Mobile Communications Research Group
Tokyo Institute of Technology

2010 Annual Report

Contents

TOKYO INSTITUTE OF TECHNOLOGY

Main Building in Ookayama Campus gives the precious memory of Entrance and Graduation ceremony.

The Centennial Hall is famous for its unique architecture.

The statue of Dr. Tejima in autumn

A better future through science and technology

Tokyo Institute of Technology(Tokodai) is a top tier university, leading the world in Science and Technology. As one of Japan's most reputable institutions of higher learning, the Institute has undertaken education and research of the highest quality since 1881. The coming 130th anniversary is a perfect reminder to refocus on our three pillars: People, Reserch and Contribution. Through the nurturing of creative people at the top of their scientific fields, and the promotion of cutting edge research, we always strive to contribute in meaningful ways to society.

The institute has three undergraduate schools, six graduate schools, four leading laboratories and multiple research and education centers producing graduates who excel on conducting research that meets the demands of society and industry.

The mission of 2010 Tokodai seeks to contribute to civilization, peace and prosperity in the world, and aims at developing global human capabilities par excellence through pioneering research and education in science and technology, including industrial and social management.

Also, Tokodai has been working on scores of projects with a view to making the 130th anniversary in 2011 the most of the opportunity for achieving a truly reliable science and enginnering university:

- Strengthening of "education research and contribution to society"
- Strengthening the financial standing
- Strengthening of alumni club

(Information resources : http://www.titech.ac.jp/ and 2010 profile of Tokyo Institute of Technology.)

Tokyo Tech Seal

The Seal of Tokyo Institute of Technology was designed by Prof. Shinji HORI in 1948. The white portion represents the Japanese character '工', which is the first character of 'Engineering (工業)'. The black figure represents the Japanese character '大', which is the first character of 'University (大学)'. This figure also symbolizes a swallow, which has long been esteemed as a bird of luck in Japan.

Tokyo Tech Logo

"Tokyo Tech Pursuing Excellence" was adopted as a now strategic catchphrase with this logo in 2007. This strong message expresses our philosophy which is directed towards enhancing and strengthening our international reputation.

Mobile Communication Research Group

Mobile Communications Research Group (MCRG) of Tokyo Institute of Technology was established in 2001. The objective of the group is to conduct advanced research related to mobile communications.

Main laboratories of MCRG:

1. Signal Processing laboratory
   (Prof. Hiroshi Suzuki, Associate Prof. Kazuhiko Fukawa and Assistant Prof. Satoshi Suyama)
2. System laboratory
   (Prof. Kiyomichi Araki and Associate Prof. Kei Sakaguchi)
3. Propagation and Antenna laboratory
   (Prof. Jun-ichi Takada, Assistant Prof. Minseok Kim and Assistant Prof. Mir Ghoraishi)

Our group conducts comprehensive research on the development of mobile communication systems covering a wide range of cutting edge technologies in the fields of antenna and propagation, transmission systems, hardware development and signal processing. The synergy in the group creates an ideal environment for cross-disciplinary discussions and tapping of expertise resulting in various notable joint projects and developments. Our group has a weekly seminar to share the latest research outcomes among internal laboratories and to gain insight on our research activities by inviting guest speakers.

An Open House is yearly organized to introduce our MCRG activities and build a network with external companies, institutes and organizations in the field of mobile communications. Distinguished speakers from both the academia and industry are invited to give key note speeches and lectures to contribute their views and visions for the future development of research in mobile communications.

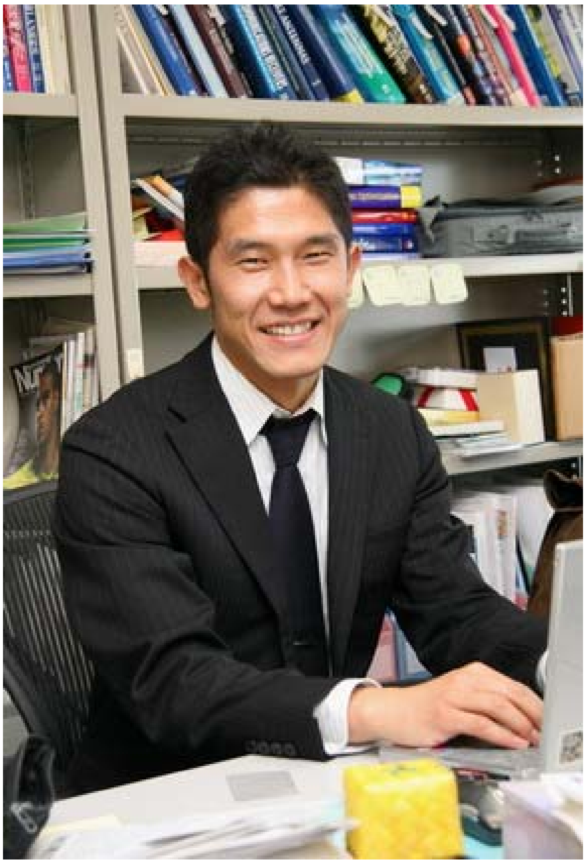
MCRG member

Laboratory Introduction
&
Annual Report 2010

ARAKI-SAKAGUCHI LABORATORY

Professor Kiyomichi Araki

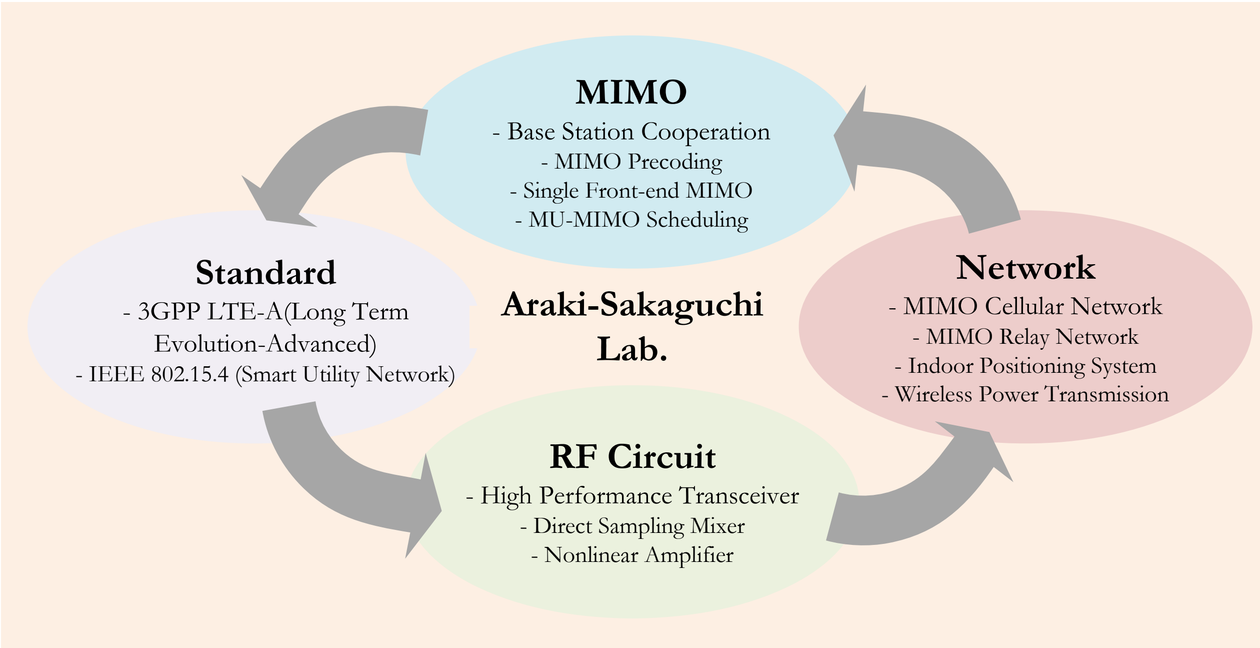
Prof. Araki was born in 1949. He received the B.S. degree in electrical engineering from Saitama University, in 1971, and the M.S. and Ph.D. degrees in physical electronics both from Tokyo Institute of Technology in 1973 and 1978 respectively. In 1973-1975, and 1978-1985, he was a Research Associate at Tokyo Institute of Technology, and in 1985-1995 he was an Associate Professor at Saitama University. In 1979-1980 and 1993-1994 he was a visiting research scholar at University of Texas, Austin and University of Illinois, Urbana, respectively. Since 1995 he has been a Professor at Tokyo Institute of Technology. His research interests are in information security, coding theory, communication theory, ferrite devices, RF circuit theory, electromagnetic theory, software defined radio, array signal processing, UWB technologies, wireless channel modeling and so on. Prof. Araki is a member of IEEE, IEE of Japan, Information Society of Japan and fellow of IEICE.



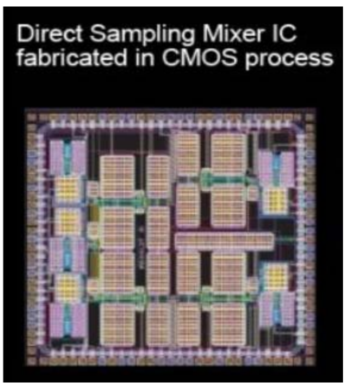
Associate Professor Kei Sakaguchi

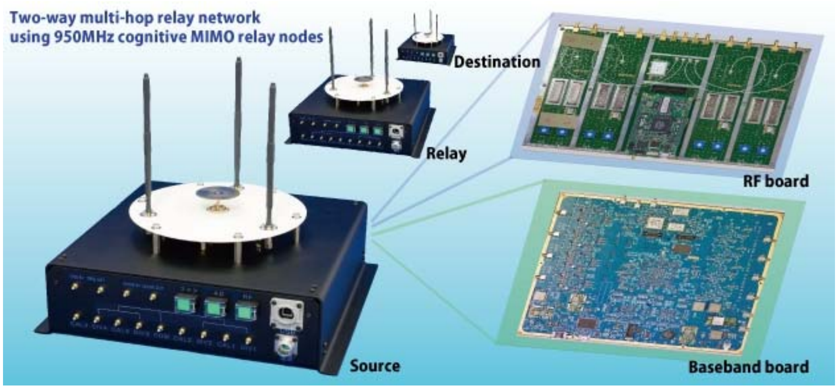
Assoc. Prof. Sakaguchi was born in Osaka, Japan, on November 27, 1973. He received the B.E. degree in electrical and computer engineering from Nagoya Institute of Technology, Japan, in 1996, and the M.E. degree in information processing and the Ph.D. degrees in electrical & electronic engineering both from Tokyo Institute of Technology, Japan, in 1998 and 2006, respectively. In 2000-2008, he was an Assistant Professor at Tokyo Institute of Technology, and from 2008, he has been an Associate Professor at the same university. He received the Young Engineer Awards both from IEICE and IEEE AP-S Japan chapter in 2001 and 2002 respectively, and Outstanding Paper Award both from SDR Forum and IEICE in 2004 and 2005, respectively, and Tutorial Paper Award from IEICE communication Society in 2006. His current research interests are in MIMO propagation measurement, MIMO communication system, distributed MIMO network, and cognitive radio. He is a member of IEICE and IEEE.

The Araki-Sakaguchi laboratory was established in 1995. Based on wireless communication system, our lab has been broadened widely through a range of experiments from the theoretical analysis to the implementation of the measurement devices. Also, not only the study in university but also co-works with various industrial companies has been conducted for developing application products and contributing to the next generation standards.



RESEARCH AGENDA		SYSTEM DEVELOPMENT
Nonlinear Analysis for Direct Sampling Mixer (p.6) Nonlinear Analysis with Memory Effect (p.6)	**Digital RF**	CMOS Implementations of Direct Sampling Mixer
Single Front End MIMO (p.7) User Scheduling for Multi-user MIMO (p.8)	**RF-MIMO**	4X4 MIMO fading simulator for LTE, Mobile Wi-MAX, and 802.11n W-LAN
Resource Management for Heterogenious Network (p.9) Two-way MIMO Multi-hop Network (p.10,11) Optimization of MIMO Antenna Directivities (p.12) Dynamic Fractional CoMP using RRH Network (p.13)	**Distributed MIMO**	Prototype hardware for MIMO relay networks at 950 MHz band LTE and LTE-Advanced Simulators





www.mobile.ee.titech.ac.jp

Nonlinear Analysis for Direct Sampling Mixer[26]

In a digital transceiver, Direct Sampling Mixers (DSM) is a circuitry that performs down-conversion, filtering, and decimation (Figure.1). However, a one of the serious problems of DSM is nonlinearity. In addition, DSM has frequency conversion of periodically time-variant system due to some MOS switches and frequency response of current sampling and filtering, and so generally this nonlinear analysis is known to difficult. In this research, we present new analysis method and distortion compensation method. We present Fundamental matrix with Volterra series expansion and frequency conversion. From comparison between this analysis method and circuit simulation (ADS), the fundamental component and 3rd inter-modulation distortion (IMD3) are almost same up to 1dB compression point. Moreover, from postdistortion, 1dB compression point is improved about 3dB, and Error Vector Magnitude (EVM) is improved about 10% (Figure.2).

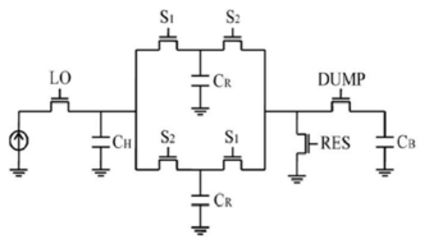


Figure.1 Direct-Sampling-Mixer

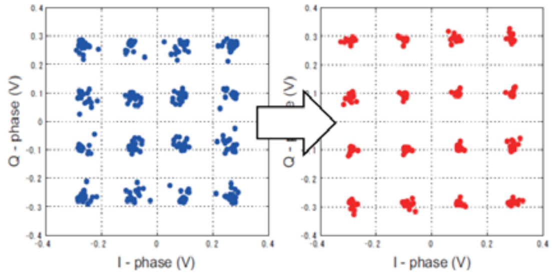


Figure.2 Constellation after Postdistortion

Nonlinear Analysis of Power Amplifier with Memory Effect

We present PA modeling result by Volterra series expansion. Target modeling characteristic is a non-flat peak frequency characteristic, which is originated from the resonance frequency of bias circuit. Fundamental tone and IMD3 varies drastically when the frequency spacing of two-tone input signal is near of resonance frequency of bias circuit [10].

To model these characteristics, We've designed serial cascade model of two nonlinear components. The two nonlinear components are transistor and output conductance. And linear L-C parallel resonance circuit of bias circuit is also considered to represent peak characteristic near of resonance frequency.

Two important targets, fundamental tone and IMD3, are modeled with varying input power and frequency spacing. This PA model leads to the nonlinear compensation such as a predistorter design.

