High Frequency Radio Channel Measurement toward 5G Mobile Systems

2nd WEIE @ Aizu Univ.

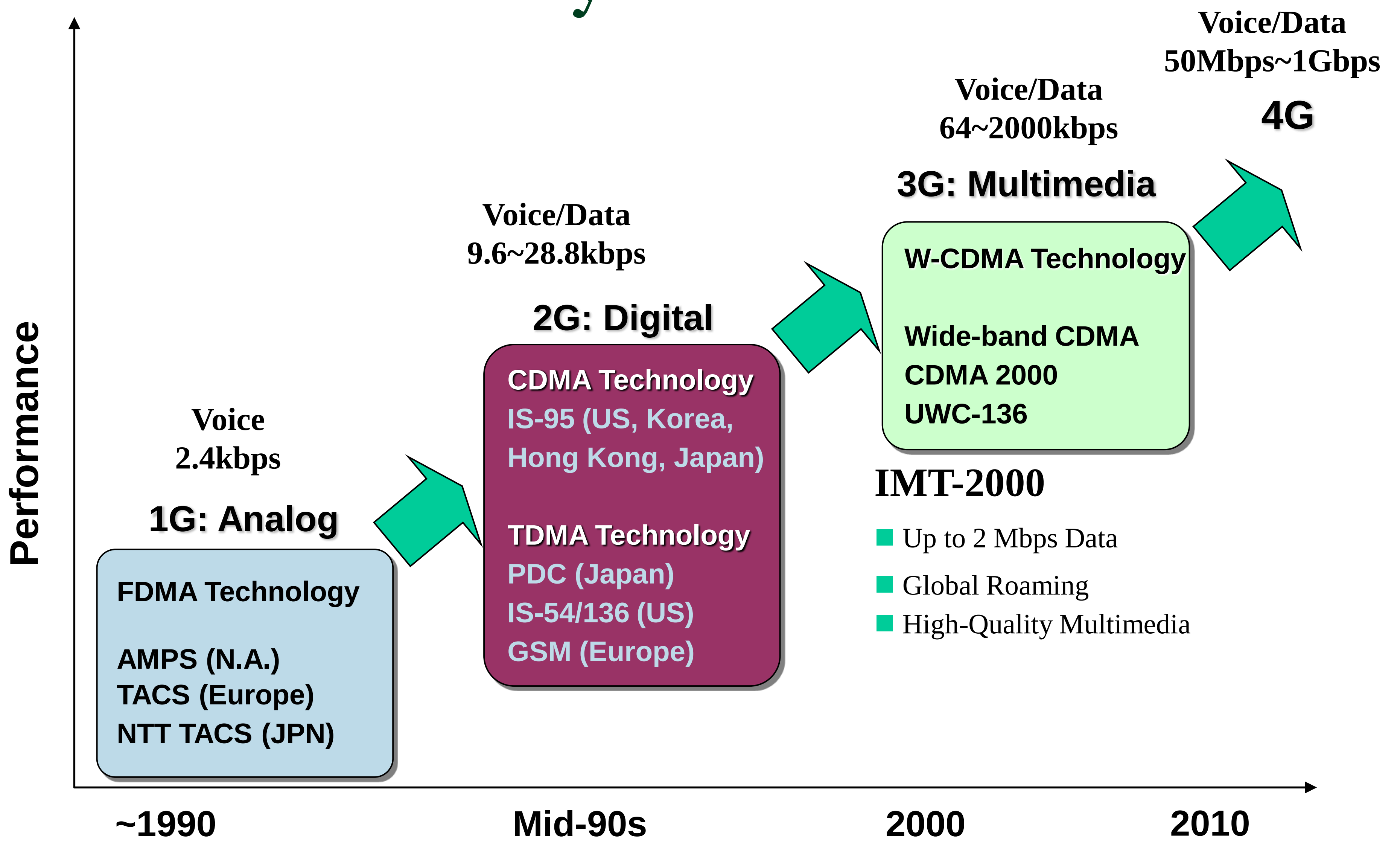
May 29, 2015

Minseok Kim, Ph.D
mskim@eng.niigata-u.ac.jp

Graduate School of Science and Technology,
Niigata University

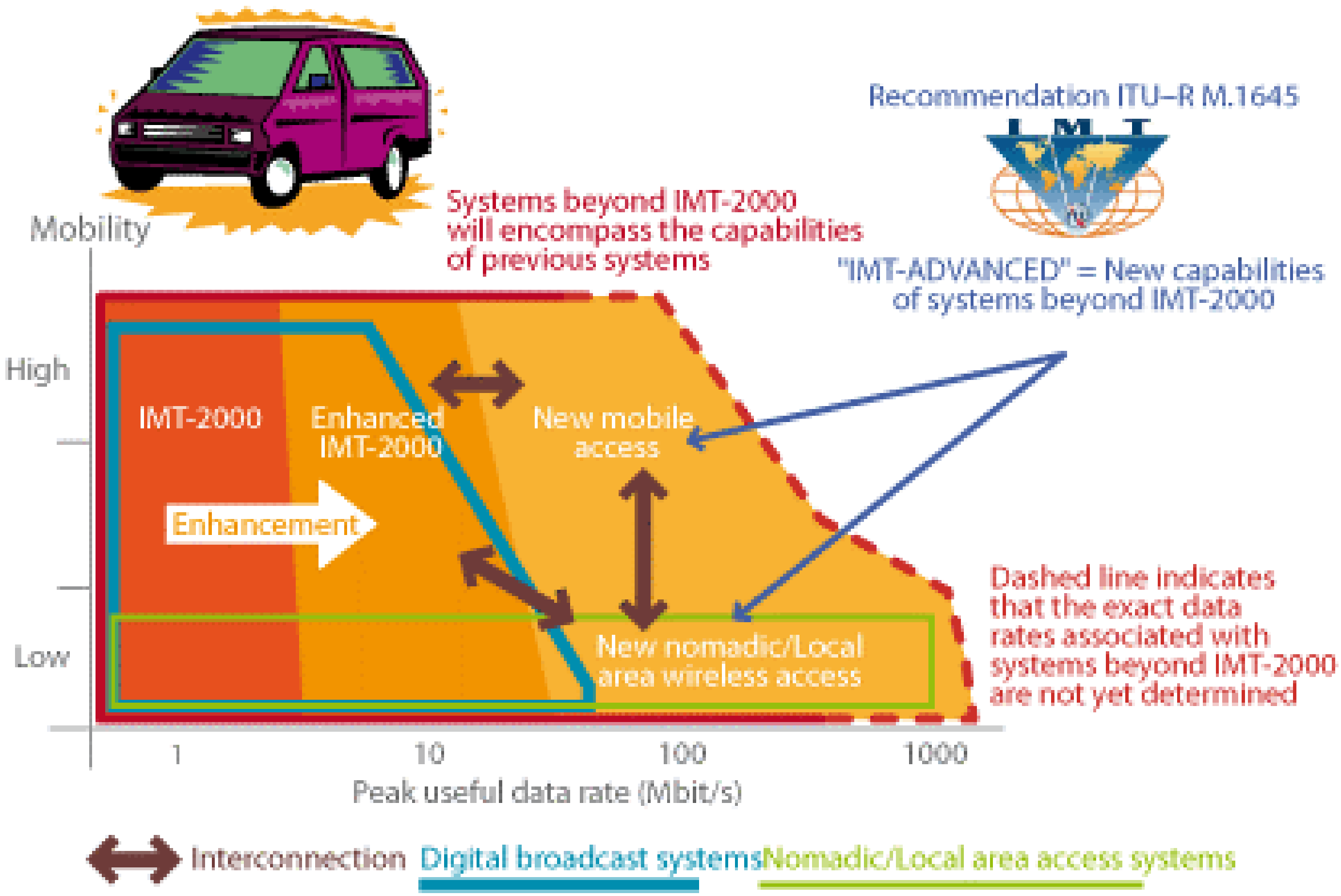
NIIGATA UNIVERSITY

Wireless System Evolution



Progress of Mobile Communication Systems

- データレートの高速化



http://www.itu.int/itunews/manager/display.asp?lang=en&year=2008&issue=10&ipage=39

Is High Bit-Rate Still a Target?

- Digital divide is not yet fully resolved in rural areas / developing countries
- How can mobile terminal handle such a high data rate?

Feature Phones

NTT DoCoMo 2008 Winter Model

Is High Bit-Rate Still a Target?

- How can mobile terminal handle such a high data rate?

•Smartphone

• Tablet

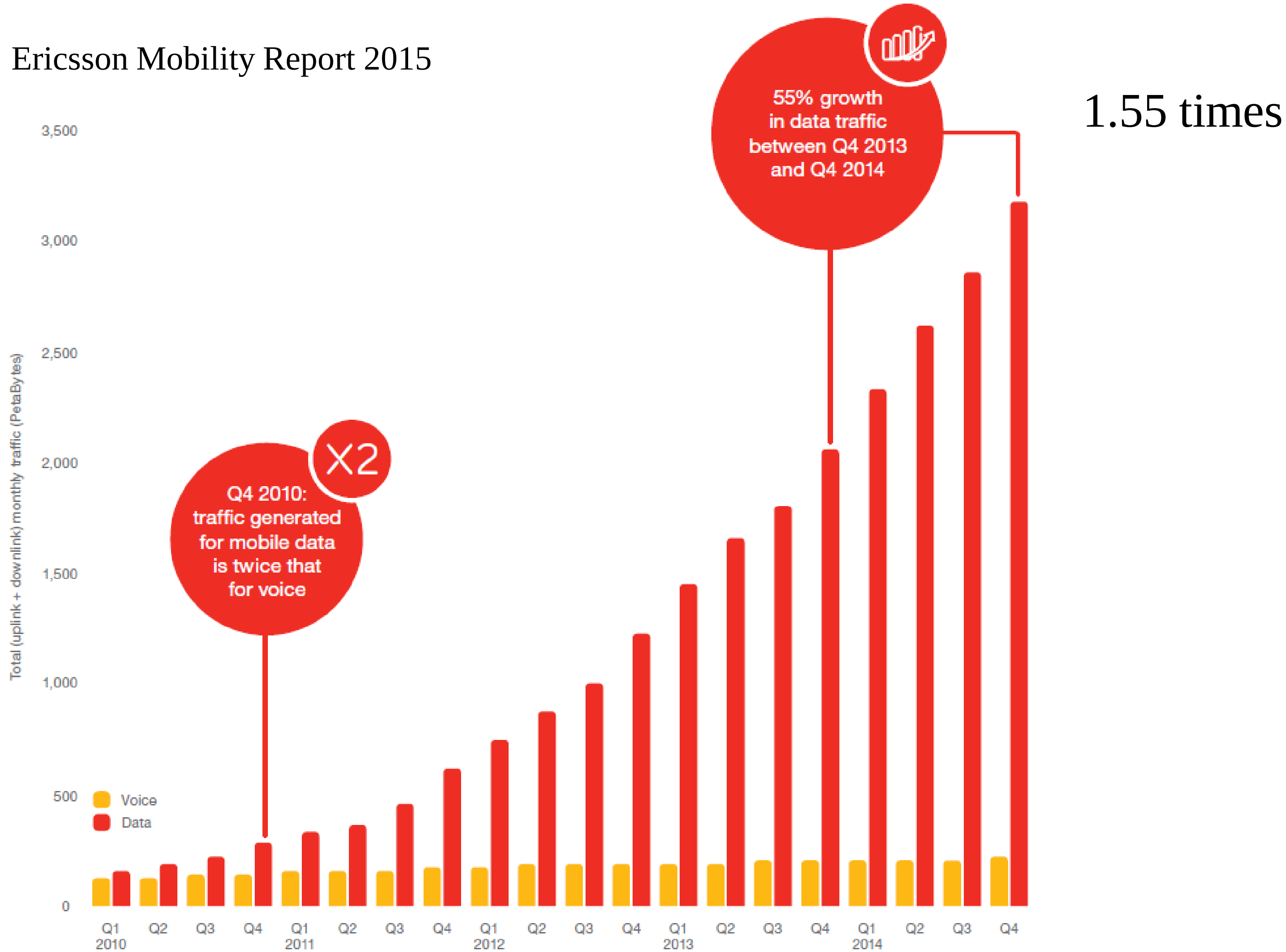
Is High Bit-Rate Still a Target?

