2017 2Q

Wireless Communication Engineering

#0 Introduction to Course

Kei Sakaguchi
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June 12, 2017

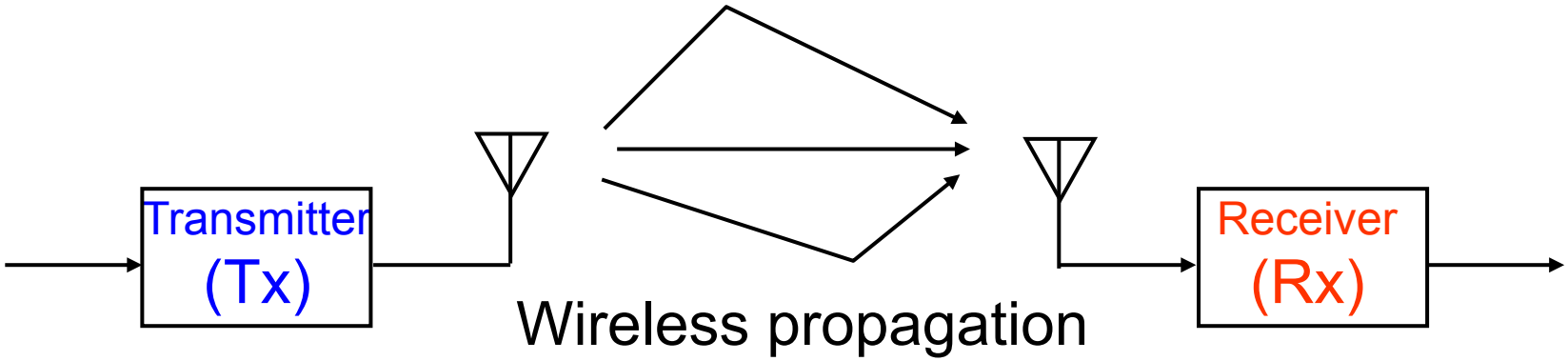
Wireless Communication Systems

- Your surrounding wireless communications

1) Pick up your surrounding wireless communication systems as many as possible

2) Explain specifications (frequency, modulation schemes, etc.) of those systems

- Wireless communication systems



Aims of Course

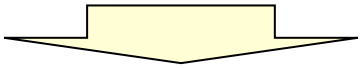
- Aims
  This course enables students to have basic techniques to design wireless communication systems such as wireless LANs and cellular systems as in our daily life.

- Measure
  By picking up IEEE802.11a as a representative of modern wireless communication systems, the lecture gives details about technologies used in the system such as interference management, diversity combining, and multplexing.

- Outcomes
  The studetnts will be able to understand the design concept, transceiver architecture, role of components, and specifications of IEEE802.11a wireless LAN.

Related Courses

- Fourier Transform and Laplace Transform
  Spectrum, Convolution, Frequency conversion
- Applied Probability and Statistical Theory
  Gaussian distribution, Stochastic process, Auto correlation, Power spectral density
- Communication Theory
  Source & channel coding theory, Mutual Information
- Signal Systems
  Linear time-invariant system, Signal space analysis



- Wireless Communication Engineering (this course)

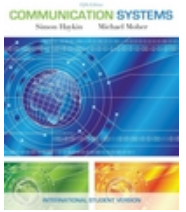
Textbooks

- Textbook
  H. Matsue, M. Morikura, A. Sato, K. Watanabe, “Broadband Wireless Access Technologies,” IEICE, 2004. (in Japanese)

- Reference books
  S. Taromaru, K. Sakaguchi, “Design of Software Defined Radio,” Kagakujyoho Shuppan, 2016. (in Japanese)

  K. Sakaguchi, S. Sampei, “Wireless Distributed Networks,” IEICE, 2011. (in Japanese)

  S.Haykin, “Communication Systems,” 5th Edition International Student Version, Wiley, 2013.



Contents of Textbook

Chapter	Contents	Notes
1	Introduction to wireless access	
2	Propagation modeling for wireless access	Not so much With other prints
3	Digital modulation & demodulation	Major scope
4	Factor of performance degradation and technologies to mitigate them	Major scope
5	Antenna	Out of scope
6	Access scheme	Major scope
7	WLAN system	Major scope
8	WLAN other than IEEE802.11	Out of scope
9	Fixed Wireless Access (FWA)	Out of scope

Course Schedule (1)

	Date	Text	Contents
#1	June 12	1, 7	Introduction to wireless communication systems
#2	June 15	2, 5, etc	Link budget design of wireless access
#3	June 19		Up/down conversion and equivalent baseband system
#4	June 22	3.3, 3.4	Digital modulation and pulse shaping
#5	June 26	3.5	Demodulation and detection error due to noise
#6	June 29		Collaborative exercise for better understanding 1
#7	July 3	4.4	Channel fading and diversity combining
#8	July 6	4.6	Error correction coding

Course Schedule (2)

	Date	Text	Contents
#9	July 10		Adaptive modulation coding
#10	July 13	4.3	Inter symbol interference and adaptive equalizer
	July 17		No class
#11	July 20	3.6, 4.5	Spread spectrum and code division multiple access (CDMA)
#12	July 24	3.5	Orthogonal frequency division multiplexing (OFDM)
#13	July 27		Array signal processing and MIMO communications
#14	July 30		Collaborative exercise for better understanding 2
#15	TBD	All	Final examination

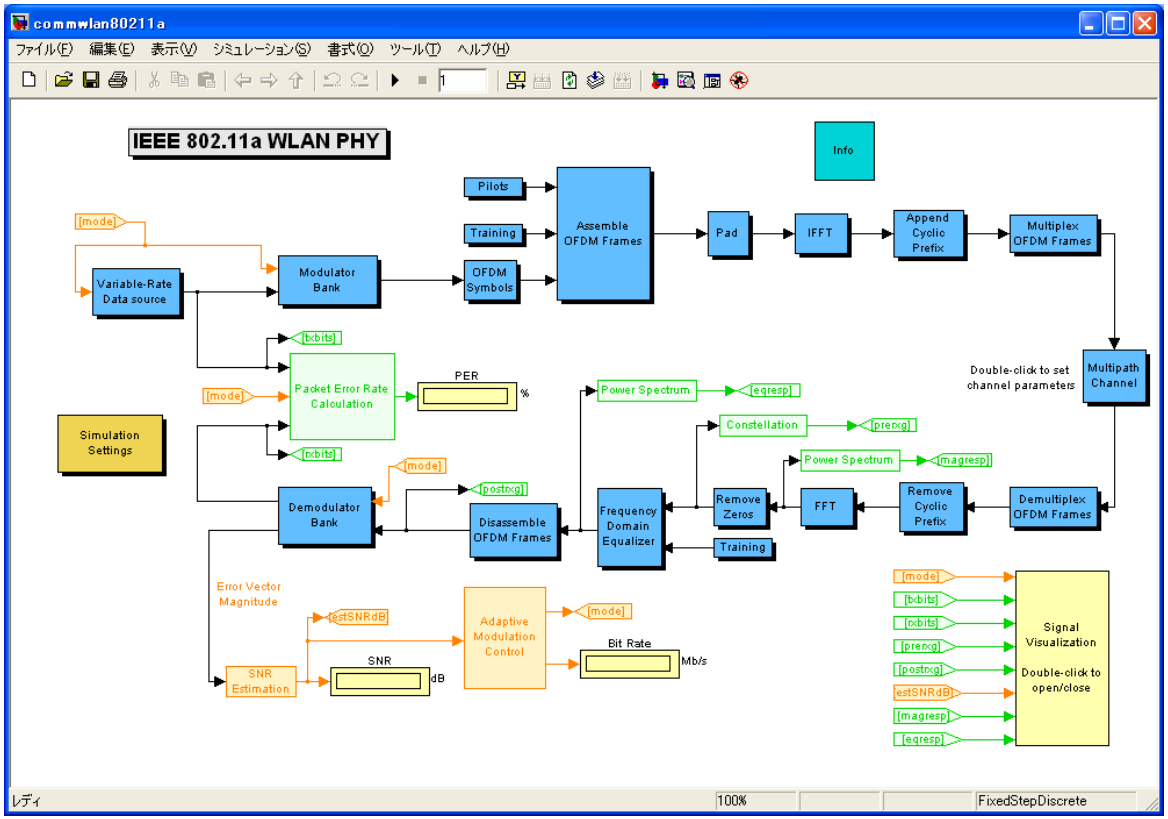
Assessment Criteria

- Collaborative exercise (50 points)
  Date: June 29 (Thu) and July 30 (Mon)
  Method:
  Collaborative exercise between students
  Questions are given in advance for better understanding
  Evaluation on the answer after collaborative discussions

- Final examination (50 points)
  Date: Beginning of august
  Method: Paper test to check technological understanding

MATLAB Simulator

- Demonstration
  IEEE802.11a WLAN demo is available in MATLAB
  (Download MATLAB from http://tsubame.gsic.titech.ac.jp/MATLAB-TAH)



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#1 Introduction to Wireless Communication Systems

