2010 2nd semester
Wireless Commun. Eng. Ⅱ

#0: Guidance

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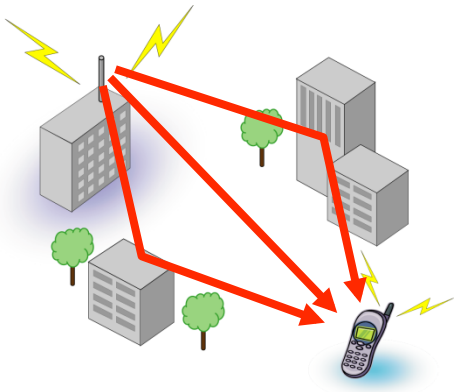
Oct. 6, 2010

Lecturer

- Kei Sakaguchi (Assoc. Professor)
- 35 years old
  Master degree in 1998
  Doctor degree in 2006
- 1 daughter and 1 son (not single)
- Research topics
  MIMO communication systems
  MIMO antenna & propagation
  Cognitive & software radio design

Warm up



- Question

Given a communication system below,
double the transmission rate by some means.

Commun. system with transmission power of 10W and bandwidth of 10MHz that realizes 100Mbps throughput.

- Channel Capacity Theorem

Maximum information transmission rate

$$C = B\log_2\left(1+\frac{P_s g_h}{P_n}\right) \quad \text{[bits/s]}$$

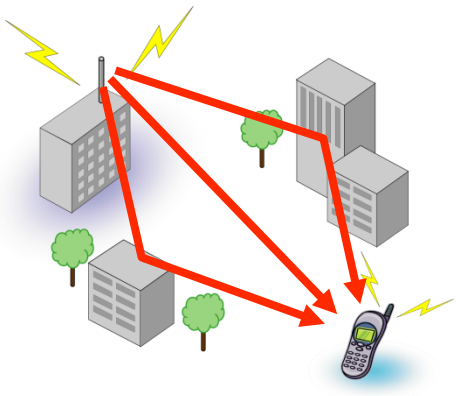
B : Frequency bandwidth

P_s : Transmission power

P_n : Noise power

g_h : Gain of channel

Warm up



- Question

Given a communication system below,
double the transmission rate by some means.

Commun. system with transmission power of 10W and bandwidth of 10MHz that realizes 100Mbps throughput.

Answer: Square the power, Double the bandwidth,
Double the number of antennas

- Channel Capacity Theorem

Maximum information transmission rate

$$C = B\log_2\left(1+\frac{P_s g_h}{P_n}\right) \quad \text{[bits/s]}$$

B : Frequency bandwidth

P_s : Transmission power

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g_h : Gain of channel

Summary of Class

- Aim of class

To provide various aspects of MIMO communication systems. The class supports information theory, signal processing, transceiver system, and access schemes. Basics on wireless communication and array signal processing are provided ahead. Future perspective on wireless LAN and mobile phone with MIMO schemes is also provided.

- Prerequisite
  - Commun. Engineering (undergraduate 6th semester)
  - Wireless Commn. System (undergraduate 7th semester)
  - Wireless Commun. Engineering I (graduate 1st semester)
- How to Grade

Reports (40 points): At least 4 times in the course
Final exam. (60 points): will be held on Feb. 2, 2011 (Wed)

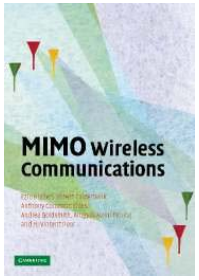
Text Book

- Lecture notes

  Lecture notes are provided by OCW-i.

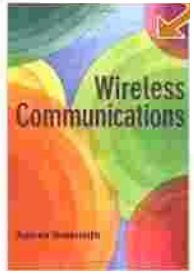
- Related text book

  A) MIMO communications



E.Biglieri, R.Calderbank, A.Constantinides, A.Goldsmith, A.Paulraj, and H.V.Poor, "*MIMO Wireless Communications*," Cambridge Univ. Press, 2007.

  B) Fundamentals of wireless communications



A.Goldsmith, "*Wireless Communications*," Cambridge Univ. Press, 2005.

