Mobile Communications Research Group
Tokyo Institute of Technology

2012

ANNUAL REPORT

Contents

TOKYO INSTITUTE OF TECHNOLOGY

MCRG Tokyo Tech

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

The statue of Dr. Tejima in autumn

The Centennial Hall is famous for its unique architecture.

Leading the World in Science And Technology

Tokyo Institute of Technology (Tokyo Tech) is the largest science and engineering university in Japan and marked its 130th anniversary in 2011. Focusing on technical ingenuity, Tokyo Institute of Technology is a top tier university, leading the world in science and technology.

Tokyo Institute of Technology includes three undergraduate schools, six graduate schools, five leading laboratories and multiple research and education centers producing graduates who excel on conducting research that meets the demands of society and industry.

Mission

As one of Japan's top universities, Tokyo Institute of Technology 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. To achieve this mission, we have an eye on educating highly moral students to acquire not only scientific expertise but also expertise in the liberal arts, and a balanced knowledge of the social sciences and humanities, all while researching deeply from basics to practice with academic mastery. Through these activities, we wish to contribute to global sustainability of the natural world and the support of human life.

(Source: Tokyo Institute of Technology Profile 2012-2013, http://www.titech.ac.jp)

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 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.

Laboratory Introduction
&
Annual Report 2012

TAKADA LABORATORY (http://www.ap.ide.titech.ac.jp)

Professor Jun-ichiTakada

Prof. Jun-ichi 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 white space and spectrum sharing, and information technology for regional/rural development. He is fellow of IEICE, senior member of IEEE, and member of 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, Yokohoma 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.

Researcher Yu-Yang Chang

Dr. Chang was born in 1975. He received the B.E. and M.E. degrees from Department of Electrical Control Engineering, National Chiao Tung University, Hsinchu, Taiwan, R.O.C. in 1997 and 1999 respectively. He served at the Industrial Technology Research Institute, Hsinchu, Taiwan, R.O.C. from 2000 to 2005. In 2007 he received another M.E degree and in 2011 the Ph.D. degree from Electrical and Electronic Engineering Department, Tokyo Institute of Technology, Tokyo, Japan. Since 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.

TAKADA LAB's Recent Research Topics

Radio Propagation & Channel Model

- **MIMO Channel Sounding and Modeling for Super High Bit-Rate Mobile Communication Systems**
  - Scalable MIMO Channel Sounder Development at 11 and 60 GHz
  - Frequency-Dependent I/Q Imbalance Compensation Technique for Quadrature Modulator of Channel Sounder
  - Measurement Campaigns in Indoor (Tokyo Tech) and Outdoor (Ishigaki City).
- **Radio Wave Propagation Through Foliage**
- **Body Area Network (BAN)**
  - Propagation Modeling by Using Spherical Waves
  - Body Area Network (BAN) Channel Modeling
  - Dynamic Characteristics of UWB BAN Channel under Walking Motion
  - Cooperator Selection in Narrow-band BAN using Multi-link Channel Measurements

International Development Engineering

- **Case Study of Maternal and Child Health in Remote Mountainous Region of Nepal by Using ICT**

MIMO Channel Sounding and Modeling for Super High Bit-Rate 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.)

(a) 11-GHz Microwave MIMO Channel Sounder [4,12]

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 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.

Fig. 1 Double directional channel measurement in 24 × 24 MIMO configuration

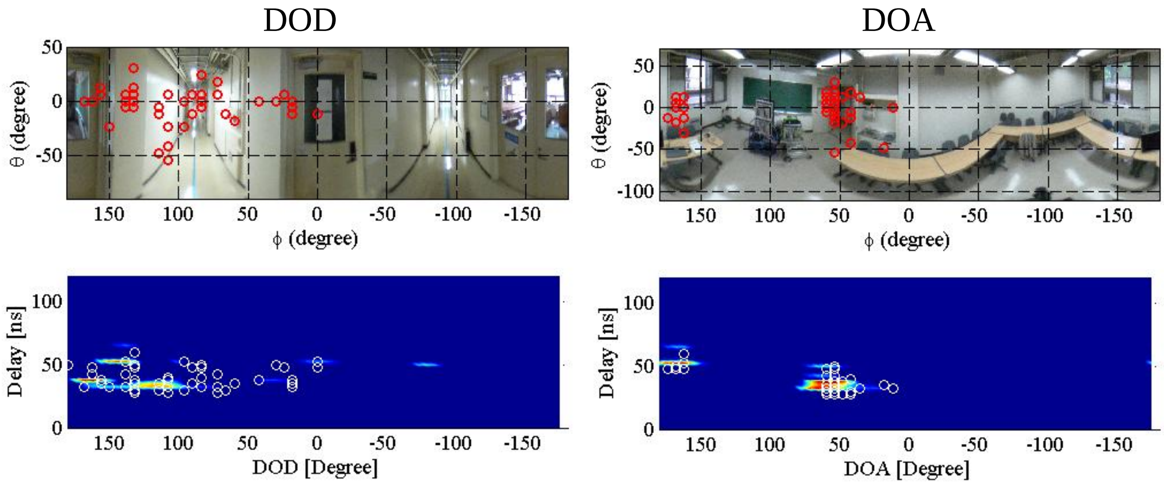


Fig. 2 Indoor double directional measurement example; results of beamforming and SAGE (space-alternating generalized expectation-maximization)

Visualization and in-situ validation :

The measured transfer functions of the MIMO channel can be analyzed with the beamforming algorithm that utilized the antenna array responses of the Tx and Rx antenna arrays, during the measurement. The results of the DoA and delay spectrum, DoD and delay spectrum or DoA and DoD spectrum can be shown in the GUI of measurement, which can be compared with the real-time panorama pictures of the measured environment. The panorama pictures are combined from the fisheye pictures that are taken from the Tx and Rx arrays with the fisheye cameras fixed on the arrays. For each array antenna, there are two fisheye cameras on it, which can tack the fisheye pictures of the front and back spaces of the array. With the in-situ data analysis, we can confirm the measured results easily during the measurements.

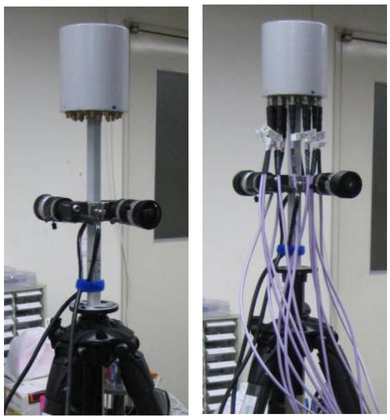


Fig. 3 The assembly of fisheye cameras and circular array antenna (Left: w/o RF cable. Right: with RF cables).

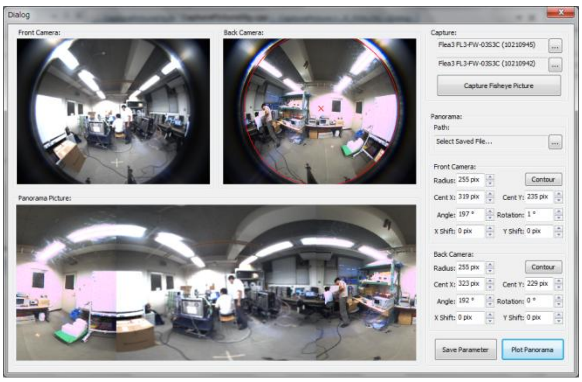


Fig. 4 The GUI of camera selection and setting, in where the upper two pictures are taken with the fisheye cameras and the lower picture is the panorama combined from the upper two fisheye pictures.

