Polarization behavior of Polarized MIMO System

Measurement, Modeling and Statistical Validation

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MCRG Joint Seminar

11 June, 2009

Outline

I. Motivation

- MIMO: Benefits and Issues
- Objective of This Study

II. Previous Work

- Measurement and Parameter estimation
- Regression analysis of polarization behavior

III. Main Results

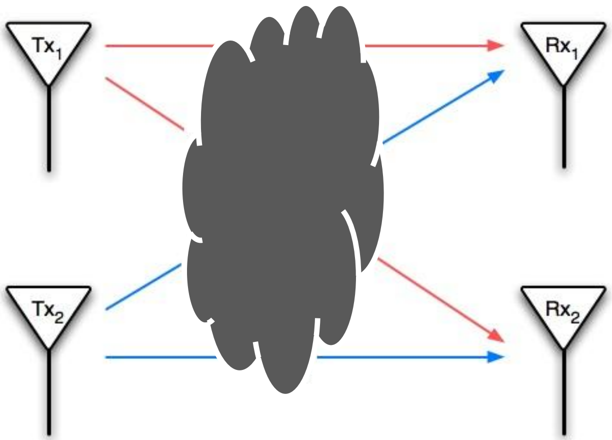
- Procedure of Hypothesis Testing
- Results

IV. Conclusions

Benefits of MIMO

- MIMO:

  Multiple antennas at both Tx and Rx
- Benefits
  - Higher spectral efficiency
  - Higher throughput
  - Higher reliability



Pre-Condition: Multipath rich environment

⟹ Receiver can separate the data stream

- "The benefits" heavily depends on the propagation channel

"Channel" is a main factor which we can not control.

Issues of MIMO

In the real world

- Inadequate scattering environment = Ricean fading
- Inadequate antenna spacing = Data stream correlation

- "MIMO" discovered new dimension = Space
  ..but Space is also finite.
- New dimension again: Polarization
  - Orthogonal by nature (V and H)
  - At least two data streams even in the severe environment
  - Realize compact antenna system

MIMO Wireless Router
(D-Link Systems Inc.)

Polarization diversity
is essential for MIMO (Spatial diversity) system

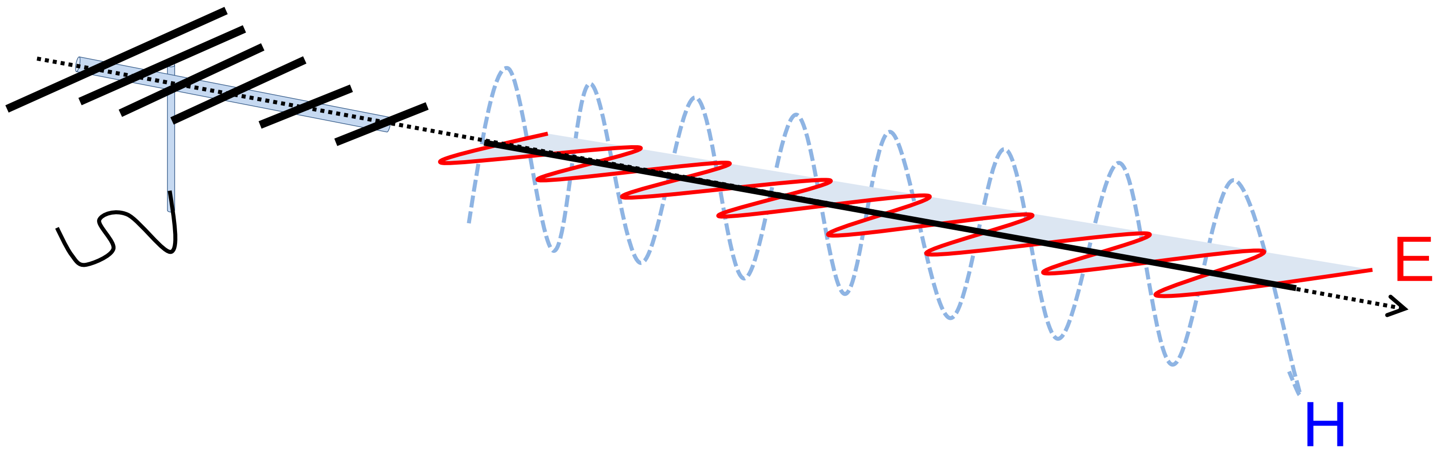
Objective

Quantifying the degree of depolarization to compare different measurement data in a strictly same sense.

- Establishment of good channel model is essential for the all aspects of radio system design
  - Antenna, Signal processing algorithm and Modulation/coding technique
- What kind of factors are insufficient in the current channel model?
  - Investigation of temporal behavior caused by moving scatterers
  - Including diffuse scattering in the model
  - Consideration of spherical mode expansion (solving plan wave limitation)
  - Polarization model
    - Most of the existence models use very simplistic assumptions.
    - How does the co-polar ratio vary in different environments?
    - How can we compare existence measurement based models in a strictly same sense? Advanced statistical analysis is necessary.