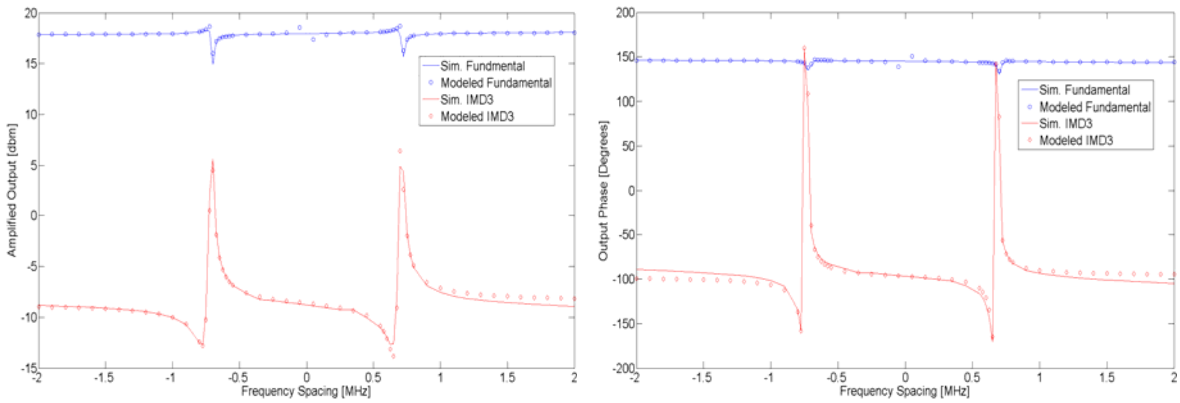


Figure1. Modeled Amplitude and Phase of Fundamental and IMD3

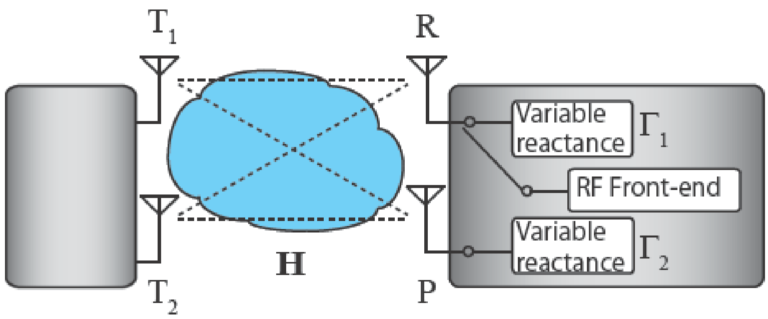
Single RF Front-end MIMO receiver with parasitic antenna elements

MIMO(Multiple-Input Multiple-Output) using several transmit and receive antenna is a key technology enhancing spectral efficiency. In particular, the architecture of compact MIMO transceiver has been studied intensively interesting with transmitting several data efficiently. MIMO system is required for RF front-end configuration per an antenna and each low spatial correlation between antennas. Therefore, the conventional MIMO architecture could not realize the device's miniaturization and the cost reducing of RF front-end. We proposed new architecture for single front-end MIMO system and proved the effectiveness by evaluation simulation..

Techniques for single RF front-end MIMO(SF-MIMO)

(1) Antenna switching

Single front-end MIMO structure by fast switching of the antenna, where the period is within one symbol, is fed to the receiver for signal multiplexing. This system is very attractive since post-detection diversity and digital beamforming can be done with a single receiver circuit. Switching is the easiest and least power consuming of the antenna diversity processing techniques as faster than twice of the bandwidth.



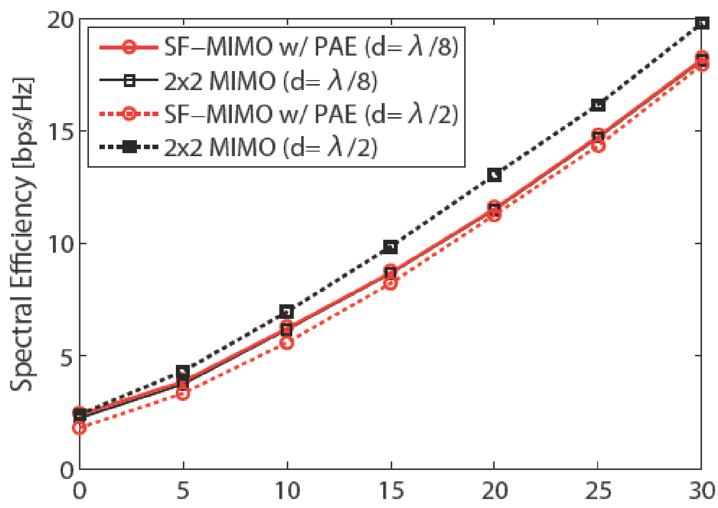
Structure of SF-MIMO system

(2) Parasitic Antenna Elements(PAE)

Parasitic antenna can improve transmission capacity by the mutual coupling actively using parasitic elements from switching frequency above the signal bandwidth. Parasitic antenna uses only one active RF front end along with two or more parasitic elements which can be placed much closer resulting in a compact design. The parasitic elements can be electronically switched to form different antenna.

Construction of system

We propose SF-MIMO with PAE using multiple antennas and single RF front-end. It can realize single RF front-end as transceiver's fast switching for signal multiplexing. The unconnected antenna is adopted as PAE for improving effectively in highly correlated systems which each antenna can be placed near. Also, matching circuit can improve better performance of received power and MIMO capacity.



Performance of SF-MIMO

Simplified User Scheduling Algorithm for Multiuser MIMO Systems

Multiple-input multiple-output (MIMO) wireless communications systems have attracted a lot of attention because of their potential for high gain in channel capacity. Recently, attention has shifted to multiuser MIMO (MU-MIMO) systems, which serve several users simultaneously in frequency and time domain. For a system with multiantenna users, block diagonalization (BD) is an effective technique, where the transmit precoding matrix of each user is designed such that its subspace lies in the null space of all other remaining users, so that multiuser interference is completely cancelled.

However the number of users that can be simultaneously supported with BD is limited by the number of transmit antennas, the number of receive antennas and the richness of the channels. The problem becomes how to choose a subset of users that maximizes the total throughput of a multiuser system containing a large number of users. An exhaustive search over all possible user sets guarantees that the total throughput is maximized, but the complexity of computation is prohibitive if the number of users in the system is large.

Two suboptimal user selection algorithms for MU-MIMO systems with BD were proposed of with the aim of maximizing the total throughput while keeping the complexity low. Both algorithms iteratively select users until the maximum number of simultaneously supportable users is reached. The first one is called capacity-based user selection algorithm. In each user selection step, the algorithm selects a user who provides the maximum total throughput with those already selected users. Because capacity-based user selection algorithm still requires frequent BD capacity calculation, the second one, called Frobenius norm-based user selection algorithm, was also proposed to reduce the complexity of computation furthermore.

Simplified norm-based algorithm really reduces the complexity of computation of the user scheduling, but also reduces the sum rate capacity performance of the systems. In this research, we propose a simplified capacity-based user scheduling algorithm, by analysing the capacity-based user selection criterion. We find a new criterion that is simplified by using the properties of Gram-Schmidt orthogonalization (GSO). In simulation results, the proposed algorithm provides higher sum rate capacity with lower calculation complexity than the conventional simplified norm-based user scheduling algorithm. We also consider the PF in our algorithm. With the PF criterion, the proposed algorithm is almost as fair as simplified norm-based algorithms in low signal-to-noise power ratio (SNR) environments, and in high SNR environments, it provides higher fairness than the conventional algorithms.

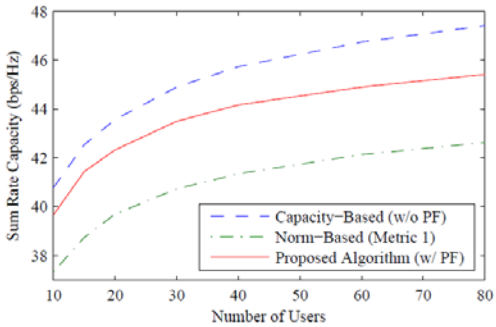


Fig. 1 Average sum rate capacity for a multiuser 2 x 8 MIMO system with PF (SNR = 20 dB).

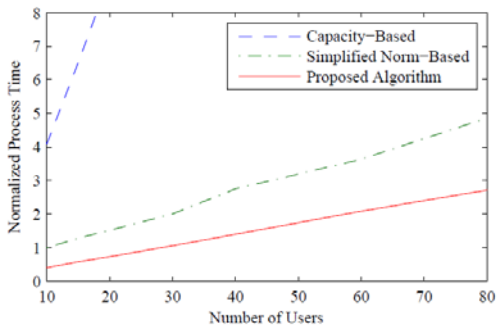
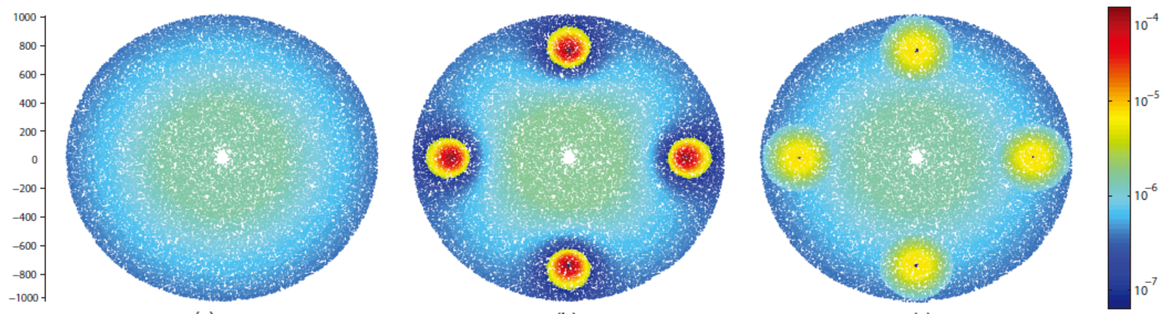


Fig. 2 Normalized process time of the algorithms for multiuser BD 2 x 8 MIMO systems.

Resource Management for Heterogeneous Cellular Network [39]

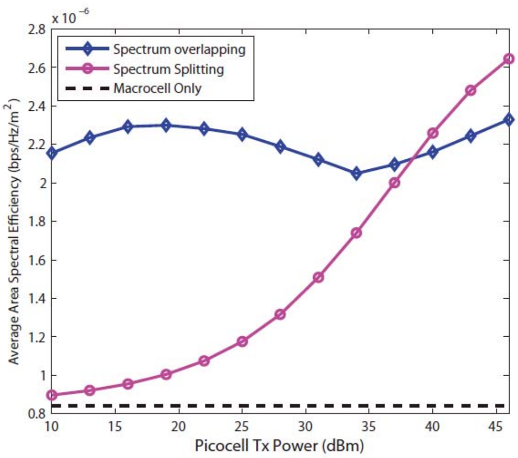
With the increasing popularity of mobile internet services, the scarcity of the spectrum poses formidable challenges for wireless network operators. To support the heavy user demand, the operators continually deploy more cells and reuse the spectrum in distant cells. To reduce the network operator's expenditure, the deployment of cheap access points at homes (femtocells) or in public hotspots (picocells) over the macrocell BS's coverage, which results in becomes heterogeneous is a good solution. Due to the coverage overlap, the major concerns are the spectrum efficiency and interference in heterogeneous networks. The main objective of introducing heterogeneous cells is to improve both the spectral efficiency and quality of service across the whole network service area. In this project, we considered the macrocell-picocell heterogeneous networks and investigated two general spectrum allocation models: spectrum overlapping and spectrum splitting. In the former, the spectrum is fully reused and an SINR-based rule is employed for cell association. In the later, orthogonal bandwidths are allocated to the macrocell and picocells to avoid the interference. Also, we introduce the picocell range expansion in the spectrum splitting model to enable a flexible load balancing between the macrocell and picocells. Our main goal is to analyze the trade-off between the area spectral efficiency and outage user rates in heterogeneous cellular networks with overlapping picocells. Numerical results showed that while the spectrum overlapping provides the highest spectral efficiency, its outage rate performance is very poor. In contrast, the spectrum splitting offered a trade-off by guaranteeing a minimum QoS for the weak user rates and by flexibly varying the spectrum splitting ratio and picocell range.



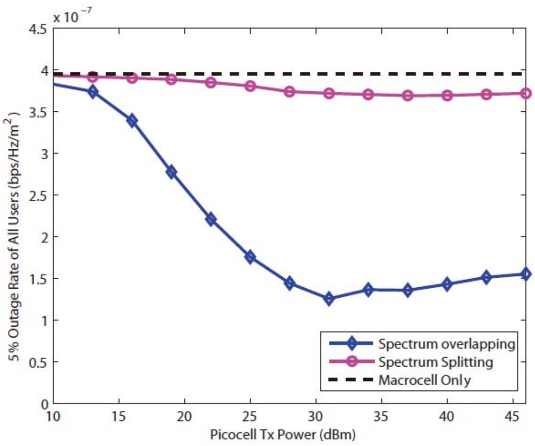
(a) No Picocells

(b) Spectrum Overlapping Pico Tx power = 28dBm

(c) Spectrum Splitting $(\rho^*, R_p^*) = (0.72\ ,\ 240\text{m})$ Pico Tx power = 28dBm



(a) Average Area Spectral Efficiency



(b) Outage Rate of all users

MIMO two-way multi-hop relay network [16][21][22][40]

Time division duplex (TDD) based two-way multi-hop relay network with MIMO multiple access has attracted much attention as a high data rate multi-hop relay network scheme. In this scheme, interference cancellation techniques such as MIMO beamforming or MIMO network coding are introduced, so that forward and backward streams can be multiplexed as shown in Fig. 1. However, this scheme has still not been implemented and realized with real hardware. Our laboratory developed prototype hardware to evaluate the TDD two-way multi-hop relay networks in real environment. Figure 2 shows the prototype hardware operating at 950MHz band. This prototype hardware consists of an array antenna, baseband board in which FPGA, four ADCs and DACs are implemented, and RF board consisting of four channel transmitters and receivers. In order to prove the realization and effectiveness of the TDD two-way multi-hop relay network with MIMO network coding, network throughput is measured in an indoor environment. Figure 3 shows system fabrication, parameters, and results of the measurement. Red, green, and blue lines show network throughputs of the TDD two-way multi-hop relay network with MIMO network coding (2-way relay network), simple TDD one-way multi-hop relay network with four phases for two-way streams (1-way relay network), and direct link without relay node (direct) respectively. The network throughput of the 2-way relay network is about twice as large as that of 1-way relay network, and higher than that of the direct link at all average end-to-end SNRs. This result shows the benefit of relaying and MIMO network coding.