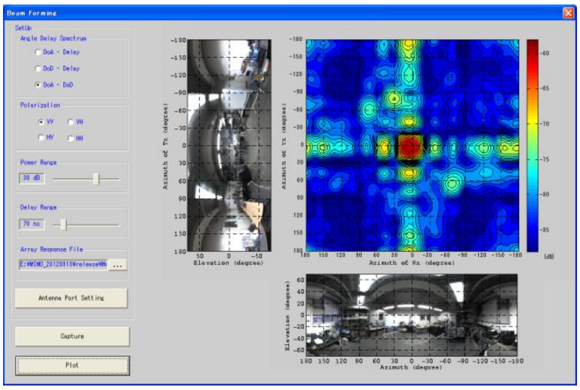


Fig. 5 The GUI of the in-situ validation tool. The measured data is analyzed and converted to angle-delay power spectrum that can be compared with the panorama pictures

(2) 60-GHz Millimeter Wave MIMO Channel Sounder

This work proposes a low-cost MIMO channel sounding technique with a fully parallel transceiver architecture that employs a simple time division multiplexing scheme. It aims at both purposes of directional channel measurement using MIMO antennas and MIMO channel measurements for transmission performance evaluation. The developed system is composed of commercial products of millimeter-wave transmitter and receiver which integrate waveguide module with standard WR15/WG25 flange interfaces (V60TXWG1/V60RXWG1, VubIQ). As shown in the figure, the RF transceivers employ a heterodyne IF architecture with variable frequency IF and RF mixers for different RF channel selection, which requires a single common synthesizer for IF and RF LO signal generation. The transmit power is approximately 5 dBm with 6 dB back-off. The baseband processing units for transmitter and receiver consist of four-channel ADCs/DACs for complex baseband I/Q signals. The transmitter up-converts I and Q input signals in the form of analog baseband capable of up to 1~5 GHz modulation bandwidth. The receiver down-converts from 60 GHz to analog baseband I and Q signal outputs. The same baseband unit with 11GHz channel sounder is utilized in this system.

Similarly to the 11GHz system, this system employs the unmodulated complex Newman phase multitone (NPM) signal. Because the phase noise of off-the-shelf transceivers is relatively large, FDM (frequency division multiplexing) and STDM (space time division multiplexing) using beamforming are disadvantageous. Therefore, this system employs the TDM (time division multiplexing) scheme for the multiple transmit signals to reduce the symbol duration. The same calibration techniques with 11GHz sounder are successfully applied.

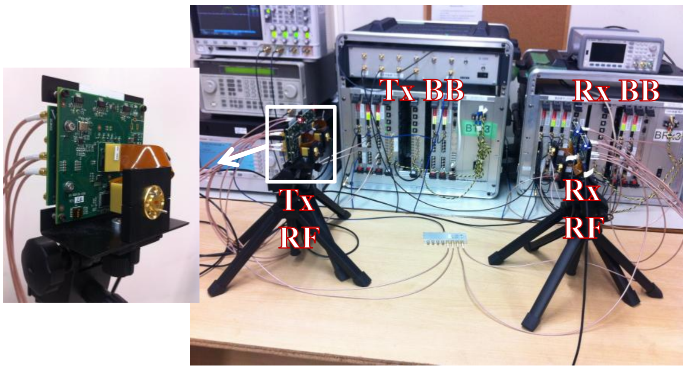


Fig. 6 60-GHz Millimeter-wave Channel Sounder

(3) Frequency-Dependent I/Q Imbalance Compensation Technique for Quadrature Modulator of Channel Sounder [1,5]

This paper proposes a parametric method of frequency-dependent I/Q imbalance compensation for wideband quadrature modulators using the spectrum measurement of a radio frequency (RF) signal that is easily performed by a general-purpose spectrum analyzer. The proposed method empirically estimates the frequency-dependent circuit parameters using only the magnitude of the frequency spectrum of the RF signal that is fed back from the spectrum analyzer. The frequency dependency of the I/Q imbalance effect generated by the difference between the overall frequency responses of the I and Q branches is modeled by frequency-dependent circuit parameters. By dividing the entire signal band into several sub-bands, the transmit signals are pre-distorted per sub-band in the frequency domain. To estimate the frequency-dependent circuit parameters, in this study, the modified method of steepest descent developed for single-band compensation is extended to the frequency-domain sub-band compensation scheme.

(4) Indoor Measurement Campaign in Tokyo Tech. [16]

Channel measurement at 11 GHz was conducted in an indoor environment at Tokyo Tech. Although only the measurement can represent the real environment precisely, huge cost and workload and limited resolution of the estimated channel parameters often restrict channel modeling suitable for the practical use in system design. In this regard, ray-tracing simulation result with its reliability verified by measurement provides us with better understanding of propagation mechanisms. For this purpose, system dependent double-directional power spectrum was obtained by the ray-tracing and the array response used in measurement (Fig. 7). Comparison with channel sounding results showed that at 11 GHz band, the influence of small scattering objects which were not included in the simulation causes significant error against measurement results. Currently, ray-tracing using detailed environment model obtained by 3D laser scanner and its effect are under investigation.

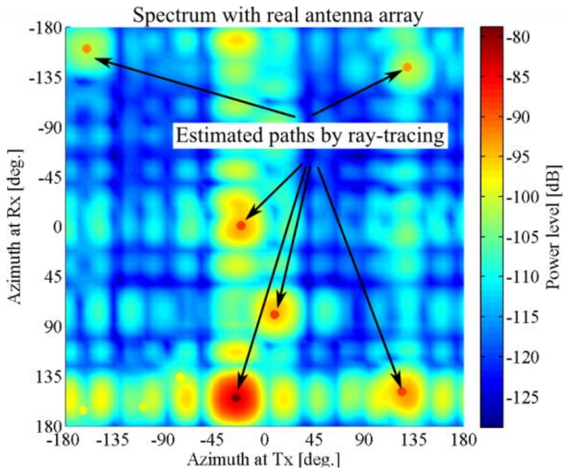


Fig. 7 Simulated double-directional angular power spectrum.

(5) Field Measurement Campaign in Ishigaki City [54,55]

In this year, several field measurements have been conducted in Ishigaki city, Okinawa, for investigation of the propagation mechanism of macro/microcell environments at 11 GHz. The measurement areas include main street, downtown and residence. The dual-polarized 24 element circular arrays at Tx and Rx and dipole/sector linear arrays were used for directional channel measurement and MIMO channel measurement, respectively. The receiver array was installed in buildings as a base station with height from 9 m to 28 m. The Tx antenna array is installed on the top of the measurement vehicle, the mobile station (MS), and the height from the ground of the Tx array is about 3 m. The snapshots were taken at constant time interval in moving MS at slower than 10 Km/h. The angle spread of AoA and AoD were estimated with beamforming and SAGE algorithms. To gain better insight of the radio propagation mechanism, we have taken the point-cloud and 3D image data of the measured area using 3D laser scanning system. We expect to get interesting results of the radio channel property and feasibility of promising small cell MIMO communication at 11 GHz in near future.