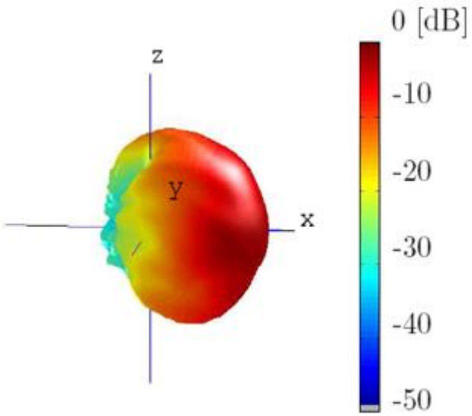
Polarization: Theory and Practice

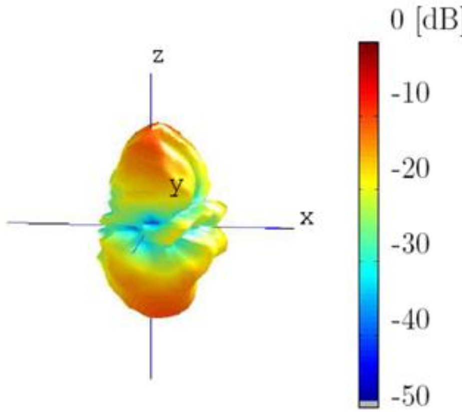
- Polarization: time variations of electric field
  - Depolarization
    - by Rain
    - by Ionosphere (Faraday rotation)
    - <u>by scattering: most significant cause for MIMO</u>



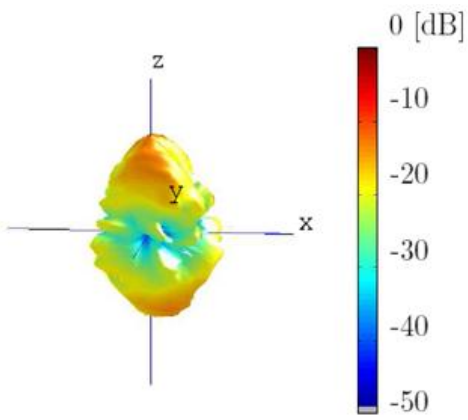
Polarization: in Practice

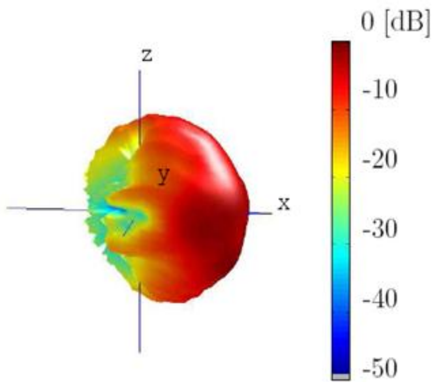
- Horizontal excitation
- Vertical excitation





H−port





V−port

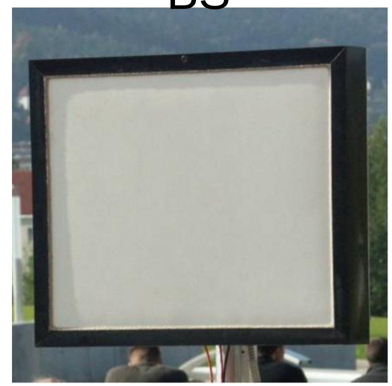
Power “Leak” exists. → Measurement based model

Channel sounding syster

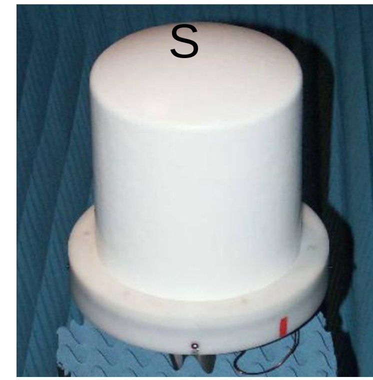
RUSK channel sounder

Carrier freq.	4.5 GHz
Bandwidth	120 MHz
BS antenna (V-H pol.)	Uniform Rectangular Array 2×4×2pol. Elements
MS antenna (V-H pol.)	Stacked Uniform Circular Array 2×24×2pol. elements
Transmit signal	Wideband multitone
Max. delay	3.2μs
No. of MIMO channels	1536

BS



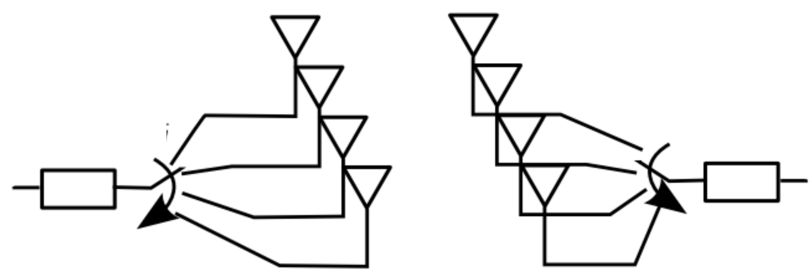
M S



- Fully switched system
- Rubidium reference clocks for switching frame synchronization

