

Experimental Analysis of Time-Varying Indoor MIMO Channel

Kei Mizutani, Kei Sakaguchi, Jun-ichi Takada, and Kiyomichi Araki

Part I

Measurement of Time-Varying MIMO Channel for
Performance Analysis of Closed-Loop Transmission

(VTC2006-Spring, May 2006)

Part II

Doppler Spectrum Analysis of
Time-Varying Indoor MIMO Channel

時変動屋内MIMO伝搬路のドップラスペクトル解析

(2006 IEICE General Conference, March 2006)

Part I

Measurement of Time-Varying MIMO Channel for Performance Analysis of Closed-Loop Transmission

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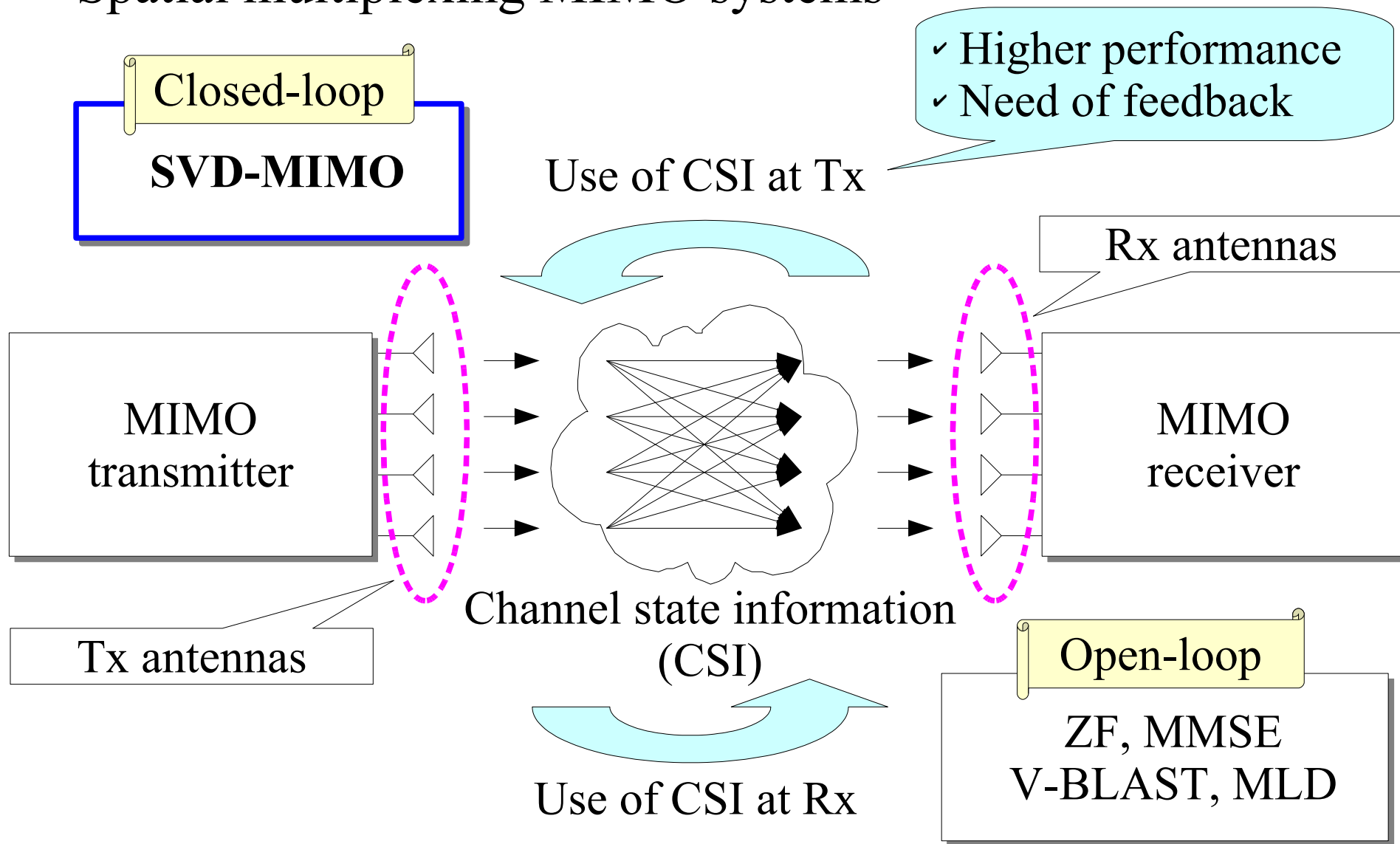
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Tokyo Institute of Technology

Outline

- Background & Objective
- Channel Measurement System
- Measurement Environment and Scenarios
- Channel Capacity
- Conclusions

