Parameter Estimation Employing Recursive Eigenvalue Decomposition for MIMO-OFDM Using Maximum Likelihood Detector with Array Combining

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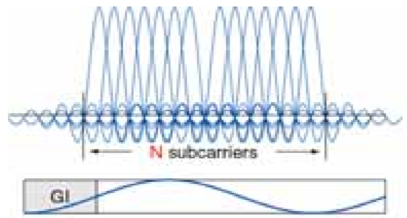
Background

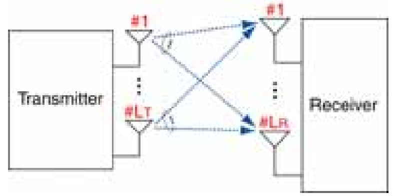
OFDM ･･･Utilize the spectrum efficiently
→high-speed data transmission

MIMO ･･･Improve the system capacity

OFDM + MIMO

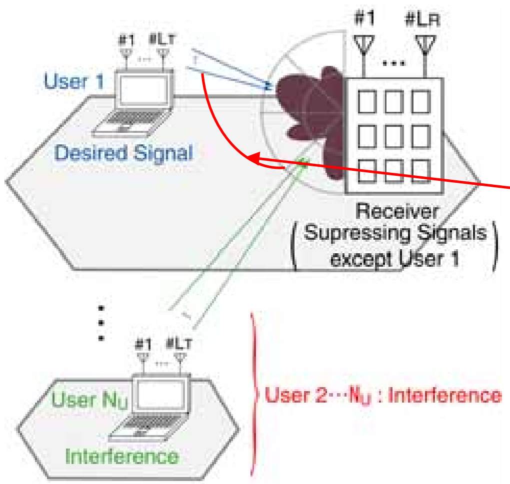
MIMO-OFDM





! Cochannel interference
→ Performance is degraded severely

Co-channel interference in the uplink of MIMO-OFDM

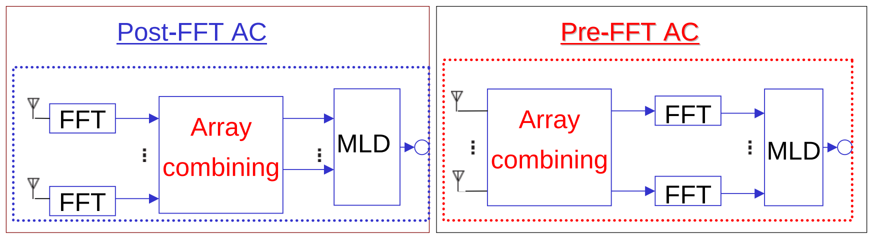


Random access

Incident angle difference

MLD with Array Combing

- ZF, MMSE, MLD cannot work
- To suppress **co-channel interference**, MLD with **the array combing** has been proposed



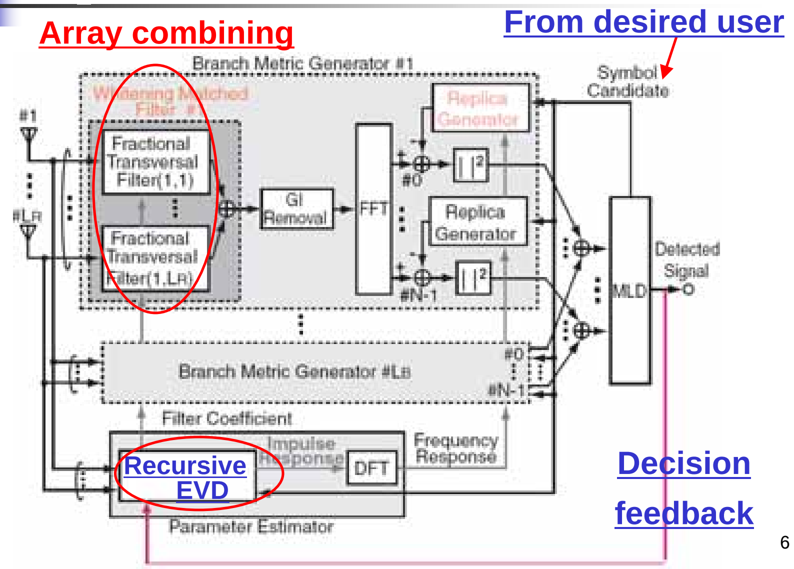
- **Array combing: Suppress the co-channel interference by prewhitening filtering**
- **Pre-FFT AC is superior when using limited preamble symbols**