↓

Double-directional measurement



Parameter estimation

- RIMAX:

  Gradient-based maximum likelihood parameter estimation
  - Including diffuse scattering components
  - Based on the conjugate gradient optimization strategy
  - Variance of estimated parameter is used to improve model reliability

- RIMAX outputs:

$\gamma_{VV}, \gamma_{VH}, \gamma_{HV}, \gamma_{HH}$	Complex polarimetric path weights
θ^{BS}, ϕ^{BS}	Elevation and Azimuth angle at BS
θ^{MS}, ϕ^{MS}	Elevation and Azimuth angle at MS
τ	Delay

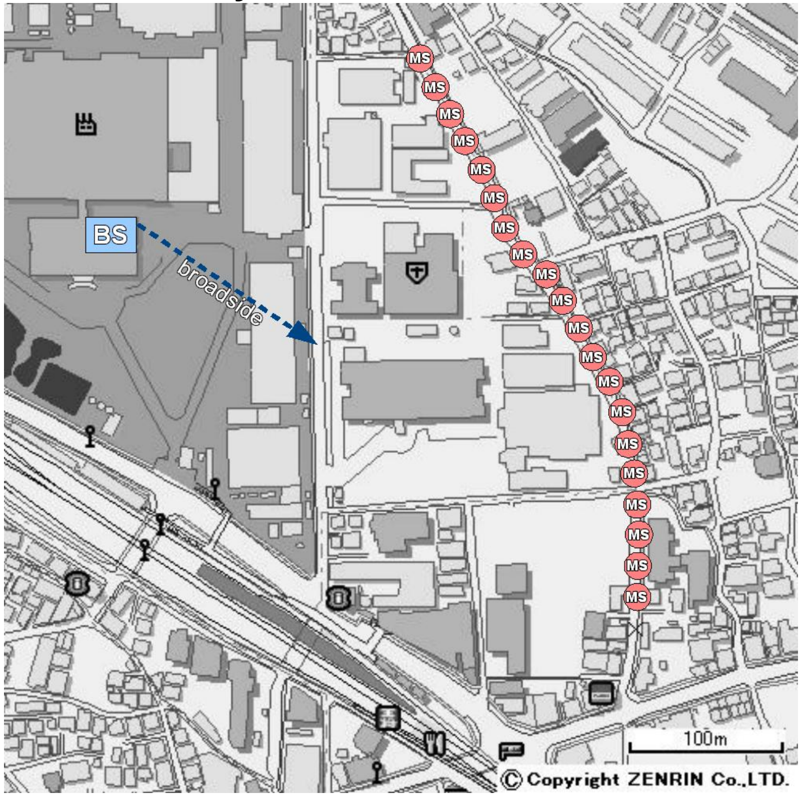
Environment

- BS : highest in the area
- MS interval: 20 m (along the street)
- 6 snapshots are taken every MS position (50-60 snapshots measured)

Small Macrocell Scenario

BS height	85 m
MS height	1.80 m
BS-MS distance	230m ~ 400 m
MS status	Static; moving (slow walk)
Structure type	Residential & industrial

Layout of the scenario.



Kawasaki City, Japan

Multipath clusterization

- Cluster:

  set of paths experienced similar propagation mechanism

  * Cluster-wise modeling approach was adopted as COST273 framwork

- Automatic multipath clusterization
  - Second treatment of measured data
  - Details can be found in [1] and [2]

- Notes for the data treatment
  - 6 snapshots for every MS position were averaged.
  - Dynamic parameters are not considered.
  - Strongest paths (corresponds to the LoS) were removed using single path estimation.

[1] L. Materum et al., Proc. Int. Symp. Antennas Propag. (ISAP), pp. 854-857, Oct. 2008.
[2] L. Materum et al., EURASIP J. Wireless Commun. and Netw., Feb.2009.

Polarization Ratio

- XPR: degree of depolarization from being V polarized to being H polarized, or vice verca.

