Mobile Communications Research Group
Tokyo Institute of Technology

2011 Annual Report

Contents

Laboratory Introduction & Annual Report 2011

TOKYO INSTITUTE OF TECHNOLOGY

Ookayama campus covered in deep snow on leap day (February 29).

February 29, 2012

Main entrance of Ookayama Campus, renewed with a large signboard.

November 22, 2011

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 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 resource : http://www.titech.ac.jp/ and 2011 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, Associate Prof. Kei Sakaguchi and Assistant Prof. Gia Khanh Tran)
3. Propagation and Antenna Laboratory
   (Prof. Jun-ichi Takada and Assistant Prof. Minseok Kim)

Our group conducts comprehensive research on the development of mobile communication systems covering a wide range of cutting edge technologies in the fields of the 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.

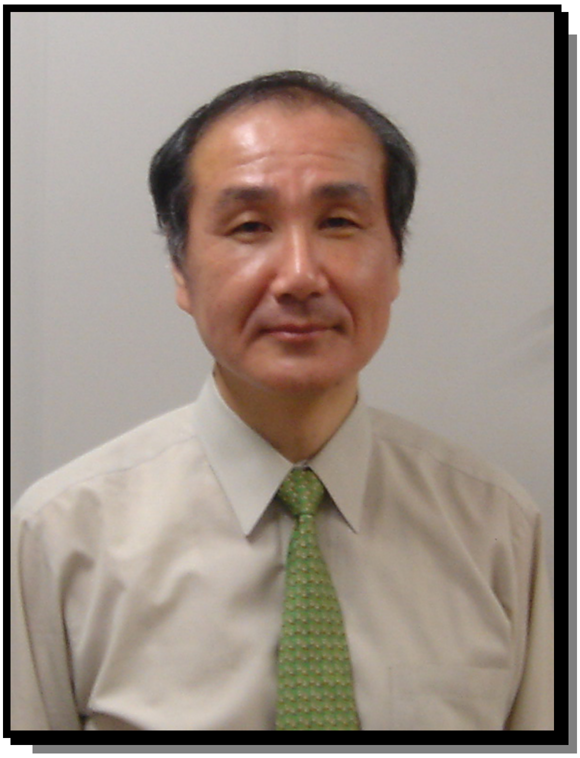
An Open House is yearly organized to introduce our MCRG activities and build a network with external companies, institutes and organizations in the field of mobile communications. Distinguished speakers from both the academia and industry are invited to give key note speeches and lectures to contribute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

2011 MCRG member

Laboratory Introduction
&
Annual Report 2011

SUZUKI-FUKAWA LABORATORY

Website: 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 [2]
    - Factor graph [27]
    - MMSE detection avoiding noise enhancement [1], [3], [5], [14], [22], [24]
  - 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
  - PAPR reduction
    - Block diagonalization with selected mapping (BD-SLM)
    - Partial transmit sequence (PTS)
  - Joint BER and PAPR improvement
    - SPH-SLM
    - Eigenmode transmission with PAPR reduction
  - Relaying system improvement
    - Amplify-and-Forward (AF) / Decode-and-Forward (DF) switching

- *super high-bit rate mobile communications*
  - millimeter-wave multi-Gbps systems [7], [9], [15], [20], [21], [23], [28], [29]

Multiple Access

- *Interference mitigation*
  - Spatial filtering
  - MBER precoding for cochannel interference environment

- *Access scheme*
  - IDMA with iterative detection [11]
  - Random packet collision solution [13], [16]

Modulation and Demodulation for Cognitive Radio

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

RF Impairment Compensation

- *Phase noise compensation* [6], [8], [10], [19], [25], [31], [32]
- *I/Q imbalance compensation* [30]
- *Real zero coherent detection*

In-House Simulator Design and Implementation

- *FPGA on-board system simulators* [6], [12]
- *4×4 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.

Joint Signal Detection and Channel Estimation using Differential Models via EM Algorithm for OFDM Mobile Communications [2]

The optimal receiver for the OFDM system is one based on the maximum *a posteriori* (MAP) criterion and should be capable of performing joint signal detection and channel estimation. An ideal receiver, however, would involve prohibitive computational complexity as it would need to perform channel estimation for all hypothetical transmitted signal sequences. What is needed then, is a suboptimal receiver that can drastically reduce complexity, but without increasing the packet error rate (PER). One solution to the problem of realizing such a suboptimal receiver is to apply the expectation-maximization (EM) algorithm, which approximates the MAP estimation in an iterative manner, involves feasible computational complexity. Specifically, the EM algorithm for OFDM systems iterates joint signal detection and channel estimation so that the *a posteriori* probability density function of signals and channel parameters increases monotonically with the iteration step.

A major problem associated with suboptimal receivers employing the EM algorithm is that they cannot accurately estimate time-variant channel impulse responses. Some receivers perform channel estimation using the Kalman filter and use the random walk model or the first-order autoregressive (AR) model to derive its process equation in order to track the time-varying channel. The first-order AR model requires information on both the maximum Doppler frequency and the average power of each propagation path, and thus requires the estimation of these parameters. Although the random walk model does not require this additional information, it cannot track fast-fading channels, as is also the case when the AR model is used. Other work uses a basis expansion model, which expresses each propagation path as a superposition of complex basis functions. The tracking ability of the scheme using the basis expansion model depends on the number of basis functions which increases along with the maximum Doppler frequency, although the computational complexity of the scheme increases in proportion to the square of the number. Thus, high computational complexity is required to track fast-fading channels

Using the differential model to derive the process equation for the Kalman filter, we propose a new approach to the joint processing of signal detection and channel estimation which is based on the EM algorithm for OFDM mobile communications. The EM algorithm can be applied to joint signal detection and channel estimation for OFDM systems in two schemes: one that regards transmitted signals as hidden variables and another that treats channel impulse responses as hidden variables, both recursively perform MAP-based signal detection. The proposed MAP receiver can maintain a low PER even under fast-fading conditions. Furthermore, a forward recursive form of channel estimation along both the frequency and time axes is used in order to reduce the computational complexity.

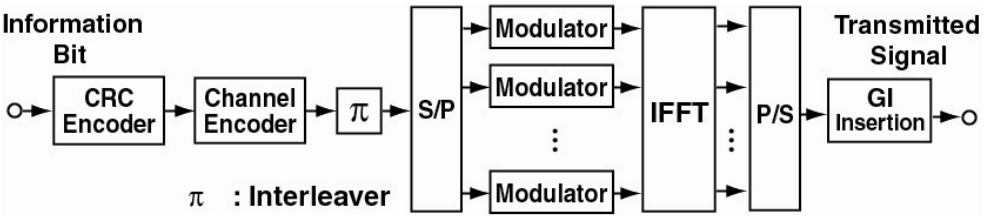


Fig. 1 Structure of an OFDM transmitter

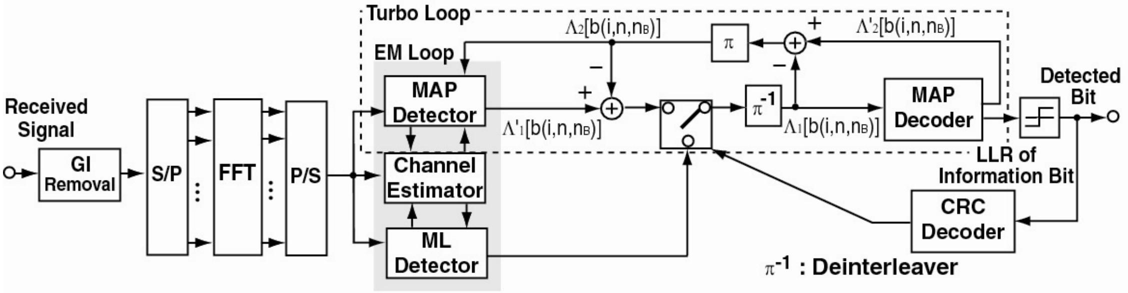


Fig. 2 Structure of an OFDM receiver

A block diagram of an OFDM transmitter is shown in **Fig. 1**. An information bit sequence is passed through a cyclic redundancy check (CRC) encoder and a channel encoder. The encoded bit sequence is then fed into a block interleaver, and then the resulting output is transformed into a number of parallel sequences in the serial-parallel converter. These sequences are mapped onto modulation signals when they pass into an inverse fast Fourier transform (IFFT) processor. Finally, the output signals are transformed into OFDM signals with N subcarriers, into which a guard interval (GI) is inserted.

The proposed MAP receiver, whose structure is shown in **Fig. 2**, is based on the turbo principle. Specifically, the MAP decoder for channel decoding iteratively exchanges extrinsic information with a soft demodulator that consists of a maximum likelihood (ML) detector, a MAP detector, and a channel estimator. The demodulator performs joint signal detection and channel estimation.

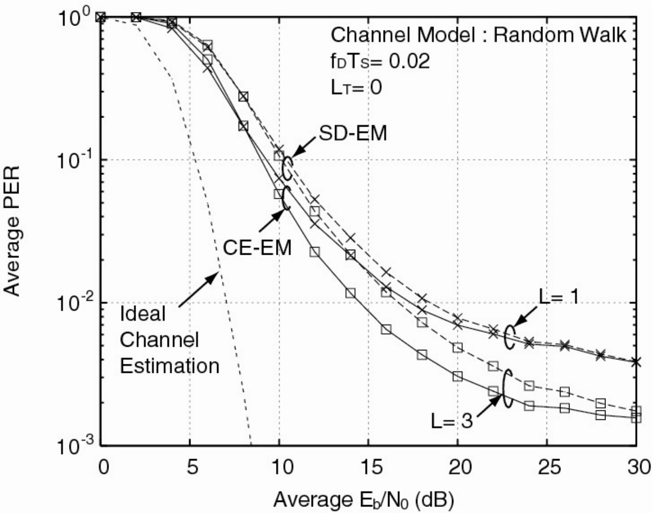


Fig. 3 Performance of CE-EM and SD-EM

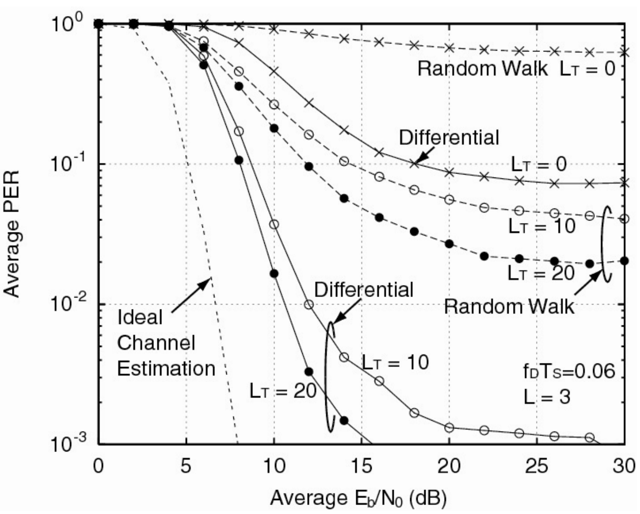


Fig. 4 Performance CE-EM with $f_DT_S = 0.06$

Fig. 3 shows the average PER performance of the CE-EM and SD-EM methods with $f_DT_S = 2.0 \times 10^{-2}$ (f_D is the maximum Doppler frequency of the channel, T_S is duration of the OFDM symbol). Both methods used the random walk model with λ (forgetting factor) equal to 0.1. L (maximum number of iterations) was set to 1 or 3, whereas L_T (maximum turbo iterations) was set to 0 (ML mode). With low E_b/N_0, the SD-EM method is inferior to the CE-EM method.

Fig. 4 shows the average PER performance with $f_DT_S = 6.0 \times 10^{-2}$. L was set to 3, while L_T was set to 0, 10, or 20. Since the random walk model has insufficient tracking ability, an error floor appears at PER = 2.0×10^{-2}, even with L_T=20. In contrast, the differential model is much more robust to fast fading and can achieve PER = 10×10^{-2} with E_b/N_0=10.5dB.

Low-complexity Signal Detection by Multi-dimensional Search for Correlated MIMO Channels [5]

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 increases exponentially with the number of data streams. Thus, suboptimal detection algorithms that can reduce the complexity are required.

The minimum mean-square error (MMSE) detection, which is a suboptimal detection scheme, needs a very low level 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 results on the basis of the log likelihood function. The conventional algorithm shows almost the same BER performance as MLD over uncorrelated MIMO channels. However, it suffers severe degradation of BER performance over spatially correlated MIMO channels, because plural dominant directions of the noise enhancement are likely to appear.

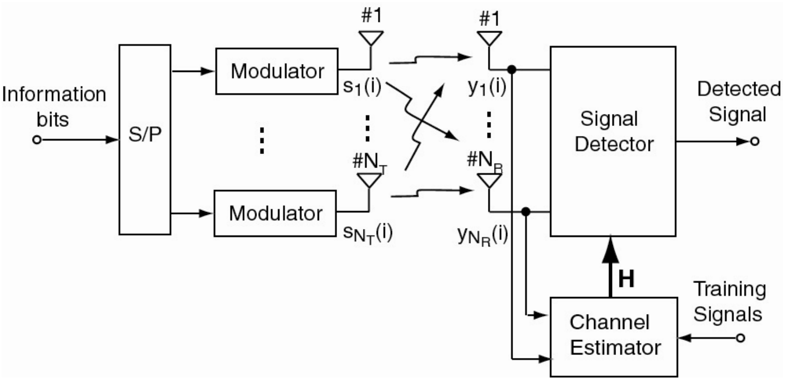


Fig. 5 MIMO system

Multi-dimensional search algorithms for correlated MIMO channels are expected to solve the above problem. **Fig. 5** shows a MIMO system with N_T transmit antennas and N_R ($N_R \geq N_T$) receive antennas. The channel is assumed to be quasi-static and time-invariant flat fading during one frame. The proposed algorithm sets an MMSE detection result to a starting point, and searches for unquantized signal candidates in multi-dimensions of the noise enhancement from which 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 the complexity of the multi-dimensional search, this paper proposes a low-complexity algorithm that limits the number of signal candidates to $O(N_T)$ where N_T is the number of transmit antennas. Specifically, 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 equal to a constellation point. The detected signal is selected from hard decisions of both the MMSE detection result and the 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.

