

Chapter 1. Introduction

Abstract: Today's wireless industry is built on a long and rich history of significant discoveries and innovations over many decades. While the existence of electromagnetic waves, the most fundamental ingredient of wireless communications, was discovered way back in 1880s, there was no specific commercial goal behind the discovery at the time. Since then, many significant developments have taken place, which made the wireless technology more affordable, effective, and reliable. This chapter first takes a chronological journey through the history of wireless networking highlighting the major milestones achieved including the launch of the first cellular networks, release of the first standards for Bluetooth and WiFi, introduction of digital TV, trial of the first packet radio network, and the new standards to facilitate connectivity at scale for the Internet of Things. Then the recent trends and growth forecast for the wireless industry is reviewed. Finally, this chapter provides a detailed outline of the contents covered by the rest of the book. [158 words]

Chapter 2. Wireless Coding and Modulation

Abstract: Coding and modulation refers to techniques that a transmitter can use to map digital information to the underlying wireless signal so that a receiver can retrieve the information from the signal using appropriate decoding and demodulation. Coding and modulation directly affect the achievable capacity, data rate, and reliability of the wireless communication. This chapter begins with an introduction to the basic concepts of wireless signals: frequency, wavelength, amplitude, phase, I-Q plots of amplitude and phase, time and frequency domain representations of wireless signals, wireless spectrum, and decibel, followed by key modulation techniques, namely Amplitude Shift Keying, Frequency Shift Keying, Phase Shift Keying, and Quadrature Amplitude and Phase Modulation, that are used in practical wireless and mobile networking systems. This chapter also covers a range of other important topics that directly or indirectly influence the wireless information transmission: Nyquist's and Shannon's theorems for channel capacity estimation, application of Hamming distance for error detection and correction, multiple access methods including Time Division Multiple Access, Frequency Division Multiple Access, and Code Division Multiple Access, spread spectrum techniques including Frequency Hopping Spread Spectrum and Direct-Sequence Spread Spectrum, Doppler shift and Doppler spread, coherence time and duplexing including Frequency Division Duplexing and Time Division Duplexing. [200 words]

Chapter 3. Wireless Signal Propagation

Abstract: In contrast to wired communications, the radio channel in wireless networks is "open" in the sense that it does not have anything to protect or guide the signal as it travels or propagates from source to destination. As a result, the wireless signal is subject to many issues that affect its propagation in the air. This chapter examines these issues and the relevant tools and solutions to combat them. Specific topics covered include the basic types of antennas used in wireless communications, signal reflections leading to multipath propagation, signal fading, delay spread, and inter-symbol interference, mathematical models to estimate pathloss, i.e., the amount of signal power lost as it propagates from the transmitter to the receiver, basics of multiple-input-multiple-output (MIMO) systems that exploit spatial diversity in signal propagation to improve coverage and throughput of wireless communications using multiple antennas, and the frequency-sensitive multiplexing techniques such as Orthogonal Frequency Division Multiplexing (OFDM) and Orthogonal Frequency Division Multiple Access (OFDMA). [158 words]

Chapter 4. WiFi Basics

Abstract: WiFi, which stands for “Wireless Fidelity”, is one of the most widely used wireless networking technology today with millions of them deployed in our homes, workplaces, airports, shopping malls, community parks, and university campuses. All personal mobile devices, such as smartphones, tablets, and laptops are fitted with WiFi interfaces, making them very easy to be connected to such networks wherever they are available. In most cases, WiFi is available for free to use or at least there is no limit imposed on the volume of data for paid subscriptions, making it the most desired and economical option to get connected to the Internet. This chapter explain the basic features and functions of the WiFi technology including the numbering convention used to refer to different generations of the technology, the spectrum bands and channels used for communications, medium access control, addressing and power saving. [131 words]

Chapter 5. Mainstream WiFi

Abstract: Since the introduction of the basic WiFi technology in 1997, there have been many amendments and advancements to date to address the requirements of new applications and demands. These amendments can be categorized into two groups, mainstream and niche. Mainstream WiFi versions are those that are used by the mass population to access the Internet, while the others target some niche applications to further extend WiFi’s utility beyond just Internet access. This chapter systematically examines the evolution in mainstream WiFi covering all the successive amendments including 802.11b, 802.11a, 802.11g, 802.11n (WiFi 4), 802.11ac (WiFi 5), 802.11ax (WiFi 6), and the upcoming 802.11be (WiFi 7). Data rate is the key feature that was consistently pushed to higher and higher limits through these new generations. This chapter explains how factors such as modulation, coding, guard interval, channel width and MIMO streams influence the achievable data rates in WiFi, which helps appreciate the various data rates offered by different WiFi versions. [158 words]