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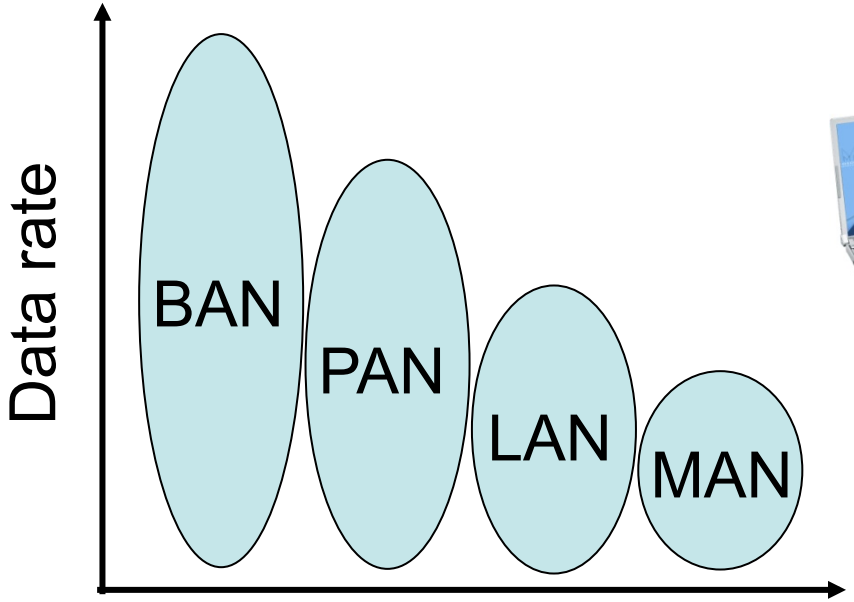
Contents

- Introduction to wireless communication systems
- Design of wireless communication systems
- Performance degradation factors
- Technologies to mitigate them
- Introduction of IEEE802.11a WLAN
- MATLAB demonstration

Classification of Wireless Communication Systems

Body
Area Network

Personal
Area Network

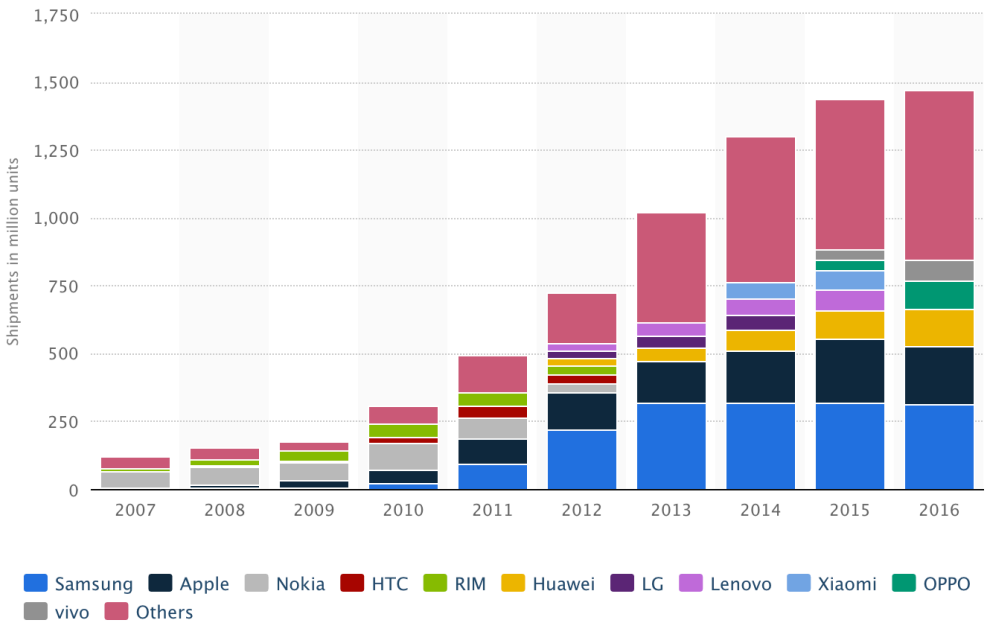


Local
Area Network

Metropolitan
Area Network

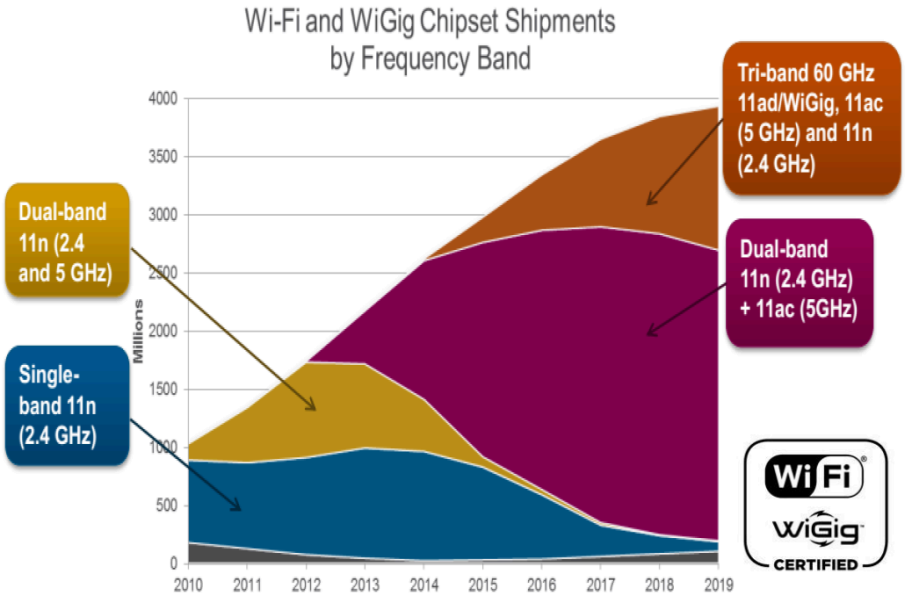
Status of Cell-phone and WLAN

of shipments of cell-phone



(@ Statista)

of Wi-Fi chipset shipment



(@ ABI Research)

International Harmonization & Spectrum Regulation

ITU
(International Telecommunication Union)

- International spectrum recommendation
- 3kHz ～ 300GHz

WRC
(World Radio Conference)

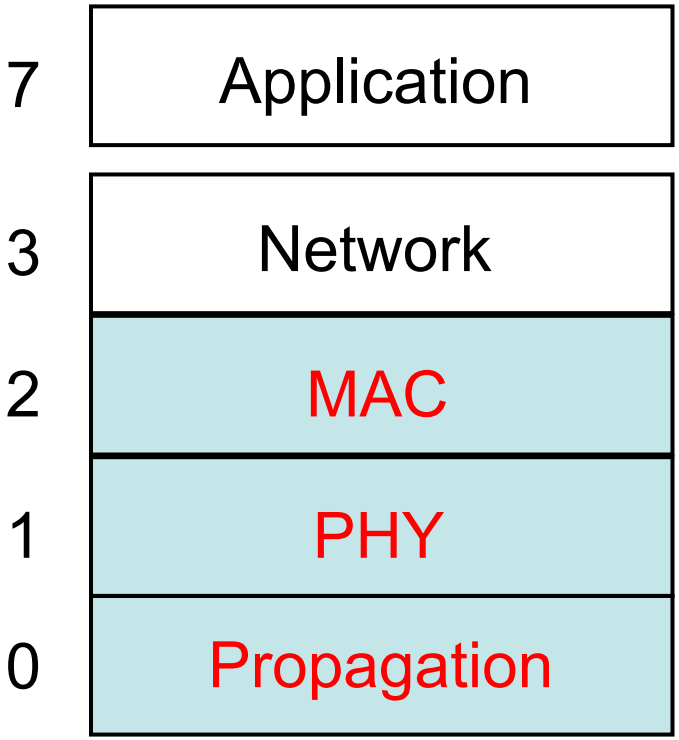
- Amendment of international treaty
- Every 4 years
- Latest meeting at Nov. 2015

