A Pioneering Perusal of Mimo- OFDM Realy Guesstimate Disposition

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Abstract: A multiple-input multiple-output (MIMO) communication system combined with the orthogonal frequency partition multiplexing (OFDM) modulation technique can achieve reliable high data rate show over broadband wireless channels. Channel state information for both single-input single-output (SISO) and MIMO systems based on pilot aided arrangement is investigated in this paper. The estimate of channel at pilot frequencies with conventional Least Square (LS) and Minimum Mean Square (MMSE) estimation algorithms is carried out through Matlab simulation. For outdoor communicationscenarios, where wireless channels are sparse in nature, pathinterruptions of different transmit-receive antenna couples share a jointsparse decoration due to the spatial correlation of MIMO channels. By simultaneously exploiting those MIMOchannel characteristics, the proposed scheme performs better thanpresent state-of-the-art systems. Furthermore, by joint processingof signals associated with different antennas, the pilot overheadcan be reduced the performance of MIMO OFDM and SISO OFDM are assessed on the basis of Bit Error Rate (BER) and Mean Square Error (MSE) level. Further enhancement of presentation can be attained through maximum diversity Space Time Block Coding and Maximum Likelihood Detection at transmission and reception ends respectively. MMSE estimation has been shown to perform much better than LS but is more complex than LS for the MIMO system using pilot carriers.

Keywords: Antenna, BER, Detection, MIMO, OFDM, SISO, LS, MSE, MMSE

I. Introduction

Wireless technologies have evolved remarkably since Guglielmo Marconi first demonstrated radio's ability to provide continuous contact with ships sailing in the English channel in 1897. New theories and applications of wireless technologies have been developed by hundreds and thousands of scientists and engineers through the world over since. Wireless communications can be regarded as the most important development that has an extremely wide range of applications from TV remote control to cordless phones to cellular phones and satellite-based TV systems. It changed people's life style in every aspect. Especially during the last decade, the mobile radiocommunications industry has grown by an exponentially increasing rate, fueled by the digital and RF (radio frequency) circuits design, fabrication and integration techniques and more computing power in chips. This trend will continue with an even greater pace in the near future.

One natural question is: how can we put high-rate data streams over radio links to satisfy our needs? New wireless broadband access techniques are anticipated to answer this question. For example, the coming 3G (third generation) cellular technology can provide us with up to 2Mbps (bits per second) data service. But that still does not meet the data rate required by multimedia media communications like HDTV (high-definition television) and videoconferencing. Recently MIMO-OFDM systems have gained considerable attentions from the leading industry companies and the active academic community. A collection of problems including channel measurements and modeling, channel estimation, synchronization, IQ (in phase-quadrature)imbalance and PAPR (peak-to-average power ratio) have been widely studied by researchers.

![Figure 1.0: OFDM System Block Diagram](image-url)
System Model

The OFDM technology is widely used in two types of working environments, i.e., a wired environment and a wireless environment. When used to transmit signals through wires like twisted wire pairs and coaxial cables, it is usually called as DMT (digital multi-tone). For instance, DMT is the core technology for all the xDSL (digital subscriber lines) systems which provide high-speed data service via existing telephone networks. However, in a wireless environment such as radio broadcasting system and WLAN (wireless local area network), it is referred to as OFDM. Since we aim at performance enhancement for wireless communication systems, we use the term OFDM throughout this thesis. Furthermore, we only use the term MIMO-OFDM while explicitly addressing the OFDM systems combined with multiple antennas at both ends of a wireless link. The history of OFDM can all the way date back to the mid 1960s, when Chang [2] published a paper on the synthesis of bandlimited orthogonal signals for multichannel data transmission. He presented a new principle of transmitting signals simultaneously over a bandlimited channel without the ICI and the ISI. Right after Chang's publication of his paper, Saltzburg [3] demonstrated the performance of the efficient parallel.

With OFDM systems getting more popular applications, the requirements for better performance are becoming higher. Hence more research efforts are poured into the investigation of OFDM systems. Pulse shaping [7, 8], at an interference point of view, is beneficial for OFDM systems since the spectrum of an OFDM signal can be shaped to be more well-localized in frequency; Synchronization [9, 10, 11] in time domain and in frequency domain renders OFDM systems robust against timing errors, phase noise, sampling frequency errors and carrier frequency offsets; For coherent detection, channel estimation [46, 49, 48] provides accurate channel state information to enhance performance of OFDM systems; Various effective techniques are exploited to reduce the relatively high PAPR [12, 13] such as clipping and peak windowing. The principle of OFDM is to divide a single high-data rate stream into a number of lower rate streams that are transmitted simultaneously over some narrower subchannels. Hence it is not only a modulation (frequency modulation) technique, but also a multiplexing (frequency-division multiplexing) technique. Before we mathematically describe the transmitter-channel-receiver structure of OFDM systems, a couple of graphical intuitions will make it much easier to understand how OFDM works. OFDM starts with the 'O', i.e., orthogonal. That orthogonality differs OFDM from conventional FDM (frequency-division multiplexing) and is the source where all the advantages of OFDM come from. The difference between OFDM and conventional FDM is illustrated in Figure 1.1.