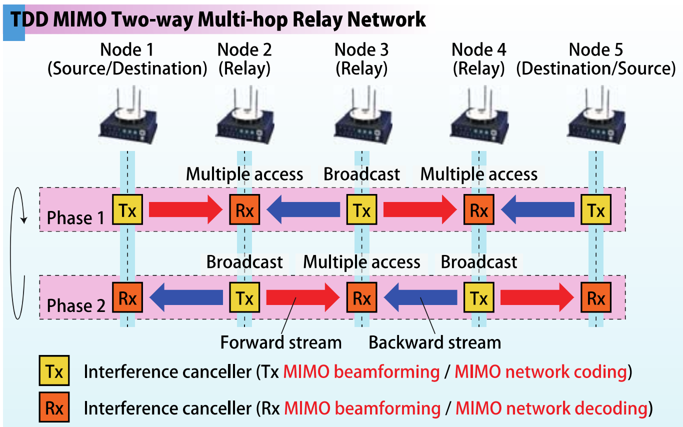


Fig. 1 TDD MIMO two-way multi-hop relay network.

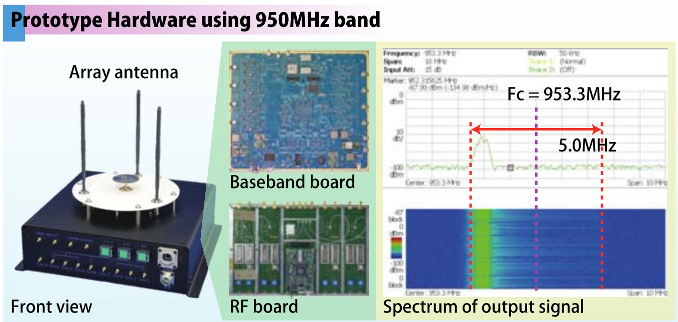
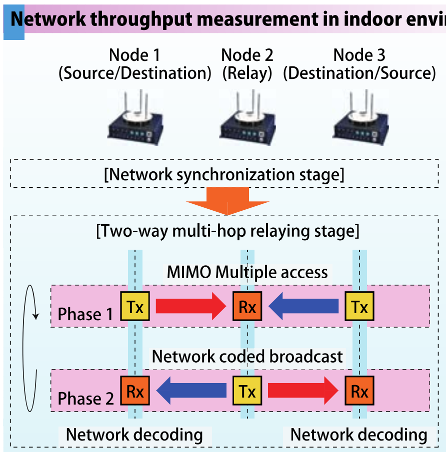


Fig. 2 Prototype hardware operating at 950MHz band.



Parameters of measurement.

FFT points	256
Sampling frequency	5.0 MHz
Guard interval rate	1/8
One symbol duration	51.2 us
Center frequency	951.2 MHz
Bandwidth	600 kHz
Number of subcarriers per channel	26
Number of symbol in one frame	90
Modulation	BPSK
Coding rate	1/2
Number of bits in one packet	1063 bits

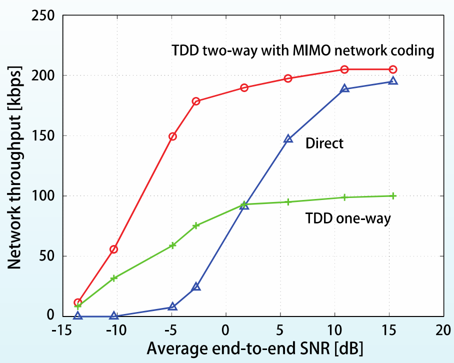


Fig. 3 Network throughput measurement of TDD two-way multi-hop relay network using MIMO network coding in an indoor environment.

Wireless energy transmission in the next generation sensor network

Recently, we propose wireless grid which allows wireless sensor nodes reuse energy transmitted with data signal from a backbone mesh network by applying RFID technology. Fig. 1 shows a building control system as one of applications for wireless grid. In this system, sensor nodes can operate without external power supply. Furthermore, in Japan, 950 MHz frequency band has been assigned for data and power transmission in RFID. Therefore, the study in this research is performed in this frequency band.

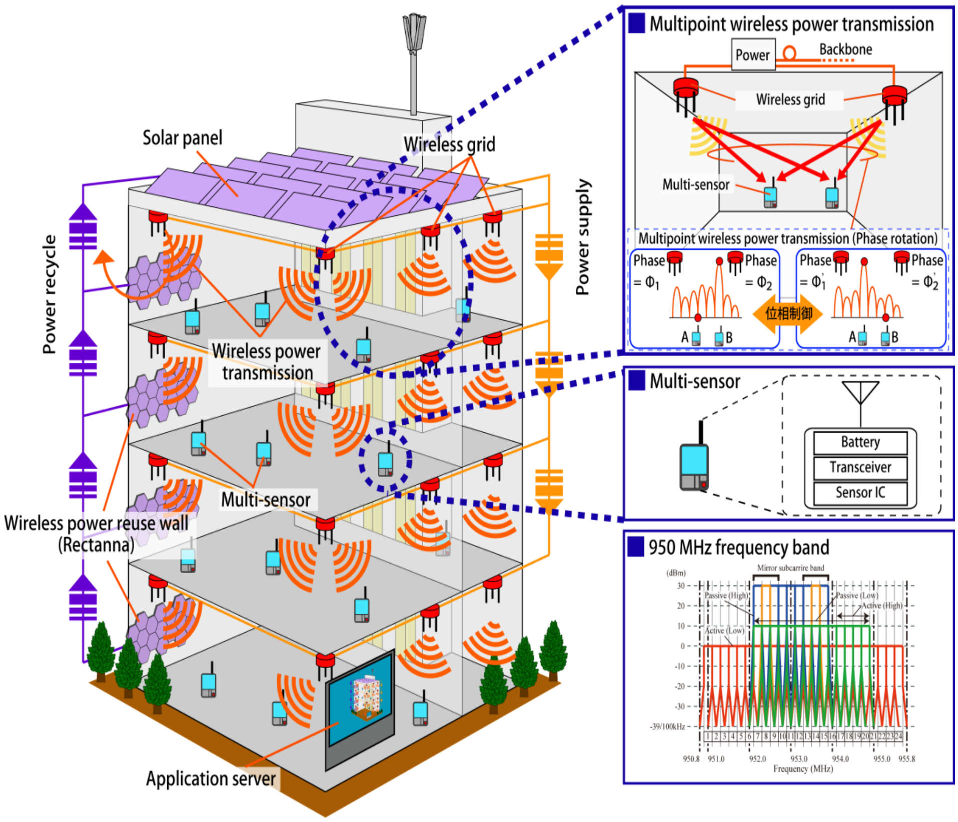
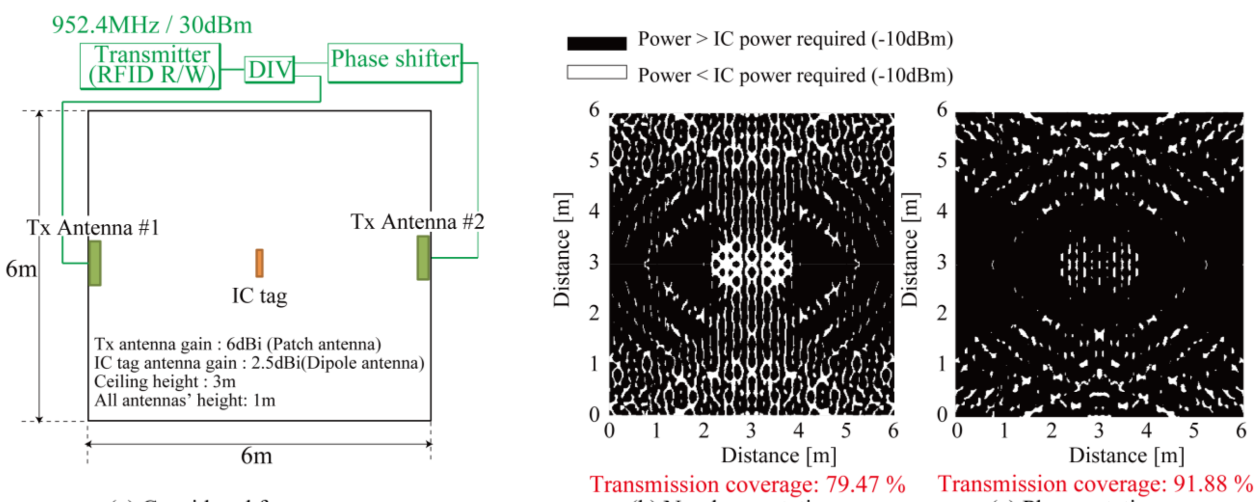


Fig. 1 Building control system with wireless grid

However, in a real indoor environment, a sensor node cannot receive signal in some positions due to the problem of standing wave. In order to solve this problem, we propose a phase rotation scheme for multi-point power transmission as shown in Fig. 1. In order to evaluate the proposed scheme, the simulation of transmission signal in a free-space room shown in Fig. 2a has been performed. Fig 2b and 2c show that the power transmission with phase rotation scheme can cover the space in the room more than the case not applying the proposed scheme.



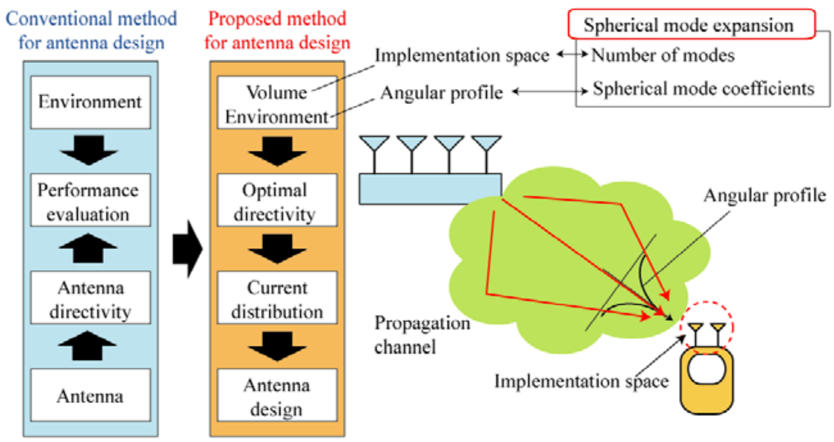
(a) Considered free-space room (b) No phase rotation (c) Phase rotation

Fig. 2 Coverage of wireless energy transmission using multi-point

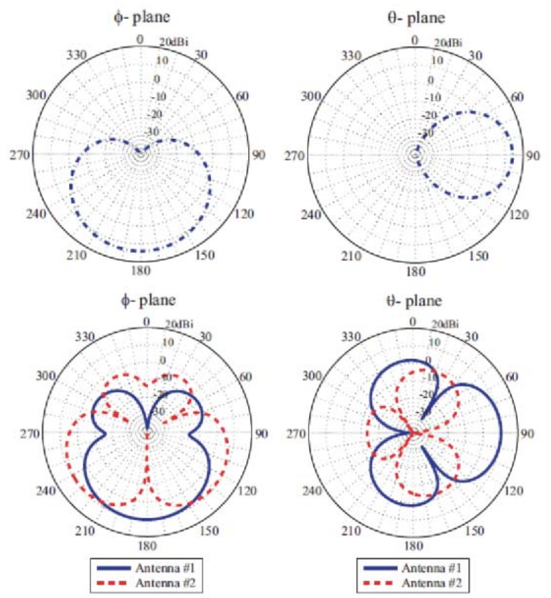
Optimization of MIMO Antenna Directivities [12][13]

Design of MIMO Antenna Directivities based on Spherical Mode Expansion

We propose a new MIMO antenna design scheme to achieve the best performance under a given propagation environment. For that purpose, Spherical Mode Expansion (SME) of an antenna directivity is introduced. In SME, an electrical and magnetic field is expanded into orthogonal spherical wave functions with their weights of Spherical Mode Coefficients (SMCs). In a fixed size or volume of array antenna, the number of effective SMCs to be radiated from the volume is limited. Therefore, optimal antenna directivity in a given volume of array antenna can be achieved by designing limited SMCs. This directivity optimization based on SME is effective in not only single user MIMO system but also base station cooperation (BSC) MIMO system. We also propose an optimization method of tilt angles in BSC system and a design method of a fading emulator based on Clarke's model for MIMO Over-The-Air measurements. These researches are useful to design future wireless communication systems.



MIMO antenna design based on SME

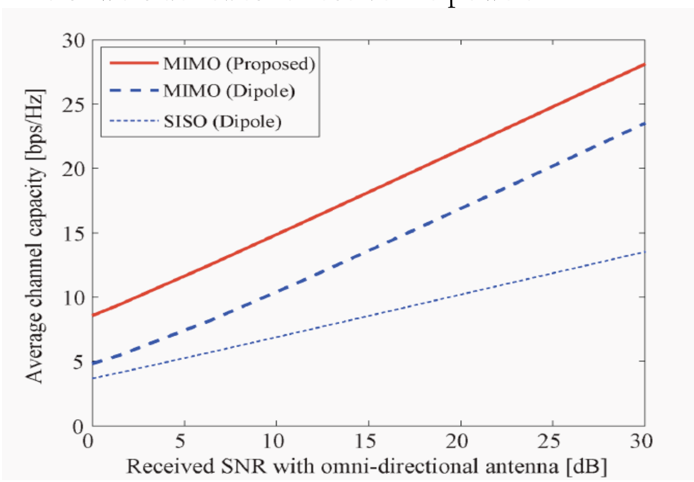


Angular profile and optimal directivities

Numerical Examples of Optimal Antenna Directivities

By using SME, optimal antenna directivities are derived at given power angular profile under the constraint of antenna design space. The main beam of antenna #1 is directed to the nominal incident angle while antenna #2 steers its null to the nominal angle and controls two side-lobes to receive the power.

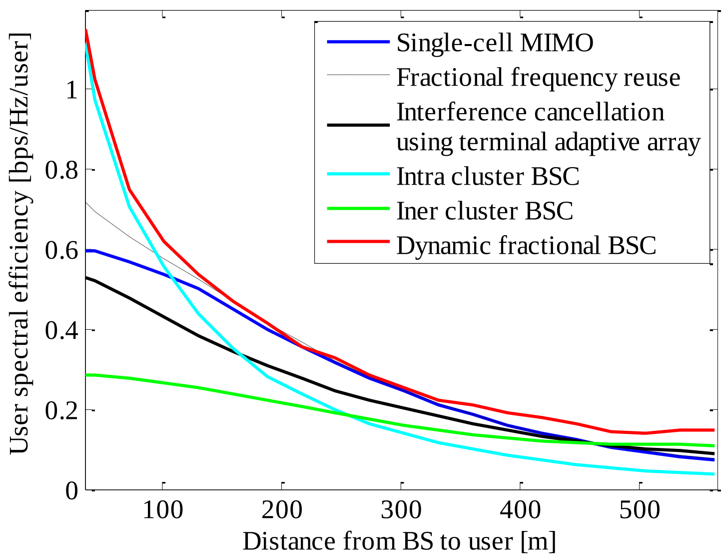
As a result, it achieves both high effective gain and low spatial correlation. Furthermore, the optimal antenna directivities achieve much higher channel capacity than that of typical dipole antennas.



