

2011 1st semester MIMO Communication Systems

#0: Guidance

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Lecturer

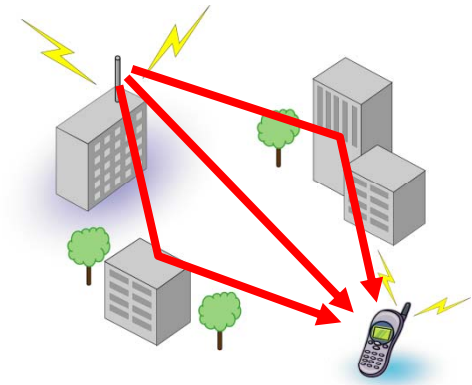
- Kei Sakaguchi (Assoc. Professor)
- 37 years old
- Master degree in 1998
- Doctor degree in 2006
- 1 daughter and 1 son
- Research topics
- MIMO communication systems
- MIMO antenna & propagation
- Cognitive & software radio design

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



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 (45 points): At least 3 times in the course

Final exam. (55 points): will be held on July 12, 2011 (Tue)

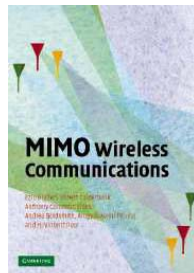
Text Book

- 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	Apr. 12	A-1, B-1	Introduction
#2	Apr. 19	B-5, B-6	Fundamentals of wireless commun.
#3	Apr. 26	B-12	OFDM for wireless broadband
	May 3		No class
#4	May 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
	May 28		

Schedule (2nd half)

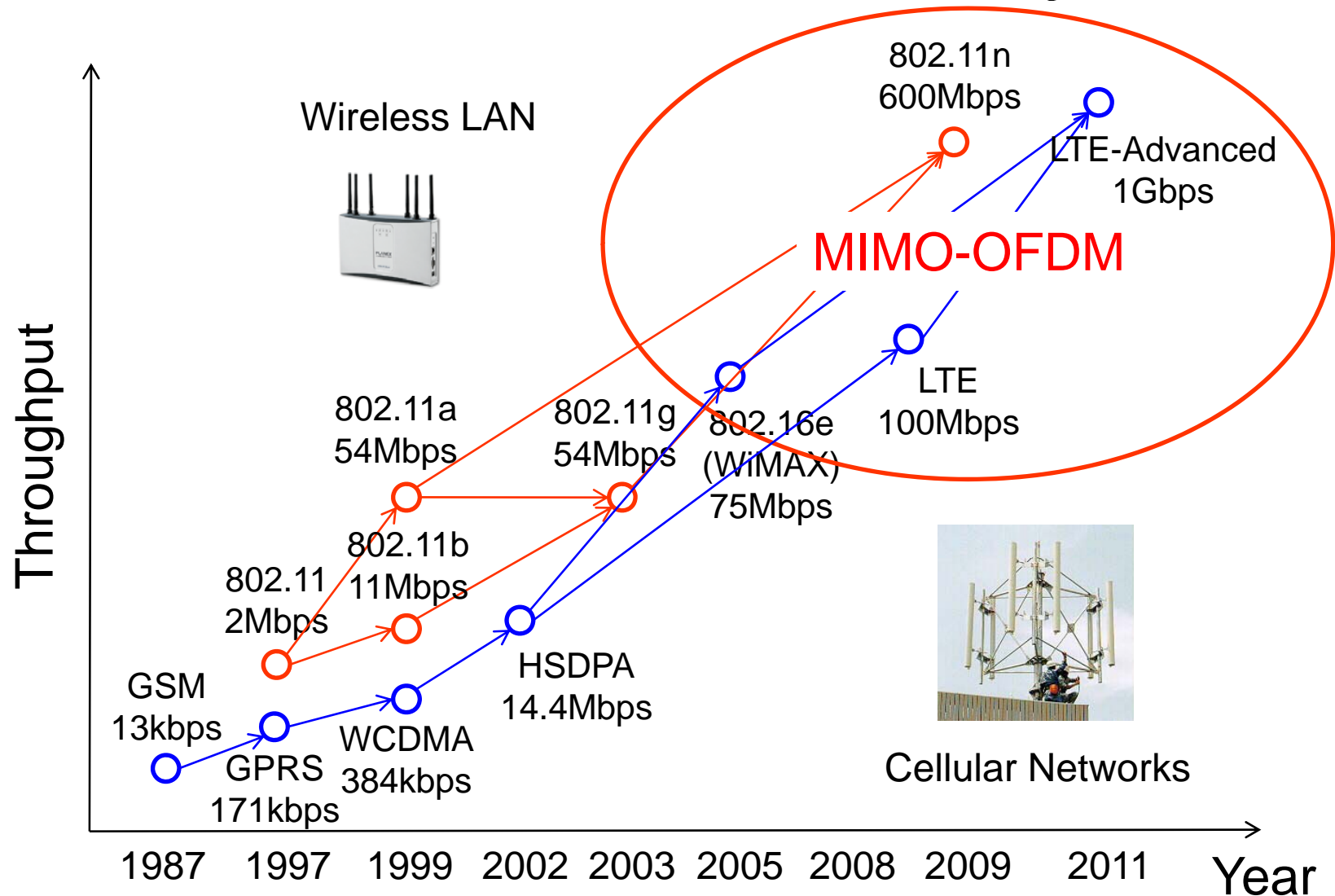
	Date	Text	Contents
#7	May 31	A-5	MIMO receiver
#8	June 7	A-3, 4	MIMO transmitter
#9	June 14	B-9	Adaptive commun. system
#10	June 21	A-6, B-14	Multi-user MIMO
#11	June 28	B-15, 16	Distributed MIMO networks
#12	July 5		Standardization of MIMO
	July 12		Final Examination