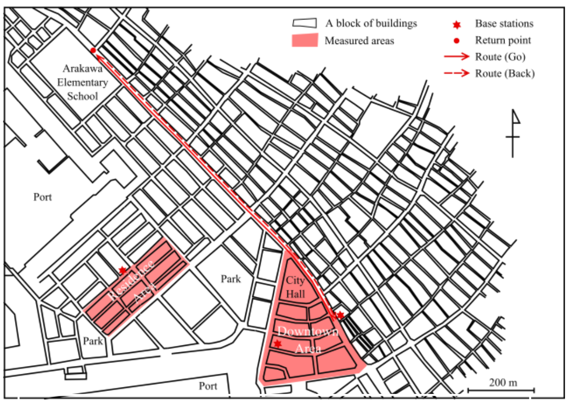


Fig. 8 The measured areas and routes.

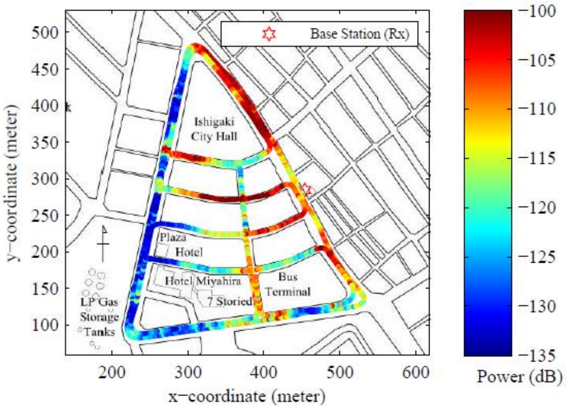


Fig. 9 Path gain result of the downtown area.

Radio Wave Propagation Through Foliage
Modeling of Radio Wave Scattering from Trees
(Joint Research with NTT DOCOMO)

Introduction

The propagation of radio waves is largely dependent on the obstacles that are present in the propagation environment. These obstacles introduce absorption, scattering and diffraction to the propagating radio waves, which may degrade the performance of wireless systems. One type of obstacles that is predominant in rural environments, which may also be present in urban and sub-urban environments, are foliage obstacles. The leaves, branches and trunks of these trees serve as complex obstacles for the propagating radio waves. Due to the complex physical geometry as well as the random nature of these obstacles, a significant challenge is presented in modeling their effects on the propagating radio waves.

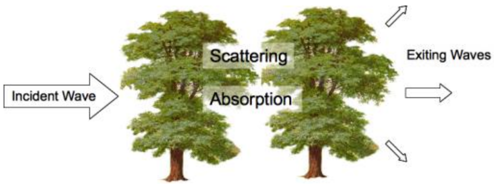


Fig. 10 Propagation Through Foliage

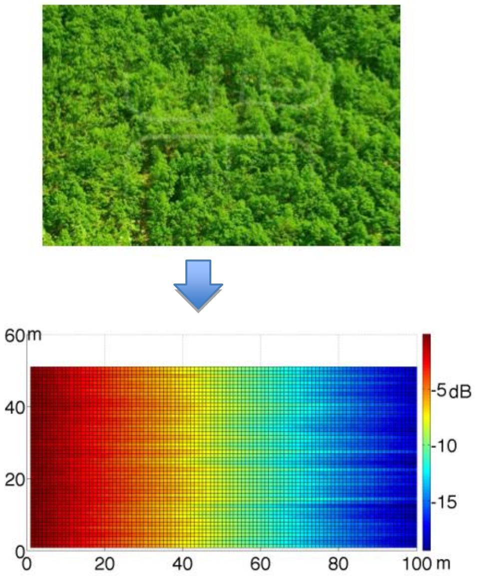


Fig. 11 Attenuation Predicted by RET Model

Large Scale Model

One approach to modeling the effects of these foliage obstacles in the propagation environment is through the use of the Radiative Energy Transfer (RET) model. The RET model describes the transfer of energy through a medium with random scatterers. This model can model the scattering of the propagating waves in the foliage environment better by discretizing the foliage medium to take into account the inhomogeneity of the scattering parameters of the medium.

Small Scale Model

The scattering parameters used by the RET model is largely base on empirical results. One approach used to model the scattering of the individual elements of the foliage obstacles is the use of approximate analytical electromagnetic models to estimate the scattering of these obstacles. The Generalized Rayleigh-Gans (GRG) approximation models the leaves, branches and trunks of these trees as dielectric discs and cylinders. From this simplified approximate geometry, the electromagnetic fields that are scattered and absorbed by these obstacles can be approximated. These parameters may now be used in the RET model to model the effects of these foliage obstacles on the propagating radio waves.

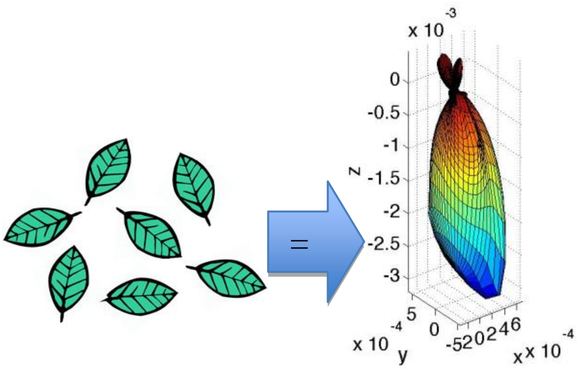


Fig. 12 Scattered Electromagnetic Fields from Leaves

Body Area Network (BAN)

(a) Propagation Modeling by Using Spherical Waves

Introduction

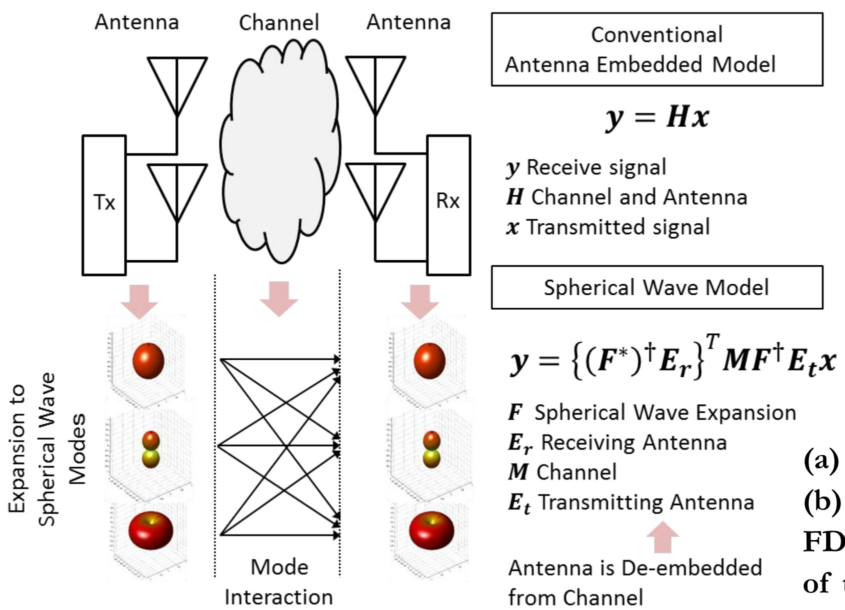
Spherical wave expansion has been emerging as a new means of propagation channel modeling. In this approach, the antenna is modeled as a series of the spherical wave modes and the propagation channel is modeled as the interaction between the modes as shown in Figure (a). The advantage of the spherical waves is that the antennas and the propagation channel are modeled separately (antenna de-embedding) with finite series. For more practical use, we are currently working on the double directional channel modeling and the propagation simulation using finite-difference time-domain (FDTD) Method.