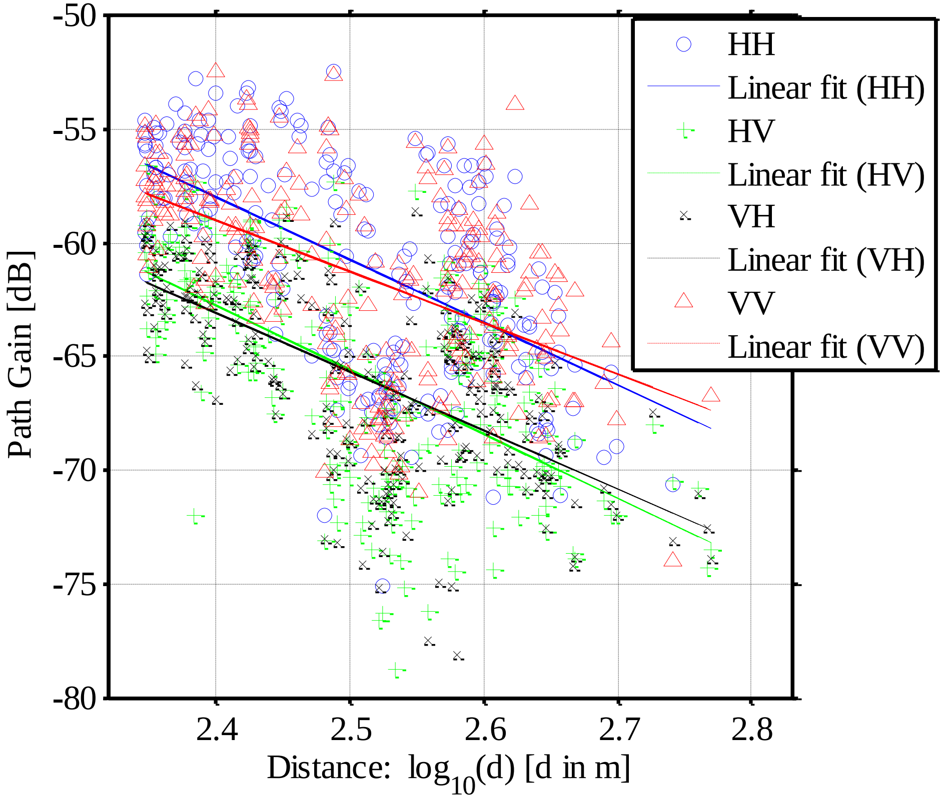
$$\mathrm{XPR}_{\mathrm{V}}^{\mathrm{BS}} = 10\log_{10}\left(\frac{\sum_{l\in\mathcal{C}_k} |\ \gamma_{\mathrm{VV},l}\ |^2}{\sum_{l\in\mathcal{C}_k} |\ \gamma_{\mathrm{VH},l}\ |^2}\right) \qquad \mathrm{XPR}_{\mathrm{V}}^{\mathrm{MS}} = 10\log_{10}\left(\frac{\sum_{l\in\mathcal{C}_k} |\ \gamma_{\mathrm{VV},l}\ |^2}{\sum_{l\in\mathcal{C}_k} |\ \gamma_{\mathrm{HV},l}\ |^2}\right)$$

$$\mathrm{XPR}_{\mathrm{H}}^{\mathrm{BS}} = 10\log_{10}\left(\frac{\sum_{l\in\mathcal{C}_k} |\ \gamma_{\mathrm{HH},l}\ |^2}{\sum_{l\in\mathcal{C}_k} |\ \gamma_{\mathrm{HV},l}\ |^2}\right) \qquad \mathrm{XPR}_{\mathrm{H}}^{\mathrm{MS}} = 10\log_{10}\left(\frac{\sum_{l\in\mathcal{C}_k} |\ \gamma_{\mathrm{HH},l}\ |^2}{\sum_{l\in\mathcal{C}_k} |\ \gamma_{\mathrm{VH},l}\ |^2}\right)$$

- CPR: degree of V polarization with respect to the H polarization.

$$\mathrm{CPR} = 10\log_{10}\left(\frac{\sum_{l\in\mathcal{C}_k} |\ \gamma_{\mathrm{VV},l}\ |^2}{\sum_{l\in\mathcal{C}_k} |\ \gamma_{\mathrm{HH},l}\ |^2}\right)$$

Polarization Path Gain



$$P_{\mathrm{HH}} = -27.57\log_{10}(d) + 8.21$$

$$P_{\mathrm{HV}} = -28.28\log_{10}(d) + 5.12$$

$$P_{\mathrm{VH}} = -25.81\log_{10}(d) - 1.14$$

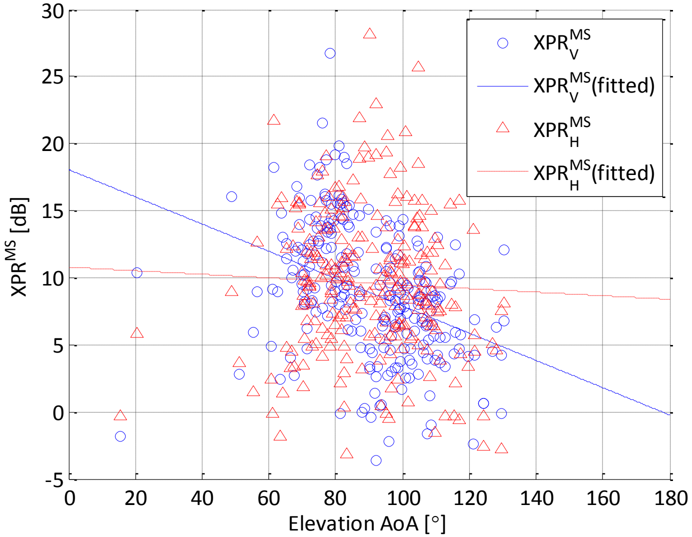
$$P_{\mathrm{VV}} = -22.55\log_{10}(d) - 4.88$$