- Evolution of mobile applications
  - Cloud computing / SaaS
  - SNS and communication
  - Video-on-demand

Forecast of Mobile Data Traffic

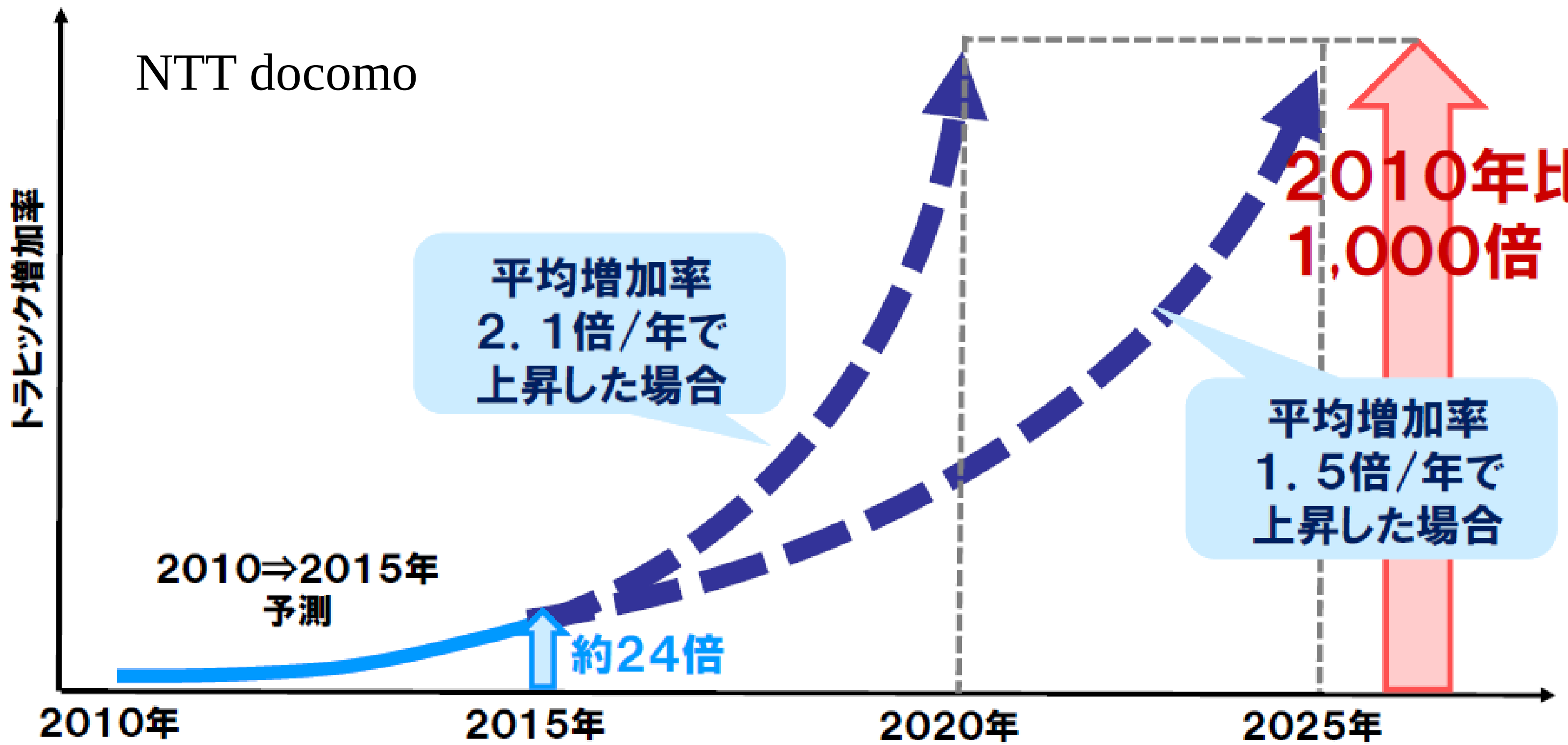
- Mobile data traffic is continuously increasing

Ericsson Mobility Report 2015



Mobile Communication in 2020's

- In 2020, the traffic will be approximately 1,000 times than that of 2010
- Further demand to data rate: 30~100 Gb/s per BS



Mobile Communication in 2020's

- Realization of ultra high bit rate mobile communication
  - MIMO Multiplexing
  - Wider Bandwidth
  - Radio resource management

Shannon's channel capacity

$$C = B \log_2\left(1 + \frac{S}{N}\right)$$

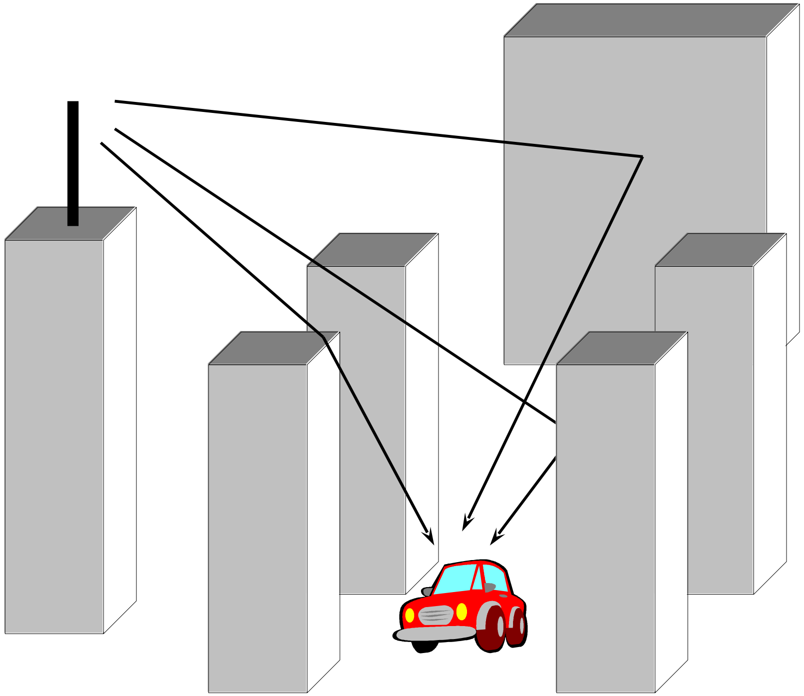
⇒

MIMO extension

$$C = B \sum_{m=1}^{M} \log_2\left(1 + \frac{S_m}{N}\right)$$

MIMO Multiplexing

Multipath Environment

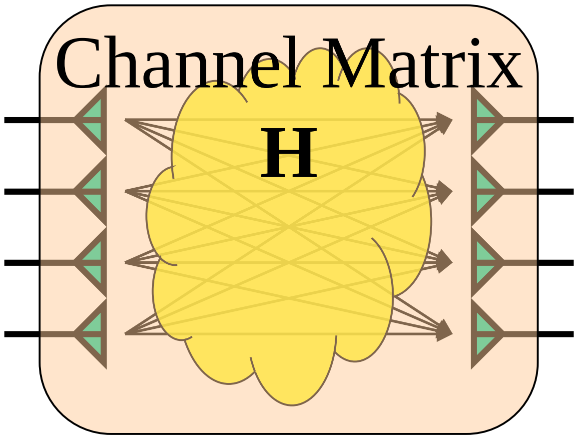


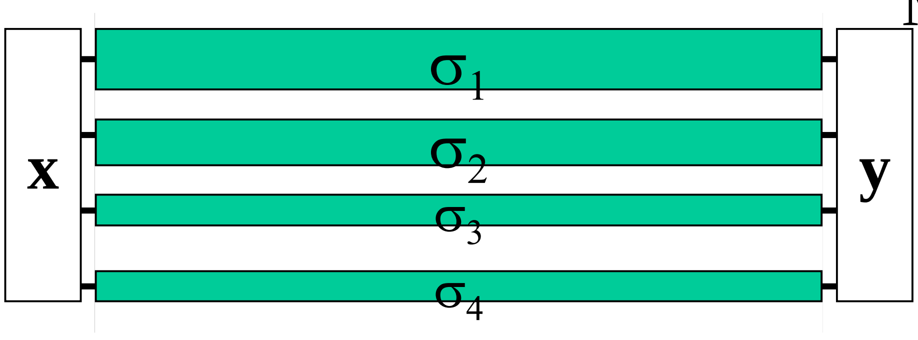
MIMO transmission

→ Utilization of different propagation paths
for different data stream

MIMO Multiplexing

- Principle





Singular value decomposition

$$\mathbf{H} = \mathbf{U}\mathbf{\Sigma}\mathbf{V}^{\mathrm{H}},$$

$\mathbf{U}, \mathbf{V}$: unitary matrices

$\mathbf{\Sigma}$: real diagonal matrix

MIMO eigenmode transimission

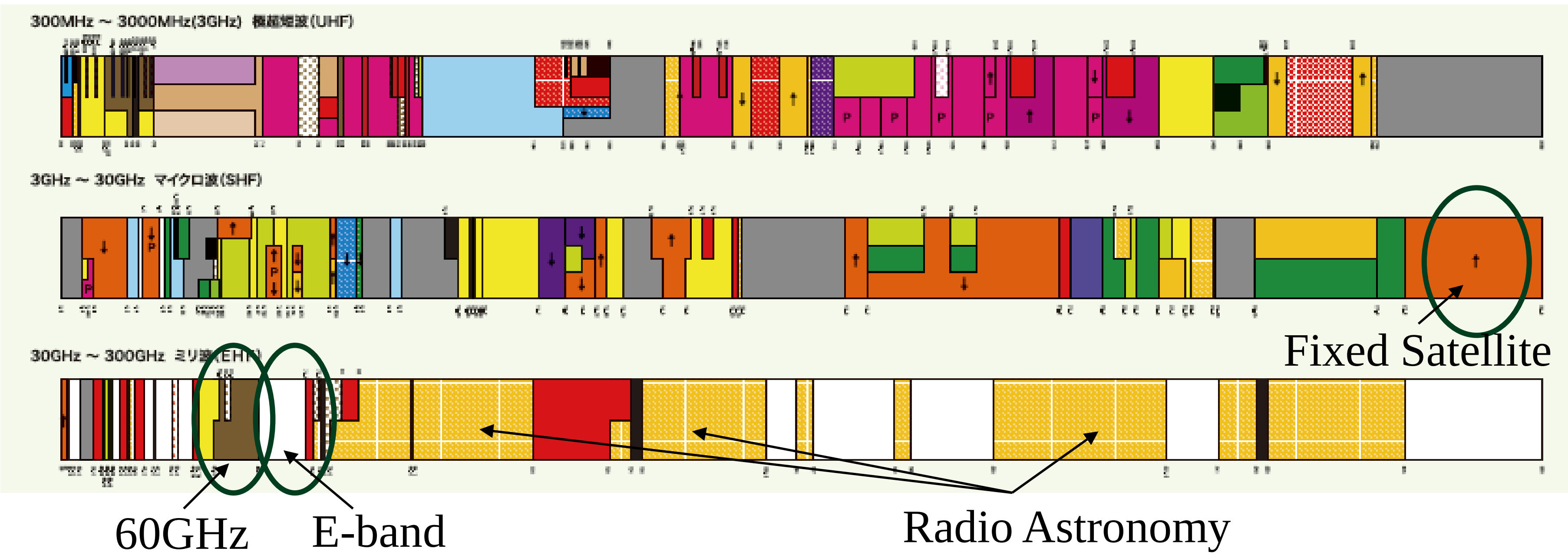
$$\mathbf{y} = \mathbf{U}^{\mathrm{H}}\mathbf{U}\mathbf{\Sigma}\mathbf{V}^{\mathrm{H}}\mathbf{V}\mathbf{x}$$