2011 1st semester MIMO Communication Systems

#1: Introduction

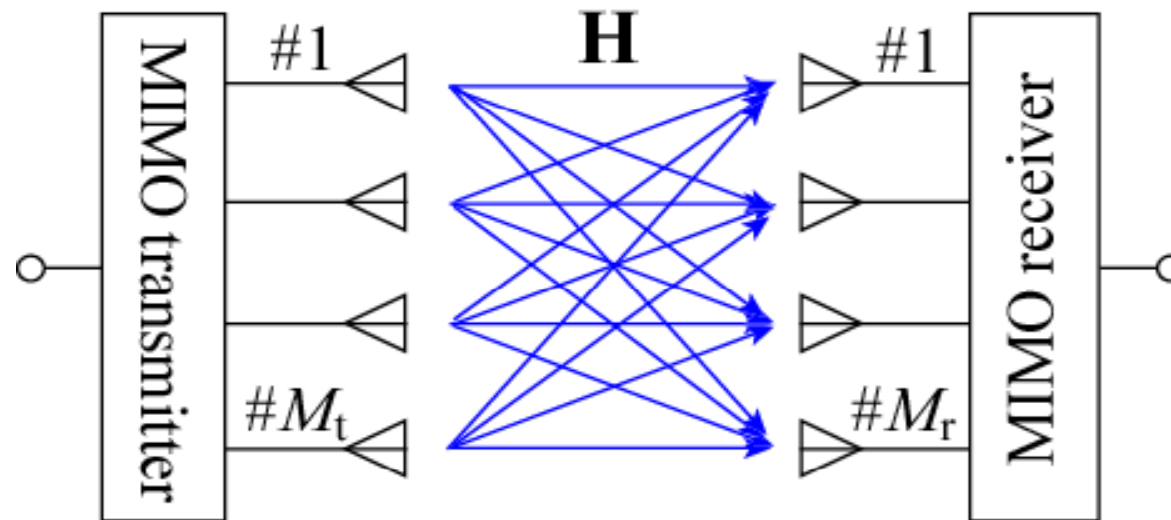
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Innovation of Wireless Systems



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 [Telatar]
- 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



MIMO in LTE (3GPP Release 8)

■ Standardization

- Long term evolution of 3GPP-HSPA (Release 5/6)
- Standardization started in 2004 and was ratified in 2008
- NTT docomo launched the service of LTE on Dec. 24, 2010

■ Feature

- Up to 2 layers MIMO spatial multiplexing with scalable OFDMA
- Various MIMO schemes (SM, STBC, Precoding, MU-MIMO)
- 100Mbps maximum data rate is available (37.5Mbps in Xi)