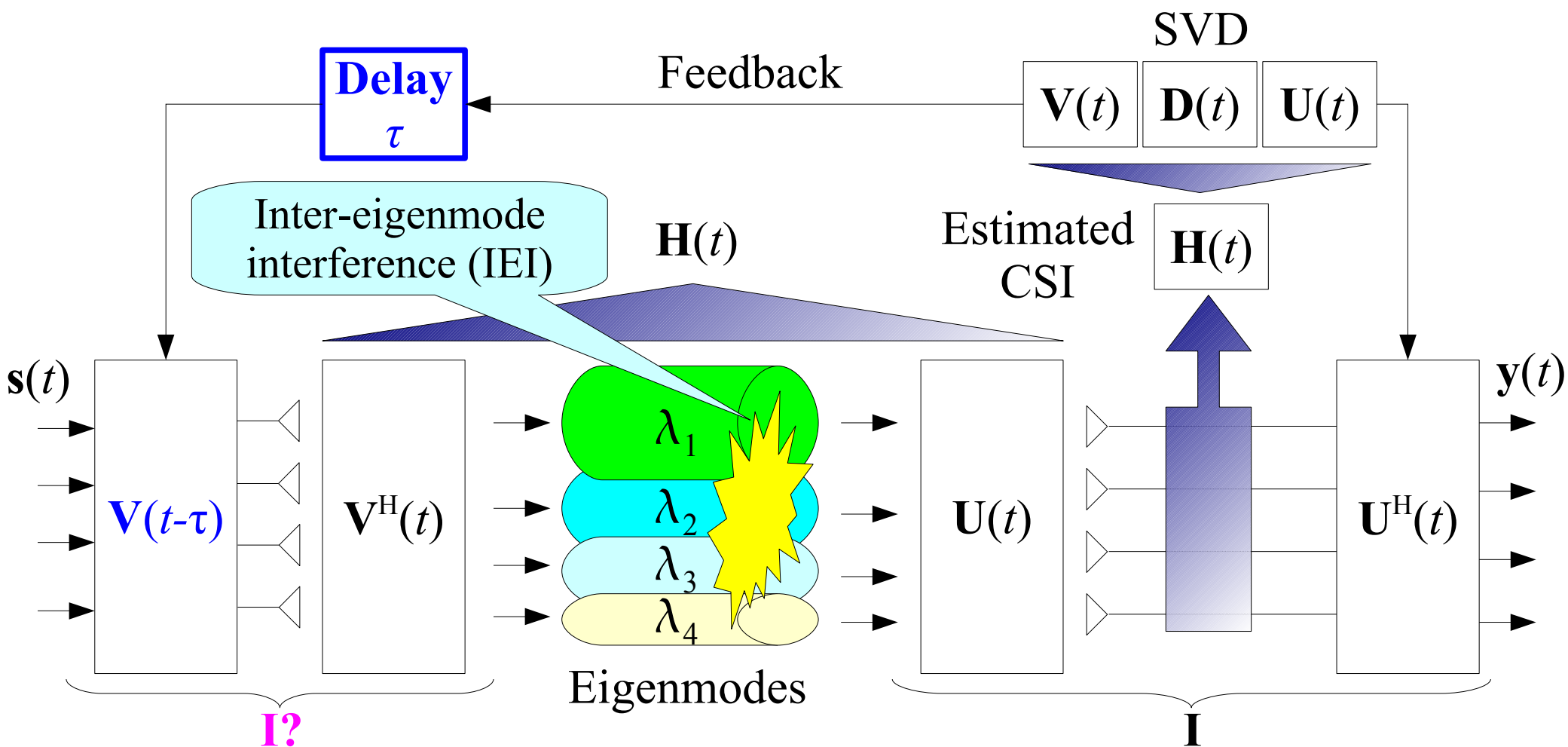
Background

- Spatial multiplexing MIMO systems



Objective

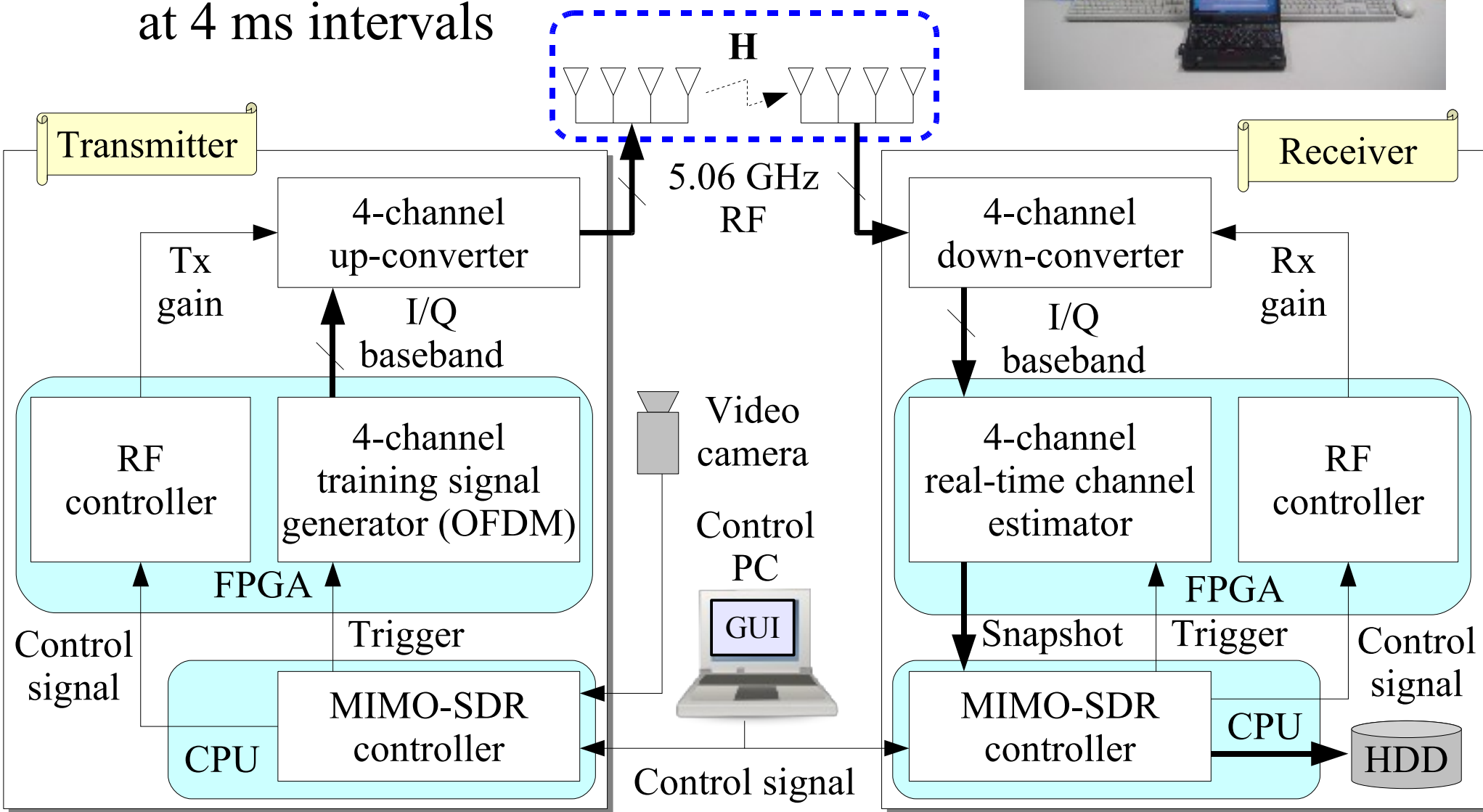
- Performance analysis of closed-loop transmission in time-varying channels by using measured channel data