$$= \mathbf{\Sigma}\mathbf{x}$$

Isolation of parallel channels

Frequency Allocation in Japan

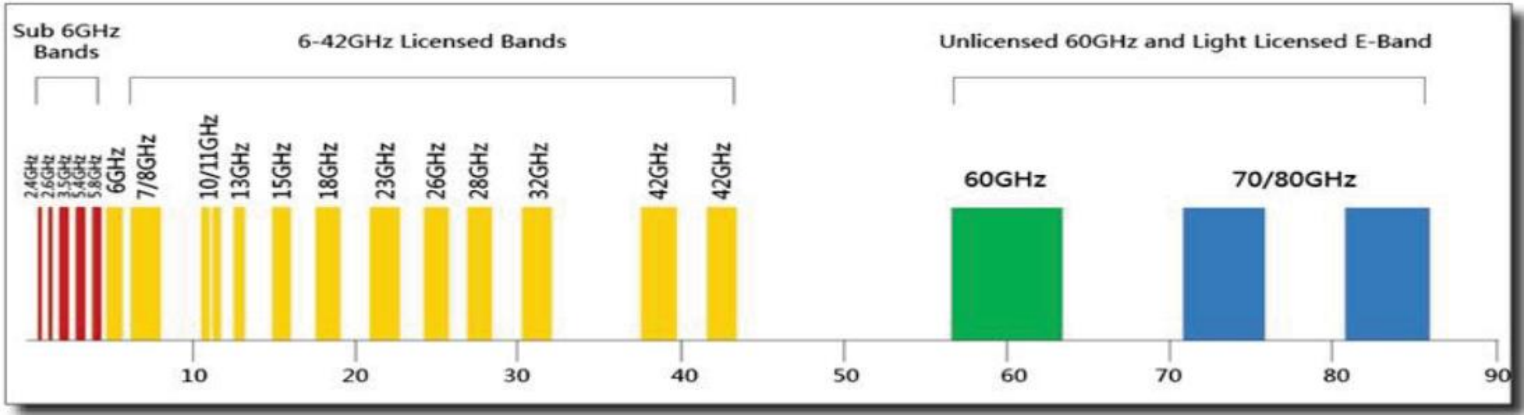
Ministry of internal affairs and communications (Mar. 2015)



- Serious congestion of the frequency spectrum at lower microwave bands (below 6 GHz)
- Exploring new frequency bands above 6 GHz is an inevitable choice to utilize much wider bandwidth in the future

High frequency bands

- Various high frequency bands being interested in the world
  - 11 GHz: broadband fixed microwave relay in Japan
  - 27~29.5 GHz: LMDS (US)
  - 38~39.5 GHz: Fixed p-p link (US)
  - 57~66GHz: offers 5~9 GHz of unlicensed bandwidth across most of the world. 2 GHz/channel
  - 71-76 GHz, 81-86 GHz: Light-licensed E-Band (fixed p-p link), 5 GHz/channel



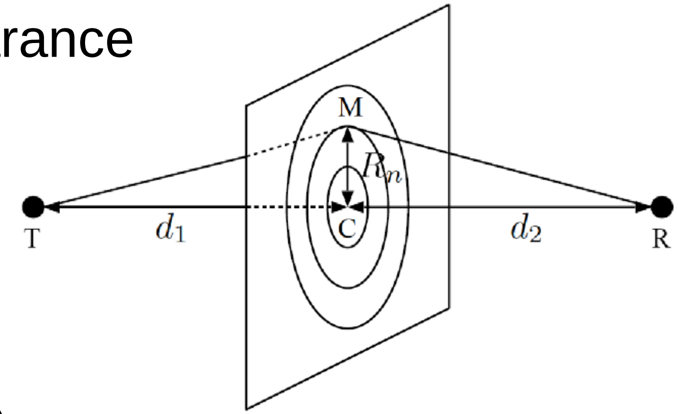
Features of High Frequency Band

- Advantages: wider bandwidth
- Disadvantages:
  - Friis' formula for free space link

$$G = \frac{P_\mathrm{r}}{P_\mathrm{t}} = \left(\frac{c}{4\pi d f}\right)^2$$

  - First Fresnel zone for line-of-sight clearance

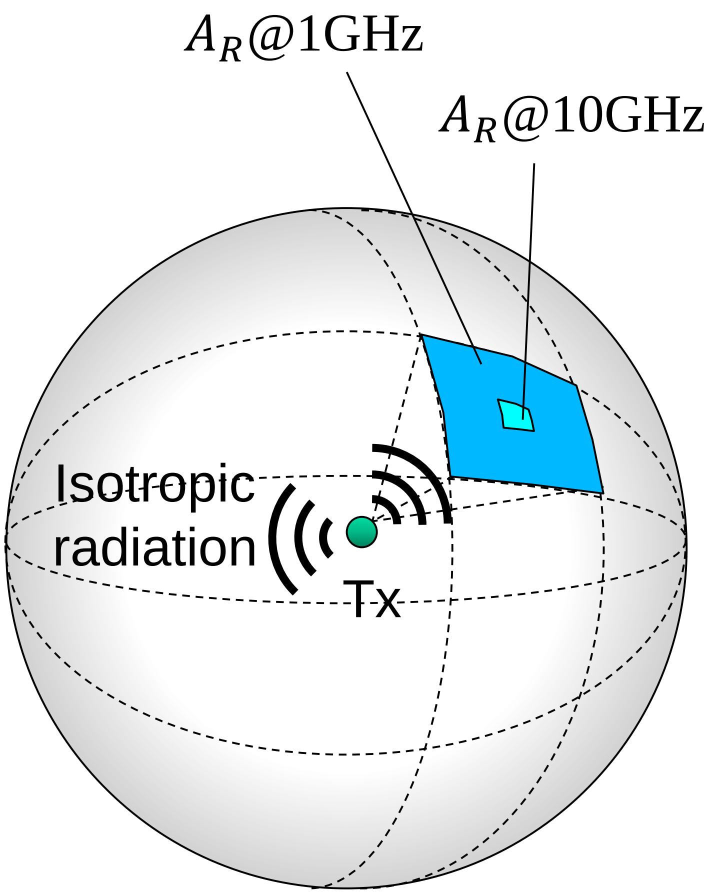
$$R_1 = \sqrt{\frac{c d_1 d_2}{(d_1 + d_2) f}}$$



  - Shannon's channel capacity

$$C = B \log_2\left(1 + \frac{S}{N_0 B}\right)$$

Free Space Path Loss



- Received power is proportional to the antenna aperture

$$P_r(d) = P_t \frac{1}{4\pi d^2} A_R$$

- Antenna aperture

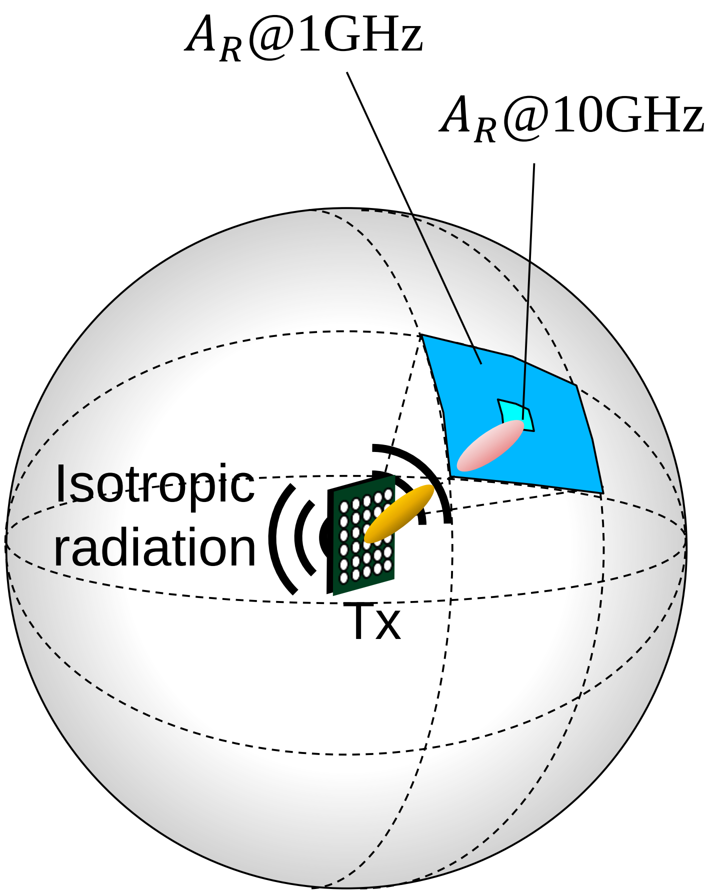
$$A_R = \frac{\lambda^2}{4\pi} G_R$$

where G_R: gain of Rx antenna

- Path loss

$$L(d) = \frac{1}{4\pi d^2} \frac{\lambda^2}{4\pi} G_R$$

Free Space Path Loss



- Isotropic radiation and reception

$$L(d) = \frac{1}{4\pi d^2}\frac{\lambda^2}{4\pi}G_R$$

- Isotropic radiation and reception by beamforming

$$L(d) = \frac{1}{4\pi d^2}\frac{\lambda^2}{4\pi}\left(\frac{4\pi}{\lambda^2}\right)$$

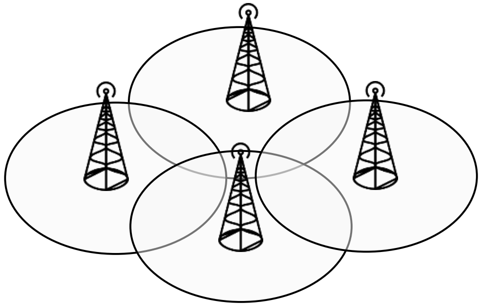
- Both of radiation and reception by beamforming

$$L(d) = \frac{1}{4\pi d^2}G_T$$

Perspective of 5G Cellular Networks

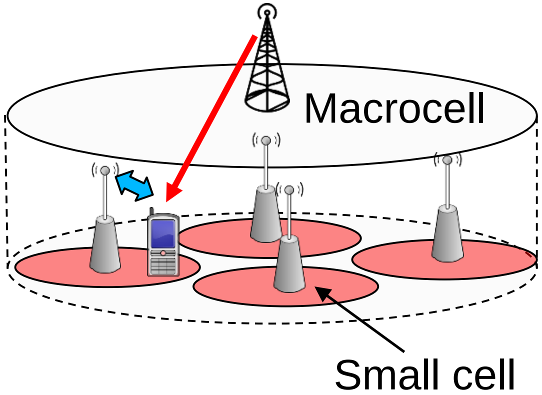
Conventional Macrocell

NLoS, Wide Coverage



Super high bit-rate
Data transmission
(>10Gbps)

Small cells
(Femto / Microcell / Street-cell)



Macrocell
+
Small cell overlay
at high frequency band
(>5GHz)

- Need information about channel parameters
- Appropriate channel models at high frequency bands

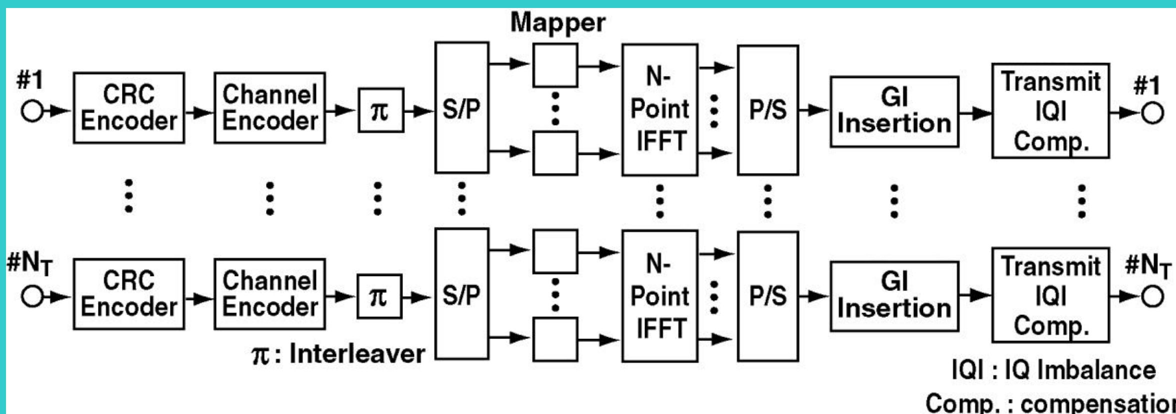
R&D Project for Expansion of Radio Spectrum Resources