Motivation

- The **drawback** of Pre-FFT AC
  - **Large complexity** in parameter update due to the **non-recursive eigenvalue decomposition (EVD)**

- A **recursive EVD** is applied to the parameter estimation of Pre-FFT AC
  - Reduce the complexity to about **25 percents**
  - Suitable for **real-time** application

Pre-FFT AC



Error signal in the time domain

- $\alpha(l_b, m) = y_r(l_b, m) - y_s(l_b, m)$
  - $\alpha(l_b, m)$: **Error signal** of the branch metric generator **caused by the interference and noise**

- $y_r(l_b, m)$ **: AC output** $\cong \mathbf{w}_{l_b}^H \mathbf{x}(m)$
  - $\mathbf{w}_{l_b}$: Coefficient of AC
  - $\mathbf{x}(m)$: Received signal

- $y_s(l_b, m)$ **: Replica signal** $\cong \mathbf{c}^H(l_b, m)\hat{\mathbf{s}}(m)$
  - $\mathbf{c}(l_b, m)$: Channel impulse response
  - $\hat{\mathbf{s}}(m)$: Candidate of the transmitted signal

Parameter estimation

•To suppress the interference, **prewhitening filtering is employed to the error signal**:

$\langle \alpha^*(l_b, m)\alpha(\tilde{l}_b, m)\rangle = 0$ **when** $l_b \neq \tilde{l}_b$

$\mathbf{w}_{l_b,\mathrm{ext}}^{\mathrm{H}} = [\mathbf{w}_{l_b}^{\mathrm{H}} \quad -\mathbf{C}_{l_b}^{\mathrm{H}}]$ $\quad$ $\mathbf{x}_{\mathrm{ext}}^{\mathrm{H}}(m) = [\mathbf{x}^{\mathrm{H}}(m) \quad \hat{\mathbf{s}}^{\mathrm{H}}(m)]$

Parameter vector

Autocorrelation matrix

$$\mathbf{w}_{l_b,\mathrm{ext}}^{\mathrm{H}} \langle \mathbf{x}_{\mathrm{ext}}(m)\mathbf{x}_{\mathrm{ext}}^{\mathrm{H}}(m)\rangle \mathbf{w}_{\tilde{l}_b,\mathrm{ext}} = 0$$

The parameter estimation should be **based on EVD**

Comparison between EVD methods

Nonrecursive EVD	Recursive EVD
▪ Cyclic Jacobi algorithm ▪ Large computational complexity	▪ Newton's iterative search ▪ Low computational complexity

Recursive EVD

- Auto-correlation matrix of $\mathbf{x}_{\text{ext}}(m)$ is

$$\mathbf{R}_x(m) = \sum_{m_1=D_0}^{m} \lambda^{m-m_1} \mathbf{x}_{\text{ext}}(m_1)\mathbf{x}_{\text{ext}}^H(m_1)$$

  - λ : Forgetting factor
- **Solve the eigenvalues of the current matrix** $\mathbf{R}_x(m)$ based on the EVD result of previous matrix $\mathbf{R}_x(m-1)$

- $\{\xi_i \mid 1 \le i \le L\}$: Eigenvalues of the previous matrix $\xi_1 \ge \xi_2 \cdots \ge \xi_L$
- $\{\mathbf{q}_i \mid 1 \le i \le L\}$: Eigenvectors of the previous matrix

↓

- $\{\beta_i \mid 1 \le i \le L\}$: Eigenvalues of the current matrix
- $\{\mathbf{p}_i \mid 1 \le i \le L\}$: Eigenvectors of the current matrix