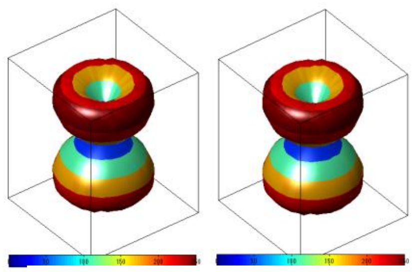
Double Directional Channel Modeling by Using Spherical Waves

The study of double directional channel enables to analyze the interaction between antennas and the propagation environment, and furthermore enables to design the antennas which fit the propagation environment best. Traditional plane wave model is based on the far-field assumption among both ends of antennas and the scatterers, as well as the assumption that the surface of the scatterer is smooth. In contrast, the spherical wave model does not rely on the plane wave assumption. The static double-directional channel model by spherical vector waves has been researched in detail in recent years. However, there is no detailed study on whether the spherical wave model is suitable for the dynamic channel environment or not. Currently, the study on the static and dynamic double-directional channel model by using spherical waves, theoretically and experimentally, is ongoing.

Propagation Simulation in FDTD Method

For the propagation simulation using FDTD method and the spherical waves, the techniques to handle the spherical waves in transmitter and receiver are necessary. We have already achieved the spherical wave source in the standard FDTD grid by using the dipole array. The excitation current of the array is obtained by point-matching technique such that the desired spherical waves are excited. As shown Figure (b), the result is successful. We are currently working on the modeling of the receiving side. This technique will be used in the channel simulation of the Body Area Network (BAN).





(Left) Theoretical
(Right) Excited in FDTD

(a) Spherical Wave modeling
(b) Spherical wave source in the FDTD method (the θ-component of the j = 20 mode).

(b) Body Area Network (BAN) Channel Modeling

Introduction

BAN is the fundamental technology of the wireless vital data monitoring which is the key function of the future health-care. In BAN, Many sensors attached to the human body measure various vital data such as electrocardiogram, blood pressure, and temperature. These data are collected wirelessly via a coordinator and an access point for the medical-care purpose. By using BAN, patients get free from cabling and the mental and physical burden are expected to be reduced. The application of BAN is not limited to this medical but fitness, public safety, and entertainment are also expected. For the reliable design of the BAN system, the channel study is important. Therefore, we are currently working on the following topics.

Dynamic Pathloss Simulation towards Antenna De-embedding

Since in the conventional channel model antennas are embedded, i.e. the channel is strongly antenna dependent, new means of channel modeling that achieve antenna de-embedding are required from the view point of antenna design. To address this issue, we are developing antenna de-embedded simulation methodology by using spherical waves. The preliminary simulation is already achieved under the simplified assumption that the antenna is an infinitesimal dipole. Specifically, the dynamic pathless behavior during various human motions is achieved with the high performance simulation using Finite-Difference Time-Domain Method on GPGPU clusters of TSUBAME 2.0. Figure (a) shows the snapshot of the simulation result that shows the electric field strength around the human body when the transmitter is at naval.

Synchronized Dynamic Measurement and Simulation by Kinect

Kinect is a low-cost gaming device for the motion capture. However, Kinect potentially can be a core of the integrated environment for the dynamic BAN channel simulation and measurement. With this environment, we can obtain simultaneously the dynamic human motion data for simulation as well as the measurement channel response data from vector network analyzer associated to the motion. The system serves as a tool to identify the source of discrepancy between the simulation and the measurement.

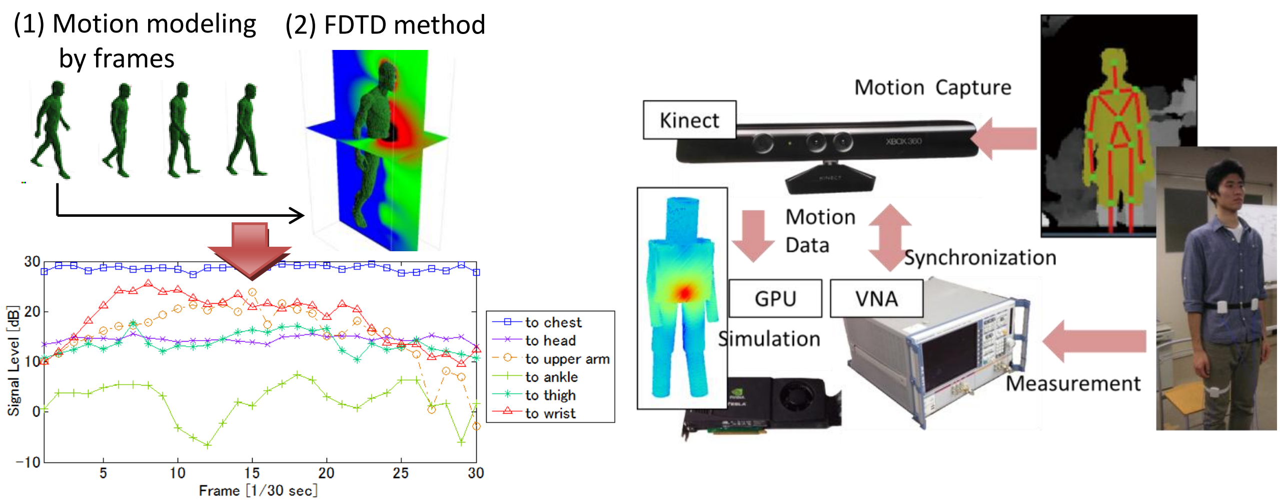


Fig. 13 (a) FDTD Simulation procedure and obtained result of link fluctuation (b) Integrated simulation and measurement environment using Kinect

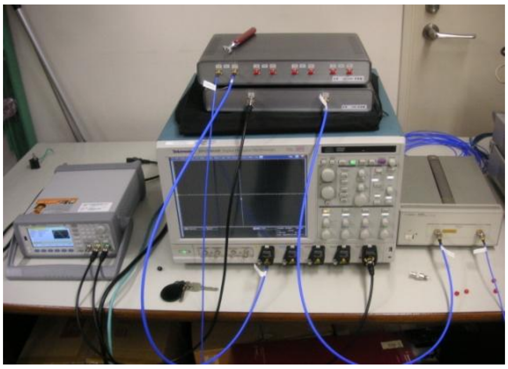
(c) Dynamic Characteristics of UWB BAN Channel under Walking Motion [42]

In IEEE 802.15.6 standard, Ultra-wide-band (UWB) technology has been adopted as a wide bandPHY specification which enables high data rate transmissions at very low transmitting power. In BAN systems, thechannel response between the transmitter and receiver is inevitably influenced by the body status and movement.Therefore the dynamic property of the propagation channel and interlink correlation should be carefully investigatedfor successful device and network design. Firstly, we developed a multi-port time-domain channel measurement system for dynamic UWB channel characterizationusingdigital sampling oscilloscope because it is difficult to usedue to long measurementtime. Next, we try simultaneous measurement of multiple channels using 4 antennas attached around the body. To make channel model, we analyzed the channel properties by looking at the power delay profile and the crosscorrelation between antennas under the waking motion.