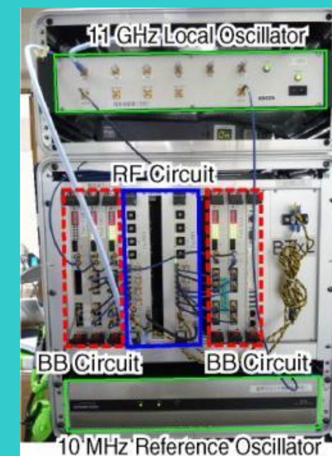
- Fundamental study for future mobile system at higher frequency band (> 5 GHz)
  - MIMO transmission over 10 Gbps
  - Bandwidth → 400 MHz
  - Carrier frequency → 11 GHz (Microwave band)
    → 60 GHz (Mm-wave band)

- This work was partly supported by The Ministry of Internal Affairs and Communications (MIC), Japan.
  - "The Strategic Information and Communications R&D Promotion Program (SCOPE: No.145004102)" 2014~
  - "The Research and Development Project for Expansion of Radio Spectrum Resources" 2009~2012

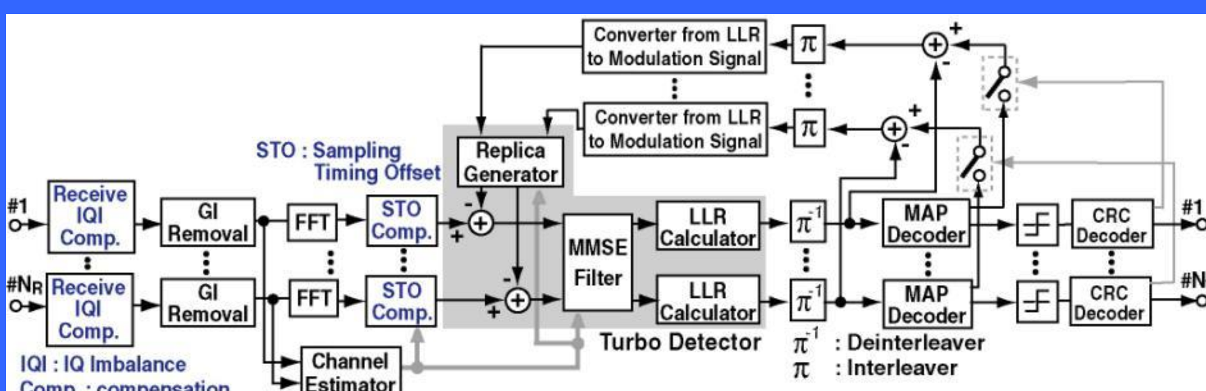
Development of 11GHz MIMO-OFDM transceiver

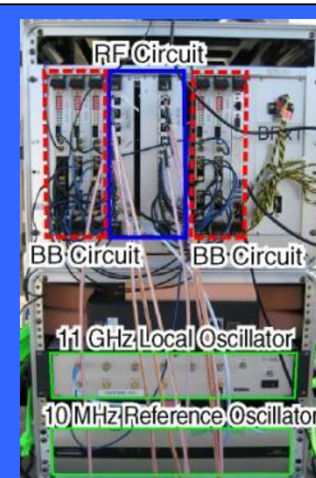
Tx





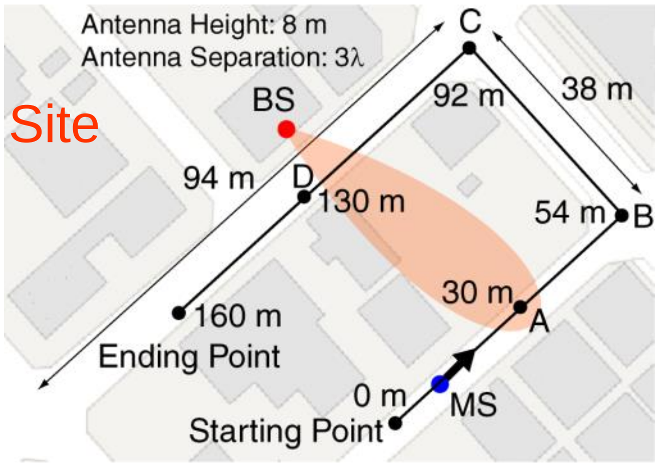
Rx

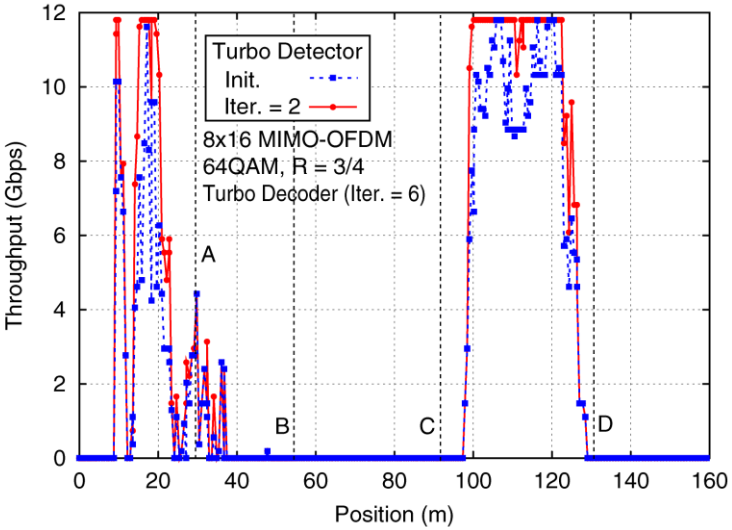




Suyama et. al., IEICE Technical Report, RCS2012-40, May 2012.

First success of above 10 Gb/s transmission in outdoor mobile scenario





Suyama et. al., IEICE General Conference, B-5-110, Mar. 2013.

NTT Docomo tests 10Gbps uplink

Japanese carrier conducts first experiment of mobile packet transmission at this speed, in 400MHz of bandwidth

CAROLINE GABRIEL

Published: 28 February, 2013

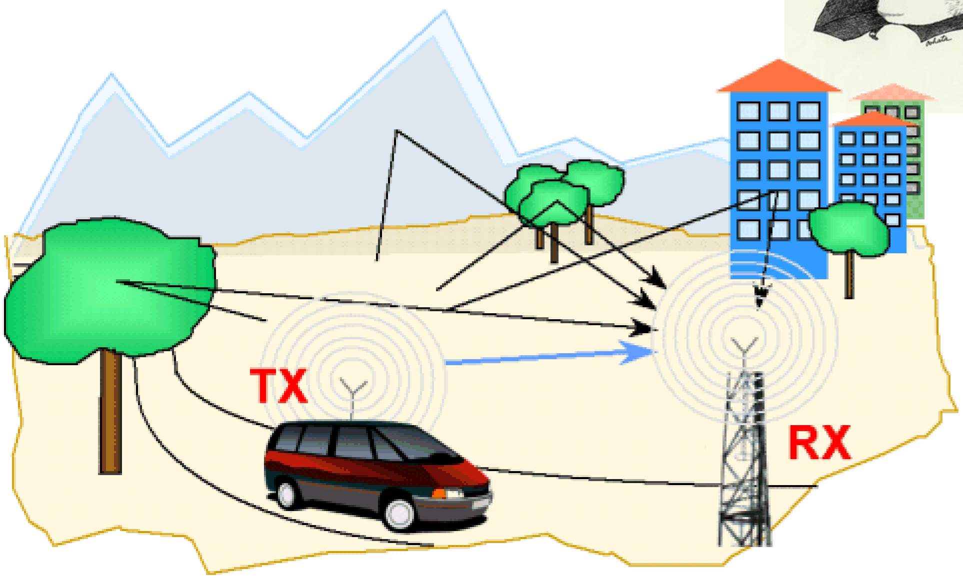
Japan's NTT Docomo is sometimes outshone by Softbank and SK Telecom in terms of real world deployments of cutting edge technology, but it remains hard to beat in terms of its futuristic R&D. Its latest test saw the world's first uplink packet transmission to reach 10Gbps.

The outdoor experiment was conducted recently with the Tokyo Institute of Technology, and the cellco said it would help to pave the way for future superfast mobile standards in '5G' and beyond. In the test, which took place in Ishigaki City of Okinawa Prefecture, 400MHz in the 11GHz band was used to transmit from a terminal moving at nine kilometers and hour. MIMO smart antenna arrays, with eight transmitting and 16 receiving antennas, was usedfor spatial multiplexing of different data streams.

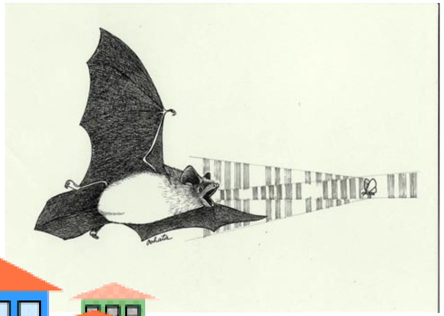
http://www.rethink-wireless.com/2013/02/28/ntt-docomo-tests-10gbps-uplink.htm

What is MIMO Channel Sounder?

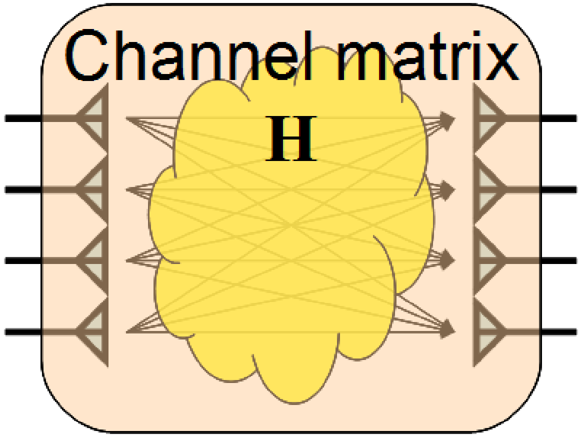
- Instrument to measure MIMO channel matrix



Source: www.channelsounder.de



Source: nature-sanbe.jp



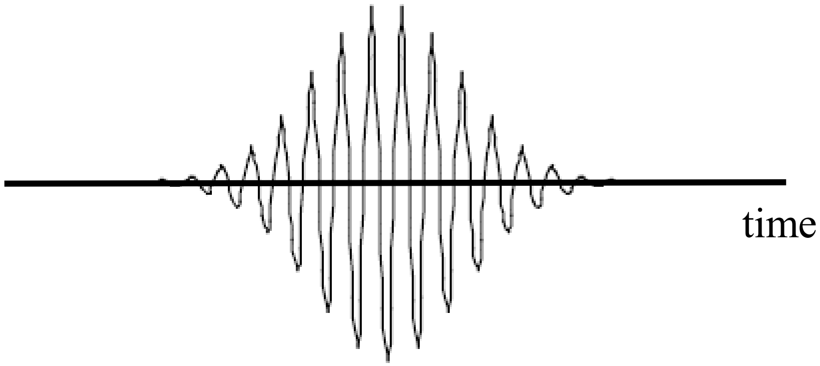
Radio Channel Sounding

- Radio channel properties
  - Transmission system design and evaluation
  - Coverage design
- Characterization of a random process
  - Temporal property → Doppler power spectrum
  - Frequency property → Delay power spectrum
  - Spatial (directional) property → Angular power spectrum
- How to measure ?
  - Sweep in time, frequency, and angle
  - Repetitive measurement, broadband signaling, antenna array

