LDS-RS Design and Channel Estimation for FDD Massive FD-MIMO Systems

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2016.12.9

Outline

- Background
- System model
- Proposal
- Simulation results
- Conclusions

Background

- Full-dimension MIMO (FD-MIMO) is the promising structure to arrange massive MIMO in practical implementation
- Large downlink training overhead in frequency division duplex (FDD) protocol with massive antennas at the base station
- Compressive-sensing based downlink reference signal (RS) designs are sparsely scattered in time/frequency domain to reduce the overhead
- Propose the low-density spatial RS design based on channel correlation of 3D spatial channel model (3D SCM)

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3D SCM

- Single-cell multiuser scenario
  - $M \times M$ URA
  - K single-antenna users
- 3D spatial channel model $\boldsymbol{h}_k \in \mathbb{C}^{1\times M^2}$

$$\boldsymbol{h}_k = \mathrm{cvec}\left(\sum_{p=1}^{P} \rho_k^p \mathbf{e}\left(\beta_k^p\right) \otimes \mathbf{a}^{\mathrm{T}}\left(\beta_k^p, \theta_k^p\right)\right)^{\mathrm{T}}$$

  - P： number of multi-paths
  - $\mathrm{cvec}(\cdot)$： column vectorization
  - $\otimes$ ： Kronecker-product operation
  - ρ_k^p： large-scale fading coefficient
  - β_k^p, θ_k^p： angle-of-arrival in elevation and azimuth direction

3D SCM

- Channel steering vector in elevation domain

$$\mathbf{e}(\beta) = \left[e^{-j2\pi m\frac{D}{\lambda}\sin\beta}\right]_{0\le \boldsymbol{m} \le M-1}$$

- Channel steering vector in azimuth domain

$$\mathbf{a}(\beta,\theta) = \left[e^{-j2\pi m\frac{D}{\lambda}\cos\beta\cos\theta}\right]_{0\le \boldsymbol{m} \le M-1}$$

  - D： antenna spacing
  - λ： wavelength

Downlink Training

- Downlink reference signal (RS) matrix $\Phi_k \in \mathbb{C}^{M^2 \times \tau}$ is transmitted

$$\boldsymbol{r}_k = \boldsymbol{h}_k \boldsymbol{\Phi}_k + \boldsymbol{n}_k$$

  - τ: number of time slots for downlink training, $\tau_0 > \tau \geq M^2$
  - τ_0: channel correlation time

- Channel estimation

$$\widehat{\boldsymbol{h}}_k = \boldsymbol{r}_k \boldsymbol{\Phi}_k^{\mathrm{H}}$$

  - $\boldsymbol{\Phi}_k^{\mathrm{H}}$: Conjugate-transpose of $\boldsymbol{\Phi}_k$, $\boldsymbol{\Phi}_k \boldsymbol{\Phi}_k^{\mathrm{H}} = \mathbf{I}_{M^2}$

- Downlink training overhead becomes excessive large with growing M in massive MIMO systems

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Proposal

- Spatial Correlation
- LDS-RS Design
- Channel Estimation

Spatial Correlation

- Spatial correlation for the pth sub-path between $\Delta=(u,v)$ and $(0,0)$ elements