(d)Cooperator selection in Narrow-band BAN using Multi-link Channel Measurements [23, 44].

In applications of Body Area Network like patient monitoring, reliable and low-power communication over a long period is very important. It is expected that in a BAN there will be at least few sensors nodes in the vicinity of one another communicating with the central coordinator. We can exploit the data received at the neighboring nodes using different cooperative schemes in order to improve the communication reliability.

For healthcare applications we know where the major sensor nodes will be located. Therefore a very simple way of choosing cooperator for anynode will be to use the multi-link channel measurements and characterize the multi-hop links according to the probability of fading and the type of processing (decode-and-forward, Amplify-and-forward etc.) at the cooperator node. Predefined cooperator selection has the advantage of not needing the extra network overhead involved in case of dynamic selection. In our work we have characterized the nodes into potential cooperators and then identified the best cooperator based on different body movement scenario. We found that the performance gain in using cooperators is much higher in case of links with higher probability of fading.



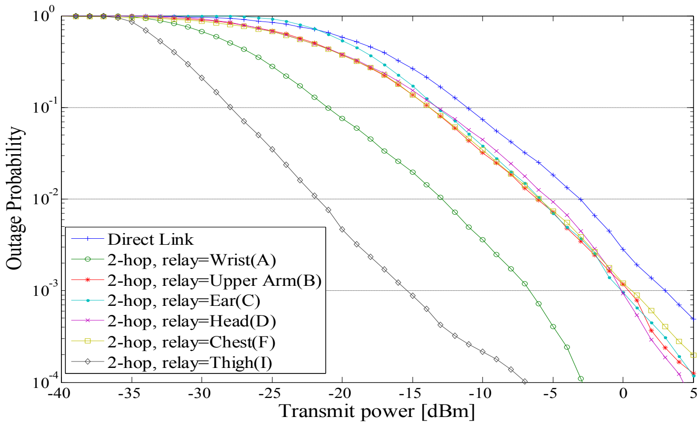


Fig.14 (Left) UWB Measurement System. (Right) Outage probability of ankle-navel link compared with two-hop links in 2.4GHz BAN while walking.

International Development: Case Study of Maternal and Child Health in Remote Mountainous Region of Nepal by Using ICT

Nepal is known as being one of the poorest countries in the world. This is evidenced by the high rate of maternal deaths through, in particular, complications related to pregnancy or childbirth. The situation is more serious in the marginalized and poor communities living at high altitude and in remote rural areas of Nepal. There are various reasons for this such as traditional customs, cultural barriers, lower literacy rates, as well as lack of infrastructure and qualified doctors. It is known that antenatal care is an important factor in reducing the maternal mortality, and information and communication technology (ICT) can be an effective tool to connect pregnant women to health services in remote areas.

A member of Takada Lab, focusing on the antenatal health care, has joined the Child Protection Program being implemented by Internet Society (ISOC) Next Generation Leadership (NGL) program under small community grant funding. It has being implemented by Yagiten Pvt. Ltd and E-Networking Research and Development (ENRD). ENRD is a non-profit and non-governmental organization in Nepal. ENRD is well-known by its successful Nepal Wireless project to establish the Internet connection to the remote villages in Nepal. Its goal is to empower and support rural communities through the use of ICT. Figure 1 shows the schematic view of Child Protection Program. In this project there are four primary stake holders; 1) the city hospital doctors in Kathmandu, 2) female community health volunteers (FCHV), 3) community health worker and 4) pregnant women. The city doctors develop the education contents of antenatal care for pregnant women and make it available on the Internet by uploading them to the Yagiten servers. Due to the Internet bandwidth constraints at the remote villages the contents are mainly texts and audio recordings. The FCHV, nominated be individual villages, are trained by the project to handle the laptop or tablet PC. They download the information onto a laptop or tablet and take it to the pregnant women's home. The field survey was conducted to clarify the change in behavior of pregnant women in remote villages of Nepal after they received antenatal health care information through ICT and how their lives have been improved by the project.

Through the field observation, questionnaire and interview survey at project site, i.e. remote villages in Nepal, it is found that the ICT is expected to enhance the antenatal care information to pregnant women and to let them get rid of the traditional behavior related to pregnancy issue by giving the correct information.

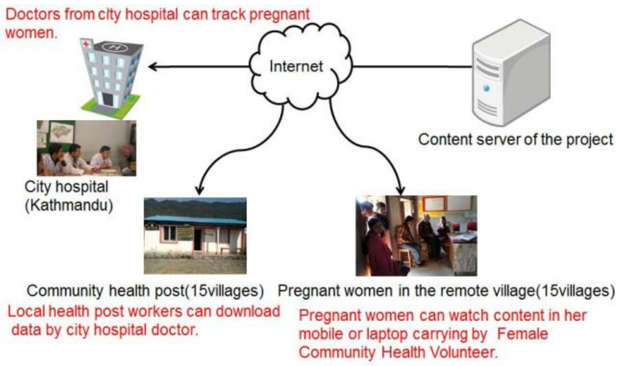


Fig. 15 Schematic view of the project

Fig. 16. Field survey at Shikha

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.