Channel Measurement System

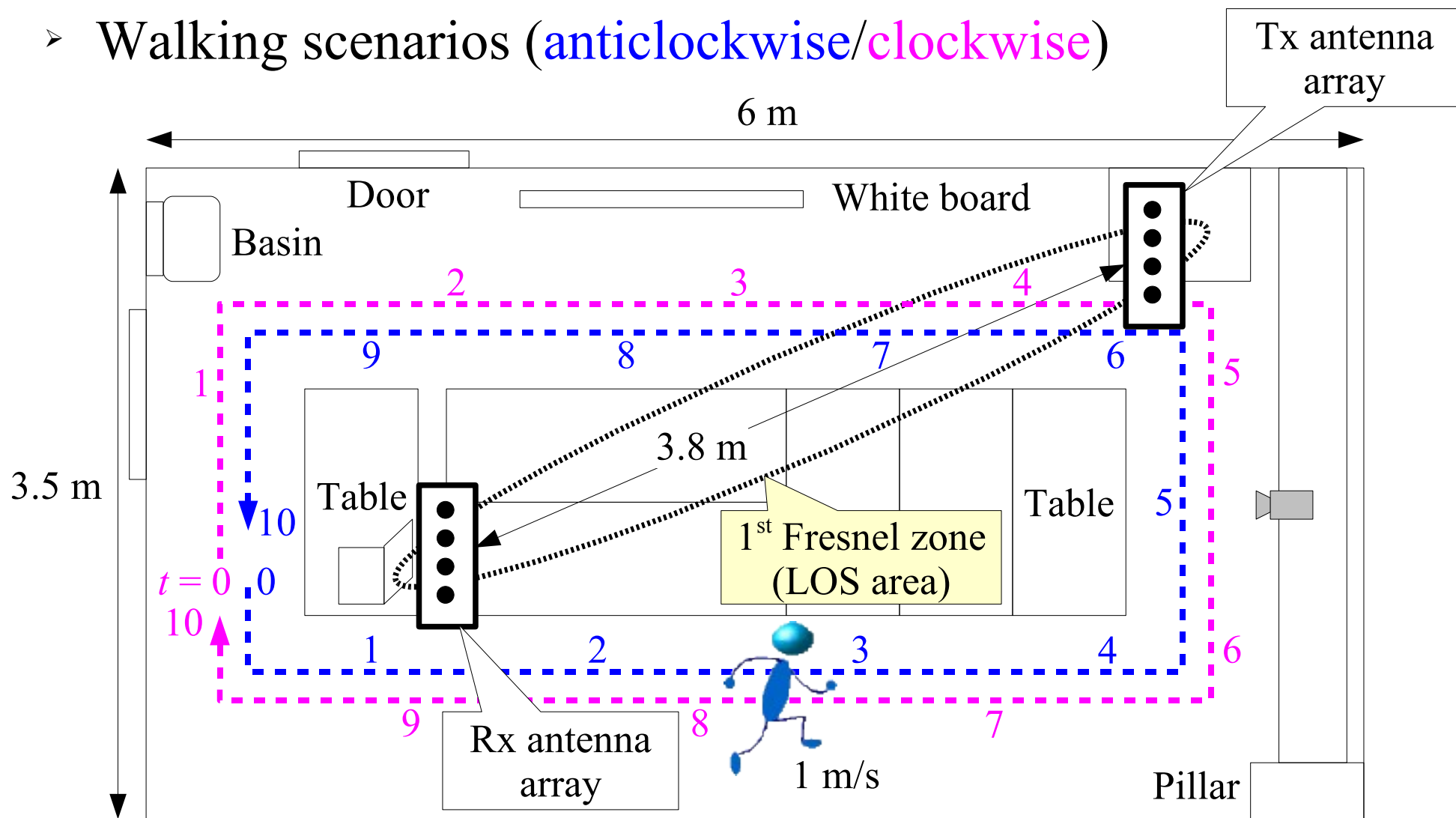


- Frequency domain channel estimation at 4 ms intervals



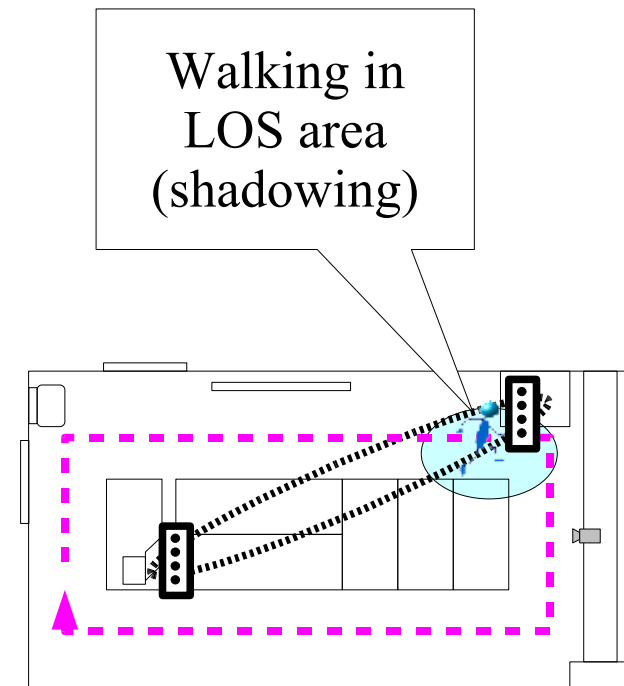
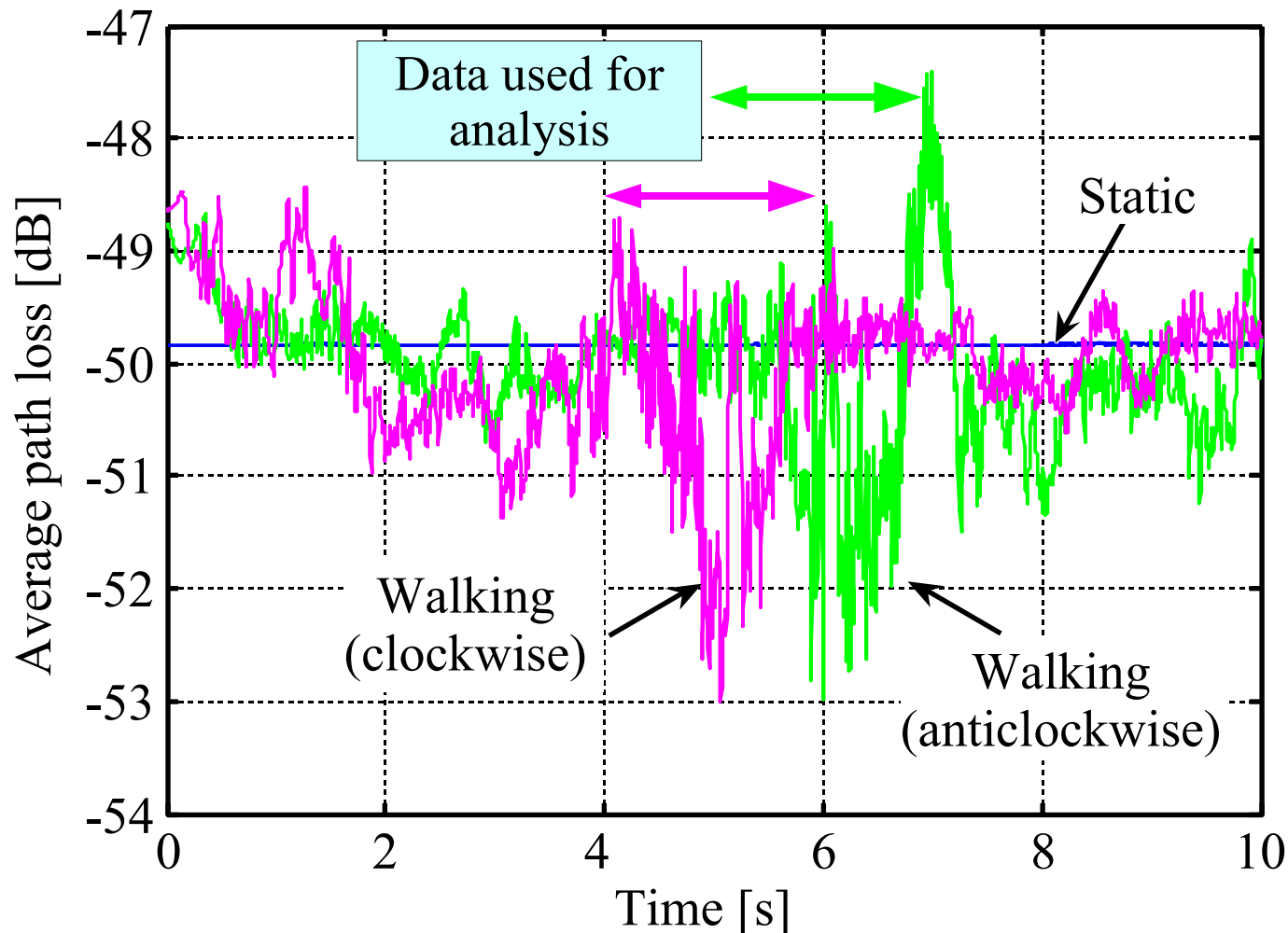
Measurement Environment and Scenarios

- Static scenario
- Walking scenarios (anticlockwise/clockwise)



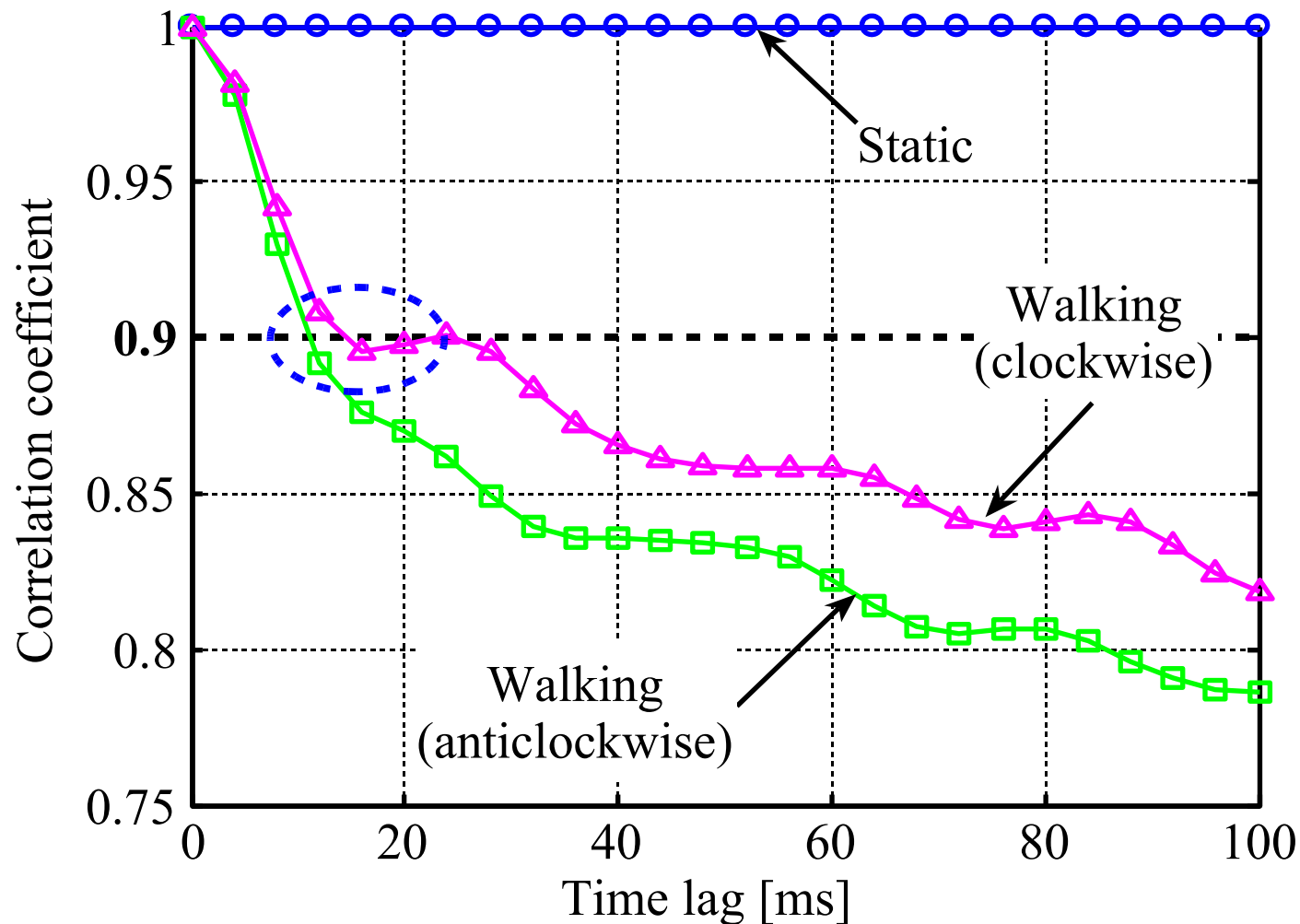
Path Loss

- Average: 4 Tx antennas, 4 Rx antennas, and 52 subcarriers
- Data used for the analysis: 500 snapshots (2 seconds)



Autocorrelation

- Autocorrelation in the walking scenarios falls below 0.9 within 20 ms.



Channel Capacity

- Channel capacity

$$C(t) = \sum_{m=1}^m \log_2 \{ 1 + \gamma_i(t) \} \quad (m = 4)$$

SNR of i^{th} stream

- Standard SVD (SVD)

$$\begin{aligned} \tilde{\mathbf{y}}(t) &= \mathbf{U}^H(t) \{ \mathbf{H}(t) \mathbf{V}(t-\tau) \mathbf{s}(t) + \mathbf{n}(t) \} \\ &= \tilde{\mathbf{H}}_{\text{eff}}(t) \mathbf{s}(t) + \mathbf{U}^H(t) \mathbf{n}(t) \\ &= \mathbf{D}(t) \mathbf{V}^H(t) \mathbf{V}(t-\tau) \mathbf{s}(t) + \tilde{\mathbf{n}}(t) \end{aligned}$$

IEI from j^{th} eigenmode to i^{th} eigenmode

$$G_{ij}(t) = | \mathbf{v}_i^H(t) \mathbf{v}_j(t-\tau) |^2$$

Signal power: p (equal power allocation)
 Noise power: σ^2

$$\gamma_i(t) = \frac{p \lambda_i(t) G_{ii}(t)}{\sigma^2 + \sum_{j=1, j \neq i}^m p \lambda_i(t) G_{ij}(t)}$$

Loss of eigenbeamforming gain appears as interference.

