Efficient Channel Estimation for MIMO Single-carrier Block Transmission with Dual Cyclic Timeslot Structure

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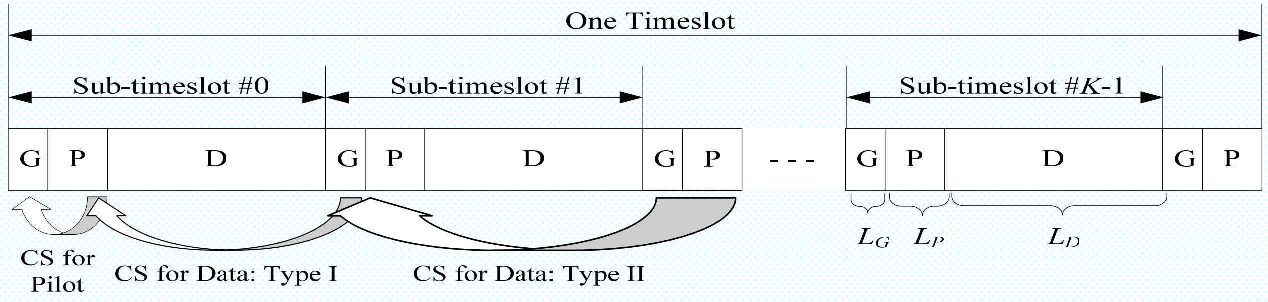
Introduction

- Single-carrier block transmission (SCBT) has appeared to be an alternative promising technique.
- The shortcomings of the OFDM in peak-to-average power ratio (PAPR) and sensitivity to frequency shifts can be avoided in the SCBT.
- In MIMO channels, the number of the channel parameters to be estimated increases in proportional to that of the transmit antennas and the receive antennas.
- It is important, challenging as well, to design accurate and efficient channel estimation schemes for real MIMO system.
- In this work, we investigate channel estimation for timeslot-structured SCBT over space-, time- and frequency-selective fading MIMO channels.

MIMO-SCBT with Dual Cyclic Timeslot Structure

- In the SCBT system, the signal is transmitted block by block.
  - Each block typically consists of a data sequence and a cyclic prefix or zero padded suffix.
- In this work, we consider the timeslot-structured SCBT
  - The transmitted signal sequence is composed of one by one timeslots.
  - In each timeslot, there are several transmission blocks referred to as sub-timeslots.
- Dual cyclic timeslot structure
  - There is a cyclic guard prior to each pilot segment, and there is also a "cyclic guard" G (and P) prior to each segment of D plus G (and P).



Signal model for channel estimation

- The received signal for the *k*-th pilot segment after the removal of CP can be written as

$$\mathbf{y}(k) = (\mathbf{I}_{N_R} \otimes \mathbf{S})\mathbf{h}(k) + \mathbf{z}(k)$$

- To achieve optimal channel estimation in the whole timeslot, we needs to deal with the received pilot signals simultaneously.

$$\mathbf{y} = \mathbf{X}\,\mathbf{h} + \mathbf{z}$$

where $\mathbf{y} = [\mathbf{y}^T(0), \mathbf{y}^T(1), ..., \mathbf{y}^T(K)]^T$, $\mathbf{X} = \mathbf{I}_{(K+1)N_R} \otimes \mathbf{S}$,
$\mathbf{h} = [\mathbf{h}^T(0), \mathbf{h}^T(1), ..., \mathbf{h}^T(K)]^T$, and $\mathbf{z} = [\mathbf{z}^T(0), \mathbf{z}^T(1), ..., \mathbf{z}^T(K)]^T$

Channel Estimation and Pilot Design

Channel estimation

- The linear MMSE solution of the channel vector is

$$\hat{\mathbf{h}} = \mathbf{R}_{\mathbf{h}}(\mathbf{X}^H\mathbf{X}\mathbf{R}_{\mathbf{h}} + \sigma_z^2\mathbf{I}_{(K+1)N_RN_TN_P})^{-1}\mathbf{X}^H\mathbf{y}$$

