HIGH DATA RATE TRANSMISSION FOR MIMO OFDM SYSTEMS UNDER VEHICULAR CHANNEL ENVIRONMENT

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ABSTRACT

A novel approach for channel estimation is proposed in this paper based on finite rate of innovation. The channel estimation in multiple input multiple output (MIMO) OFDM is a challenging task due to its high data rate and for acquiring the better accuracy for this challenging task an parametric sparse scheme is proposed in this paper. Further to estimate the path delays with arbitrary values can be achieved a super resolution technique. To improve the channel estimation in an accurate manner in this paper we exploit the spatial and temporal correlation of MIMO OFDM. This paper is mainly written for outdoor communication scenarios and the main intention of proposed work is to view the wireless channels in OFDM system are sparse in nature or not. Most of transmit receive antenna pairs in OFDM system share a common sparse pattern mainly due to the spatial correlation of MIMO channels. The temporal correlations show that adjacent OFDM symbols is nearly unchanged in process of measuring sparse pattern in MIMO system. In outdoor communication scenario this unchanged approach of OFDM symbols are mainly due to the temporal correlation of MIMO mechanism. In the process of exploiting the MIMO channel statistics the proposed work simulation results yields better result over the conventional works which are proposed in literature.

Index Terms — Super-resolution, sparse channel estimation, MIMO-OFDM, finite rate of innovation (FRI), spatial and temporal correlations.

INTRODUCTION

Wireless systems are expected to require high data rates with low delay and low bit-error-rate (BER). In such situations, the performance of wireless communication systems is mainly governed by the wireless channel environment. In addition, high data rate transmission and high mobility of transmitters and/or receivers usually result in frequency-selective and time selective, i.e., doubly selective, fading channels for future mobile broadband
wireless systems. Therefore, mitigating such doubly selective fading effects is critical for efficient data transmission. Moreover, perfect channel state information (CSI) is not available at the receiver. Thus in practice, accurate estimate of the CSI has a major impact on the whole system performance. It is also because, in contrast to the typically static and predictable characteristics of a wired channel, the wireless channel is rather dynamic and unpredictable, which makes an exact analysis of the wireless communication system often difficult.

For a typical wireless system, RF signal transmission between two antennas commonly suffers from power loss, which affects its performance. This power loss between transmitter and receiver is a result of three different phenomena: 1) distance-dependent decrease of the power density called path loss or free space attenuation, 2) absorption due to the molecules in the atmosphere and 3) signal fading caused by terrain and weather conditions in the propagation path. Atmospheric absorption is due to the electrons, uncondensed water vapor and molecules of various gases. Path loss is a theoretical attenuation which occurs under free-line-of-sight conditions and which increases with the distance between base station and mobile.

Fading refers to the variation of the signal amplitude over time and frequency. In contrast with the additive noise as the most common source of signal degradation, fading is another source of signal degradation that is characterized as a non additive signal disturbance in the wireless channel. Fading may be either due to multipath propagation, referred to as multi path (induced) fading, or to shadowing from obstacles that affect the propagation of a radio wave, referred to as shadow fading. Fading channel models are often used to model electromagnetic transmission of information over wireless media such as cellular phone and broadcast communication.
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The shadow fading occurs when terminals move through areas with obstacles of various sizes, such as mountains, buildings and tunnels. Occasionally, these obstacles will shadow or completely cut off the signal. Although the consequences of such shadowing effects will depend on the size of an obstacle and on the distance to it, the received signal strength will inevitably vary. The effect of shadow fading can be decreased with some awareness in network planning. For example, by placing base stations as high as possible or close to each other it is possible to avoid some obstacles in transmission. However, it is not only the shadow fading that is the most unpredictable power loss. Multi-path fading, Rayleigh fading (Figure 1) or short term fading are another types of fading, involving irregular signal strength variations and are usually problematic to overcome.

For MIMO-OFDM systems, accurate channel estimation is essential to guarantee the system performance. Generally, there are two categories of channel estimation scheme for MIMO-OFDM systems. The first one is nonparametric scheme, which adopts orthogonal frequency-domain pilots or orthogonal time-domain training sequences to convert the channel estimation in MIMO systems to that in single antenna systems. However, such scheme suffers from high pilot overhead when the number of transmit antennas increases. The second category is parametric channel estimation scheme, which exploits the sparsity of wireless channels to reduce the pilot overhead. The parametric scheme is more favorable for future wireless systems as it can achieve higher spectral efficiency. However, path delays of sparse channels are assumed to be located at the integer times of the sampling period, which is usually unrealistic in practice.