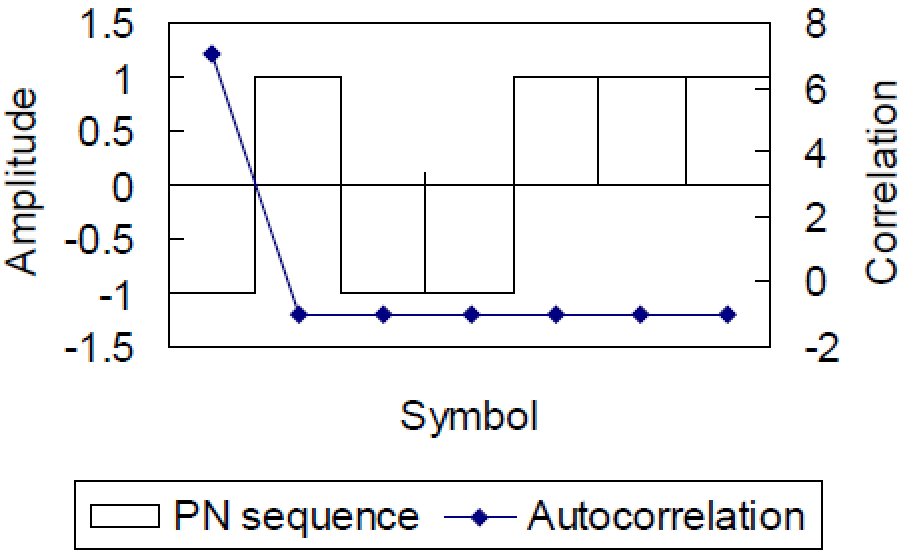
Signaling

- Impulse
- PN sequence
- Chirp signal
- Multitone

Impulse



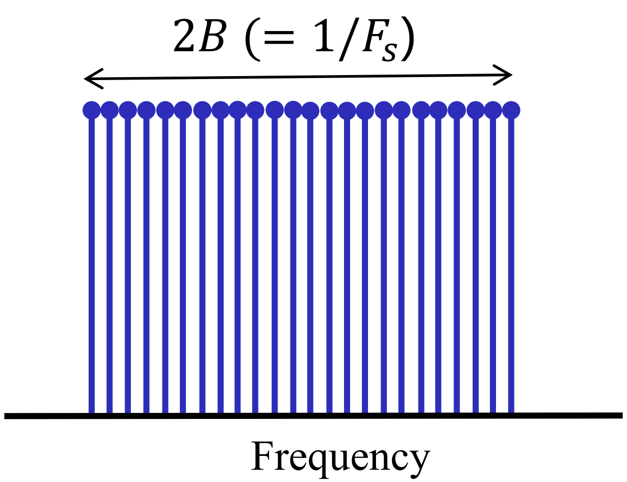
PN Sequence

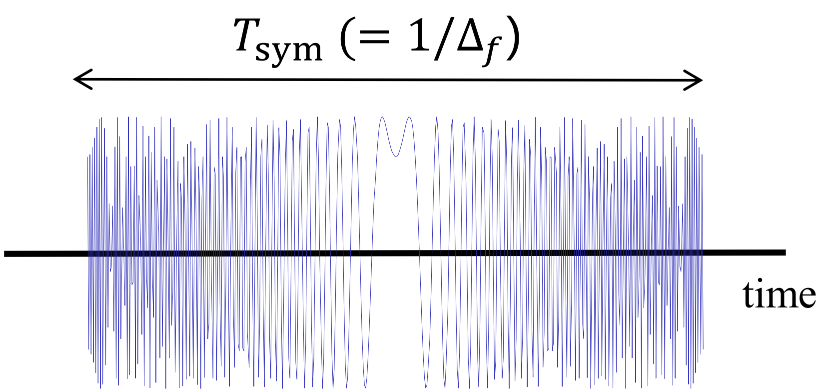


Signaling

- Multitone

$$s(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} \exp\left(j2\pi n\Delta_F t + j\phi(n)\right) \qquad \phi(n) = \frac{n^2\pi}{N} : \text{Newman Phase}$$





- Features: flat spectrum shape, constant envelope (CAZAC; good PAPR)

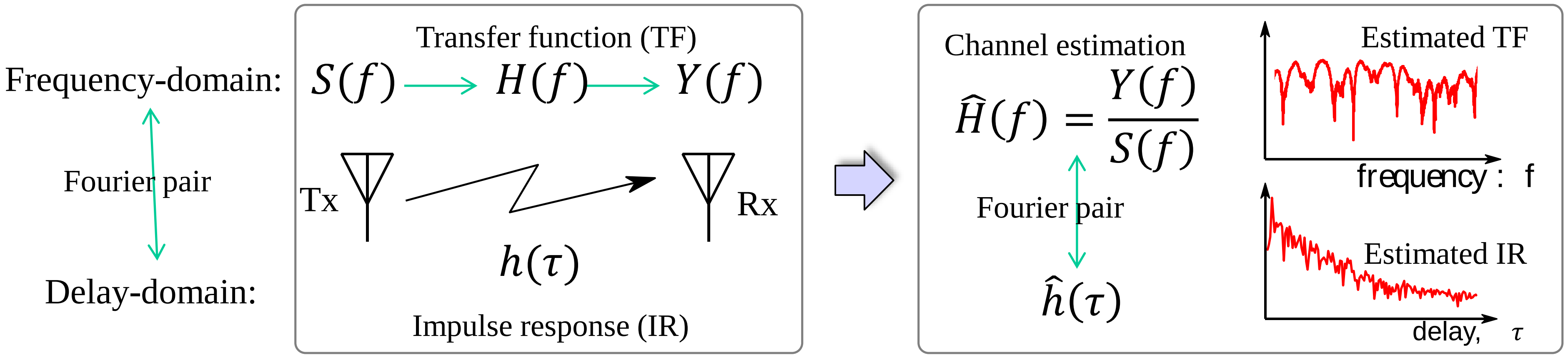
Radio Channel Sounding

- Instrument to estimate unknown channel response

$$y(t) = \int h(\tau)s(t-\tau)d\tau + w(t)$$

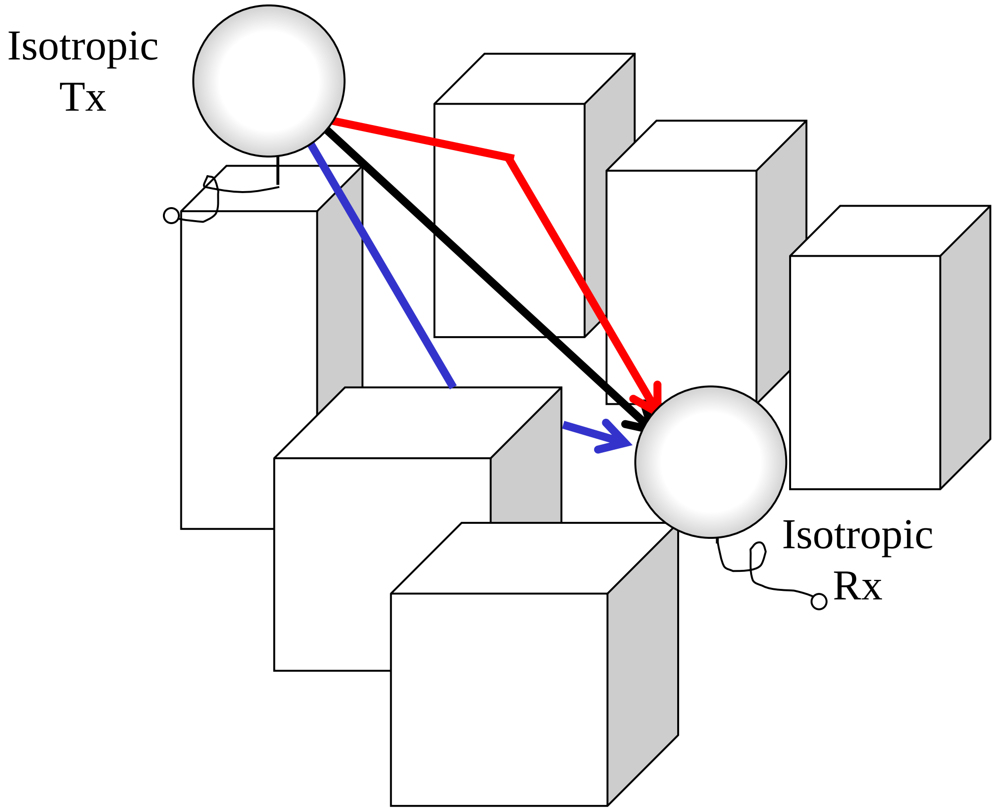
$$Y(f) = H(f)S(f) + W(f)$$

where s(t):sounding signal, h(t):channel response, w(t):AWGN



Double-directional Channel

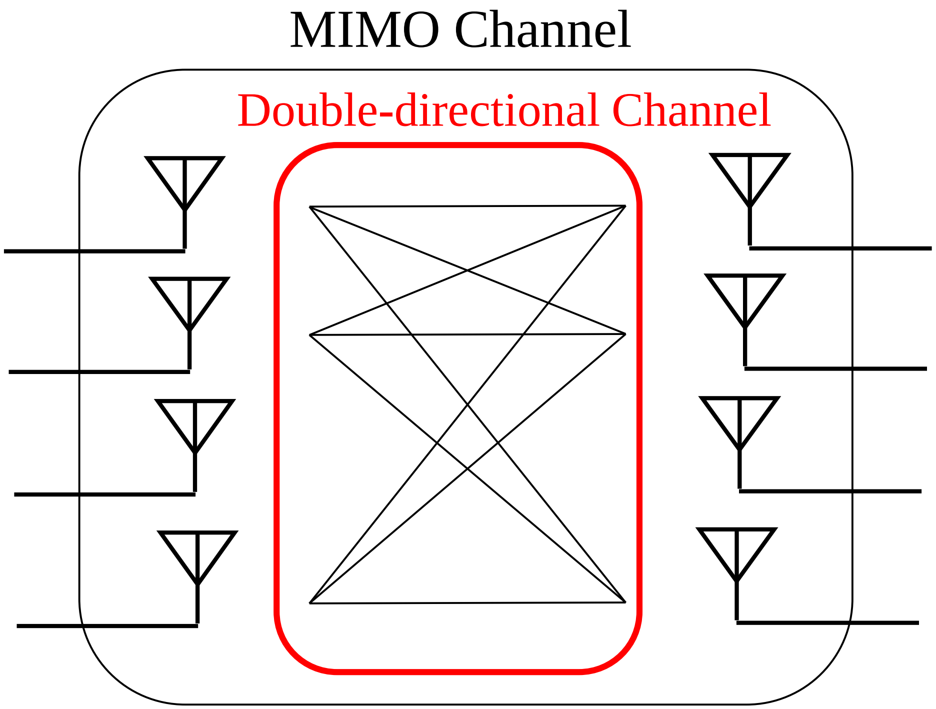
- Double-directional channel response means the channel response with isotropic antennas