Recursively solving the eigenvalues

$$(\mathbf{R}(m) - \beta_i \mathbf{I})\mathbf{p}_i = 0$$

$$y = \mathbf{X}_{\text{ext}}^H(m)\mathbf{p}_i \qquad \mathbf{R}(m) = \lambda\mathbf{R}(m-1) + \mathbf{X}_{\text{ext}}(m)\mathbf{X}_{\text{ext}}^H(m)$$

$$\{1 + \mathbf{X}_{\text{ext}}^H(m)[\lambda\mathbf{R}(m-1) - \beta_i\mathbf{I}]\mathbf{X}_{\text{ext}}(m)\}y = 0$$

- $y = 0$ → $\mathbf{X}_{\text{ext}}^H(m) \parallel \mathbf{p}_j$ → $\beta_j = \lambda\xi_j + \mathbf{X}_{\text{ext}}^H(m)\mathbf{X}_{\text{ext}}(m)$
- $y \ne 0$ → $1 + \mathbf{X}_{\text{ext}}^H(m)[\lambda\mathbf{R}(m-1) - \beta_i\mathbf{I}]\mathbf{X}_{\text{ext}}(m) = 0$

  $f(\beta) = 1 + \mathbf{X}_{\text{ext}}^H(m)[\lambda\mathbf{R}(m-1) - \beta\mathbf{I}]\mathbf{X}_{\text{ext}}(m)$

↓

Find a accurate root of $f(\beta) = 0$

Newton's iterative search

The interlacing property:

$$\mathbf{B} = \mathbf{A} + \lambda\mathbf{c}\mathbf{c}^H$$

$\mathbf{A}$ **: Symmetric matrix**, $\lambda > 0$ → $\beta_i(\mathbf{B}) \in [\beta_i(\mathbf{A}), \beta_{i-1}(\mathbf{A})]$

→ $\beta_i \in [\lambda\xi_i, \lambda\xi_{i-1}]$

Newton's iterative search algorithm:

$f(\beta_i) = 0$

$$\beta_i^{\eta+1} = \beta_i^{\eta} - \frac{f(\beta_i^{\eta})}{f'(\beta_i^{\eta})}$$

← **Increasement**

η **: number of iterations**

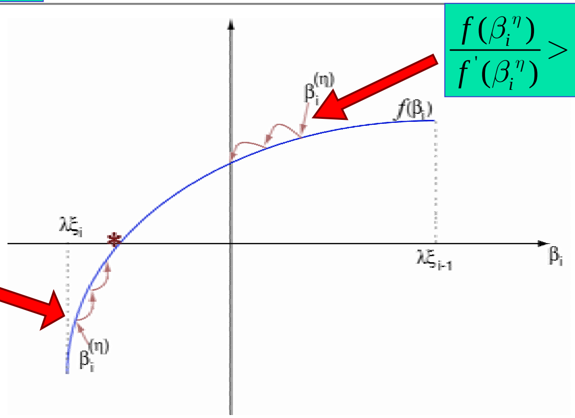
Small increasement

$$f'(\beta)=\sum_{j=1}^{L}\frac{\left|\mathbf{q}_j^H\mathbf{X}_{\text{ext}}(m)\right|^2}{(\lambda\xi_j-\beta)^2}>0$$

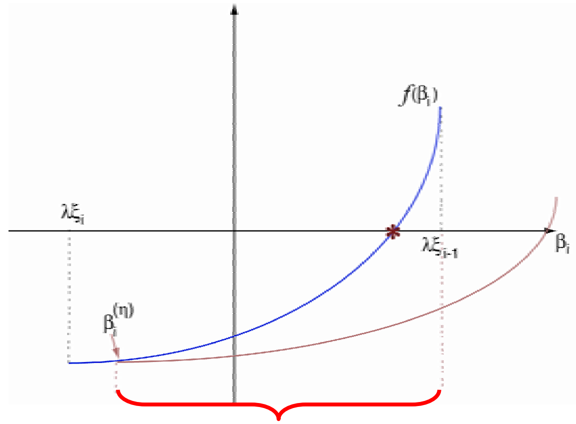
$f(\beta)$ is a monotone increasing function