Channel capacity

Dynamic Fractional CoMP Using RRH Network [43]

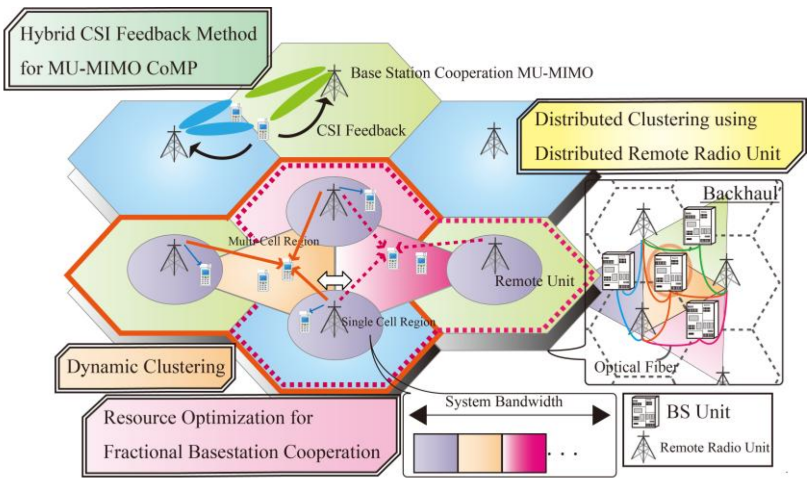
Dynamic fractional cooperation with distributed cooperation controllers is proposed. Fractional cooperation where single-cell single-user MIMO is performed at the cell-inner and cooperative BSC multi-user MIMO is performed at the cell-edge, is proposed to achieve high throughput both at the cell-inner and the cell-edge. Fractional cooperation contributes to reduce scheduling complexity because user grouping is constructed by "cooperation region". Since dynamic clustering selects cooperation sets and cooperation users based on user locations or SINRs, fractional cooperation with dynamic clustering can efficiently provide to cell-edge users better throughput performance. Furthermore, this scheme proposes a coordination protocol and cooperation cellular network topology to facilitate the complexity of dynamic clustering requiring high complexity. To reduce coordination control complexity, a master base station is selected. Based on the information from the user terminal selected by the master base station, a cluster of base station cooperation is dynamically established. After that, other users joining base station cooperation are sequentially chosen based on a coordinated scheduling protocol. Moreover, the proposed cooperation cellular network topology using shared remote units can easily realize BSC with low latency.



Performance result of the proposed system

RRH network

One of the problems in implementation of BSC is processing delay due to sharing information of cooperation control between cooperation BSs. Conventional backhaul is not designed for transportation of enormous data. Optical fiber line can be used instead, however, at the expense of increasing to cost. Base station cooperation employing Remote Radio Head (RRH) connected to a base station unit by optical fiber has also been considered. However, such network suffers from cluster-edge problem. In this paper, a distributed base station cooperation network topology using shared RRHs is proposed. The shared RRH is connected to multiple adjacent base station units.



Dynamic Fractional CoMP using RRH Network

SUZUKI-FUKAWA LABORATORY

web site: http://www.radio.ss.titech.ac.jp/

Professor Hiroshi Suzuki

received the B.S. degree in electrical engineering, the M.S. degree in physical electronics, and the Dr. Eng. Degree in electrical and electronics engineering, all from the Tokyo Institute of Technology, Tokyo, in 1972, 1974, and 1986, respectively. He joined the Electrical Communication Laboratories, Nippon Telegraph and Telephone Corporation (NTT), Japan, in 1974. He was engaged in research on devices in millimeter-wave regions. Since 1978, he has been engaged in fundamental and developmental researchers on digital mobile communication systems. He was an Executive Research Engineer in the Research and Development Department, NTT Mobile Communications Network, Inc. (NTT DoCoMo) from 1992 to 1996. Since September 1996, he has been a Professor at the Tokyo Institute of Technology. He is currently interested in various applications of the adaptive signal processing to radio signal transmission: adaptive arrays, multiuser detection, interference canceling, and MIMO-OFDM for future advanced multiple access communication systems. Prof. Suzuki is a member the Institute of Electronics, Information, and Communication Engineers (IEICE) of Japan, and of IEEE. He received the Paper Award in 1995, 2007, and 2009 the award of Fellow in 2006, and the Achievement Award in 2009 from IEICE.

Associate Professor Kazuhiko Fukawa

received the B.S. and M.S. degrees in physics, and the Dr. Eng. degree in electrical and electronics engineering, all from Tokyo Institute of Technology, Tokyo, Japan, in 1985, 1987, and 1999 respectively. He joined Nippon Telegraph and Telephone Corporation (NTT), Japan, in 1987. Since then, he has been engaged in research on digital mobile radio communication systems and applications of the adaptive signal processing, including adaptive equalization, interference cancellation, and adaptive arrays. He was a Senior Research Engineer at NTT Mobile Communications Network Inc. (NTT DoCoMo), from 1994 to 2000. Since April 2000, he has been an Associate Professor at the Tokyo Institute of Technology. Prof. Fukawa is a member of IEEE and the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan. He received the Paper Award in 1995, 2007, and 2009, and the Achievement Award in 2009 from IEICE.

Assistant Professor Satoshi Suyama
received the B.S. degree in electrical and electronic engineering, M.S. degree in information processing, and the Dr. Eng. degree in communications and integrated systems, all from Tokyo Institute of Technology, Tokyo, Japan, in 1999, 2001, and 2010, respectively. Since 2001, he has been an Assistant Professor in the Department of Communications and Integrated Systems at the Tokyo Institute of Technology. He is currently interested in various applications of the adaptive signal processing to radio signaling: turbo equalization, interference cancellation, and channel estimation for OFDM, MC-CDMA, and MIMO-OFDM. He is also interested in implementation of the radio signal processing by DSP and FPGA. Dr. Suyama is a member of IEEE and the Institute of Electronics, Information, and Communication Engineers (IEICE) of Japan. He received the Young Researchers' Award from the IEICE in 2005, and the Best Paper Prize from the European Wireless Technology Conference (EuWiT) in 2009.

SUZUKI-FUKAWA LABORATORY

Our Research Interests

At Suzuki-Fukawa laboratory, we have been conducting both fundamental and applied researches involving signal processing techniques for mobile communications. Recently, we have focused on transmission systems, especially MIMO-OFDM, multiple access, modulation and demodulation schemes for cognitive radio, and RF circuit impairment compensation techniques. Below is a detailed list of our research topics in recent five years.

Research Topics in Recent Five Years

Transmission System

- *MIMO detection and CSI estimation*
  - Suboptimal MLD
    - EM algorithm with factor graphs
    - MMSE detection avoiding noise Enhancement [21][37]
  - Adaptive blind method for heterogeneous streams
  - Soft decision-directed channel estimation (SDCE)
- *MIMO-OFDM system optimization*
  - BER improvement
    - Subcarrier phase hopping (SPH)
    - Minimum BER (MBER) precoding [5]
  - PAPR reduction
    - Block diagonalization with selected mapping (BD-SLM)
    - Partial transmit sequence (PTS) [3][4]
  - Joint BER and PAPR improvement
    - SPH-SLM
    - Eigenmode transmission with PAPR reduction
  - Relaying system improvement
    - Amplify-and-Forward (AF) / Decode-and-Forward (DF) switching

Multiple Access

- *Interference mitigation*
  - Spatial filtering
  - MBER precoding for cochannel interference environment
- *Access scheme*
  - IDMA with iterative detection [2], [15], [28], [36]
  - Random packet collision resolution [20], [24], [32]

Modulation and Demodulation for Cognitive Radio

- *Gaussian multicarrier (GMC)*
- *SSB*

RF Impairment Compensation

- *Phase noise compensation* [1], [8], [18], [30], [31], [33],
- *I/Q imbalance compensation*
- *Real zero coherent detection*

In-House Simulator Design and Implementation

- *FPGA on-board system simulators* [30][31]
- *4x4 MIMO fading simulators*

In this report, we will present some of the above research topics that have been recently presented at international conferences or accepted for publication in international journals.

Robust Precoding Scheme in Downlink Multiuser MIMO-OFDM Systems with Imperfect CSI [6]

Multiple-input multiple-output (MIMO) mobile communications have received a great deal of attention because of its potential to increase the channel capacity. The combination of MIMO with orthogonal frequency division multiplexing (OFDM) is a promising technique to attain robustness against frequency-selective channels and to improve the spectral efficiency. As an application of MIMO-OFDM, downlink multiuser MIMO-OFDM systems have been intensively investigated, in which a base station (BS) with multiple antennas simultaneously communicates with several mobile stations (MSs).

In the downlink multiuser MIMO-OFDM systems, BS usually employs linear precoding for reducing cochannel interference among MSs. When MSs have one receive antenna and can not suppress cochannel interference by multiple antennas, one of the most effective precoding schemes to reduce such interference is zero-forcing (ZF), which is also called channel inversion. With perfect channel state information at the transmitter (CSIT), ZF multiplies a signal vector to be transmitted by the inverse of the channel matrix, and thus can achieve orthogonal channels among MSs. Although the receivers can estimate channel impulse responses accurately, perfect CSIT is unrealistic due to quantization errors and limited, delayed or noisy feedback from the receivers. In fact, ZF is sensitive to CSIT errors and the bit error rate (BER) performance severely degrades when the CSIT is imperfect. Therefore, robust precoding schemes that can operate properly even with imperfect channel state information (CSI) are required.

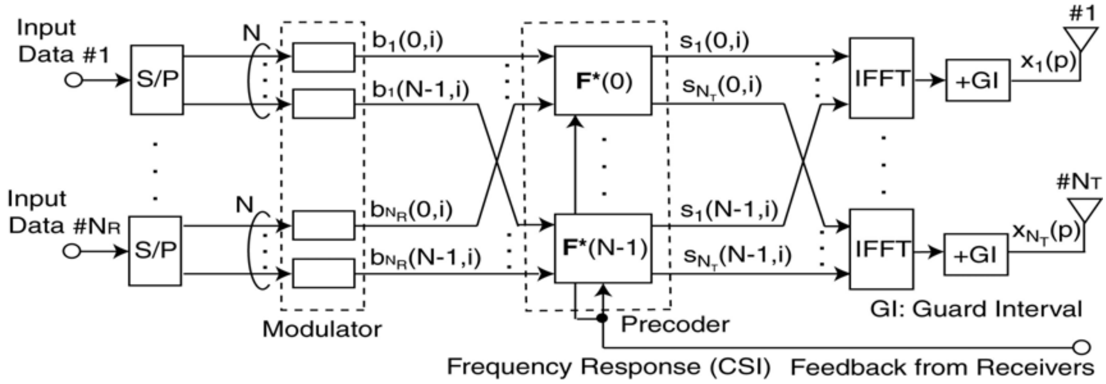


Fig. 1 Transmitter in downlink multiuser MIMO-OFDM

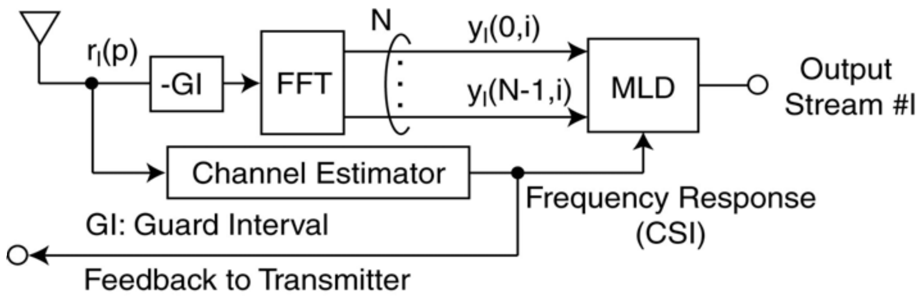


Fig. 2 Receiver in downlink multiuser MIMO-OFDM

Fig. 1 and **Fig. 2** show structures of a transmitter and a receiver, respectively, in a downlink multiuser MIMO-OFDM system. The transmitter has N_T transmit antennas while all the N_R receivers have single receive antenna. In the transmitter, N_R information bit sequences are divided into N streams, where N is the number of subcarriers in OFDM.

The proposed precoding employs the minimum bit error rate (BER) criterion and estimates precoding matrices to minimize total BER of mobile stations by the steepest descent algorithm. As the cost function of the proposed scheme, an upper bound of the total BER is derived from the pairwise error probability (PEP) and is averaged with respect to channel state information (CSI) errors. Thus, the proposed scheme can be robust to imperfect CSI.

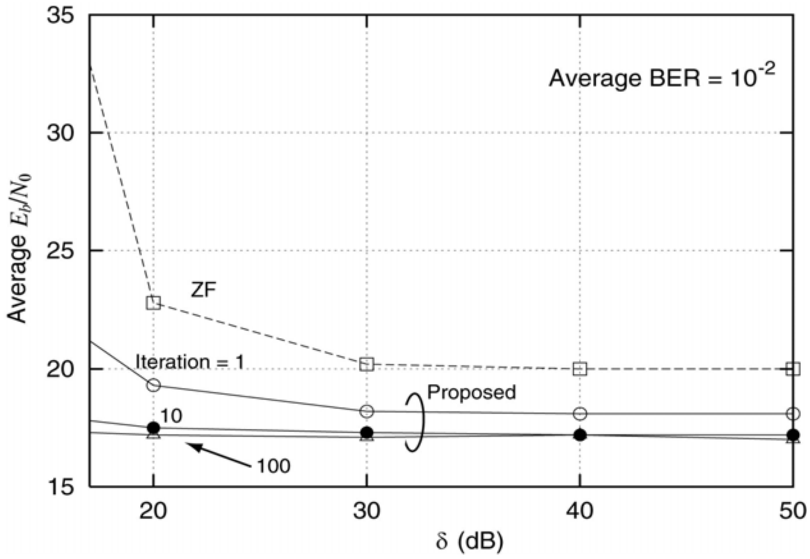


Fig. 3 Required E_b/N_0 for BER of 10^{-2}

Fig.3 shows average E_b/N_0 that the proposed precoder requires to achieve average BER of 10^{-2}, with the iteration number as a parameter. For comparison, that of ZF was also plotted. The proposed precoder is much more robust to the CSI errors than the conventional scheme. Especially when the iteration number is 100, the proposed scheme does not suffer from degradation due to the CSI errors, with δ being greater than 17 dB.