Spectrum allocation in Japan

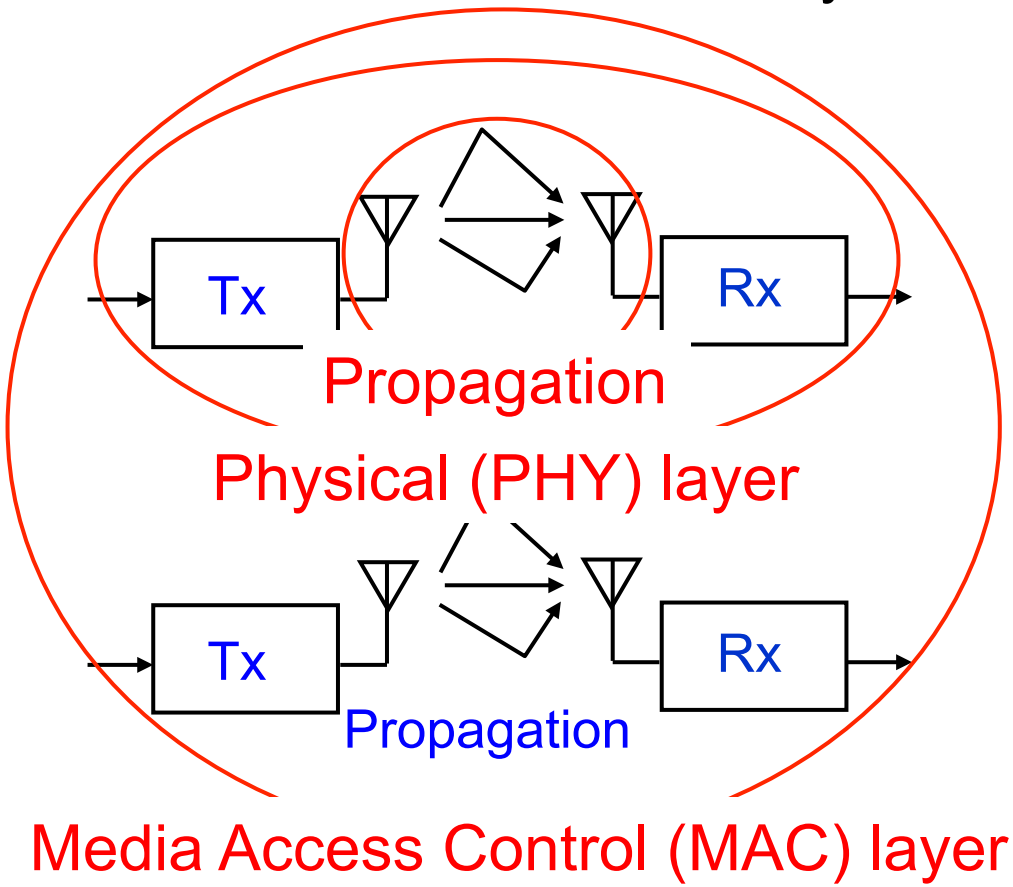
Milli	60GHz	Ultra high speed WLAN
	38GHz	Fixed Wireless Access (FWA)
Sub-milli	26GHz	
	19GHz	High speed WLAN
Micro	5GHz	High speed WLAN
Sub-micro	2.5GHz	High speed WMAN (WiMAX)
	2.4GHz (ISM band)	Low power data access (WLAN)
	2GHz	4G cell phone (LTE)
	1.9GHz	PHS
	1.5GHz	3G cell phone (WCDMA)
	900MHz	
	800MHz	

Wireless Communication Systems

Layer structure

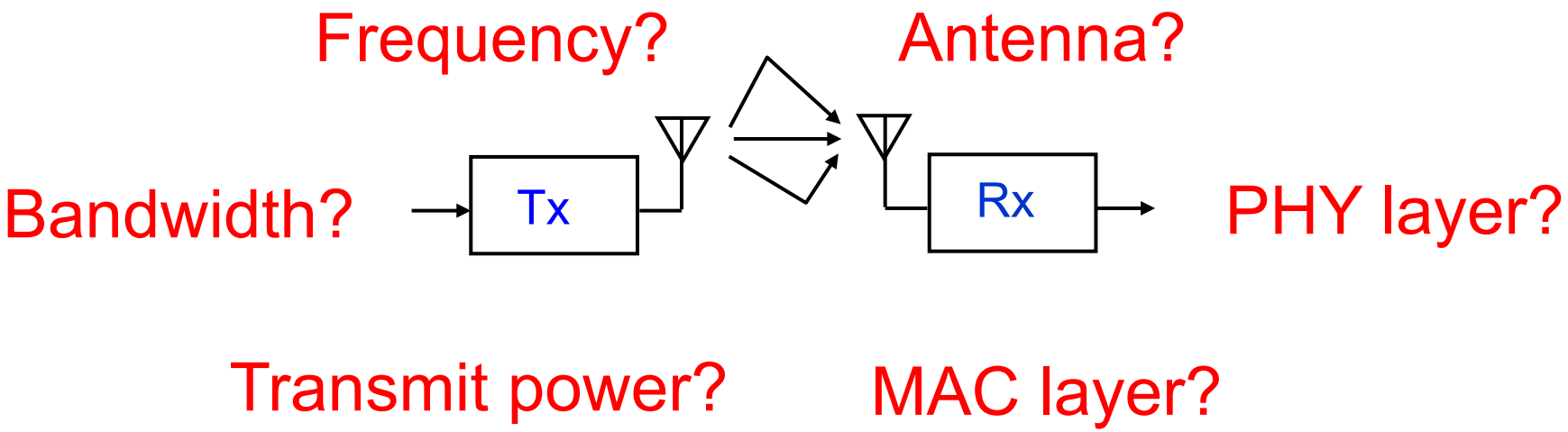


Wireless communication system



Design of Wireless Communication Systems

How to design wireless communication systems?



Frequency, Bandwidth, Tx Power

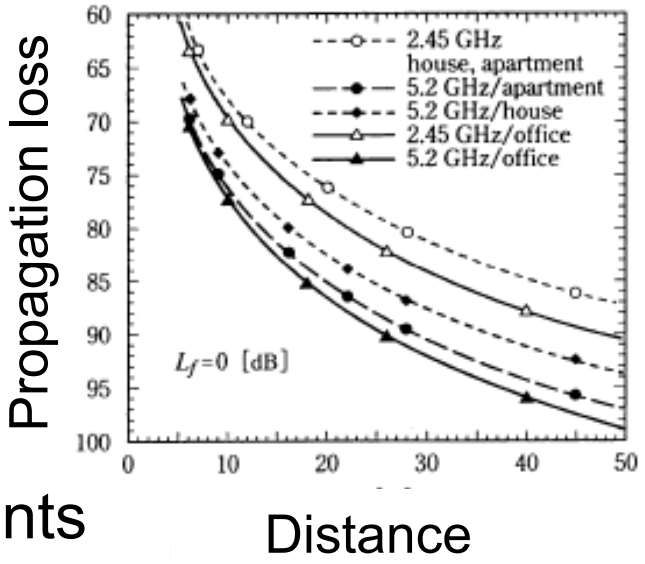
1. Scenarios
   Indoor, Outdoor, Distance, Data rate

2. Frequency and Bandwidth
   Politically determined based on
   ITU-R recommendation

3. Propagation loss
   Depends on frequency and environments

4. Transmission power
   Minimum data rate → Minimum Rx power
   Minimum Rx power + Propagation loss = Minimum Tx power
   Unnecessary increase of Tx power causes interferences

