Part One

Concepts and Background

1

Introduction

Wireless mobile communication has evolved over three generations, with the fourth generation yet to come. As a new generation stepped forward, it accompanied the implementation of new air interface technologies as well as the enhancement of system performances. In the early generations, performance enhancements stemmed mainly from physical layer technologies such as modulation, multiple access, and multiple-antenna technologies but the contribution of resource management has increased with each generation. The role of resource management is expected to become even more important in the next-generation wireless communication systems. In essence, maximized performance of a future wireless system will likely be attained by optimized resource management implemented on the basis of matured physical layer technologies.

1.1 Evolution of Wireless Communications

Recent decades have witnessed a great evolution of wireless communication systems. It was in the 1970s when the *first-generation* (1G) wireless communication systems such as the *advanced mobile phone system* (AMPS) were first deployed to support circuit-switched voice telephony based on the analog *frequency-division multiple-access* (FDMA) method.

In the early 1990s, the 1G wireless systems evolved to become *second-generation* (2G) systems by virtue of the advances in digital technologies. The 2G wireless systems also were targeted at voice telephony with circuit switching, but digital modulation and multiple access methods were incorporated as well based on digital technologies. *Time-division multiple access* (TDMA) was employed in the *global system for mobile* (GSM), and *code-division multiple access* (CDMA) was used in the IS-95 CDMA system.

The late 1990s saw an increasing demand for high data rate services such as video telephony, Web browsing, and e-mail, and this demand motivated the development of the *third-generation* (3G) systems, such as WCDMA and CDMA2000, which supported both circuit- and packet-switched services with broader bandwidths. The 3G systems were followed by enhanced systems such as CDMA2000 EV-DO (*enhanced version for data optimization*) and EV-DV (*enhanced version for data and voice*), which were developed for optimized data services, with a compatibility maintained with the earlier systems.

Wireless Communications Resource Management Byeong Gi Lee, Daeyoung Park, and Hanbyul Seo

Now, we are facing the advent of *fourth-generation* (4G) wireless communication systems. The requirements for 4G systems set by the International Telecommunication Union (ITU) include the provision of a 1 Gbps data rate in nomadic state and a 100 Mbps rate in moving state (ITU, 2003). Applications of 4G systems are expected to range very wide, from classical voice telephony to new more modern services such as the uploading of *user-created content* (UCC).

As stated above, the evolution of wireless communications is characterized by a shift from analog, small-capacity, single-target services to digital, large-capacity, integrated multiple services. For the next generation to be successfully implemented, systems should be designed to meet a number of requirements arising from that trend.

First, they should be capable of providing high transmission rates. Users want to send and receive by broadband services with very fast response times, and some applications such as *video-on-demand* (VoD) cannot be supported without broad bandwidth.

Second, they should have a flexible service architecture to integrate different types of user services on a single air-interface. If the architecture is rigidly optimized only for a single service type, the other types will suffer from poor service quality within the system.

Third, they should be equipped with the functionality of *quality-of-service* (QoS) management. The metrics of QoS may differ among different applications. For example, voice telephony has a strict delay requirement whereas e-mail is not sensitive to delays as long as data delivery is reliable. Unless the system satisfies the service-dependent QoS metric, even high throughput may fail to satisfy the users.

One might think that the above requirements could be fulfilled by enhancing the transmission technology in a physical layer. In reality, the enhancements solely due to transmission technology (or physical-layer technologies in general) are limited in various aspects.

First, transmission technologies are already matured and there is not much scope for further improvements without some unexpected breakthroughs. For example, the channel coding technologies, such as turbo code and *low-density parity-check* (LDPC) code, permit a transmission rate very close to the information-theoretic capacity in Gaussian channels (Chung *et al.*, 2001).

Second, most transmission technologies are developed to accomplish specific objectives, so each individual technology cannot yield a universally optimal performance solution. If one considers, for example, the diversity and multiplexing techniques supported by multiple transmit and receive antennas, the diversity technique is the better choice when the channel condition is hostile as it can improve the signal quality and transmission reliability. However, when the channel condition is favorable, the additional improvement of signal quality supported by the diversity technique does not contribute much, so multiplexing becomes the better choice as it can increase the overall transmission rate. (See Section 7.2 for a discussion of MIMO transmission modes.) For a system to operate successfully over a universal communication environment, it is necessary to employ a management technique that can intelligently determine the transmission technology that is optimal to the given situation.

