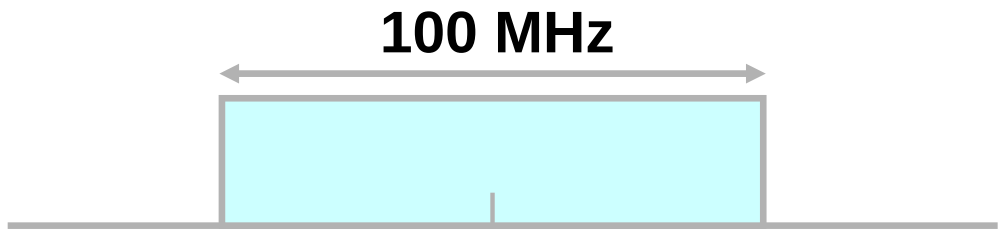
Experiments on MIMO Multiplexing with Peak Frequency Efficiency of 50 Bps/Hz Using MLD Based Signal Detection for OFDM High-Speed Packet Access

Hidekazu Taoka
Radio Access Network Development Department
NTT DOCOMO, INC.
16th November, 2009

DOCOMO’s Research Activities for 4G

- Oct. 2002: 100 Mbps in laboratory experiment
- May 2003: 100 Mbps in field experiment
- Aug. 2004: 1 Gbps in laboratory experiment
- May 2005: 1 Gbps in field experiment
- Dec. 2005: 2.5 Gbps in laboratory and field experiments
- <u>Dec. 2006：5 Gbps in laboratory and field experiments</u>



Mobility	High	↔	Low
Data rate	100 Mbps (1 bps/Hz)	1 Gbps (10 bps/Hz)	2.5 ~ 5 Gbps (25 ~ 50 bps/Hz)

Objective

November 16, 2009/ NTT DOCOMO, INC.

Objective of this presentation

- **Demonstrate ultimate spectrum efficiency of approximately 50 bit/sec/Hz (i.e., 5 Gbps using 100 MHz channel bandwidth) based on indoor and field experiments**

Overview of 5Gbps (50 bps/Hz) Experimental Configurations

Features of Experimental Configuration

November 16, 2009/ NTT DOCOMO, INC.

(1) OFDM radio access with 100-MHz transmission bandwidth

(2) Efficient modulation and channel coding scheme

- **64QAM modulation**
- **Turbo code with coding rate of *R* = 8/9**
- **Multiple codeword**

(3) 12-by-12 MIMO multiplexing

(4) MLD-based signal detection

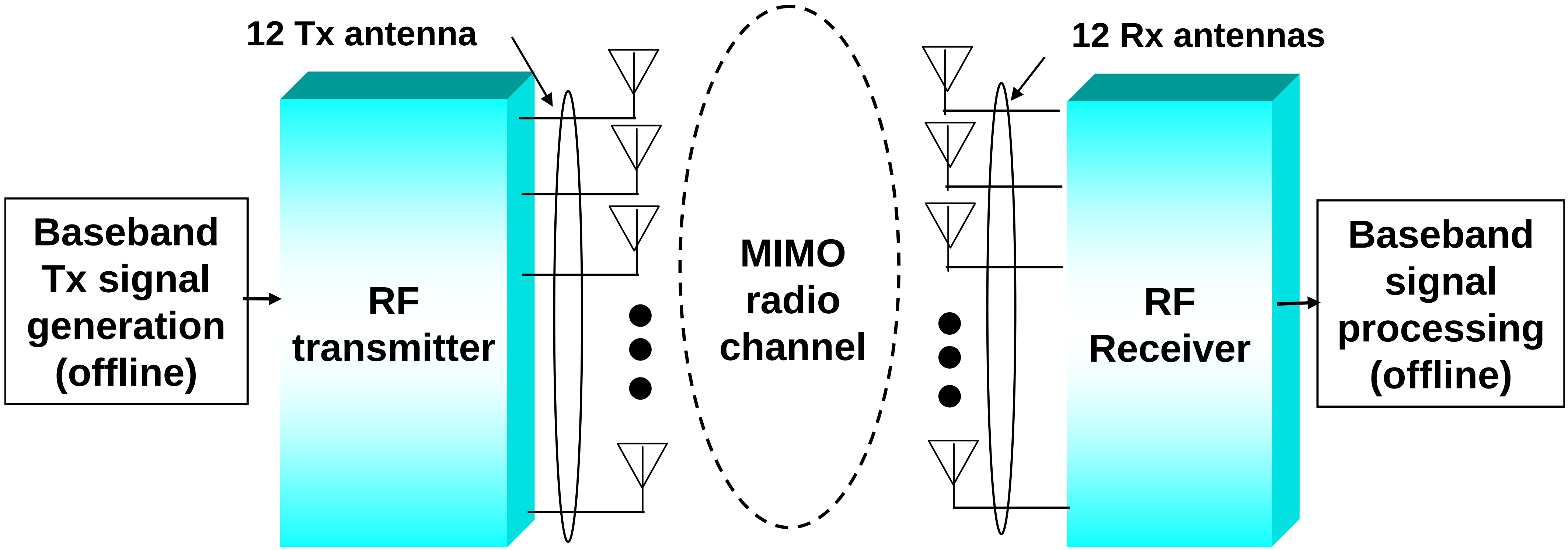
- **QRM-MLD[1] with ASESS[2] (adaptive selection surviving symbol replica candidates based on maximum reliability)**
- **LLR (log-likelihood ratio) generation appropriate to QRM-MLD**

[1] K. J. Kim, *et al.*, IEEE Trans. on Wireless Commun., vol. 4, no. 2, pp. 710 - 721, March, 2005.

[2] K. Higuchi, *et al.*, in Proc. IEEE Globecom'2004, Nov. 2004.

Overview of 5 Gbps Experiments

November 16, 2009/ NTT DOCOMO, INC.

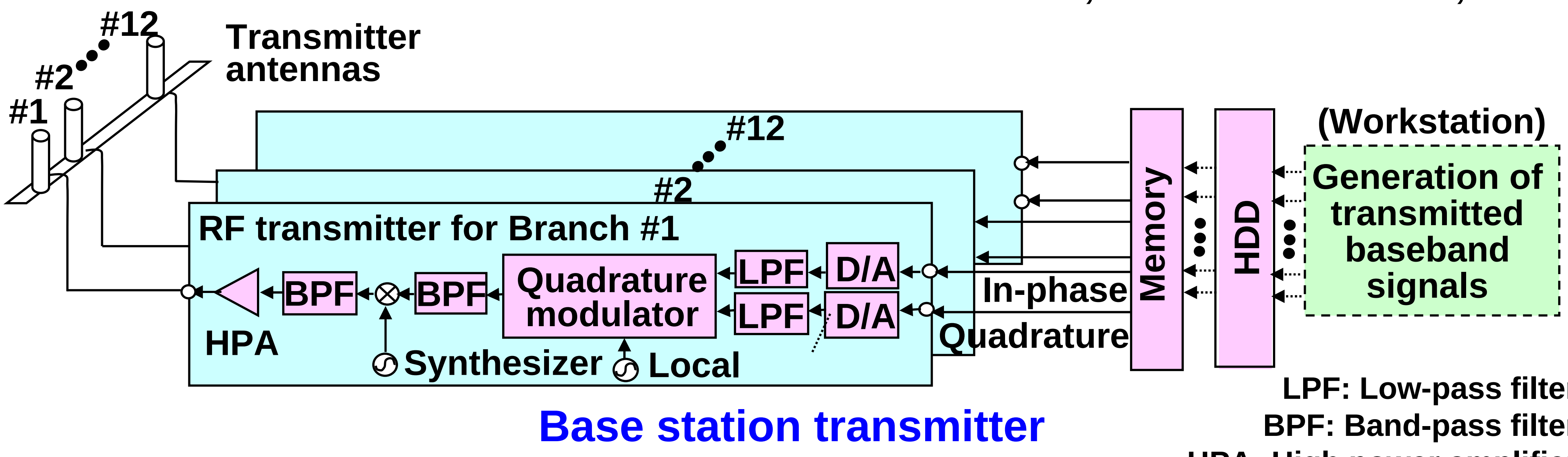


The MIMO transmitter and receiver comprise of RF transmitter / receiver, D/A(A/D) converter, and Data Storage (Memory and HDD)

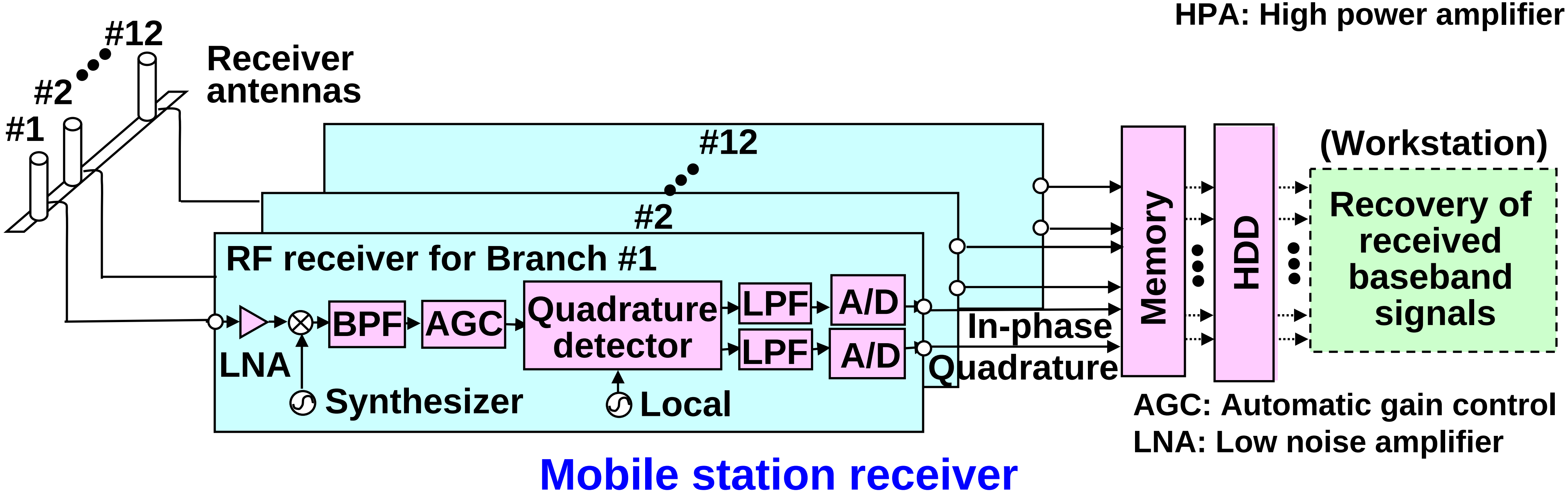
➔Baseband signal processing is done offline (Radio channel performance is basically identical)

Structure of 12-by-12 MIMO Transceiver

November 16, 2009/ NTT DOCOMO, INC.