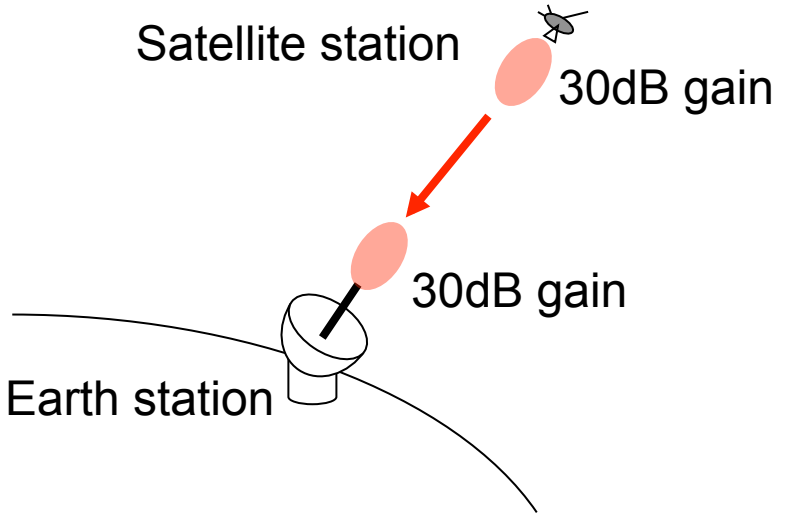
Indoor propagation



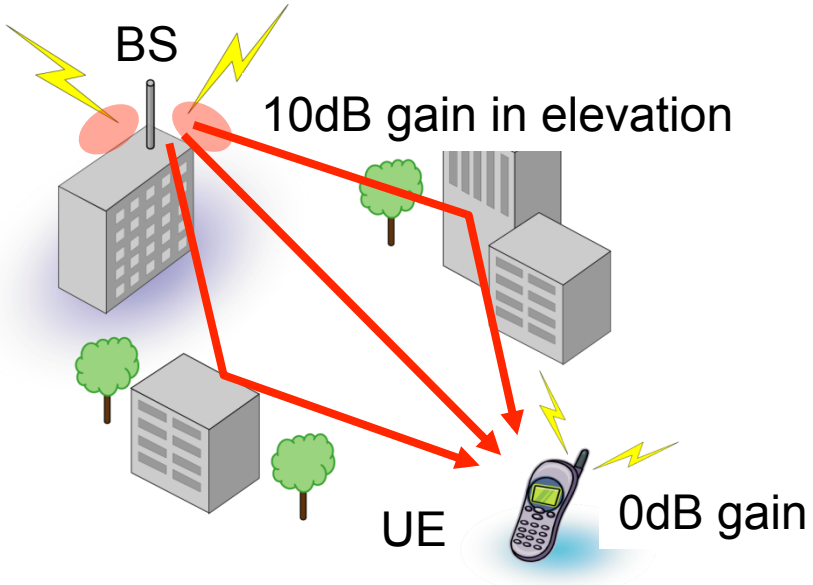
Antenna

5. Antenna
   To compensate propagation loss due to distance
   Design of antenna location and directivity

Satellite communication



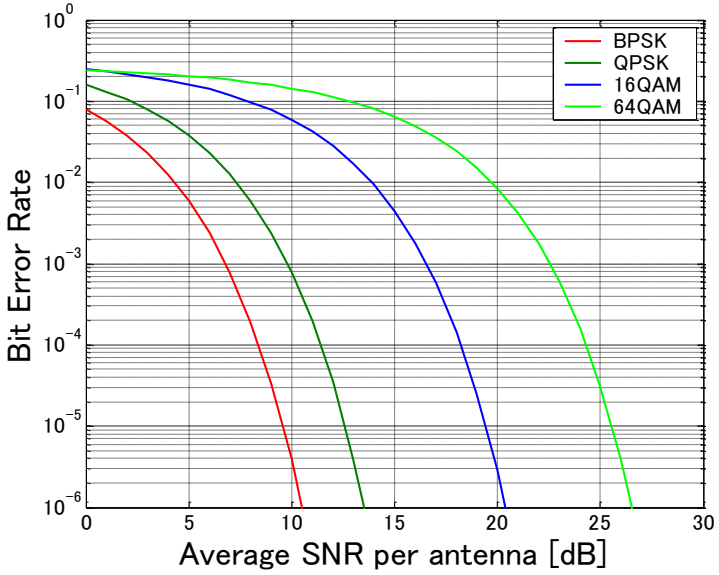
Mobile communication



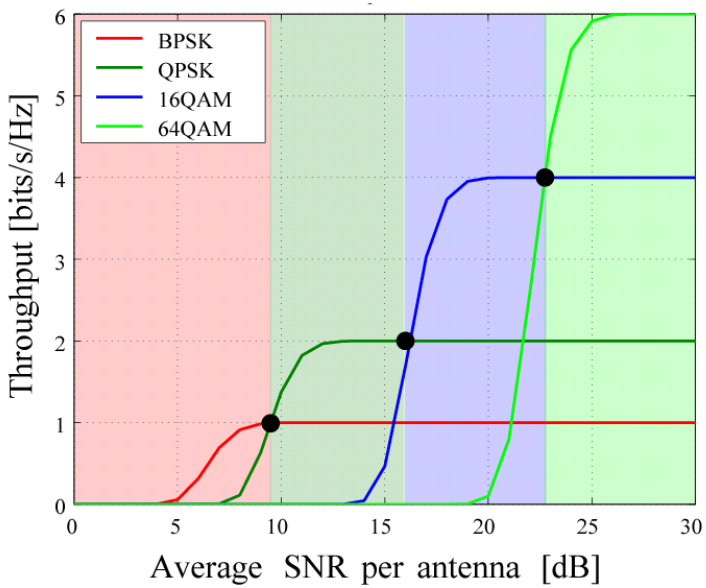
PHY Layer

6. Physical (PHY) layer scheme
   Maximization of reliability → Forward error correction
   Maximization of data rate → Adaptive modulation & coding
   Tradeoff between performance and complexity

Error rate performance



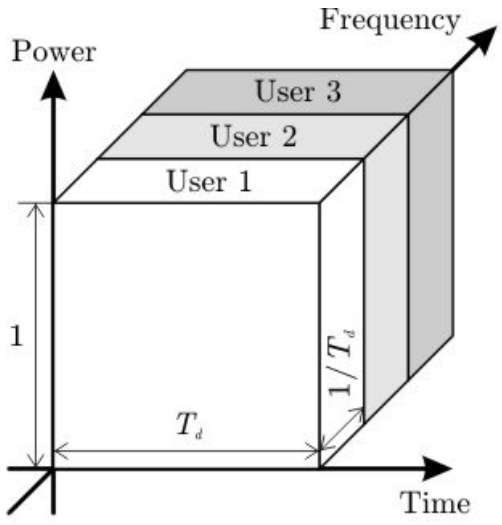
Throughput performance



MAC Layer

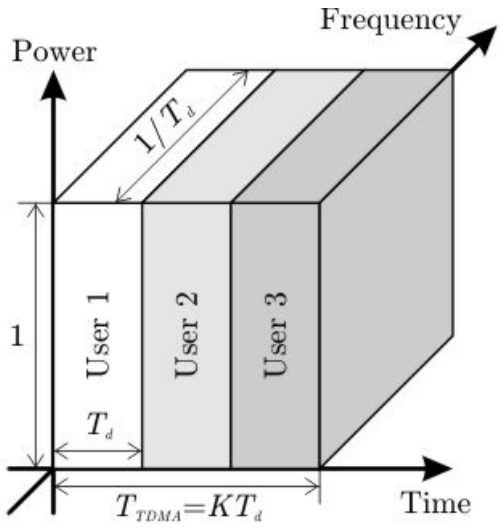
7. Media Access Control (MAC) scheme
   Resource allocation rule for multiple terminals
   Reserved: FDMA、TDMA、CDMA
   Contention: ALOHA、CSMA (Carrier Sense Multiple Access)

Frequency division



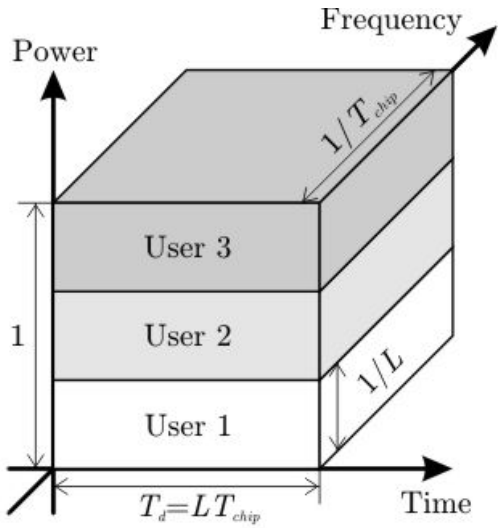
FDMA

Time division



TDMA

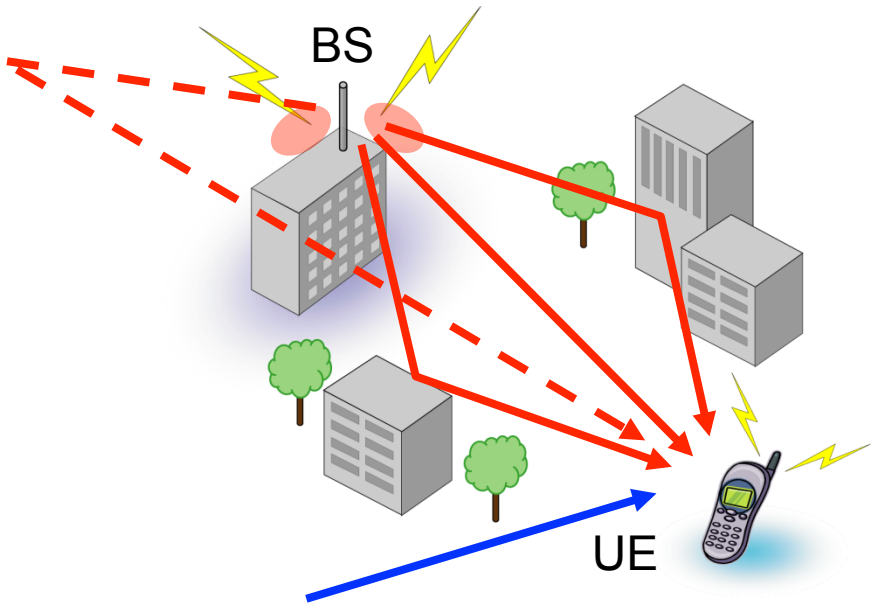
Code division



CDMA

Performance Degradation and Technologies to Mitigate

Factor of performance degradation in wireless communications



Fading (standing wave)

Superposition of multi-path signals

Inter symbol interference

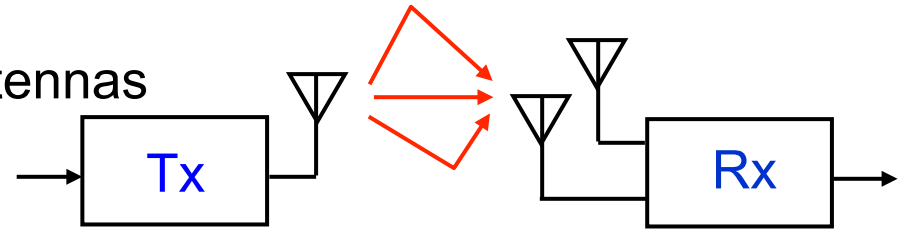
Due to long delayed signals

Inter system interference

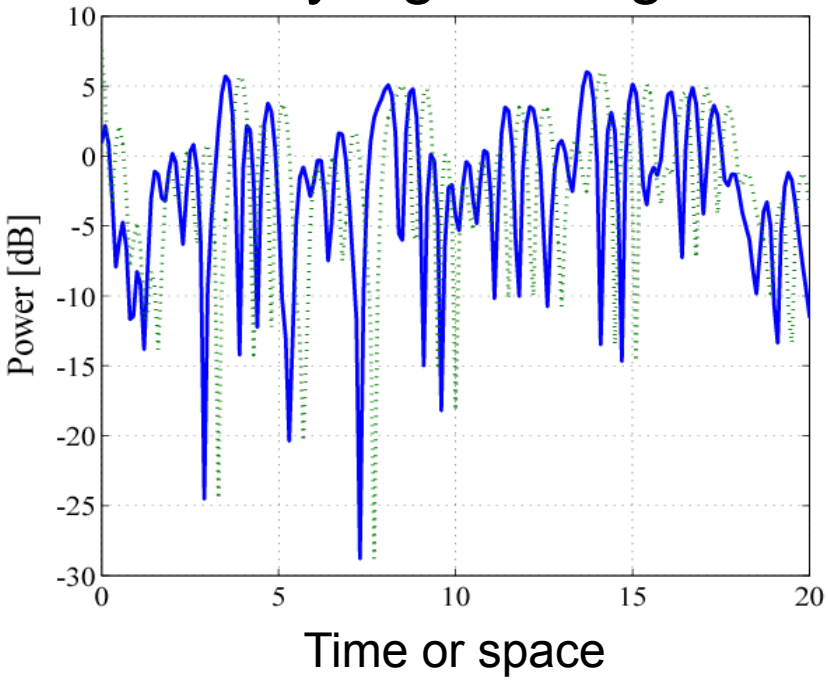
Due to shared radio channels (ISM)

