MIMO Channel Capacity of A Measured Radio Channel for Outdoor Macro Cellular Systems at 3GHz-band

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Introduction (1)

- The outdoor MIMO channel characteristics measured by a 2×2 MIMO channel sounding system 3GHz-band in urban environment.
  - Measurements at the center frequency of 3.35 GHz in urban environment.
  - We get the complex impulse responses that is changed each Tx antennas distance (d_{Tx}) and Rx antennas distance (d_{Rx})
- From the measured MIMO channel characteristics, we computed the channel capacity based on each .
  - Analysis of MIMO channel capacities
    - Channel responses are computed from measured impulse responses
    - Eigenvalue that was obtained through singular value decomposition (SVD)
    - MIMO channel capacities are computed by the eigenvalues

Introduction (2)

- Results of the capacity in MIMO channel that is changed each d_{Tx} and d_{Rx}
  - 2.4dB (d_{Tx}=20λ) and 1.8dB (d_{Tx} =2λ) gain at the SNR of 15 dB comparing with theoretical values of SISO channel capacity.

    ※ λ : wavelength
  - The results indicate if distance of Tx antennas is short, MIMO transmission efficiency is lower down.

- Results of dynamic characteristics of MIMO channnel
  - In contrast, with d_{Tx}=20λ, the capacity is almost the same (i.e., 6.9 bits/s/Hz) in LOS, and NLOS.
  - In LOS environment, with d_{Tx}=2λ, MIMO channel capacity is lower (i.e., -1.2dB).

Back Ground (1)

- We studies several researches in the literatures to used frequency bands used for the 4G mobile communication systems.
  - 3.35GHz-4.2GHz frequency bands (SISO system)→
    - Measurement of 3GHz-band Radio Propagation in Macro Cellular Environments（(Funada et al@NICT）2006RCS）→Measurements YRP・Yokosuka city in Japan[1]
  - 4.4GHz～4.9GHz freqauency bands→
    - Delay spread measurements in a 5GHz macro-cellar system（(Yonezawa el al @KDDI&Harada@NICT）2003IEICE Society Conf.）→measured at 2003[2]
- IMT-Advanced through global discussion at ITU World Radio communication Conference (WRC-07)
  - In Japan, 3.4-3.6 GHz band will be allocated as one of frequency bands for IMT-Advanced

Reference:
[1]R. Funada, H. Harada "Measurement of 3GHz-band Radio Propagation in Macro Cellular Environments", IEEE PIMRC2006, 2006.
[2] K. Yonezawa, T. Maeyama, H. Iwai, and H. Harada, "Delay spread measurements in a 5GHz macro-cellar system", IEICE Society Conf., B-1-39, p.39, Sept. 2003.
[3 Press information from Ministry of Internal Affairs and Communications, "http://www.soumu.go.jp/menu_news/snews/2008/081112_8.html", Nov. 2008

Back Ground (2)

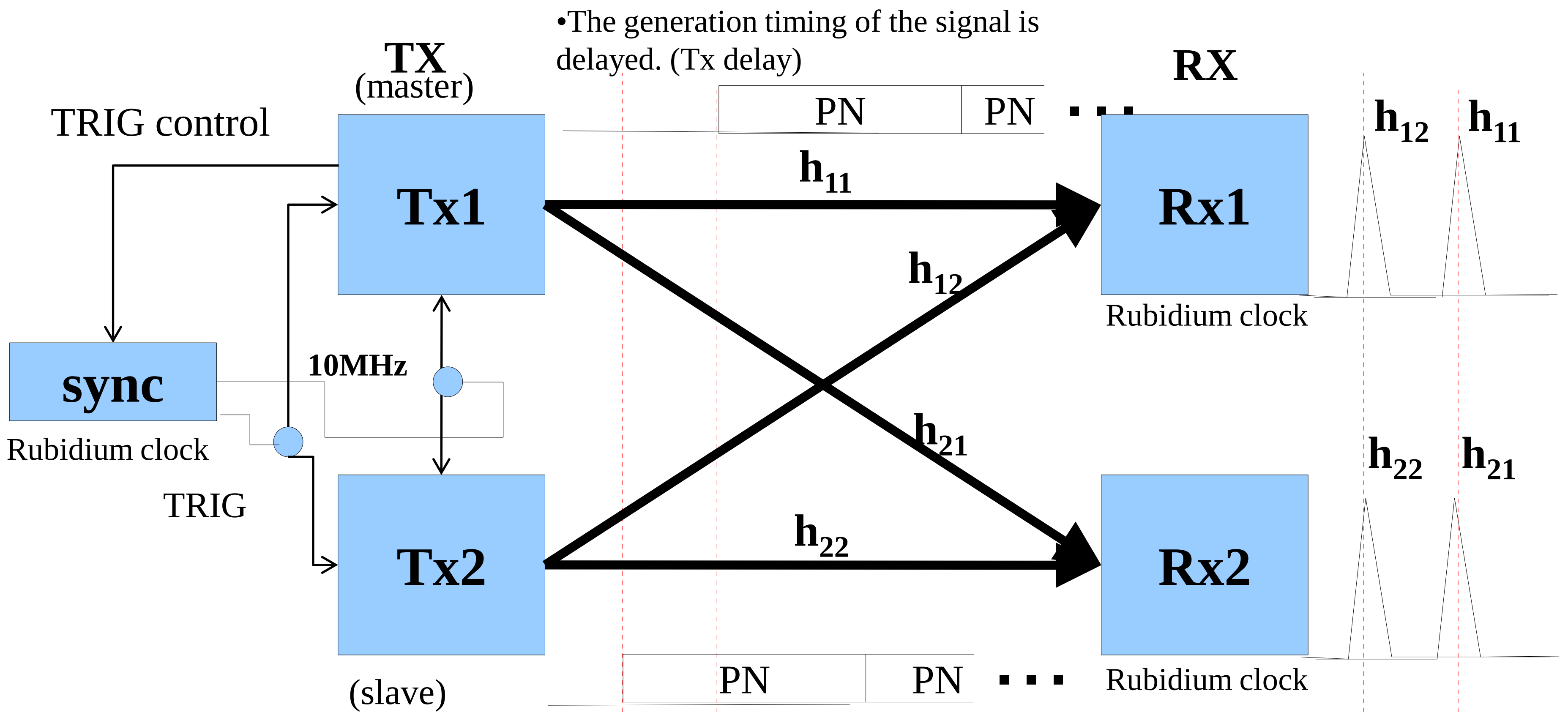
- We have to study an emerging technology due to the capability of high-speed data transmission, because carrier frequency bands for IMT-Advanced have been identified.
  - Considering a Multi-Input-Multi-Output (MIMO) system.
- The study based on measurement of propagation characteristics at such carrier frequency bands for the 4G mobile communication systems is a little.