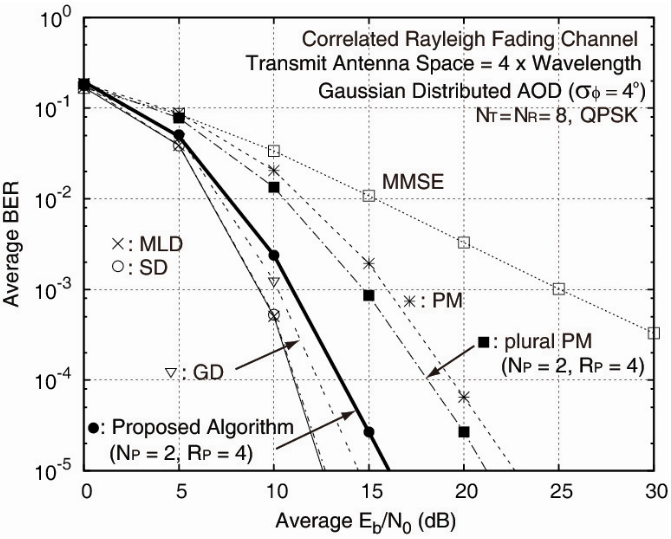


Fig. 6 Average BER over correlated channel with $N_T = N_R = 8$

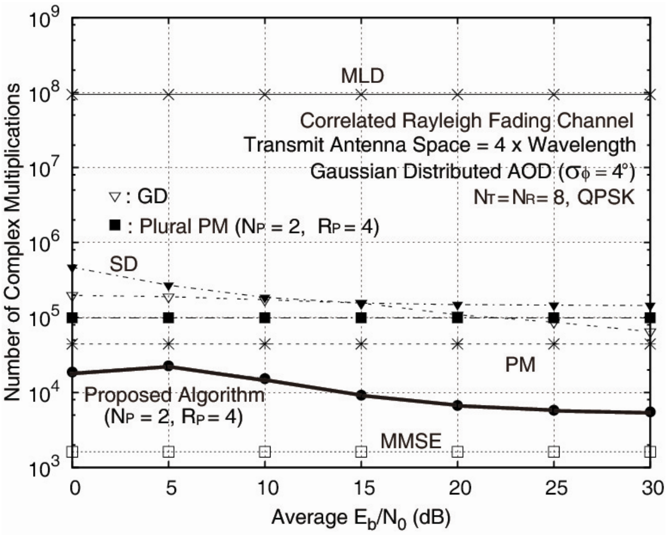


Fig. 7 Computational complexity with $N_T = N_R = 8$

Fig. 6 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 performance of MLD can be considered the lower bound. Sphere decoding (SD) can maintain almost the same performance as that of MLD, while geometric decoding (GD) can not. The proposed algorithm is a little inferior to GD but outperforms plural projection method (PM) and PM. Therefore, the proposed scheme is more robust against the correlated MIMO channel than plural PM and PM.

Fig. 7 shows the average number of complex multiplications which the proposed and conventional algorithms require during one frame. The proposed algorithm needs much less computational complexity than MLD. When average E_b/N_0 is equal to 30 dB, the proposed algorithm can reduce the complexity to about 8.5% of that required by GD, 12.5% of that required by PM, and 5.9% of that required by plural PM. SD requires more computational complexity than the other suboptimal algorithms. Note that the complexity of the proposed algorithm increases monotonically with average E_b/N_0 when average $E_b/N_0 \leq 5$ dB. It is also noteworthy that MLD, SD, and GD which outperform the proposed algorithm require much more complexity than the proposed algorithm.

Experimental Evaluation of Phase Noise Compensation for 60-GHz OFDM System [6]

Wireless personal area network (WPAN) systems in 60-GHz millimeter-wave band have been extensively studied, and 60-GHz WPAN standardization in IEEE 802.15.3c investigates OFDM transmission because of multipath channels. However, it is difficult to make a frequency synthesizer with the sufficiently low-level phase noise that can tune four channels of 2-GHz bandwidth in the 60-GHz band. On the other hand, it is well known that OFDM with the multi-level QAM is sensitive to the phase noise. In order to solve this problem, decision-directed phase noise compensation (DD-PNC) has been proposed for OFDM and single-carrier transmissions. These investigations, however, have verified the effectiveness of DD-PNC only by computer simulations.

The experimental system consists of both a baseband (BB) signal processing circuit including analog-to-digital converter (ADC) and digital-to-analog converter (DAC) with sampling frequency of 3.2 GHz, and a commercial 60-GHz transceiver. DD-PNC is applied to the BB OFDM demodulation processing. Experimental result demonstrates that DD-PNC can drastically alleviate performance degradation of OFDM/16QAM with 1.2 GHz bandwidth under the severe phase noise condition of -77 dBc/Hz at 1 MHz offset.

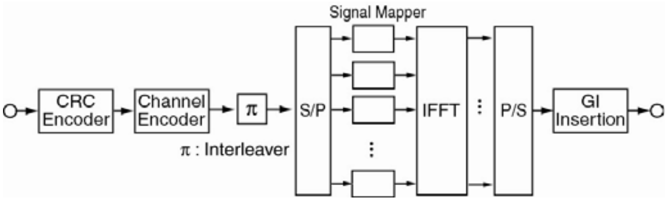


Fig. 8 OFDM modulation

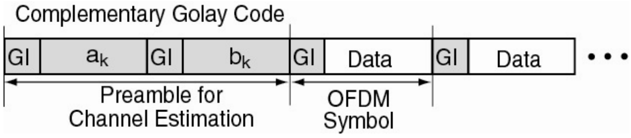


Fig. 9 Packet configuration

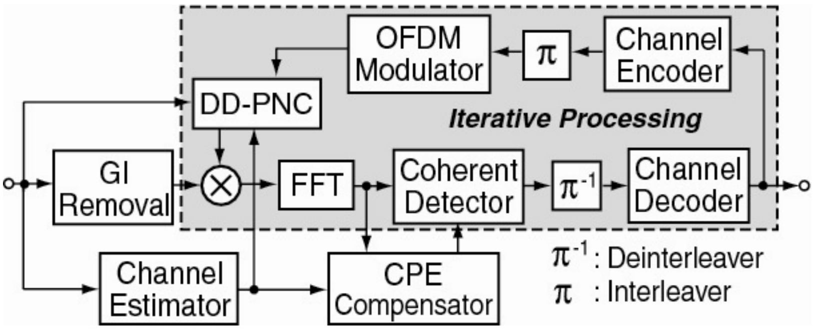


Fig. 10 OFDM demodulation employing DD-PNC

The BB OFDM modulation processing is shown in **Fig. 8**. Information bits are encoded by the cyclic redundancy check (CRC) code and the convolutional code. After interleaving the coded bits, the modulation processing maps them into the modulation signal at each subcarrier. Inverse fast Fourier transform (IFFT) converts the modulation signals into the time-domain signal and then the guard interval (GI) is inserted. Note that as shown in **Fig. 9**, complementary Golay code is time-multiplexed at the head of the packet as a preamble for the timing recovery and the channel estimation. Complete orthogonality of the complementary Golay code is exploited for the timing recovery and the channel estimation.

Fig. 10 shows a block diagram of the OFDM demodulation processing with DD-PNC. The OFDM demodulation copes with the phase noise by (i) common phase error (CPE) compensation, which compensate for CPE by using pilot signals inserted in each OFDM symbol, and by (ii) DD-PNC, which compensate for the phase noise by using received signal replicas which are generated from an output of a channel decoder. Iteration of the phase noise compensation, the coherent detection, and the channel decoding can alleviate the performance degradation. The OFDM demodulation performs FFT timing synchronization and then estimates a channel impulse response by using the preamble at the head of the packet. Next, it estimates CPE by using the pilot signals and the post-FFT received signals. Then, by using the estimated CPE and the estimated channel frequency response which is transformed from the estimated impulse response by FFT, the coherent detection is carried out. After deinterleaving the soft decisions which the coherent detection outputs, a soft-decision Viterbi decoder calculates the decoded bits. If a CRC decoder detects a decision error from the decoded bits, the OFDM demodulation shifts the initial processing to an iterative processing.

In the iterative processing, the OFDM demodulation first generates a transmitted signal replica by exploiting the output of the decoder. Next, DD-PNC generates a received signal replica by using the transmitted signal replica and the estimated impulse response. It recursively estimates the phase noise by the one-tap least-mean-square (LMS) algorithm using the received signal replica. In addition, it smoothes the estimates by backward exponentially weighting in order to improve the estimation accuracy. Finally, it removes the smoothed estimate from the received signal. The compensated received signal is processed by the coherent detector and the Viterbi decoder. The iterative processing is repeated until the maximum number of iterations or no decision error is detected.

Packet error rate (PER) performances of the OFDM receiver with DD-PNC were measured by the 60-GHz experimental system. The measured results are shown in **Fig. 11**. For comparison, PER under the phase-noise-free condition was also plotted. This figure demonstrates that the initial processing cannot reach PER = 10^{-1} at the high SNR range, while two iterations of the OFDM demodulation with DD-PNC can achieve PER = 10^{-2} at the received SNR of 14.6 dB. It is also found that DD-PNC can limit the SNR degradation at PER = 10^{-2} against the result without the phase noise to 1.1 dB, and the performance almost converges by only one iteration even under the severe phase noise condition of -77 dBc/Hz at 1 MHz offset.

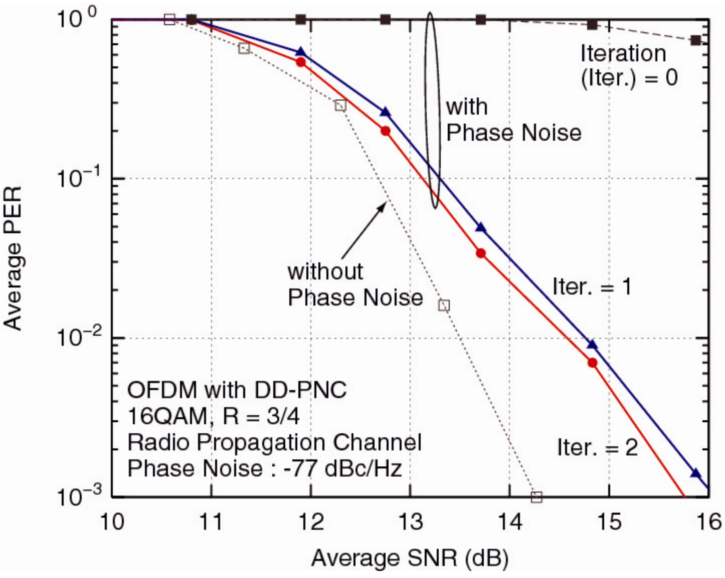


Fig. 11 Measured PER performance with 16 QAM

SUZUKI-FUKAWA LABORATORY

5 Gbps MIMO-OFDM Experimental System for Super High Bit-rate Mobile Communications [7]

In order to realize the even higher bit-rate, super high bit-rate mobile communications attaining 30-Gbps bit-rate has been investigated, which is accomplished by 24×24 MIMO with the signal bandwidth of 400 MHz. For verifying the super high bit-rate mobile communications by experiments, both baseband (BB) circuits that can support the wide bandwidth of 400 MHz and high-precision radio frequency (RF) circuits that can configure 24×24 MIMO should be developed. We introduce a BB circuit developed for 4×4 MIMO-OFDM that composes the 24×24 MIMO by six units.

800-MHz sampling analog-to-digital converter (ADC) is realized by parallel 400-MHz sampling ADCs using the reverse-phase clock. However, both characteristic deviation of analog circuits in the ADCs and difference in cable length for clock signals degrade error vector magnitude (EVM). We present a compensation method for them. Moreover, it configures a 5 Gbps BB experimental system with 4×4 MIMO-OFDM by exploiting the BB circuit, and evaluates transmission performances when turbo detection is employed as the MIMO signal detection. Finally, it is shown that the results measured by the experimental system are the same as those by computer simulations.

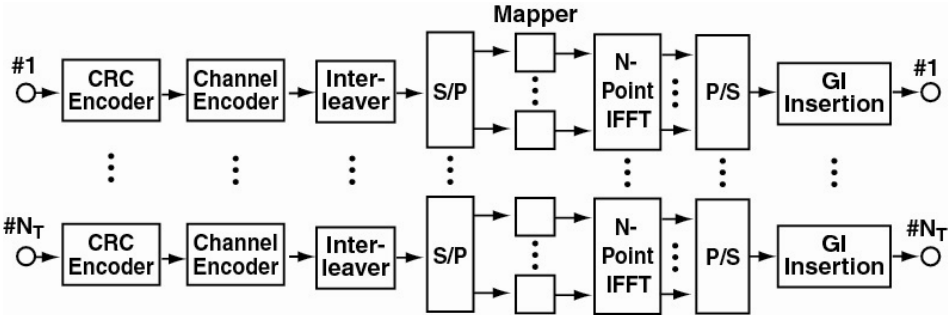


Fig. 12 MIMO-OFDM transmission processing

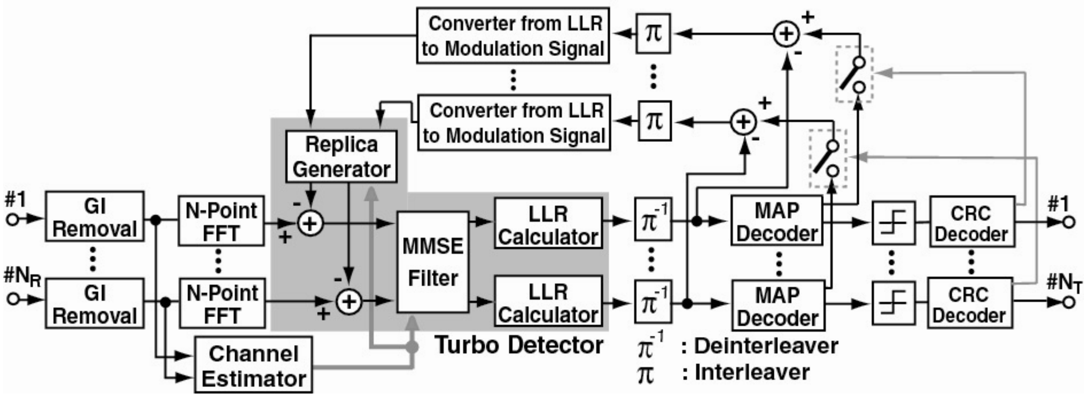


Fig. 13 MIMO-OFDM reception processing

Fig. 12 shows the MIMO-OFDM transmission processing with N_T transmit antennas. The transmission processing first adds the cyclic redundancy check (CRC) code to information bits of each OFDM symbol to detect a decision error, and then it encodes the information bits by the convolutional code. After interleaving the coded bits, it maps them into a modulation signal at each subcarrier. Next, N-point IFFT transforms the modulation signals into the time-domain signals, and then the guard interval (GI) is inserted and transmitted. Note that a preamble is time-multiplexed at the head of the packet, and is used for synchronization and channel estimation.