The main contributions of this letter are summarized as follows. 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, 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. 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 or only considers the temporal correlation for single antenna systems, 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, 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.

**SPARSE MIMO CHANNEL MODEL**

The MIMO channel is shown in Fig. 1, and its following characteristics will be considered in this letter.

**Channel Sparsity:** In typical outdoor communication scenarios, the CIR is intrinsically sparse due to several significant scatterers [3], [5]. For an \( N_t \times N_r \) MIMO system, the CIR \( h^{(ij)}(t) \) between the \( i \)th transmit antenna and the \( j \)th receive antenna can be modeled as

\[
h^{(ij)}(t) = \sum_{p=1}^{P} \alpha_p^{(ij)} \delta(t - \tau_p^{(ij)}), \quad 1 \leq i \leq N_r, 1 \leq j \leq N_t
\]

Figure 1: Spatial and temporal correlations of wireless MIMO channels.

Figure 2: Pilot pattern. Note that the specific \( N_t = 2, D = 4, N_p = 4, \) and \( N_p\text{ total} = 8 \) are used for illustration purpose, where \( \delta(.) \) is the Dirac function, \( P \) is the total number of resolvable propagation paths, and \( \tau_p^{(ij)} \) and \( \alpha_p^{(ij)} \) denote the path delay and path gain of the \( p \)th path, respectively.
Spatial Correlation: Because the scale of the transmit or receive antenna array is very small compared to the long signal transmission distance, channels of different transmit-receive antenna pairs share very similar scatterers. Meanwhile, for most communication systems, the path delay difference from the similar scatterer is far less than the system sampling period. Therefore, CIRs of different transmit-receive antenna pairs share a common sparse pattern, although the corresponding path gains may be quite different.

Temporal Correlation: For wireless channels, the path delays vary much slowly than the path gains, and the path gains vary continuously [6]. Thus, the channel sparse pattern is nearly unchanged during several adjacent OFDM symbols, and the path gains are also correlated.

SPARSE MIMO-OFDM CHANNEL ESTIMATION

In this section, the widely used pilot pattern is briefly introduced at first, based on which a super-resolution sparse MIMO-OFDM channel estimation method is then applied. Finally, the required number of pilots is discussed under the framework of the FRI theory.

Pilot Pattern

The pilot pattern widely used in common MIMO-OFDM systems is illustrated in Fig. 2. In the frequency domain $N_p$ pilots are uniformly spaced with the pilot interval $D$ (e.g., $D = 4$ in Fig. 2). Meanwhile, every pilot is allocated with a pilot index $l$ for $0 \leq l \leq N_p - 1$, which is ascending with the increase of the subcarrier index. Furthermore, to distinguish MIMO channels associated with different transmit antennas, each transmit antenna uses a unique subcarrier index initial phase $\theta_i$ for $1 \leq i \leq N_t$ and $(N_t - 1) N_p$ zero subcarriers to ensure the orthogonality of pilots [4]. Therefore, for the $i^{th}$ transmit antenna, the subcarrier index of the $l^{th}$ pilot is

$$l_{\text{pilot}}(l) = \theta_i + l D, 0 \leq l \leq N_p - 1$$  

Consequently, the total pilot overhead per transmit antenna is $N_p_{\text{total}} = N_t N_p$, and thus, $N_p$ can be also referred as the average pilot overhead per transmit antenna in this letter.

Super-Resolution Channel Estimation

At the receiver, the equivalent baseband channel frequency response (CFR) $H(f)$ can be expressed as

$$H(f) = \sum_{p=1}^{P} \alpha_p e^{-j2\pi f \tau_p}, -f_s/2 \leq f \leq f_s/2 \quad (3)$$

Where superscripts $i$ and $j$ in (1) are omitted for convenience, $f_s = 1/T_s$ is the system bandwidth, and $T_s$ is the sampling period. Meanwhile, the $N$-point discrete
Fourier transform (DFT) of the time-domain equivalent baseband channel can be expressed as [5], i.e.,

$$H[k] = H\left(\frac{k f_s}{N}\right), \quad 0 \leq k \leq N - 1$$

(4)