Fading and Diversity

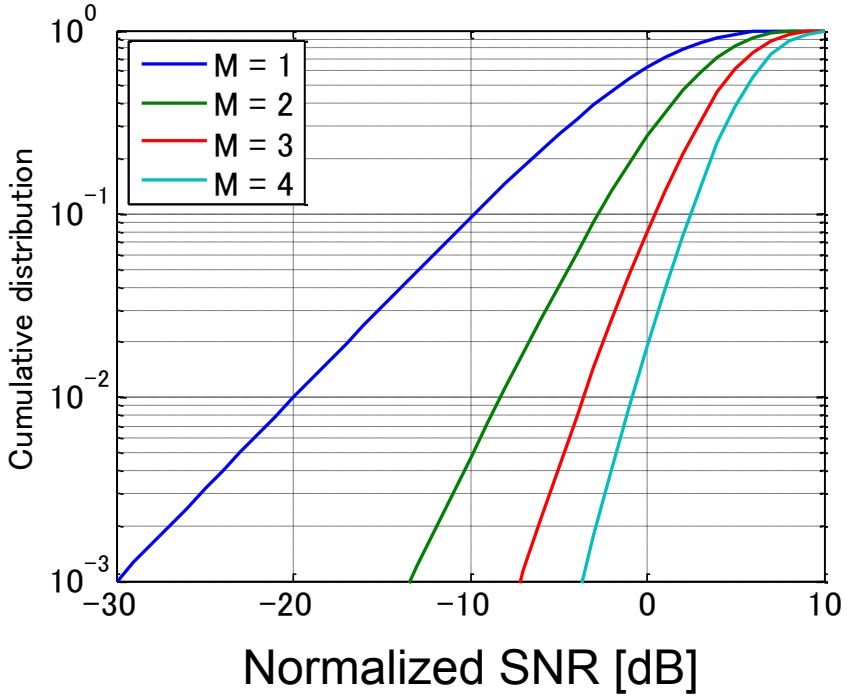
1. Diversity
   Power fluctuation due to fading
   Weighted Combining of multiple antennas
   Space/Time/Freq diversity



Rayleigh fading



CDF of SNR

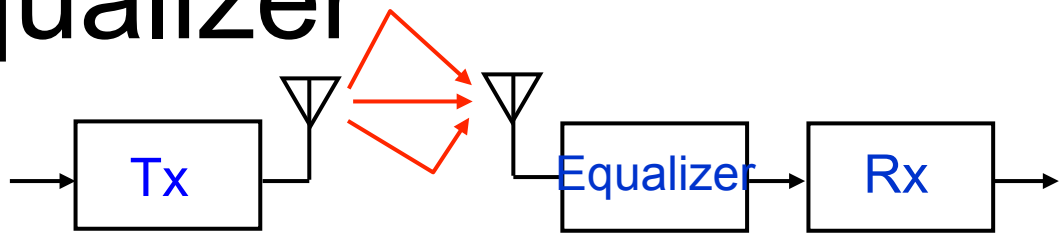


Inter Symbol Interference and Equalizer

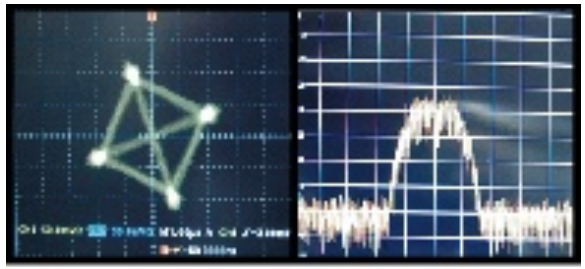
2. Equalizer

Inter symbol interference due to delayed signal

→ Equalizer to realize inverse frequency response

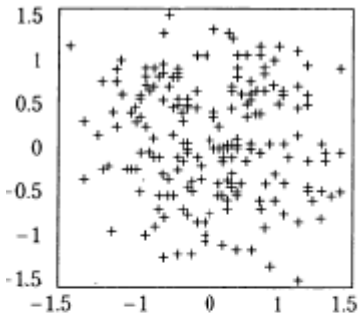


Inter symbol interference

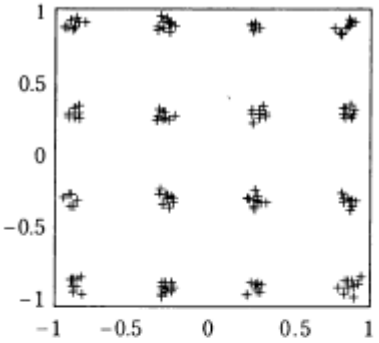


Without delay signal

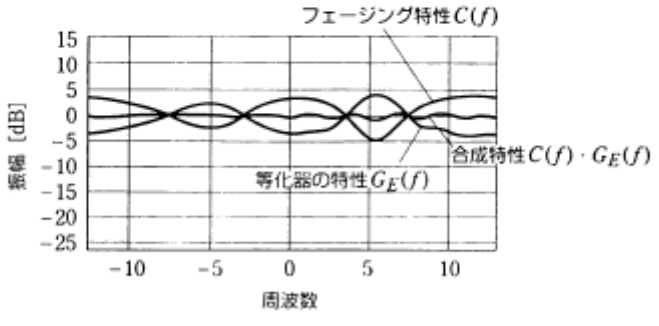
With delay signal



Before equalization



After equalization



Frequency response of equalizer

Inter System Interference and CDMA

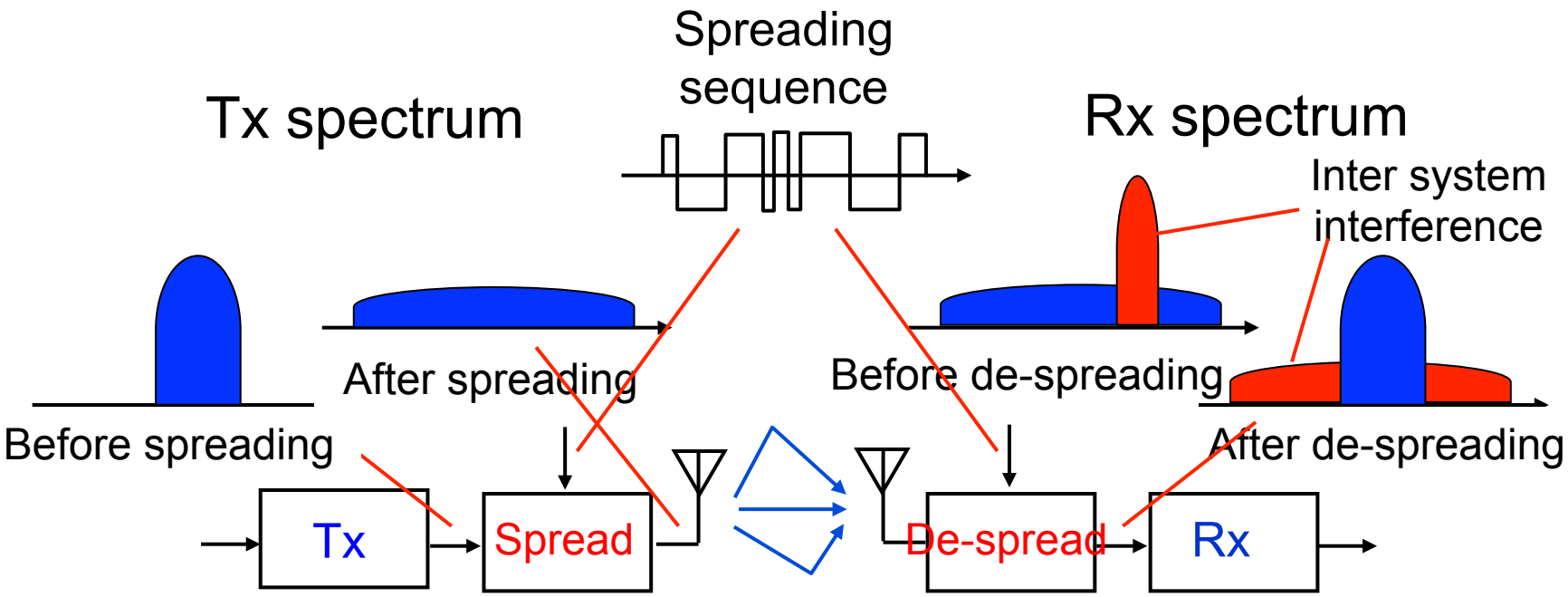
3. CDMA

   Inter system interference due to shared radio channels

   Spreading & de-spreading using common code between Tx & Rx

   Code Division Multiple Access (CDMA)