LPF: Low-pass filter
BPF: Band-pass filter
HPA: High power amplifier



AGC: Automatic gain control
LNA: Low noise amplifier

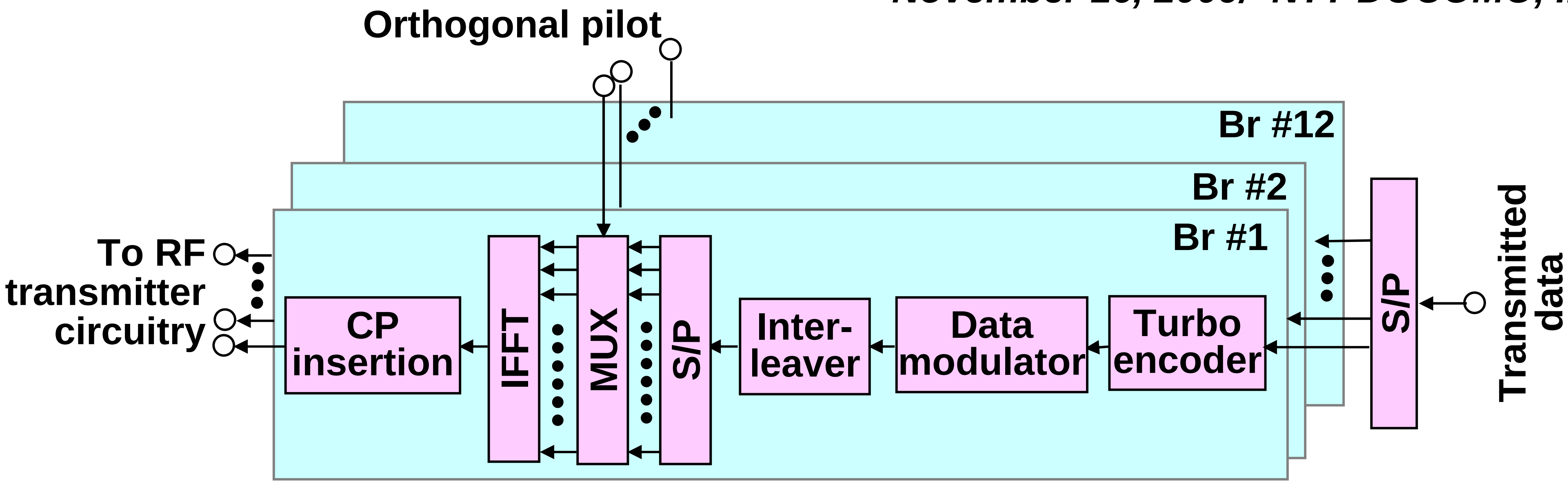
Major Radio Parameters for RF Transceiver Part

November 16, 2009/ NTT DOCOMO, INC.

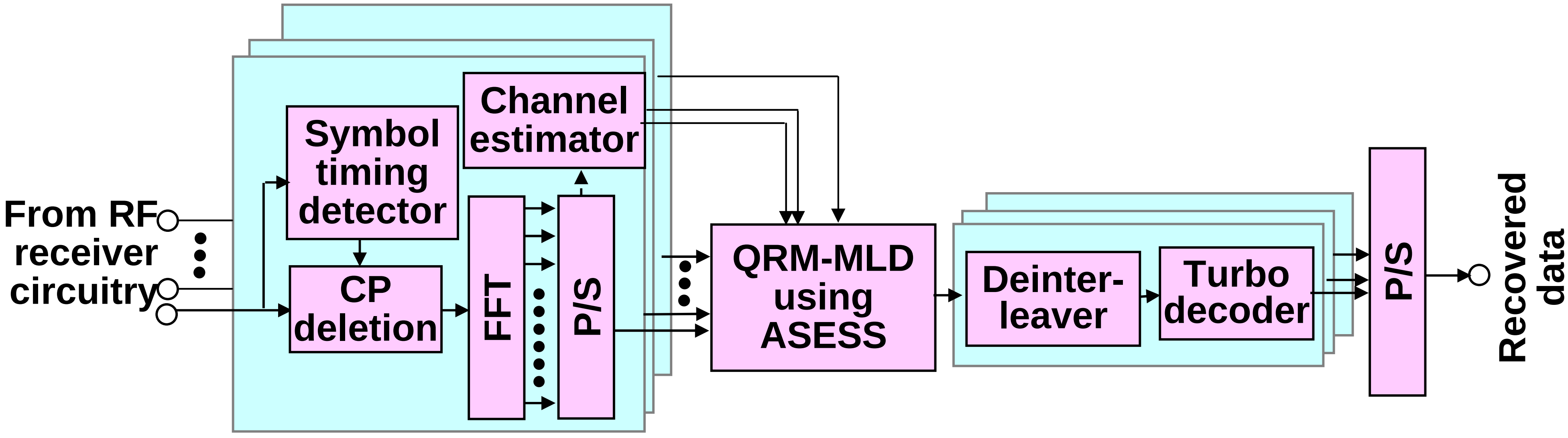
Carrier frequency	4.635 GHz
Channel bandwidth	101. 4 MHz
Number of antennas	12-by-12 MIMO
Total transmission power	1.2 W (Indoor) / 20 W (Field)
Number of quantized bits at D/A (A/D) converters	14 bits (D/A) / 12 bits (A/D)
Sampling clock rate	270 Msample/sec
Memory per branch	9 GB (Transmitter) / 18 GB (Receiver)
Hard disk capacity	480 GB

Block Diagram of Baseband Signal Processing Part

November 16, 2009/ NTT DOCOMO, INC.



BS signal processing part



MS signal processing part

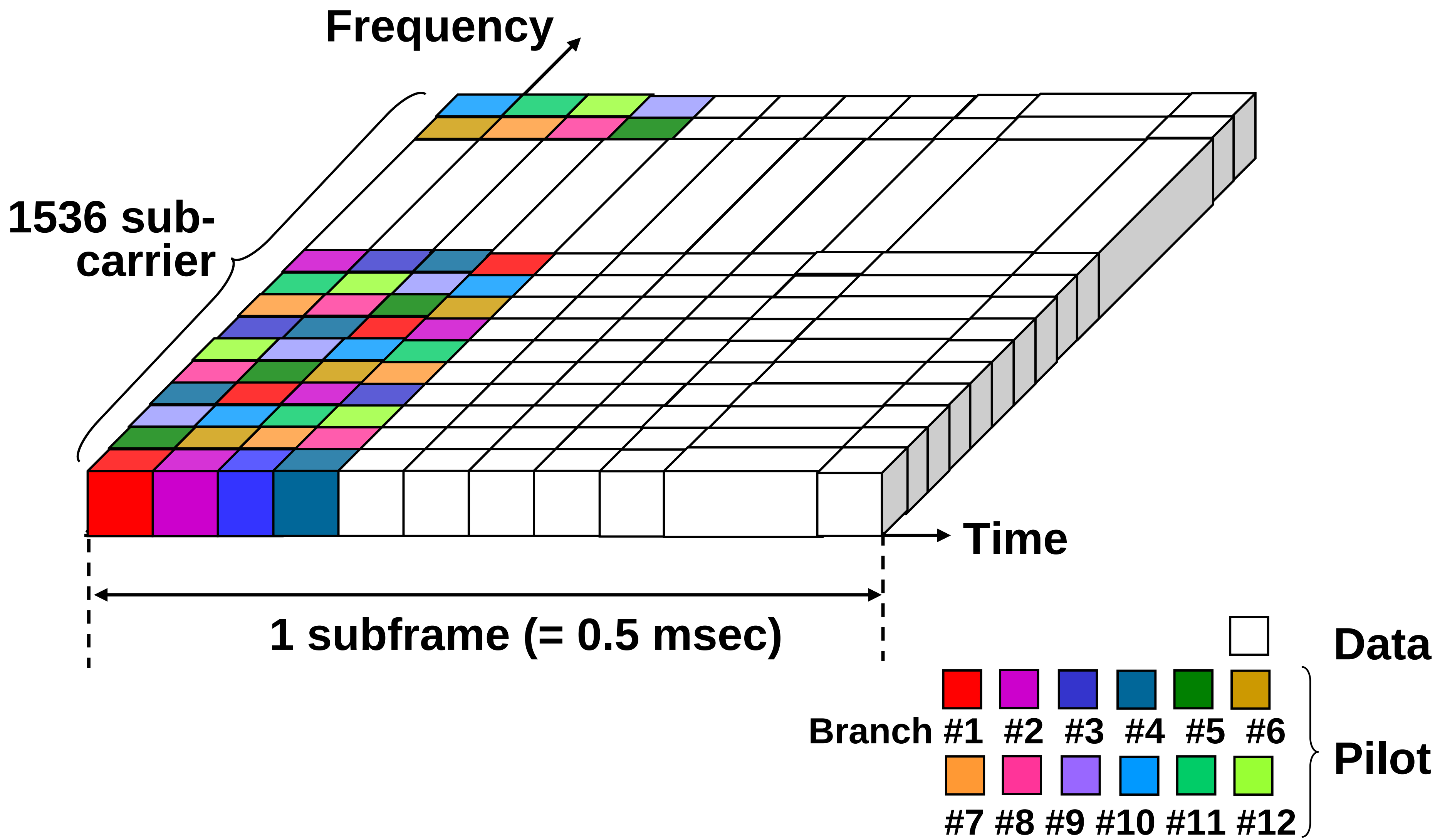
Major Radio Parameters for Baseband Signal Processing Part

November 16, 2009/ NTT DOCOMO, INC.

Radio access	OFDM
Sub-frame length	0.5 msec
Number of sub-carriers	1536 (65.919 kHz sub-carrier separation)
OFDM symbol duration	Effective data 15.170 μsec + CP 2.067 μsec
Channel coding / decoding	Turbo coding (K = 4) / Max-Log-MAP decoding
Symbol timing detection	Pilot signal-based symbol timing detection
Channel estimation	Two-dimensional MMSE channel estimation
Signal separation	QRM-MLD with ASESS

Subframe Structure

November 16, 2009/ NTT DOCOMO, INC.