Fig. 13 shows the MIMO-OFDM reception processing with N_R receive antennas. The reception processing first performs the channel estimation using the preamble. Next, the received signals which N-point FFT transforms to the frequency domain are detected by the turbo detector. In an initial processing of the turbo detection, it operates as the MMSE detection because it cannot obtain log-likelihood ratio (LLR) of the coded bit which the MAP decoders output. After deinterleaving the bit LLRs which the turbo detector calculates, the MAP decoders calculate LLR of the coded bit and that of the information bit for each stream by exploiting the bit LLRs. If the CRC decoder detects any decision errors from the information bits, the initial processing is shifted to an iterative processing. Otherwise, the reception processing ends.

In the iterative processing, the turbo detector generates received signal replicas of all the streams from the bit LLRs of the MAP decoder outputs. Next, it cancels the other streams from the received signals, and then combines the desired signal components and suppresses a residual cancellation error by using a MMSE-based linear filter. After deinterleaving the bit LLRs which the turbo detector calculates from the output of the linear filter, the MAP decoding for each stream is performed again. The reception processing repeats the iterative processing until the number of iterations exceeds a predetermined threshold or CRC does not detect any decision errors.

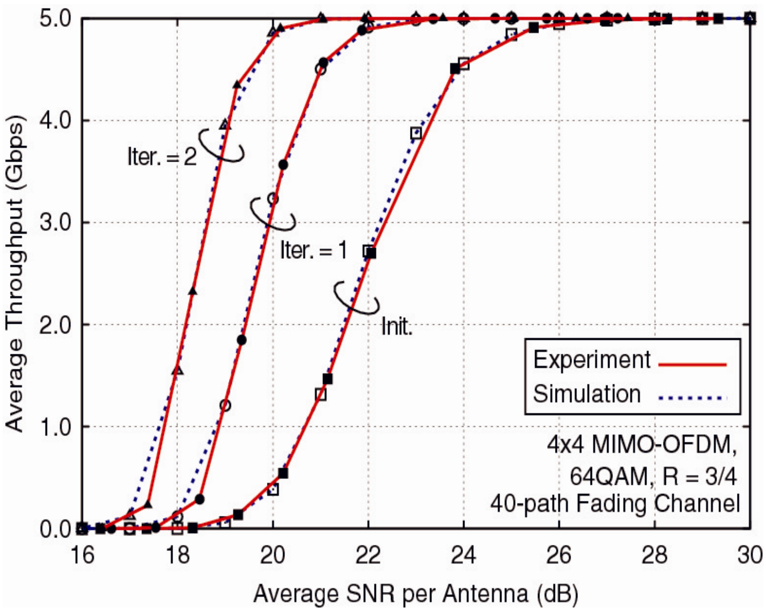


Fig. 14 Throughput Performance

Block error rate (BLER) performances measured by the experimental system. One OFDM symbol was treated as one block, and the channel coding was performed by one block unit. **Fig. 14** shows throughput performances that are calculated from the BLER performances. For comparison, computer simulation results are also plotted. This figure demonstrates that the measured results well agree with the simulation results, and that the BB experimental system can operate properly. It is also found that with 64QAM and R = 3/4, the turbo detection with two iterations can achieve the throughput of 5 Gbps at SNR = 21.0 dB, and that it can reduce the received SNR to achieve 5 Gbps by 6.0 dB in comparison with the MMSE detector in the initial processing.

TAKADA LABORATORY

Professor Jun-ichi TAKADA

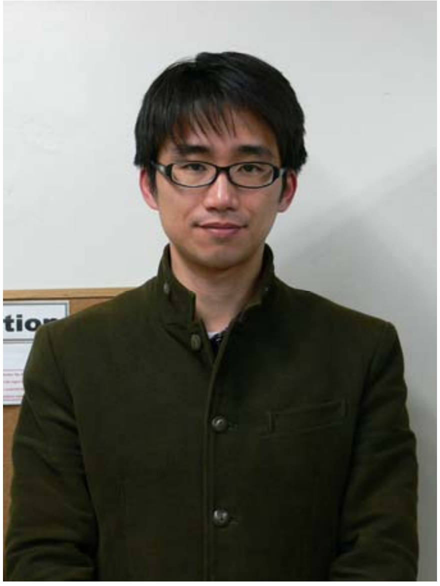
Prof. Takada was born in 1964, Tokyo, Japan. He received the B.E., M.E., and D.E. degree from Tokyo Institute of Technology in 1987, 1989, and 1992 respectively. From 1992 to 1994, he was a Research Associate at Chiba University. From 1994 to 2006, he was an Associate Professor at Tokyo Institute of 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. His current research interests are the radio wave propagation and channel modeling for various wireless systems, regulatory issues of spectrum sharing, and application of ICT for regional/rural development. He is senior member of IEEE, IEICE, and member of ITE, ACES, ECTI Association Thailand, and JASID.

Assistant Professor Minseok Kim

Prof. Kim was born in Seoul, Republic of Korea. He received the B.S degree in Electrical Engineering from Han Yang University, Seoul, Korea, M.E. and Ph.D. degrees in Division of Electrical and Computer Engineering, Yokohama National University (YNU), Japan in 1999, 2002, and 2005, respectively. He was with a startup company from 2005 and has experienced H/W and S/W development of various embedded systems. He was also with YNU as a postdoctoral research fellow shortly in 2006. He joined Tokyo Institute of Technology (Tokyo Tech) as an assistant professor from July 2007. He has been on leave to Georgia Institute of Technology as a visiting scholar in 2010. His research interests include digital signal processor implementation, radio propagation measurement, array processing, smart antenna system, software defined radio/cognitive radio. He is a member of IEEE and IEICE.

Resercher Yu-Yang Chang

Dr. Chang was born in 1975. He received the B.Eng. degree from Department of Control Engineering and the M.Eng. degree from Department of Electrical Control Engineering, National Chiao Tung University, Hsinchu, Taiwan, R.O.C. in 1997 and 1999 respectively, and another M.Eng. degree from Electrical and Electronic Engineering Department, Tokyo Institute of Technology, Tokyo, Japan, in 2007. He served in Industrial Technology Research Institute, Hsinchu, Taiwan, R.O.C. from 2000 to 2005. At Sep. 2011, he received the Ph.D. degree at Electrical and Electronic Engineering Department, Tokyo Institute of Technology, Tokyo, Japan. From Oct. 2011, 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. He is a member of IEICE, and his research interests include multi-user MIMO systems, user scheduling algorithm and MIMO sounding system.



Awards

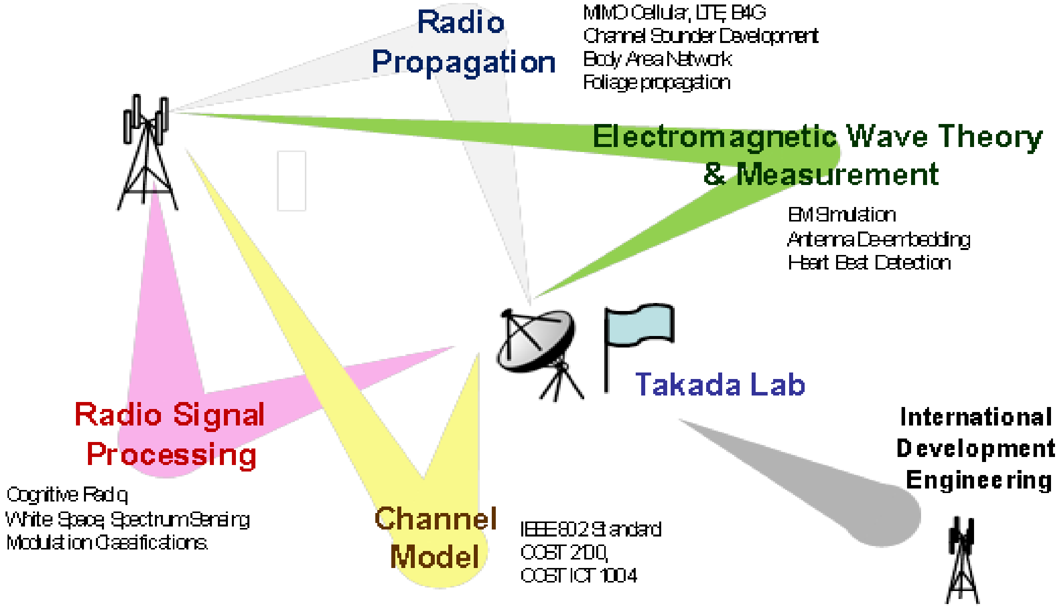
➢ Md. Abdur Rahman, Minseok Kim, Jun-ichi Takada won **the first prize** for “Pre-processing techniques to achieve robustness in blind automatic modulation classification system” in the **IEEE Student Paper Contest 2011 (IEEE Tokyo Institute of Technology Student Branch)**.

➢ The Propagation and Antenna Laboratory (SRC) team, with team leader of Md. Abdur Rahman, received one of the five ‘**Outstanding Student Humanitarian Prize Award**’ in the 2011 IEEE Presidents’ Change the World competition for “Wireless Disaster Area Emergency Network (W-DAEN) to Save Human Lives.”

➢ Yohei Konishi won **Best poster presentation award** for his paper entitled “MIMO Channel Sounding Methodology for Future Mobile Communication Systems,” in **the 3rd Multidisciplinary International Student Workshop,** Graduate School of Engineering, Tokyo Institute of Technology.

TAKADA LABORATORY

Recent Research Topics



Radio Propagation & Channel Model

- **Mobile Communication Systems**
  - Scalable MIMO Channel Sounder Development for Broadband Mobile Communication Systems[22][40]
  - Analysis of Radio Channels in Interaction to Vegetation[9][24][32][37][39][53]
- **Body Area Network (BAN)**
  - Analytic Approach of Antenna De-embedding[10]
  - Fast FDTD Simulator utilizing Parallel GPU Processing for Dynamic BAN Channel Analysis[25]
  - Wearable ZigBee Sounder / UWB Channel Sounder Development for Multi-link

Radio Signal Processing & Electromagnetic Wave Theory and Measurement

- Double Directional Channel Model by using Spherical Wave Functions
- Parametric IQ Imbalance Compensation with Spectrum Measurement[19][44]
- Automatic Modulation Classification Techniques[12][34][35][52]
- Remote Sensing of Heartbeat with Microwave

International Development Engineering

- ICT Application for Sustainable Development of World Heritage Site of Luang Prabang, Lao PDR[31][46]
- Introducing ICT to Assist Teacher Professional Development in Mongolia[45][30]

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

(supported by "The research and development project for expansion of radio spectrum resources" of The Ministry of Internal Affairs and Communications)

In this project, we aim at developing a wide band multiple-input and multiple-output (MIMO) channel sounder system at microwave frequency to exploit new frequency bands for future cellular systems where it should be necessary to operate in the microcellular environment which has smaller coverage area to increase the capacity much more. In particular, the design and analysis of multi-link technologies such as multi-user MIMO (MU-MIMO) and base station cooperation require more sophisticated channel models of correlation among the links and the ranks of the channels. In addition, it is also required to investigate the detail of the directional properties of the environment to predict the possible channel ranks and to design MIMO array antennas.

To cover the above demands, we proposed a novel scalable channel sounding concept for flexible measurements in various scenarios, which is promising for characterizing radio channels in the future wireless systems. With its inherent scalability, it is suitable for both of directional MIMO channel and multi-link MIMO channel measurements (Fig. 1). Moreover the signal processing technique of MIMO multiplexing, a novel FDM and STDM (space time division multiplexing) layered scheme on fully parallel transceiver architecture was proposed (Fig. 2).

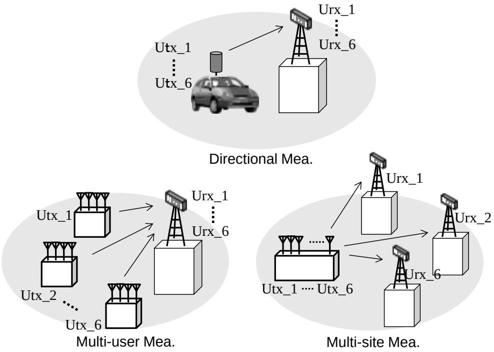


Fig. 1 Flexible Measurements by Scalable Sounding Architecture

The operating frequency of the system is 11 GHz with a bandwidth of 400 MHz that the transmitted multitone signal occupies, and the multitone signal could be generated flexibly depending on the number of the transmit RF units. The number of multitone is 2048 over the signal bandwidth, thus the tone spacing is 195 KHz. The tone spacing of 4-channel FDM reduced by a quarter (48.8 KHz) and the FDM symbol duration is 24.48 us consisting of FFT (20.48 us) and GI (4 us) durations which are 4 times of those of the fundamental multitone. Fig. 3 shows the 8 × 24 MIMO channel sounder system, that including one transmitter (BTx1) with 2 Tx units (4 Tx channels / 1 Unit); and 3 receivers (BRx 1 to 3) with 2 Rx units (4 Rx channels / 1 Unit). In this year, it will be finally extended to 24 × 24 MIMO configuration.