↓

- We study the outdoor MIMO channel characteristics measured by a 2 × 2 MIMO channel sounding system at the center frequency of 3.35 GHz in urban environment. This measurement equipment is an extended channel sounding system from Single-Input-Single-Output (SISO) that has been used in MIMO.
- MIMO channel capacities are compared in LOS and NLOS environment.

Theory of measurement of MIMO system using PN sequence with the use of TDM

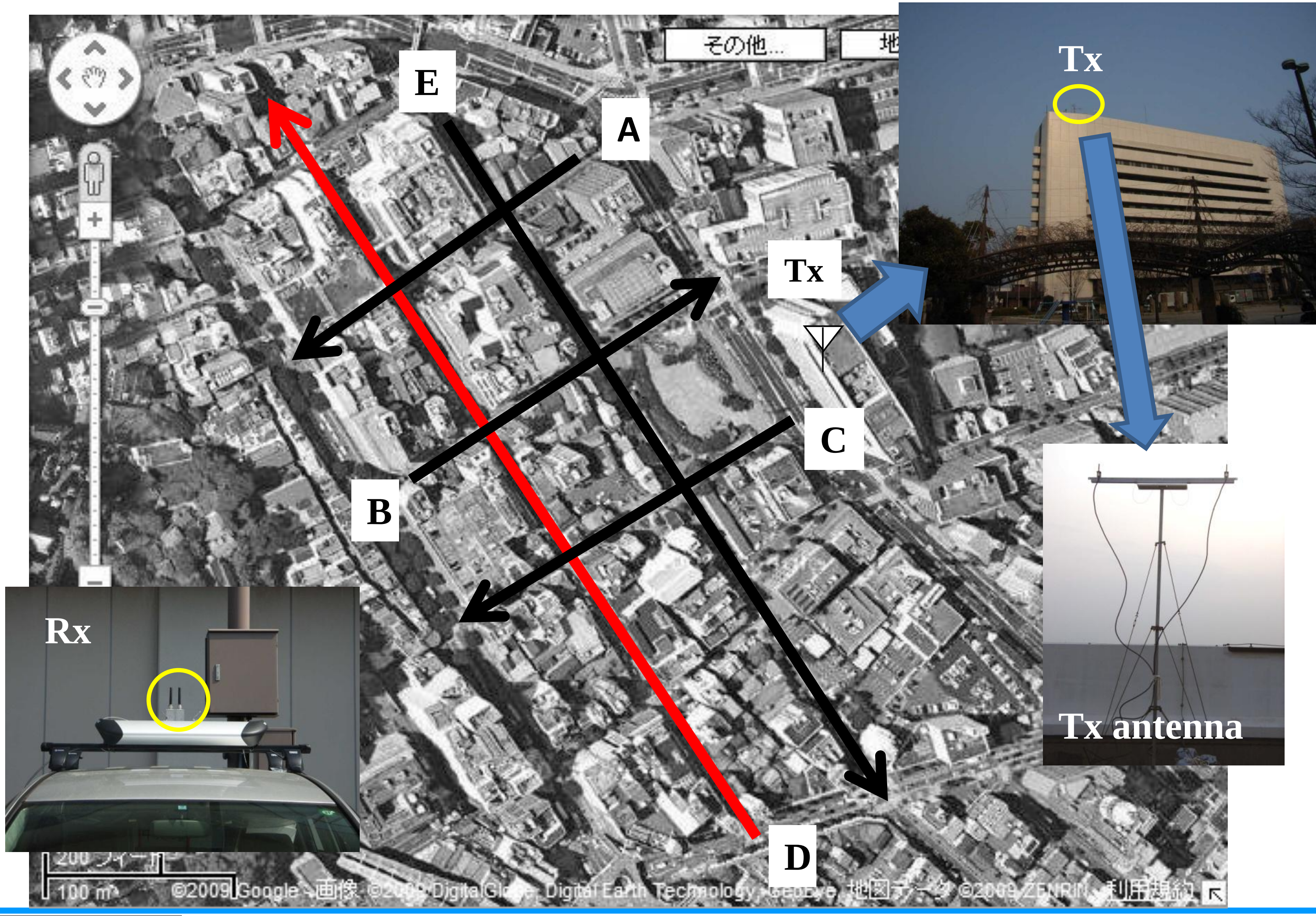
- Tx connect synchronizer, control the timing to generate the transmitted signal.
- TDM is implemented in control transmit timing.
- MIMO channel can be obtained by correlation in each Rx.



