Chapter 8, *Synchronization in Open Radio Access Networks*, covers requirements as well as implementation on CU/DU and RU side for time and frequency synchronization including relevant standards and implementation methods.

Chapter 9, *Software Performance*, discusses key performance metrics of the O-RAN systems, such as L1/L2 algorithmic performance as well as user performance in terms such as latency, throughput, and capacity.

Chapter 10, *Interoperability and Test*, establishes standards software techniques for integration and test before covering 3GPP/O-RAN specific system integration and test aspects.

Chapter 11, *Differentiation by Use Case*, shows a few “off the normal” O-RAN use-cases/ implementations to give the reader insight into what kinds of products can be established with an O-RAN systems architecture. These systems are discussed as practical implementations that showcase O-RAN strengths of ecosystem-based development and software centricity.