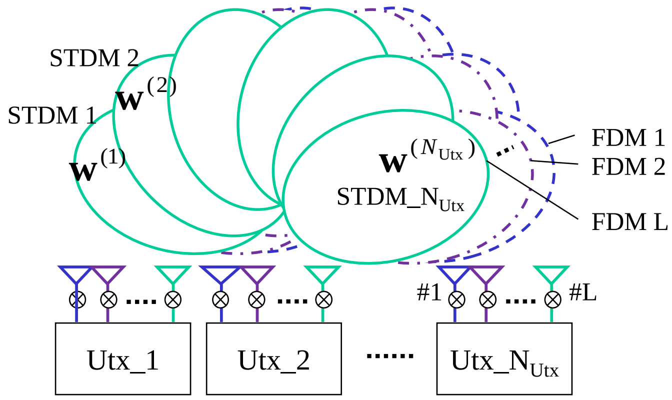


Fig. 2 Sounding Principle using FDM and STDM

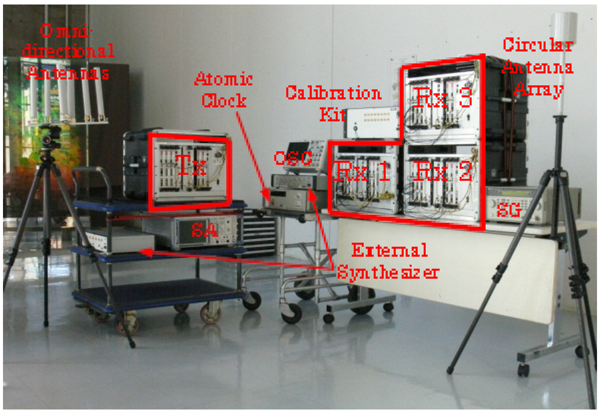


Fig. 3 MIMO Channel Sounder Configuration (8 × 24)

Fig. 4 shows an example of indoor environment channel sounding measurement, where we fixed the circular receive antenna array and set the transmit antennas in different positions. The results of the measurement are as shown in Figs. 5 to 8. In Fig. 8 (b), we show the angle delay spectrum result of the received signals, that is calculated by beamforming algorithm with the array response of the receive antenna array. It shows the angle of arrival (AoA) and the delay of each arrived element via the multipaths. Comparing with Fig. 8 (a), we can see the first arrived wave is from the direction of the transmit antennas (in the red circle), and there is a second arrived wave from the direction of about -50 degree with delay is 25 ns. The transfer function and impulse response of the measured channel (as shown in Fig. 6) are calculated from the received multi-tone signal (as shown in Fig. 5), and the cumulated distribution function of the 8 × 24 MIMO channel is also calculated (as shown in Fig. 7). From the results, the indoor environment (at 11 GHz) is considered as a strong line of sight (LoS) environment. In the future works, we will conduct more experiments to verify the 24 × 24 MIMO sounder.

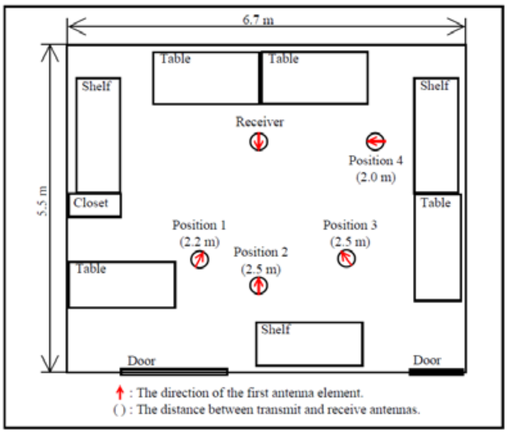


Fig. 4 Room layout and positions of antennas.

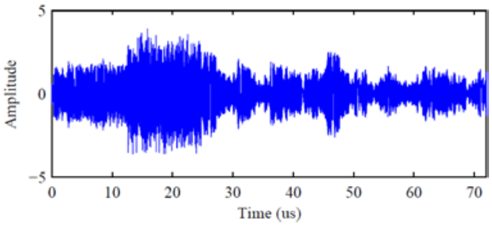
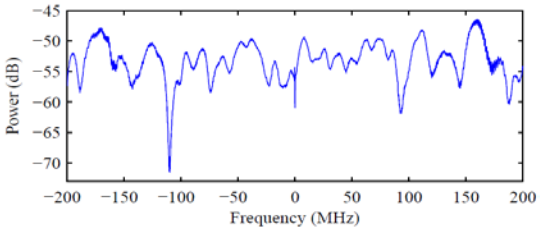
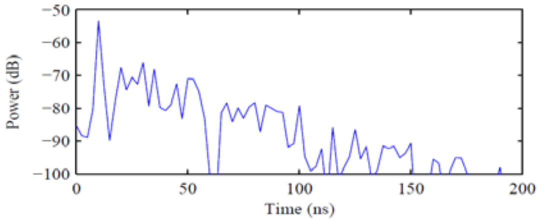


Fig. 5 Received signal of the first element.



(a) Transfer function



(b) Impulse response

Fig. 6 Channel response between the first transmit and the first receive antenna.

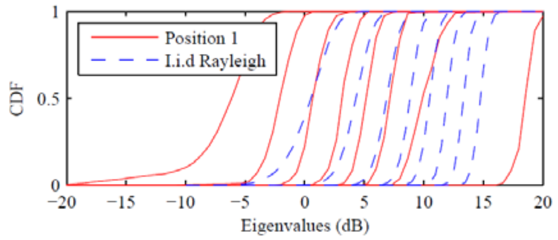
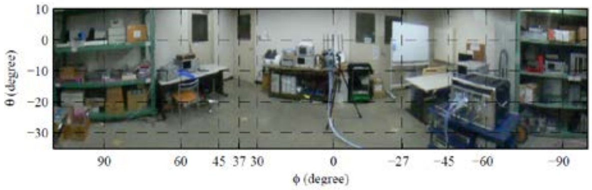
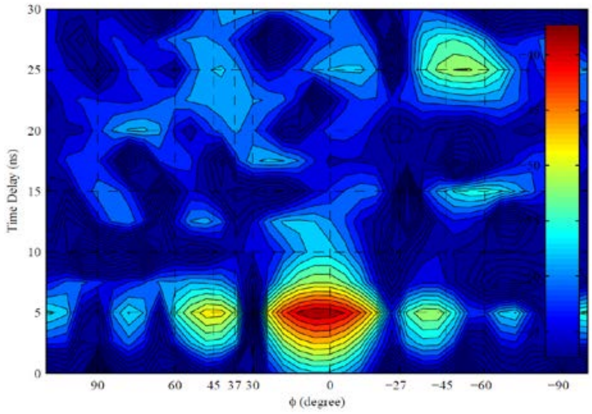


Fig. 7 CDF of the eigenvalues of the indoor MIMO channel (compared with Wishart distribution).



(a) Panorama picture looked from the receive antenna (the transmit antenna is at 0 degree of ϕ).



(b) Angle delay spectrum (power in dB)

Fig. 8 Results of beam forming for the indoor environment.

Study of Wireless Body Area Channel

Introduction

Body area network (BAN) is a promising candidate technology for enabling the wireless among wearable and or implanted devices especially in medical and healthcare applications. It differs from the general wireless system in that the BAN channel is highly influenced by the existence of body and its motion. Aiming towards more reliable channel models, we have studied the measurement with a motion capture [7], the diversity evaluation [48], and the numerical simulation [1]. Currently, we are working on dynamic channel modeling, including the cylindrical modeling, the effect of body shape, and the FDTD simulator using GPUs. Channel sounding systems using SIMO UWB and ZigBee wireless sensors are also under investigation.

Dynamic channel modeling

The dependence of BAN channels to the body motion is intensively investigated in this research through empirical, analytical and numerical simulations. To involve body motion, a set of motion capture equipment is used in the measurement, while in numerical studies animation software such as Poser is utilized to generate body voxels in specific motion, for instance in Fig. 9 (a). The human body is assumed as a simple geometrical shape such a as cylinder in the analytical studies as shown in Fig. 9 (b), and the motion can be simulated by controlling the positions of each cylinder. In this study, the skeleton body model is proposed to possible motion synchronization among them. For model assessment, on-body channels are predicted by FDTD simulation based on full-body and cylinder body models generated from the skeleton. The results in Fig. 9 (c) validate the effectiveness of the proposed model.

In addition to body motion, human body shape has effects on BAN channel. To investigate the relationship between them, measurements have been conducted in an anechoic chamber and an empty office room. Interaction between antennas and human body, i.e. changes in the antenna performance due to human body tissues depends on body shape. The path gain obtained by vector network analyzer was examined using analysis of variance (ANOVA) and regression analysis.

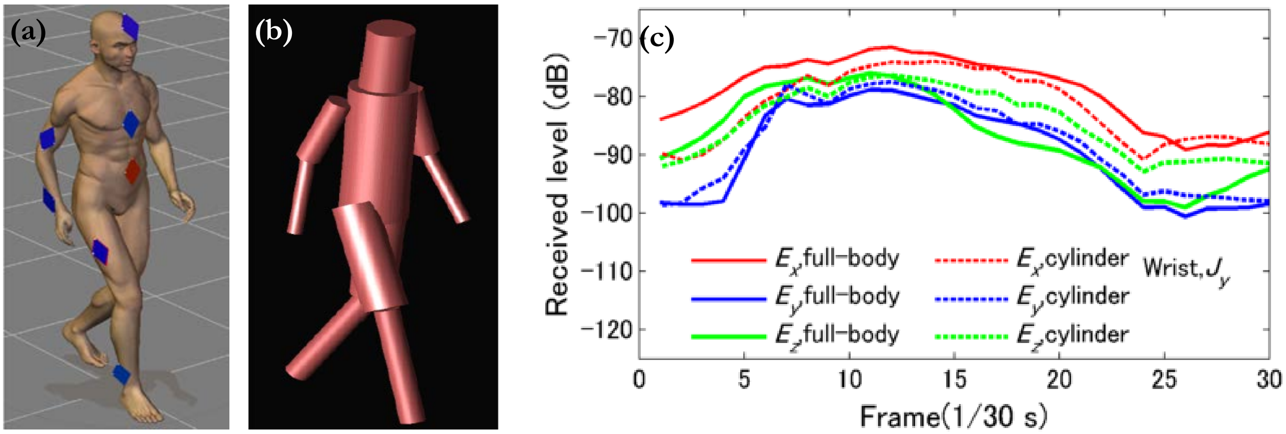


Fig.9 Body model for BAN channel modeling: (a) Full-body model. (b) Cylinder-body model. (c) Comparison of predicted channels based on both models.

Also, we are developing a FDTD simulator using GPUs on TSUBAME 2.0 high-performance computing environment because the BAN channel simulation consumes significant computational time. This computational time comes from huge cell size such as 170x400x250 for accurate human body model and the body motion decomposition, where each snapshot of human motions needs an independent simulation. However, parallel FDTD cell calculation and parallel simulations running with GPUs on TSUBAME 2.0 can effectively reduce the computational time. As an preliminary result, we achieved a speed-up factor of 129 with 3 GPUs compared to a conventional single CPU environment.

Channel sounding

A UWB channel measurement system, capable of measuring multiple dynamic BAN channels has been developed. The system has very high sampling rate, thus enabling us to study the wearable BAN UWB channels in the time domain. UWB is very resilient to multipath fading, and because of the low power transmission employed, it is a very appealing technology for WBAN. We are currently carrying out on-body finite SIMO channels measurements with one transmitting antenna and two receiving antennas attached on the body surface. By varying the distance between antennas and computing the correlation between the corresponding channels, we intend to study the diversity of on-body WBAN UWB channels.

In BAN, especially those used in medical applications, the data transmission may suffer from low reliability because of many practical limitations such as compactness of wearable and implant devices, very low power consumption requirement, transmission power restrictions due to Specific absorption rate (SAR) regulations etc. We have developed a self-contained 2.4GHz channel measurement system based on a commercially available ZigBee wireless sensor platform that can be easily scaled to a fully functional WBAN. We are measuring the shadowing correlation property between on-body WBAN links in order to gain insights to develop and evaluate cooperative transmission schemes. We want to employ cooperative communication between the various nodes in a WBAN to improve the data communication reliability and power efficiency of a WBAN system.

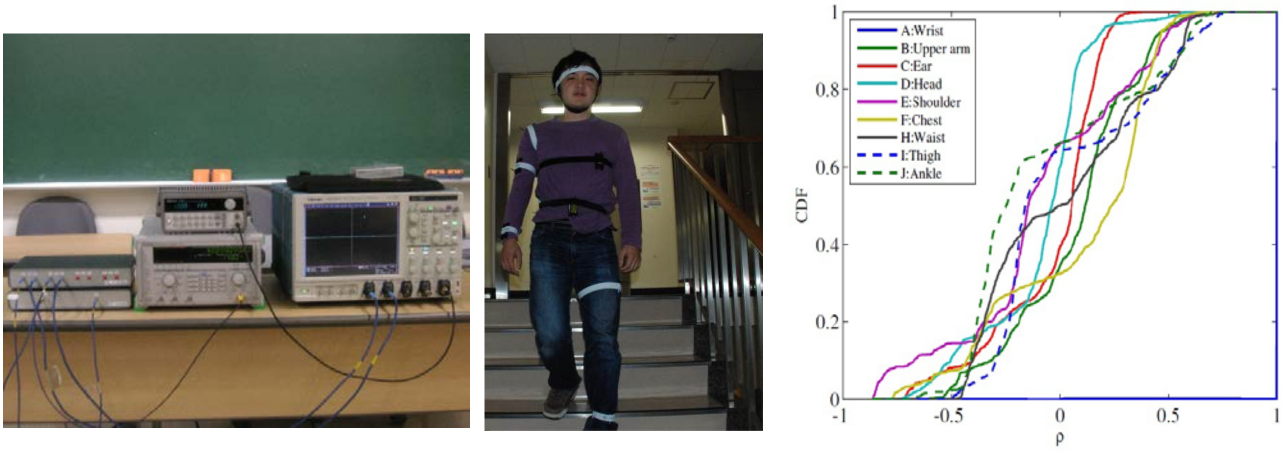


Fig. 10 UWB channel measurement system. (b) Channel measurements using 2.4GHz Zigbee system (walking stairway). (c) CDF of the correlation coefficient of different channels with respect to antenna at Wrist; 2.4GHz ZigBee measurement.

Experimental Analysis for Angular Spread Characteristics of Radio Propagation Channel through Foliage (Joint Research with NTT DOCOMO)

Introduction

The presence of foliage in the propagation medium plays a significant role in the propagation of radio waves. The foliage medium provides a rich scattering environement which largely affects the spatial and temporal characteristics of the received signal in wireless communications systems. A better understanding of the effects of foliage on the radio channel characteristics allows us to better evaluate the performance of multi-antenna systems such as diversity combining and MIMO systems. This research investigates the effects of foliage on the directional characteristics of propagating radio waves by employing the SAGE algorithm to provide angle of arrival estimates of the multipath components.

Measurement Setup

A measurement campaign was carried out in a forest at Kanagawa Fig. 11 on October 26–27, 2009. The average height of the trees is 10 m and spread out with the average density of 0.32 per square meter. The BS antenna height was varied from 4 to 15 m by using a man lift, while the MS antenna was mounted on a van at a height of 2.8 m. A total of 64 measurement points with 1 meter intervals were made for each BS antenna height.