   → Suppress interference from other systems



Inter Symbol Interference and OFDM

4. OFDM

Inter Symbol Interference due to delay

⇩

Time domain equalizer

⇩

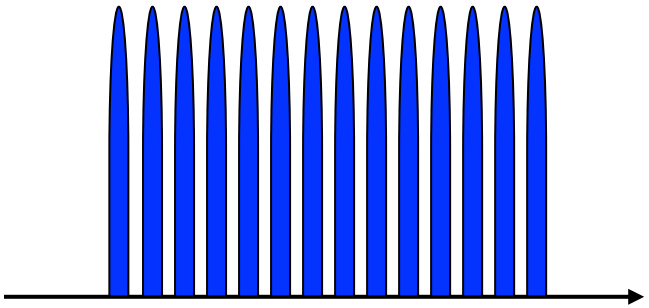
Principally infinite tap is needed

⇩

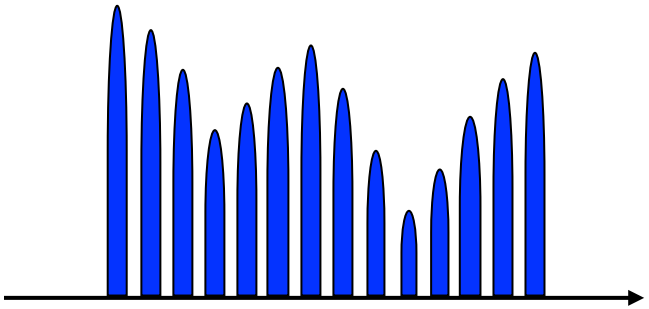
Frequency domain filter

⇩

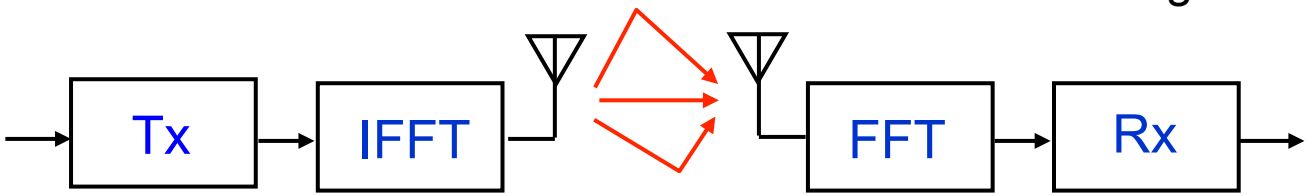
Orthogonal frequency division multiplexing



Tx signal in frequency



Rx signal in frequency

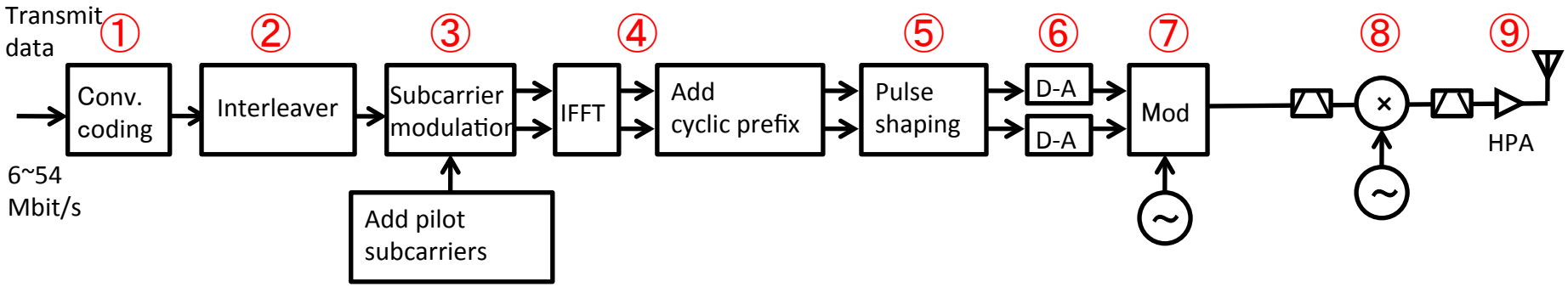


IEEE802.11 WLAN

Wireless access in indoor environment using ISM band

	802.11b	**802.11a**	**802.11g**	**802.11n**	**802.11ac**
Year of approval	1999	1999	2003	2009	2014
RF band	2.4GHz	5GHz	2.4GHz	2.4 & 5GHz	5GHz
Channel bandwidth	20MHz	20MHz	20MHz	20/40MHz	20/40/80/ 160MHz
Modulation	DSSS, CCK	OFDM, AMC	OFDM, AMC, CCK	MIMO-OFDM, AMC, CCK	MIMO-OFDM, AMC256Q, MU-MIMO
Max data rate	11Mbps	54Mbps	54Mbps	600Mbps	6.93Gbps
MAC	CSMA/CA	CSMA/CA	CSMA/CA	CSMA/CA	CSMA/CA+ MU-MIMO