■ Product examples

NTT docomo Xi L-02C 37.5Mbps



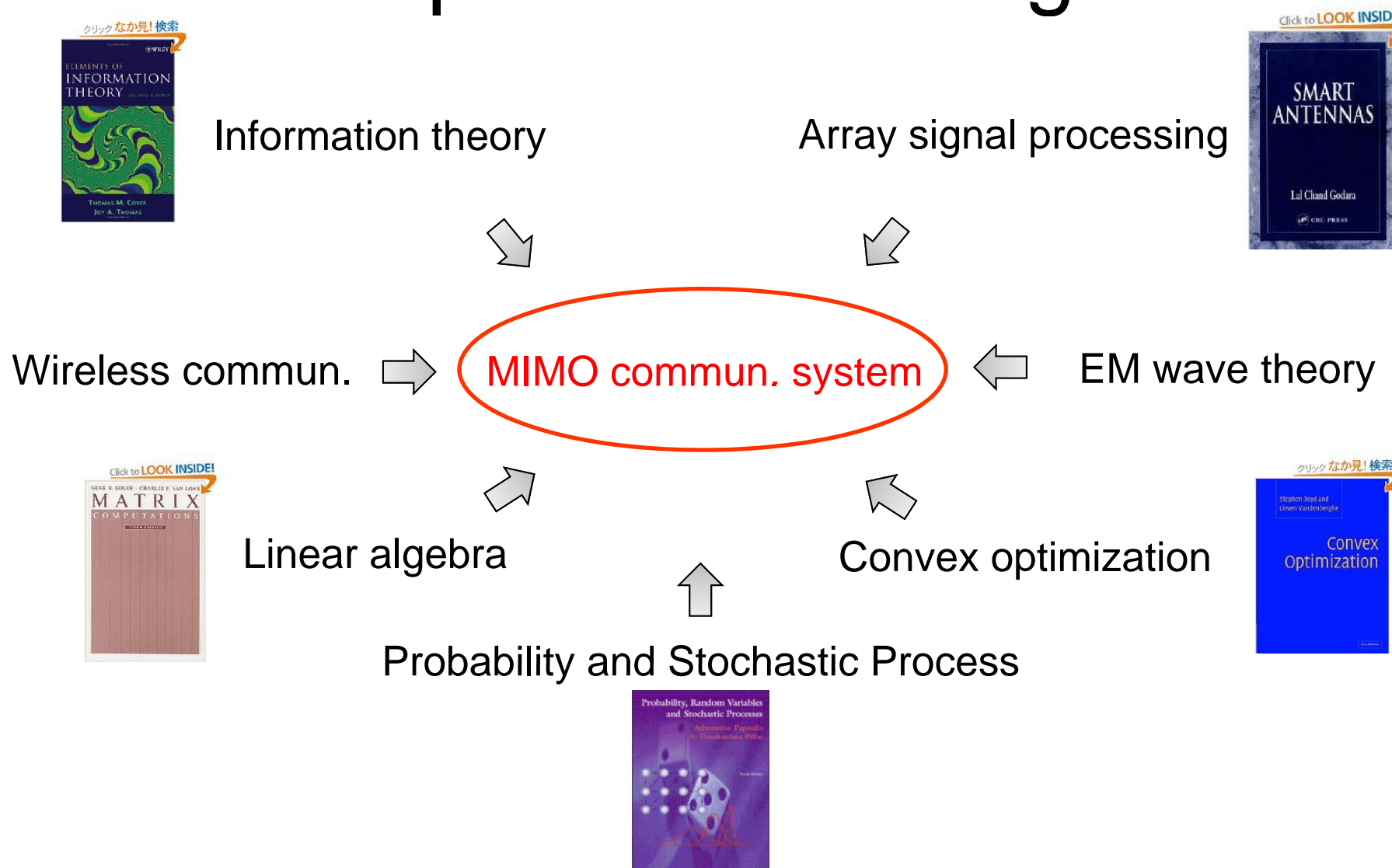
Verizon & Samsung
Smartphone 37.5Mbps



NTT docomo
LTE-MIMO 100Mbps



Required Knowledge



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.

Recommended References

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.
3. H.Boelcskei, D.Gesbert, A.J.Paulraj, "On the Capacity of OFDM-based Spatial Multiplexing Systems," IEEE Trans. Communications, vol.50, no.2, pp.225-234, 2002.
4. C.N.Chuah, D.N.C.Tse, J.M.Kahn, R.A.Valenzuela, "Capacity Scaling in MIMO Wireless Systems Under Correlated Fading," IEEE Trans. Information Theory, vol.48, no.3, pp.637-640, Mar. 2002.
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.

Recommended References

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.
4. A.F.Molisch, "A Generic Model for MIMO Wireless Propagation Channels in Macro- and Microcells," IEEE Trans. Signal Processing, vol.52, no.1, pp.61-71, Jan. 2004.
5. H.Xu, D.Chizhik, H.Huang, R.Valenzuela, "A Generalized Space-Time Multiple-Input Multiple-Output (MIMO) Channel Model," IEEE Trans. Wireless Communications, vol.3, no.3, pp.966-975, May 2004.

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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.Alamouti, "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.
5. H.Sampath, P.Stoica, A.Paulraj, "Generalized Linear Precoder and Decoder Design for MIMO Channels using the Weighted MMSE Criterion," IEEE Trans. Communications, vol.49, no.12, pp.2198-2206, Dec. 2002.
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.

Recommended References

Multi-user MIMO & others

1. S.Catreux, P.F.Driessen, L.J.Greenstein, "Attainable Throughput of an Interference-Limited Multiple-Input Multiple-Output (MIMO) Cellular System," IEEE Trans. Communications, vol.49, no.8, pp.1307-1311, Aug. 2001.
2. R.S.Blum, "MIMO Capacity with Interference," IEEE J. Selected Areas in Communications, vol.21, no.5, pp.793-801, June 2003.
3. S.Vishwanath, N.Jindal, A.J.Goldsmith, "Duality, achievable rates, and sum-rate capacity of Gaussian MIMO Broadcast Channels," IEEE Trans. Information Theory, vol.49, no.10, pp.2658-2668, Oct. 2003.
4. S.Serbetli, A.Yener, "Transceiver Optimization for Multiuser MIMO Systems," IEEE Trans. Signal Processing, vol.52, no.1, pp.214-226, Jan. 2004.
5. Q.H.Spencer, A.L.Swindlehurst, M.Haardt, "Zero-Forcing Methods for Downlink Spatial Multiplexing in Multiuser MIMO Channels," IEEE Trans. Signal Processing, vol.52, no.2, pp.461-471, Feb. 2004.
6. H.Dai, A.F.Molisch, H.V.Poor, "Downlink Capacity of Interference-Limited MIMO Systems with Joint Detection," IEEE Trans. Wireless Communications, vol.3, no.2, pp.442-453, Mar. 2004.
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