Contents of Textbook A

A) *MIMO Wireless Communications*

Chap.	Titile	Relation with the class
1	Introduction	Main topic
2	Capacity limits of MIMO systems	Main topic
3	Precoding design	Main topic (including higher level study)
4	Space-time coding for wireless communications: principles and applications	Main topic
5	Fundamentals of receiver design	Main topic (including higher level study)
6	Multi-user receiver design (multiple access)	Main topic (broadcast is not included)

Contents of Textbook B

B) *Wireless Communications*

Chap.	Title	Relation with the class
1	Overview of wireless commun.	Main topic
2	Path loss and shadowing	Main topic
3	Statistical multipath channel models	Main topic
4	Capacity of wireless channels	Main topic
5	Digital modulation and detection	Main topic
6	Performance of digital modulation over wireless channels	Main topic
7	Diversity	Main topic

Contents of Textbook B

B) *Wireless Communications*

Chap.	Title	Relation with the class
8	Coding for wireless channels	Out of scope
9	Adaptive modulation and coding	Main topic
10	Multiple antennas and space-time commun.	Main topic
11	Equalization	Out of scope
12	Multicarrier modulation	Main topic
13	Spread spectrum	Out of scope
14	Multiuser systems	Main topic
15	Cellular systems and infrastructure-based wireless networks	Main topic
16	Ad hoc wireless networks	Partially related

Schedule (1st half)

	Date	Text	Contents
#1	Oct. 6	A-1, B-1	Introduction
#2	Oct. 13	B-5, B-6	Fundamentals of wireless commun.
#3	Oct. 20	B-12	OFDM for wireless broadband
#4	Nov. 10	B-7	Array signal processing
#5	Nov. 17	A-3, B-10	MIMO channel capacity
#6	Nov. 24	B-2, 3	Spatial channel model

Schedule (2nd half)

	Date	Text	Contents
#7	Dec. 1	A-5	MIMO receiver
	Dec. 8		No class
#8	Dec. 15	A-3, 4	MIMO transmitter
#9	Dec. 22	B-9	Adaptive commun. system
#10	Jan. 12	A-6, B-14	Multi-user MIMO
#11	Jan. 29	B-15, 16	Distributed MIMO networks
#12	Jan. 26		Standardization of MIMO
	Feb. 2		Examination

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#1: Introduction

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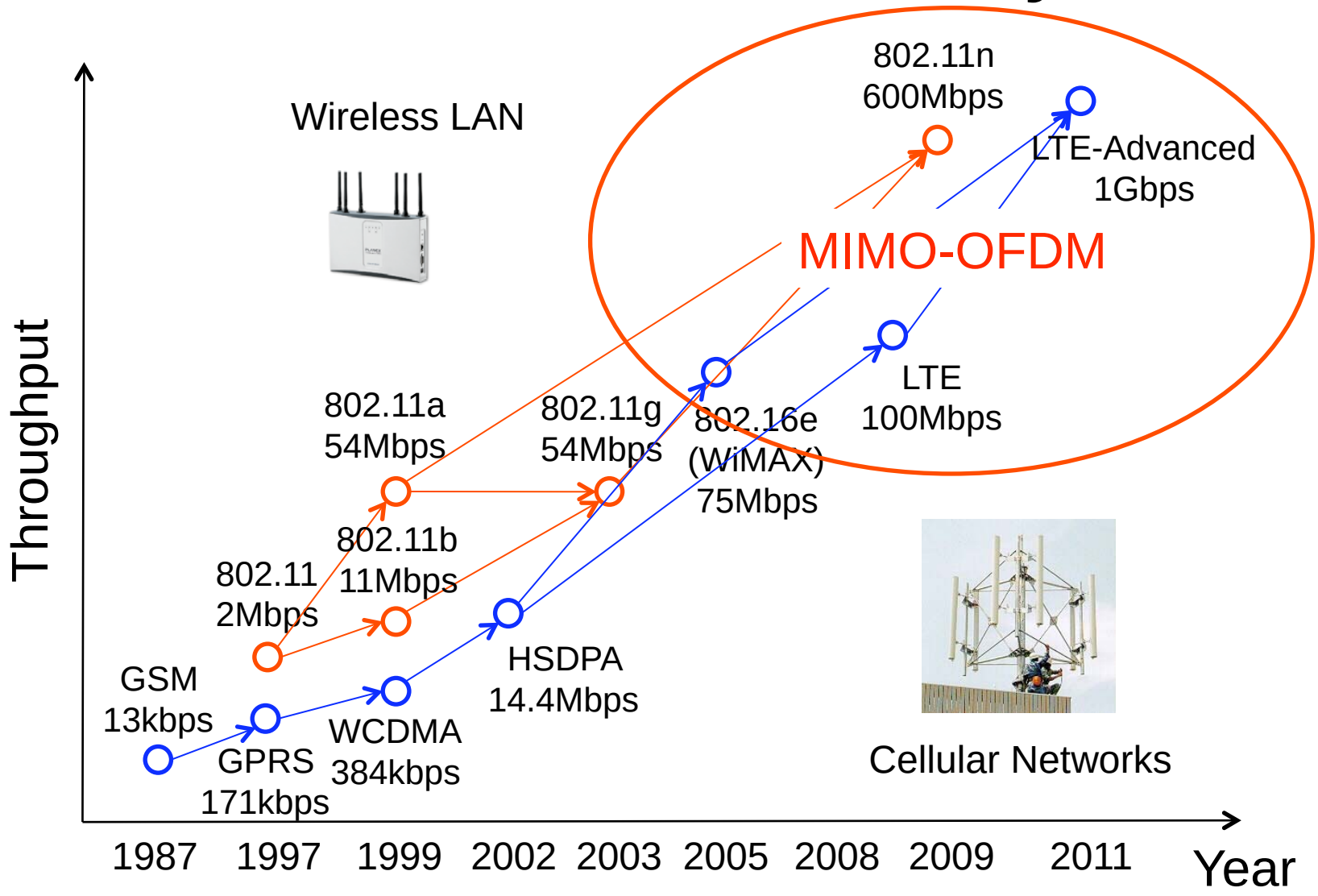
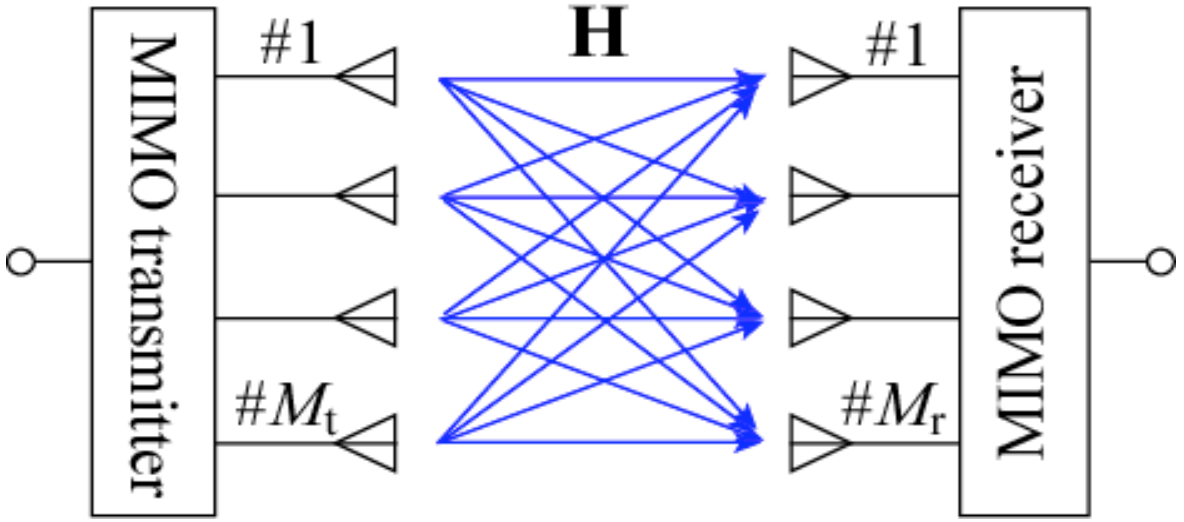
Innovation of Wireless Systems