- For a triply selective MIMO channel, it can be proved that the optimal pilots are related to the statistical CHI in eigen-mode.
- With the transmit antenna correlation unknown at the transmitter, the optimal pilots satisfy the orthogonal condition $\mathbf{S}^H\mathbf{S} = L_P\mathbf{I}_{N_TN_P}$.
- With the optimal pilots, the channel estimation can be simplified to initial block-based LS channel estimation followed by space-time post-processing.

$$\hat{\mathbf{h}}_{ini} = \tfrac{1}{L_P}\mathbf{X}^H\mathbf{y}, \qquad \hat{\mathbf{h}} = \tilde{\mathbf{U}}\tilde{\mathbf{\Lambda}}(\tilde{\mathbf{\Lambda}} + \frac{\sigma_z^2}{L_P}\mathbf{I}_{(K+1)N_RN_TN_P})^{-1}\tilde{\mathbf{U}}^H\hat{\mathbf{h}}_{ini}$$

Channel Estimation and Pilot Design

Design of optimal pilot

- From the orthogonal condition, the training sequences transmitted from multiple antennas must have impulse-like auto correlation and zero cross correlation.
- In this work, the pilot sequence for each transmit antenna is derived by cyclically right shifting a single base sequence.

$$s_n(l) = a(((l - nN_P))_{L_P}), \quad \mathbf{S} = circ\{\mathbf{a}\}[\mathbf{I}_{N_T N_P} \quad \mathbf{0}]^T$$

- If the base sequence is cyclically orthogonal, then the **S** satisfy the orthogonal condition.
  - The Chu sequence: $a(l) = \begin{cases} e^{j\pi r l^2 / L_P}, & \text{for even } L_P, \\ e^{j\pi r l(l+1)/L_P}, & \text{for odd } L_P. \end{cases}$
  - The DFT-based sequence: $\mathbf{a} = [a(0) \quad a(1) \quad \cdots \quad a(L_P - 1)] = vec\{\tilde{\mathbf{W}}_N\}$

Fast Implementation

Initial channel estimation

- For any cyclic orthogonal pilot sequence, we have

$$\hat{\mathbf{h}}_{ini,m}(k) = \frac{1}{L_P}[\mathbf{I}_{N_T N_P} \quad \mathbf{0}]\mathbf{W}_{L_P}^H \mathbf{\Lambda}_a^H \mathbf{W}_{L_P} \mathbf{y}_m(k)$$

- With the Chu sequence and the DFT-based sequence as the base sequence, we have

$$\hat{\mathbf{h}}_{ini,m}(k) = \frac{1}{L_P}[\mathbf{I}_{N_T N_P} \quad \mathbf{0}]\mathbf{\Psi}^H \mathbf{W}_{L_P}^H \mathbf{P}_\gamma^H \mathbf{\Phi}^H \mathbf{y}_m(k)$$

$$\hat{\mathbf{h}}_{ini,m}(k) = \frac{1}{L_P}[\mathbf{I}_{N_T N_P} \quad \mathbf{0}]\mathbf{P}_\alpha^H (\mathbf{I}_Q \otimes \mathbf{W}_N^H)\mathbf{P}_\beta^H \mathbf{\Sigma}^H (\mathbf{I}_Q \otimes \mathbf{W}_N)\mathbf{P}_\alpha \mathbf{y}_m(k)$$

- The implementation complexity can be reduced by half.