Low-Complexity PAPR Reduction Method for Multiuser MIMO-OFDM Systems with Block Diagonalization [4]

In downlink mobile communications, multiuser (MU) MIMO-OFDM has attracted much attention. Base station (BS) in MU-MIMO-OFDM simultaneously transmits multiple streams of several users by using multiple antennas. MU-MIMO-OFDM can accommodate more users by increasing the number of the transmit antennas, and can improve cell throughput. As a linear precoding method for MU-MIMO-OFDM, block diagonalization (BD) that orthogonalizes the multiple streams among the users by using channel state information (CSI) has been proposed. A major problem of BD for MU-MIMO-OFDM is that the transmitted signal has high peak-to-average power ratio (PAPR) due to OFDM characteristics. Therefore, BD suffers from waveform distortion caused by a nonlinear transmit power amplifier (PA), when the number of transmit antennas or multiple streams is large..

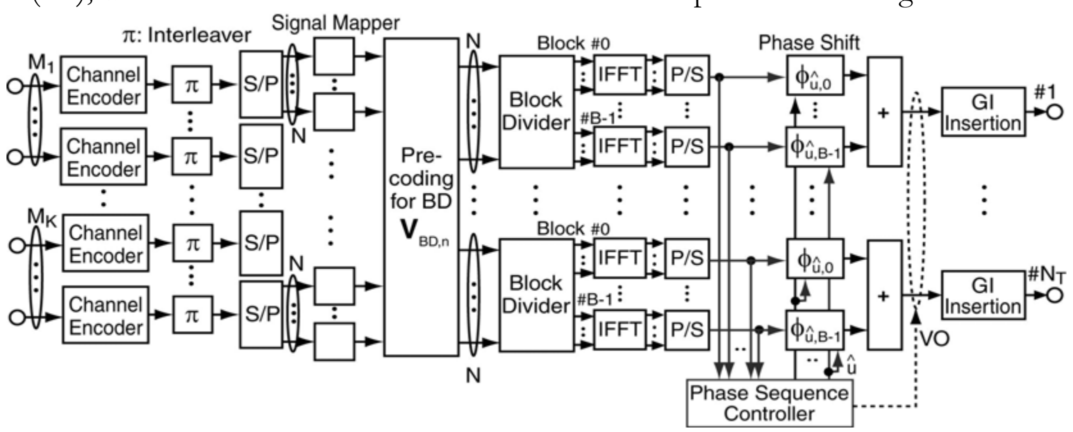


Fig. 4 BD-PTS transmitter

Fig. 4 shows a block diagram of the BD-PTS transmitter. BD-PTS divides the modulation signals into the B blocks, and performs the phase shift to the time-domain signals of each block. Note that the phase shift should be performed not to disturb the effect of BD.

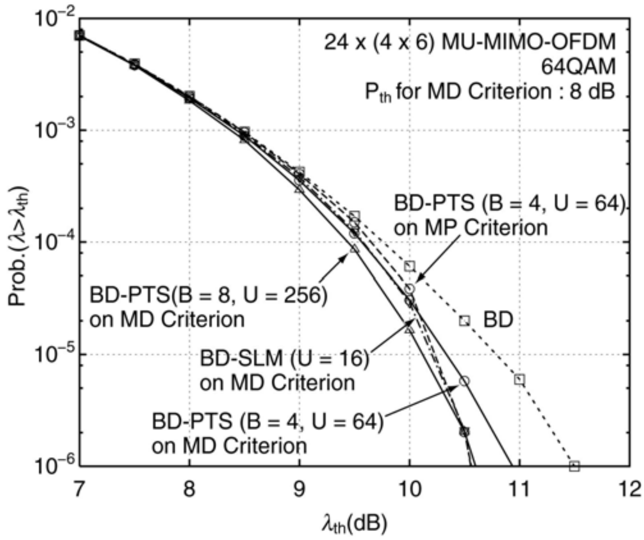


Fig. 5 CCDF of instantaneous power

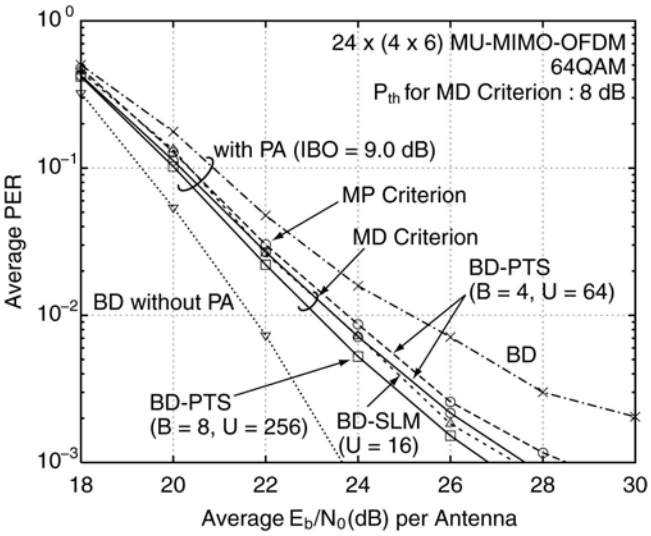


Fig. 6 Average PER performances of BD-PTS

Fig 5. shows CCDF of the instantaneous power of the transmitted signal in BD-PTS based on two criteria. For comparison, CCDFs of BD and BD-SLM with U = 16 were also plotted. the threshold P_{th} for the MD criterion was set to 8.0 dB, which was optimized by the computer simulation. It can be seen that BD-PTS with B = 4, U = 64 based on the MP criterion can reduce the instantaneous power at CCDF = 10^{-6} to 1.0 dB in comparison with normal BD, and that BD-PTS with B = 4, U = 64 based on the MD criterion can also reduce it to 0.6 dB. In comparison with the two criteria, when the instantaneous power is more than 10 dB, the MP criterion is superior to the MD criterion because the MD criterion, which selects the phase sequence that minimizes the distortion power, cannot perfectly reduce CCDF of the higher instantaneous power. Average packet error rate (PER) performances of BD-BTS based on the two criteria were investigated to evaluate the influence of the nonlinear distortion by PA with IBO = 9.0 dB. PERs of BD-PTS are shown in **Fig. 6**. For comparison, PERs of BD and BD-SLM with U = 16 based on the MD criterion were also plotted. This figure demonstrates that BD suffers from the nonlinear distortion by PA with IBO = 9.0 dB, while BD-PTS with B = 4, U = 64 can significantly alleviate the performance degradation. It is also found that BD-PTS based on the MD criterion slightly outperforms that based on the MP criterion, and that it can drastically reduce the E_b/N_0 degradation at PER = 10^{-2} to 1.8 dB in comparison with BD without PA.

Minimizing BER Precoding and Channel Estimation for MIMO-OFDM Systems under Co-Channel Interference [5]

In mobile communications, a multiple-input multiple-output (MIMO) system combined with orthogonal frequency division multiplexing (OFDM) is one of the most promising techniques to realize higher bit-rate transmission by improving spectral efficiency. Future-generation mobile communication systems are expected to adopt MIMO-OFDM and are required to reuse the same frequency channel in closely located cells, owing to lack of frequency spectrum,. Such frequency reuse, however, causes co-channel interference (CCI) from more than one of base stations to mobile stations at cell edges, and degrades the overall performance of the MIMO-OFDM downlink systems.

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This paper proposes channel estimation employing Zadoff-Chu sequences as preambles of both desired and interfering BSs, and calculates the covariance matrix from the estimated channel impulse responses for the MBER precoding under CCI. Moreover, this paper presents another method that can estimate the channel impulse responses of the interfering BSs without information on their preambles, and verifies the effectiveness of the proposed methods by computer simulations..

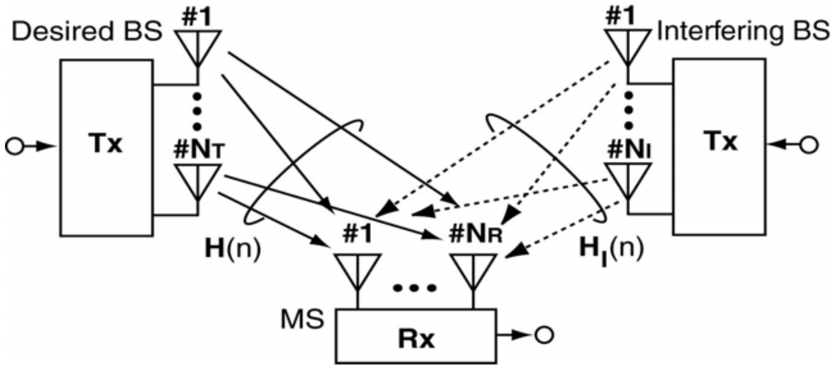


Fig. 7 MIMO-system

This paper considers a MIMO-OFDM downlink system with CCI as shown in **Fig. 7**. The desired BS and MS have N_T transmit antennas and N_R receive antennas, respectively, and the interfering BS has N_I transmit antennas..

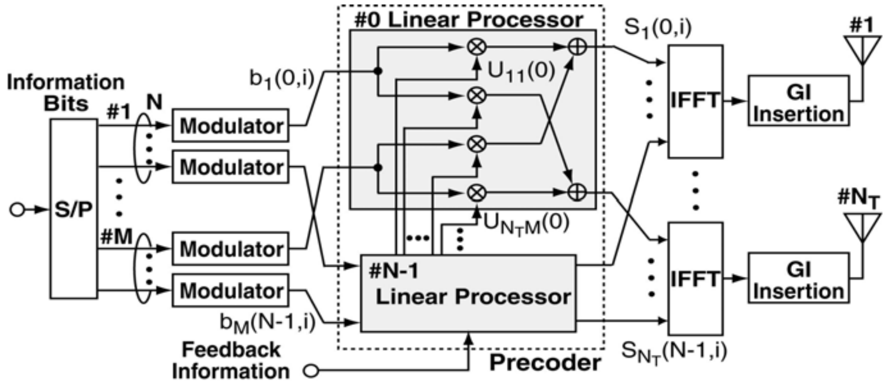


Fig. 8 Transmitter employing MBER precoding

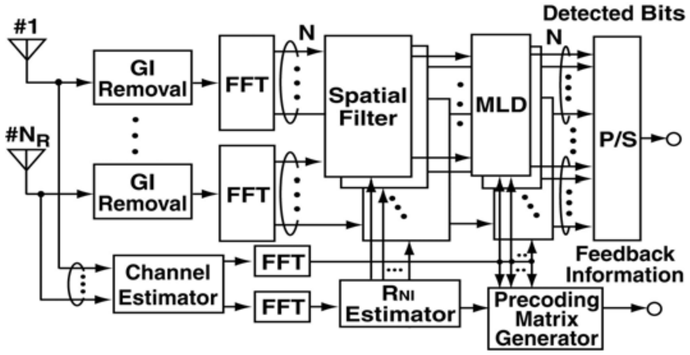
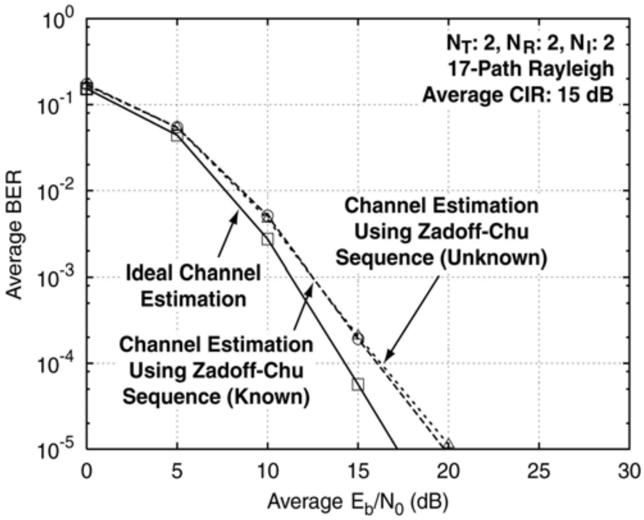


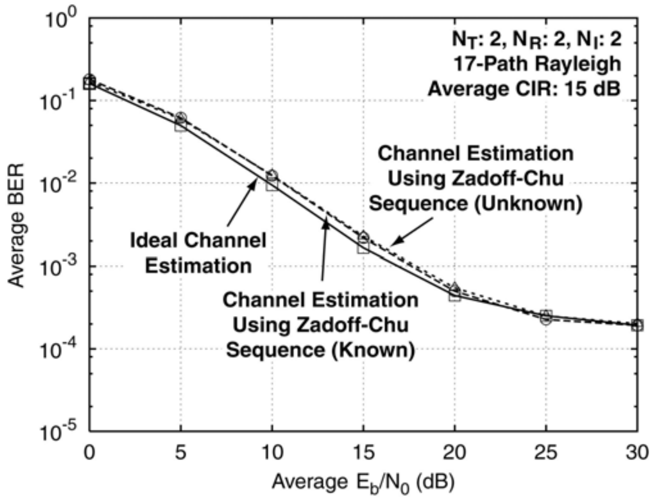
Fig. 9 Receiver employing spatial filters and MLD

Fig. 8 shows a block diagram of the MIMO-OFDM transmitter of BS that employs the MBER precoding. M ($<N_T$) data streams are modulated into OFDM signals having N subcarriers. bm(n,i) is a modulation signal of the m-th ($1 < m < M$) stream at the n-th subcarrier of the i-th OFDM symbol. Let $Sn_t(n,i)$ denote a transmitted signal of the n_t-th ($1 < n_t < NT$) antenna at the n-th subcarrier of the i-th OFDM symbol.

Fig. 9 shows a block diagram of the MIMO-OFDM receiver of MS with N_R receive antennas. The receiver has frequency domain spatial filters followed by the maximum likelihood detector (MLD).



(a)Constraint of transmit power 1



(b) Constraint of transmit power 2

Fig. 10 Average BER performance with MBER precoder

Fig. 10 shows effects of the MBER precoding that employs the steepest descent method with constraints 1 and 2. "Channel Estimation Using Zadoff-Chu Sequence (Known)" and "Channel Estimation Using Zadoff-Chu Sequence (Unknown)" indicate that the preambles of the interfering BS are known and unknown, respectively. With constraint 1, **Fig. 10(a)** shows that the MBER precoding can significantly improve the BER performance in comparison with only the spatial filters and MLD. This figure also demonstrates that the E_b/N_0 degradation of the proposed method to achieve BER of 10^{-3} is 1.2dB from the ideal channel estimation. **Fig. 10(b)** shows that with constraint 2, the E_b/N_0 degradation of the proposed method at BER of 10^{-3} is also 1.2dB. Moreover, in the case of the unknown preambles of the interfering BS, the performance degradation is negligible.

