Int. J. Electron. Commun. (AEÜ) 66 (2012) 797–805

Contents lists available at SciVerse ScienceDirect

International Journal of Electronics and Communications (AEÜ)

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

Performance analysis of MIMO–OFDM in various outdoor fading environments

Sarma Sandeep Jayakrishnan, Vidhyacharan Bhaskar*

Department of Electronics and Communication Engineering, SRM University, Kattankulathur, Kancheepuram Dt. 603203, Tamilnadu, India

ARTICLE INFO

Article history:
Received 7 July 2011
Accepted 21 January 2012

Keywords:
Spectral efficiency
Bit error rate
Shadowing
Foliage
Doppler effect
Outdoor environment

ABSTRACT

Multiple-input Multiple-output (MIMO) technology is being combined with Orthogonal Frequency Division Multiplexing (OFDM) for use in next generation broadband wireless communication systems, and there has been an increase in the study of MIMO–OFDM systems. IEEE 802.11n specification uses MIMO–OFDM system to improve network throughput and coverage over the two previous standards, 802.11a and 802.11g, in indoor and outdoor environments, respectively. With an extended range of about two hundred meters in the outdoor environment, the use of 802.11n has increased. This paper analyzes the effect of shadowing, moving user and foliage in outdoor environment. There is a special need to analyze performance measures such as Spectral Efficiency and Bit Error Rate (BER), and this is the subject matter of interest in this paper.

1. Introduction

Outdoor environment for WiFi networks, such as those built to provide public Wi-Fi access or support public safety, meter reading, or intelligent traffic systems must overcome its unique challenges.

Links traverse distances an order of magnitude longer than those in indoor networks, resulting in lower signal strengths, and a greater variety of paths a signal can take from the origin to the destination. Interference is a much bigger factor, and occurs from sources not usually from indoors, including powerful rooftop or tower transmitters. Outdoor networks must scale differently than indoor networks. Outdoor networks often consist of thousands of access points, with each one within range of tens of neighbors, requiring better coordination and sharing of airtime resources. In other words, an outdoor environment plays a very important role in the whole process of designing the system, and fading depends upon various scattering and propagation paths due to periodic structures which cause transmission phenomena, such as scattering, reflection, shadowing effect, and diffraction. Fading plays an important role in the final analysis of the received signal [1]. Due to these signal degradations, the channel characteristics vary, and system capacity depends upon the channel characteristics.

A method of implementing a MIMO–OFDM-based wireless LAN system was provided in [2]. The authors proposed a coding technique for MIMO–OFDM based broadband wireless systems in [3]. In [4], the system throughput of a Wireless Local Area Network (WLAN) based on MIMO–OFDM was discussed. In [5], a Body-Shadowing model for indoor radio communication environment was proposed. The method is suitable for indoor network planning tools for indoor radio LAN. A Radar Cross-Section-Based Pedestrian Model was introduced in [6]. The effect of pedestrian movement on MIMO–OFDM channel capacity in an indoor environment using experiments and simulation was investigated in [7]. In [8], an outdoor MIMO Wireless Channel model which can predict the performance of a MIMO–OFDM system was discussed. Investigation of foliage effect on wireless communication systems was made in [9].

MIMO channel capacity of a measured radio channel for outdoor macro cellular systems at 3 GHz-band was investigated in [10]. Experiments were conducted on propagation characteristics in an urban environment at center frequency of 3.35 GHz, and the related eigenvalue and channel capacity of an equivalent MIMO channel for a 2×2 MIMO system was presented, and a comparison of channel capacity for LOS and NLOS environments vs. antenna distance was performed. Information about the products based upon the IEEE draft 2.0 802.11n specifications was provided in [11].

In this paper, to limit the numerous scenarios that can occur in an outdoor environment, three scenarios have been considered. They are: (i) Shadowing effect, (ii) Moving User, and (iii) Foliage. These three scenarios are dealt in the following sections. Section 2 discusses the system model. The spectrum efficiency and Bit Error Rate for the mentioned scenarios are derived in Section 3. Analytical and simulation results are shown in Section 4. Finally, Section 5 presents the conclusions.

* Corresponding author. Tel.: +91 9884661184.
E-mail addresses: sandeepjk1@gmail.com (S.S. Jayakrishnan), meetvidhyacharan@yahoo.com, vcharan@gmail.com (V. Bhaskar).

1434-8411/$ – see front matter © 2012 Elsevier GmbH. All rights reserved.
doi:10.1016/j.aeue.2012.01.013

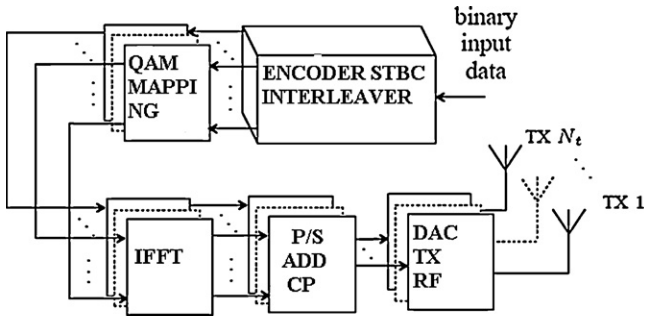

Fig. 1. Schematic representation of the transmitter of a MIMO–OFDM system [4].