![Figure 1.1: Comparison between conventional FDM and OFDM](image)

Motivation

The sparse common support (SCS) model [6, 2] is a reasonable assumption for many real-world channels. Sparsity is often observed in multipath environments, where each individual path gives rise to an impulse in the channel response function [1, 7]. The common support assumption is relevant when the distances between sensors are much smaller than the distance traveled by the electromagnetic (or sound) wave in a time related to the inverse signal bandwidth (see [2] for a more detailed justification). In this case, certain frequency subbands of the channel response functions are well approximated by the SCS model, even though the full channel response functions might not agree with this assumption. First, the proposed scheme can achieve super-resolution estimates of arbitrary path delays, which is more suitable for wireless channels in practice. Second, due to the small scale of the transmit and receive antenna arrays compared to the long signal transmission distance in typical MIMO antenna geometry, channel impulse responses (CIRs) of different transmit-receive antenna pairs share common path delays [5], which can be translated as a common sparse pattern of CIRs due to the spatial correlation of MIMO channels. Meanwhile, such common sparse pattern is nearly unchanged along several adjacent OFDM symbols due to the temporal correlation of wireless channels [6, 7]. Compared with previous
work which just simply extends the sparse channel estimation scheme in single antenna systems to that in MIMO by exploiting the spatial correlation of MIMO channels [5] or only considers the temporal correlation for single antenna systems [6], [7], the proposed scheme exploits both spatial and temporal correlations to improve the channel estimation accuracy. Third, we reduce the pilot overhead by using the finite rate of innovation (FRI) theory [8], which can recover the analog sparse signal with very low sampling rate, as a result, the average pilot overhead per antenna only depends on the channel sparsity level instead of the channel length.

II. MIMO-OFDM Channel Estimation

With the ever increasing number of wireless subscribers and their seemingly "greedy" demands for high-data-rate services, radio spectrum becomes an extremely rare and invaluable resource for all the countries in the world. Efficient use of radio spectrum requires that modulated carriers be placed as close as possible without causing any ICI and be capable of carrying as many bits as possible. Optimally, the bandwidth of each carrier would be adjacent to its neighbors, so there would be no wasted bands. In practice, a guard band must be placed between neighboring carriers to provide a guard space where a shaping filter can attenuate a neighboring carrier's signal. These guard bands are waste of spectrum. In order to transmit high-rate data, short symbol periods must be used. The symbol period $T_{sym}$ the inverse of the baseband data rate $R$ ($R = \frac{1}{T_{sym}}$), so as $R$ increases, $T_{sym}$ must decrease. In a multipath environment, however, a shorter symbol period leads to an increased degree of ISI, and thus performance loss. OFDM addresses both of the two problems with its unique modulation and multiplexing technique. OFDM divides the high-rate stream into parallel lower rate data and hence prolongs the symbol duration, thus helping to eliminate ISI. It also allows the bandwidth of subcarriers to overlap without ICI as long as the modulated carriers are orthogonal. OFDM therefore is considered as a good candidate modulation technique for broadband access in a very dispersive environment [42, 43]. However, relying solely on OFDM technology to improve the spectral efficiency gives us only a partial solution. At the end of 1990s, seminal work by Foshini and Gans [21] and, independently, by Teltar [22] showed that there is another alternative to accomplish high-data-rate over wireless channels: the use of multiple antennas at both ends of the wireless link, often referred to as MA (multiple antenna) or MIMO in the literature [21, 22, 17, 16, 25, 26]. The MIMO technique does not require any bandwidth expansions or any extra transmission power. Therefore, it provides a promising means to increase the spectral efficiency of a system. In his paper about the capacity of multi-antenna Gaussian channels [22], Telatar showed that given a wireless system employing $N_T$ (transmit) antennas and $N_R$ (receive) antennas, the maximum data rate at which error-free transmission over a fading channel is theoretically possible is proportional to the minimum of $N_T$ and $N_R$ (provided that the $N_T N_R$ transmission paths between the TX and RX antennas are statistically independent). Hence huge throughput gains may be achieved by adopting $N_T N_R$ MIMO systems compared to conventional 1 £ 1 systems that use single antenna at both ends of the link with the same requirement of power and bandwidth. With multiple antennas, a new domain, namely, the spatial domain is explored, as opposed to the existing systems in which the time and frequency domain are utilized.