The main parameters of measurement system.

Center frequency	3.35 GHz
Bandwidth	80 MHz
Transmission power	10 W (40 dBm) (Cable loss of 2 dB included)
Transmission signal	9-stage PN sequence(40 Mcps)
Modulation	BPSK
Sampling rate	160 Msample/s (with 4 oversampling)
TX antenna	Omni-directional with 2.15 dBi
TX antenna height	60 m (urban area)
RX antenna	Omni-directional with 2.15 dBi
RX antenna height	2.2 m
Number of antennas (antenna distance)	2 (d_{Tx}=2λ, 20λ), 2 (d_{Rx}=0.5λ, 2λ) λ:wavelength
Measurement data Acquisition	Every 1 ms
Average speed of measurement car	20 km/h

Measurement scenario in Yokosuka-city, Japan



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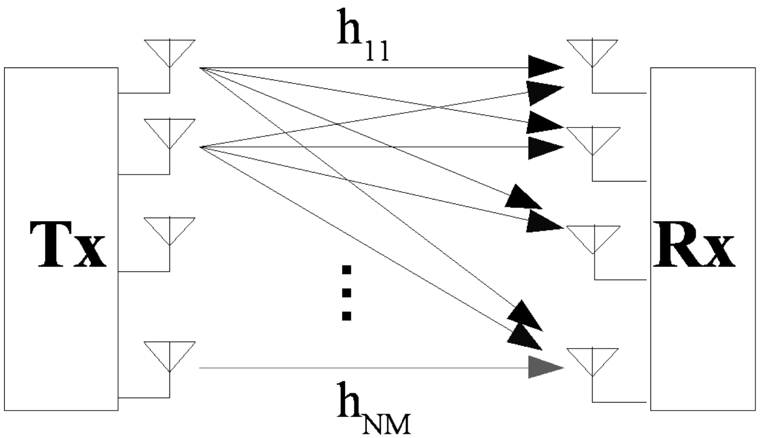
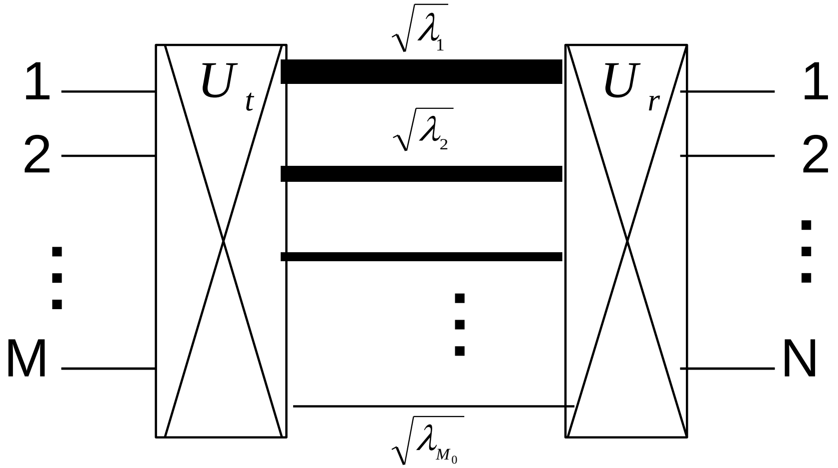
Eigenvalue of equivalent circuit of MIMO channnel(1)



< M×N MIMO channel response matrix >



< Equivalent circuit of M×N MIMO channel based on SVD>

•Derivation method of eigenvalues for 2×2 MIMO

1. channel responses antenna are computed from the measured complex impulse responses in Fast Fourier transform (FFT) as shown Eq.(1).

$$\mathbf{H(f,t)} = F(\mathbf{h}(\boldsymbol{\tau},\mathbf{t})) \quad (1)$$

2. The 2×2 channel response matrix *H is obtained from Eq.(2)*

$$\mathbf{H(f,t)} \equiv \begin{bmatrix} H_{11}(f,t) & H_{12}(f,t) \\ H_{21}(f,t) & H_{22}(f,t) \end{bmatrix} \quad (2)$$

3.Equivalent MIMO channels are obtained from (3) in by SVD.

$$\mathbf{H(f,t)} = \mathbf{U(f,t)}\boldsymbol{\Sigma}\mathbf{(f,t)}\mathbf{V}^{H}\mathbf{(f,t)} = \sum_{i=1}^{2}\sqrt{\lambda_i}u_i v_i \quad (3)$$

where ,

$$\Sigma \equiv diag[\sqrt{\lambda_1}\sqrt{\lambda_2}]$$

$$\mathbf{U} \equiv [u_1 u_2]$$

$$\mathbf{V} \equiv [v_1 v_2]$$

※λ_i : eigenvalue before normalize

Eigenvalue of equivalent circuit of MIMO channnel(2)