Antenna De-embedding

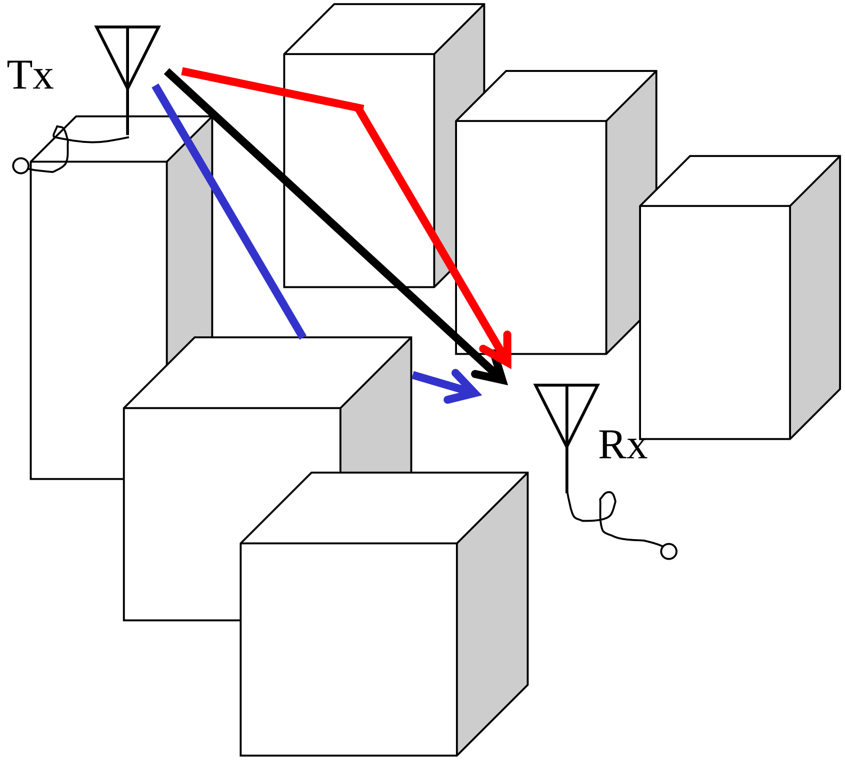
- MIMO Channel (antenna embedded) vs. Double-directional Channel (antenna de-embedded)
- Antenna is designable but channel is uncontrollable

→ Antenna and channel should be separately considered

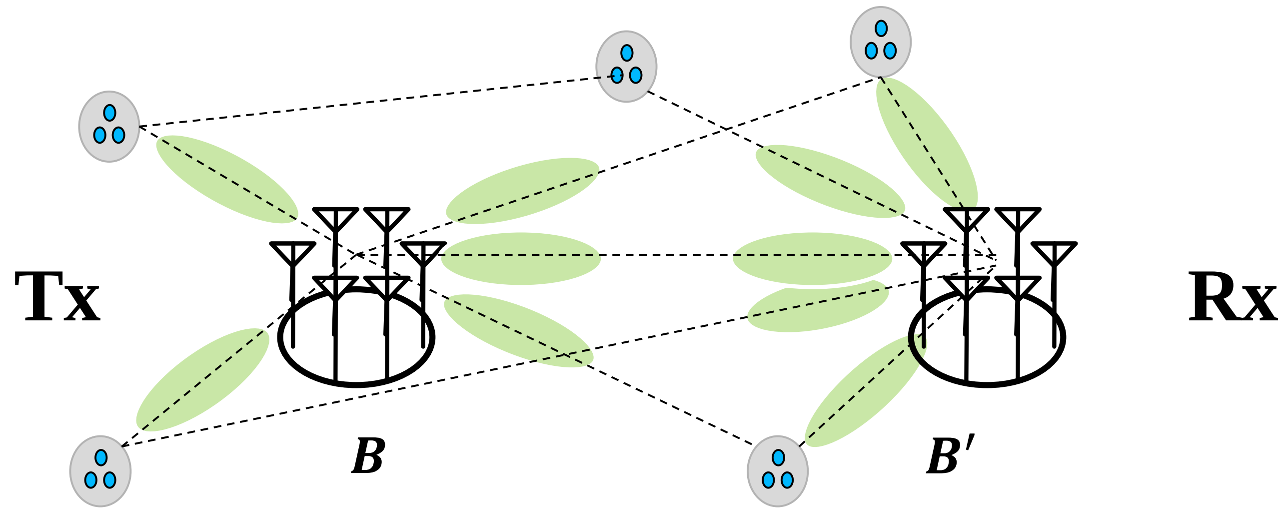


Double-directional Channel

- Channel response is defined between Tx and Rx ports



Double Directional Channel Model



- Signal Model

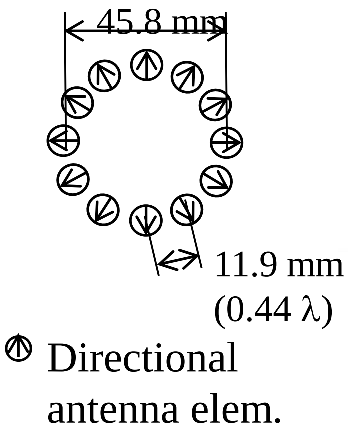
$$\boldsymbol{H}(f) = \sum_{l=1}^{L} e^{-j2\pi f \tau_l} \boldsymbol{B}'(f, \phi_l') \boldsymbol{\Gamma}_l \boldsymbol{B}(f, \phi_l)^T \quad \boldsymbol{\Gamma}_l = \begin{bmatrix} \gamma_{l,\mathrm{VV}} & \gamma_{l,\mathrm{VH}} \\ \gamma_{l,\mathrm{HV}} & \gamma_{l,\mathrm{HH}} \end{bmatrix}$$

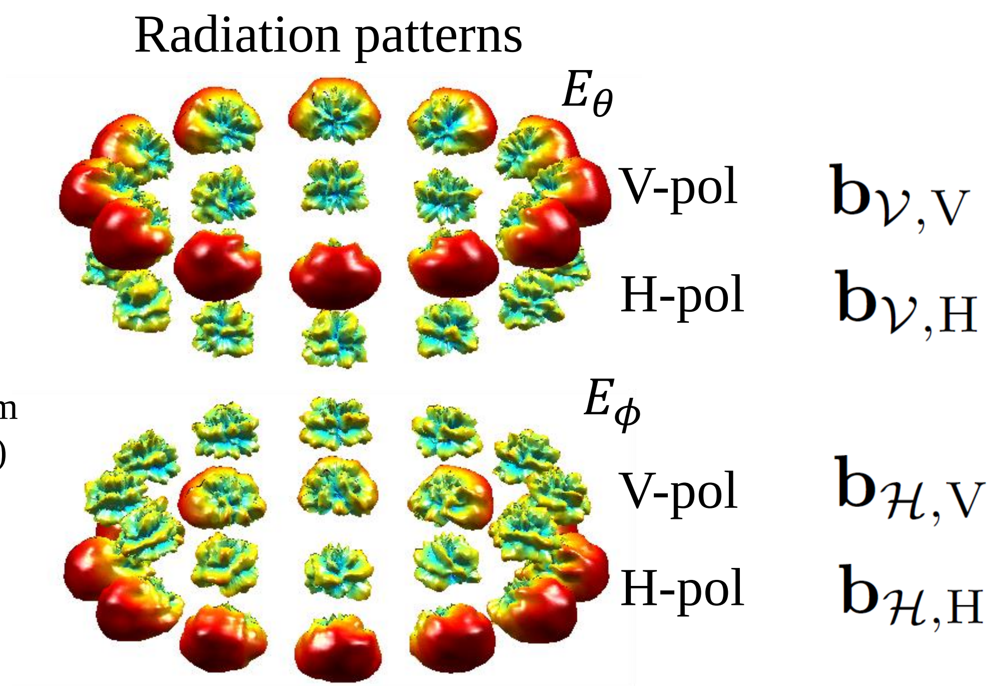
Complex path weight

$\tau_l, \phi_l, \phi_l', \boldsymbol{\Gamma}_l$ are estimated by ML method

Antenna Array

- Dual-pol 12 element UCA（12V/12H)





Path Parameter Estimation

- Maximum likelihood estimation (MLE) of parameter set $\hat{\boldsymbol{\mu}}$ from measured $\boldsymbol{y}$

$$\hat{\boldsymbol{\mu}} = \arg\min \|\boldsymbol{y} - \boldsymbol{h}(\boldsymbol{\mu})\|^2$$

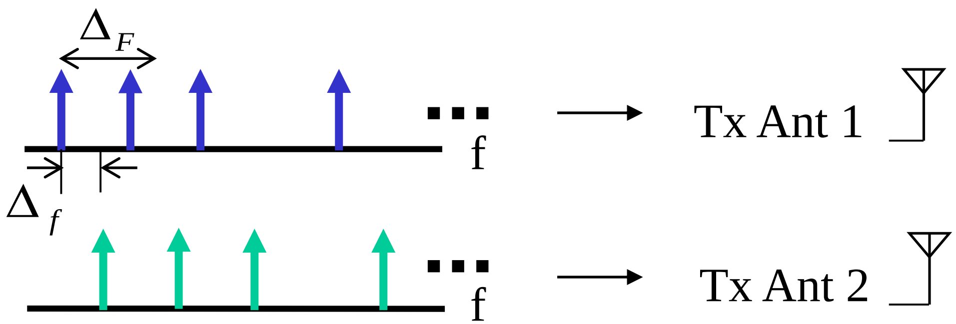
$$\boldsymbol{\mu} = \{\tau_l, \phi_l, \phi_l', \boldsymbol{\Gamma}_l, l = 1..N\}$$

→ Minimization of reconstruction error

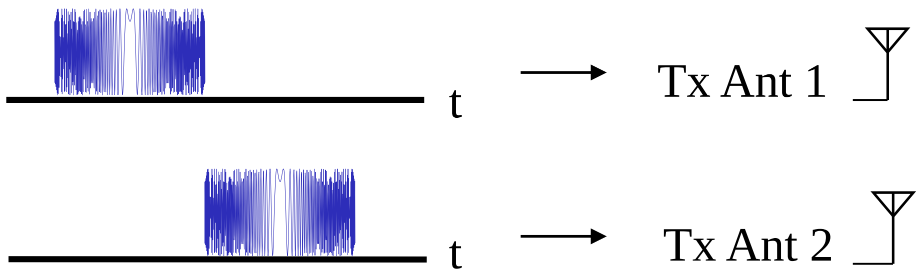
- SAGE, RIMAX etc: successful approach in channel sounding

MIMO Multiplexing

- Frequency division multiplexing (FDM)

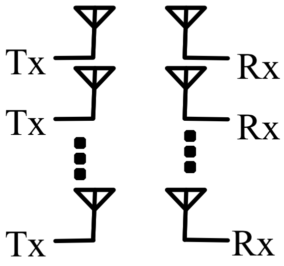


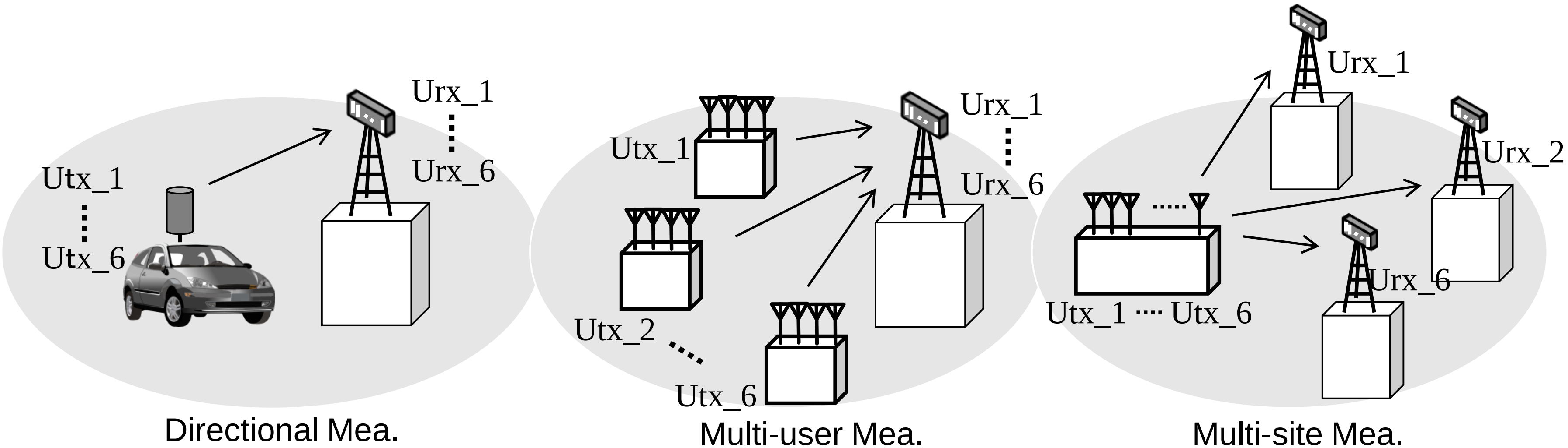
- Time division multiplexing (TDM)