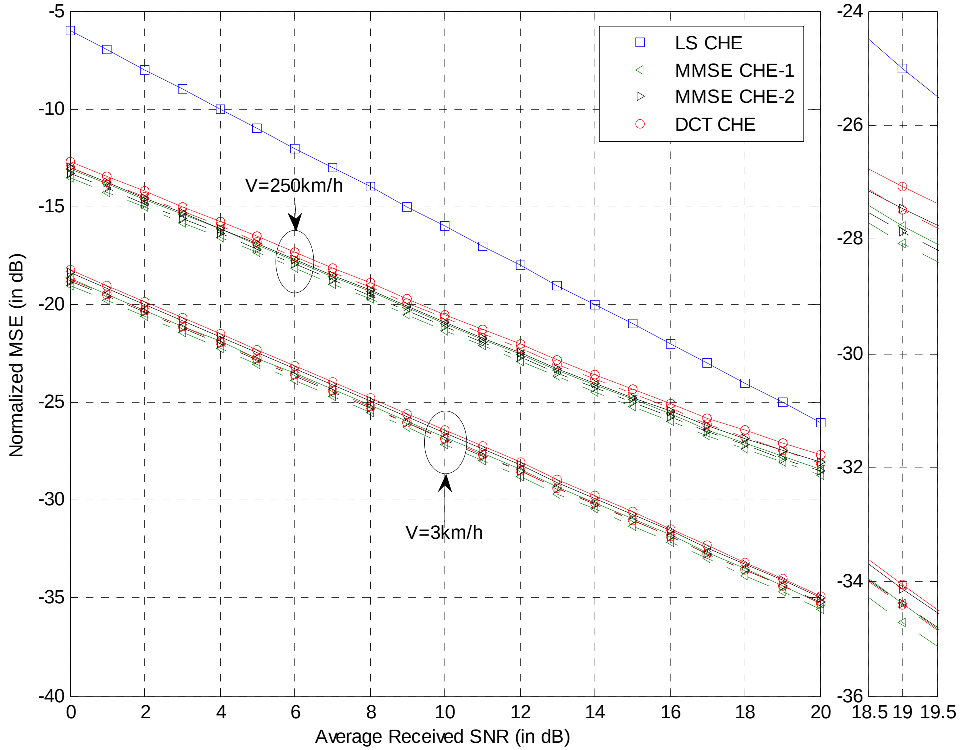
Fast Implementation

Space-time post-processing

- The space-time post-processing is related to eigen-decomposition of the channel correlation matrices.
  - This means that online estimation of the correlation matrices and online eigen-value decomposition (EVD) should be performed.
  - The eigen-matrix serves as the optimal de-correlation transform.
- To simplify the implementation, we replace the optimal de-correlation transform by the discrete cosine transform (DCT).
  - which can approximate the optimal performance and has fast implementation.

$$\hat{\mathbf{h}} = (\mathbf{C}_{K+1}^{II} \otimes \mathbf{C}_{N_R}^{II} \otimes \mathbf{C}_{N_T}^{II})^T \mathbf{\Lambda}_{st,p} (\mathbf{C}_{K+1}^{II} \otimes \mathbf{C}_{N_R}^{II} \otimes \mathbf{C}_{N_T}^{II}) \hat{\mathbf{h}}_{ini}^{p}$$

Simulations



SIMULATION PARAMETERS

Tx antenna number	4
Rx antenna number	4
Transmit correlation factor	0 and 0.2
Receive correlation factor	0 and 0.5
Carrier frequency	3.5GHz
Symbol rate	1.28Msps
Velocity	250 and 3 km/h
Multi-path power profile	Exponentially distributed
Sub-timeslot number K	7
Guard Length L_G	8
Pilot Length L_P	32
User data length L_D	312

Conclusions

- Efficient channel estimation for the timeslot-structured SCBT over triply selective fading MIMO channels has been investigated.
- The condition on the optimal pilots has been derived, and a new design of the pilot sequences is suggested.
- With the optimal pilots, the channel estimation can be simplified to initial block-based LS channel estimation followed by space-time post-processing.
- More efficient implementations for the initial channel estimation are obtained by using the structure of the pilot sequence.
- A DCT-based implementation for the space-time post-processing is developed to approximate the optimal solution with low implementation complexity.
- Simulation results have verified the performance of the proposed channel estimation.

Thank you for your attentions !