$$\frac{f(\beta_i^\eta)}{f'(\beta_i^\eta)}>0$$

$$\frac{f(\beta_i^\eta)}{f'(\beta_i^\eta)}<0$$

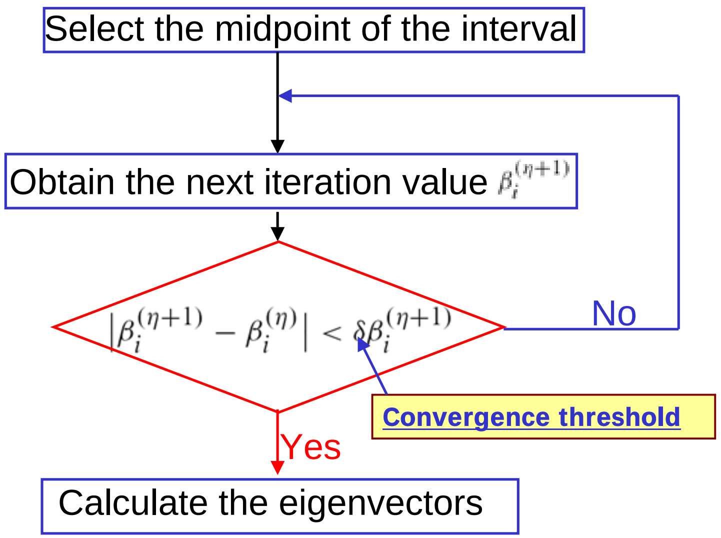


Large increasement



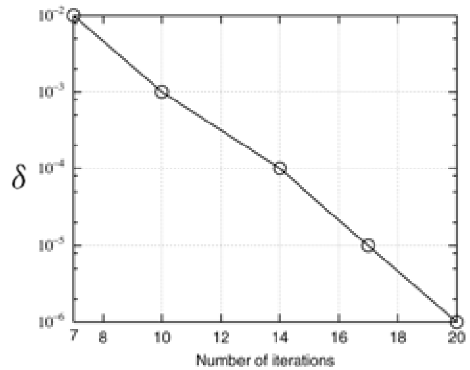
The midpoint of the new interval is used for the next iteration

Flow chart of iterative search



The convergence of the search algorithm

- Guaranteed to convergence
- Quadratic convergent



K. B. Yu, “Recursive updating the eigenvalue decomposition of a covariance matrix”, *IEEE Trans. Acoust. Speech Sig. Proc.* , vol. 39, pp. 1136-1145, May 1991.

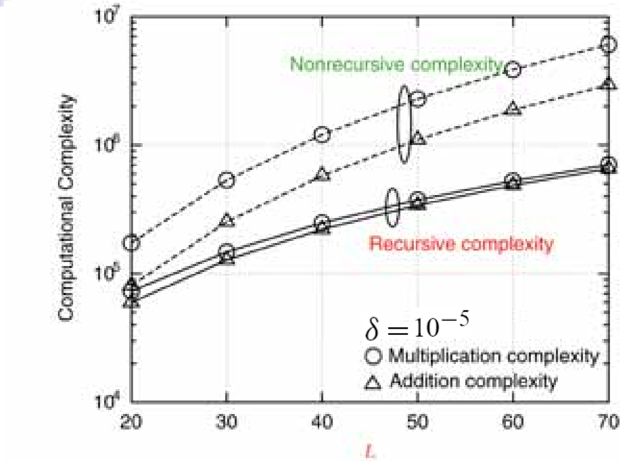
Simulation conditions

TABLE 3 Simulation Conditions

Modulation scheme	QPSK
Packet format	14 Symbols Preamble: 4, Data: 10
Number of trans. ant's (mobile): L_T	2
Number of rec. ant's (base): L_R	3
Number of interfering users	0, 1
Number of subcarriers	52 Pilot: 4, Data: 48
Subcarrier interval: Δf	312.5 kHz
Symbol duration: $T_S(=T_G+T_F)$	4.0 μs
Guard interval: T_G	0.8 μs
FFT points: N	64
Number of FTF's taps: $2M+1$	3
Sampling rate: $2N\Delta_f$	40 MHz
Carrier frequency: f_c	5.0 GHz