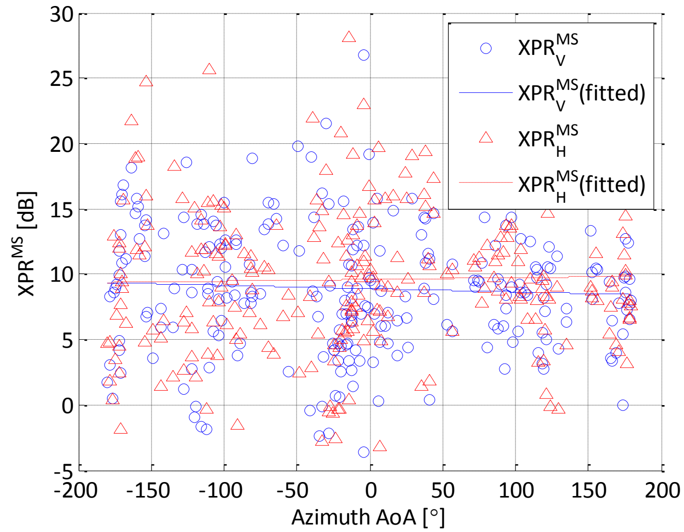
Decay coefficient

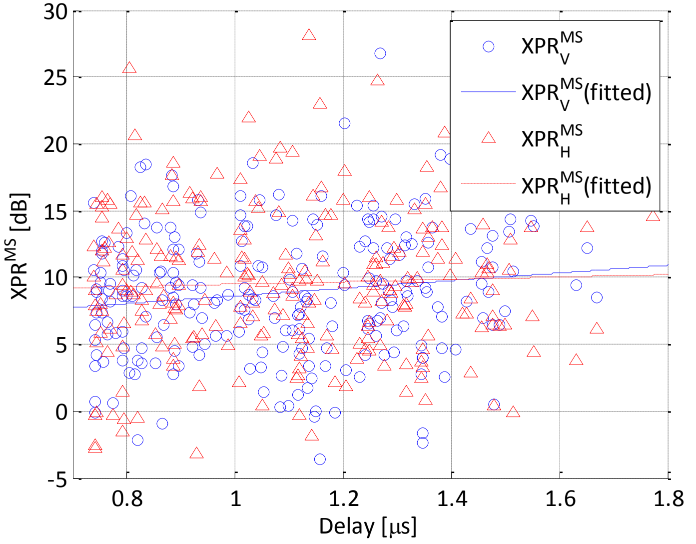
HH	VV	HV	VH
-27.58	-24.55	-28.28	-25.81

- HH polarization pairs decay faster than VV polarization pairs.
- Co-pol. path gains ware 4.65dB higher than the cross-pol. ones.
- Similar observations;
  - [5], [6] : HH decays faster than VV.
  - [3] : co-pol. is 4~10dB higher than cross-pol.
  - [4] : co-pol. is 7dB higher than cross-pol.