$$C_p(\Delta)=2\pi\frac{D}{\lambda}\Delta\cdot\varphi_p$$

  - $\varphi_p=(\sin\beta^p,\cos\theta^p\cos\beta^p)$

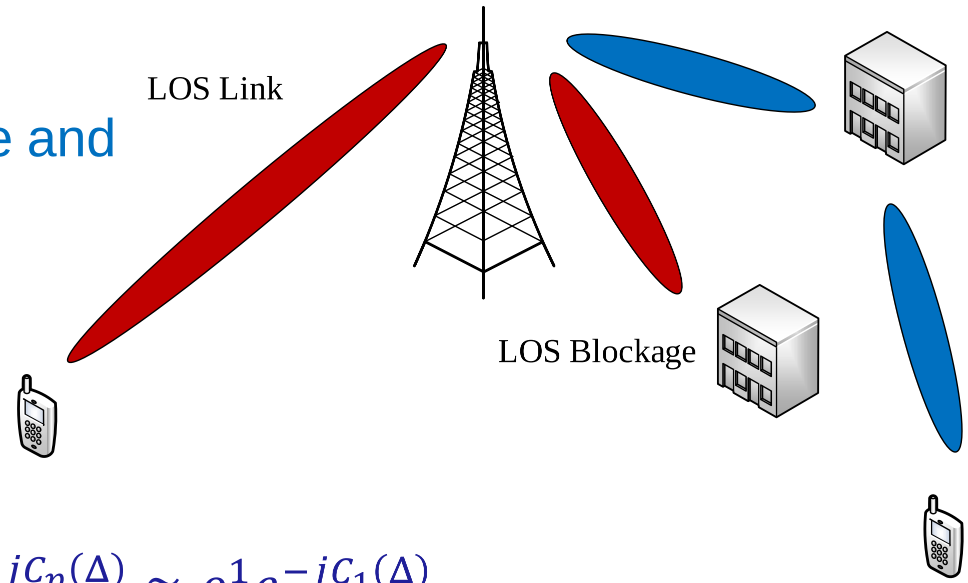
- Denote $\mathbb{S}=\{(\rho_p,\varphi_p)|1\le p\le P\}$

$$\mathbb{S}\rightarrow C_p(\Delta)\rightarrow h(\Delta)=\sum_{p=1}^{P}\rho^p e^{-jC_p(\Delta)}$$

  - Channel spatial sparsity property
  - The size of $\mathbf{\Phi}$ decreases from $O(M^2)$ to $O(P)$
  - The downlink training overhead is reduced significantly as $M\rightarrow\infty$

Single-path Channel

- Single-path channel scenario is widely utilized in millimeter-wave (mmWave) frequency
  - Line-of-Sight (LOS) link
  - NLOS link with LOS blockage and once reflection



- Simplification
  - Dominant direct path: $p = 1$
  - Power: $\rho^1 \gg \rho^p, 1 < p \le P$

$$h(\Delta) = \sum_{p=1}^{P} \rho^p e^{-jc_p(\Delta)} \approx \rho^1 e^{-jc_1(\Delta)}$$

  - Only φ_1 needs to be estimated
  - The size of RS matrix $\mathbf{\Phi}$ is decreased to $O(1)$

Multi-path Channel

- Sparsity mask set $\mathbb{M} \subseteq \mathbb{S}$ contains the primary sub-paths

$$\mathbb{M} = \left\{ \left(\rho^p, \varphi_p\right) : |\rho^p|^2 \geq \eta \max_{1 \leq p \leq P} |\rho^p|^2 \right\}$$

  - $0 < \eta < 1$: power threshold, controls the number of sub-paths in $\mathbb{M}$
- Select the sub-paths which possess enough power after the power attenuation during propagation
  - $|\mathbb{M}| = 1$ when $\eta = 1$ indicates near single-path channel
  - $|\mathbb{M}| = P, \mathbb{M} = \mathbb{S}$ when $\eta \to 0$ indicates the complete channel
  - The size of RS matrix $\mathbf{\Phi}$ is decreased to $O(|\mathbb{M}|)$

Proposal

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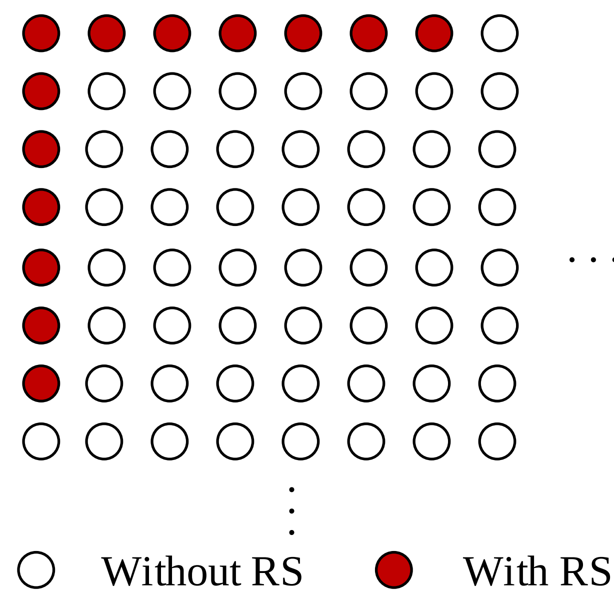
LDS-RS Design

