Chapter 1

Introduction

The prospect of modern communication systems is claimed to have advanced features: ubiquitous access to information anywhere at anytime with high-quality and high-speed service. This goal is being achieved by both wired and wireless communication systems. The rapidly emerging wireless communication systems, based on such radio transmission technologies as cellular mobile telephony, personal communications systems, and wireless networks, are dramatically changing the life style nowadays.

Following the pioneering contribution from Maxwell and Hertz, the experimental radio system that established by Marconi in 1897 on the Needles island to communicate with the English coast has declared the birth of wireless communications.

The tide of modern wireless communications is driven by the deployments of cellular mobile communication systems. Advanced Mobile Phone System (AMPS) was implemented in 1984 in North America as the analog prototype of the 1st Generation (1G) cellular mobile communication system. From 1990 the 2nd Generation (2G) digital cellular mobile systems such as Global System for Mobile Communications (GSM) have carried out the most successful story technically and commercially with providing voice and teletext communications between people. With the same network architecture as the 2G systems, the 2.5G mobile systems such as General Packet Radio System (GPRS) introduce the packet switching concept and bring data transmission service into mobile communications. The 3rd Generation (3G) mobile systems, Universal Mobile Transmission System (UMTS), are designed as wideband wireless communication prototypes to provide higher data rate service.

The growing demand of higher data rate and better quality of service (QoS) continuously drives the evolution of mobile communication systems. With very promising potential, the Orthogonal Frequency Division Multiplexing (OFDM) system is one justified major candidate for the 4th Generation (4G) mobile systems.

Multiple antenna technologies are highly recommended as the extension for the 2G and the 3G cellular mobile systems, due to their high capacities and potential to dramatically increase the system coverage and data transmission reliability. Therefore, it is a very important and valuable choice to integrate multiple antenna technologies into OFDM systems for the evolution of the 4G mobile communication systems.

1.1 Background

Wireless communication systems are a hot topic in recent years, since they are effective alternatives to the wired communication systems to provide service in scenarios where it is impossible or difficult to implement wired communication solutions.

Wireless communication is a rapidly growing segment of the communication industry. Figure 1.1 illustrates one example of the continuously increasing mobile subscribers in the Chinese market for each generation of mobile systems. The whole amount of mobile subscribers in China has already reached 380 million in November, 2005 [ZDE05]. It is predicted that there will be 118 million *3G* subscribers by 2008, and 580 million of all mobile users by 2010 in China [Vis05]. The number of mobile subscribers in the global market has the same growing trend.

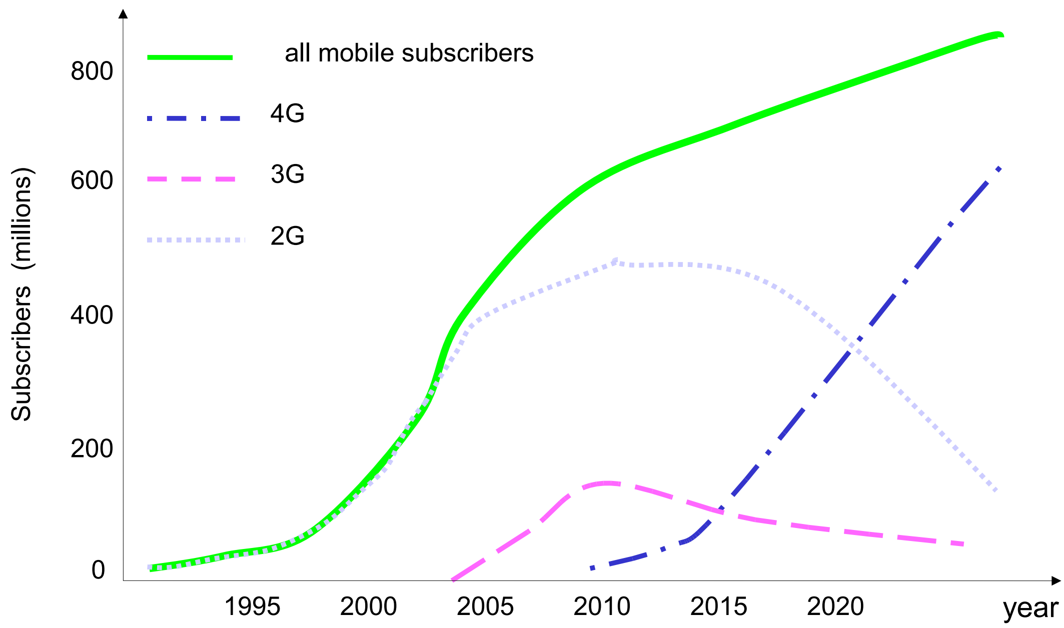

Figure 1.1: Subscribers of mobile systems in Chinese market [ZDE05] [Vis05]