Chapter 6. Niche WiFi

Abstract: WiFi has been primarily used as a networking technology for implementing wireless LAN in enterprise and residential domains, as well as connecting personal mobile devices, such as mobile phones, tablets, laptops, etc. to the Internet in homes, cafes, airports, and university campuses. These mainstream WiFi predominantly used the ISM bands 2.4GHz and 5GHz, with the new versions aiming to use the 6GHz band. In addition to these mainstream WiFi, IEEE has also released several 802.11 amendments that target some niche applications. These niche WiFi standards operate outside the mainstream bands, both at the very low end of the spectrum, i.e., below 1GHz, as well as at the very high end, i.e., 60GHz. For example, 802.11af (a.k.a. White-Fi) is targeting the exploitation of 700MHz spectrum recently vacated by TV stations due to their digitization, 802.11ah (a.k.a. HaLow) using 900MHz to connect emerging Internet of Things operating at low power, and 802.11ad/ay (a.k.a. WiGig) at 60GHz to support multi-gigabit applications at short range. This chapter examines the features and techniques used by such niche WiFi standards. [174 words]

Chapter 7. Cellular Networks

Abstract: Cellular networks are designed to provide wide area coverage to both static and mobile users, indoors as well as outdoors. All our mobile phones are connected to cellular networks and increasingly many other devices and things, such as tablets, drones and even cars are being connected to cellular networks. Cellular network is the oldest networking technology, which has now gone through four generations of evolution, each lasting approximately 10 years. This chapter begins with the history of cellular networks followed by the fundamental design concepts of hexagonal cell geometry, frequency reuse, and handoff. The treatment of frequency reuse includes design of cell clusters, frequency reuse and spectrum distribution within the cluster of cells, notations to describe frequency reuse patterns, and the design of fractional frequency reuse, which enables frequencies to cover either the entire area of the cell (including the cell edge) or restrict their coverage to only within the center area of the cell. The remaining of the chapter highlights the main features and differences between the first four generations of cellular networks with detail coverage of GSM and LTE. [181 words]

Chapter 8. 5G Networks

Abstract: 5G is the fifth and latest generation of cellular networks that has just started to roll out during 2019-2020. While the previous four generations mainly sought to improve the data rate and capacity of the cellular systems, 5G is designed to improve several other aspects of communications and connectivity beyond the data rates. 5G promises to massively surpass 4G in three main technical areas: data rates, latency, and connection density, which is expected to support new applications and services not possible before. For example, latencies below 1ms can support new applications like industrial robotics, autonomous driving, and remote medical procedures. Similarly, a million connections per square kilometers will help support many Internet of Things (IoT) applications that involve connecting billions of devices at a scale not seen before, which has the potential to revolutionize almost all vertical markets including agriculture, manufacturing, health, and defense. This chapter first explains the technical targets and potential new applications of 5G followed by the coverage of key new technologies to be used in 5G, including Non-Orthogonal Multiple Access (NOMA), Full-duplex wireless, Massive MIMO and 3D Beamforming, Mobile Edge Computing (MEC), and the use of millimeter wave bands. [193 words]

Chapter 9. Internet of Things

Abstract: Internet of Things (IoT) is a new vision to connect all types of objects or things to the Internet, making it possible to digitize every phenomenon and processes of interest. IoT is arguably seen as the next Internet revolution promising unprecedented benefits in all socio-economic sectors. Currently there is a massive interest from industry, academia, and standards organizations in this topic. This chapter begins with an introduction to IoT defining ‘things’, discussing the factors contributing to the recent surge in IoT deployments, and examining some of the real case studies of IoT such as smart whitegoods, smart gas detectors, and smart bikes. The chapter concludes with a summary of the extensions recently proposed in Bluetooth, WiFi and cellular networks to specifically address the needs of IoT connectivity. [127 words]