XPR characteristics



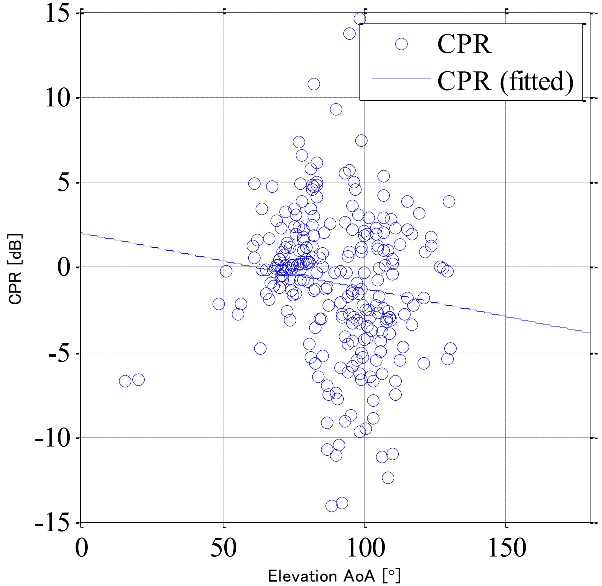


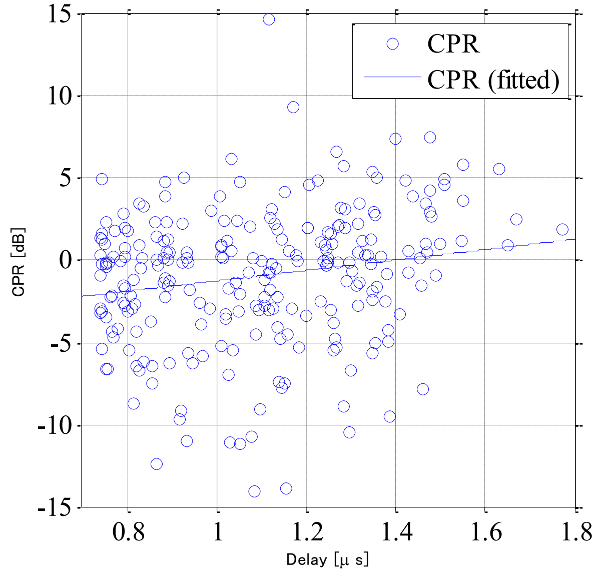


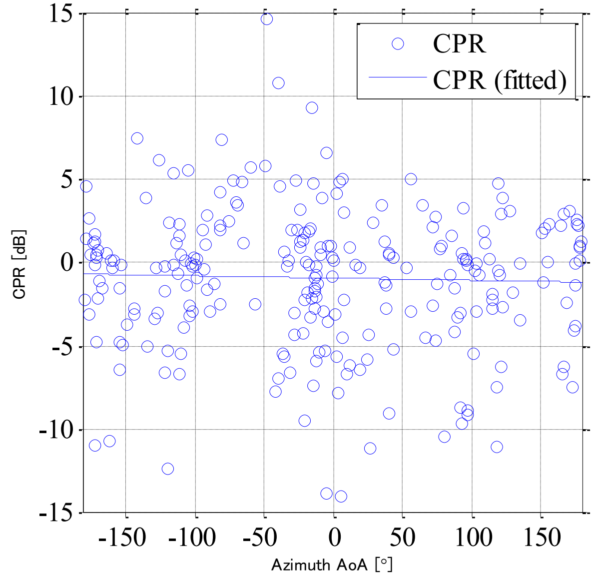
Decay coefficient

XPR vs.	V pol.	H pol.
Elevation AoA	-0.12	-0.03
Azimuth AoA	-0.003	0.001
Delay	2.97	0.96

CPR characteristics







Decay coefficient

	CPR
Elevation AoA	-0.0327
Azimuth AoA	-0.0013
Delay	3.1714

Comparison of <u>**Decay coefficient**</u>
dose not clarify the polarization behavior

Dependency quantification

- Correlation coefficient:

- Linear-Linear: Delay and Elevation

$$-1 \leq \frac{Cov(x,y)}{\sqrt{Var(x) \times Var(y)}} \leq 1$$

- Linear-Circular: Azimuth

$$R_{x\theta}^2 = \frac{r_{xc}^2 + r_{xs}^2 - 2r_{xc}r_{xs}r_{cs}}{1 - r_{sc}^2}$$

$$r_{xc} = corr(x, cos(\theta))$$
$$r_{xs} = corr(x, sin(\theta))$$
$$r_{cs} = corr(cos(\theta), sin(\theta))$$

Medium correlation is observed between XPR_V^{MS} and elevation AoA

Variable *x*	Variable y		