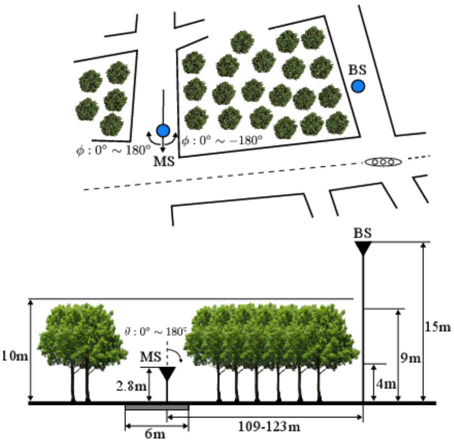


Fig.11 Measurement Setup

Analysis and Results

The parameters of each impinging wave are estimated from measurement data using the SAGE algorithm. 2-dimensional definition of Fleury's direction spread is used to represent the angular spread to avoid the ambiguity of angular definition due to the rotational periodicity. The obtained SAGE estimates of the mobile measurement at the first and last points with a BS antenna heigh of 15 m are indicated by the polar plots in Fig. 12. It can be confirmed that the direction of arrival seen from MS is quite close to the actual direction. Fig. 13 and Fig. 14 show the mean direction spread for the azimuth and the co-elevation domains. It can be confirmed that the azimuth direction spread for H polarization is always greater than that for V polarization and the opposite is true in the case of coelevation direction spread. The relatively high values of azimuth direction spread indicate that the incoming field at the MS is highly varying in azimuth. Furthermore, when the BS antenna height is 9 m, all the values are minimum. In this case, a better understanding of the mechanism of radio wave propagation is required to describe this result.

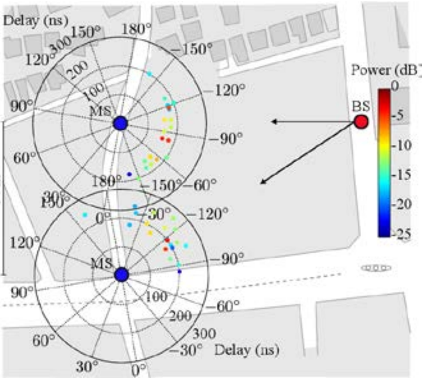


Fig.12 SAGE estimates at initial and final points of the mobile station

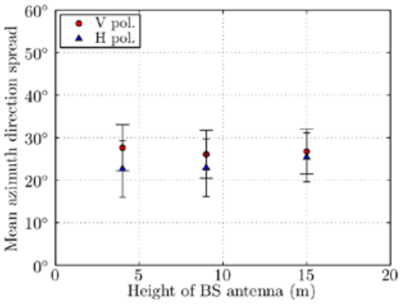


Fig. 13 Mean azimuth direction spread

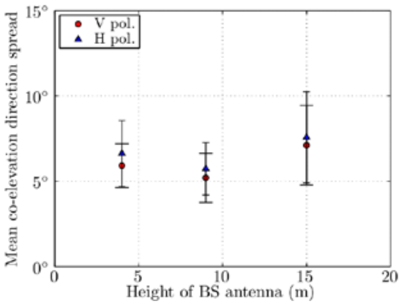


Fig. 14 Mean co-elevation direction spread

TAKADA LABORATORY

Modulation Classification Utilizing Spectral Correlation for Emergency Radios

After a major disaster, finding available frequency spectrum for the emergency radios used by rescue teams will be difficult, and this is due to the lack of a centralized management system. Therefore, there is a need to build a database of the emergency radios using the spectrum in the disaster area to alleviate this problem. Spectral correlation was utilized to classify the modulation scheme of the signal, which will help the identification of the radio. Existing techniques on modulation classification based on the spectral correlation density (SCD) is insufficient to classify the targeted modulation schemes. In this research, improvements in the SCD calculation, as well as new feature extraction methods have been introduced. A simple binary decision tree was utilized as the classifier. Together with a symbol rate estimation technique also utilizing the SCD, performance evaluation of the proposed technique showed that it could classify a total of 6 modulation schemes (BPSK, Pi/2-DBPSK, QPSK, Pi/4-DQPSK 8PSK, GMSK) with a probability of above 0.9 down to an SNR of 4 dB, for symbol rates Rs=5-30 kSymbol/s.

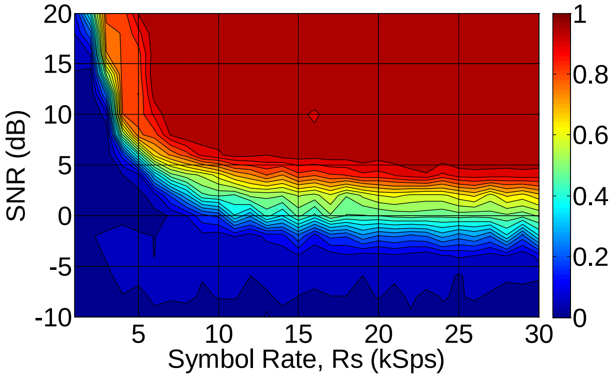


Fig. 15 Prob. of Correct Classification averaged over 6 modulations

Double Directional Channel using Spherical Wave Functions

Wireless communication system is to transfer information, from one point to another through the propagation channel. MIMO communication system has been the research focus for almost twenty years. A typical MIMO system contains array antennas at both transmitter and receiver sides, to transmit and receive electromagnetic signals through the propagation channel; quality of the communication link between antennas, in other words, speed of data transfer within finite bandwidth, is determined by the interaction between antennas and the propagation channel. The introduction of double directional channel is to study the channel model without the influence of antennas. Double directional channel, including the angular information at both link ends, extracts the transmitter and receiver antennas from multipath radio channels, enabling the comparison of performances of different antennas in the same propagation environment. We use the tool of spherical wave functions, which are the typical solutions of Maxwell's equation. For conventional plane wave model, the resolution in angular domain is infinite regardless of the antennas size; for spherical wave model, the resolution in angular domain is finite and is limited by the antenna size. Theoretical and experimental studies are conducted to derive a reasonable model for both antennas and double directional channel described by spherical wave functions.

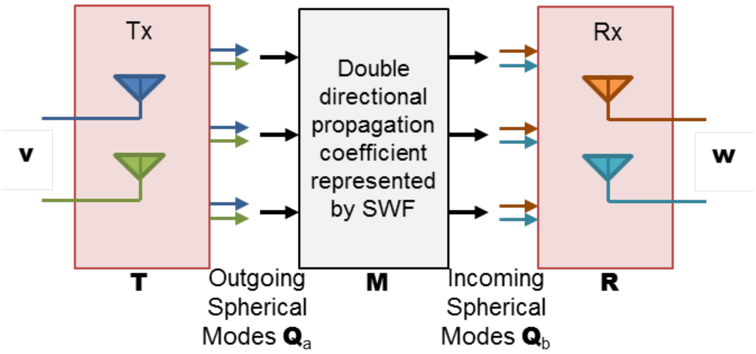


Fig. 16 Transmission Line Model of MIMO Channel

Sustainable ICT Use in Education: Development of Primary Teacher Training Material Using ICT in Mongolia

(funded by Ministry of Education, Culture, Sports, Science & Technology)

In line with UNESCO’s 'Education For All' mandate, the 'Sustainable ICT Use in Education: Developing Teacher Training Material Using ICT' project was conceived to utilize ICT tools and develop quality training materials for primary school teachers who need special methodological assistance for their new tasks associated with the recent transition to 12-year schooling in Mongolia. Based on previous long-term collaboration between the faculty members of Tokyo Tech and the educators of Mongolia, ICT use for teacher training is still at its initial stage. This project intends to further the current level of ICT use to improve the efficiency and effectiveness of delivering needed teacher training to the primary school teachers.

The design of this project that started in December 2010 was modeled as a continuation of previously implemented UNESCO project on 'Rehabilitation of rural schools and teachers training in Mongolia (2004-2006)'. Nine local Mongolian teams were formed and were responsible for the implementation of different activities of the project and these are: (1) VCD development group composed of VCD teams on 6 priority subject areas, Mongolian Language, Math, Art & technology, Teacher – student relationship, Human & Environment, and Human & Society; (2) ICT policy document review team; (3) Web portal assessment team, and (4) Training team. Teams composed of faculty members of Mongolian State University of Education (MSUE), Institute of Education, National University of Mongolia (NUM), and specialists of the Ministry of Education, Culture and Science (MECS).

It is expected that as a result of the project intervention, (i) Mongolian primary school teachers will have a set of quality teacher training materials (6 subjects in VCD format and 1 Guideline book); (ii) Teachers’ teaching skills will improve constantly with access to web-based training sources; (iii) Teacher training institutions will improve their capacity to develop digital contents for teachers continuously, including institutional setup, funding scheme, staffing and technology services; and (iv) Motivation and interest of school students in subject will improve with enrichment of quality teaching materials based on use of ICT.

The project activities were completed as planned on March 2012 with the following specific outputs: 1) primary school teacher guideline for 6 subjects; 2) VCDs in six priority subjects; 3) project brochure; 4) analysis report on ICT in education policy with recommendations; 5) manuals for trainers, teachers, and guests, 6) an analysis of current condition of ICT use in primary schools in Ulaanbaatar city, 7) training of trainers and primary school teachers. The quality of these outputs was highly evaluated and appreciated by the stakeholders. The participants of all training activities have expressed their great satisfaction with organization and content of the training.

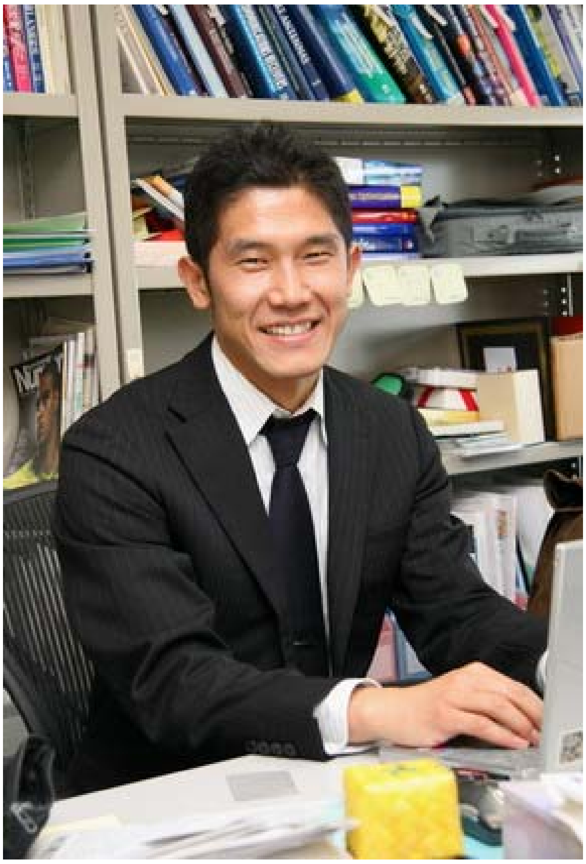
Fig.17 Primary teachers are watching VCD

Fig.18 Teaching Material

ARAKI-SAKAGUCHI LABORATORY

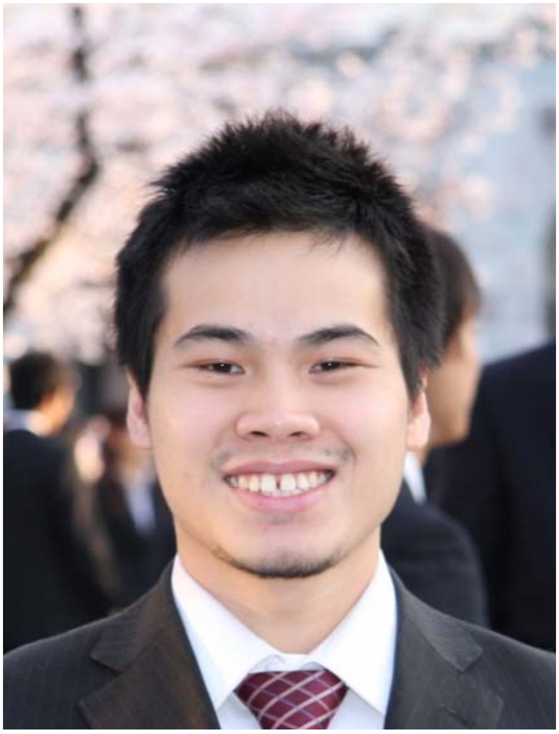
Professor Kiyomichi Araki

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

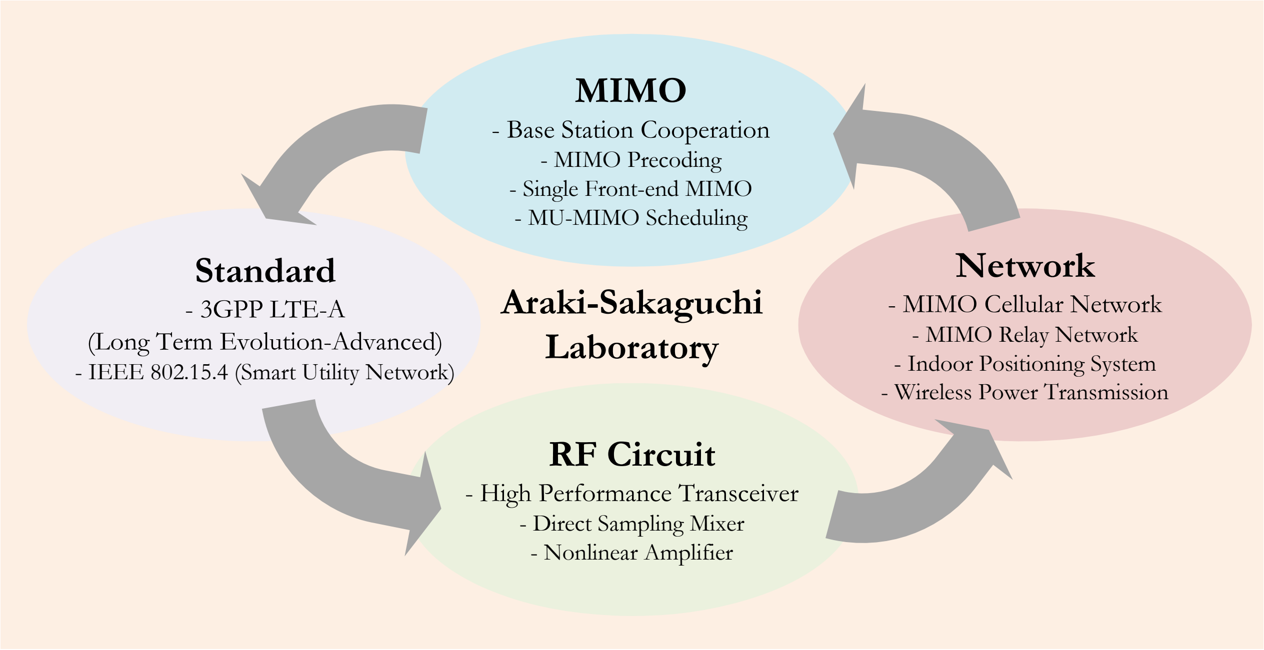
Assoc. Prof. Sakaguchi was born in Osaka, Japan, on November 27, 1973. He received the B.E. degree in electrical and computer engineering from Nagoya Institute of Technology, Japan, in 1996, and the M.E. degree in information processing and the Ph.D. degrees in electrical & electronic engineering both 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.