- Low density spatial reference signal (LDS-RS) design
  - RSs are transmitted only in part of antennas
  - $\mathbb{I}$: Antenna set used to transmit RSs
  - $\boldsymbol{\Phi}_{\mathbb{I}} \in \mathbb{C}^{|\mathbb{I}| \times \tau'}$: RSs matrix
  - $\widehat{\boldsymbol{h}}_{\mathbb{I}}$: Estimated channel on set $\mathbb{I}$

$$\widehat{\boldsymbol{h}}_{\mathbb{I}} = \boldsymbol{r}\boldsymbol{\Phi}_{\mathbb{I}}^{\mathrm{H}}$$



- For $M \times M$ URA

$$\mathbb{I} = \{(u,0) | 0 \le u < N\} \cup \{(0,v) | 0 \le v < N\} = \mathbb{I}_{\mathrm{e}} \cup \mathbb{I}_{\mathrm{a}}$$

  - $\mathbb{I}_{\mathrm{e}}$: Subset in elevation domain
  - $\mathbb{I}_{\mathrm{a}}$: Subset in azimuth domain
  - $\widehat{\boldsymbol{h}}_{\mathbb{I}} \in \mathbb{C}^{1 \times (2N-1)}$ can be separated into two parts: $\widehat{\boldsymbol{h}}_{\mathbb{I}_{\mathrm{e}}}$ and $\widehat{\boldsymbol{h}}_{\mathbb{I}_{\mathrm{a}}}$

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Channel Estimation

- FFT-based post-processing on $\widehat{\boldsymbol{h}}_{\mathbb{I}_\mathrm{e}}$ and $\widehat{\boldsymbol{h}}_{\mathbb{I}_\mathrm{a}}$

$$\boldsymbol{b}_{\mathbb{I}_\mathrm{e}} = \mathbf{F}\widehat{\boldsymbol{h}}_{\mathbb{I}_\mathrm{e}}$$
$$\boldsymbol{b}_{\mathbb{I}_\mathrm{a}} = \mathbf{F}\widehat{\boldsymbol{h}}_{\mathbb{I}_\mathrm{a}}$$

  - $\mathbf{F}$: N-points FFT matrix

- Seek $|M|$ peak values in the amplitude spectrum of $\boldsymbol{b}_{\mathbb{I}_\mathrm{e}}$ and $\boldsymbol{b}_{\mathbb{I}_\mathrm{a}}$

$$\mathbb{L}_\mathrm{e} = \left\{ l : \left| b_{\mathbb{I}_\mathrm{e}}(l) \right| \geq \eta \max_{0 \leq l < N} b_{\mathbb{I}_\mathrm{e}}(l) \right\}$$
$$\mathbb{L}_\mathrm{a} = \left\{ l : \left| b_{\mathbb{I}_\mathrm{a}}(l) \right| \geq \eta \max_{0 \leq l < N} b_{\mathbb{I}_\mathrm{a}}(l) \right\}$$

  - $|\mathbb{L}_\mathrm{e}| = |\mathbb{L}_\mathrm{a}| = |M| \leq N < M$
  - ρ^l could be estimated by the amplitude of the peaks

Channel Estimation

- Elements in $\mathbb{L}_{\mathrm{e}}$ and $\mathbb{L}_{\mathrm{a}}$ are sorted in descending order of ρ^{l}
- Every pair of $\theta(l_{\mathrm{e}}, l_{\mathrm{a}})$ and $\beta(l_{\mathrm{e}})$ could be calculated

$$\beta(l_{\mathrm{e}}) = \arcsin\frac{\lambda}{D}\left(1 - \frac{l_{\mathrm{e}}}{N}\right)$$

$$\theta(l_{\mathrm{e}}, l_{\mathrm{a}}) = \arccos\frac{\lambda}{D\cos\beta(l_{\mathrm{e}})}\left(1 - \frac{l_{\mathrm{a}}}{N}\right)$$