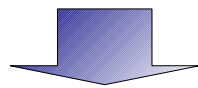
ZF Interference Canceller

- Standard ZF interference canceller (ZF)

$$\mathbf{y}(t) = \mathbf{H}^\dagger(t) \{ \mathbf{H}(t) \mathbf{s}(t) + \mathbf{n}(t) \}$$

Pseudo inverse matrix of $\mathbf{H}(t)$

$$= \mathbf{s}(t) + \mathbf{H}^\dagger(t) \mathbf{n}(t)$$



$$y_i(t) = \frac{p}{\mathbf{H}_i^\dagger(t) \{ \mathbf{H}_i^\dagger(t) \}^H \sigma^2}$$

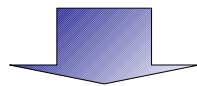
i^{th} row of $\mathbf{H}^\dagger(t)$

Eigenbeamforming improves performance of interference canceller.

- SVD with ZF interference canceller (SVD+ZF)

$$\hat{\mathbf{y}}(t) = \tilde{\mathbf{H}}_{\text{eff}}^\dagger(t) \{ \tilde{\mathbf{H}}_{\text{eff}}(t) \mathbf{s}(t) + \tilde{\mathbf{n}}(t) \}$$

$$= \mathbf{s}(t) + \tilde{\mathbf{H}}_{\text{eff}}^\dagger(t) \tilde{\mathbf{n}}(t)$$

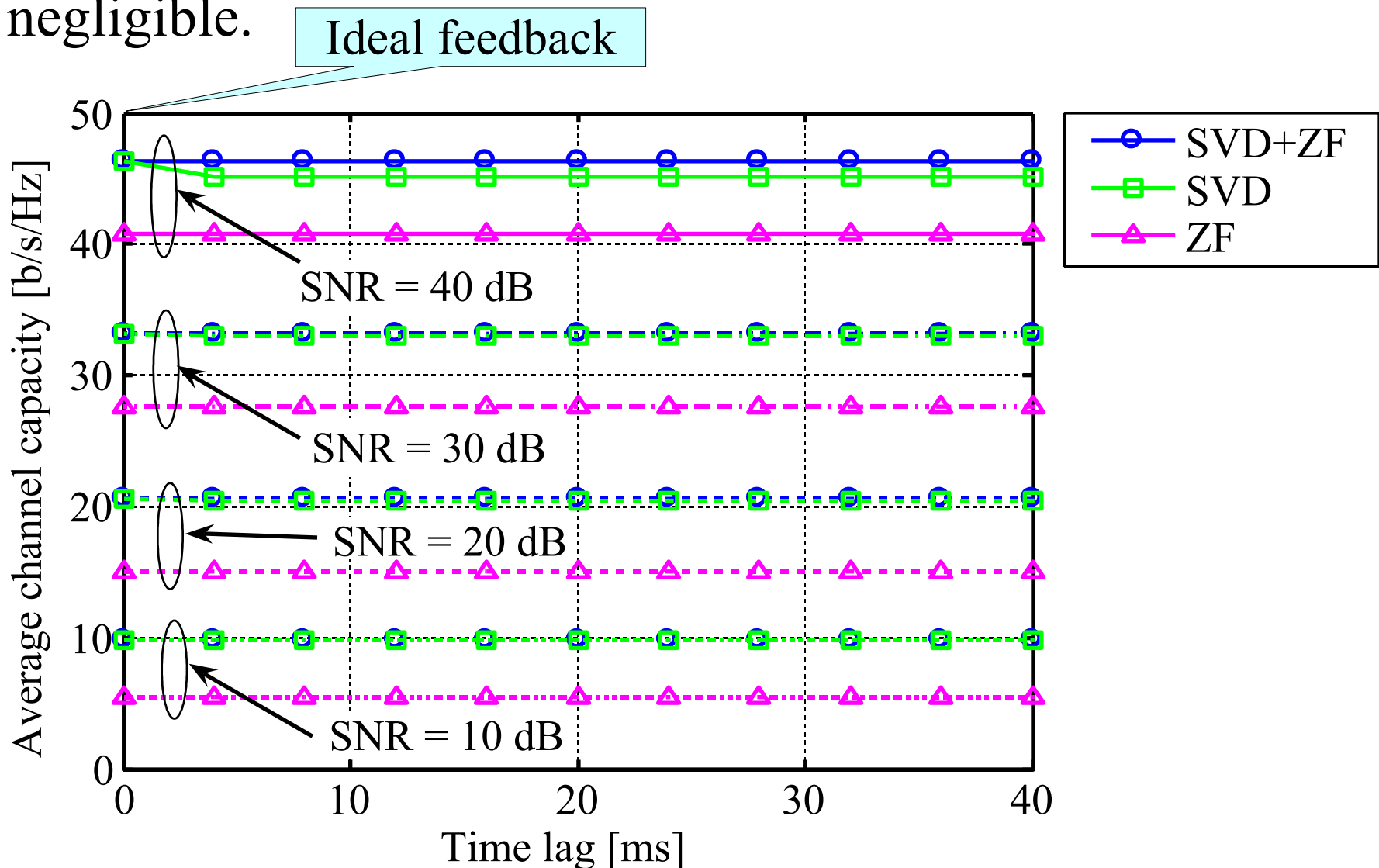


$$y_i(t) = \frac{p}{\tilde{\mathbf{H}}_{\text{eff},i}^\dagger(t) \{ \tilde{\mathbf{H}}_{\text{eff},i}^\dagger(t) \}^H \sigma^2}$$

$\tilde{\mathbf{H}}_{\text{eff}}(t) = \mathbf{U}^H(t) \mathbf{H}(t) \mathbf{V}(t-\tau)$:
Effective channel matrix

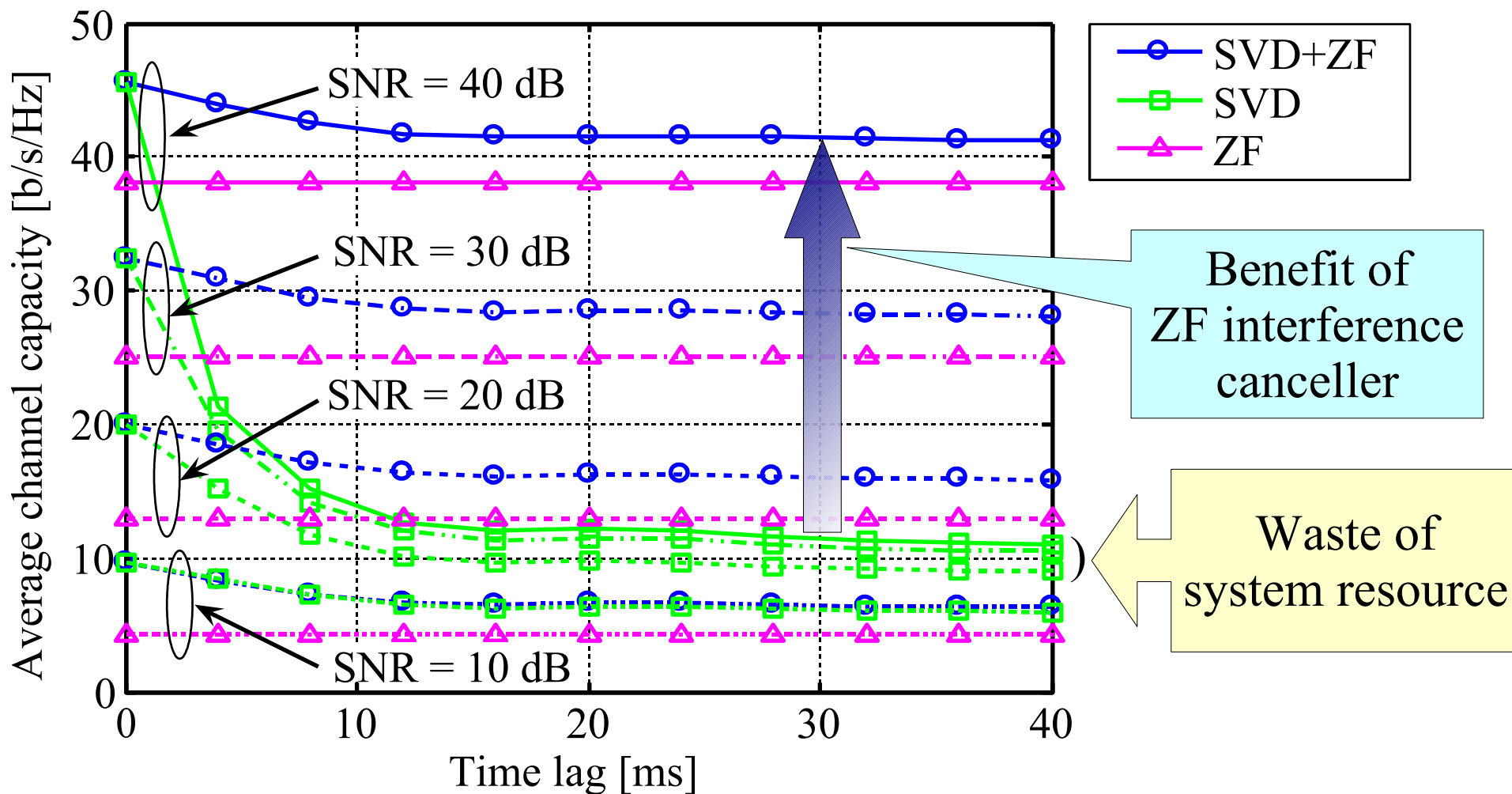
Static Scenario

- Degradation from ideal feedback (without feedback delay) is negligible.