Third, the QoS requirements of user traffic ffect the optimized solution when selecting the transmission technology. As an example, compare the water-filling and the truncated channel inversion methods, each of which can be the optimal transmission policy under its own system assumption. Interestingly, the two policies yield opposite results even though they share the common objective of maximizing channel capacity under limited battery charge. When the current channel condition is good, water-filling – the optimal policy with a loose delay requirement – can send more data with more transmission power to enjoy the hospitality of the wireless channel. In contrast, truncated channel inversion – the optimal policy with a stringent delay requirement – expends less transmission power to save the limited battery charge. (See Section 6.3.1 for a comparison of water-filling and truncated channel inversion policies.) As demonstrated in this example, a different QoS requirement leads to a different choice of transmission technology. Therefore, in future wireless systems that are expected to support various different services, it is essential to manage the transmission technologies in relation with the QoS requirement.

1.2 Wireless Resource Management

The above discussion, in effect, points to the necessity for wireless resource management. Wireless resource management refers to a series of processes that determine timing, ordering, procedures, and the amount of wireless resources to allocate to each user. This determines the optimal use of wireless resources according to the wireless channel information and the QoS requirements of each user.

The importance of resource management originates from the scarceness of wireless resources. The requirements could be met simply if we had unlimited access to the three fundamental resources – bandwidth, transmission power, and antennas, but in practice there are various limitations.

First, the frequency spectrum is limited, and licensing fees increase with bandwidth. Second, battery power is limited for each mobile device, and it is necessary to use more expensive signal amplifiers to use more transmission power. Third, the size of a mobile device limits multiple antennas, and more complicated space–time signal processing is needed to use more antennas. These problems become more complicated in the multiuser environment as an increase of transmission power of a user means an increase of interference to other users.

Thus, the quantity of each wireless resource is limited, and the use of more wireless resources does not necessarily bring a performance enhancement of the overall system. Therefore it is most desirable to manage wireless resources so that they are used as efficiently as possible, while maximizing the overall system performance.

By determining ways to use the available wireless resources optimally, resource management can lead to a significant improvement in transmission rate without using more bandwidth. In addition, it can make the system flexible enough to operate in adaptation to the channel characteristics and QoS requirements, thereby permitting a flexible service architecture for integrating various different services in a single air-interface.

1.2.1 Bandwidth Management

Bandwidth is a fundamental wireless resource which refers to the range of frequencies occupied by a transmitted signal. Since bandwidth determines the maximum symbol transmission rate, it puts a fundamental limit on the channel access rate. Broadly, bandwidth may be considered as the transmission opportunity to access the wireless medium; that is, how often we can transmit symbols over the wireless medium. If this transmission opportunity is shared by multiple users, the *scheduling* that determines the order of user access over time becomes the essential part of bandwidth management. There are various different scheduling methods having different objectives. Another important part of bandwidth is the *admission control*, which determines the admissibility of a new connection in relation with QoS. Admission control may be regarded as a long-term bandwidth management and is strongly related to scheduling.

1.2.2 Transmission Power Management

Transmission power is another important wireless resource that can determine the quality of the wireless link. A wireless link, in general, becomes more reliable as the transmission power is increased.

There are three aspects to transmission power management. The first is *power control*, which focuses on how to support a harmonized coexistence of mutually interfering transmitter–receiver pairs. The second is *power allocation*, which distributes a given amount of transmission power over multiple orthogonal subchannels with the intention of maximizing the efficiency of the transmission power. The third is *power adaptation*, which determines the transmission power adaptively according to the time-varying environments, caused by the randomness of traffic arrival or the fading process of the channel.

1.2.3 Antenna Management

Recently, antennas have become the most attractive wireless resource as they can contribute to increasing the channel capacity without requiring additional bandwidth or transmission power. However, as antennas need circuitry operating at radio frequency in the transmitting and receiving devices, increasing the number of antennas implies an increased device cost. In addition, the channel capacity heavily relies on the usage of antennas, and their optimal use varies depending on the channel that connects the transmitter–receiver pair. This implies that, for an effective operation of antennas, it is necessary to adopt an antenna management method adequate to the current channel state.

There are various *multiple-input multiple-output* (MIMO) technologies, including *diversity transmission* and *spatial multiplexing transmission*. Also, there are multiuser MIMO transmission technologies, such as *space-division multiple-access* (SDMA) and dirty paper coding.

1.2.4 Inter-cell Resource Management

For efficient spectrum use, wireless communication systems have a cellular structure in which the whole service area is divided into multiple smaller service areas, called *cells*, and deploy one *base station* (BS) at each cell. The cellular concept uses limited wireless resources very efficiently. It permits repeated use of the given frequency spectrum, reduces the distance from each BS to the users within each cell, and thus can provide the desired level of service quality using a much smaller amount of transmission power and bandwidth.