Suboptimal signal detection for spatially-correlated MIMO channels [21]

Multiple-input multiple-output (MIMO) mobile communications have attracted much attention because MIMO can increase system capacity and data-rate without expanding frequency bands. The optimal signal detection for the MIMO system is the maximum likelihood detection (MLD), which can achieve the minimum bit error rate (BER). Unfortunately, the computational complexity of MLD is prohibitive because it exponentially increases with the number of data streams. Therefore, suboptimal detection algorithms that can reduce the complexity are required.

The minimum mean-square error (MMSE) detection, which is such a suboptimal detection scheme, needs a very small amount of complexity but exhibits poor BER performance owing to the noise enhancement. To alleviate the degradation caused by the noise enhancement, a one-dimensional search algorithm has been proposed. This search algorithm sets an MMSE detection result to a starting point, and searches for signal candidates in one dominant direction of the noise enhancement. The detected signal is selected from the signal candidates and the quantized MMSE detection result on the basis of the log likelihood function. The conventional algorithm shows almost the same BER performance as that of MLD over uncorrelated MIMO channels. However, it incurs severe degradation of BER performance over spatially correlated MIMO channels, because plural dominant directions of the noise enhancement are likely to exist.

To cope with such a problem, this paper proposes a multi-dimensional search algorithm for correlated MIMO channels. The proposed algorithm searches for signal candidates in multi-dimensions of the noise enhancement, in contrast with the conventional algorithm. For reducing computational complexity of the multi-dimensional search, the proposed algorithm limits the number of signal candidates that grows linearly with the number of transmit antennas. The signal candidates, which are unquantized, are obtained as the solution of a minimization problem under a constraint that a stream of the candidate should be a constellation point different from that of the quantized MMSE detection result.

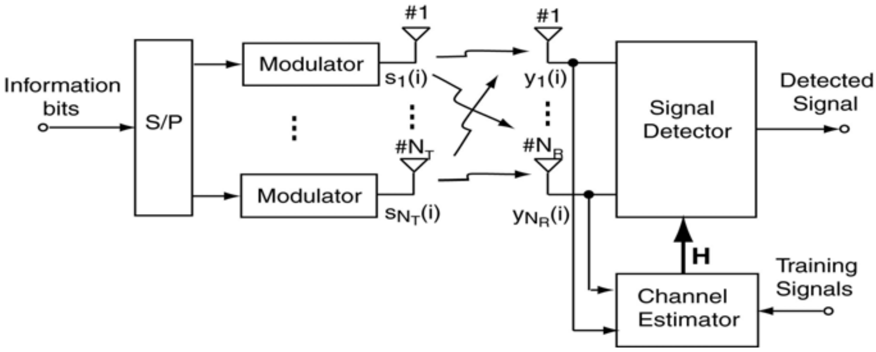


Fig. 11 MIMO system

Fig. 11 shows a MIMO system with N_T transmit antennas and N_R ($N_R < N_T$) receive antennas. The channel is assumed to be quasi-static and time-invariant flat fading during one packet. The proposed algorithm sets a MMSE detection result to a starting point, and searches for signal candidates in multi-dimensions of the noise enhancement from which the MMSE detection suffers. The multi-dimensional search is needed because the number of dominant directions of the noise enhancement is likely to be more than one over the correlated MIMO channels. To reduce computational complexity of the multi-dimensional search, the proposed algorithm limits the number of signal candidates to $O(N_T)$. Specifically, the signal candidates, which are unquantized, are obtained as the solution of a minimization problem under a constraint that a stream of the candidates should be equal to a constellation point. Finally, the detected signal is selected from hard decisions of both the MMSE detection result and unquantized signal candidates on the basis of the log likelihood function. For reducing the complexity of this process, the proposed algorithm decreases the number of calculations of the log likelihood functions for the quantized signal candidates.

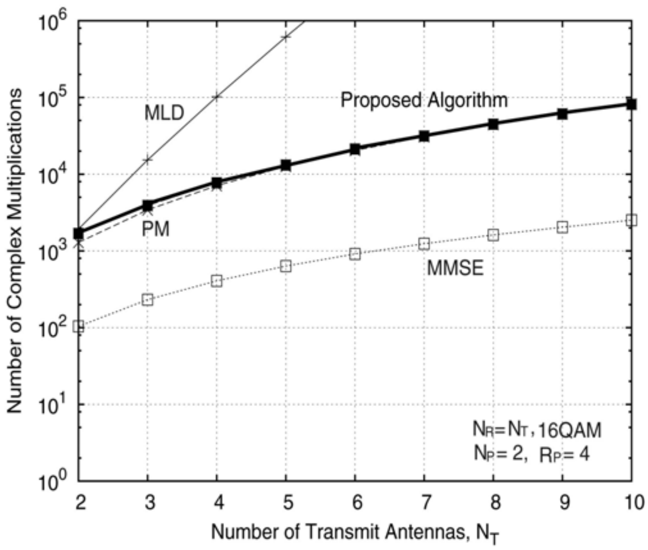


Fig. 12 Complex Multiplications

Fig. 12 shows the number of complex multiplications which the proposed and conventional algorithms require during an N_S(=20)-symbol long packet, when N_T=N_R and 16QAM was assumed as the modulation scheme. The parameters N_P and R_P of the proposed algorithm were set to 2 and 4, respectively. It can be seen that MLD requires the largest amount of complexity while MMSE needs the smallest complexity. The computational complexity of the proposed algorithm is almost same as that of PM.

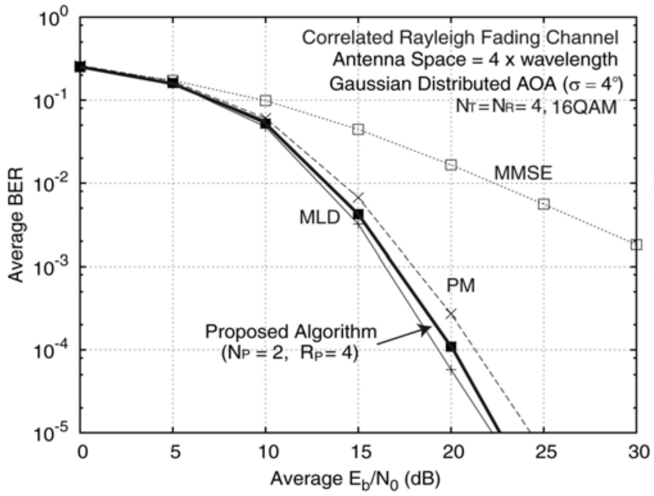


Fig. 13 Average BER over correlated channel with N_T= N_R=4

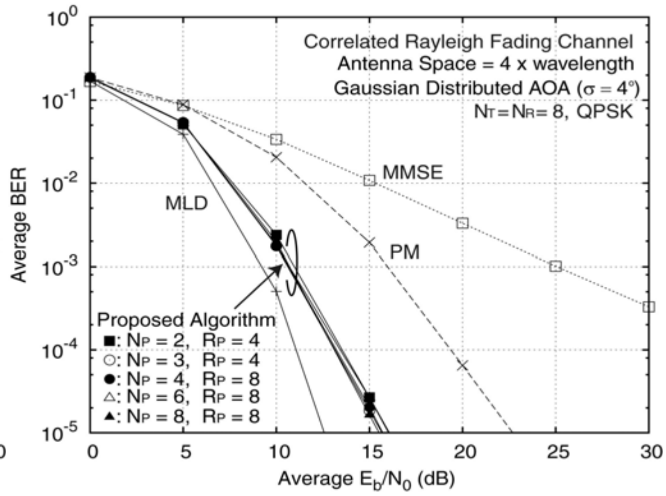


Fig. 14 Average BER over correlated channel with N_T= N_R=8

Fig.13 shows the BER performance of the proposed and conventional algorithms with 16QAM modulation and N_T=N_R=4 on the correlated Rayleigh fading channel. It can be seen that the BER performance of PM is worse and that a difference in BER between PM and MLD becomes larger. On the other hand, a difference in BER between the proposed scheme and MLD on the uncorrelated channel is almost the same as that on the uncorrelated channel. Thus, the proposed scheme is more robust against the correlated MIMO channel than PM.

Fig.14 shows the BER performance of the proposed and conventional algorithms with QPSK modulation and N_T=N_R=8 on the correlated Rayleigh fading channel. The BER performance of the proposed algorithm improves as N_P increases, and the improvement is saturated with N_P=3. The reason why more N_P is needed is that more dimensions of the search area are required as N_T and N_R increases. It can be also seen that a difference in BER between the proposed algorithm and MLD is considerable and the average E_b/N_0 which the proposed scheme requires to achieve average BER of 10^{-3} is about 3.0 dB greater than that of MLD.

TAKADA LABORATORY

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was born in Tokyo, Japan, in 1964. He received the B.E., M.E., an D.E. degrees from the Tokyo Institute of Technology in 1987, 1989, and 1992 respectively. From 1992 to 1994, he was a Research Associate at Chiba University. From 1994 to 2006, he was an Associate Professor at Tokyo Institute of Technology, where he has been a Professor since 2006. He was also a part time researcher in National Institute of Information and Communications Technology from 2003 to 2007. He is currently serving as an assistant secretary of URSI Japan National Committee. His current research interests are the radiowave propagation and channel modeling for various wireless systems, MIMO OTA test, regulatory issues of spectrum sharing and information technology for regional/rural development. He is senior member of IEEE, IEICE, and member of ITE, ACES, ECTI Association Thailand, JASID.

Assistant Professor Minseok Kim

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Assistant Professor Mir Ghoraishi received his BSc. from Isfahan University of Technology, Esfahan, Iran, and his MSc. from Amirkabir University of Technology, Tehran, Iran, both in electrical engineering in 1993 and 1999 respectively. From 1993 to 1996 he worked for a hardware company as a service engineer and in 1999 worked as a research engineer in a major Telecom company, both in Iran. From October 1999 he is with the Tokyo Institute of Technology where after getting the PhD degree he was a senior researcher and then assistant professor from April 2009. From December 2009 his work is dedicated to the "Research and Development Project for Expansion of Radio Spectrum Resources" of the Ministry of Internal Affairs and Communications, Japan, where he is responsible for the wireless channel analysis. His research interests are radio channel analysis and modeling, array signal processing, parameter estimation, positioning and tracking of wireless nodes and objects and adaptive and statistical signal processing. He has been an active member of the European Cooperation in Science and Technology, COST Actions 273 and 2100. He is a member of IEEE, IEICE and EURASIP.


May 12, 2010 10:00 AM Eastern Daylight Time

Wireless Innovation Forum Announces Winners of 3rd Annual Smart Radio Challenge

University of Calgary, Worcester Polytechnic Institute and Tokyo Institute of Technology Teams Top Winners of Scholarship Awards

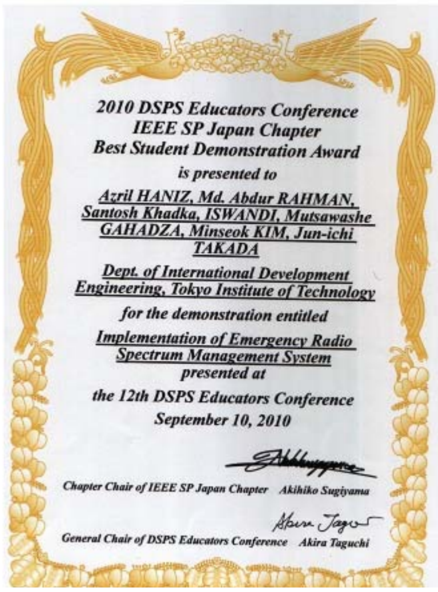
⋮

Winners were:

- First place and a scholarship prize of $4000: University of Calgary team
- Second place and a scholarship prize of $3000: Tokyo Institute of Technology team
- Best Design and a scholarship prize of $2000: University of Calgary team
- Best Presentation and a scholarship prize of $2000: WPI team
- Best Report and a scholarship prize of $1000: WPI team

2nd place in the 3rd Annual Smart Radio Challenge organized by Wireless Innovation Forum

*Screenshot from Business Wire, (http://www.businesswire.com/news/home/20100512005390/en/Wireless-Innovation-Forum-Announces-Winners-3rd-Annual)


2010 DSPS Educators Conference
IEEE SP Japan Chapter
Best Student Demonstration Award
is presented to
Azril HANIZ, Md. Abdur RAHMAN, Santosh Khadka, ISWANDI, Mutsawashe GAHADZA, Minseok KIM, Jun-ichi TAKADA
Dept. of International Development Engineering, Tokyo Institute of Technology
for the demonstration entitled
Implementation of Emergency Radio Spectrum Management System
presented at
the 12th DSPS Educators Conference
September 10, 2010

Chapter Chair of IEEE SP Japan Chapter Akihiko Sugiyama

General Chair of DSPS Educators Conference Akira Taguchi

Best Student Demonstration Award in the 2010 DSPS Educators Conference

TAKADA LAB's Recent Research Topics

Channel Characterization and Modeling for Wireless Communication Systems

- **Mobile Communication Systems**
  - MIMO Channel Sounder Development for Broadband Mobile Communication Systems [29,41]
  - MIMO Channel Analysis for Outdoor Micro Cell System [18]
  - Analysis of the Radio Channel in Interaction to Vegetation [42]
- **Body Area Network (BAN)**
  - Analysis of On-Body Propagation with Specific Actions using Finite State Markov Model [10]
  - Motion Analysis of On-body Antennas for BAN Channel Modeling [40]
  - Numerical Simulations for Wearable BAN Propagation Channel for Various Actions [38]
  - Development of Time domain UWB Channel Sounder for Multi-link Measurement
- **Specific Wireless Systems**
  - Application of Reflection on Curved Rough Surface in Ray Tracking in Tunnel Propagation [21,30]
  - Double Directional Channel Representation by using Spherical Wave Functions [47]

Cognitive Radio Systems and Radio Signal Processing

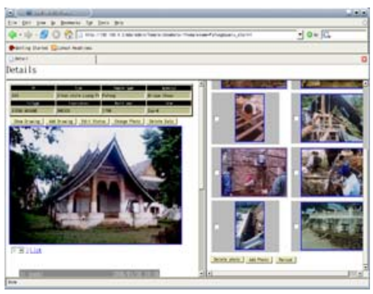
- Radio Spectrum Management System for Emergency Radios in Post Disaster Scenario [28]
- Automatic Modulation Classification Technique using Cyclostationarity [19]
- Performance Enhancement of Multi-cyclic Detector for Cognitive Radios with OFDM Primary System [9]
- The Effect of Antenna Pattern Distortion on UWB Ranging Accuracy [31,39]
- Remote Sensing of Heartbeat with Microwave