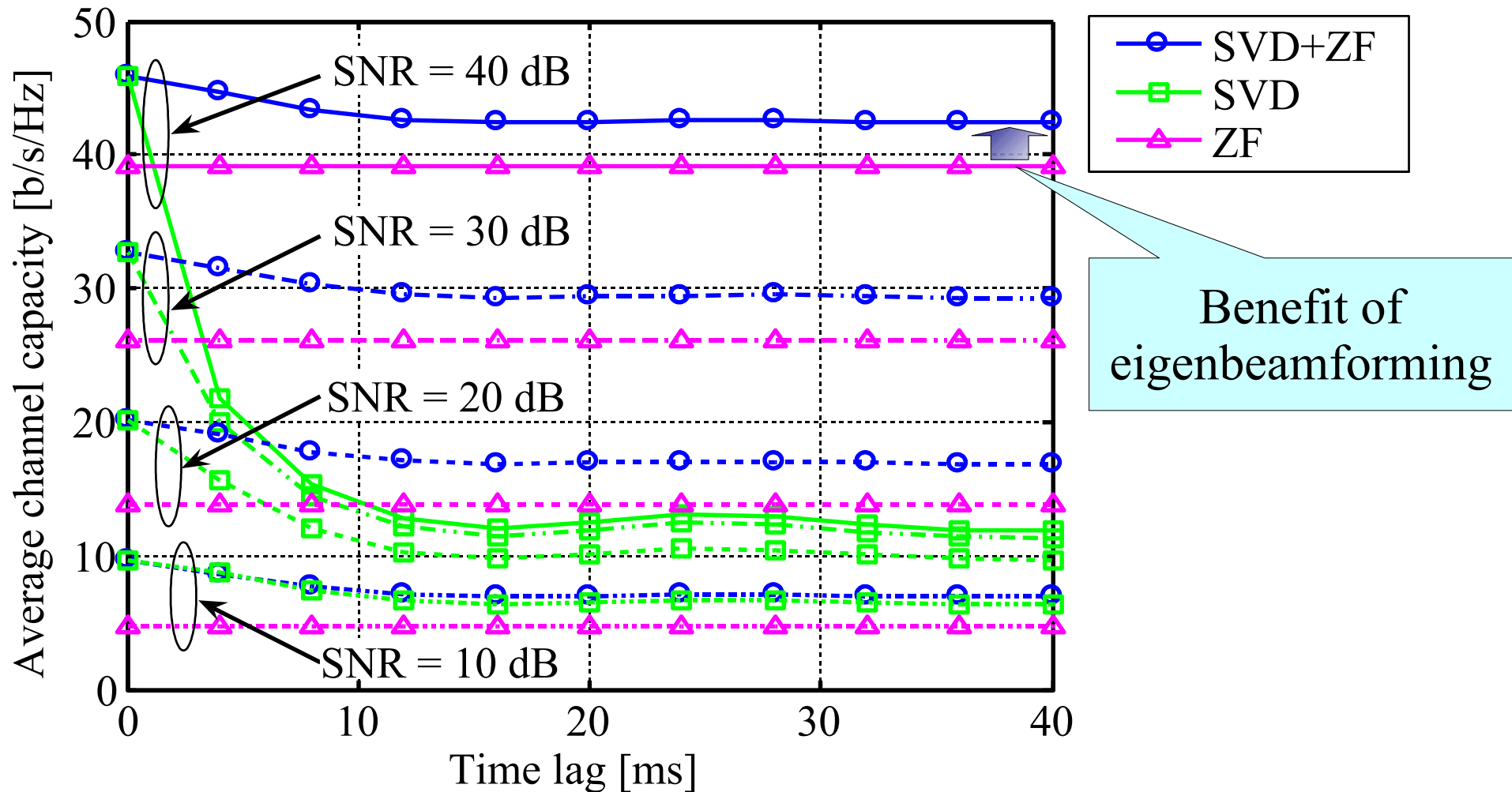
Walking (Anticlockwise) Scenario

- Large degradation of channel capacity is observed in high SNR cases (SVD).



Walking (Clockwise) Scenario

- Similar characteristics to those in the walking (anticlockwise) scenario are observed.



Conclusions

- We carried out
 - ➔ measurements of time-varying MIMO channels at 5 GHz,
 - ➔ analysis of channel capacity by using the measured channel data.
- The measurement results showed that
 - ➔ the time-varying channel considerably degrades channel capacity of the standard SVD-MIMO system,
 - ➔ an interference canceller in eigenbeam space, e.g. ZF, is indispensable to achieve the benefit of CSI feedback and eigenbeamforming.

More measurements in various environments and scenarios are required to discuss the performance in general cases.

Part II

時変動屋内MIMO伝搬路の ドップラスペクトル解析

Doppler Spectrum Analysis of
Time-Varying Indoor MIMO Channel

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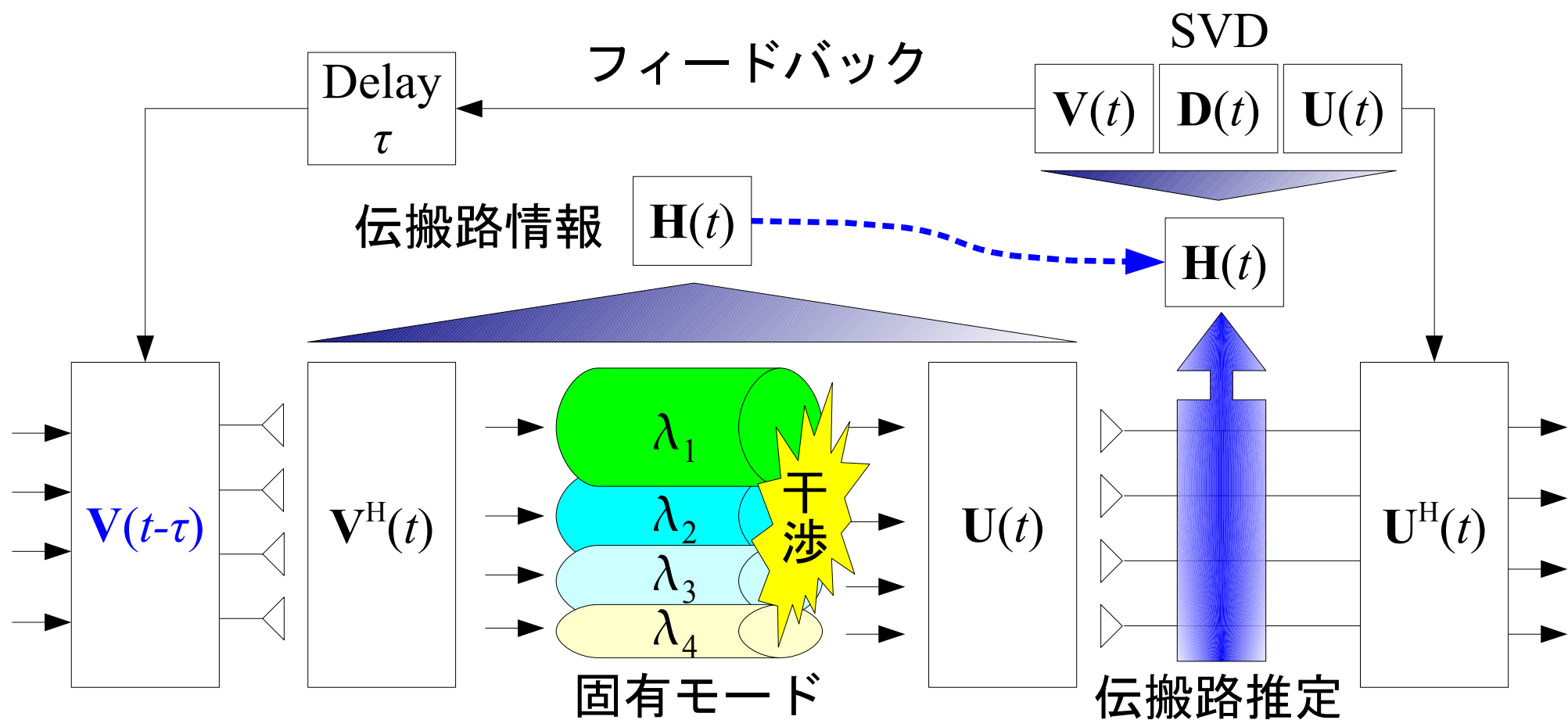
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目次