Assistant Professor Gia Khanh Tran

Assist. Prof. Tran was born in Hanoi, Vietnam, on February 18, 1982. He received the B.E., M.E. and D.E. degrees in electrical and electronic engineering from Tokyo Institute of Technology, Japan, in 2006, 2008 and 2010 respectively. He became a faculty member of the Department of Electrical and Electronic Engineering, Tokyo Institute of Technology since 2012. He has been awarded a bronze medal in National History Contest of Vietnam in 1999. He received IEEE VTS Japan 2006 Young Researcher's Encouragement Award from IEEE VTS Japan Chapter in 2006 and the Best Paper Award in Software Radio from IEICE SR technical committee in 2009. His research interests are MIMO transmission algorithms, multiuser MIMO, MIMO mesh network, wireless power transmission, cooperative cellular networks, sensor networks and smart grids. He is a member of IEEE and IEICE.

The Araki-Sakaguchi laboratory was established in 1995. Founded on wireless communication system, the lab has been extended widely from theoretical analysis to hardware implementation, measurement system construction and empirical experiments. Moreover, not only academic works within the university but also co-works with various industrial companies have been conducted for developing new wireless applications and contributing to the next generation wireless system standards.



MIMO
- Base Station Cooperation
- MIMO Precoding
- Single Front-end MIMO
- MU-MIMO Scheduling

Standard
- 3GPP LTE-A (Long Term Evolution-Advanced)
- IEEE 802.15.4 (Smart Utility Network)

Araki-Sakaguchi Laboratory

Network
- MIMO Cellular Network
- MIMO Relay Network
- Indoor Positioning System
- Wireless Power Transmission

RF Circuit
- High Performance Transceiver
- Direct Sampling Mixer
- Nonlinear Amplifier

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ARAKI-SAKAGUCHI LABORATORY

Optimal Low Noise Design for Single Front-end MIMO Receiver with Parasitic Antenna Element(PAE) [3][16][24][45]

Single front-end architecture is a suitable solution to alleviate technical problems with the device's miniaturization and high cost. Also, parasitic antenna element(PAE) which are another characteristic of proposed system can improve transmission capacity by the mutual coupling actively using parasitic elements. We established low-noise principles for coupled receivers and a front-end circuit model concerned with signal correlation and mutual coupling between its branches in fig. 1. The optimal noise matching was applied for minimizing noise figure of single front-end and the optimal PAE was derived with effect of revised channel model and noise figure. The numerical result showed the validity of proposed system with the derived optimal PAE with specific system parameters.

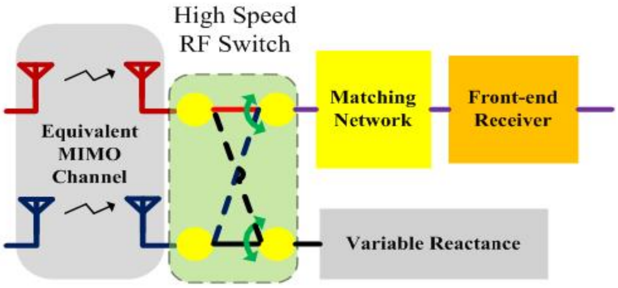

Fig. 1 Single Front-end MIMO Concept

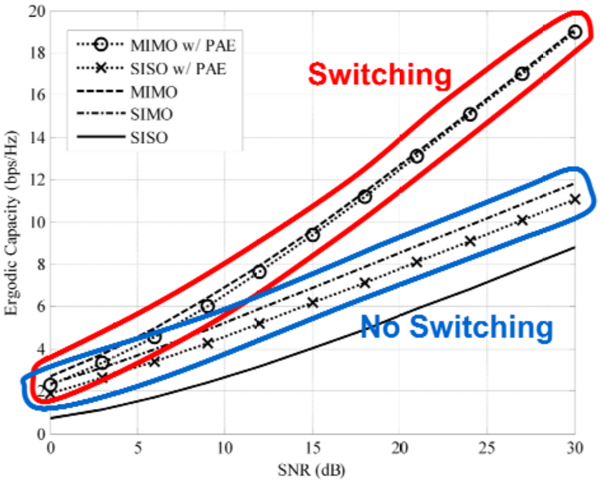

Fig. 2 Spectral Efficiency as SNR (d=λ/8)

Theoretical analysis of multi user MIMO user scheduling with Block Diagonalization [5][6][10][27][34]

In multi user MIMO system, when the number of active users exceeds the supportable number of users, the user scheduling is needed. Here we consider the user scheduling for MU-MIMO system with Block Diagonalization where users are selected by using simplified capacity based. We theoretically analysis System capacity and theory of order statistics gives MU-MIMO system capacity. In fig.3 and 4, we compare the proposed theoretical and simulation sum rate capacity under various active users $\hat{K}$ and total user numbers 80 in two case of transmit and receive antennas (12×2, 8×2).

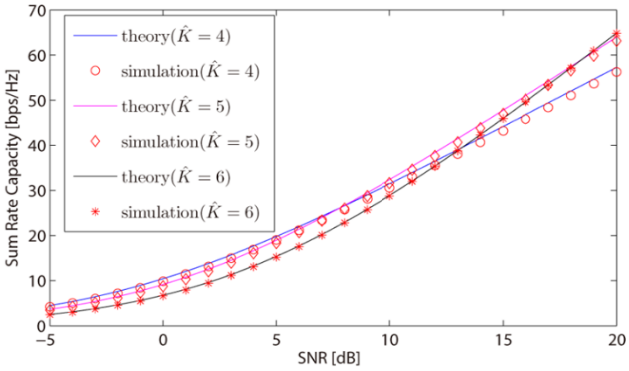

Fig. 3 Estimate Capacity (12×2)

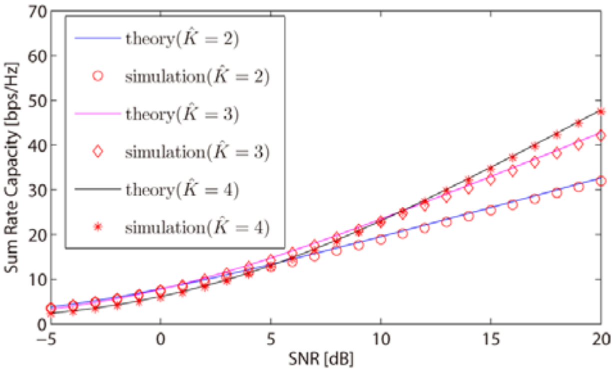

Fig. 4 Estimate Capacity(8×2)

Modeling and multiband predistortion for broadband amplifier [26]

Flexible wireless system which is a new heterogeneous network system supporting for a wide variety of wireless systems has been proposed. The transmit amplifier for the system is required to amplify multiband signals simultaneously. It causes intermodulation distortion and harmonic distortion. We consider nonlinear Wiener Model to model and evaluate a broadband amplifier covering a range of 100MHz to 10GHz. After that we try to compensate the harmonic distortion signal, using multiband distortion compensation technology. The achieved model can restore up to 99.9% of the original signal. And with multiband predistortion, the output power has been improved in the quantity of 4dBm compared to original signal.

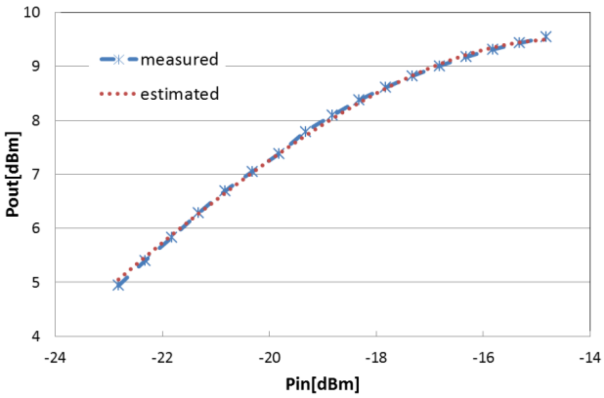

Fig. 5 Model of 250MHz band signal

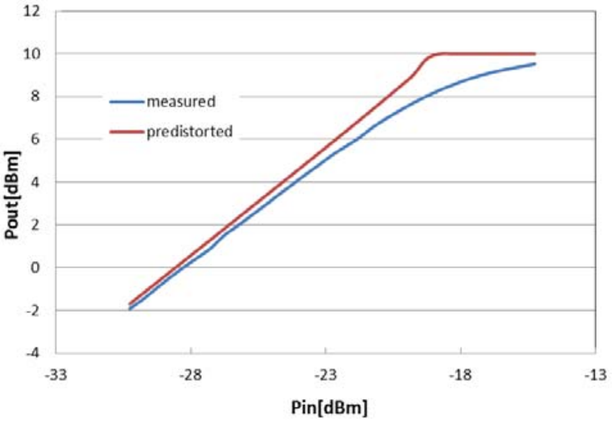

Fig. 6 Multiband predistortion result (750MHz band signal)

Inter-carrier Interference(ICI) analysis of OFDM [25]

Standardization data IEEE802.15.3c, ad is written about HD A/V. Now, single carrier transmission is used but we are going to introduce OFDM. OFDM problem in millimeter wave band is ICI caused by local oscillator (LO) and multipath environment. We analyzed the situation of ICI. A spectrum spread occurs by LO phase noise in Fig.7. This LO has -96dBc/Hz at 1 MHz offset and 3.5 kHz (3dB cut-off Frequency). In this work, the number of subcarrier is 128, and the system bandwidth is 1.76GHz. Subcarrier offset is chosen as 13.8 MHz, and the noise power in this frequency range is determined by the VCO. We have assumed that power spectral density follows Lorentz model and the channel response is fixed using two path channel model. The difference between the two path channel scenarios 1,2,3 is the phase of reflected wave. As a result, we found that ICI has frequency selectivity characteristics (Fig.8).

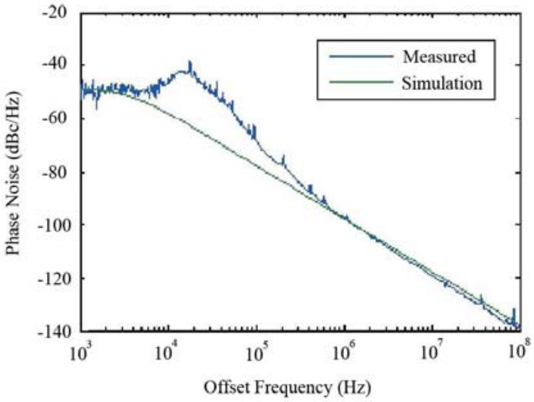

Fig. 7 LO Characteristic

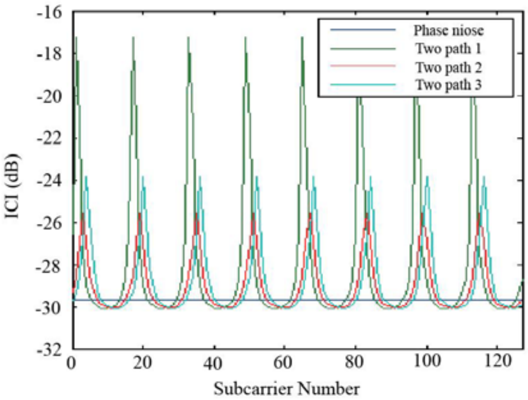

Fig. 8 ICI situation in multipath

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RF-DC conversion circuit for wireless power transmission [17]

In microwave wireless power transmission systems, the rectifying antenna (Rectenna) is an important component. The rectenna consists of the radio frequency to the direct current and a receive antenna. A single shunt rectenna circuit was reported (Fig. 9). A single shunt rectenna behaves as full-wave rectifier at the center frequency. Because of minimal use of the diode, a single shunt rectenna is an optimal configuration for rectenna. However, it ought not to behave as full-wave rectifier at the out of center frequency due to frequency characteristic of transmission line. We propose a frequency analysis method of rectenna circuit using equivalent network and Fourier analyses. From the numerical analysis, the 3dB bandwidth of RF-DC conversion efficiency was analyzed and was found to be about 80MHz for an optimized 1GHz rectenna circuit. Furthermore, the performance degradation was analyzed using harmonic balance method and it was concluded that the reason is due to the nonlinearity. The input power characteristic is analyzed (Fig. 10), and it is important for system design.

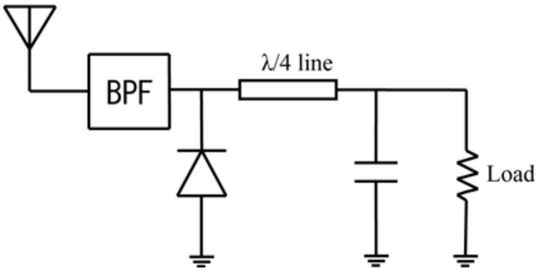

Fig. 9 Single shunt rectenna

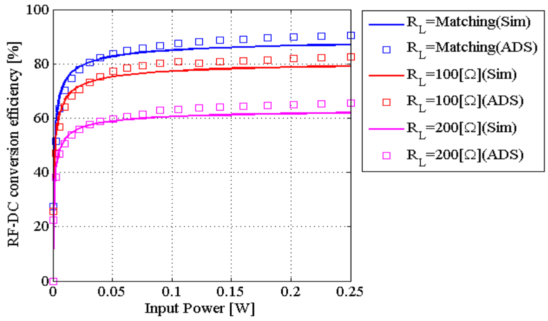

Fig. 10 Input power characteristic

Performance Evaluation Method for Body Area Networks [18]

Body Area Networks (BAN) is short range wireless communication from the body vicinity or inside body to 5 meters away. Fig. 11 shows the examples of BAN's application. For the designing BAN systems, it is very important to understand the radio channel characteristics around or inside the human body. In this study, we focused on Nakagami-m fading channel model to simulate on-body communication system close to the real environment, and this model was found to be suitable for the simulation of narrowband BAN systems. Fig. 12 shows the simulation results of the communication between the wrist and the navel and the relationship between transmission power and packet error rate for the case of the packet length is 256 byte. It is found that the Nakagami-m fading model and experimental data are better fit in both of actions.