MIMO Channel Sounder Development

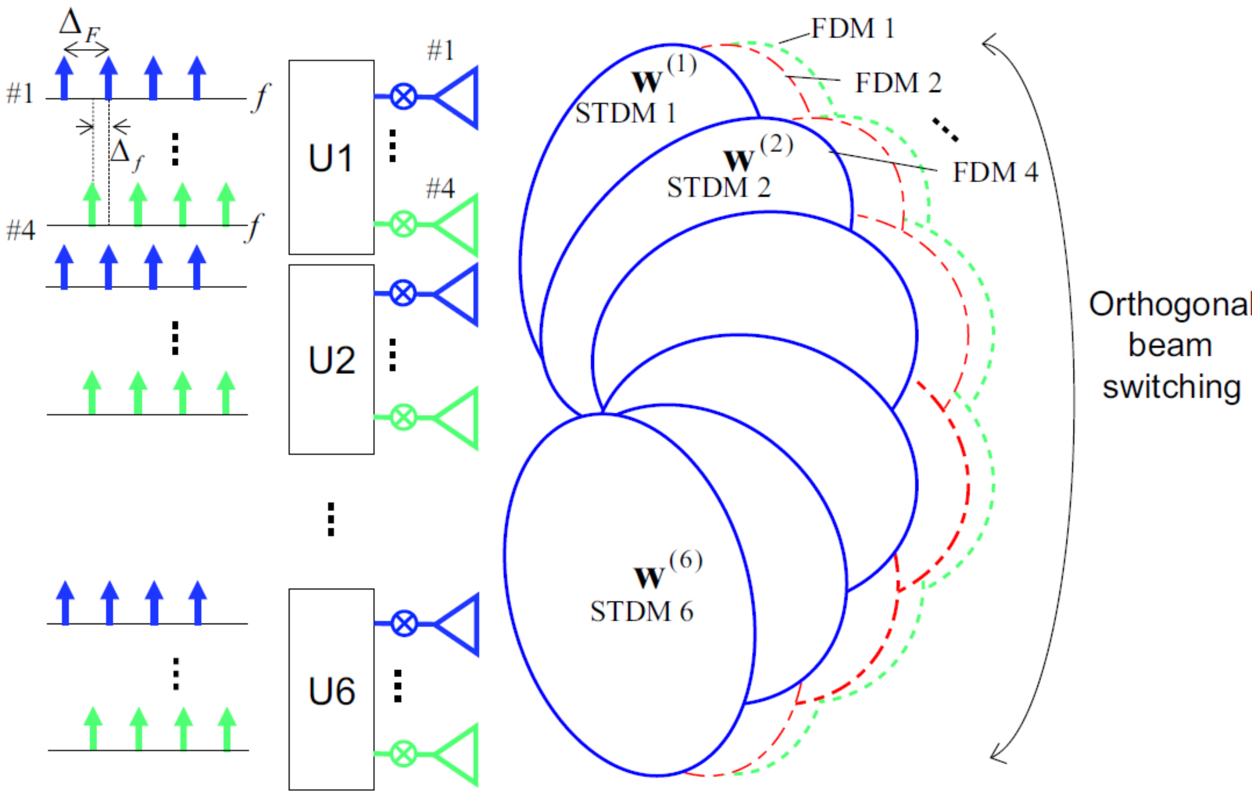
- Fully parallel transceivers (up to 24x24 MIMO)
  - Complete RF circuits both at Tx and Rx
  - Transmission techniques' evaluation
- Scalability : modular architecture with 4 antennas
  - Double directional channel measurement
  - Multilink (Multi-user/Multi-site) MIMO measurement





MIMO Channel Sounder

- Layered multiplexing scheme (FDM/STDM)



M. Kim, et al., "`Novel Scalable MIMO Channel Sounding Technique and Measurement Accuracy Evaluation with Transceiver Impairments," ***IEEE Trans. Instrum. Meas.***, Vol.61, No.12, 2012

Hardware Setup

- System parameters

Basic signal parameters

Carrier frequency	11 GHz
Signal bandwidth ($2B$)	400 MHz
Sampling rates (f_s)	800 MHz (oversampling)
No. tones/subcarriers (N)	2, 048
Carrier spacing (Δ_F)	195 kHz
FFT length (N_f)	4, 096
GI length ($N_{\rm GI}$)	800

Preamble and T-symbol

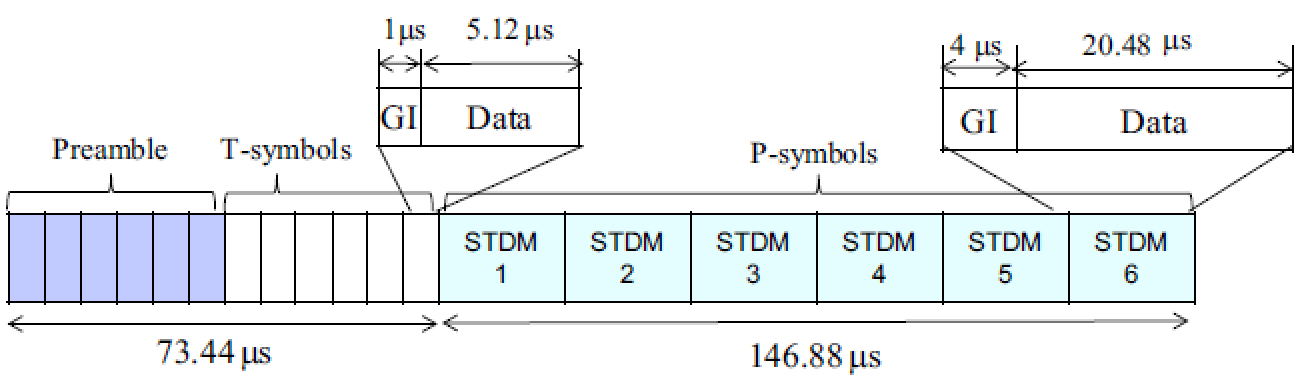
T-symbol duration ($T_{\rm T}$)	6.12 μs
Payload duration	5.12 μs
GI duration	1 μs

P-symbol

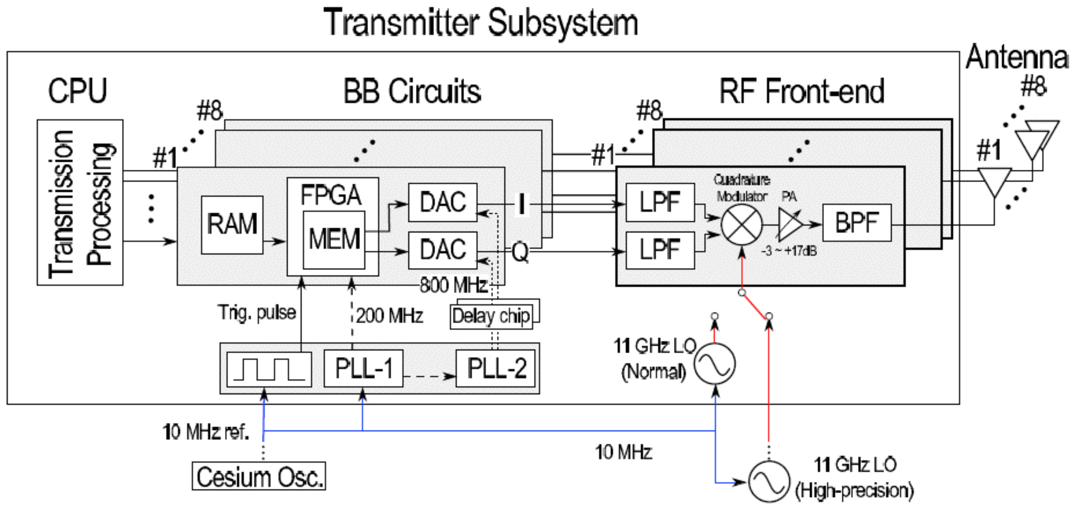
P-symbol duration	24.48 μs
Payload duration	20.48 μs
GI duration	4 μs
FDM tone spacing (Δ_f)	48.8 kHz

Scalable frame format

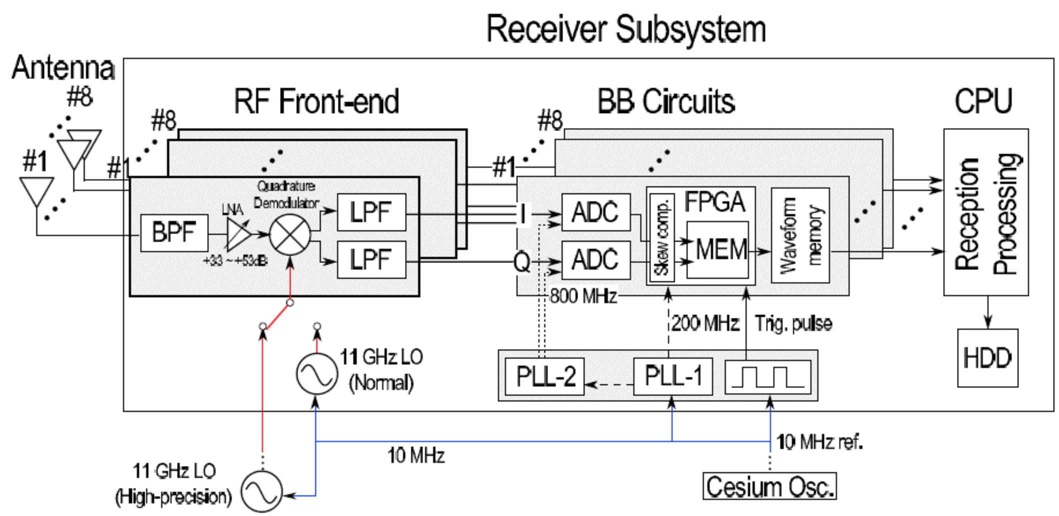
No. Tx units ($N_{\rm Utx}$)	1 $\sim$ 6 (scalable)
No. Rx units ($N_{\rm Urx}$)	1 $\sim$ 6 (scalable)
No. ant. per unit (N_A)	4
No. Preamble symbols No. T-symbols No. P-symbols	$N_{\rm Utx}$
Frame duration	36.72 $\sim$ 220.32 μs