	Elevation	Azimuth	Delay
XPR_V^{MS}	**-0.3705**	0.0013	0.1535
XPR_H^{MS}	-0.0437	0.0079	0.0433
CPR	-0.1354	0.0005	0.1926

Summary of Previous Work

Achievement

- Polarization behavior is analyzed by Regression approach
- Only the rough characteristics were studied

Problem

- The correlation coefficient indicates only the ordinal relation
- Difficult to compare with other results

Solution

- Strictly statistical analysis: Hypothesis testing

Procedure of Hypothesis Testing: T–Test

- Step 1
  - Assume "total correlation coefficient" = 0 (null hypothesis)
- Step 2
  - Compute the test statistics: $t = \frac{\overline{x} - \mu}{\sqrt{\sigma^2 / n}}$
- Step 3
  - Plot the probability density of T distribution with

    Significance level = 0.05

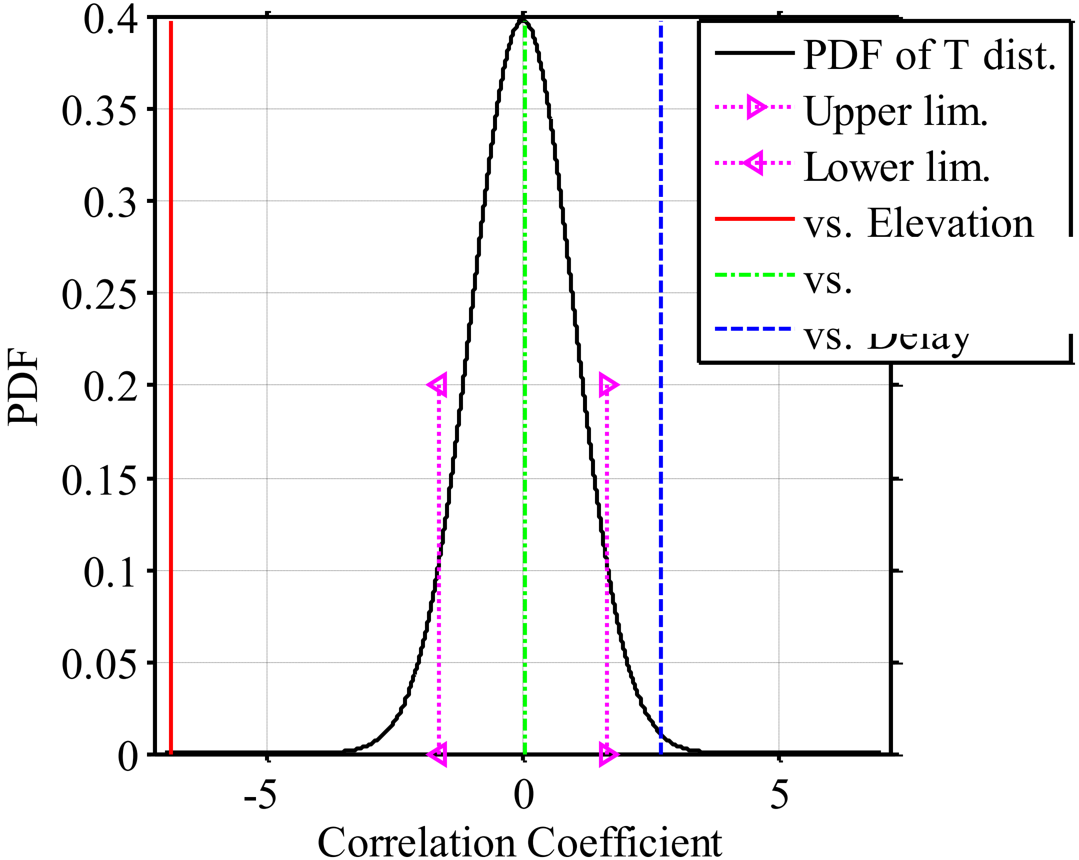
    Degree of freedom = 251 (Sample size)
- Step 4
  - Judgment: in the PDF plot,
    1. 5% < "total correlation coefficient" < 95%