- 背景・目的
- MIMO伝搬測定
- ドップラスペクトル解析
- まとめ

背景

- クローズドループ型MIMO通信システム
(例えばMIMO固有モード伝送)
- ➔ 伝搬路の時変動により特性劣化



目的

- IEEE802.11n伝搬路モデルにおける時変動の要因
 - ➔ 人の動き・・・釣鐘形ドップラスペクトル
 - ➔ 移動する車からの反射
 - ➔ 蛍光灯

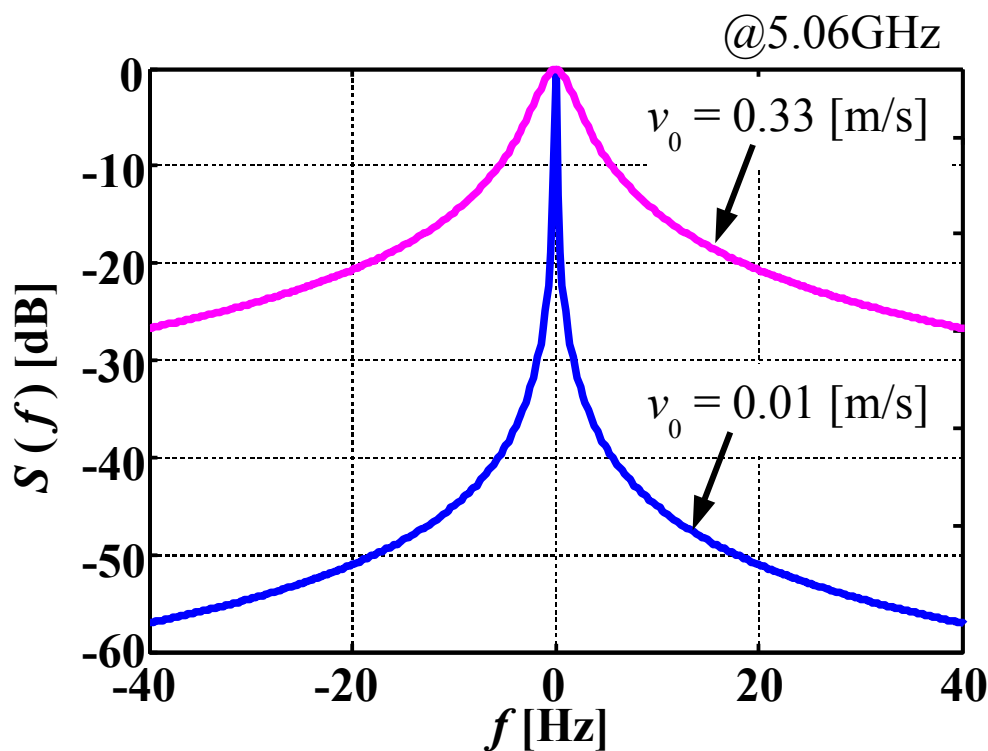
$$S(f) = \frac{1}{1 + A \left(\frac{f}{f_d} \right)^2} = \frac{1}{1 + 9 \left(\frac{f}{f_c} \frac{c}{v_0} \right)^2}$$

f_d : ドップラ周波数

f_c : 搬送波周波数

c : 光の速度

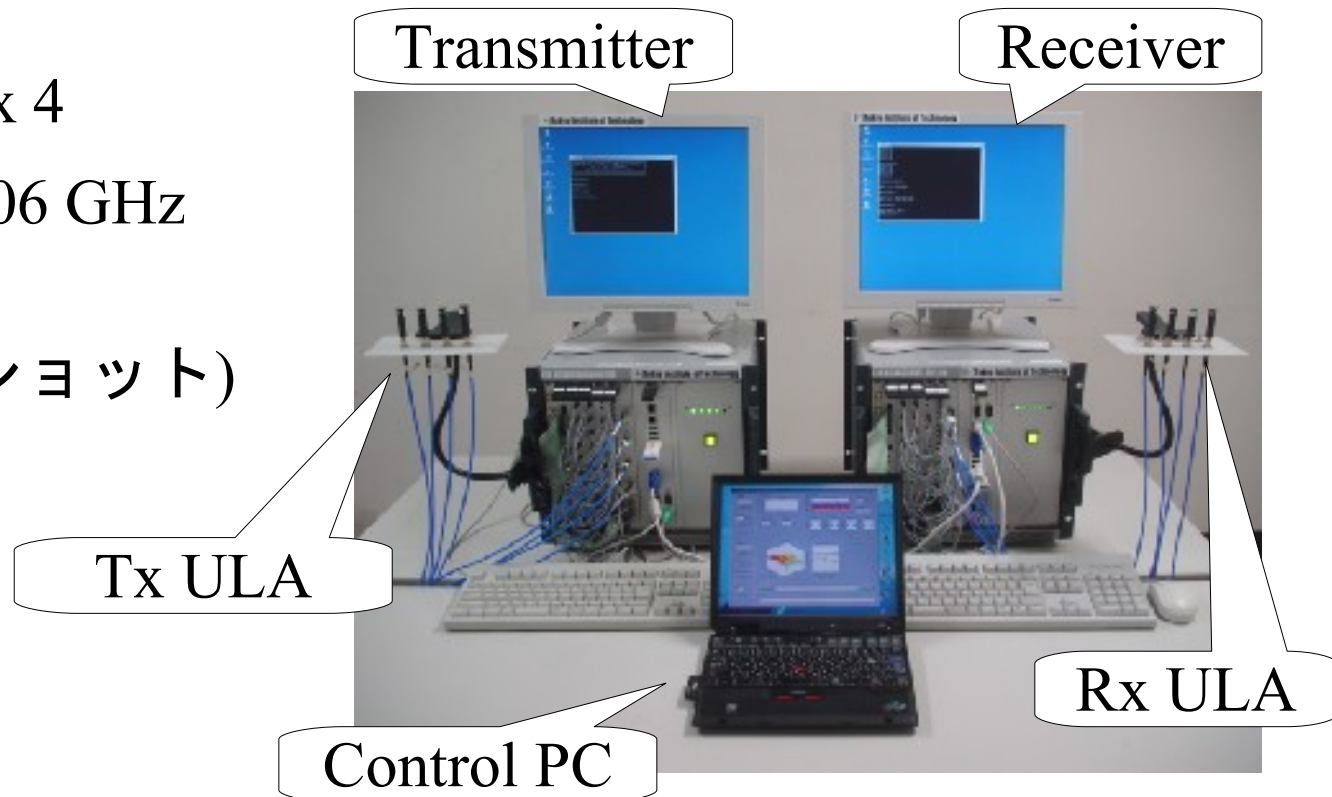
v_0 : 環境の変動速度



実シナリオにおける
時変動パラメータの推測

MIMO伝搬測定

- ▶ リアルタイムMIMO伝搬測定システム
 - IEEE802.11a準拠OFDM
 - 4 ms 間隔で52サブキャリアのMIMO応答行列を推定
- ▶ 測定諸元
 - アンテナ数 : 4 x 4
 - 中心周波数 : 5.06 GHz
 - 測定時間 : 10 s
(2500スナップショット)