4.The eigenvalues are normalized by arithmetic average of channel responses as shown Eq.(4).(In order to cut off the effect of variance of received power by path loss)

$$\frac{\lambda_i}{S} = \hat{\lambda}_i(f,t) \quad (4)$$

whrer

$$S = (|H_{11}(f,t)|^2 + |H_{12}(f,t)|^2 + |H_{21}(f,t)|^2 + |H_{22}(f,t)|^2)/4$$

- **Derivation method of MIMO channel capacity**

According to Shannon's information theory, *the transmission channel capacity C* in per second per Hz is given by

with SISO system

$$C = \log_2(1+\gamma) \quad (5)$$

with 2×2MIMO system

$$C = \sum_{i=1}^{2} \log_2(1+\frac{\lambda_i \gamma}{2}) \quad (6)$$

where, γ : received SNR

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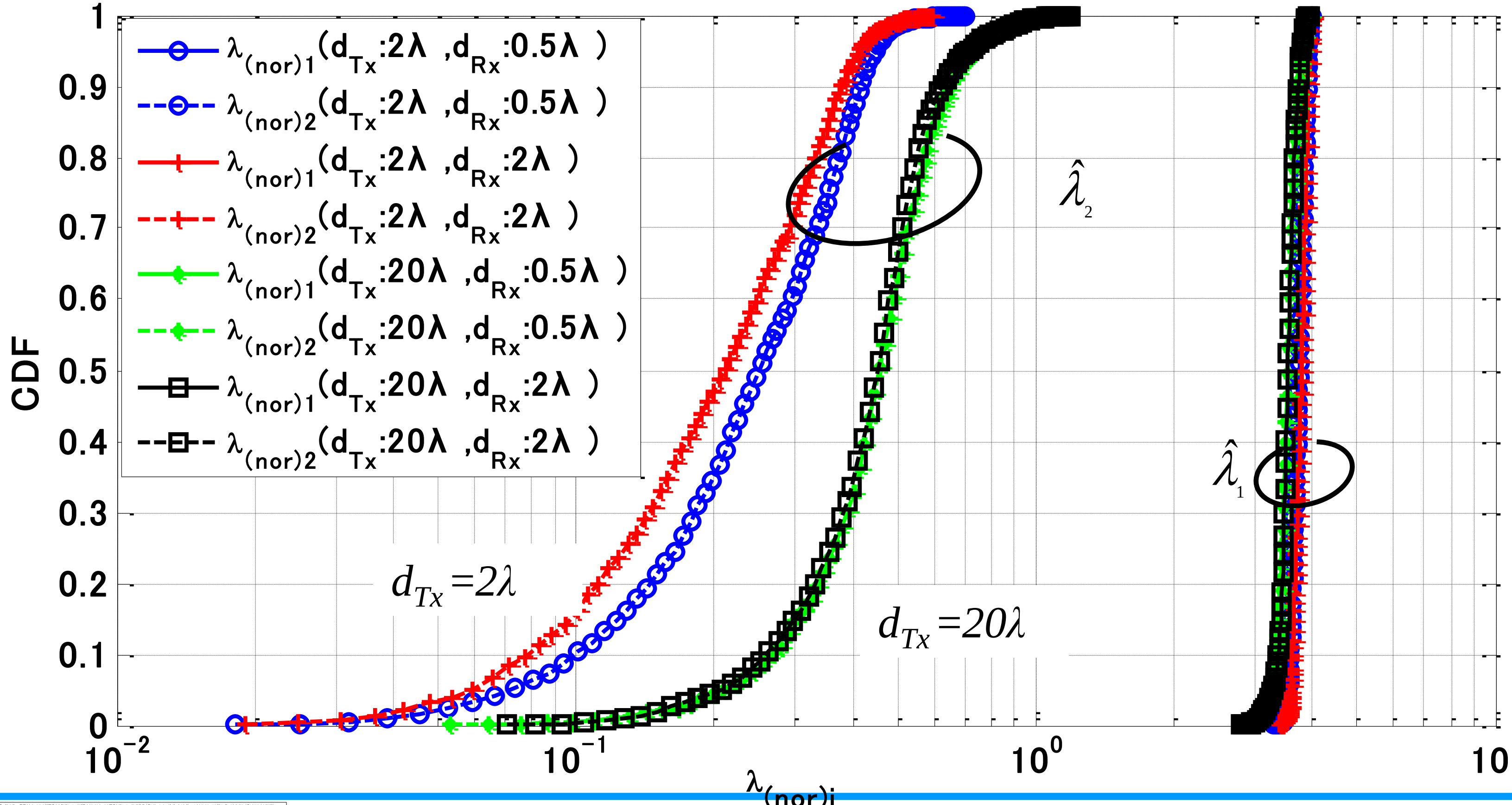
CDF of eigenvalues