ICT Applications for International Development

- ICT application for sustainable development of world heritage site of Luang Prabang, Lao PDR [34]
- ICT Applications for teacher training in rural schools of Mongolia [69]

< BAN Channel Measurement>

<Broadband MIMO Channel Sounder>



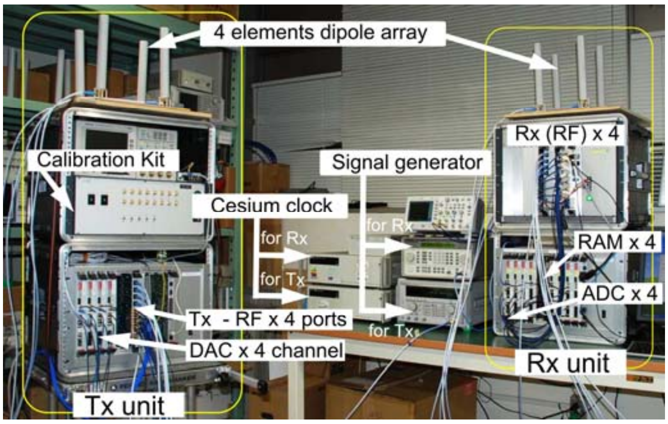
<Heritage database>

Development of Software Radio based MIMO Channel Sounder for Microwave Broadband Mobile Communication Systems

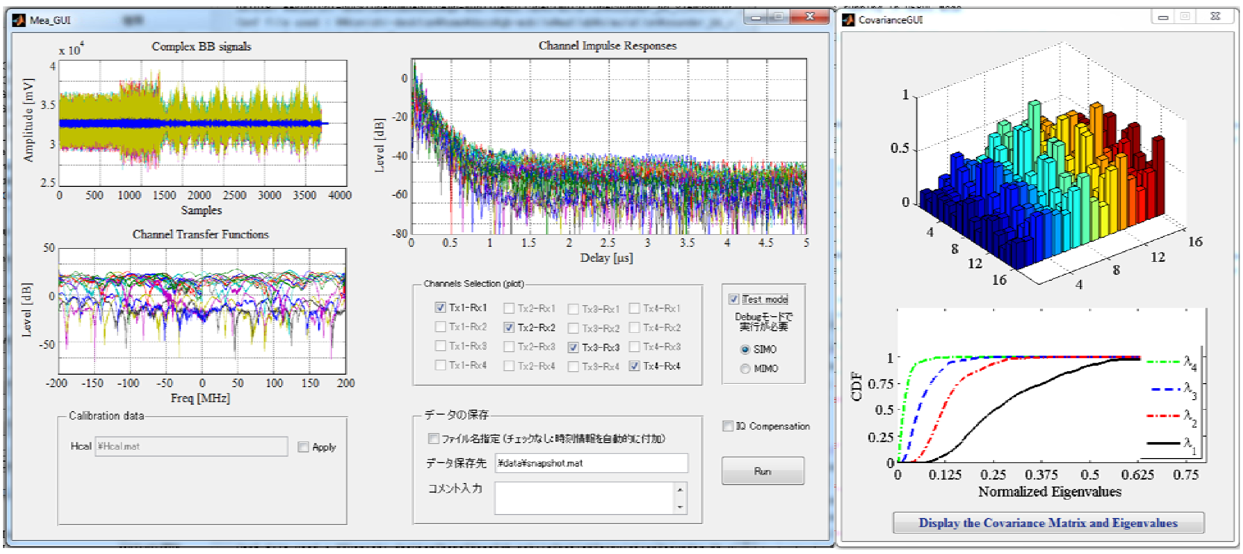
This work is supported by "The research and development project for expansion of radio spectrum resources" of The Ministry of Internal Affairs and Communication Japan.

The ultimate goal of this project is to investigate the future broadband mobile communication system operating at microwave frequency. The project team consists of NTT DOCOMO, Tohoku University and Tokyo Tech. Takada laboratory is responsible for the development of channel sounding technique to assess achievable transmission performance in the real propagation environment. The channel sounder under development in this study is utilizing MIMO software radio architecture. This is measure the full MIMO channels simultaneously, since the same hardware can be also used to test the real-time data transmission. Currently 4×4 MIMO channel sounder has been implemented, and it is under the expansion to 8×24 so as to conduct the directional measurement at receiver unit. Finally by year of 2012, 24×24 MIMO sounder is planned to be developed, and the field measurement in and picocell are planned.

The operating frequency is 11 GHz a bandwidth of 400 MHz for the transmitter multitone signal. The channel sounder is designed with full MIMO architecture in which each antenna is connected to individual transmitter of receiver module. This is in contrast with most existing sounders. Also the unit based modular configuration is adopted so as to measure and analyze multi-link communication scenarios.



Prototype 4×4 MIMO Channel Sounder



Measurement GUI

(Data measured in an indoor environment)

TAKADA LABORATORY

Body Area Network Channel Measurement and Modeling

Introduction

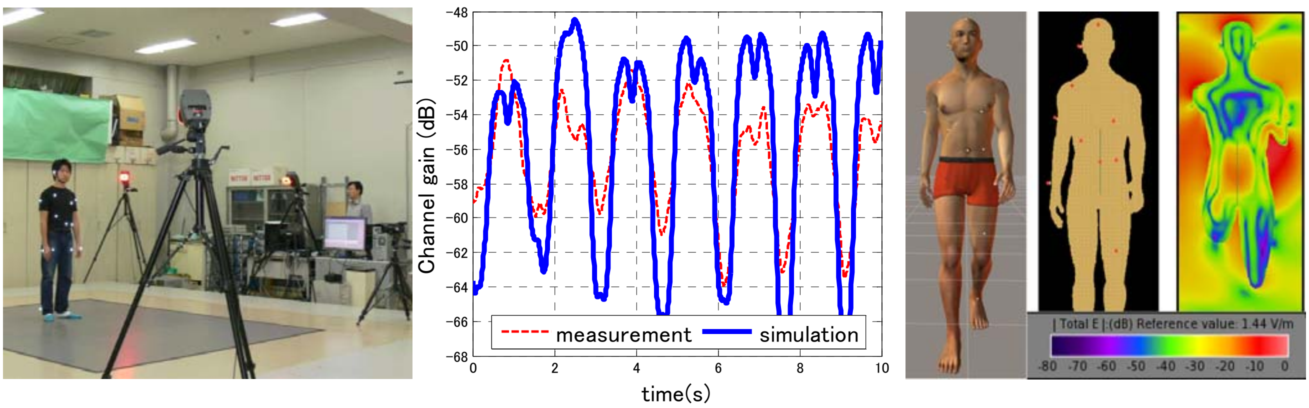
Body area network (BAN) is a promising candidate technology for enabling the wireless interconnection among wearable and or implanted devices especially in medical healthcare applications. Differs from the general wireless system, BAN channel is highly influenced by the existence and motion of human body nearby the channel. This research focuses on dynamic BAN channel and the effort to de-embed the antenna effect to channel. Initially, we have studied a statistical channel model at 4.5 GHz for dynamic scenarios [5, 10]. Currently, physical modeling of channel behavior is mainly studied by using analytical and numerical approaches and employing the motion capture equipment to observe the on-body antenna motions.

Measurement and Analytical Modeling

In the measurement, the motion capture equipment is utilized to acquire the on-body antenna motions by which the analytical model of dynamic BAN channel is developed [22] by considering the temporal propagation distance and antenna rotation. The first aspect is brought into channel model by using free-space path-loss model, and the second is using on-body antenna radiation pattern calculated by the infinitesimal dipole near the dielectric cylinder. Figure (a) and (b) show the measurement campaign and the simulation example result compared to measured channel response. .

Electromagnetic FDTD Simulations

The purpose of this simulation is to investigate the propagation characteristics of Body Area Network (BAN) communication. The commercial animation software (POSER 8) was used to generate the human body postures to be exported to the commercial FDTD simulator software (XFdtd) as can be seen on figure (c). The exported postures were filled with a homogeneous material (average muscle), and the propagation characteristics were simulated by using an ideal antenna of half-wave dipole.



(a) (b) (c)

Research on BAN (a) measurement with motion capture (b) result of analytical simulation based on antenna motion (c) numerical simulation by Poser and XFdtd software

Design and Implementation of Wireless Disaster Area Emergency Network (W-DAEN)

Disasters are becoming quite common in recent years. Wireless systems are part and parcel of the rescue operations conducted after a disaster. Probability of interference increases when rescue teams from all over the world come to the affected area. Wireless disaster area emergency network (W-DAEN) is helpful for monitoring active emitters and avoiding interference in the post-disaster scenario. This is done by maintaining a database of basic PHY parameters (i.e. carrier frequency, bandwidth, modulation type, symbol rate etc.). Spectrum sensors placed in the disaster area receives non-stationary noisy signals affected by slow fading channel. Carrier frequency and bandwidth can be estimated by energy detection, whereas modulation type and symbol rate estimations require further signal processing operations. Total processing time (from reception to detection) is one of the important performance parameters for such systems. Research has been carried out in the laboratory on five different areas. 1) network setup, 2) spectrum sensing, 3) emergency propagation channel and geolocation, 4) parameters extraction and 5) database maintenance. Figure 1 represents the functional blocks of the system. Inter-agency communications among the rescue teams also play a vital role for emergency networks. W-DAEN implemented in the disaster area can also be used for the interoperability among different teams. Figure 2 shows the architecture of post disaster communication systems. Interference avoidance and interoperability is achieved by placing the system in layer 2 and 3 of the figure.

A prototype has been implemented by using mostly software defined radio (SDR) and open source software. GNU radio with universal software radio peripherals (USRP) is used to make one transmitter and two sensor nodes. Signal processing has been accomplished by using python and matlab. Database maintenance and dissipation is done by using PHP and MySQL. The prototype (shown in figure 3) is able to develop and maintain a database of active emitters within the sensing range. Eight modulation types (analog and digital) have been identified with more than 80% success rate.

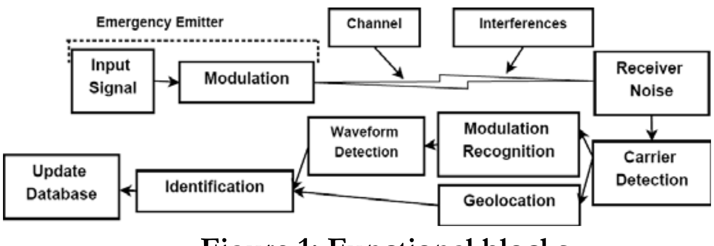


Figure 1: Functional blocks

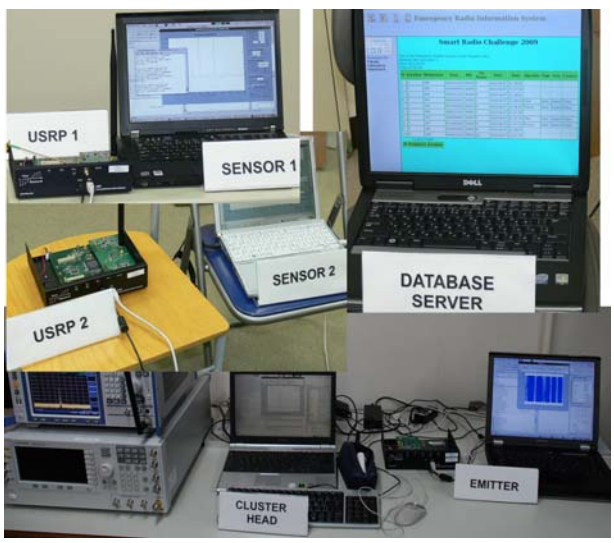


Figure 3: Implemented prototype

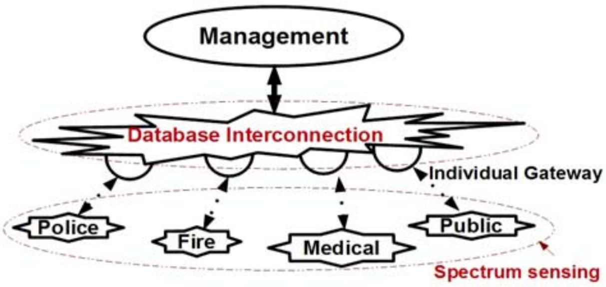


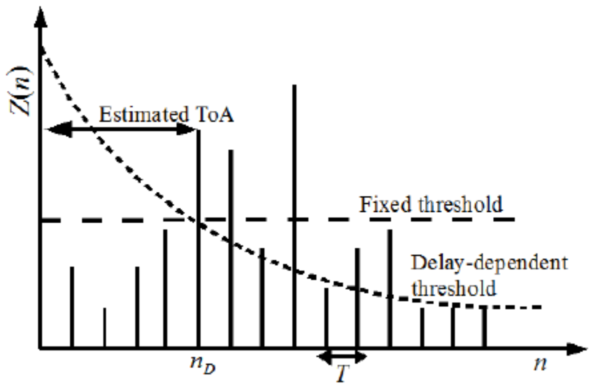
Figure 2: Emergency communication system

TAKADA LABORATORY

Optimum Threshold for Indoor UWB ToA-based Ranging

(Joint research with Aalto University School of Science and Technology, Finland)

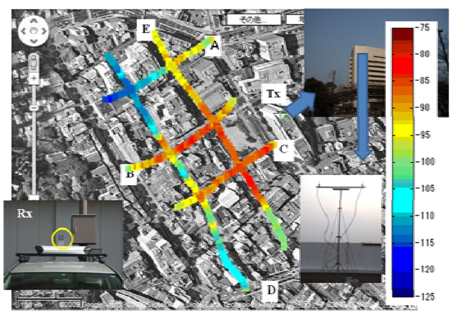
The optimum threshold for UWB threshold-based ranging is derived based on the full analysis of the ranging error, which is equivalent to the probability of correct detection of first arriving signal in time-based ranging techniques. It is shown that the probability of correct detection is a function of first arriving signal, which has variations with two independent distributions. First, it varies on different positions with the same range due to multipath interference. Second, it is a function of distance due to free space path-loss. These distributions are considered in the derivation of probability of correct detection to provide for the full analysis of the ranging error, based on which is derived. A practical method to derive this threshold is introduced based on the standard channel model. Extensive Monte Carlo simulations, ray-tracing simulations and ranging measurements confirm the analysis and the superior performance of the proposed threshold scheme.