IEEE802.11a Transmitter



① Convolutional coding + Puncture
Adaptive parity bit control

② Interleaver
Subcarrier randomization

③ Subcarrier modulation
BPSK～64QAM adaptive modulation

④ IFFT＋Add cyclic prefix
OFDM modulation

⑤ Pulse shaping
Reduce power leakage

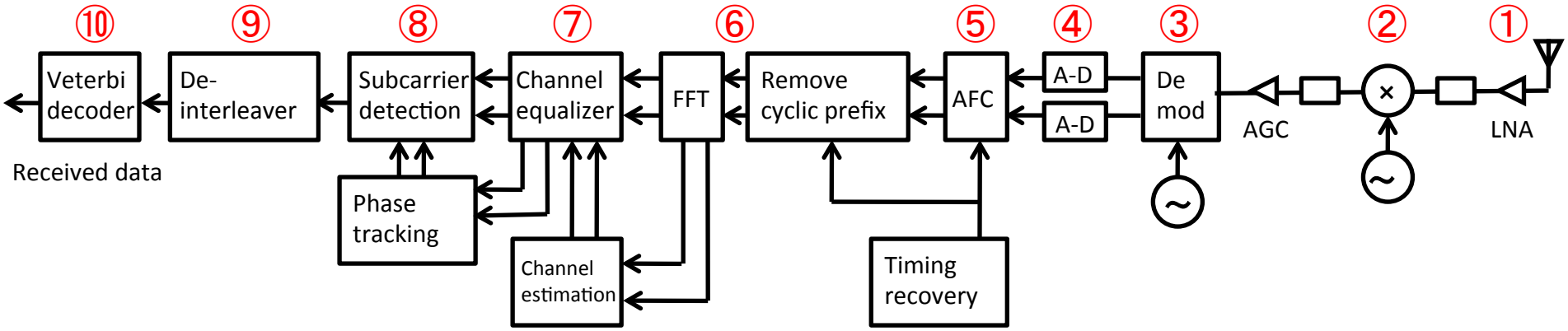
⑥ D-A
Digital-Analog conversion

⑦ Modulation
Conversion to IF signal

⑧ Mixer
Conversion to RF(5GHz) signal

⑨ High power amplifier + antenna
Transmission of RF signal

IEEE802.11a Receiver



① Antenna + Low noise amplifier
Receiption of RF signal

② Mixer
Frequency conversion to IF

③ Demodulator
Conversion to baseband signal

④ A-D
Analog-Digital conversion

⑤ AFC、Timing recovery
Time frequency synchronization

⑥ Remove cyclic prefix + FFT
OFDM demodulation

⑦ Channel equalizer
Frequency domain equalizer

⑧ Subcarrier detection
BPSK～64QAM demodulation

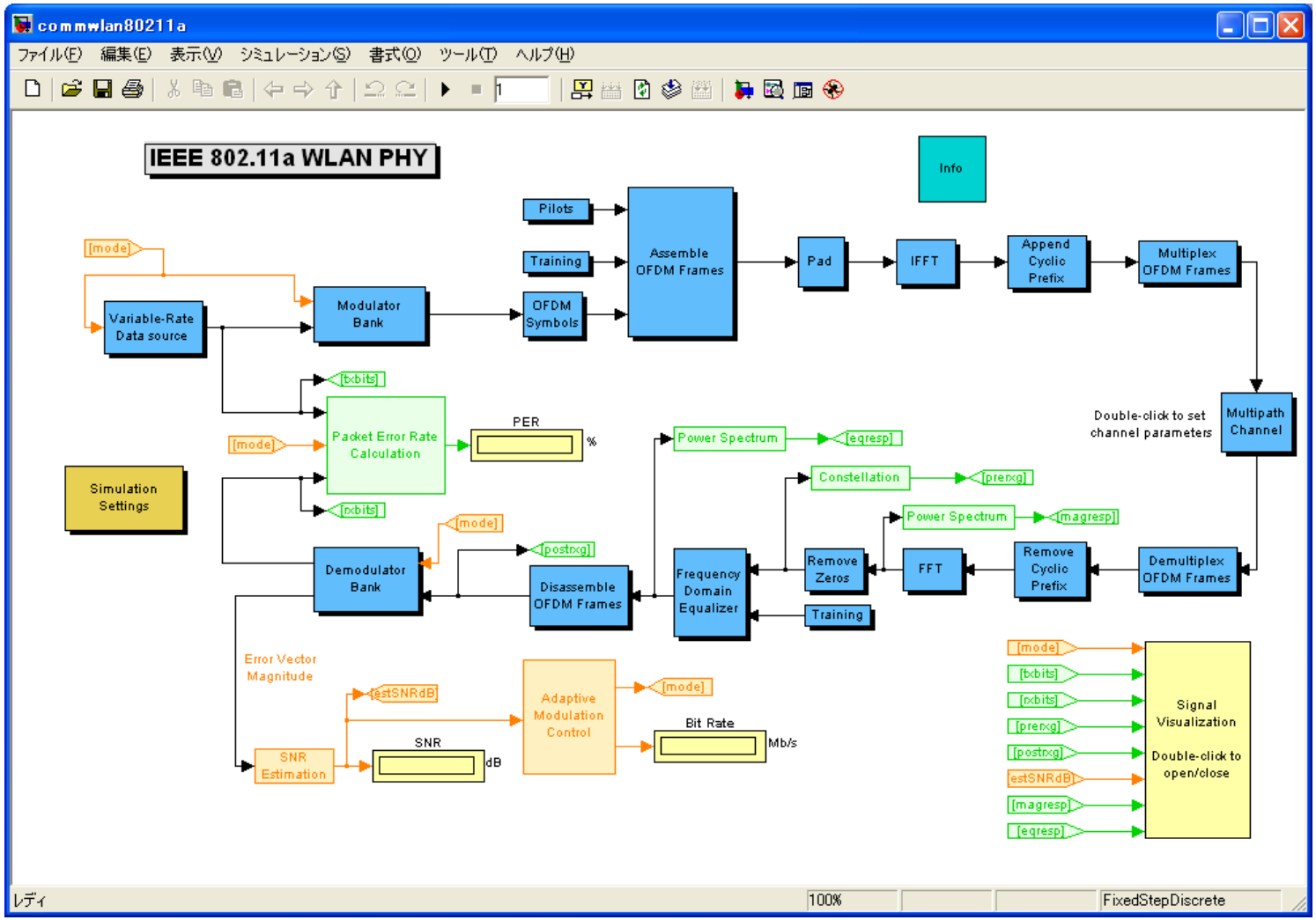
⑨ De-interleaver
Inverse of interleaver

⑩ Viterbi decoder
Forward error correction

Specification of IEEE802.11a

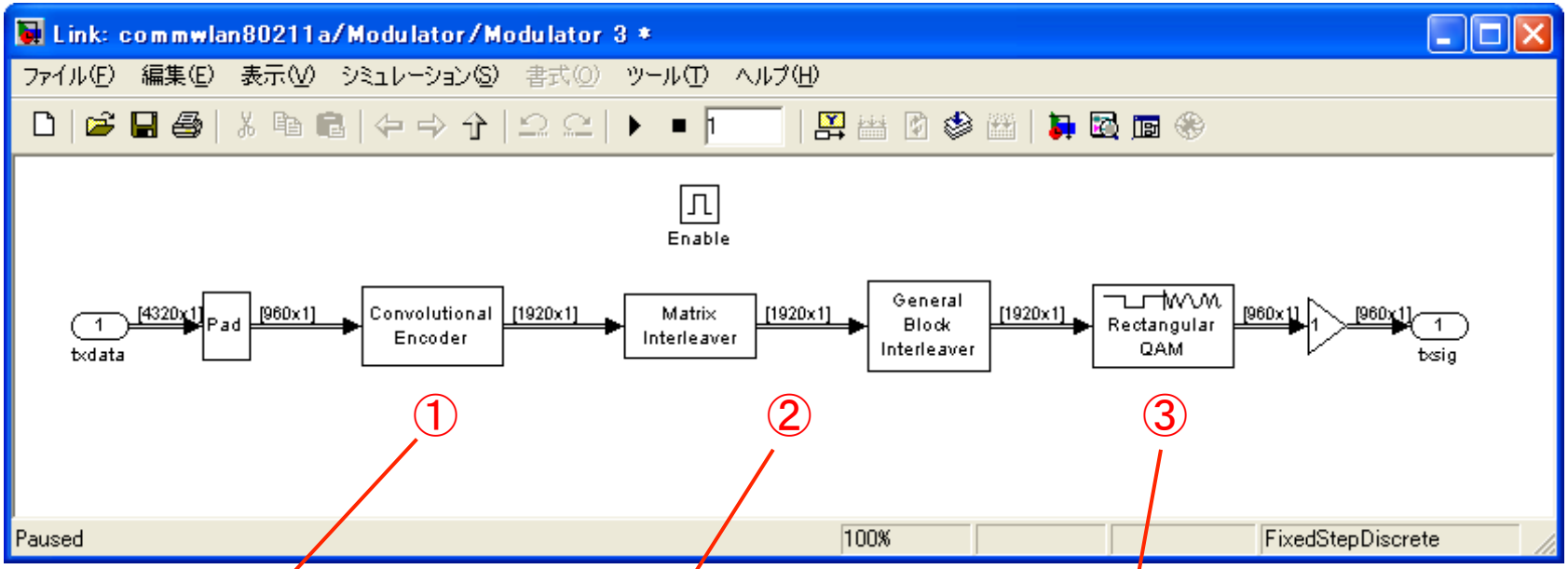
Modulation	OFDM (Orthogonal Frequency Division Multiplexing) （Subcarrier modulation: BPSK, QPSK, 16QAM, 64QAM）
Subcarriers	52 (including 4 pilot subcarriers) Assuming 64 point FFT
Error correction	Convolutional coding with subcarrier interleaver constraint length: K=7, coding rate: R=1/2, 2/3, 3/4 Viterbi decoding
Data rates	6 Mbit/s (BPSK, R=1/2) mandatory 9 Mbit/s (BPSK, R=3/4) option 12 Mbit/s (QPSK, R=1/2) mandatory 18 Mbit/s (QPSK, R=3/4) option 24 Mbit/s (16QAM, R=1/2) mandatory 36 Mbit/s (16QAM, R=3/4) option 48 Mbit/s (64QAM, R=2/3) option 54 Mbit/s (64QAM, R=3/4) option
OFDM symbol	4.0 μs
Guard interval	0.8 μs
Bandwidth	16.6 MHz
Channel	4 (Available frequency: 5.150～5.250 MHz [Japan]) Channel spacing：20MHz

IEEE802.11a Demonstration



IEEE802.11a Demo (Tx1)

Subcarrier modulation



① Convolutional coding

② Interleaver

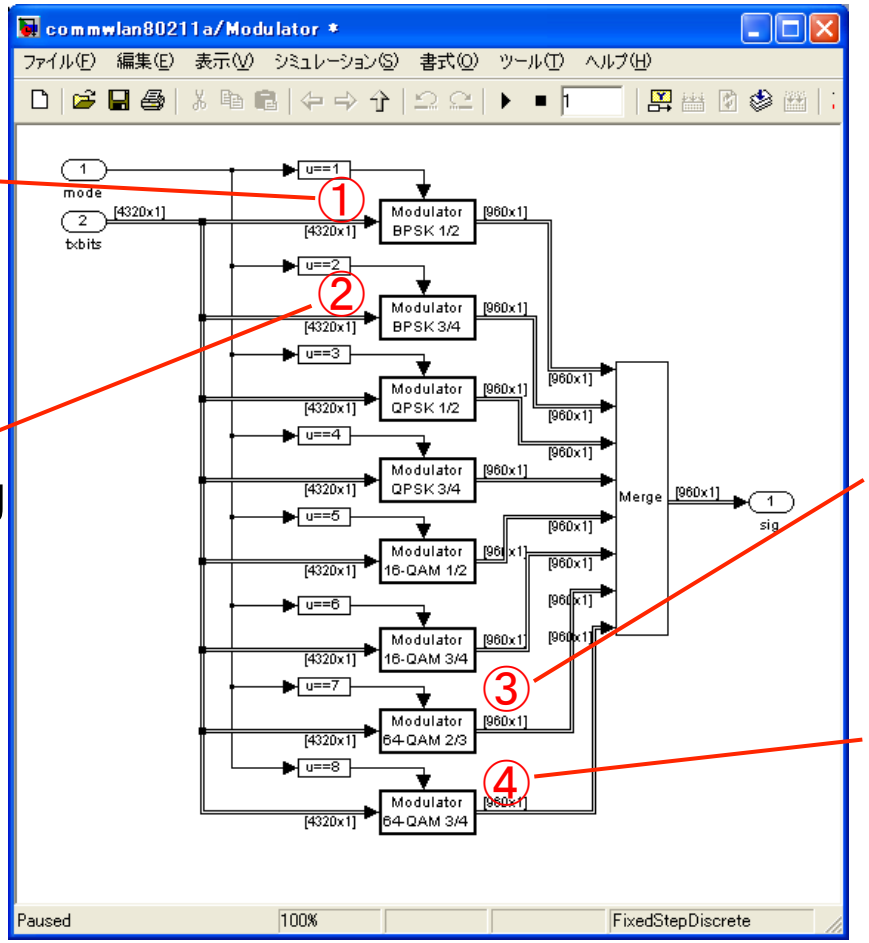
③ QAM modulation

IEEE802.11a Demo (Tx2)