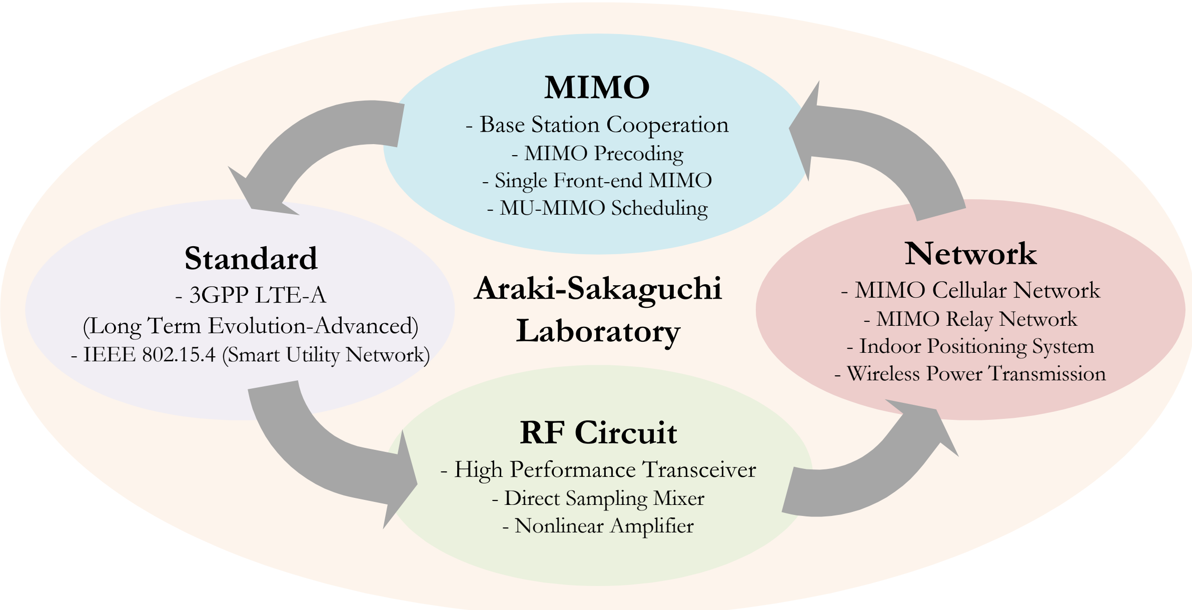
Associate Professor Kei Sakaguchi

Assoc. Prof. Kei Sakaguchi received the M.E. degree in Information Processing from Tokyo Institute Technology in 1998, and the Ph.D. degree in Electrical & Electronics Engineering from Tokyo Institute of Technology in 2006. From 2000 to 2007, he was an Assistant Professor at Tokyo Institute Technology. Since 2007, he has been an Associate Professor at the same university. In April of 2012, he also joined Osaka University as an Associate Professor, namely he has two positions in Tokyo Institute of Technology and Osaka University. He received the Outstanding Paper Awards from SDR Forum, IEICE, and IEICE communication society in 2004, 2005, and 2012 respectively. He also received the Tutorial Paper Award from IEICE communication society in 2006. He served as a TPC co-chair in the ICST CrownCom in 2011 and as a General co-chair of IEEE WDN-CN in 2012. His current research interests are MIMO cellular networks, smart grid, and wireless energy transmission. 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 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.



www.mobile.ee.titech.ac.jp

ARAKI-SAKAGUCHI LABORATORY

Shared Remote Radio Head Architecture to Realize CoMP [8]

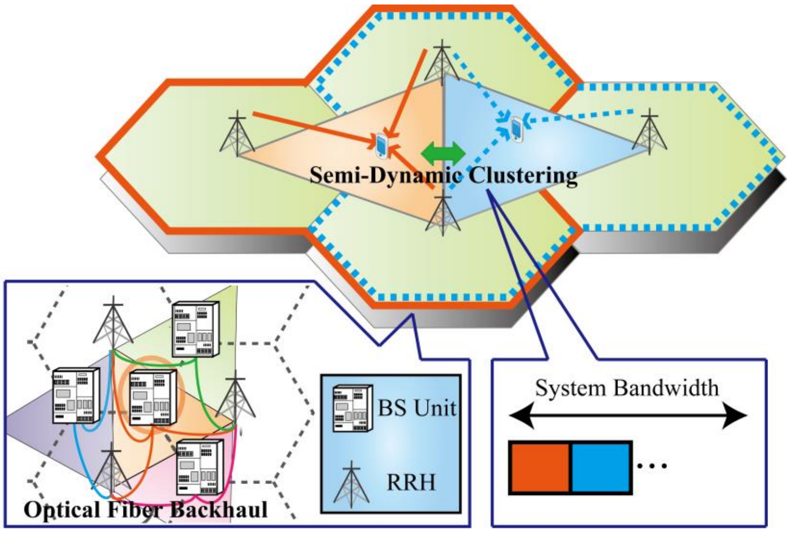


Fig. 1 Shared Remote Radio Head Architecture

Coordinated Multi-Point (CoMP) technique can convert inter-cell interference signals from neighbor base stations (BSs) to desired signals. However, CoMP requires accurate synchronization among cooperative BSs as well as Channel State Information between target user and all cooperative BSs. For practical realization of CoMP, new BS architecture in which a BS unit is connected to multiple Remote Radio Heads (RRHs) located apart through optical fiber has been proposed. Even with this architecture, however, CoMP can only be realized within the predefined connected RRHs. Therefore, we propose a novel BS architecture called shared RRH network, in which each RRH is additionally connected to multiple BS units. As flexible clustering is made possible by this architecture, semi-dynamic clustering using overlapped cluster patterns allocated with orthogonal resources can be achieved. Cell-edge user throughput can be improved effectively by employing CoMP with semi-dynamic clustering.

Large Scale Cooperation in Cellular Networks with Non-uniform User Distribution [36]

Coordinated multipoint (CoMP) was basically proposed to improve performance for users in the cell-edge area of a cellular network. The main idea of CoMP is to mitigate interference through cooperation among base stations (BSs). We change the traditional image of CoMP. In real-world networks, user density and traffic demand depend on the time of the day. Traditionally, networks are designed for the worst case or the busiest time. Quite the contrary, our idea is to dynamically transfer network resources from sparse areas to dense areas. To realize this, we employ large-scale CoMP with flexible coverage control. Coverage control is accomplished through antenna vertical/ horizontal beam direction. Our idea is to focus on user dense areas and form large clusters around them to borrow base stations (BS) from vacant areas. To implement this, we have to solve an optimization problem, which selects best BSs for the cluster and finds their optimum beam direction/pattern subject to maximizing the overall network sum rate. Our results show that the system rate can be multiplied several times with the proposed scheme.

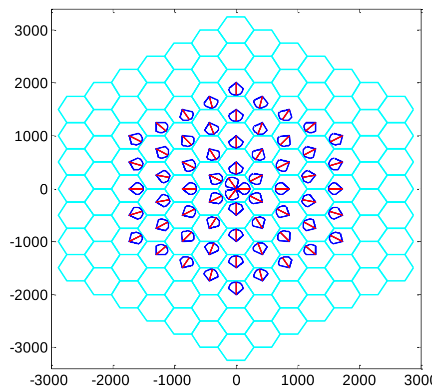


Fig. 2 A 5-Tier Cluster Around a Single Hotspot Zone

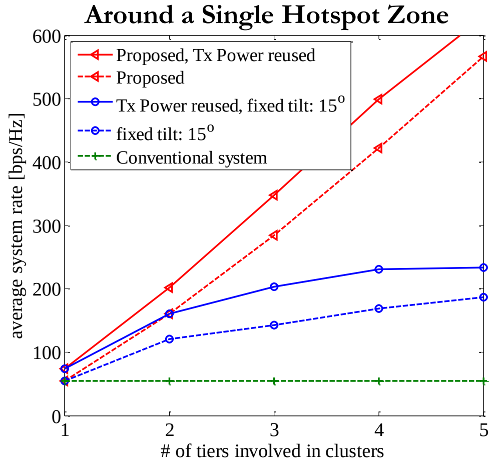


Fig. 3 System Rate

Diamond Cellular Network [14][35][48]
-Combination of Small Power Base stations and CoMP Cellular Networks-