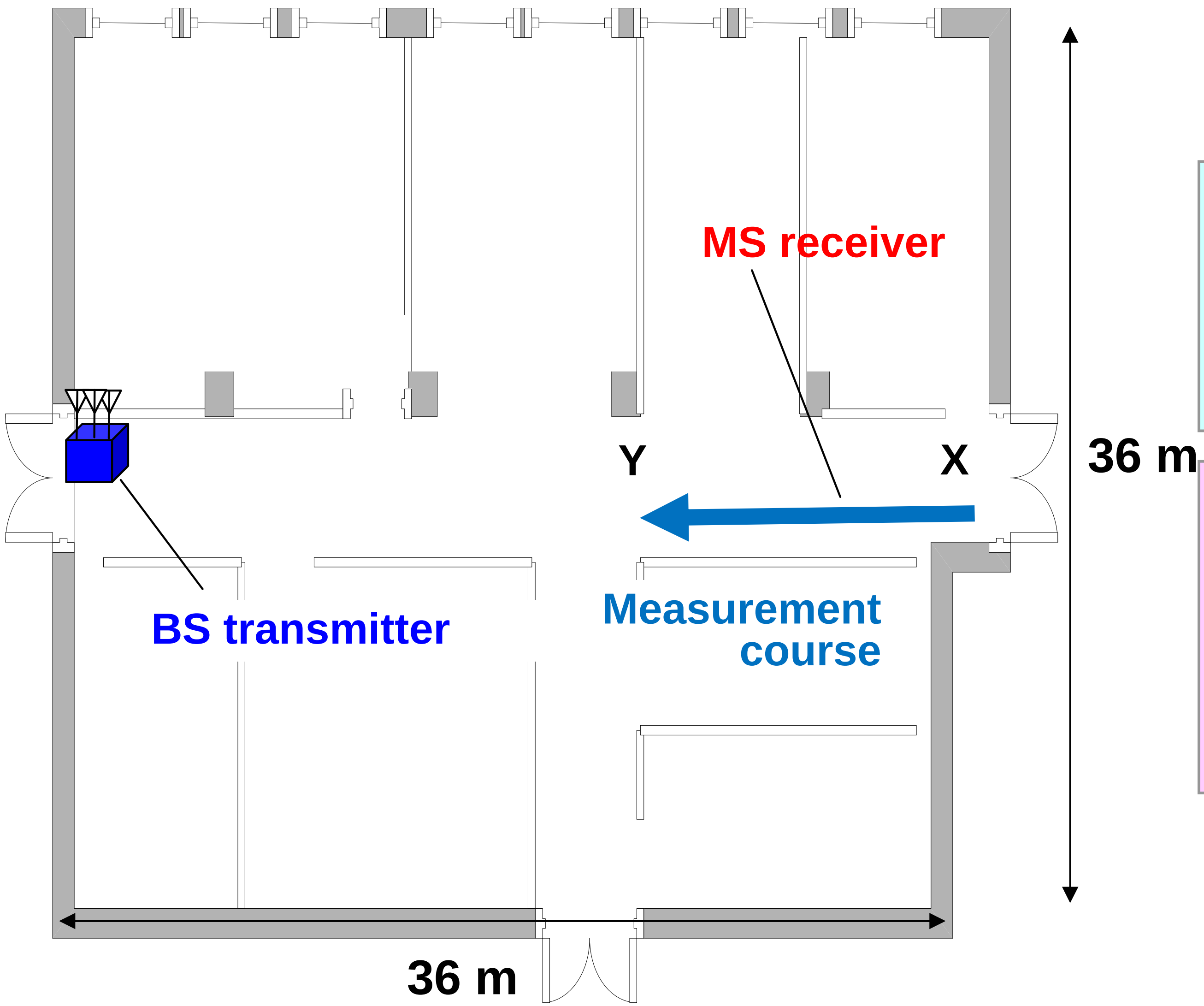


Indoor Experiments
（Laboratory Room）

Measurement Course in Indoor Experiments

November 16, 2009/ NTT DOCOMO, INC.

Laboratory room of DOCOMO R&D center

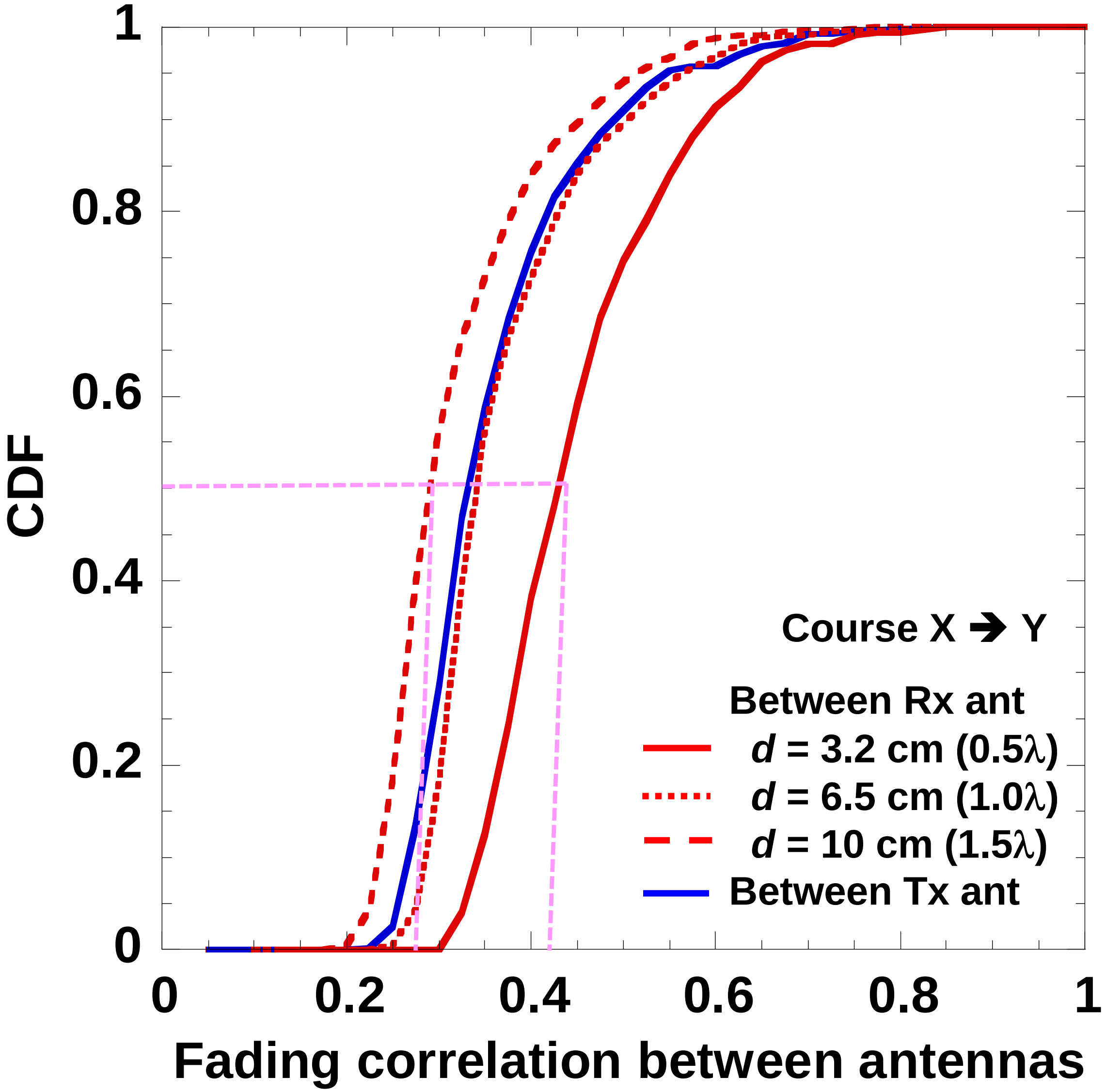


BS transmitter
- ✧ Total Tx power: 1.2W
- ✧ Antenna height: 2.5 m
- ✧ Antenna space: 10 cm

MS receiver
- ✧ Average speed: 4 km/h
- ✧ Antenna height: 1.5 m
- ✧ Antenna space: 3.2-10 cm (adjustable)

Cumulative Distribution of Fading Correlation (Impact of Receiver Antenna Spacing)

November 16, 2009/ NTT DOCOMO, INC.



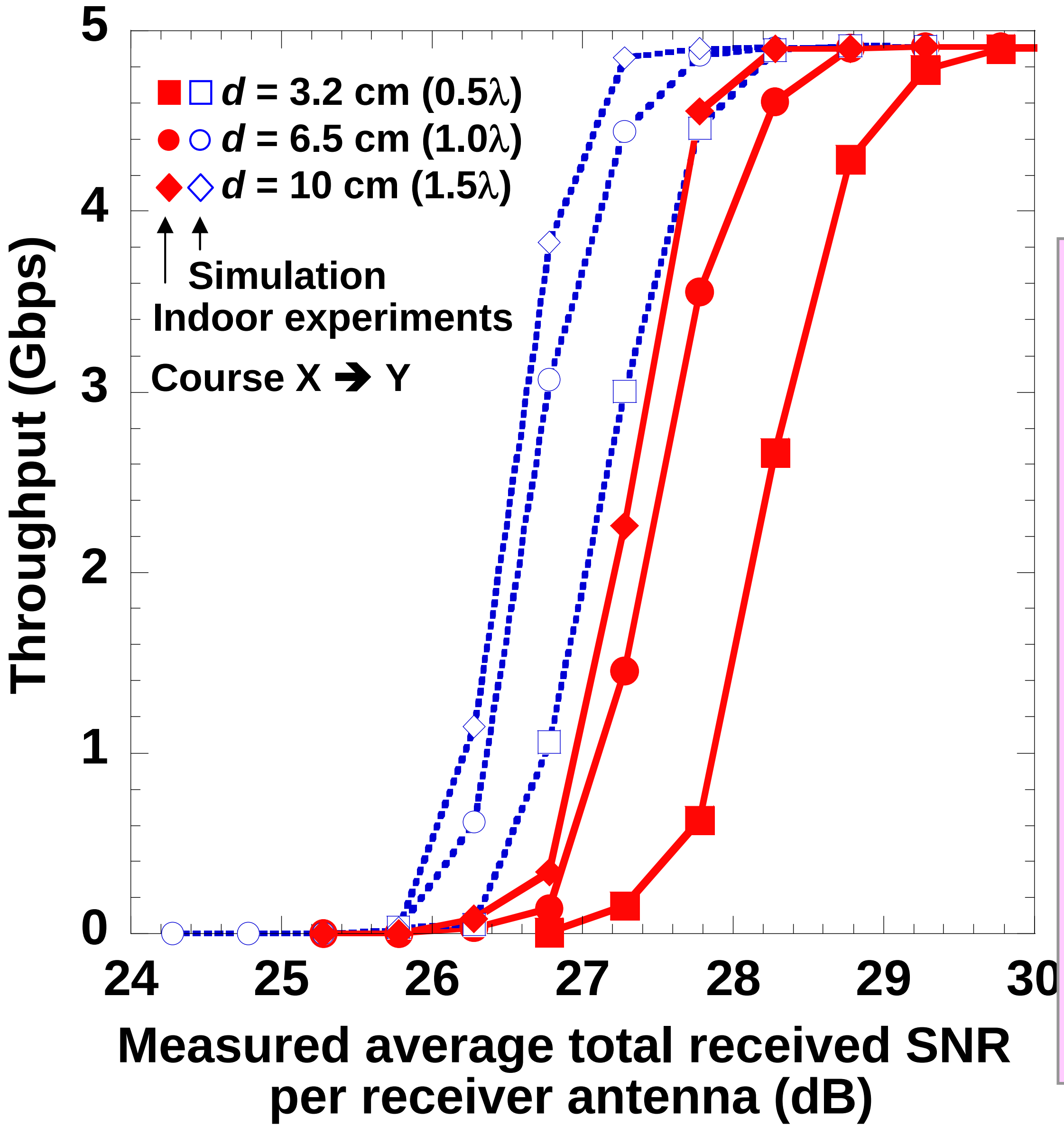
- **12-by-12 MIMO Multiplexing**
- **Total Tx power: 1.2W**
- **Average speed: 4 km/h**