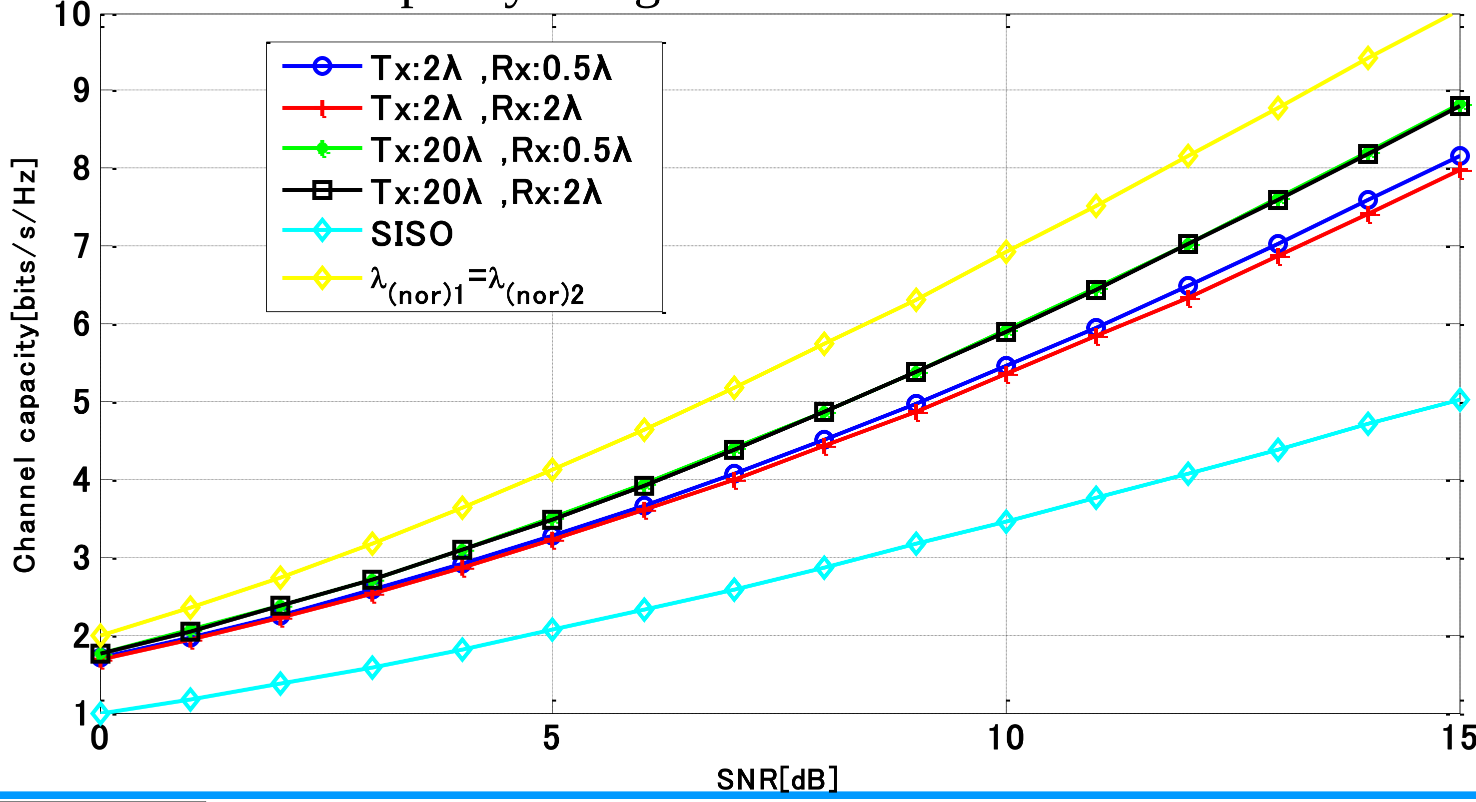
- Average of eigenvalue :
  λ_1=3.74, λ_2=0.26 @ $d_{Tx}=2\lambda$, $d_{Rx}=0.5\lambda$
  λ_1=3.78, λ_2=0.22 @ $d_{Tx}=2\lambda$, $d_{Rx}=2\lambda$
  λ_1=3.53, λ_2=0.47 @ $d_{Tx}=20\lambda$, $d_{Rx}=0.5\lambda$
  λ_1=3.54, λ_2=0.46 @ $d_{Tx}=20\lambda$, $d_{Rx}=2\lambda$

•When Tx antennas distance is long as $d_{Tx}=20\lambda$, λ_2 is large value
•Rx antenna distance have little effect on CDF of eigenvalues, because difference in d_{Tx} is larger than difference in d_{Rx}