- Subsystem



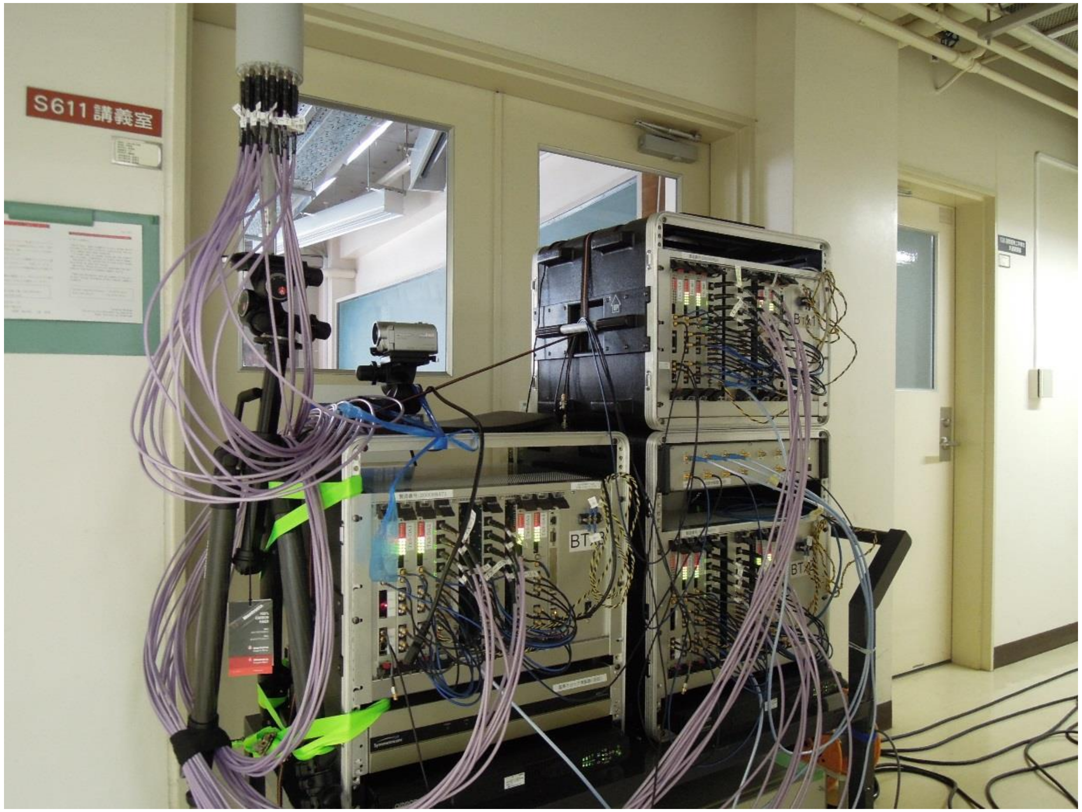
(a) 8 channels Tx subsystem

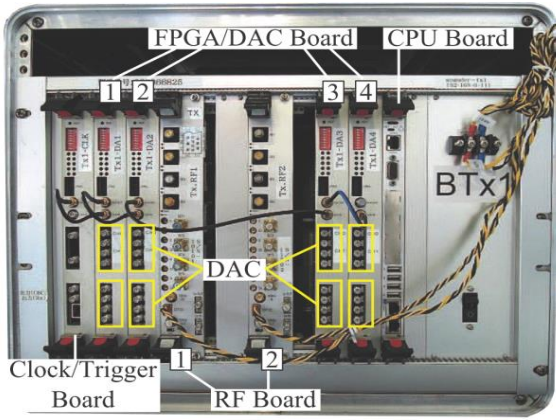


(b) 8 channels Rx subsystem

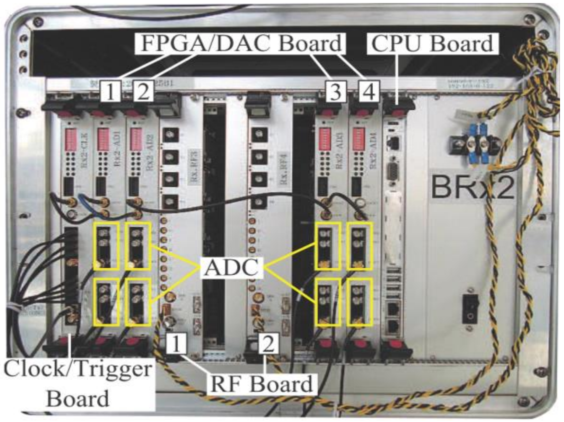
: 10 MHz reference
: FPGA clock (200 MHz)
: 11 GHz LO
: Sampling clock (800MHz)

- Transmitter with 24 antennas composed of 3 sub-systems



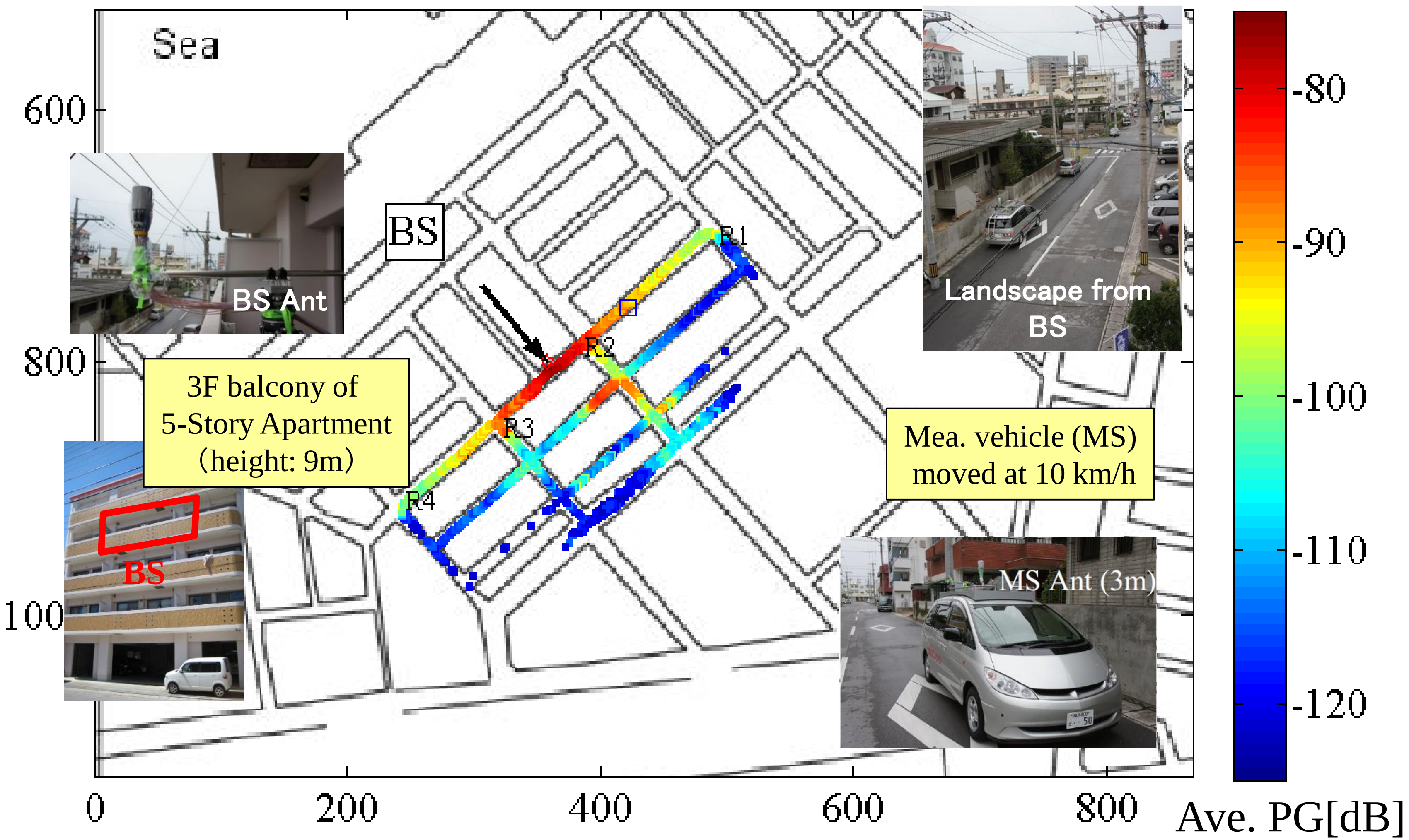


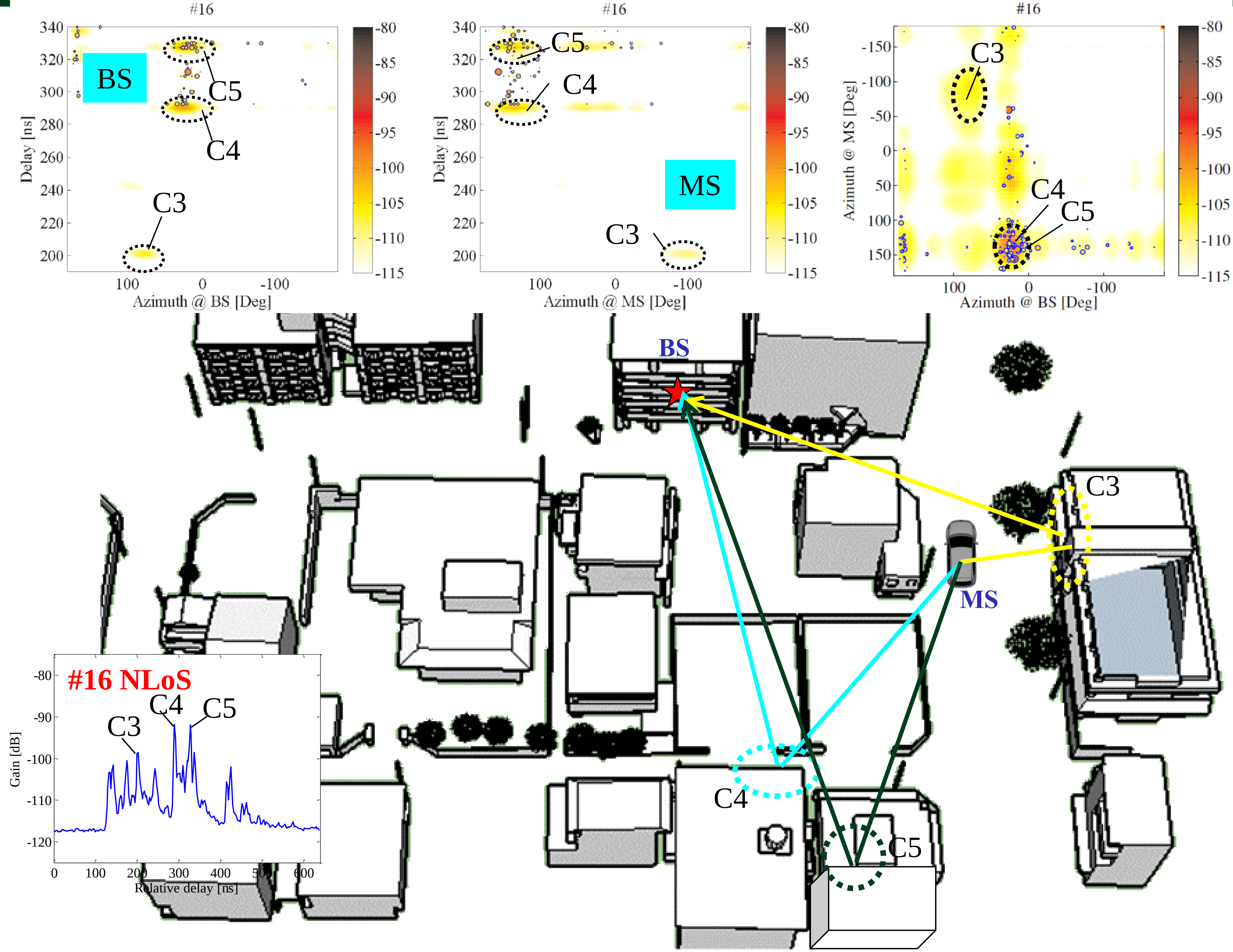
Tx sub-system



Rx sub-system

Measurement Example





#16
Delay [ns]
Azimuth @ BS [Deg]
BS
C3
C4
C5
#16
Delay [ns]
Azimuth @ MS [Deg]
MS
C3
C4
C5
#16
Azimuth @ MS [Deg]
Azimuth @ BS [Deg]
C3
C4
C5
BS
MS
C3
C4
C5
#16 NLoS
C3
C4
C5
Gain [dB]
Relative delay [ns]

Summary

- 5G mobile system trend
  - High bit-rate mobile communication systems
  - Microwave and MIMO
- Channel sounding principle
  - Channel sounding
  - Double-directional channel model
- Hardware architecture
  - General architecture
  - Developed hardware architecture

Challenges

- Lack of appropriate channel models at high frequency bands
  - Outdoor, Outdoor-Indoor, and with mobility
  - Site-specific characteristics
- Lack of information about channel parameters
  - Large scale parameters: path loss, delay/Doppler/angular spread
  - Small scale parameters:
- Importance in
  - Develop and test the required physical and higher layer components
  - Perform link and system level feasibility studies
  - Investigate spectrum engineering regulatory issues such as interference risks and co-existence