Therefore, for the \((i, j)\)th transmit-receive antenna pair, according to (2)–(4), the estimated CFRs over pilots can be written as

$$\tilde{R}^{(i,j)}[l] = H^t \left[ l_{\text{pilot}}^{(i)} \right]$$

$$= H \left( \frac{(\theta_i + l D) f_s}{N} \right)$$

$$= \sum_{p=1}^{P} \alpha_p^{(i,j)} e^{-j 2 \pi \frac{(\theta_i + l D) f_s}{N} \tau_p^{(i,j)}}$$

$$+ W^{(i,j)}[l]$$

(5)

where \(\tilde{R}^{(i,j)}[l]\) for \(0 \leq l \leq N_p - 1\) can be obtained by using the conventional minimum mean square error (MMSE) or least square (LS) method [2], and \(W^{(i,j)}[l]\) is the additive white Gaussian noise (AWGN). Eq. (5) can be also written in a vector form as

$$\tilde{R}^{(i,j)}[l] = (\nu^{(i,j)}[l])^T \alpha^{(i,j)} + W^{(i,j)}[l]$$

(6)

where \(\nu^{(i,j)}[l] = [y^{D_{1}^{(i,j)}} \ldots y^{D_{N_p}^{(i,j)}}]^T\)

$$\alpha^{(i,j)} = \left[ \alpha_1^{(i,j)} \alpha_2^{(i,j)} \ldots \alpha_p^{(i,j)} \right]^T$$

$$\gamma = e^{-j 2 \pi \frac{D f_s}{N}}$$

Because the wireless channel is inherently sparse and the small scale of multiple transmit or receive antennas is negligible compared to the long signal transmission distance, CIRs of different transmit-receive antenna pairs share common path delays, which is equivalently translated as a common sparse pattern of CIRs due to the spatial correlation of MIMO channels [5], i.e., \(\tau_p^{(i,j)} = \tau_p\) and \(\nu^{(i,j)}[l] = \nu[l]\) for \(1 \leq p \leq P, 1 \leq i \leq N_t, 1 \leq j \leq N_r\). Hence, by exploiting such spatially common sparse pattern shared among different receive antennas associated with the \(i\)th transmit antenna, we have

$$\tilde{H}^i = VA^i + W^i, \quad 1 \leq i \leq N_t$$

(7)

Where the \(N_p \times N_r\) measurement matrix \(\tilde{H}^i\) is

$$\tilde{H}^i = \left[ \begin{array}{ccc} \tilde{R}^{(1,1)}[0] & \tilde{R}^{(1,2)}[0] & \ldots & \tilde{R}^{(1,N_r)}[0] \\
\tilde{R}^{(2,1)}[1] & \tilde{R}^{(2,2)}[1] & \ldots & \tilde{R}^{(2,N_r)}[1] \\
\vdots & \vdots & \ddots & \vdots \\
\tilde{R}^{(N_t,1)}[N_p - 1] & \tilde{R}^{(N_t,2)}[N_p - 1] & \ldots & \tilde{R}^{(N_t,N_r)}[N_p - 1] \end{array} \right]$$

\(V = [\nu[0], \nu[1], \ldots, \nu[N_p - 1]]^T\) is a Vandermonde matrix of size \(N_p \times N_p\), \(A^i = [\alpha^{(i,1)}, \alpha^{(i,2)}, \ldots, \alpha^{(i,N_r)}]\) of size \(N_p \times N_r\) and \(W^i\) is an \(N_p \times N_r\) matrix with \(W^{(i,j)}[l]\) in its \(j\)th column and the \((i+1)\)th row.

When all \(N_t\) transmit antennas are considered based on (7), we have

$$\tilde{H} = VA + W$$

(8)
Where $\tilde{H}^i = [\tilde{H}^1 \tilde{H}^2 \ldots \tilde{H}^{N_t}]$ of size $N_p \times N_t N_r$, $A = [A^1, A^2, \ldots, A^{N_t}]$

And $W = [W^1, W^2, \ldots, W^{N_t}]$

Comparing the formulated problem (8) with the classical direction-of-arrival (DOA) problem [9], we find out that they are mathematically equivalent. Specifically, the traditional DOA problem is to typically estimate the DOAs of the $P$ sources from a set of time-domain measurements, which are obtained from the $N_p$ sensors outputs at $N_t N_r$ distinct time instants (time-domain samples). In contrast to our problem in (8), we try to estimate the path delays of $P$ multipaths from a set of frequency-domain measurements, which are acquired from $N_p$ pilots of $N_t N_r$ distinct antenna pairs (antenna-domain samples). It has been verified in [10] that the total least square estimating signal parameters via rotational invariance techniques (TLS-ESPRIT) algorithm in [9] can be applied to (8) to efficiently estimate path delays with arbitrary values.