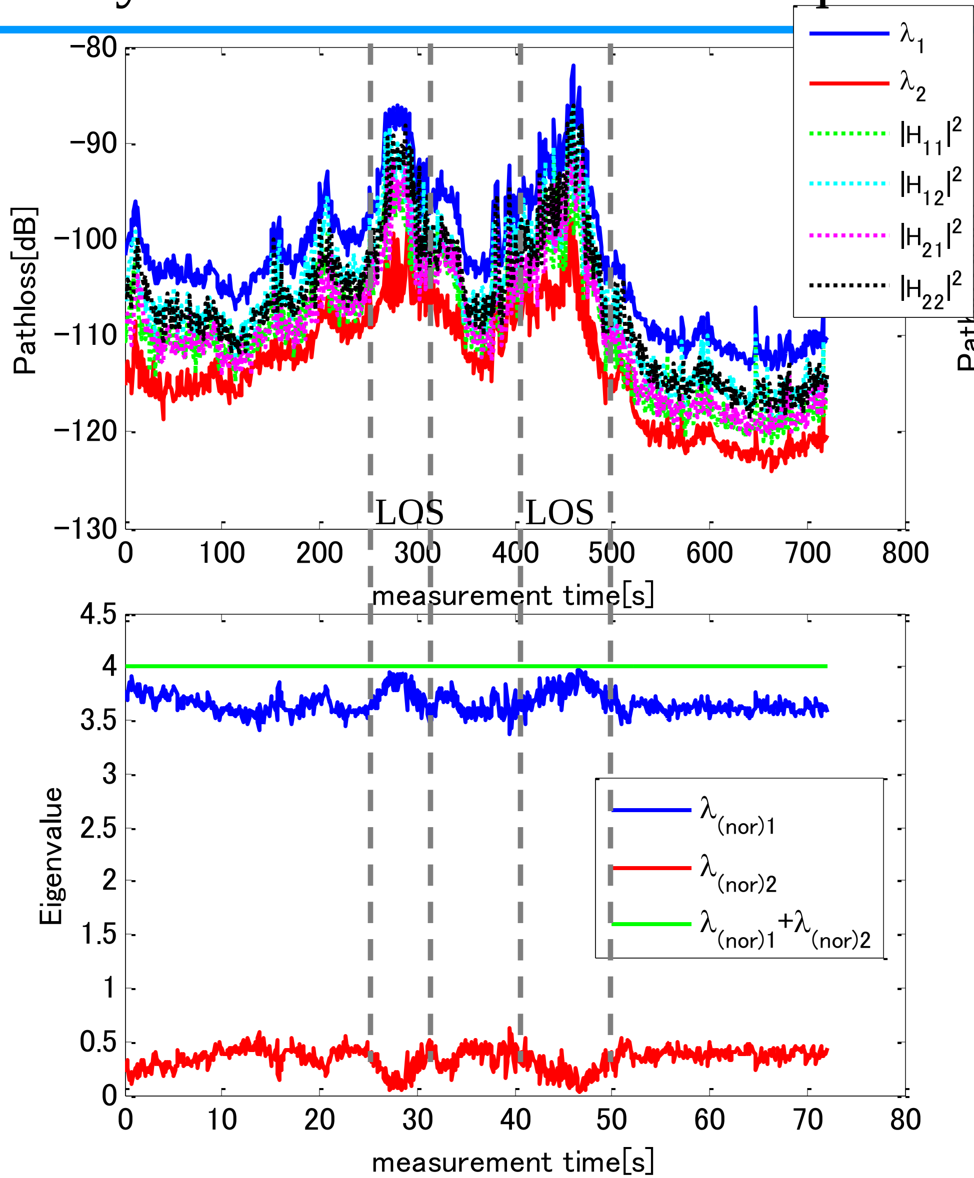


MIMO channel capacity

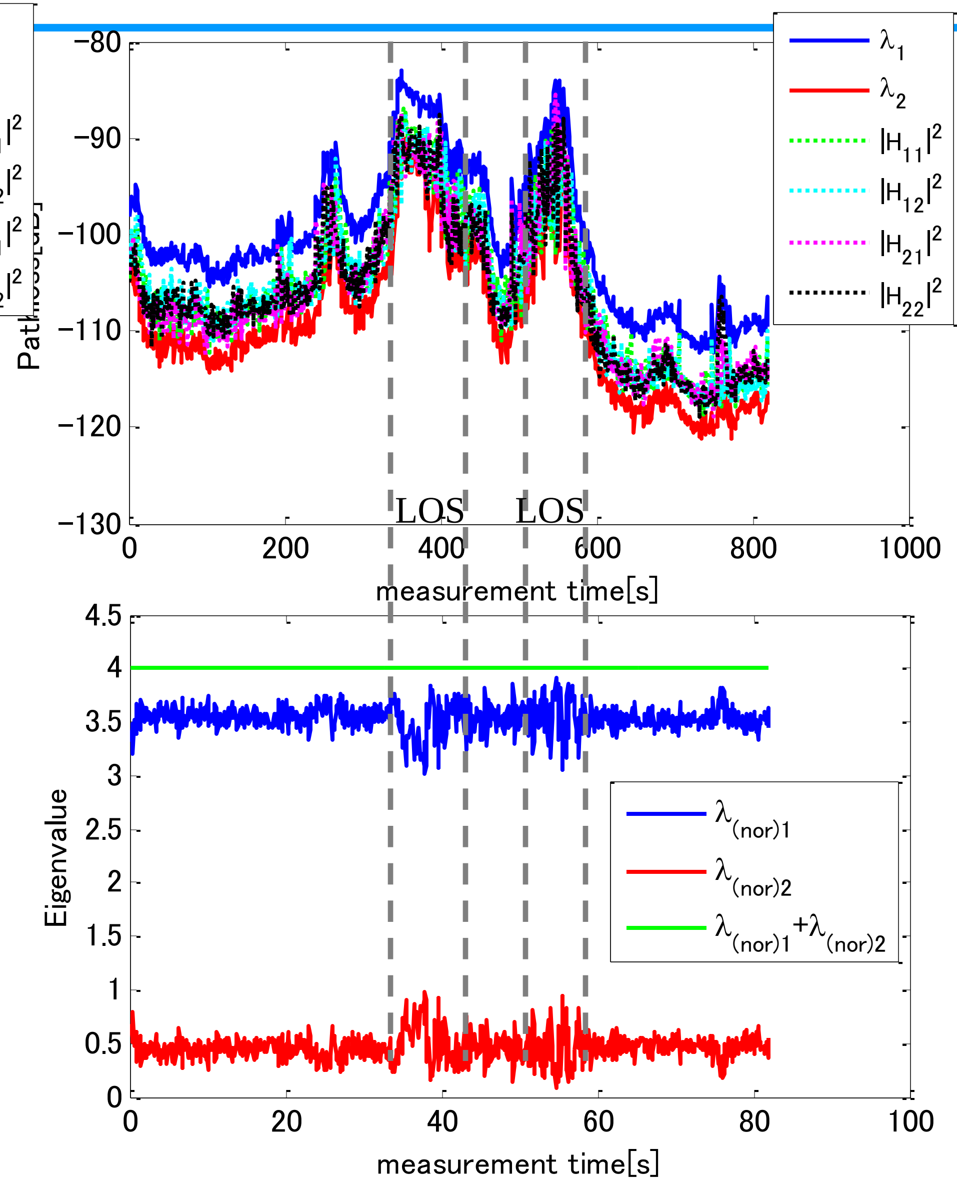
- When SNR = 15 dB,
  - 5.0 bits/s/Hz @ siso, 8.1 bits/s/Hz @ $d_{Tx}=2\lambda$, 8.8 bits/s/Hz @ $d_{Tx}=20\lambda$
  - Compare with SISO, 1.6 times @ $d_{Tx}=2\lambda$, 1.7 times @ $d_{Tx}=20\lambda$
- The larger the antenna distance or the lower the correlation among paths, then the channel capacity is high.