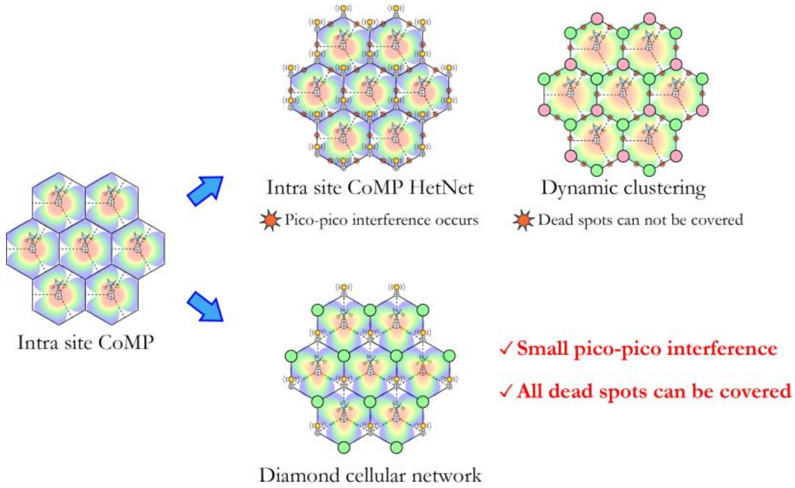


Fig4. Conventional cellular network and Diamond cellular network

Coordinated multipoint (CoMP) transmission has been proposed to solve the "cell edge problem" in cellular network. Even though there is still "cluster edge problem" if only the static clustering of CoMP is considered. Although this problem can be overcome by the introduction of the dynamic clustering method, which switches clustering patterns dynamically, it needs a complicated backhaul network. Without increasing the number of cluster patterns like dynamic clustering, our work proposes a new concept of heterogeneous cellular network which aggregates the cluster edge to change the beam pattern and deploys pico base stations at the aggregated dead spots to reduce the backhaul complexity.

Optimization of base station antenna beam tilt angle for base station cooperation cellular systems [53]

Base Station Cooperation (BSC) can improve cell-edge capacity, in which different base stations cooperatively transmit signals to cell-edge users at the same channel. 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 cell capacity is defined, and the optimal beam tilt angle is derived by solving the corresponding optimization problem. By introducing the BSC system, channel capacity is greatly improved, especially at the cell-edge. By using the optimal beam tilt angle, channel capacity at the cell-edge is further improved.

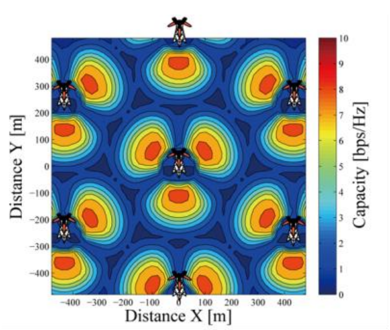


Fig.5 Single cell by conventional tilt angle

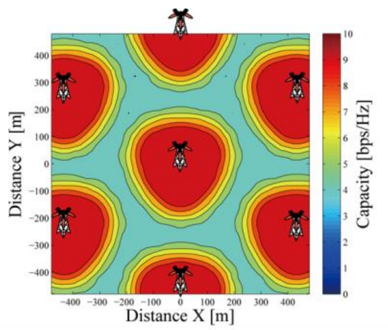


Fig.6 BSC by conventional tilt angle

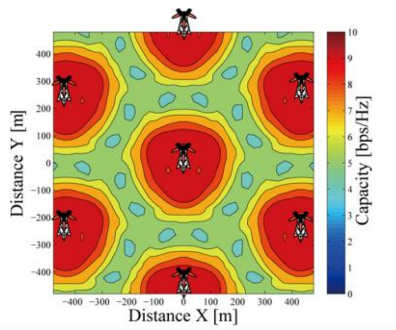


Fig.7 BSC by optimal tilt angle

ARAKI-SAKAGUCHI LABORATORY

Optimum Relay Placement of MIMO Two-Way Multi-hop Networks in U-shaped Corridor Environment [47]

MIMO Two-way Multi-hop Networks (M2WMN) has been proposed to enhance the performance of multi-hop relay network. This research investigates the optimum relay node placement for M2WMN in real U-shaped corridor environment (Fig. 8) by performing 3D ray-tracing simulation. The analysis is to find the best locations of relay node 2, 3 and 4 at which the network achieve the highest performance when using different comparison relaying scheme, i.e. MIMO one-way relaying with dual channels, M2WMN and M2WMN with power control (Fig. 9). Fig. 10 shows the network performance against different transmit power constraint. The result shows that our proposed relaying scheme i.e. M2WMN with power control outperforms the other ones. Interestingly, we find that the optimum relay locations in this case are not anymore at the intuitive locations i.e. the corner of the corridor in high SNR regime as to avoid interference.

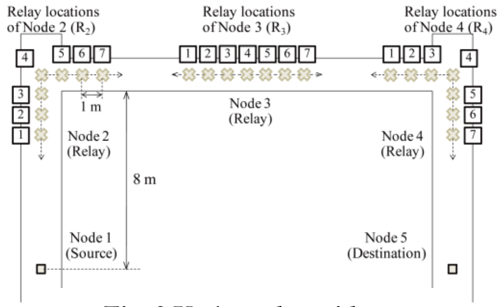


Fig. 8 U-shaped corridor

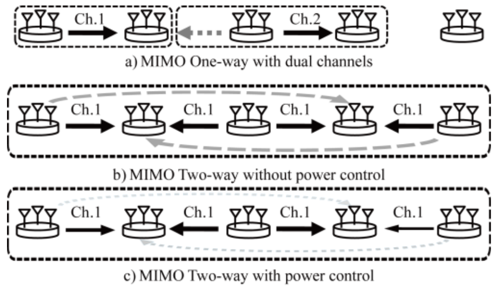


Fig. 9 Analysis relaying schemes

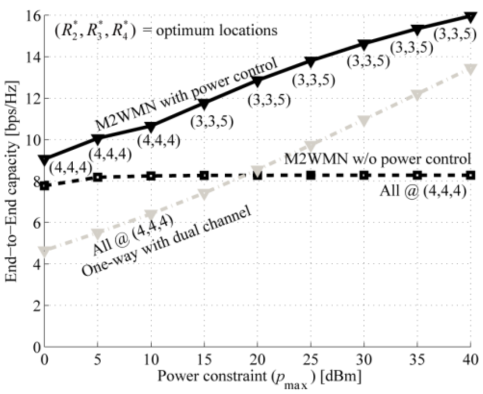


Fig. 10 Capacity result

Space Division Duplex (SDD) MIMO two-way relay using Tx beamforming [15]

For efficient two-way relay, interference cancellation techniques such as beamforming (BF) and network coding (NC) must be introduced. However employing NC has a restriction that the relay cannot modify the in-the-middle relaying data packets. BF technique, on the other hand, allows modification of relaying packets at the relay, which is preferable for future systems such as smart grid, factory automation systems, etc. where sensing and control signals are exchanged. To realize this technique which requires Channel State Information at Tx (CSIT), our system is designed to be Time Division Duplex (TDD) with over-the-air RF calibration to make use of the CSI reciprocity. We succeeded in realizing the calibration method (Fig. 11) and thus became the first to successfully implement two-way relay using Tx BF. We also developed a demonstrator for our system using hand game of rock-paper-scissors (Fig. 12).