By using the TLS-ESPRIT algorithm, we can obtain superresolution estimates of path delays, i.e., $\hat{\tau}_p$ for $1 \leq p \leq P$, and thus, $\hat{V}$ can be obtained accordingly. Then, path gains can be acquired by the LS method [7], i.e.,

$$\hat{A} = \hat{V}^H \tilde{H} = (\hat{V}^H \hat{V})^{-1} \hat{V}^H \tilde{H}$$

(9)

For a certain entry of $A$, i.e., $\hat{a}^{(ij)}_p \theta_i \tau_p$, because $\theta_i$ is known at the receiver and $\hat{\tau}_p$ has been estimated after applying the TLS-ESPRIT algorithm, we can easily obtain the estimation of the path again $\hat{a}^{(ij)}_p$ for $1 \leq p \leq P$, $1 \leq i \leq N_t$, $1 \leq j \leq N_r$. Finally, the complete CFR estimation over all OFDM subcarriers can be obtained based on (3) and (4).

Furthermore, we can also exploit the temporal correlation of wireless channels to improve the accuracy of the channel estimation. First, path delays of CIRs during several adjacent OFDM symbols are nearly unchanged [6], [7], which is equivalently referred as a common sparse pattern of CIRs due to the temporal correlation of MIMO channels. Thus, the Vandermonde matrix $V$ in (8) remains unchanged across several adjacent OFDM symbols. Moreover, path gains during adjacent OFDM symbols are also correlated owing to the temporal continuity of the CIR, so $A$s in (8) for several adjacent OFDM symbols are also correlated. Therefore, when estimating CIRs of the $q$th OFDM symbol, we can jointly exploit $\hat{H}s$ of several adjacent OFDM symbols based on (8), i.e.,

$$\sum_{p=q-R}^{q+R} \sum_{\rho=q-R}^{q+R} \frac{1}{2R+1} \frac{1}{2R+1} + \frac{\sum_{\rho=q-R}^{q+R} W_{\rho}}{2R+1}$$

(10)
Where the subscript $p$ is used to denote the index of the OFDM symbol, and the common sparse pattern of CIRs is assumed in $2R + 1$ adjacent OFDM symbols [7]. In this way, the effective noise can be reduced, so the improved channel estimation accuracy is expected. In contrast to the existing nonparametric scheme which estimates the channel by interpolating or predicting based on CFRs over pilots [1], [2], our proposed scheme exploits the sparsity as well as the spatial and temporal correlations of wireless MIMO channels to first acquire estimations of channel parameters, including path delays and gains, and then obtain the estimation of CFR according to (3) and (4).

**Discussion on Pilot Overhead**

Compared with the model of the multiple filters bank based on the FRI theory [10], it can be found out that CIRs of $N_t N_r$ transmit-receive antenna pairs are equivalent to the $N_t N_r$ semi period sparse subspaces, and the $N_p$ pilots are equivalent to the $N_p$ multichannel filters. Therefore, by using the FRI theory, the smallest required number of pilots for each transmit antenna is $N_p = 2P$ in a noiseless scenario. For practical channels with the maximum delay spread $\tau_{\text{max}}$ although the normalized channel length $L = \tau_{\text{max}}/T_s$ is usually very large, the sparsity level $P$ is small, i.e., $P \ll L$ [3]. Consequently, in contrast to the nonparametric channel estimation method where the required number of pilots heavily depends on $L$, our proposed parametric scheme only needs $2P$ pilots in theory. Note that the number of pilots in practice is larger than $2P$ to improve the accuracy of the channel estimation due to AWGN.

**CONCLUSION**

To achieve best possible system performance, receivers must have knowledge of the communication channel – Direct or indirect channel estimation is essential. Due to the existence of noise, interference, distortion and channel variation, the channel estimates can be expressed as the true channel with estimation error. The objective is to attain the best possible estimate under realistic channel conditions. Using detected data symbol to improve estimation accuracy – When considering achievable channel estimation accuracy, we mainly assume the estimation are based on known data symbols such as pilot symbols – By using detected data symbols, estimation accuracy can be further improved, e.g., with “SPARSE” channel estimation.

**SIMULATION RESULTS**
Channel estimation is a challenging task in the orthogonal frequency division multiplexing, in our proposed work we use estimated power delay profile algorithm for channel estimation using additive white Gaussian noise channel. Estimation of channel estimation is done by using the ETU channel for better performance and low run time complexity.

REFERENCES