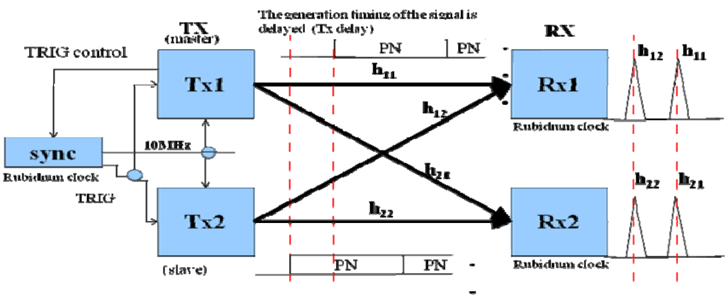
Threshold based ToA Estimation

Measured MIMO Channel Capacity in Outdoor Macro Cell at 3GHz-Band *(Joint research with NICT)*

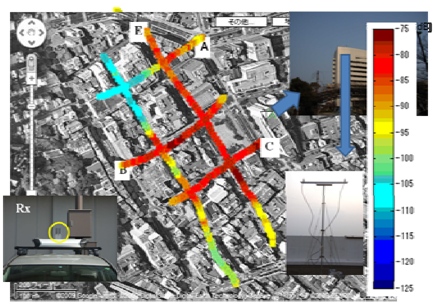
This study investigates the outdoor MIMO channel characteristics measured by a 2×2 MIMO channel soundings system at the center frequency of 3.35 GHZ in urban environment. In this measurement system, the 9-stage PN signals are transmitted by controlling the transmission timing in each transmitter, and hence, the complex MIMO channel impulse responses can be obtained by using same PN sequence in the receiver. From the measured MIMO channel matrix, we computed the eigenmode channel gain and capacity via singular value decomposition (SVD). The channel capacities are compared between line-of-sight (LOS) and non-line-of-sight (NLOS) environments, as well as with different antenna separation.



(a) SISO



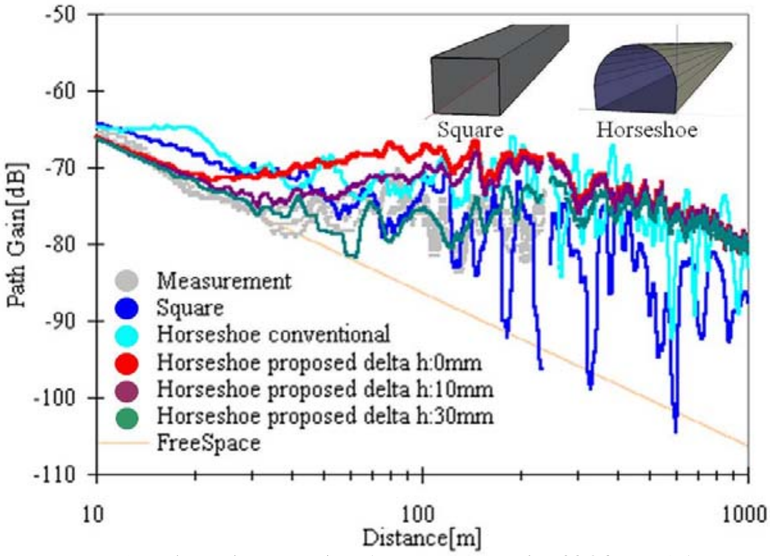
TDM MIMO channel sounding by using PN sequence



(b) First singular value of MIMO
Path gain map in the suburban city

Investigation of Caustics Region using Physical Optics for Ray Tracing Simulations

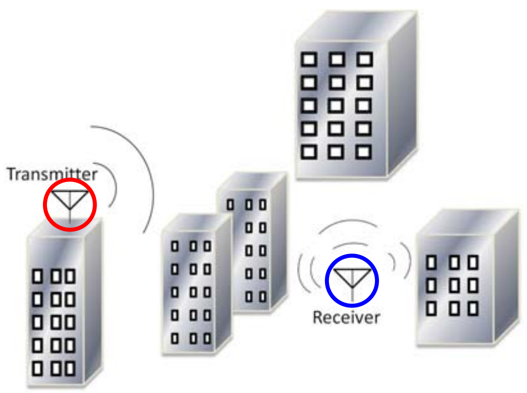
In ray tracing simulations, curved surfaces and edges are difficult to handle. The approximation of dividing the curved surface into smaller flat plates is not so accurate as the size of smaller plates may not satisfy geometrical optics assumption, and the reflection point which satisfies Fermat's principle may not exist. In this work, a new ray tracing method which models the reflection on the curved surface was implemented and the physical optics method was applied on the caustics region. To test this method, path gain simulation results for a square and horseshoe cross-section model are compared with measurements made inside an arched tunnel. To further improve the simulation results, the effect of rough surface is introduced, and the results are again compared with measurement.



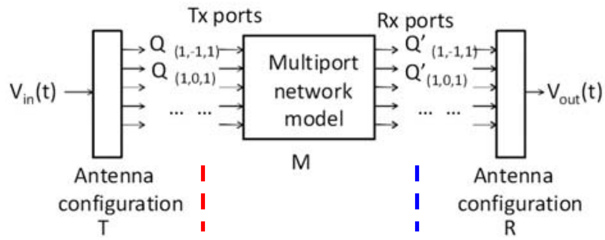
Path gain results (Frequency is 4920MHz)

Double-directional channel model using spherical harmonics

Double-directional channel model tries to de-embed transmitting and receiving antennas from the multipath radio channels, which enables the comparison of performances of different antennas in the same propagation environment. This study investigates such a model that is expressed as finite sums of spherical harmonics at both antennas. This modeling approach can be better described by the multiport equivalent circuit. Spheres enclosing Tx and Rx antennas are interpreted as reference planes of equivalent multiport network. Individual spherical harmonics correspond to the different ports. Both antennas and propagation channel can be represented by the multiport network, and therefore completely separated from one another.



Double-directional channel using spherical harmonics



Equivalent circuit model of double-directional channel

TAKADA LABORATORY

Experimental Study of Frequency Characteristics and Spatial Characteristics of Propagation through Foliage (Joint Research with NTT DOCOMO) [42]

Introduction

Coverage prediction of wireless communication systems requires a precise knowledge of how the environments surrounding the base station and mobile station influences radio propagation. In residential and rural areas, vegetation is one of the major propagation loss factors. In context of wireless communications, signal attenuation caused by the forest is due to absorption and scattering by branches and leaves of the trees.

This research investigates spatial characteristics of the propagation through foliage. Angular spread is a key parameter for the multi antenna systems such as diversity, adaptive array antenna, and MIMO systems.

Measurement

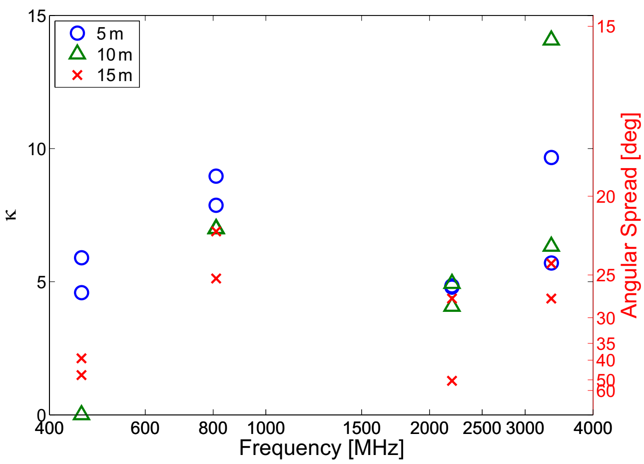
The measurement was performed in the forest at Yanashima-Kaigan, Kanagawa, as can be seen on figure (a). The height of base station was varied from 5 m to 15 m by using a man lift, whereas the mobile station was fixed on the horizontal positioner with a height of 1.5 m. At each position of the base station, the mobile station was moved within 1.5 m along the horizontal direction to receive the spatial distribution of signal level.

(a) Measurement field at Yanashima

Analysis and Results

Clarke's theory of Rayleigh fading is introduced. If the multipath fading is Rayleigh distributed, auto covariance of the received power and autocorrelation of complex signal are directly related. Thereofore, CDF of measured voltage was compared with Rayleigh CDF by one-sample Kolmogolov-Smirnov (KS) test for equality. Once the test is successful, the auto covariance coefficient of the received power is calculated, and the coherence distance is determined at its value of 0.5.

To relate the coherence distance and angular spread, angular power spectrum (APS) model is introduced. In this study Von-Mises APS model is introduced: $S_\psi(\psi) = \frac{\exp(\kappa \cos\psi)}{2\pi I_0(\kappa)}$ where $I_0(\kappa)$ is 0th order modified Bessel function of first kind, and $\kappa \approx \frac{1}{\Delta\psi^2}$, where $\Delta\psi$ is angular spread. Spatial correlation of Von-Mises APS is given in closed form, and the measured and model coherence distances are compared to identify κ. The results are summarized in figure (b).



(b) Spread parameter κ

Average κ among all these cases is 5:3, which corresponds to the angular spread of about 25 deg.

GIS Development in World Heritage Sites in Developing Countries "Preventing from becoming Heritage in Danger": Case of Luang Prabang, Lao P.D.R (Joint Research with Yamaguchi Lab, GSIC)

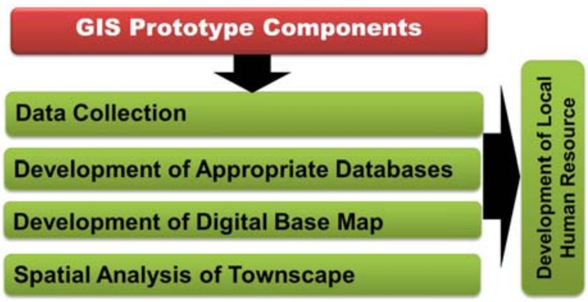
Introduction

Luang Prabang of Lao P.D.R is inscribed as World Heritage Site in 1995. The town currently is facing rapid increase of tourists and as a result, touristic accommodations increased in order to cope up with increasing demand. GIS (Geographical Information System) was introduced in Luang Prabang with the aim to visualize and analyze the changes in the townscape after world heritage inscription. Analysis of such changes is expected to provide sufficient information to assist local government to identify the major problems of the development and formulate strategies to counter the problems.

Development of GIS Prototype

The GIS prototype is designed to analyze the townscape by comparing the landscape documented in 2001 with 2009. The building information was taken from Safeguarding and Preservation Plan map of 2001 (PSMV) and field survey data of 2009. A localized GIS prototype considering data availability and local human resource are being developed to cater to the needs of local community (figure b). The prototype is comprised of collection of data, development of appropriate databases, development of digital base map, spatial analysis of townscape, and development of local human resource.

(a) Luang Prabang Heritage Site



(b) Components of GIS prototype

Base map provide a spatial reference for users to locate and identify objects in the surrounding terrain. Five mapping resources were identified to develop good quality map (figure c); 1) scanned topographic maps, 2) CAD drawn map, 3) Lao national base map, 4) satellite image, and 5) Google Earth image. A total of 743 buildings are documented in the base map. Spatial analysis was done to study changing patterns in buildings. The analysis was carried out on general information of buildings such as usage, architecture, building material, height and land use.

(c) Developed base map

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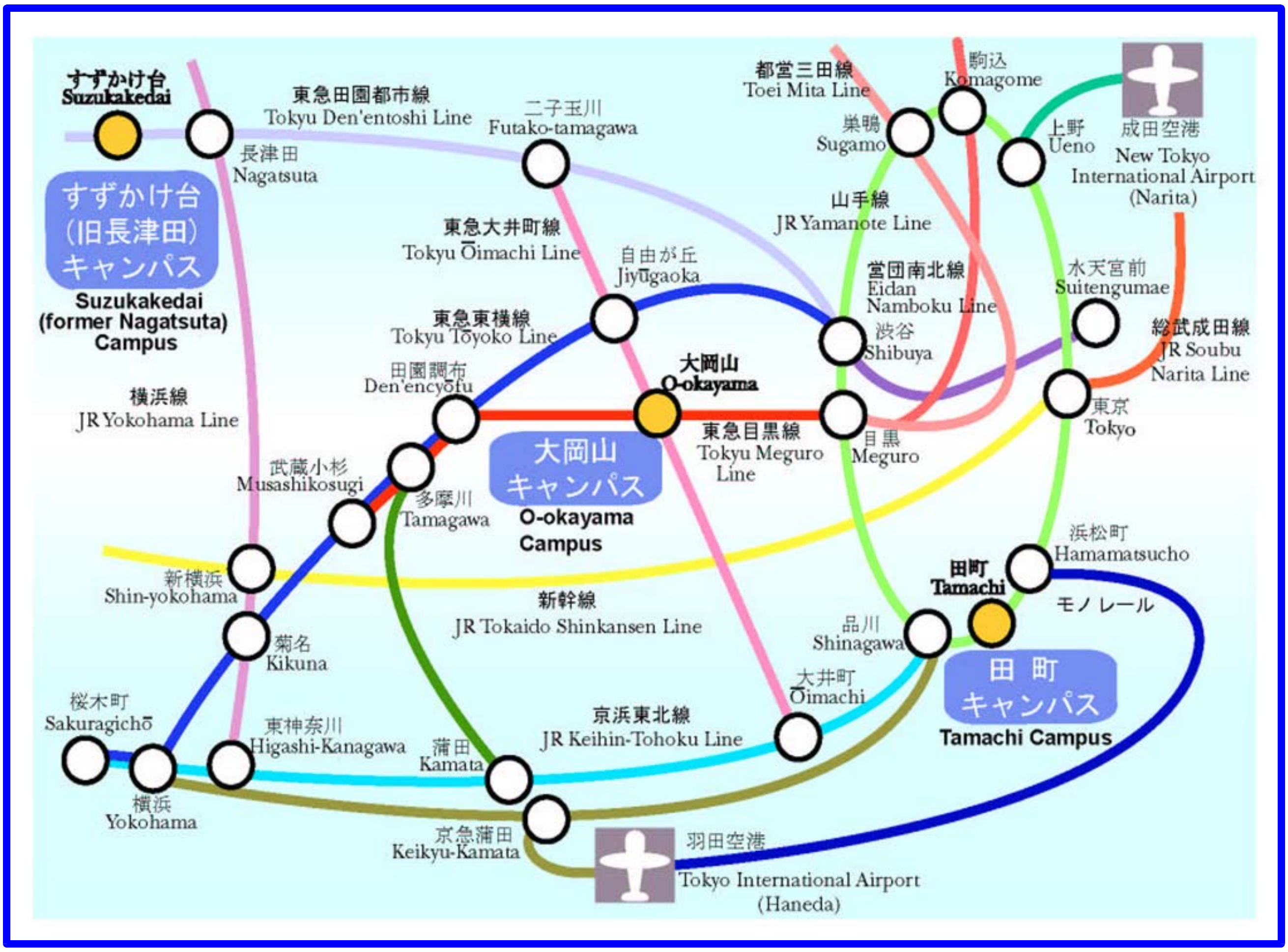

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