Chapter 10. Bluetooth

Abstract: Bluetooth is the oldest and the most pervasive technology to connect a wide range of devices and ‘things’ around us. Since its inauguration in 2002, it has gone through several upgrades and is continuing to play a dominant role in providing short-range connectivity for smart objects. This chapter begins with the history, markets, and applications of Bluetooth, followed by detailed coverage of the core technologies behind the three generations of Bluetooth. For the classical Bluetooth that forms the bedrock of all subsequent versions of the technology, the following fundamental concepts are covered: Bluetooth piconet, Bluetooth spectrum and channels, modulation and data rates, frequency hopping structure and algorithms, packet format and MAC address, Bluetooth operational states and connection establishment procedure, Bluetooth power saving, and Bluetooth protocol stack. The chapter concludes with an examination of the new developments in Bluetooth Low Energy (BLE), a.k.a. Bluetooth 4, Bluetooth 5, and Bluetooth 5.3. [149 words]

Chapter 11. LoRa and LoRaWAN

Abstract: Pervasive IoT deployments demand low-power wide area networking (LPWAN) solutions that can connect hundreds of thousands of sensors and ‘things’ over a large area with minimal infrastructure cost. The low-power solution is needed to ensure that the battery-powered sensors can last for many years with a tiny battery. While Bluetooth is certainly low-powered, it works only for short ranges. Cellular networks are designed for wide area coverage, but they consume too much power which requires large batteries and frequent battery recharging for the end nodes. Consequently, there is a significant momentum in standardizing new networking solutions for LPWAN. New developments are emerging from both cellular and WiFi standard bodies, i.e., from the 3GPP and IEEE/WiFi-alliance, respectively, to fill this gap, but there is a third momentum that is proving very successful. It is called LoRa Alliance (LoRa stands for *long range*), which is a industry alliance committed to accelerate the development and deployment of LPWAN networks. This chapter covers details of the LoRa technology including its frequencies, modulation and coding, network protocol stack, and device classes. [176 words]

Chapter 12. Artificial Intelligence Assisted Wireless Networking

Abstract: Artificial intelligence (AI) has emerged as an effective tool to combat many complex decision-making tasks across a wide variety of domains including vision, natural language processing, and automated text processing where precise mathematical modeling is not feasible. AI, which includes techniques such as machine learning and deep learning, has advanced to the point where they can outperform humans for many tasks including winning CHESS and GO. Future wireless systems are facing major challenges arising from the growing demand for higher capacity and quality of user experience. To address this future need, wireless systems are increasingly required to solve much more complex problems in real-time without compromising accuracy. The rising complexity is motivating recent interest in exploring AI as an additional aid to design future wireless systems. This chapter examines what, why, and how questions for AI in wireless. Specific case studies are presented to show how AI can help reduce latency, power consumption, and computation overhead in practical wireless communication systems. The chapter concludes with a discussion of some common hurdles for applying AI to wireless communications along with their potential remedies. [182 words]

Chapter 13. Wireless Sensing

Abstract: While wireless has revolutionized mobile data communications, it also plays a major role as a sensing technology. Meteorologists routinely use wireless signals to scan the atmosphere for weather forecasts, astronomers use radio to probe deep space, geologists use radio frequencies for remotely sensing various Earth phenomenon, and airport authorities are increasingly using wireless signals at security gates to detect prohibited materials concealed by passengers. Recently, scientists are discovering techniques to monitor human activities and even vital signs, such as heart and breathing rates, simply by analyzing the wireless signals reflected by the human body. These advancements have created the potential for wireless to penetrate the growing mobile and IoT sensing market. This chapter first discusses the motivation and advantages for radio-based sensing followed by the working principles of the popular wireless sensing tools and techniques targeted at the IoT market. Specifically, this chapter covers wireless sensing based on WiFi and millimeter wave radars. **[153 words]**

Chapter 14. Aerial Wireless Networks

Abstract: Miniaturization of electronics has created an opportunity to fit wireless communications equipment into the payload of various aerial platforms such as drones, a.k.a. unmanned aerial vehicles (UAVs), aerostats, and high-altitude platforms (HAPs). Aerial networks, which are a special category of non-terrestrial networks placed within the Earth's atmosphere, can be deployed quickly and cost-effectively to provide coverage in remote areas where terrestrial infrastructure is difficult to build, in disaster zones with damaged cellular towers, and even in urban areas to absorb sudden peaks in data traffic. Aerial wireless networks are currently being investigated as a promising new dimension for the next generation communication networks. This chapter explains the air-to-ground radio propagation and path loss models for aerial networks and examines options, characteristics, and design considerations for both HAP- and UAV-based networks. **[130 words]**