解析手法

手順

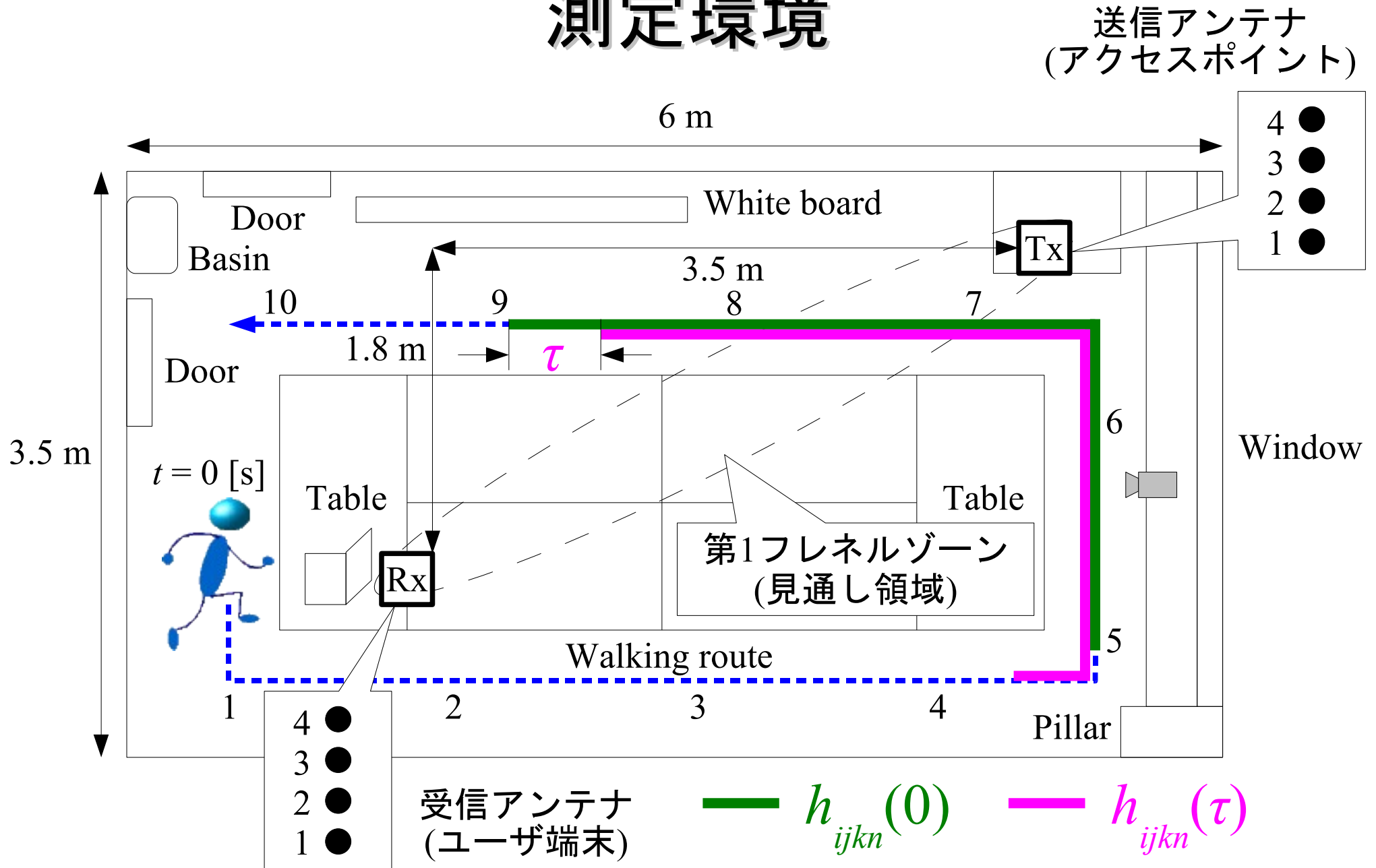
1. MIMO応答行列 \mathbf{H} の要素 h_{ijkn} ごとに自己相関 $\rho_{ijk}(\tau)$ を算出
2. アンテナ(空間), サブキャリア(周波数)で平均

$$\rho(\tau) = \frac{1}{m_r m_t m_f} \sum_{i=1}^{m_r} \sum_{j=1}^{m_t} \sum_{k=1}^{m_f} \frac{\sum_{n=1}^N h_{ijkn}(0) h_{ijkn}^*(\tau)}{\sqrt{\sum_{n=1}^N |h_{ijkn}(0)|^2 \sum_{n=1}^N |h_{ijkn}(\tau)|^2}}$$

i : 受信アンテナ (1~ m_r)
 j : 送信アンテナ (1~ m_t)
 k : サブキャリア (1~ m_f)
 n : 時間サンプル (1~ N)

3. 自己相関のフーリエ変換からドップラスペクトル $S(f)$ を導出
 4. 釣鐘形に最小二乗法でフィッティング
- 時間間隔 τ はデータ取得間隔4 msの整数倍