■ **Fading correlation between receiver antennas is increased from 0.26 to 0.42 at 50% CDF when *d* is reduced from 10 cm to 3.2 cm**

■ **Fading correlation between transmitter antennas is comparable to that between receiver antennas**

Throughput Performance (Impact of Receiver Antenna Spacing)

November 16, 2009/ NTT DOCOMO, INC.



- **12-by-12 MIMO Multiplexing**
- **64QAM, *R* = 8/9 (Max: 4.915 Gbps)**
- **Average speed: 4 km/h**

■ Achieved 4.9 Gbps at received SNR of 28 dB when *d* is 10 cm.

■ Even when *d* is 3.2 cm, the loss in the required received SNR is only 1 dB.

■ Loss in the required average received SINR compared to simulation is 1 dB

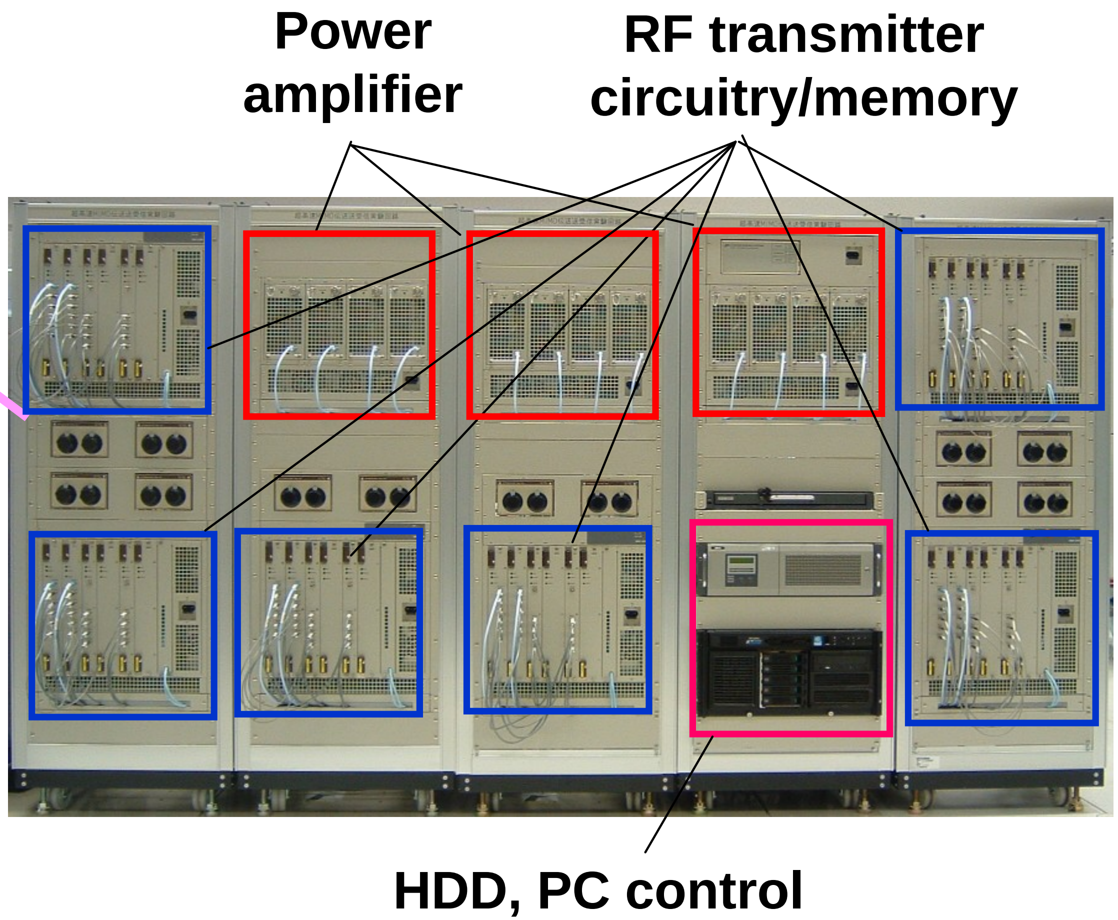
- **Quantization error in A/D**
- **Difference in the propagation channel**

Field Experiments
（YRP District）

Views of BS Transmitter for 5 Gbps Experiments

November 16, 2009/ NTT DOCOMO, INC.

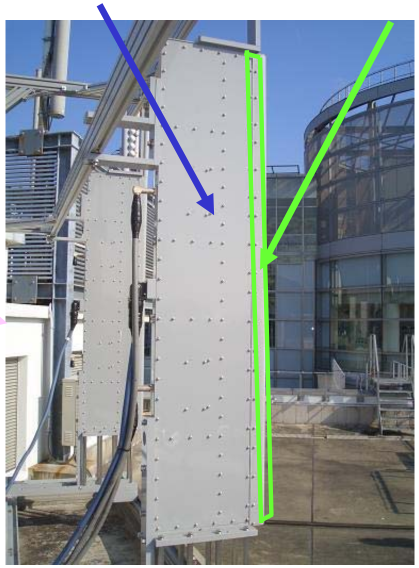
Installation space of
BS transmitter
(Rooftop of R&D center)



BS transmitter

Views of BS Antennas for 5 Gbps Experiments

November 16, 2009/ NTT DOCOMO, INC.

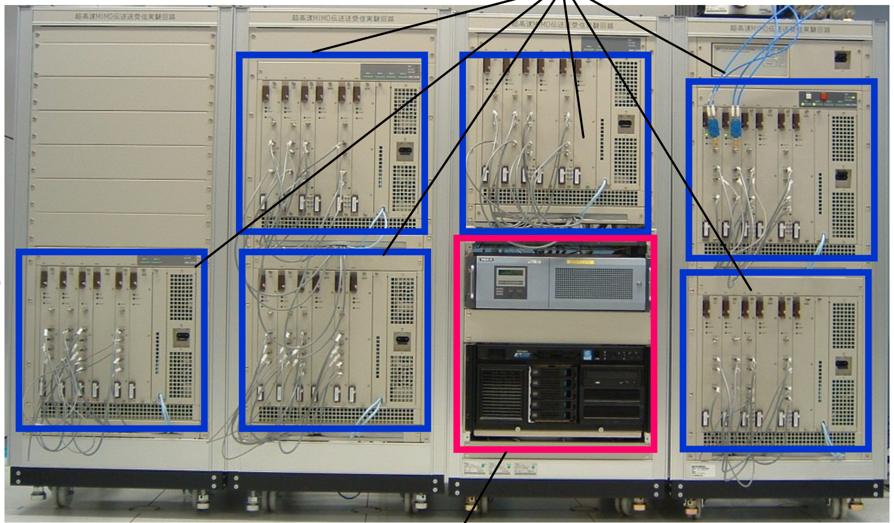


BS transmitter antennas for 5 Gbps experiments
- 12 branch cross-polarized antennas
- Antenna gain: 19 dBi/antenna
- 3 dB beam width: 90 degrees (horizontal), 5 degrees (azimuth)
- Polarization: linear polarization (vertical/horizontal)
- Antenna space: 30-70 cm (adjustable)
- Antenna height: 26 m

Views of MS Receiver / Antennas for 5 Gbps Experiments

November 16, 2009/ NTT DOCOMO, INC.