Such a rapid increase of mobile subscribers needs a great improvement not only for the system capacity, but also for such high-speed services as data transmission and video streaming. One solution to enlarge system capacity is to apply Multiple-Input Multiple-Output (MIMO) signal processing with multiple physical antennas in the wireless systems. In order to optimize the radiation and reception pattern, MIMO processing usually combines signals from antenna array elements with powerful digital signal processing algorithms. The scope of multiple antennas technologies includes spatial diversity, spatial multiplexing, phased arrays, adaptive arrays, and digital beamforming.

AMPS and GSM systems are narrowband cellular systems which are designed for such low-rate application as voice communication. Wideband wireless communication systems are being deployed to enable high-speed services. The UMTS and 4G mobile systems are wideband wireless communication solutions, which are able to provide high-quality and high-rate mobile communication services.

Due to its resistance to multipath fading and ability to support a very high data rate transmission, the OFDM transmission technique is a major candidate for the 4G air interface. The basic idea of OFDM is to send signals over multiple low-rate subcarriers instead of a single high-rate carrier. The OFDM transmission can totally eliminate the inter-symbol-interference (ISI) with the guard interval of the OFDM symbol blocks. When multiple OFDM subcarriers are modulated with such symbol mapping schemes as Multiple constellation Quadrature Amplitude Modulation (MQAM), a high data rate transmission becomes possible in the OFDM system with a low equalization complexity. There are many variants of OFDM that are optimized for particular applications and channel conditions, including coded OFDM, wideband OFDM, flash OFDM, and vector OFDM.

The general requirements for the 4G mobile communication systems can be characterized as follows [Roh05]:

- High *spectral efficiency* with digital MQAM;
- High user *mobility*;
- High *flexibility* to deal with various users and traffic scenarios;
- High *adaptivity* to react to changing transmission environments.

Figure 1.2 shows the data rate and mobility capabilities for different mobile systems with their typical service applications [Leg05] [Roh05].

Therefore, the vision for 4G mobile communication systems requires a high-quality high-rate service anywhere at anytime. Future mobile systems should be designed with a high flexibility and support high user mobility. These challenging requirements can be fulfilled by wideband MIMO-OFDM mobile systems, since OFDM is well suited for wideband wireless communication applications. By integrating MIMO signal processing with multiple antennas a wideband MIMO-OFDM system requires a low signal

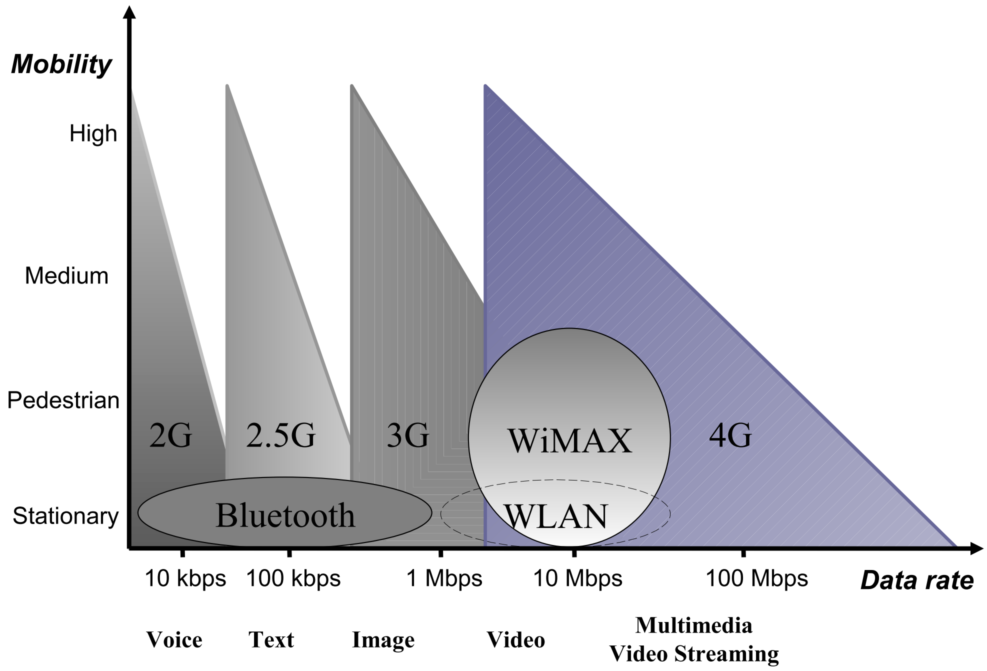

Figure 1.2: Data rate versus mobility in different mobile systems [Leg05] [Roh05]

processing power, because the OFDM symbol detection is simple in the frequency domain and the subcarrier-based MIMO signal processing is operated in the same way as in flat-fading scenarios.