Adaptive Modulation Coding

BPSK＋
rate 1/2 conv. coding
= 6Mbps

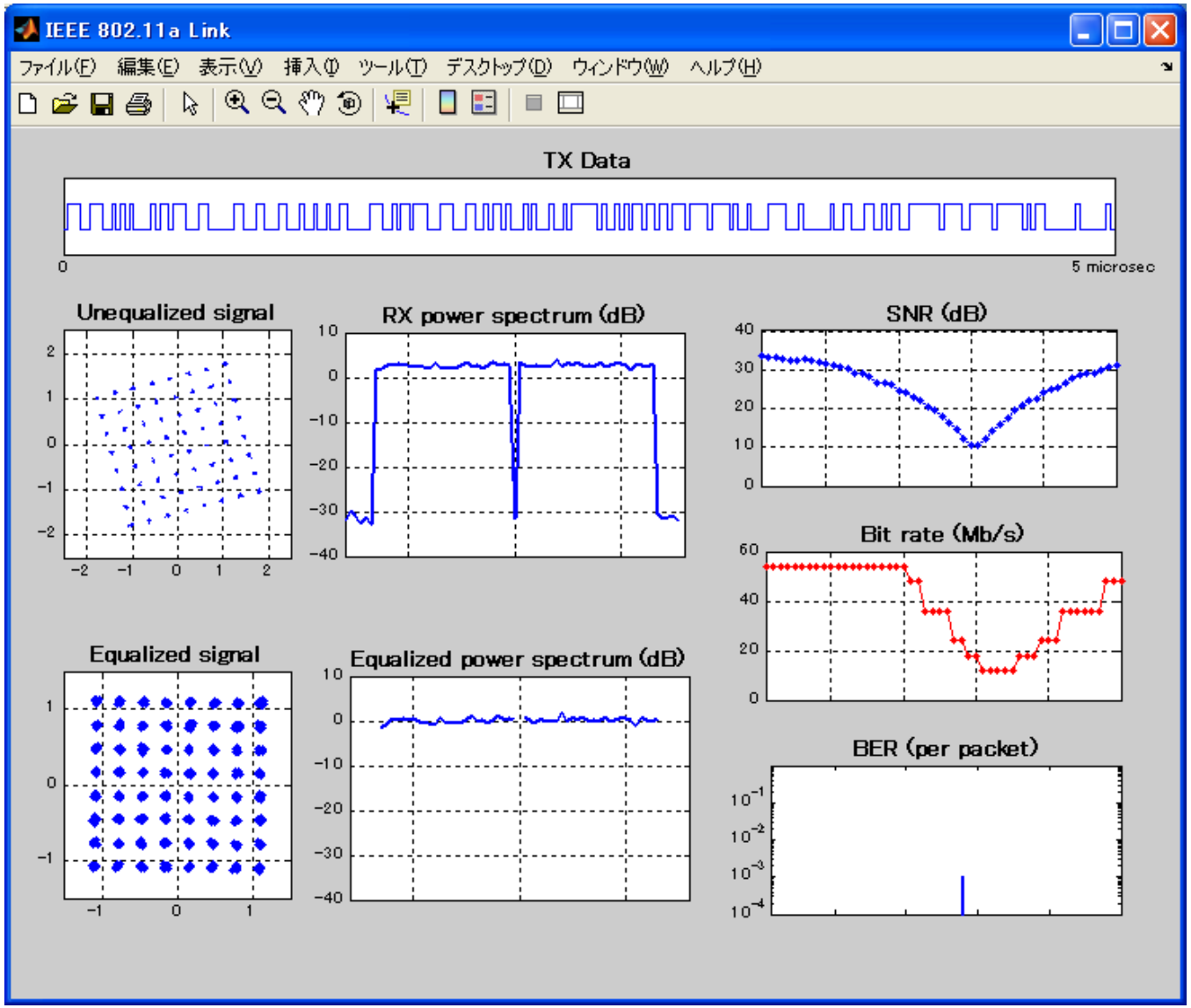
BPSK＋
rate 3/4 conv. coding
= 9Mbps



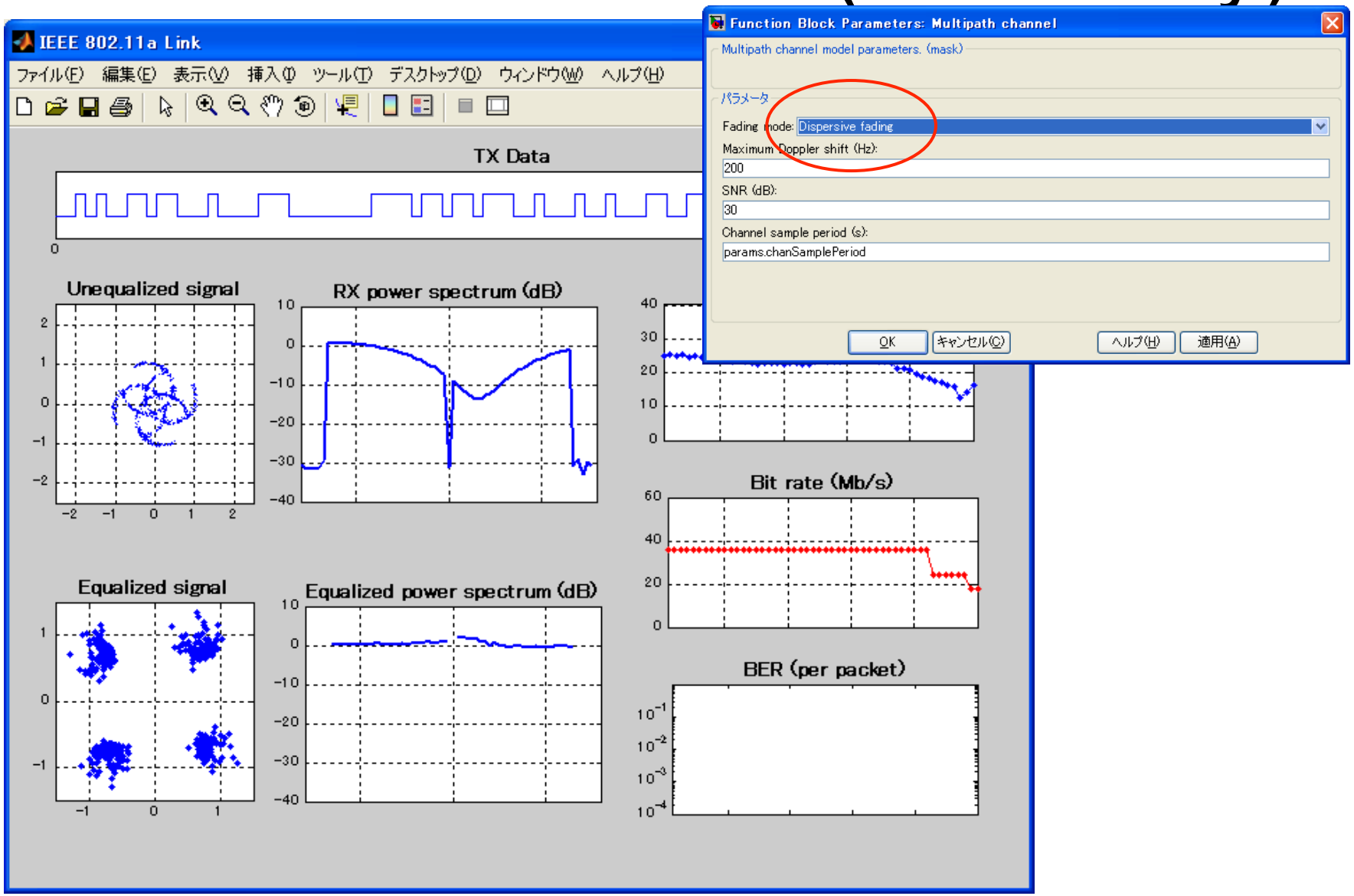
64QAM＋
rate 2/3 conv. Coding
= 48Mbps

64QAM＋
rate 3/4 conv. coding
= 54Mbps

IEEE802.11a Demo (no delay)



IEEE802.11a Demo (with delay)



Summary

- Introduction to wireless communication systems
  BAN, PAN, LAN, MAN, ITU, PHY, MAC
- Design of wireless communication systems
  Frequency, Bandwidth, Tx power, Antenna, PHY scheme
- Factor of performance degradation
  Fading, Inter symbol interference, Inter system interference
- IEEE802.11a WLAN
  WLAN using OFDM and adaptive modulation coding