RF receiver circuitry/memory



HDD, PC control

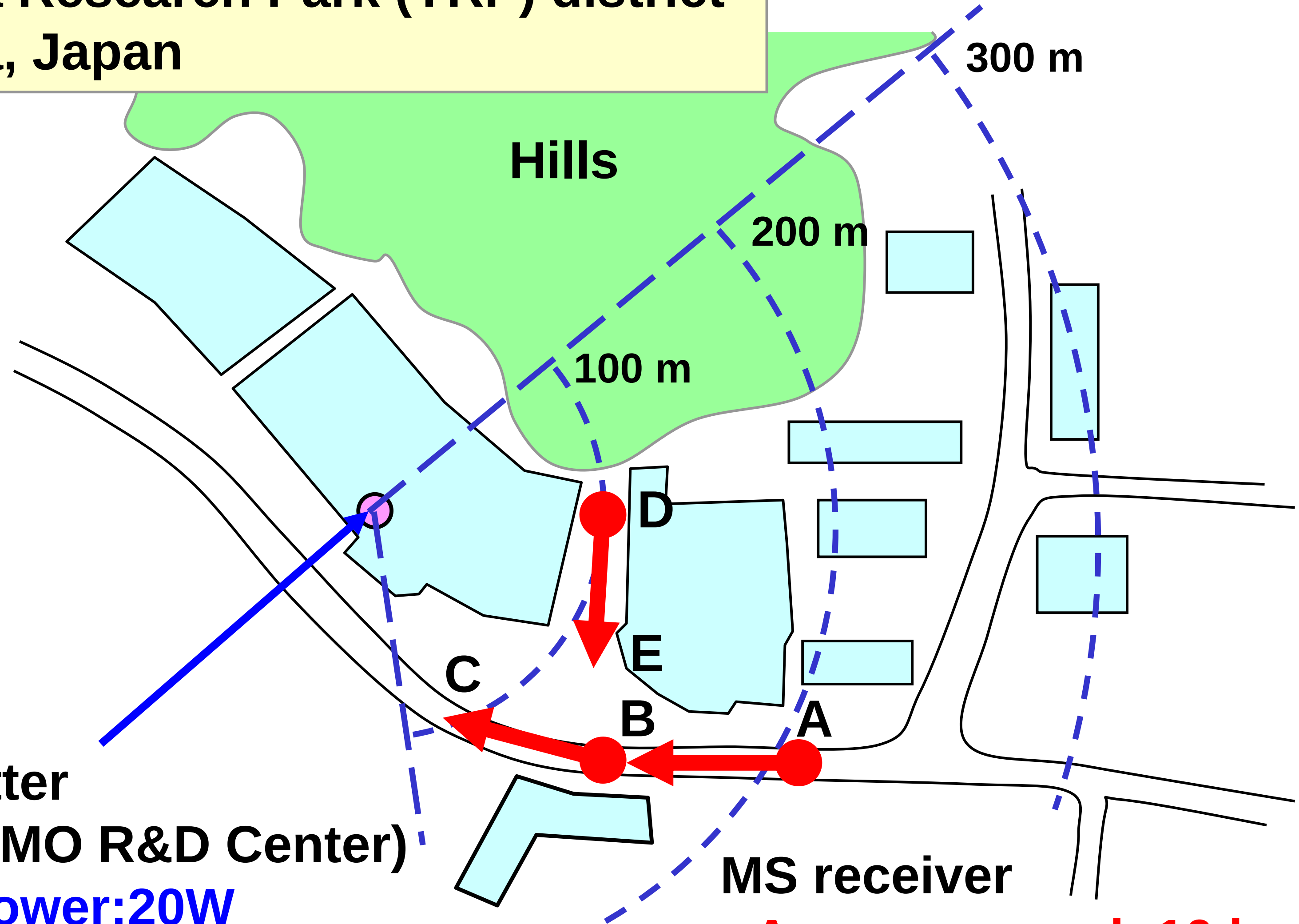
MS receiver

◆MS receiver antenna for 5Gbps experiments

- 12 branch cross-polarized antennas
- Antenna gain: 2 dBi/antenna
- Polarization: linear polarization (vertical/horizontal)
- Antenna space: 10-40 cm (adjustable)
- Antenna height: 3.5 m

Measurement Course in Field Experiments

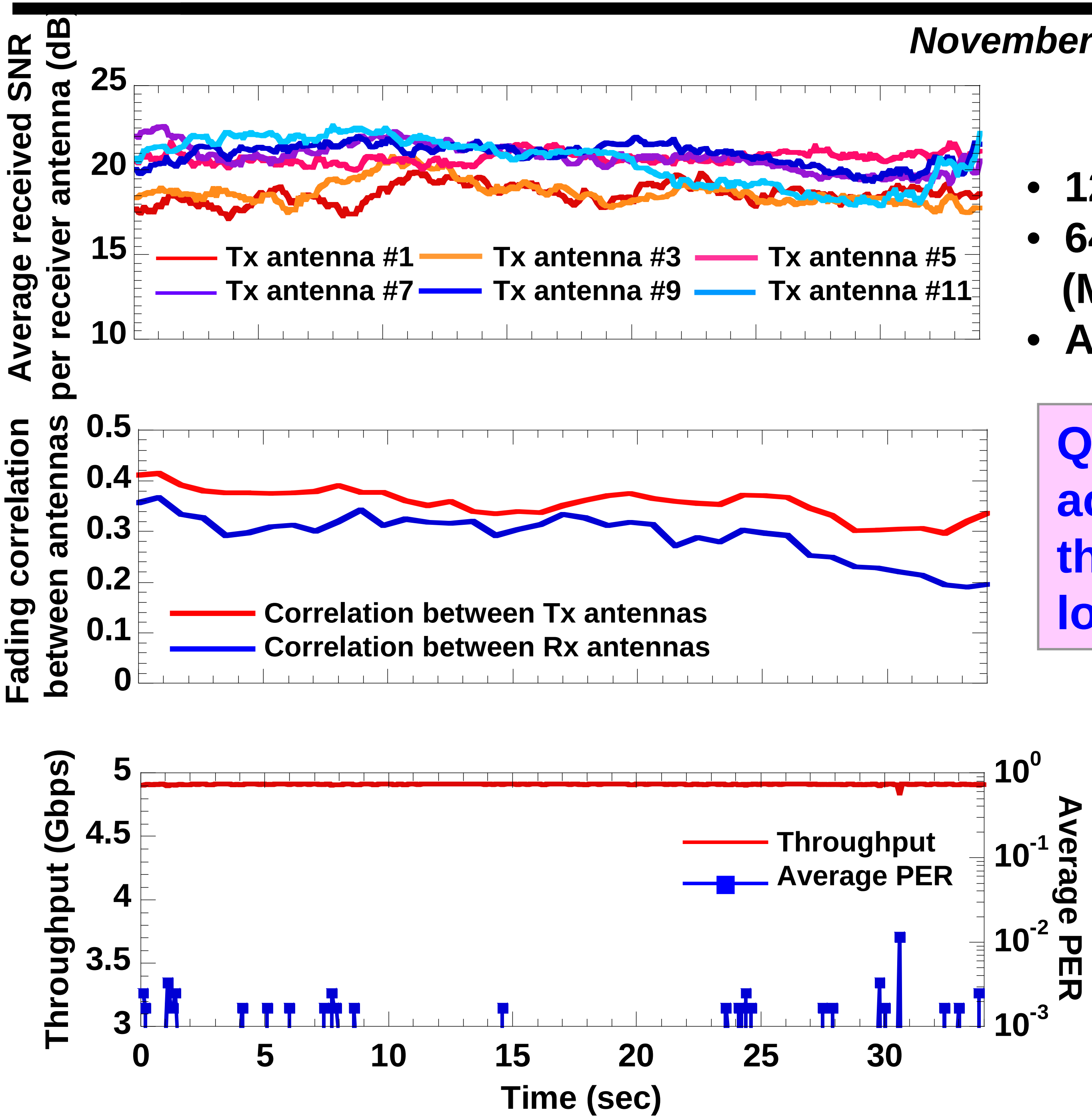
Yokosuka Research Park (YRP) district
Yokosuka, Japan



BS transmitter
(NTT DOCOMO R&D Center)
- Total Tx power:20W
- 3-dB beamwidth: 90 degrees
- Antenna height: 26 m
- Antenna separation: 20-70 cm

MS receiver
- Average speed: 10 km/h
- Antenna height: 3.5 m
- Antenna separation: 10-40 cm

Time Variation of Measured Throughput

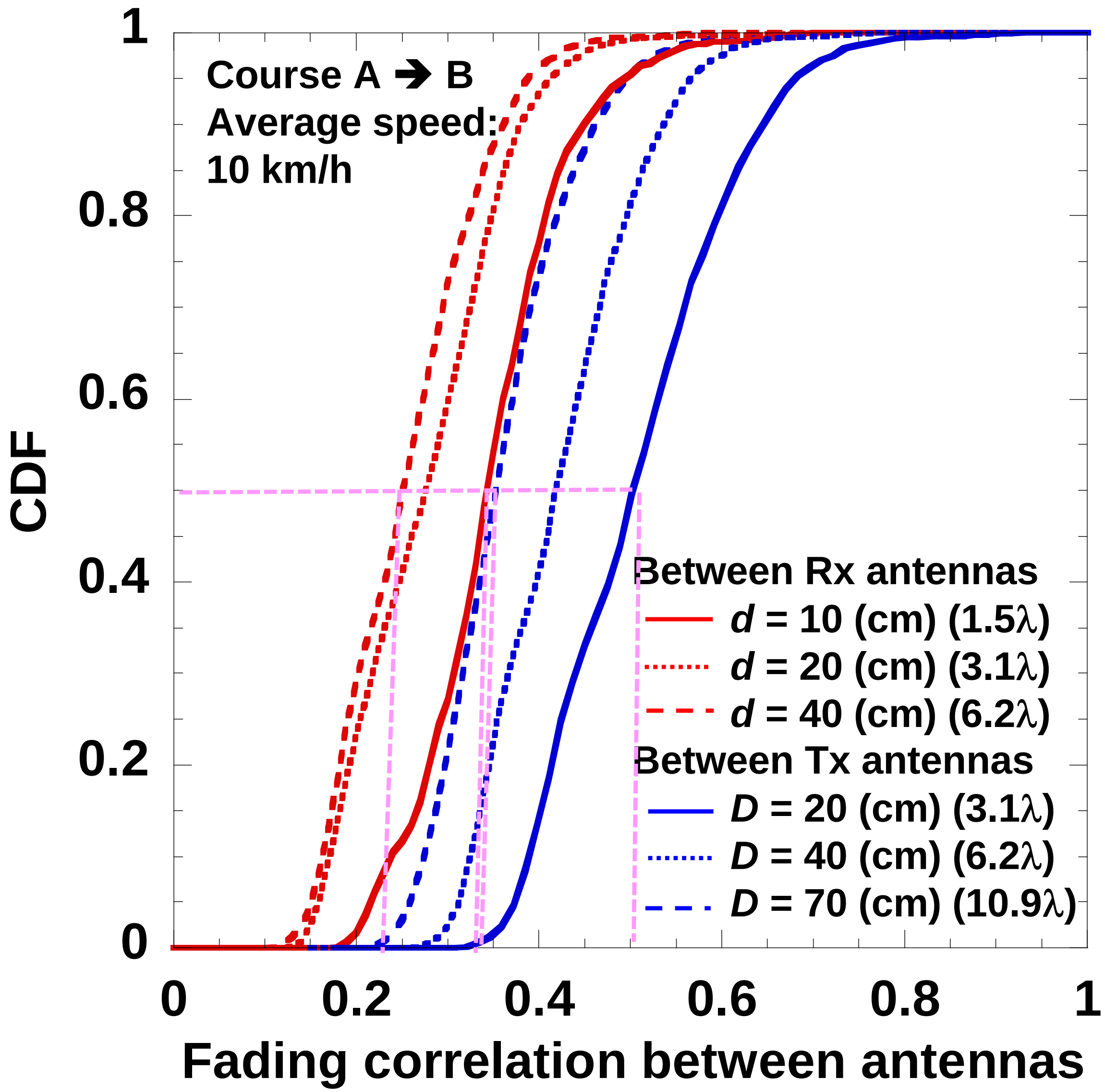


- **12-by-12 MIMO multiplexing**
- **64QAM, *R* = 8/9 (Max: 4.915 Gbps)**
- **Average speed: 10 km/h**

QRM-MLD with ASESS achieves over 4.9 Gbps throughput at 99% of the locations in the course

Cumulative Distribution of Fading Correlation (Impact of Transmitter / Receiver Antenna Spacing)

November 16, 2009/ NTT DOCOMO, INC.