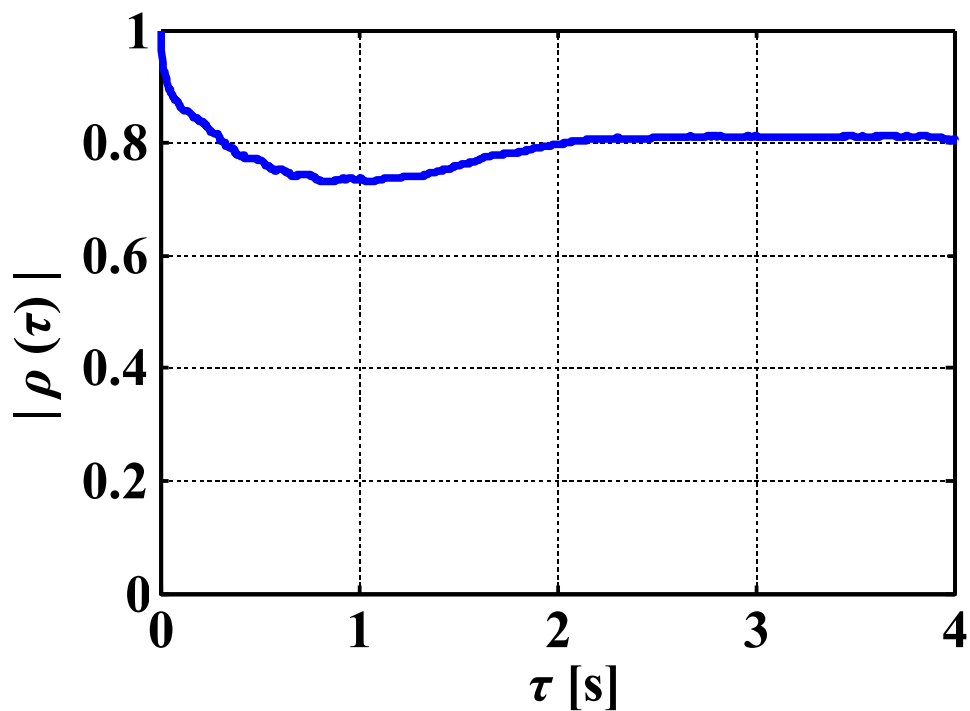
測定環境



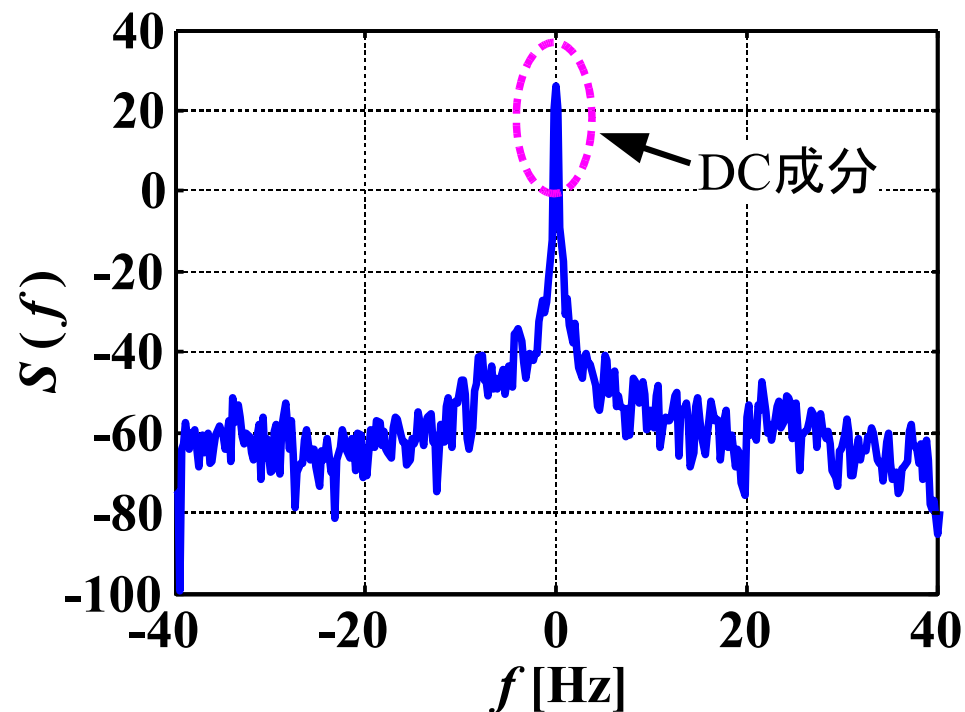
ドップラスペクトル解析

見通し環境

- アンテナの配置や部屋の構造で決まる静的成分の寄与が大 (高い自己相関特性)
- フィッティング時はDC成分を除去



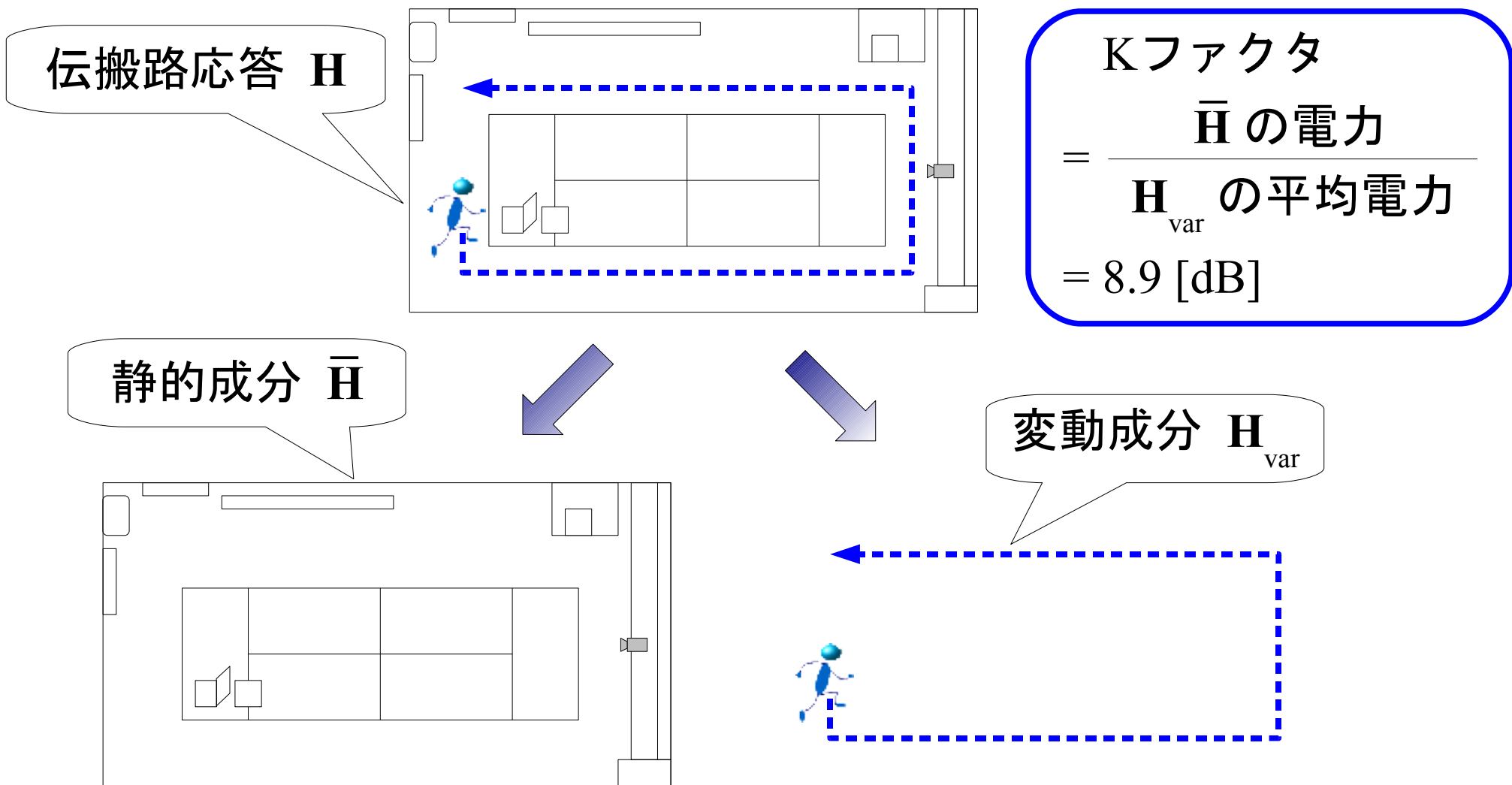
自己相関



ドップラスペクトル

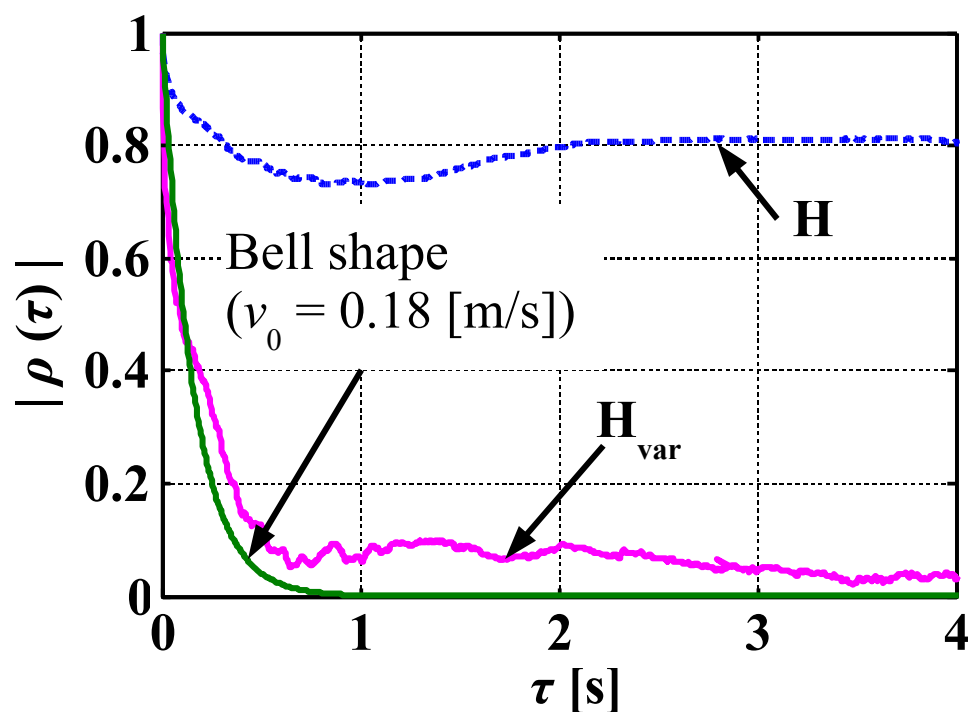
時変動成分の抽出

- 伝搬路応答 H から，静的成分として平均値 \bar{H} を減算

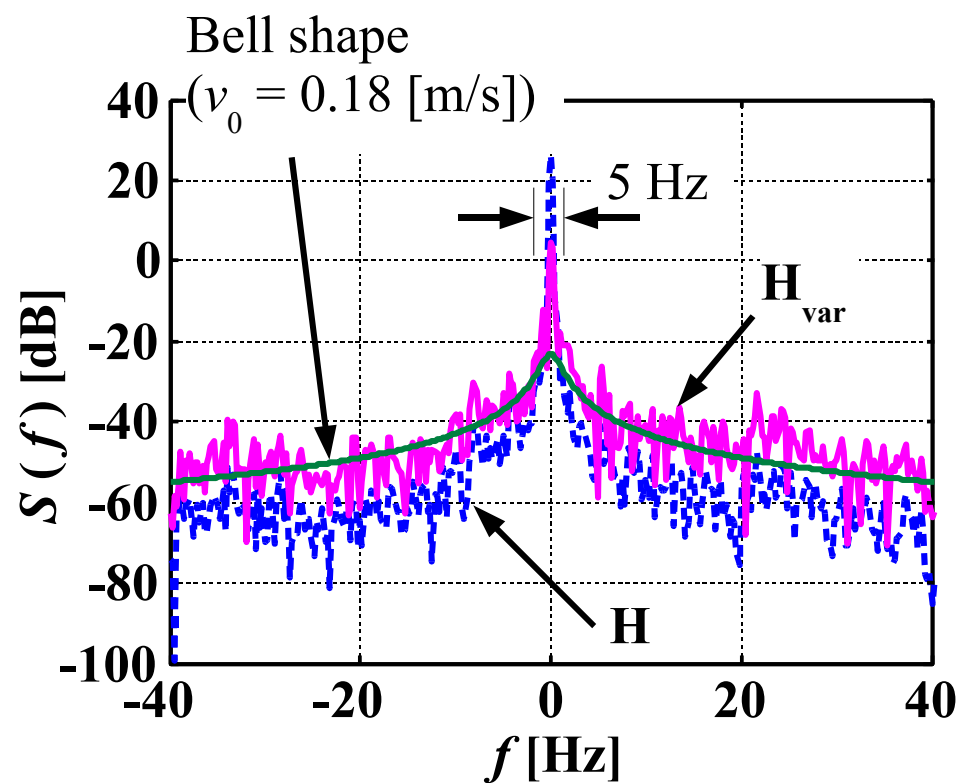


環境の変動速度

- $v_0 = 0.18$ [m/s] の釣鐘形に最小二乗近似
- ➔ ただしDC近傍5 Hzをフィッティングに含めない場合



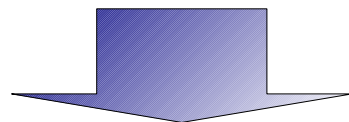
自己相関



ドップラスペクトル

まとめ

- MIMO伝搬測定データを用いたドップラスペクトル解析



実シナリオにおける
環境の変動速度を推測

- 今後の課題
 - 見通しによる影響
 - 見通しを遮ると自己相関は下がるか？
 - アンテナ間の特性
 - アンテナ間で時変動特性が異なるときその影響は？