1.2 Motivation and Contributions

For practical reasons, it still poses significant technical challenges to build a wideband wireless system with the MIMO-OFDM transceiver architecture. The basic questions raised for designing such a coherent-detection communication system are:

- How to design a flexible and reliable system to ensure data transmission under high dynamic and frequency-selective radio channel conditions?
- What are the practical channel estimation methods and how critical is the system performance degraded by estimated channel state information (CSI) errors?
- What is the achievable system data rate and its channel capacity with multiple antennas?
- What are the signal processing algorithms and their complexity?

- What is the influence of environmental conditions for system data transmission performance?

All the above questions motivate the investigations and discussions in this thesis. The contributions of this thesis are the conceptional extensions and investigations for MIMO-OFDM systems. This includes the aspects of

- the channel capacity with multiple antennas for both cases of ideal CSI and estimated CSI;
- the system performance for different MIMO signal processing algorithms under various channel conditions;
- the investigation on system performance with estimated CSI by pilot-based channel estimation (PBCE) methods;
- the indicator-based link adaptation proposal, the applicable indicator candidates, and the average system throughput results with the indicator-based link adaptation procedure for MIMO-OFDM systems.

The channel capacity in multiple antenna systems is addressed with both cases of the ideal CSI and the estimated CSI available in the system. Multiple antennas can improve the channel capacity dramatically compared to single antenna systems, while some errors in the CSI estimation can significantly degradate the system channel capacity.

Therefore, there must be some metric to determine a trade-off between the channel estimation accuracy and the overhead that the system has to sacrifice for it. Based on the MIMO-OFDM transceiver structure, investigations on PBCE have been done by evaluating different pilot patterns, pilot density, pilot power distribution levels, and various interpolation methods.

In a MIMO-OFDM system, it is very flexible to choose such global parameters as different MIMO techniques, antenna setup, power allocation and bit loading schemes in order to achieve a required system performance. Based on the investigations, diversity techniques are robust to channel fluctuations, and in favor of a concentrated power distribution in the spatial domain, whereas multiplexing techniques works well only in the rich-scatterer propagation scenarios.

Link adaptation is a well-known concept to optimize the system performance regarding the instantaneous fading dynamics in the channel. In a MIMO-OFDM system, this idea implies that other than the Physical (PHY) mode (combination of channel coding rate and digital modulation scheme) selection approach, different MIMO techniques can be treated as one more system parameter to improve the system performance. Therefore, the concept of Transmission Mode Selection (TMS) is proposed to integrate the idea of selecting a favorite MIMO technique together with a proper PHY mode. The TMS procedure is presented for MIMO-OFDM systems in this thesis. Different indicator candidates are proposed. The average system throughput results of the indicator-based TMS procedure are listed to verify the link adaptation framework in MIMO-OFDM systems.

1.3 Outline

Figure 1.3 shows the outline of this thesis. Chapter 1 presents an introduction on the history of wireless communication, followed with the description of the background, motivation, contributions, and outline of the thesis.

In chapter 2 the physical characteristics of mobile radio channels are addressed, and the modeling issues for wideband radio channels are also mentioned. Chapter 3 discusses channel capacity with multiple antennas for both cases with ideal CSI and estimated CSI.

Chapter 4 introduces the idea of OFDM modulation in wideband systems, where the radio channel has a frequency-selective behavior. The fundamentals of an OFDM transmission system are listed. By integrating multiple antennas into the OFDM system, a flexible, reliable MIMO-OFDM system is presented in chapter 5. For each MIMO technique, the details of the MIMO encoding and decoding algorithms on each OFDM subcarrier are described in chapter 6.

Chapter 7 presents the simulation results with ideal channel state information, and addresses the performance analysis for different MIMO-OFDM systems under various radio channel conditions.

The pilot-based channel estimation methods for MIMO-OFDM systems are described in chapter 8. With estimated CSI for MIMO processing and data detection, the system performance is reasonably degraded due to channel estimation errors. The simulation results are illustrated, and the impact of channel estimation error on system performance is analysed.