- 12-by-12 MIMO multiplexing
- Total Tx power: 20W
- Average speed: 10 km/h

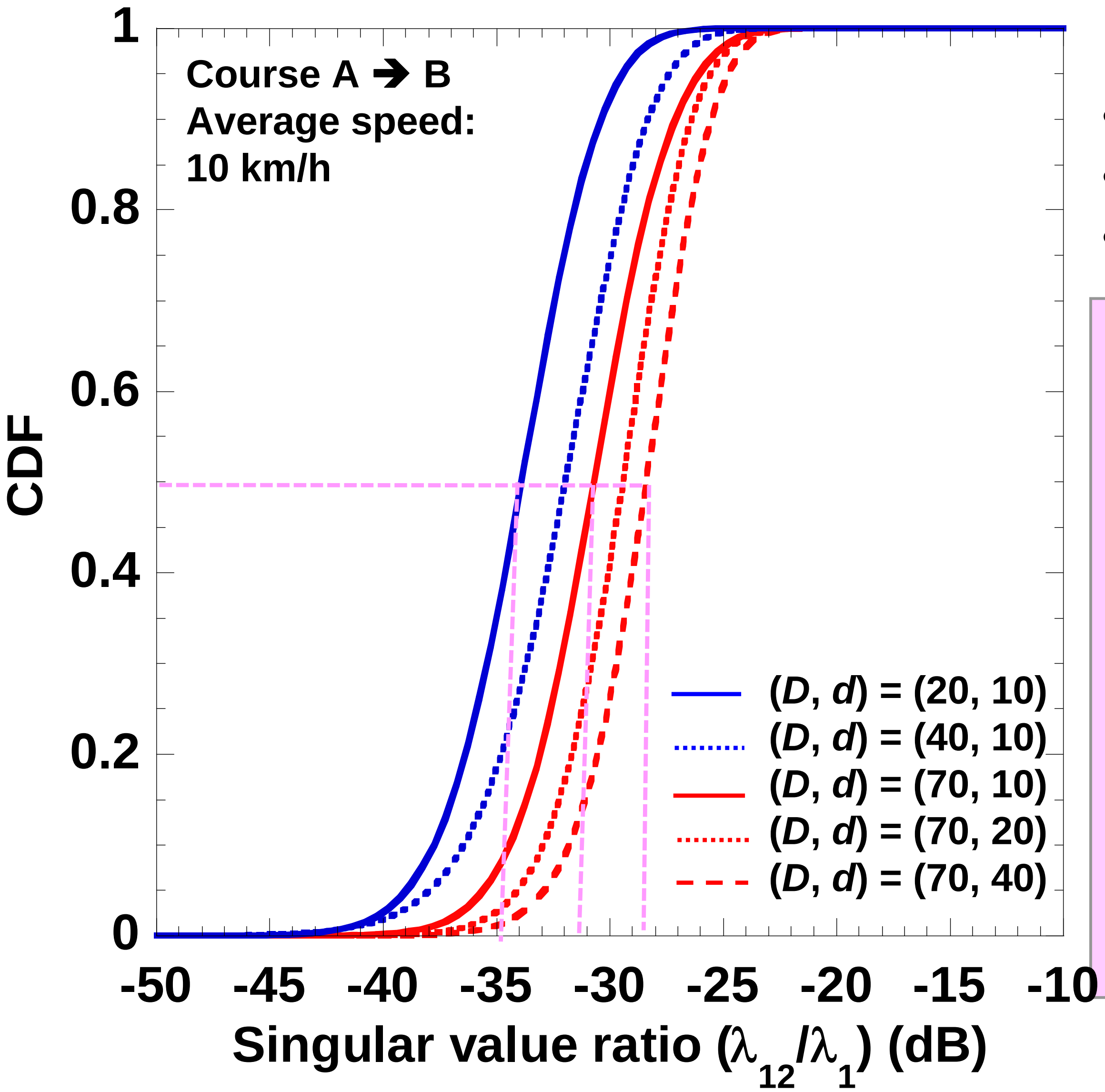
■ Fading correlation between receiver antennas is increased from 0.25 to 0.35 at 50% CDF when *d* is reduced from 40 cm to 10 cm

■ Fading correlation between transmit antennas is increased from 0.36 to 0.51 when *D* is reduced from 70 cm to 20 cm

■ Fading correlation between transmitter antennas is greater than that between receiver antennas

Cumulative Distribution of Singular Value Ratio (Impact of Transmitter / Receiver Antenna Spacing)

November 16, 2009/ NTT DOCOMO, INC.



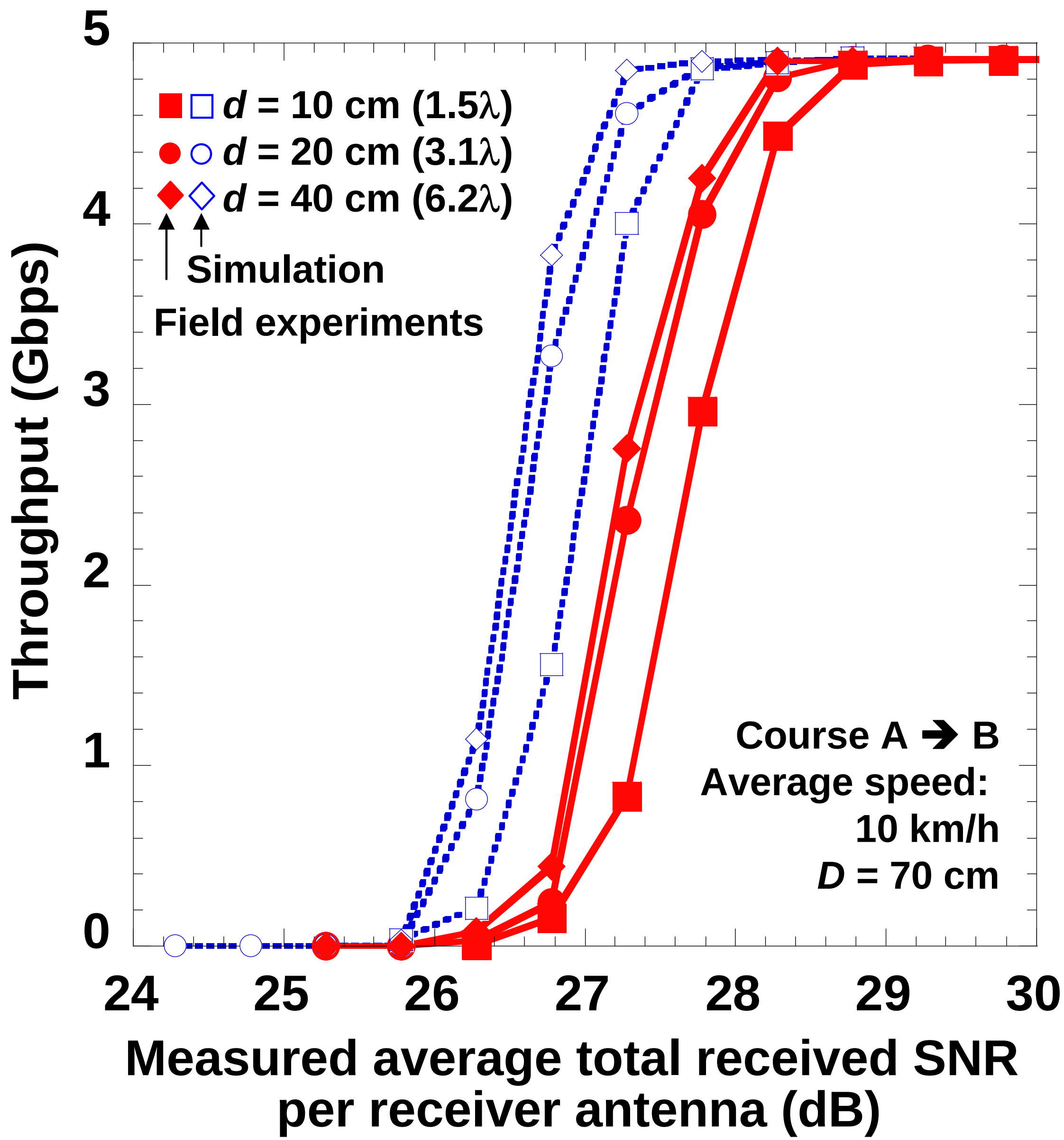
- 12-by-12 MIMO multiplexing
- Total Tx power: 20W
- Average speed: 10 km/h

■ Singular value ratio is decreased by approximately 3 dB according to the reduction of receiver antenna space from 40 cm to 10 cm.

■ Singular value ratio is decreased by approximately 4 dB according to the reduction of transmitter antenna space from 70 cm to 20 cm.

Throughput Performance (Impact of Receiver Antenna Spacing)

November 16, 2009/ NTT DOCOMO, INC.