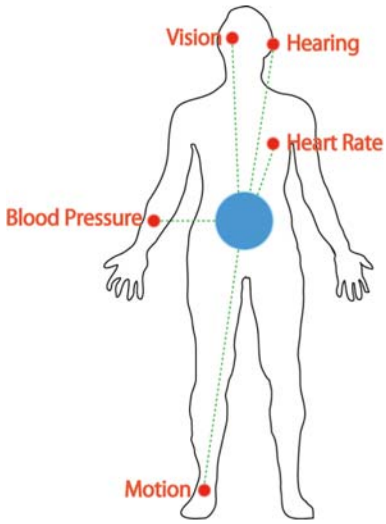

Fig. 11 Applications of BAN

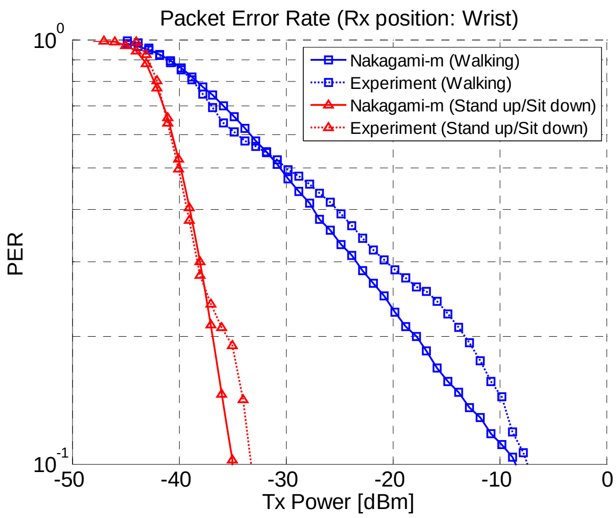

Fig. 12 Simulation Results

Optimization of MIMO antenna directivity and current distribution based on spherical mode expansion [37]

An antenna directivity is expanded by spherical wave functions and spherical mode coefficients. Spherical mode coefficients specify the antenna directivity and that is to be designed. The optimal spherical mode coefficients, which maximizes average channel capacity of the MIMO system, can be derived from a given antenna volume and an angular profile. Furthermore, a current distribution for the optimal antenna directivity is derived from the optimal spherical mode coefficients via Galerkin method. The optimal antenna directivity that matched to a propagation environment can be designed by using this approach.

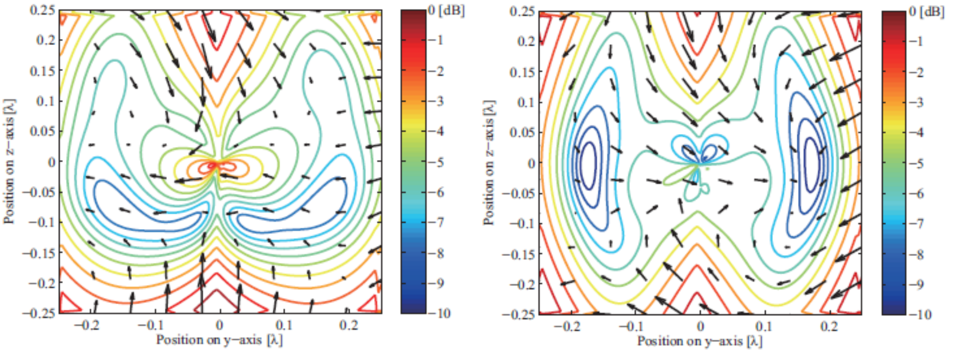

Fig. 13 Optimal current distribution of Planar antenna

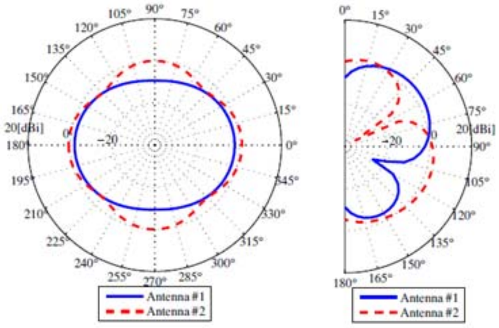

Fig. 14 Optimal Optimal directivity of Planar antenna

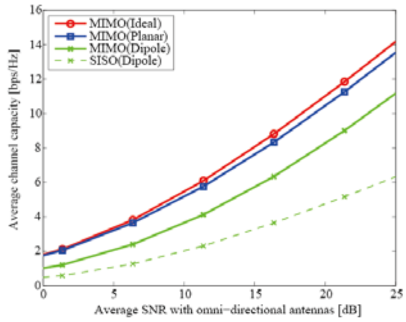

Fig. 15 Comparison of capacity

Optimal beam tilt angle of base station antennas for base station cooperation systems [19]

In BSC systems, beam tilt angle is required to be designed differently from a conventional way since the problem of inter-cell interference (ICI) is removed. Therefore, we derive optimal beam tilt angle for the BSC systems. An objective function to maximize average channel capacity of cooperative cell is defined, and the optimal beam tilt angle is derived by solving the problem. By using the optimal base station antennas, channel capacity of the BSC system is greatly improved, especially at the cell-edge.

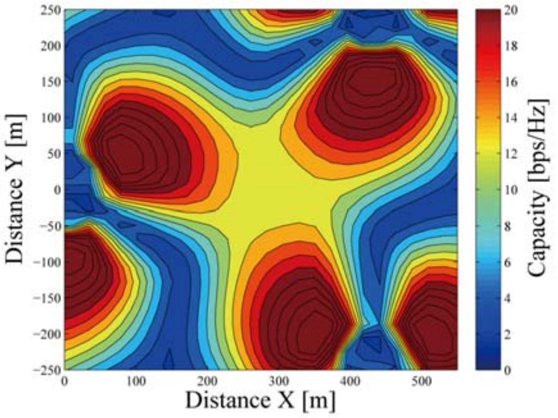

Fig. 16 Capacity by optimal beam tilt angle

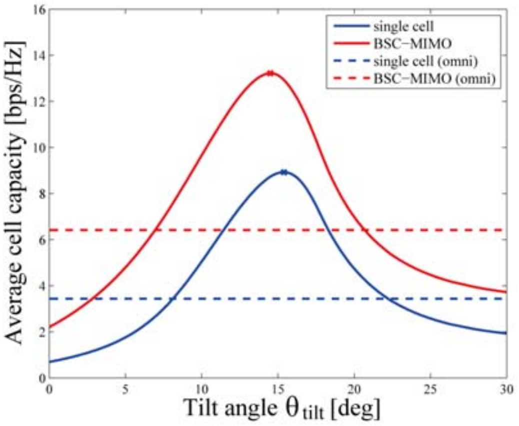

Fig. 17 Average cell capacity

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Dynamic Fractional CoMP using RRH Network [4]

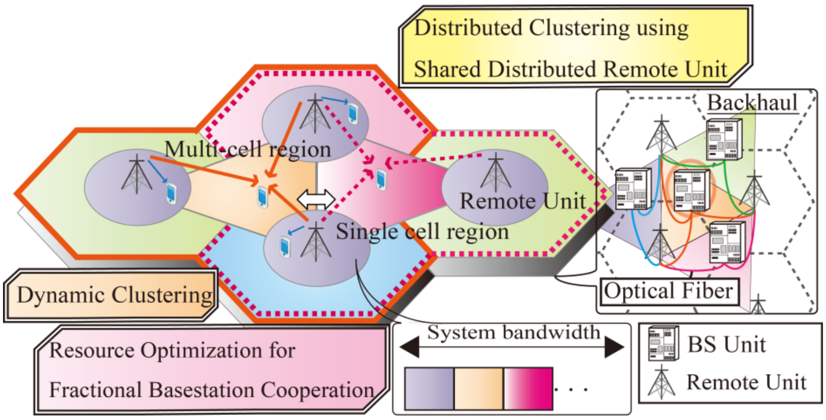


Fig. 18 Dynamic Fractional CoMP using RRH Network

We proposed Dynamic fractional cooperation with distributed cooperation controllers. 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.

Resource Optimization for Heterogeneous Networks [1]

Recently, there is demand to construct wireless communication systems which can adapt to tremendous increase of network traffic. Heterogeneous Networks (HetNet) consisting of small and low-power nodes deployed inside the conventional macro cell areas is considered as solution. By using HetNet, the network performance is improved by interference control in terms of resource allocation and cell range expansion. In this work, we formulate three HetNet resource allocation model: spectrum overlapping, spectrum splitting and fractional spectrum overlapping, and derive the optimal network parameters to maximize the achievable system rate by solving the corresponding optimization problem.

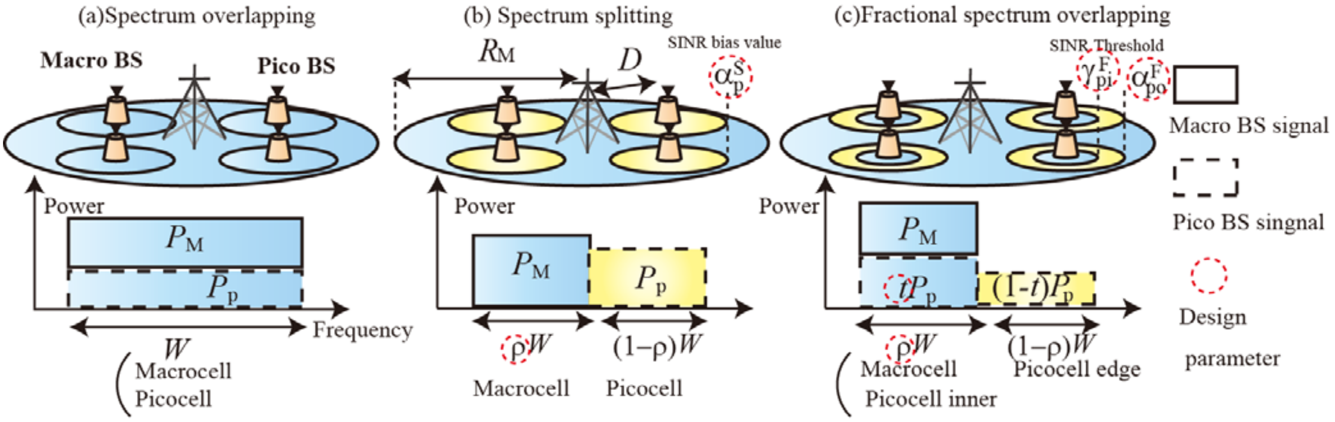


Fig. 19 Resource allocation model in frequency domain for HetNet

Distributed control algorithm for power peak load control with blackout prevention

Demand response is a control mechanism to reduce electricity consumption at peak time with the prevention of a large area blackout. However, in real time control systems, long latency due to the large number of smart meters reduces the system performance. We propose an hiaracial distributed load control system which divides the system into several multi-tier sub-systems as shown in Fig. 20. Here, a higher tier sub-system provides the policy of power control to its lower sub-systems updately with the feedback of power consumption from them, such that the overall power consumption can be kept at the reference level as shown in the left-hand side of Fig. 21. By comparing the proposed distributed algorithm with centralized algorithm, the right-hand side graph in Fig. 21 shows that the overload time can significantly reduce.

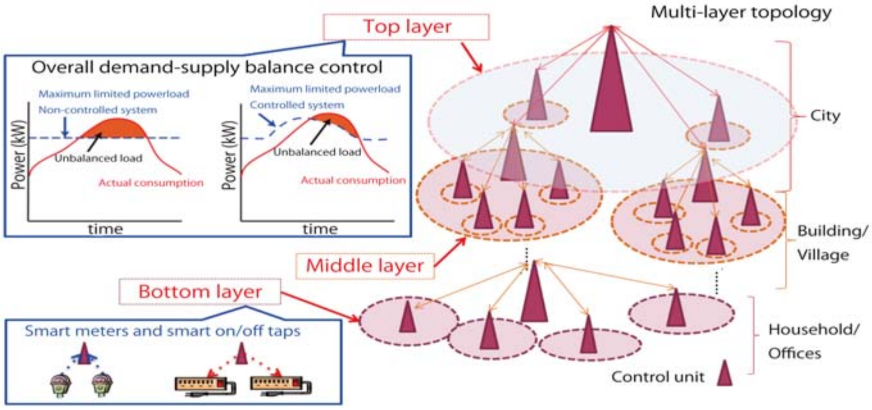


Fig. 20 Distributed power control system

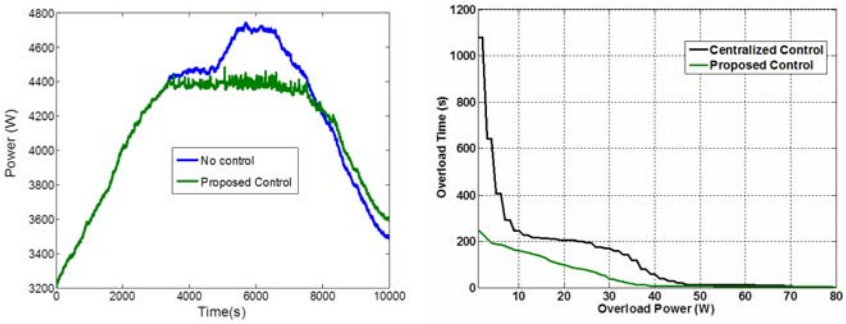
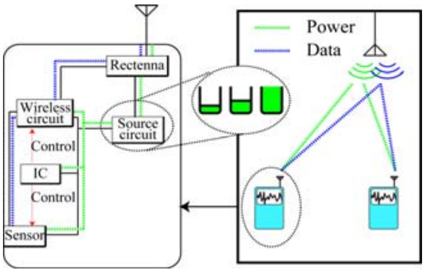
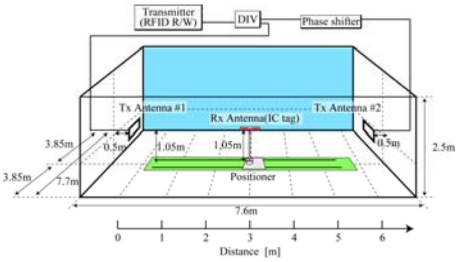


Fig. 21 Results of peak power & overload time

Wireless energy transmission

Wireless energy transmission is a technique to allow sensor nodes in wireless smart grid reuse the energy sent with wireless signal from the backbone nodes, as shown in Fig. 22, however, standing wave effect still affects to the coverage of energy transmission. Recently, we have proposed multi-point wireless energy transmission with carrier-shift diversity to extend the coverage. In order to verify this concept in practical environment, the experiment has been conducted as shown in Fig. 23. The results in Fig. 24 show that the system of single-point and multi-point transmissions without carrier shift diversity does not provide seamless energy transmission along the path of the positioner due to free space path loss and standing-wave problem while that of multi-point transmission with carrier shift diversity does.