Chapter 9 addresses the link adaptation issue in a MIMO-OFDM system. The TMS procedure with 2D indicators is proposed. A set of indicator candidates and their approximation functions are derived. Based on the derived indicator functions, the average throughput results of the indicator-based link adaptation approach are plotted and compared with the performance results for conventional link adaptation method.

Conclusions are drawn in chapter 10. It summarizes the general performance results of MIMO-OFDM systems, and discusses the issue of how to design a MIMO-OFDM system in wideband mobile communication applications.

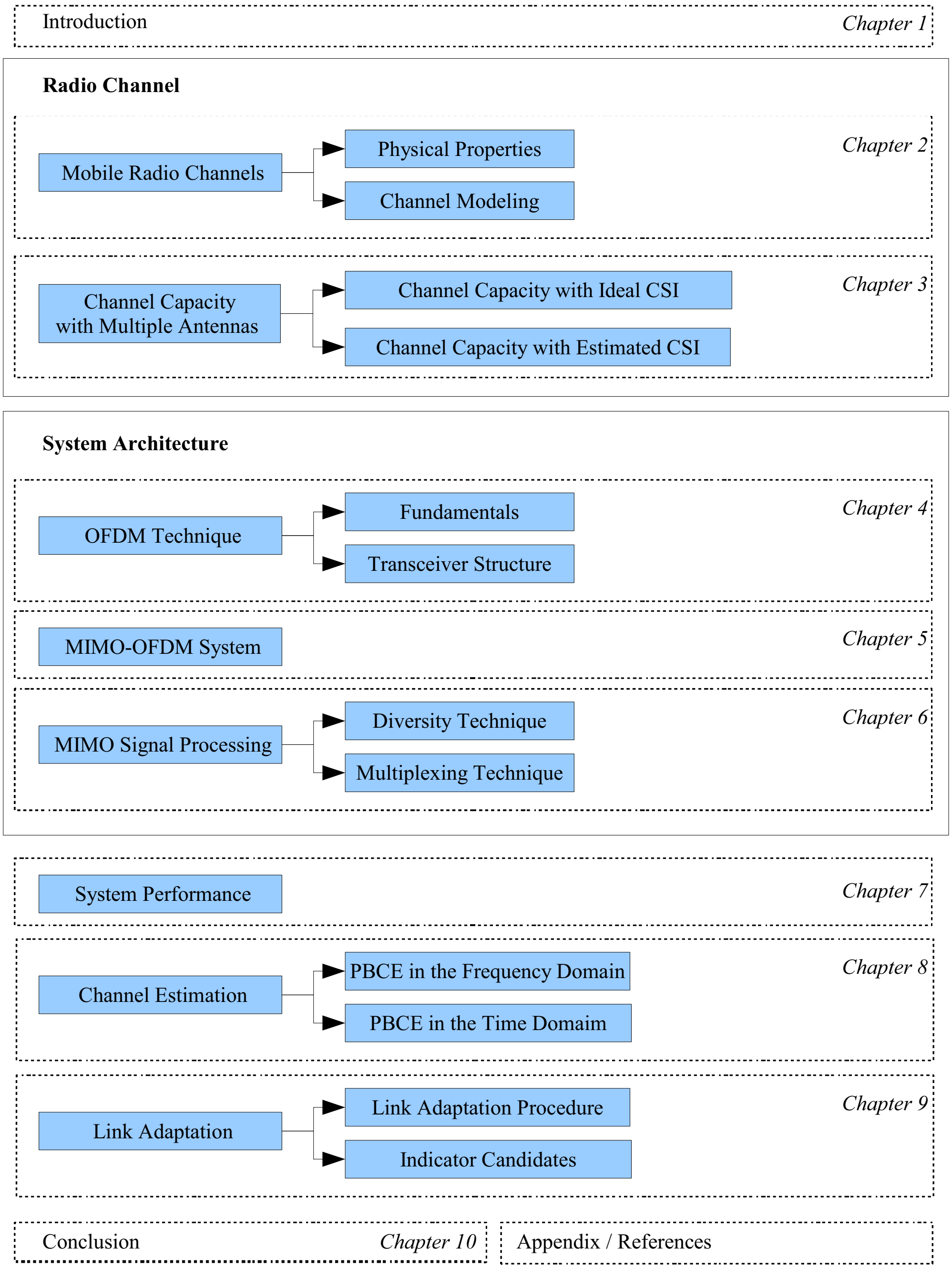

Figure 1.3: Outline of this thesis