- **12-by-12 MIMO Multiplexing**
- **64QAM, *R* = 8/9 (Max: 4.915 Gbps)**
- **Average speed: 10 km/h**

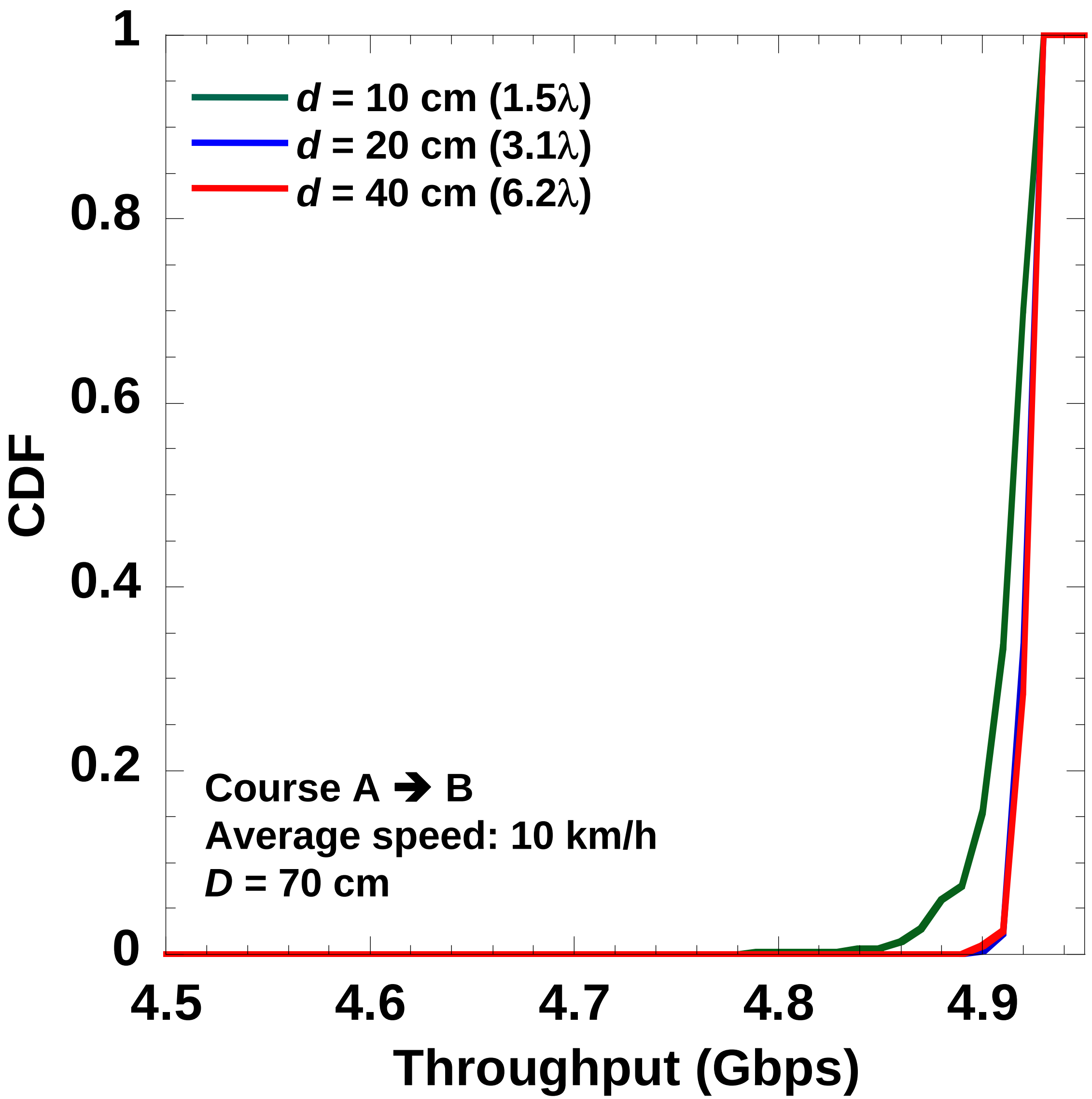
■ Achieved 4.9 Gbps at received SNR of approximately 28 dB when *d* is 40 cm.

■ Even when *d* is 10 cm, the loss in the required received SNR is only 0.5 dB.

■ Loss in the required average received SINR compared to simulation is approximately 1 dB

Cumulative Distribution of Throughput (Impact of Receiver Antenna Spacing)

November 16, 2009/ NTT DOCOMO, INC.

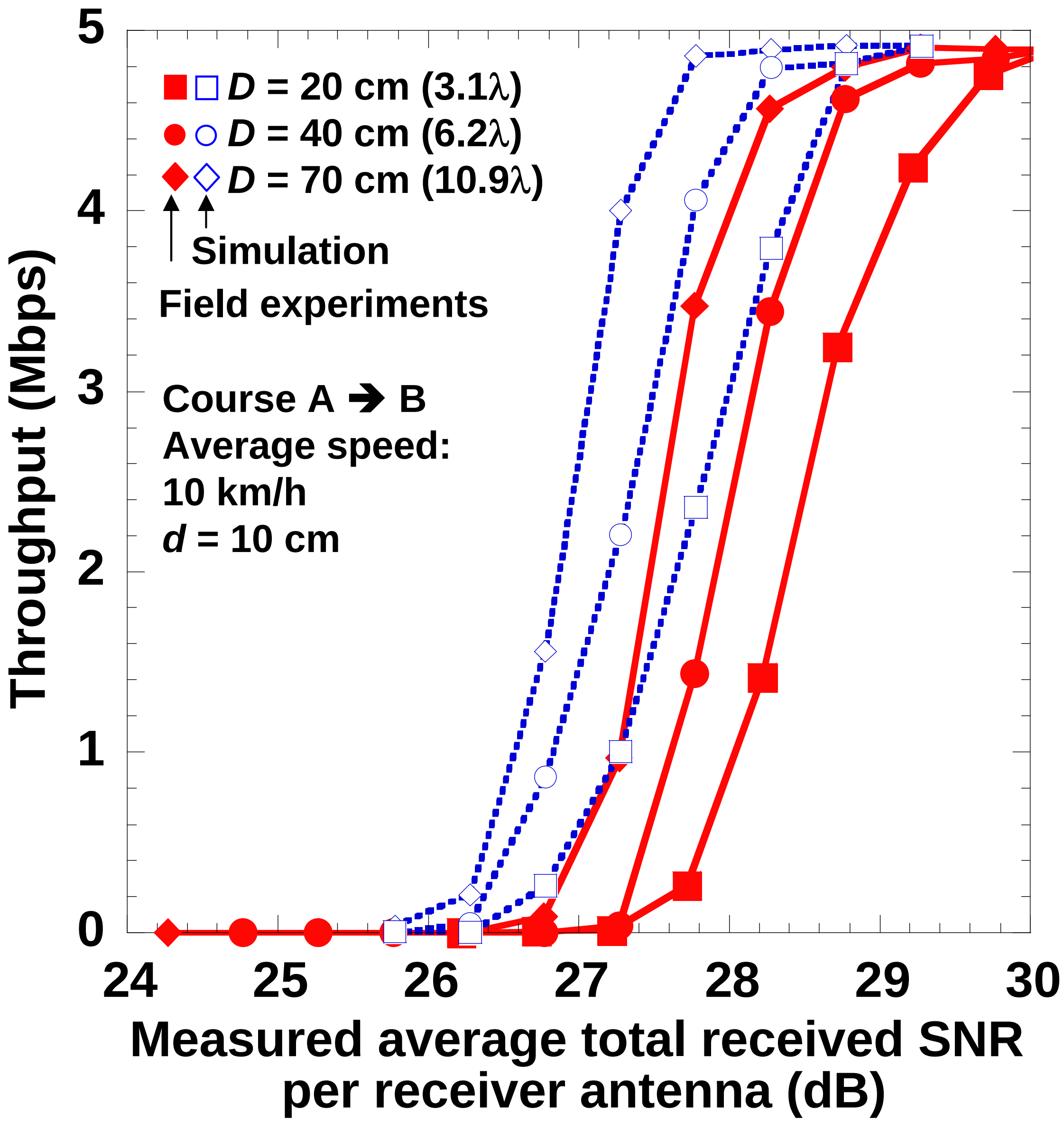


- **12-by-12 MIMO Multiplexing**
- **Total Tx power: 20W**
- **64QAM, *R* = 8/9 (Max: 4.915 Gbps)**
- **Average speed: 10 km/h**

■Throughput exceeding 4.9 Gbps is achieved at the location probability over 85% even when *d* is 10 cm.

Cumulative Distribution of Throughput (Impact of Trasmitter Antenna Spacing)

November 16, 2009/ NTT DOCOMO, INC.

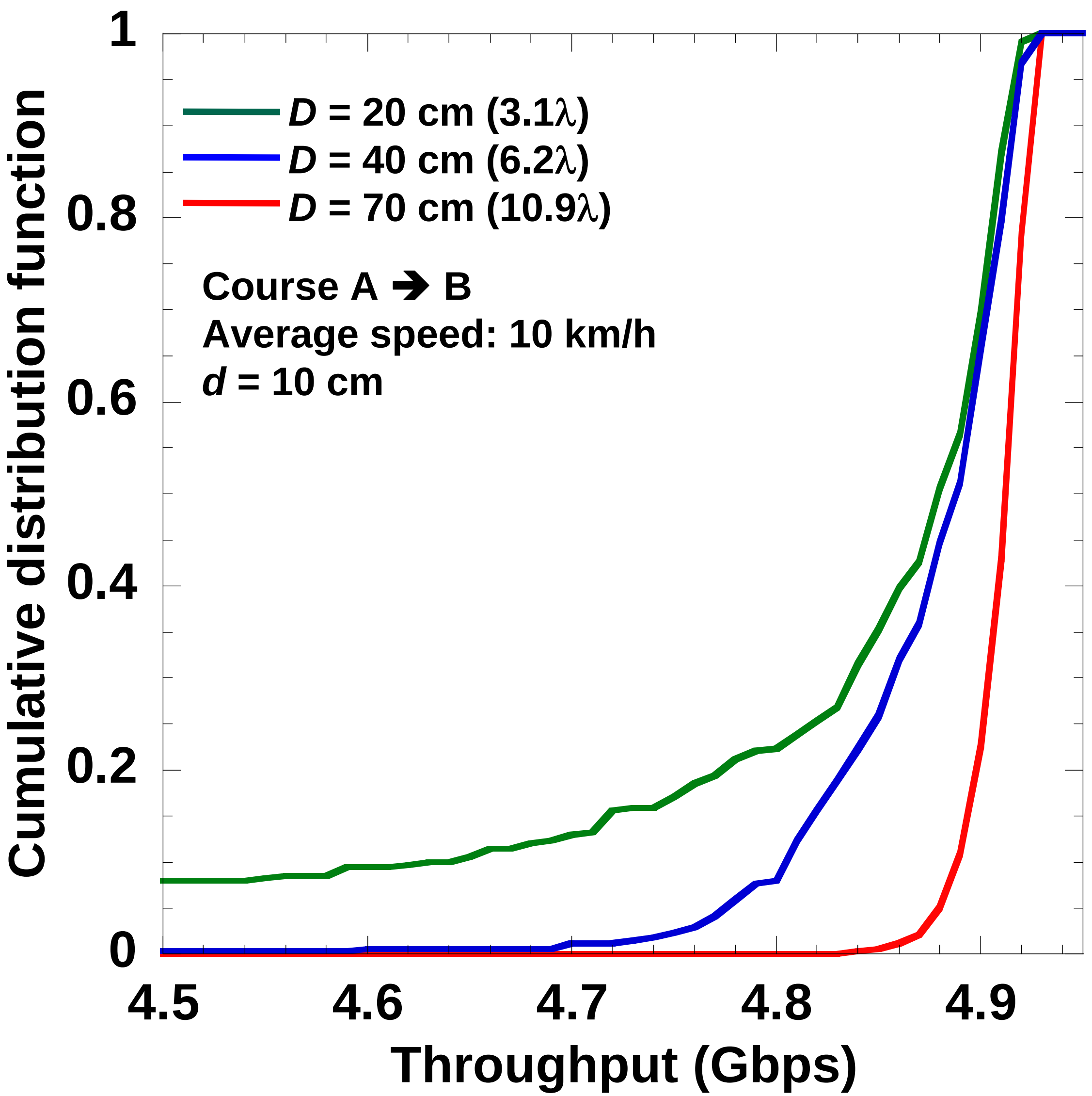


- 12-by-12 MIMO Multiplexing
- 64QAM, *R* = 8/9 (Max: 4.915 Gbps)
- Average speed: 10 km/h

■ Achieved 4.9 Gbps at received SNR of approximately 30 dB when *D* is 20 cm.