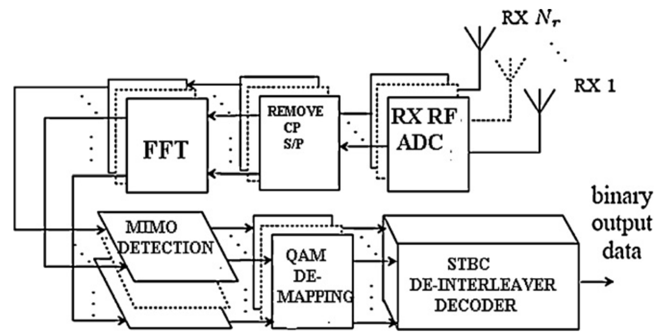

Fig. 2. Schematic representation of the receiver of a MIMO–OFDM system [4].

2. System model

2.1. Transmitter section

MIMO is a technology which uses multiple antennas to coherently resolve more information than possible using a single antenna. In OFDM, a single high-data-rate stream is divided into a number of low rate data streams that are transmitted simultaneously over some narrower subchannels. The basic N_t transmitter section of a MIMO–OFDM system is shown in Fig. 1. Here, the incoming bits through N_c sub-carriers are multiplexed, and each branch in parallel performs encoding, interleaving, Quadrature Amplitude Modulation (QAM) mapping, and Inverse Discrete Fourier Transform (IDFT). A Cyclic Prefix (CP) is then added before the final transmitted signal is upconverted to Radio Frequency (RF) and transmitted.

After encoding and Space Time Block Coding (STBC), it is an alternative to spatial multiplexing, which is more complicated and expensive but gives better performance, particularly for systems where the number of receive antennas is less than the number of transmit antennas. A typical case is that of a transmitter transmitting to a handset or a handheld client; the transmitter supports multiple transmit antennas, but the client may only have room and battery power for a single receiver. In this case, STBC is used to significantly increase the Signal to Noise Ratio (SNR) at the receiver, thereby improving the range. After that, the data is mapped to complex QAM symbols [4].

After Parallel-to-Serial (P/S) conversion, CP creatively fills the empty guard interval with a cyclic extension of the OFDM symbol. If the length of CP is longer than the impulse response of the channel, the Inter Symbol Interference (ISI) can be eliminated completely. Furthermore, this effectively simulates a channel performing cyclic convolution which implies orthogonality between subcarriers over a time dispersive channel. After conversion from digital to analog, the signals are upconverted to Radio Frequency (RF) and transmitted through N_t antennas [4].

2.2. Receiver section

The receiver receives the various multipath signals arriving at N_r receive antennas, and these signals are processed to estimate the transmitted signal. The receiver estimates and corrects the frequency offset and symbol timing, e.g., by using training symbols in the preamble. Subsequently, the CP is removed to decrease the influence of multipath induced ISI, and the N-point DFT is performed per receiver branch. The symbols per transmitted stream are combined, and the signals are transformed to frequency domain using DFT, then QAM demapper converts the detected complex symbols to binary data streams.

Deinterleaving introduces noise in the transmission channel to be statistically independent at the receiver, thus allowing better error correction. This process is done exactly in the opposite way at the receiver as the data is interleaved at the transmitter, and then decoding is performed at the N_t parallel streams, and the resulting data is combined to obtain the binary output data [8]. Fig. 2 is a schematic representation of the receiver of a MIMO–OFDM system.

The number of simultaneous data streams is limited by the minimum number of antennas in use on both sides of the link. However, individual radios often limit the number of spatial streams that may carry unique data. The notation $a \times b$:c helps identify what a given radio is capable of [11]. The first number, a, is the maximum number of transmit antennas or RF chains that can be used by the radio. The second number, b, is the maximum number of receive antennas or RF chains that can be used by the radio. The third number, c, is the maximum number of data spatial streams the radio can use. For example, a radio that can transmit from two antennas and receive from three, but can only send or receive two data streams would be 2×2:2.

The 802.11n allows up to 4×4:4. Common configurations of 11n devices are 2×2:2, 2×3:2, and 2×3:2. All three configurations have the same maximum throughput and features, and differ only in the amount of diversity the antenna systems provide.

2.3. Outdoor environment

Characterisation of MIMO–OFDM channel capacity in outdoor environments plays a key role to characterize the performance of MIMO–OFDM systems. The MIMO–OFDM spectrum efficiency, without the channel knowledge at the transmitter is given by (from [3], p. 682)

$$C = \frac{1}{N_c}\sum_{k=1}^{N_c}\sum_{j=1}^{N_t}\log_2\left(1+\frac{\rho\gamma_j(f_k)}{N_t}\right), \tag{1}$$

where C is the normalised capacity in bit/s/Hz, N_c is the number of OFDM subcarriers, N_t is the number of transmit antennas, ρ is the average Signal-to-Noise Ratio (SNR), γ_j is the eigenvalue of $H(f_k)H^{\mathrm{H}}(f_k)$, f_k, is the kth subcarrier frequency, and $^{\mathrm{H}}$ denotes Hermitian transpose.

The capacity per unit bandwidth (spectrum efficiency) is directly affected by the channel in which the signals are transmitted. Eq. (1) is used for the analysis of three previously mentioned scenarios in this section. Spectrum efficiency gives the measure of the quantity of users or services that can be simultaneously supported by a limited radio frequency bandwidth in a defined geographical area.

3. Performance analysis of the system

3.1. Shadowing effect

In an outdoor environment, the effect of shadowing is unavoidable and occurs due to many reasons. The occurrence of pedestrians,