- The whole channel could be reconstructed by the estimated angle-of-arrivals

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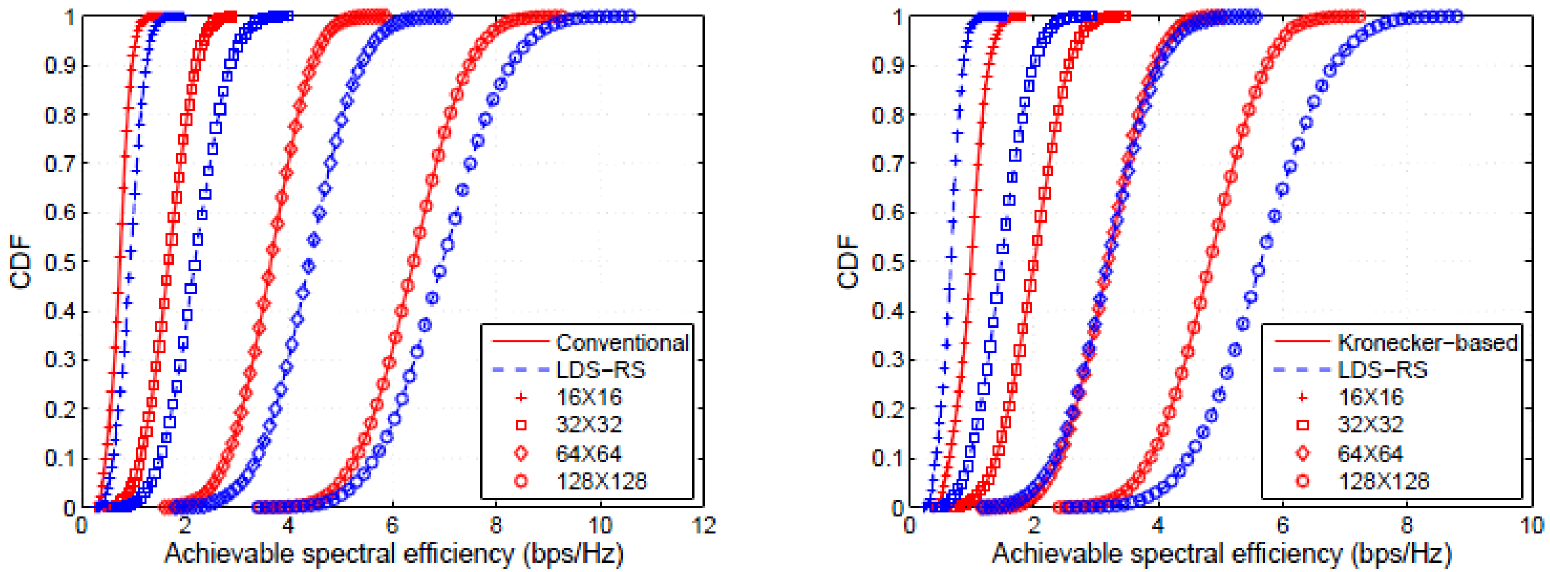
Simulation Parameters

- Single-cell multi-user scenario

Cell radius	500m
Height of BS	35m
Height of users	1.5m
Number of users	8
Path loss exponent	3.5
Variance of shadow fading	8dB
Carrier frequency	2GHz
Antenna spacing	$\lambda/2$
Number of paths	10
Angle spread of A-AoA	180 degrees
Angle spread of E-AoA	5 degrees

Performance Comparison

- Achievable spectral efficiency comparison between LDS-RS and convention RS designs
  - Left: Full-precoding
  - Right: Kronecker-product based precoding



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Conclusions

- LDS-RS design is proposed for downlink training in FDD massive FD-MIMO systems
  - Utilized the spatial correlation
  - Reduce the overhead considerably
  - Improve the downlink spectral efficiency
- The corresponding channel estimation algorithm
  - Low-complexity FFT-based post-processing

Thank you and questions please!