However, this cellular concept brings in some new problems to solve, including the inter-cell interference problem. The *inter-cell resource management* is intended to solve such problems arising in the multiple-cell environment. There are two aspects to inter-cell resource management. The first is *inter-cell interference management* that tries to mitigate interference from neighboring cells while maximizing reuse of the spectrum at the base stations. The second is *handoff management* that tries to maintain the QoS of an ongoing connection while the user moves across the cell boundary.

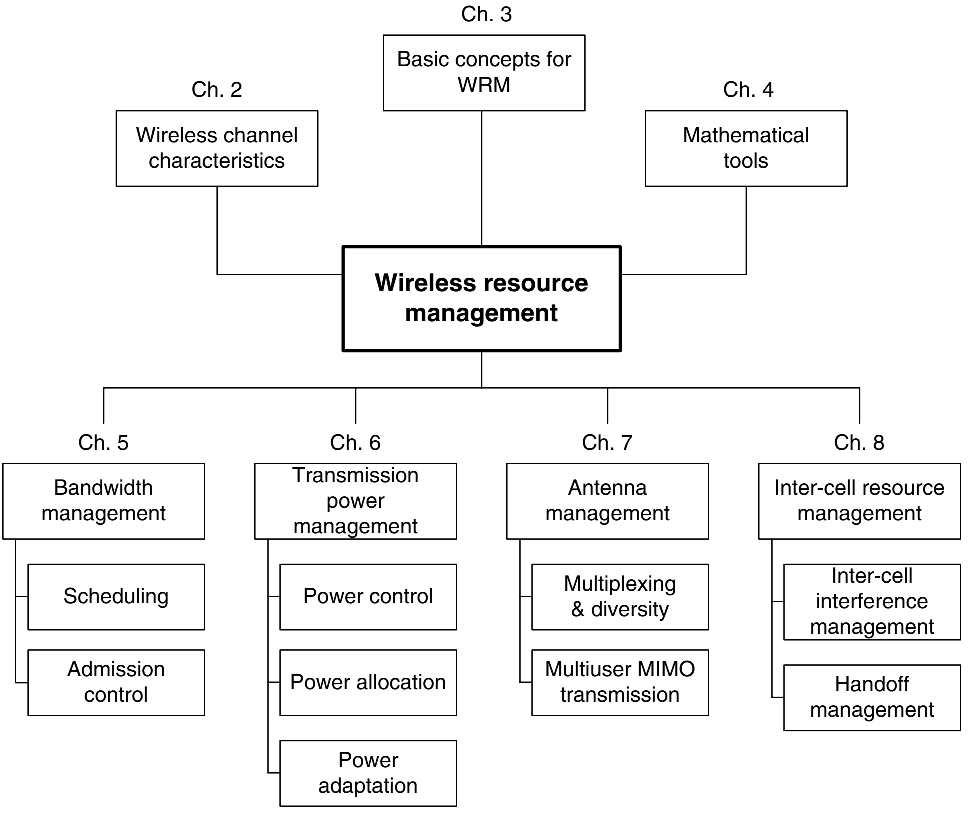

Figure 1.1 Organization of the book

1.3 Organization of the Book

This book is intended to provide comprehensive and in-depth discussions on wireless resource management, from the preliminary concepts to specific resource management techniques. Figure 1.1 depicts the overall structure of the book.

Chapters 2–4 deal with the preliminaries needed to understand and develop resource management. Chapter 2 discusses the characteristics of wireless channels and provides models that describe wireless channels mathematically. Chapter 3 covers several basic concepts needed to formulate wireless resource management problems, including the definitions of wireless resources, different multiple-access methods, and QoS-related issues. Chapter 4 introduces the basic mathematical tools useful for solving the wireless resource management problems, including convex optimization theory and dynamic programming.

Chapters 5–8 deal with the four different types of resource management discussed in the previous section. Specifically, Chapter 5 deals with bandwidth management, Chapter 6 with transmission power management, Chapter 7 with antenna management, and Chapter 8 with inter-cell resource management.

References

Chung, S.-Y., Forney, G.D., Richardson, T.J. and Urbanke, R. (2001) On the design of low-density parity-check codes within 0.0045 dB of the Shannon limit. *IEEE Communications Letters*, **6** (2), 58–60.

ITU-R (2003) Recommendation M.1643: Framework and Overall Objectives of the Future Development of IMT-2000 and Systems beyond IMT-2000.