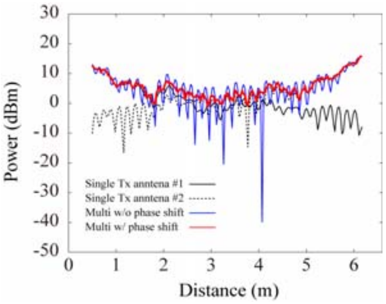


Fig. 22 Wireless energy reuse **Fig. 23 Experiment environment** **Fig. 24 Experiment**

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TDD two-way multi-hop relay network [13]

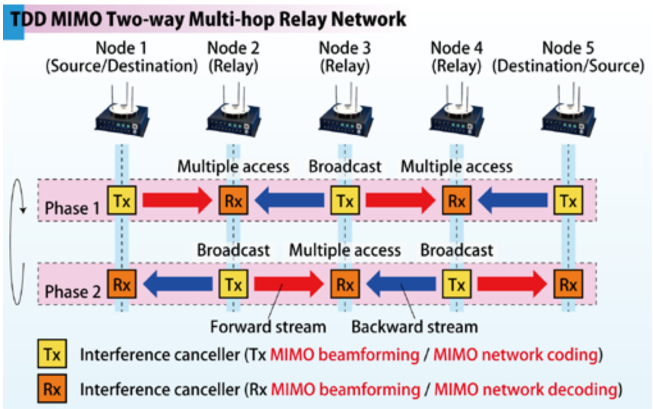

Fig. 25 Two-way multi-hop relay network

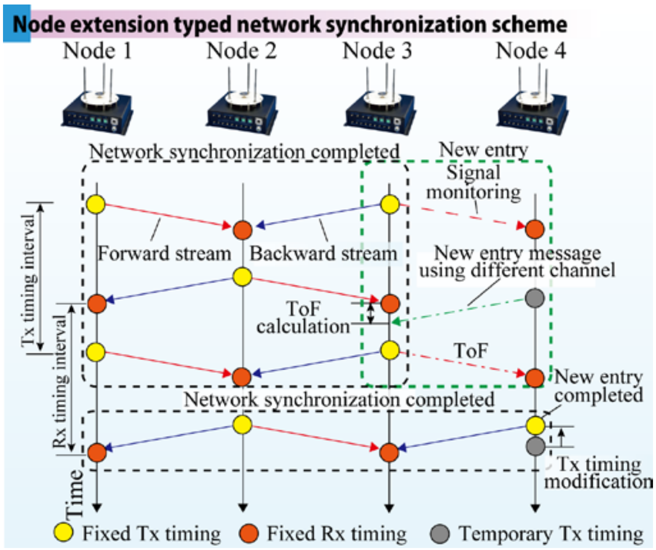

Fig.26 Node extension network synchronization

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 and MIMO network coding are introduced, so that forward and backward streams can be multiplexed as shown in Fig. 25. However, this network requires network synchronization (NW synch) among the nodes and the time of establishing NW synch should be as short as possible. Thus effective NW synch scheme is shown in Fig. 26. In this NW synch scheme a node which tries to join the two-way multi-hop relay network monitors the communication of the network. The new entry node transmits a control message to the network at its temporary transmission timing. Owing to the proposed scheme, a node can join the network by establishing NW synch without affecting the current communication, therefore the time efficiency of this NW synch scheme is improved because NW synch and data communication can be performed simultaneously. In order to prove the realization and effectiveness of the TDD two-way multi-hop relay network with MIMO network coding (2-way relay network), network throughput is measured in an indoor environment. Fig. 27 shows the system parameters, and measurement results using 3 nodes. Red, green, and blue lines show network throughputs of the 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 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. At the average end-to-end SNR of 20dB, the 2-way relay network can achieve around a network throughput of 2.3 Mbps (3.83bps/Hz). The results of this indoor experiment prove the effectiveness of the 2-way relay network.

Network throughput measurement in indoor environment

Parameters of indoor measurement with AMC

FFT points	256
Sampling frequency	5.0MHz
Guard interval (GI) rate	1/8
One symbol duration (including GI)	51.2 us (57.6 us)
Center frequency	951.2MHz
Channel bandwidth	600kHz
Number of subcarriers per channel	26 (25 for data, 1 for pilot)
Number of symbols for payload and header in one frame	86
Number of symbols for preamble in one frame	4
Modulation	BPSK,QPSK,16QAM,64QAM
Number of bits in one packet	1000 bits
Number of packets in one frame	$2\times\log_2(M_{ary})$

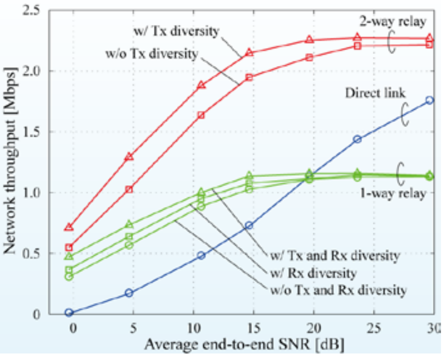

Fig. 27 Network throughput measurement

Location Estimation [30] [33] [39]

Nowadays, as the evolution of wireless communication system, location estimation of illegal radio emitter by using multi sensors has been becomingmore important and attention.

Conventional location estimation methods can be listed as received signal strength indicator (RSSI), time difference of arrival (TDOA), or direction of arrival (DOA). However, the accuracy of these estimation methods is degraded due to multipath fading especially in urban areas or indoor environment. So that, we propose a new location estimation method generalizing RSSI, TDOA and DOA.

The proposal method is a location fingerprint scheme in which the statistical characteristics of the signal cross correlation among multiple sensors is employed. Besides, different from the conventional methods, which utilize the locality of spatial correlation, thus require fine-grid location measurements. The proposal one invokes statistical learning technique and estimates location based on the correlation of received samples with the statistical learning database. Our statistical learning method is categorized into mainly two situations. When there is no information about the illegal radio emitter, we employ ray tracing information calibrated by estimated propagation channels from known sources. When there exist specific information about the illegal radio emitter, we detect the location of this source using camera and learn the statistical channel at this location by estimating training signals from the source. In the next experiment, the later statistical learning method is employed.

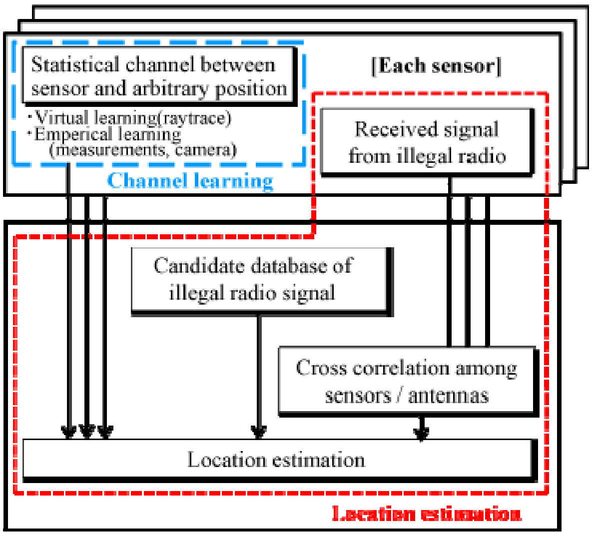

Fig. 28 Approach method

Indoor Experiment of Location Estimation

We conducted an experiment to validate the superiority of the proposal method in indoor environment. The proposal location estimation accuracy improves by 10-fold compared to the conventional methods (RSSI, TDOA). As a result, we can more correctly specify the location of illegal radioemitter.

Center frequency	1.9575[GHz]
Receive filter bandwidth	14[MHz]
Signal bandwidth	3.6[MHz]
Sampling frequency	100[MHz]
Sensor	5
Antenna	3(Center)/1(Edge)

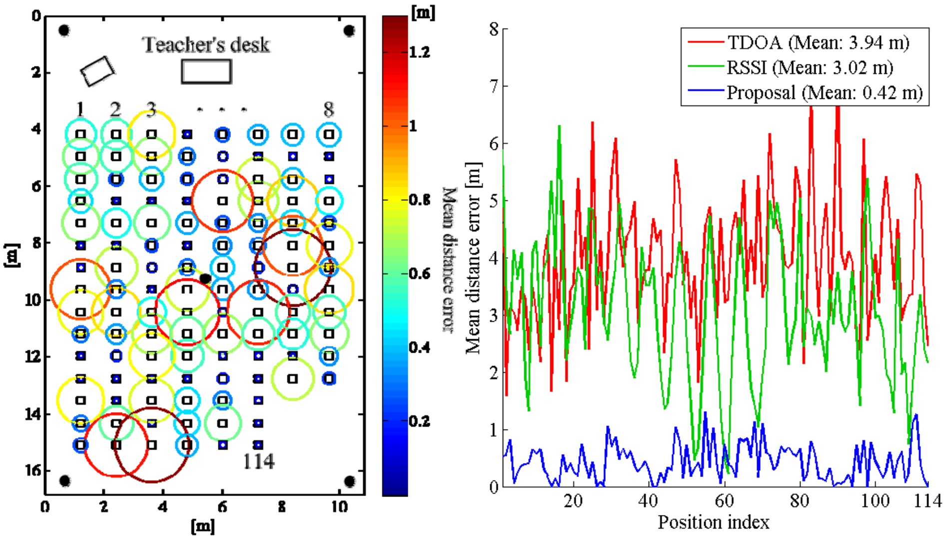

Fig. 29 Mean distance error as position index

CONTRIBUTIONS

SUZUKI-FUKAWA LAB

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[1] L.Zheng, J. Woo, K. Fukawa, H. Suzuki, and S. Suyama, “Low-complexity algorithm for log likelihood ratio in coded MIMO-OFDM communications,” IEICE Trans. On Commun., vol. E94-B, no. 1, pp. 183-193, Jan. 2011.

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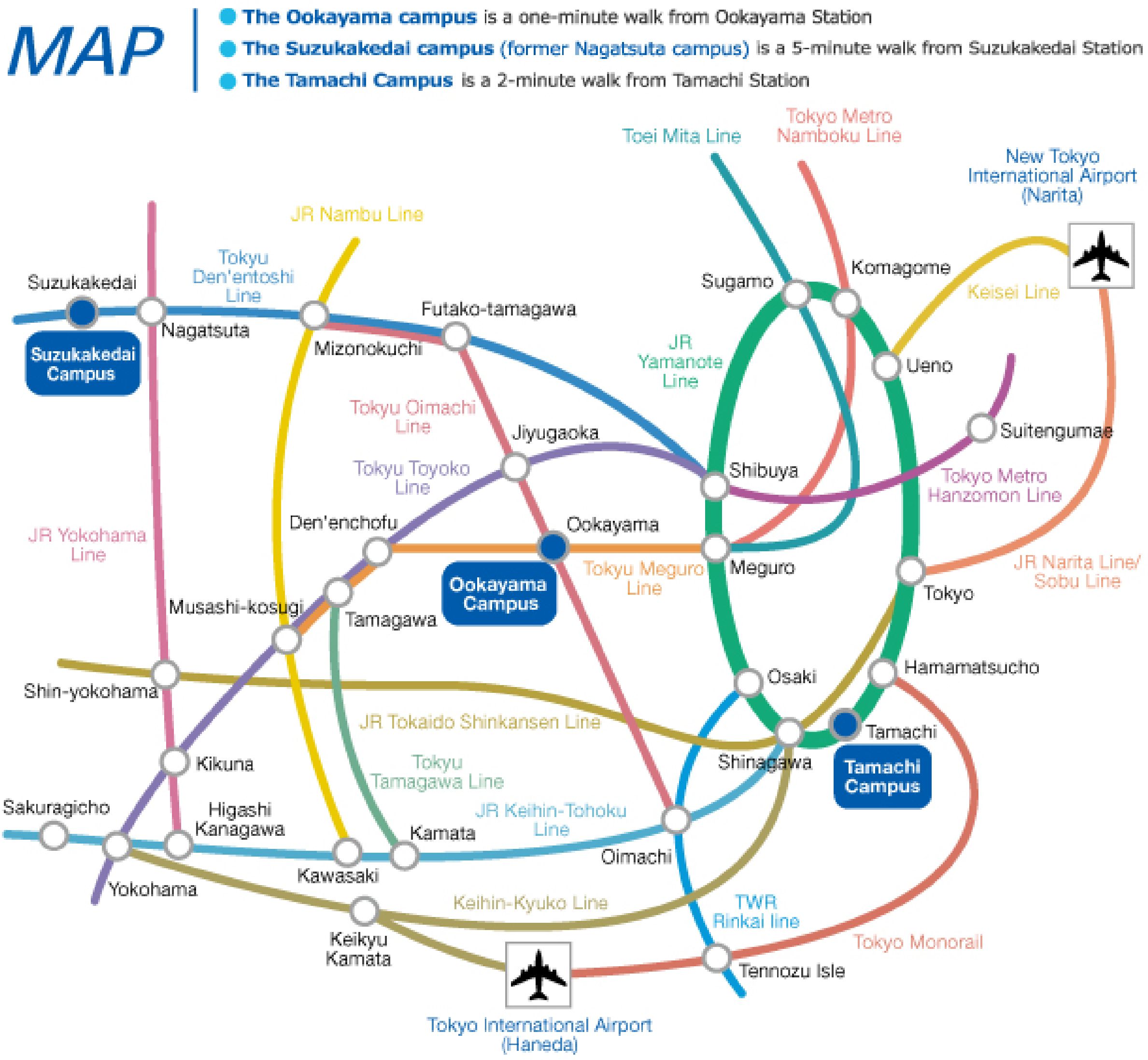

MAP

- **The Ookayama campus** is a one-minute walk from Ookayama Station
- **The Suzukakedai campus** (former Nagatsuta campus) is a 5-minute walk from Suzukakedai Station
- **The Tamachi Campus** is a 2-minute walk from Tamachi Station

Ookayama Campus: Ookayama Station of Tokyu Oimachi Line/Tokyu Meguro Line
Suzukakedai Campus: Suzukakedai Station of Tokyu Den-en-toshi Line
Tamachi Campus: Tamachi Station of JR Yamanote Line/Keihin-Tohoku LIne

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