What is MIMO

- Multiple antennas both at transmitter & receiver (MIMO)
- Different information streams are spatially multiplexed at the same time and same frequency
- Channel capacity of MIMO system increases linearly with respect to the number of antennas
- Benefits of MIMO are throughput & area coverage enhancement



History of MIMO

1995 Information theoretic study on MIMO commun. system [Telater]

1996 MIMO spatial multiplexing (BLAST) [Foschini]

1998 Alamouti Space Time Block Code (STBC) [Alamouti]

1998 Development on MIMO channel model [COST 273]

2003 Information theoretic study on Multi-user MIMO [Goldsmith]

2005 IEEE802.16e WMAN standard ratified

2006 IEEE802.11n WLAN draft standard approved

Pre-N WLAN was released in market

WiBro WMAN was released in market

2008 3GPP-LTE (E-UTRA) standard ratified

2009 IEEE802.11n WLAN standard ratified

MIMO in IEEE802.11n

- Standardization
  - High throughput WLAN backward compatible with 802.11a/b/g
  - Standardization started in 2004 and was ratified in 2009
  - TGnSync & WWiSE Pre-N unofficial standard in 2005
- Feature
  - Upto 4x4 MIMO spatial multiplexing with 20/40MHz bandwidth OFDM
  - Transmit beamforming with implicit/explicit feedback
  - 600Mbps maximum data rate is available
- Product examples

Buffalo WZR-APMG300NH 300Mbps I-O Data WN-GDN/R3 300Mbps Atheros AP9002AP-4XHG 600Mbps

MIMO in WiMAX (IEEE802.16e)

Standardization

- Mobility enhanced IEEE802.16 fixed wireless access
- Standardization started in 2002 and was ratified in 2005
- WiMAX forum certifies the interoperability of products

Feature

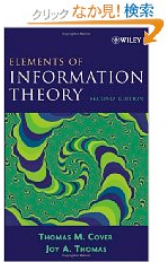
- Upto 2x4 MIMO spatial multiplexing with scalable OFDMA
- Transmit precoding based on matrix codebook
- 75Mbps maximum data rate is available (40Mbps in WiMAX wave 2)