Signal Model

![Figure 2.0: Ntx Nr MIMO-OFDM System model](image-url)
Pilot-tone Design

In order to have a simple and efficient LS algorithm for channel estimation, we have to design the square matrix $S(P)(m)$ deliberately. In this section, the design will be illustrated by a theorem and an example.

The preamble design discussed in [50] adopted Tarokh’s approach [18] to spacetime blockcode construction. It could be related to orthogonal design to which our pilot-tone design also has a connection. In each of the first $N_t$ training blocks in a frame, a group of at least $L$ pilot-tones are equally placed and all the other tones are set to zeros. LS channel estimation can then be obtained based on the known pilot-tones. The channel is assumed to be unchanged for the rest of the whole frame. In a mobile environment, however, we cannot guarantee that the channel state information estimated at the $m$-th block still holds true at the $(m + N_t)$-th block.

Hence the preamble design in [50] is not suitable to be applied to the fast time-varying channels. In addition to this common disadvantage, the training sequences designed in [48] have to satisfy a condition called local orthogonality. It requires that, for the $N$ different training sequences with length $N$, they are orthogonal over the minimum set of elements for any starting position. The pilot design proposed in this paper aims to remove the disadvantage and the constraint mentioned above. It actually has its roots to Table I in [16], but it is not implemented in space and time domain. On the contrary, it is accomplished in space and frequency domain. We explicitly connect pilot-tone design with space-frequency coding so that we have more insights on its design.

Denote $E_P$ as the fixed total power for all the pilot-tones at each transmit antenna. Then the power allocated on each pilot-tone is $E_P N_t L$ since pilot-tones are all equally spaced and equal powered. In some systems, the power of those pilot-tones could be larger than the power of data symbols for a better estimation of the wireless channel. We assume in our work that the pilot-tones and other data are all equally normalized such that the average power for all different mappings is the same. Our pilot-tone design is illustrated in the following theorem.

**Theorem 2.1** Let $S_{\text{diag},j}(m) = \alpha_{pi,j} I_{LN}, |\alpha_{pi,j}| = \sqrt{\frac{E_P}{N_t L}}$, $i, j = 1, 2, \ldots, N_t$, then

$$\frac{1}{\sqrt{E_P}} S^P(m)$$

is a unitary matrix if

$$S^P_SFC(m) = \sqrt{\frac{L}{E_P}} \begin{bmatrix} S_{\text{diag},1}(m) & \ldots & S_{\text{diag},N_t}(m) \end{bmatrix}$$

is a unitary matrix

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III. Results

![Figure 2.1 MSE vs SNR](image)

Figure 2.1 MSE vs SNR
Figure 2.2 LS Estimation

Figure 2.3 CS Estimation

Figure 2.4 CS Estimation
This paper, in the first part, addresses the problem of channel estimation of MIMO-OFDM systems. It starts from the matrix representation of the signal model of MIMO-OFDM systems, which clearly describes the relation of signals in frequency domain and time domain and expressing operations like adding CP and removing CP as matrix product. From the resulting MIMO-OFDM signal model, a pilot tone based channel estimation is proposed to estimate the fast time-varying and frequency selective fading channel via the least-squares method. The least-squares is selected for the purpose of low complexity, though some other methods such as MMSE and ML may produce better estimation performance. To further reduce the computational complexity, the pilot tone matrix is designed as a unitary matrix to save the computation of the matrix inversion in the standard LS solution. The pilot tone matrix is designed in a simple way that N disjoint pilot tone sets are placed at one OFDM block on each transmit antenna. Each pilot tone set has L pilot tones which are equally spaced and equally powered. By choosing the pilot tones based on our design, those pilot tones comprise a unitary matrix. For a simple 2 x 2 case, Alamouti’s orthogonal structure is exploited. And the design can be readily extended to a configurable MIMO-OFDM system with any number of transmit and receive antennas. For a fixed power of pilot tones, our design can be proved to be also optimal in the sense of achieving the minimum MSE of channel estimation. Compared with some relative pilot tone designs in the literature, our channel estimation method differs in its ability to estimate fast time-varying wireless channel since pilot tones are inserted into each OFDM block, and in its explicit relation with space-frequency code design which can benefit the channel estimation in return. Seeking for a robust channel estimator with lower complexity for MIMO-OFDM systems, we are looking at the following aspects in the future.

References