       XPR/CPR is independent on the parameter in 5 % significance level
    2. 5% >"total correlation coefficient" & "total correlation coefficient" > 95 %

       XPR/CPR is dependent on the parameter in 5 % significance level

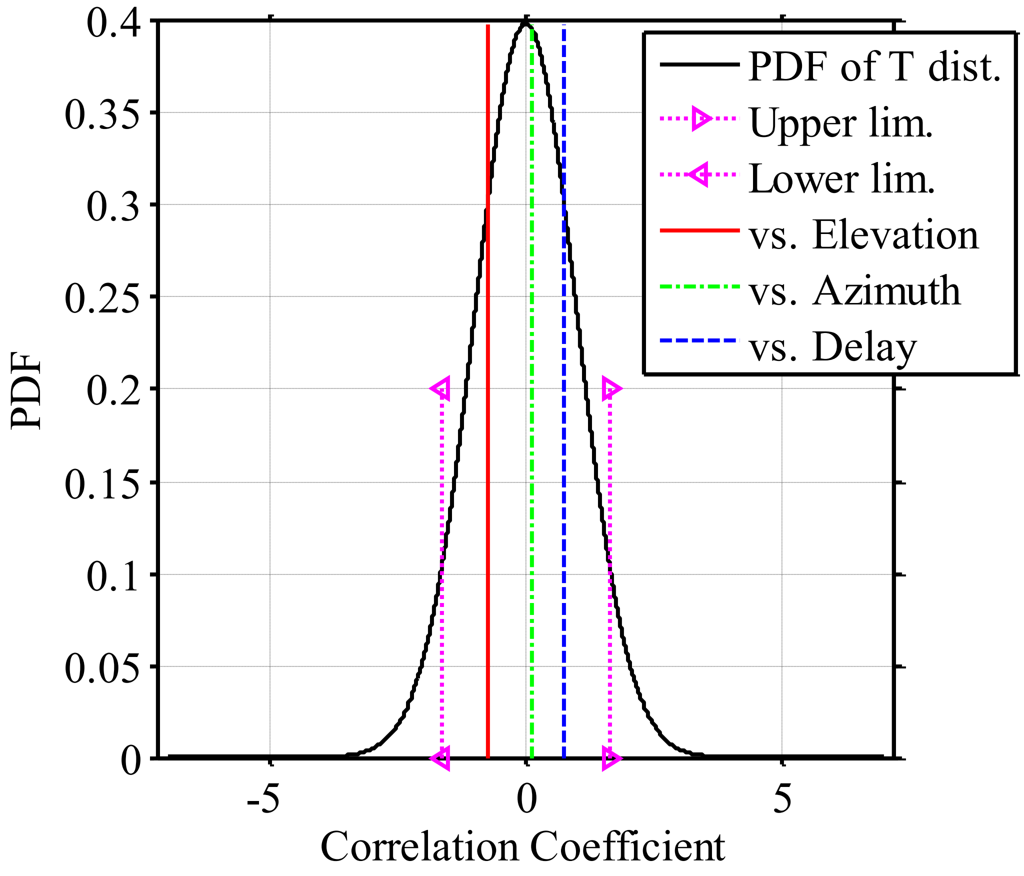
V polarization: XPR at MS

- V pol. : independent with Azimuth and Delay
  : dependent on Elevation



H polarization: XPR at MS

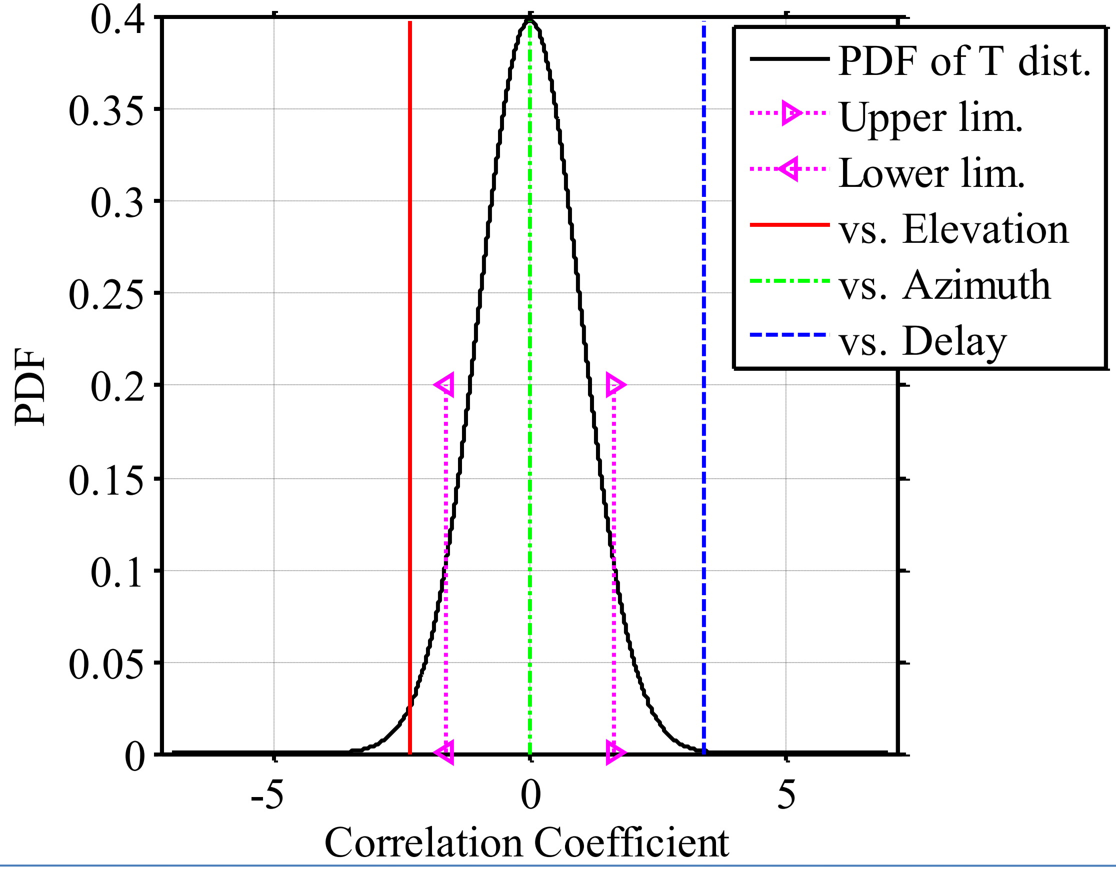
- H pol. : independent with all parameters



CPR results

- CPR : independent with Delay

  : dependent on Azimuth and Elevation



Conclusions

- Multipath cluster polarization characteristics of a small urban macrocell at 4.5 GHz has been presented
- XPR and CPR dependency on the parameters were analyzed and validated by hypothesis testing

Future works

- Comparison by presented approach
  - Different measurement sites
  - Different parameter estimation algorithms
    - RIMAX outputs (path-wise)
    - Clustering outputs
    - Beamforming outputs

      ->Need more study to analyze polarization behavior
- Planning of the new measurement campaign
  - Proper scenario selection
  - Clear objective setting: focus on polarization

References

[1] L. Materum, J. Takada, I. Ida, and Y. Oishi, “Improved multipath clustering of a small urban macrocellular MIMO environment at 4.5 GHz,”Proc. Int. Symp. Antennas Propag. (ISAP), pp. 854-857, Oct. 2008.

[2] L. Materum, J. Takada, I. Ida, and Y. Oishi, “Mobile station spatio-temporal multipath clustering of an estimated wideband MIMO double-directional channel of a small urban 4.5 GHz macrocell,” EURASIP J. Wireless Commun. and Netw., Feb.2009.

[3] R. Vaughan, “Polarization diversity in mobile communications,” IEEE Trans. Veh. Technol., vol. 39, pp. 177-186, Aug. 1990.

[4] L. M. Correia (Ed.), Mobile Broadband Multimedia Networks (Techniques, Models and Tools for 4G), Elsevier, 2006.

[5] I. Sirkova, “Overview of COST 273 Part I:propagation modeling and channel characterization”, XLI ICEST, Sofia, Bulgaria, 2006.

[6] I. Sirkova, “Overview of COST 273 Part II: Parabolic equation method application”, XLI ICEST, Sofia, Bulgaria, 2006.

[7] http://www.cost2100.org/

[8] BY P. E. JUPP, AND K. V. MARDIA, “A general correlation coefficient for directional data and related regression problems,” Biometrika, 67, 1, pp. 163-73, 1980

Thank you for listening!