Product examples

UQ-WiMAX UD03SS 40Mbps

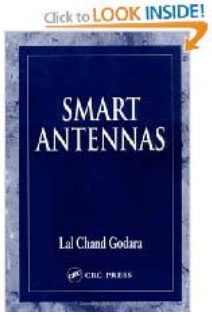
Intel WiMAX/WiFi Link 5150 40Mbps

Required Knowledge



Information theory

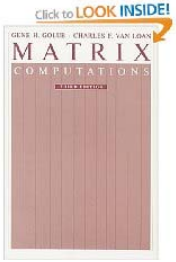
Array signal processing



Wireless commun.

MIMO commun. system

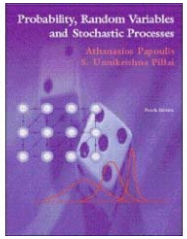
EM wave theory



Linear algebra

Convex optimization

Probability and Stochastic Process



Recommended References

Other text books

1. Da-shan Shiu, ”Wireless Communication using Dual Antenna Arrays,” Kluwer Academic, 2000.
2. Branka Vucentic, Jinhong Yuan, ”Space-Time Coding,” John Wiley & Sons, 2003.
3. Gregory D. Durgin, ”Space-Time Wireless Channels,” Prentice Hall PTR, 2003.
4. Arogyaswami Paulraj, Rohit Nabar, Dhananjay Core, Introduction to Space-Time Wireless Communications, Cambridge, 2003.
5. Erik G. Larsson, Petre Stoica, Space-Time Block Coding for Wireless Communications, Cambridge, 2003.
6. Sergio Barbarossa, “Multiantenna Wireless Communication Systems,” Artech House, 2005.
7. Claude Oestges, Bruno Clerckx, “MIMO Wireless Communications,” Academic Press, 2007.

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MIMO channel capacity

1. I.E.Telater, "Capacity of Multi-Antenna Gaussian Channels," AT&T Bell Labs Technical Memo, June 1995.
2. G.J.Foschini and M.J.Gnas, "On limits of wireless communications in a fading environments when using multiple antennas," Wireless Personal Communications, Vol.6, pp.311-335, 1998.
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5. S.Bhashyam, A.Sabharwal, B.Aazhang, "Feedback Gain in Multiple Antenna Systems," IEEE Trans. Communications, vol.50, no.5, pp.785-798, May 2002.

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MIMO propagation

1. B.Andersen, "Array Gain and Capacity for Known Random Channels with Multiple Element Arrays at Both Ends," IEEE J. Selected Areas Communications, Vol.18, No. 11, pp.2172-2178, Nov. 2000.
2. J.W.Wallace, M.A.Jensen, "Modeling the Indoor MIMO Wireless Channel," IEEE Trans. Antennas and Propagation, vol.50, no.5, pp.591-599, May 2002.
3. J.P.Kermoal, L.Schumacher, K.I.Pedersen, P.E.Mogensen, F.Frederiksen, "A Stochastic MIMO Radio Channel Model with Experimental Validation," IEEE J. Selected Areas in Communications, vol.20, no.6, pp.1211-1216, Aug. 2002.
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MIMO communications

1. G.J.Foschini, "Layered Space-Time Architecture for Wireless Communication in a Fading Environment When Using Multi-Element Antennas," Bell Lab Techn. J., Autumn, pp.41-59, 1996.
2. S.M.Alamounti, "A Simple Transmit Diversity Technique for Wireless Communications," IEEE J. Selected Areas in Communications, Vol.16, pp.151-1458, 1998.
3. V.Tarokh, H.Jafarkhani, A.R.Calderbank, "Space-Time Block Codes from Orthogonal Designs," IEEE Trans. Information Theory, vol.45, no.5, pp.1456-1467, July. 1999.
4. S.Zhou, G.B.Giannakis, “Optimal Transmitter Eigen-Beamforming and Space-Time Block Coding Based on Channel Mean Feedback,” IEEE Trans. Communications, vol.49, no.12, pp.2599-2631, Oct. 2002.
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6. D.P.Palomar, M.A.Lagunas, J.M.Cioffi, "Optimum Linear Joint Transmit-Receive Processing for MIMO Channels with QoS Constraints," IEEE Trans. Signal Processing, vol.52, no.5, pp.1179-1197, May 2004.

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Multi-user MIMO & others

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2. R.S.Blum, "MIMO Capacity with Interference," IEEE J. Selected Areas in Communications, vol.21, no.5, pp.793-801, June 2003.
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8. G.Kramer, M.Gastpar, P.Gupta, “Cooperative Strategies and Capacity Theorems for Relay Networks,” IEEE Trans. Information Theory, vol.51, no.9, pp.3037-3063, Sep. 2005