Cumulative Distribution of Throughput (Impact of Transmitter Antenna Spacing)

November 16, 2009/ NTT DOCOMO, INC.

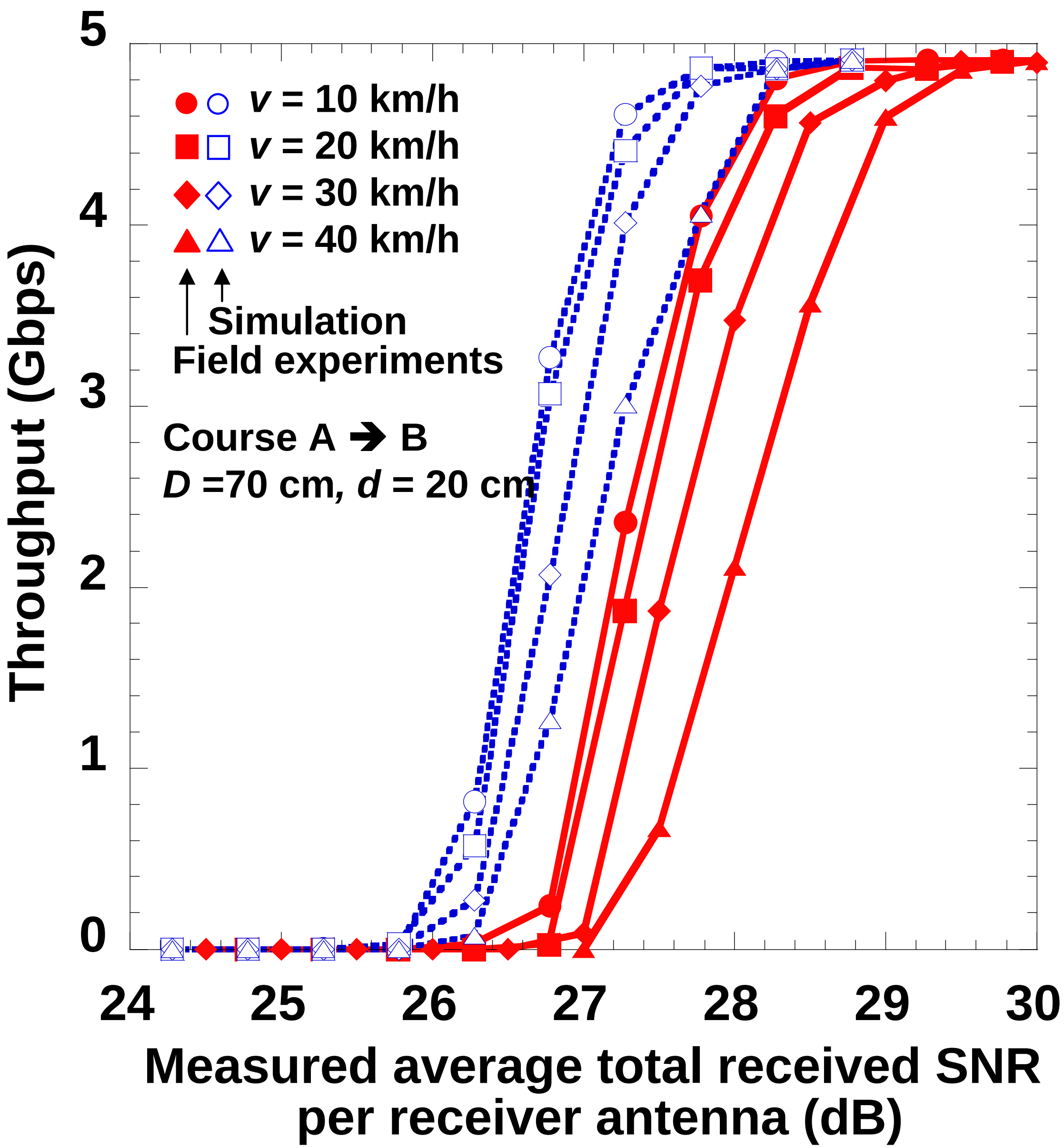


- **12-by-12 MIMO Multiplexing**
- **Total Tx power: 20W**
- **64QAM, *R* = 8/9 (Max: 4.915 Gbps)**
- **Average speed: 10 km/h**

■Throughput exceeding 4.9 Gbps is achieved at the location probability over 40% even when *D* is 20 cm.

Cumulative Distribution of Throughput (Impact of Vehicular Speed)

November 16, 2009/ NTT DOCOMO, INC.

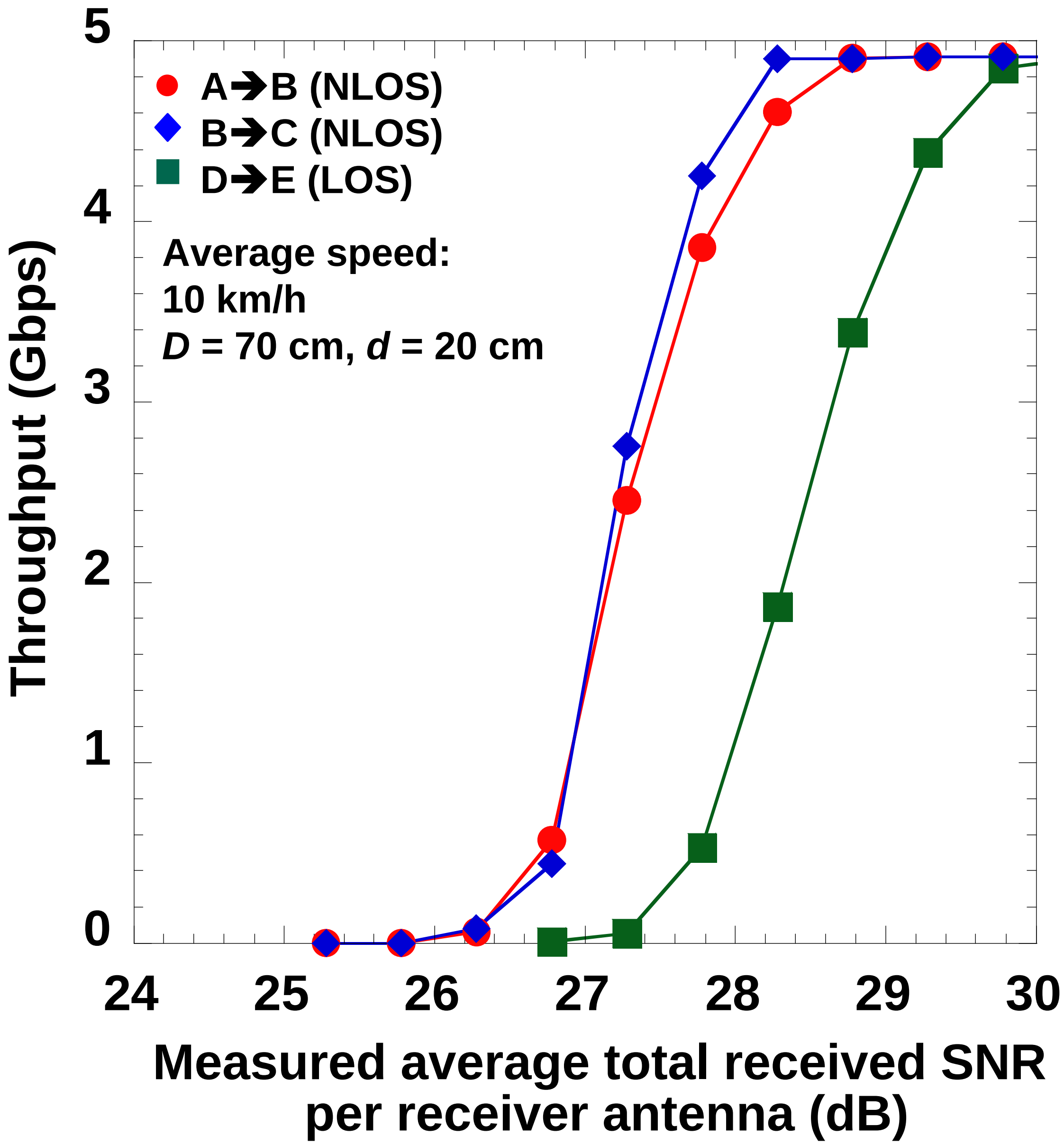


- 12-by-12 MIMO Multiplexing
- 64QAM, *R* = 8/9 (Max: 4.915 Gbps)

■ According to the increase in UE speed, throughput performance is degraded.
■ Even when v = 40 km/h, 4.9 Gbps throughput is achieved at received SNR of 29.5 dB

Cumulative Distribution of Throughput (Impact of NLOS/LOS)

November 16, 2009/ NTT DOCOMO, INC.



- **12-by-12 MIMO Multiplexing**
- **64QAM, *R* = 8/9 (Max: 4.915 Gbps)**

■ In NLOS condition, the throughput performance is almost identical irrespective of measurement courses

■ In LOS condition, the throughput performance is degraded compared to the in NLOS condition

Conclusion

- **Achieved approximately 50 bit/sec/Hz (i.e., 4.9 Gbps data transmission using 100-MHz bandwidth) at the maximum distance of 200 m between BS and MS using MLD-based signal detection.**

  ➔Required average received SNR for achieving 4.9-Gbps throughput is approximately 28.5 dB (*D* = 70 cm, *d* = 10 cm), which is near the upper limit taking into account interference from surrounding cells in multi-cell environment