Computers and Electrical Engineering 000 (2016) 1–20

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

Multiple-antenna systems and multiuser communications: Fundamentals and an overview of software-based modeling techniques☆

Guo Sheng[a], Yuxin Wang[b], Zhihan Lv[c], Houbing Song[d,*]

[a] Zhejiang Post and Telecommunication College, 474 Shanyin Road, Shaoxing, 312016, P.R. China
[b] Department of Electrical and Electronic Engineering, Imperial College London, London, SW7 2AZ, UK
[c] SIAT, Chinese Academy of Science, Shenzhen 51805, P.R. China
[d] Department of Electrical and Computer Engineering, West Virginia University, WV 25136, USA

ARTICLE INFO

Article history:
Received 5 April 2016
Revised 18 August 2016
Accepted 18 August 2016
Available online xxx

Keywords:
Multiple-antenna systems
MIMO
Multiuser communications
Random access methods
Review

ABSTRACT

In this paper, advanced contemporary multiple communication techniques, including multiple-antenna systems and multiuser communications are introduced and analyzed in details. Moreover, their supportive software-based modeling techniques are also detailed with appropriate mathematical derivations and simulations. Additionally, random access methods, as a promising and efficient implementation of multiuser communications are also briefly introduced for industrial use purposes. By reading this paper, the readers are expected to have a broad understanding of these advanced contemporary multiple communication techniques and acquire the technical know-hows of software-based simulation and industrial implementation of these techniques. Meanwhile, this paper is also expected to play the role of a solid reference for the relevant technicians which might require the introduced modeling techniques in this paper.

1. Introduction

As can be concluded in many academic works, various multiple communication techniques are powerful tools to increase the throughput and reliability of a communication system [1]. With the development of communication networks and FPGA technology, we are able to use them to process complicated communication signals in a rapid manner and obtain a better performance of the entire communication system [2]. Due to these progresses in peripheral and supportive subjects, two advanced contemporary multiple communication techniques have been invented and become the core of research for next generation communication systems, which are multiple-antenna systems and multiuser communications [3]. A large number of experimental tests and simulations have firmly validated their extensive applicability and excellent improvement effects on the existing communication infrastructure and the quality of service (QoS) [4].

Currently, a number of useful modeling techniques and architectures regarding communication networks have been proposed and attract researchers' attention [5]. A comprehensive evaluation report of IEEE 802.15. 4 for cyber-physical systems is published, in which relevant applications imposing considerable requirements on robustness of the employed network-

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Guest Editor Dr. T. Qiu.

* Corresponding author.
E-mail addresses: sg@zptc.cn (G. Sheng), yuxin.wang14@imperial.ac.uk (Y. Wang), lvzhihan@gmail.com (Z. Lv), h.song@ieee.org (H. Song).

http://dx.doi.org/10.1016/j.compeleceng.2016.08.015
0045-7906/

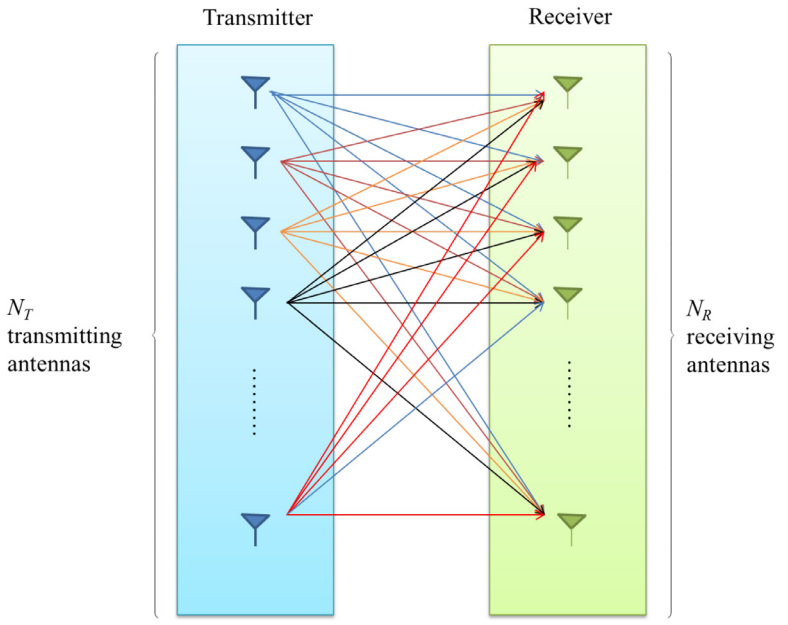

Fig. 1. A generic and simplified model of MIMO system.

ing infrastructure have been evaluated [6]. Meanwhile, energy consumption and routing issues, as two important topics for personal communications have also been reviewed with proper modeling techniques [7,8]. Moreover, another modeling techniques for dual-band microstrip antenna for wireless local area network (WLAN) have been well developed recently [9].

However, there is a lack of systematic review of these modeling techniques for multiple-antenna systems and multiuser communications. Therefore, for further investigation purpose, it is necessary to review these two advanced techniques and analyze the relevant mathematical models of their supportive software-based modeling techniques. The contributions of this paper are summarized as follows:

- Review the fundamentals of multiple-antenna systems and multiuser communications comprehensively.
- Review a number of important and influential papers in both fields.
- Point out several potential directions for further investigations.
- Review the details of random access methods as a specific example to the generic technologies.

The rest of this paper is organized as follows. In Section 2, the fundamentals of multiple-antenna systems are presented. Specifically, the signal and channel models of multiple-antenna systems are first analyzed as a foundation of further modeling and performance analysis; then, we also perform the channel capacity analysis and illustrate the improvement effects of multiple-antenna systems from the information-theoretic point of view. Also, to implement this technique successfully, the signaling, transmission, detection and coding techniques are discussed seriatim. After multiple-antenna systems, multiuser communications are reviewed in Section 3. Similarly, the relevant signal and channel models are first introduced and analyzed. Then the information-theoretic issues are discussed and signaling techniques are expatiated with detailed derivations. In addition, we also introduce random access methods in Section 4, which are promising and efficient implementations of multiuser communications. Finally, we conclude this paper in Section 5.

2. Fundamentals of multiple-Antenna systems

2.1. Signal, system and channel model of multiple-antenna systems

MIMO system is a powerful tool to provide spatial diversity and thereby overcome deep fading as well as improve the system performance. In general, a MIMO system consists of N_T transmitting antennas at the transmitter and N_R receiving antennas at the receiver. There are several special cases of MIMO system. If $N_T = N_R = 1$, then the system is called single-input, single-output (SISO) system; If $N_T = 1$ and $N_R \geq 2$, then the system is termed single-input, multiple-output (SIMO) system and multiple-input, single-output (MISO) system vice versa [10]. A generic and simplified model of MIMO system can be shown in Fig. 1. From this figure, it is clear that for a MIMO system with N_T transmitting antennas and N_R receiving antennas, $N_R \times N_T$ channels will be constructed. To model such a system, a $N_R \times N_T$ channel matrix would be useful. Assume $h_{ij}(\tau; t)$ is the equivalent baseband channel impulse response between i-th receiving antenna and j-th transmitting antenna, where $i \in \{1, 2, \ldots, N_R\}$, $j \in \{1, 2, \ldots, N_T\}$, τ represents the propagation delay and t is the time variable. The time-varying

Please cite this article as: G. Sheng et al., Multiple-antenna systems and multiuser communications: Fundamentals and an overview of software-based modeling techniques, Computers and Electrical Engineering (2016), http://dx.doi.org/10.1016/j.compeleceng.2016.08.015