Dynamic characteristics of equivalent MIMO channels in course D

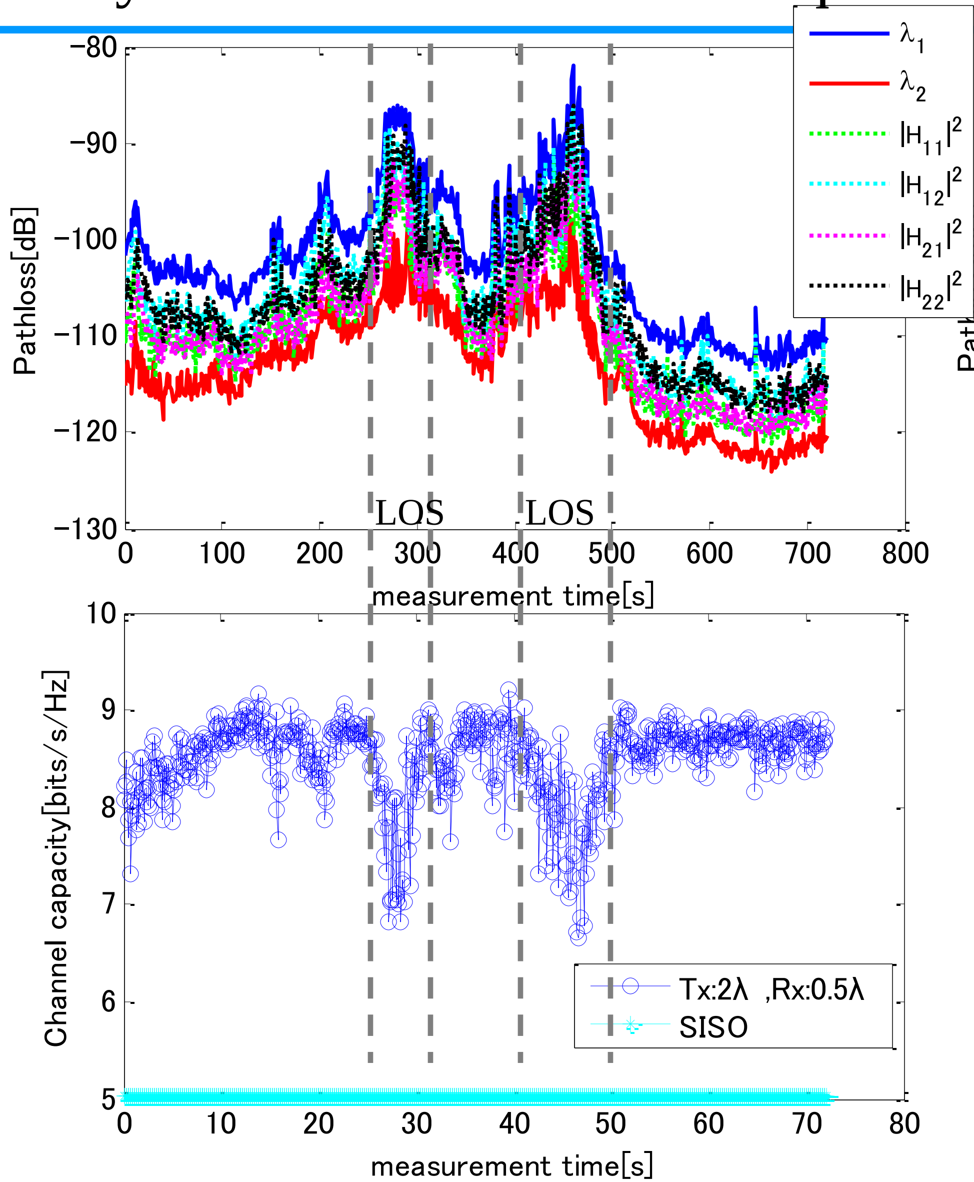


<d_{Tx}=2λ, d_{Rx}=0.5λ >

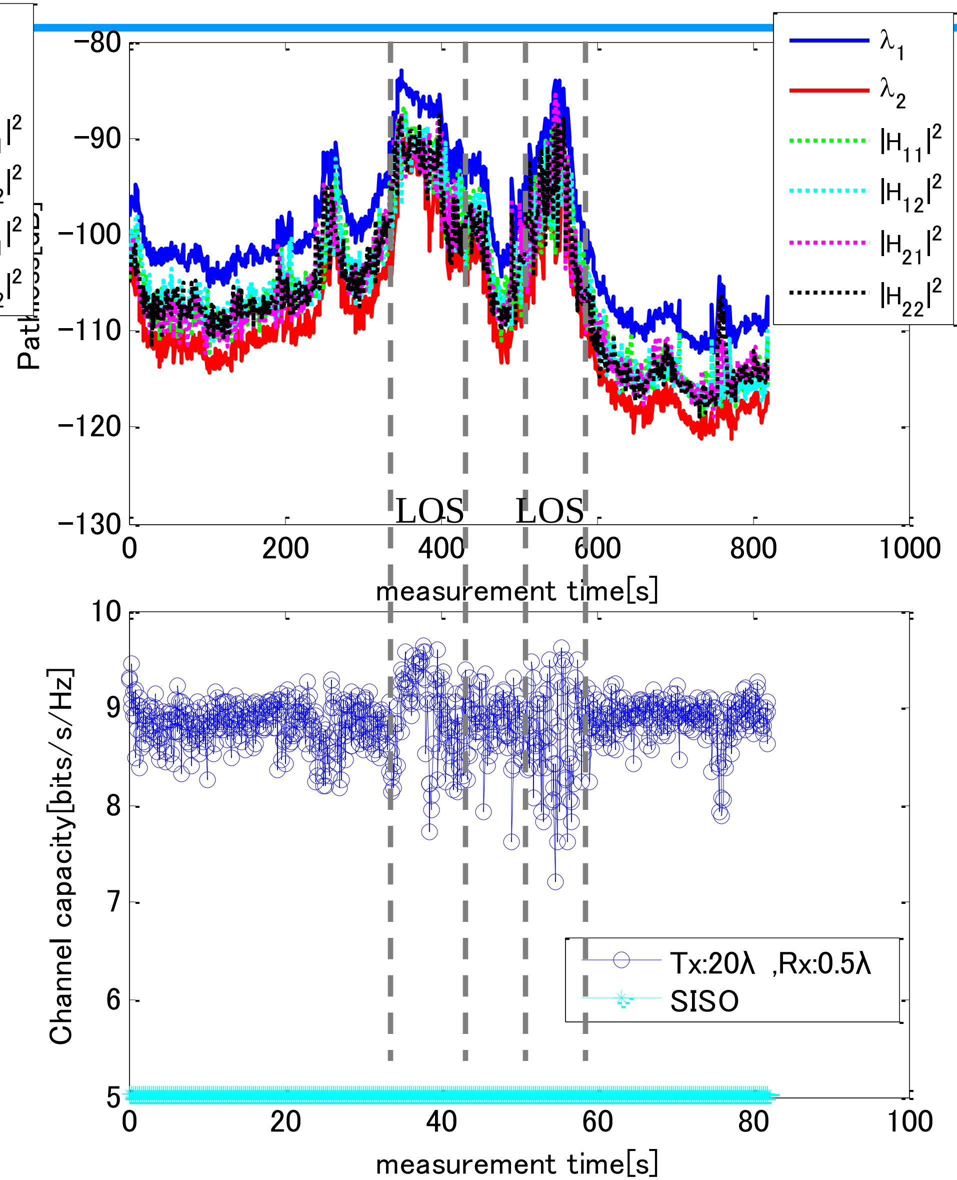


<d_{Tx}=20λ, d_{Rx}=0.5λ >

Dynamic characteristics of equivalent MIMO channels in course D



$< d_{Tx}=2\lambda,\ d_{Rx}=0.5\lambda >$



$< d_{Tx}=20\lambda,\ d_{Rx}=0.5\lambda >$

Conclusion

- conclusion
  - MIMO channel capacity is compared LOS with NLOS environment.
    - d_{Tx}=20λ average 8.7 bits/s/Hz @ LOS
      average 8.8 bits/s/Hz @ NLOS (SNR = 15 dB)
    - d_{Tx}=2λ average 7.9 bits/s/Hz
      minimum 6.7 bits/s/Hz @ LOS
      average 8.6 bits/s/Hz @ NLOS (SNR = 15 dB)
  - The results indicate if distance of Tx antennas is short, MIMO transmission efficiency is lower down.
  - The capacity in MIMO channel has 1.7 times (d_{Tx}=20λ) and 1.6 times (dTx =2λ) gain at the SNR of 15 dB comparing with theoretical values of SISO channel capacity.

Thanks for your attentions