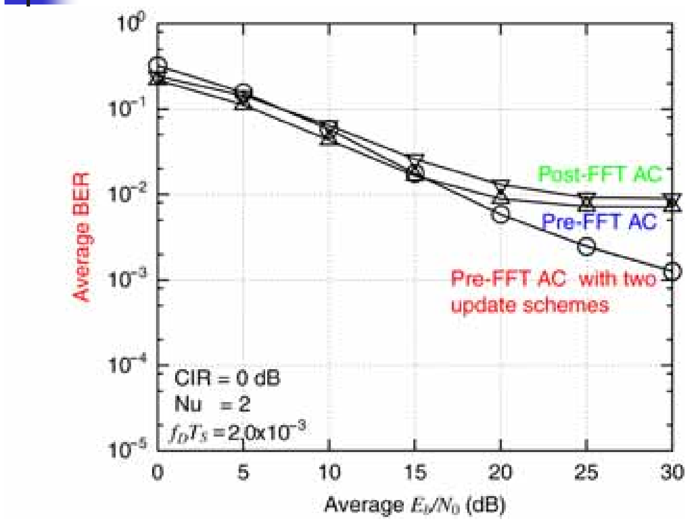
- Incident angle
  - Difference: 60 Deg
  - Deviation: 4 Deg

Computational complexity

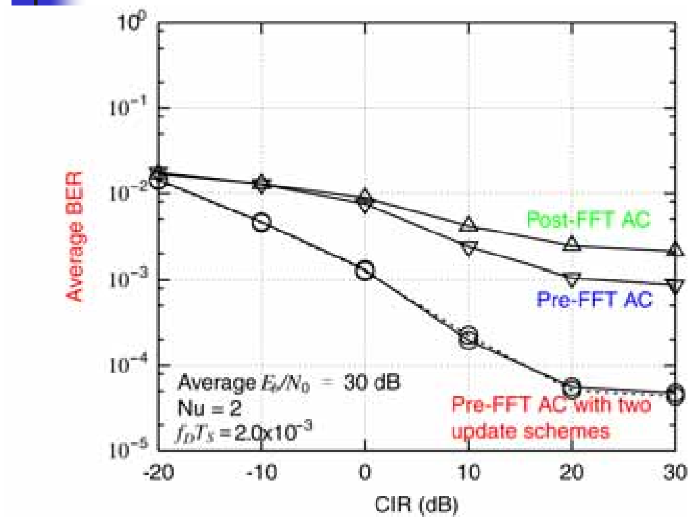


(Dimension of the auto-correlation matrix)

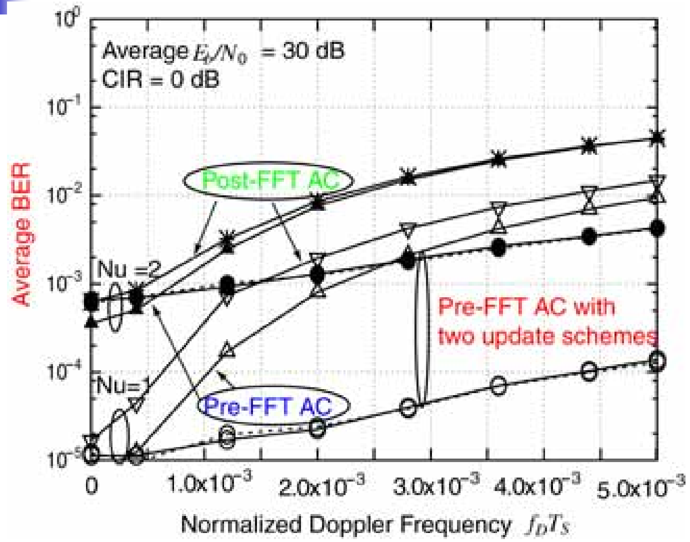
Average BER versus average CNR



Average BER versus average CIR



Average BER versus Doppler Spread



Conclusion

- A **recursive EVD** based algorithm was applied to the parameter estimation of Pre-FFT AC
- It can reduce the total computational complexity to **less than 25 percents** (More suitable for real-time application)
- Pre-FFT AC with **recursive EVD** can achieve the same performance as that of Pre-FFT AC with the conventional non-recursive EVD

Thanks a lot for your attention