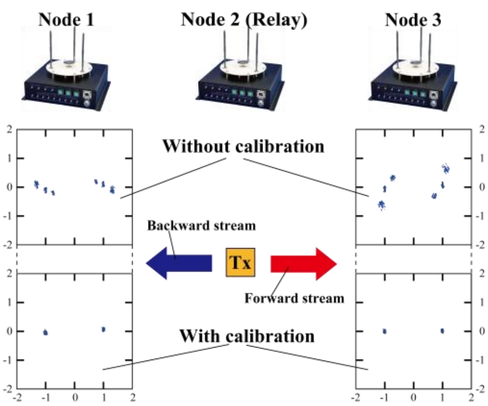


Fig. 11 Calibration effect

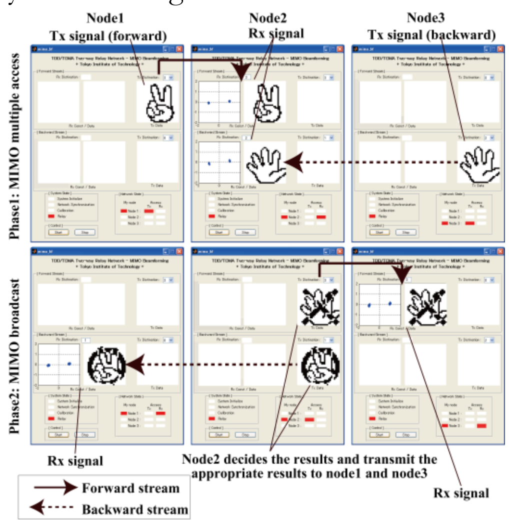


Fig. 12 Demonstration system

Low Noise Matching Design for Compact MIMO Receivers [29][44]

The noise matching problem in the presence of signal and external noise coupling for compact multiple-antenna receivers is addressed. Since optimal matching circuit has a problem to realize in practice, a suboptimal alternative matching (even-odd mode matching) is proposed for decreasing circuit complexity based on symmetrical antenna and identical front-end. The proposed matching can be designed without the crossover components (S23, S14) of matching circuit with mutual coupling in Fig. 13. Also, it is composed by 4 series and 4 shunt elements with susceptance parameters of B1~B5 in Fig. 14. We conclude the proposed matching maximize ergodic capacity with lower circuit complexity on antenna distance lambda/8 and two NF scenarios as shown in Fig. 15.

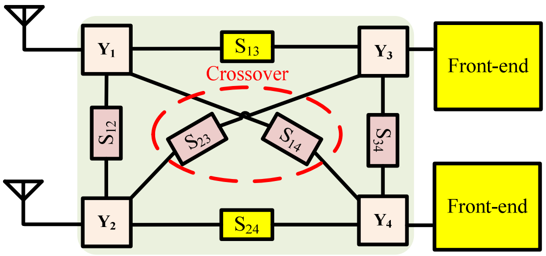


Fig. 13 Circuit model

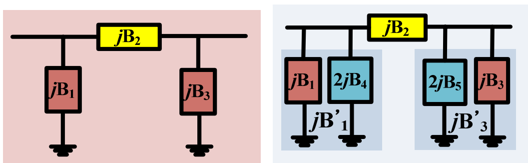


Fig. 14 Even-odd mode matching

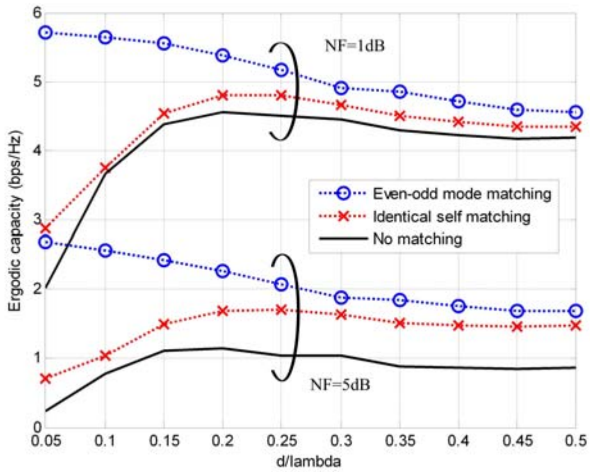


Fig. 15 Ergodic capacity as antenna distance

Multi User MIMO User Grouping with Block Diagonalization [18][50][54]

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 fair user scheduling for MU-MIMO system with Block Diagonalization where users are grouped by using a certain criteria. The concept of Look-up table (LUT) which defines the appropriate number of users per group is also included. Moreover, we evaluate the performance of the proportional fairness scheduling comparing with norm-based scheduler. In Fig. 16, we can see that the concept of LUT can provide higher sum rate capacity while the PF-based also performs better than norm-based scheduler. Moreover, PF-based scheduler with LUT provides the fairness especially for high SNR users which can be seen in Fig 17.

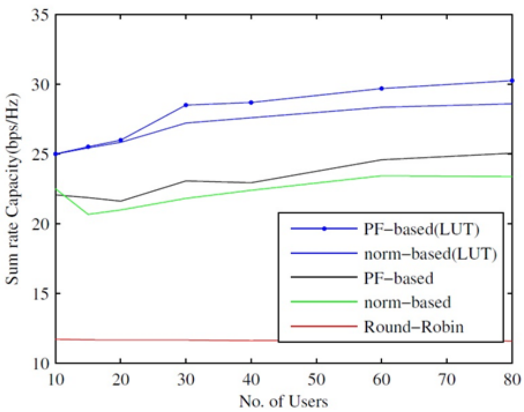


Fig. 16 System capacity vs. number of users

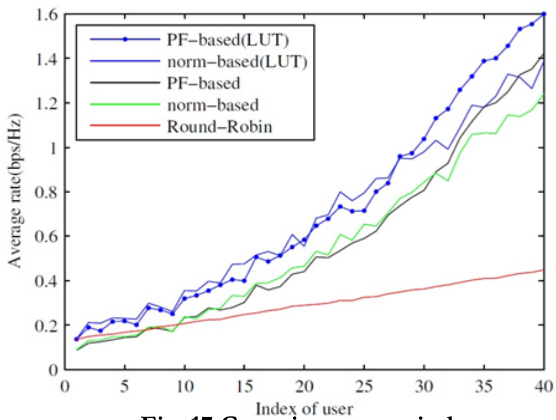


Fig. 17 Capacity vs. user index

ARAKI-SAKAGUCHI LABORATORY

Multi-point Wireless Energy Transmission [13]

The limited life-time of sensor nodes has long been an issue in wireless sensor networks. Wireless energy transmission has been introduced to extend the sensor life-time. However, due to restricted transmit power and the standing-wave occurred by indoor propagation the coverage of wireless energy transmission is limited. To solve this problem, we proposed multi-point wireless energy transmission with carrier shift diversity which can realize seamless coverage of energy supply. We also developed prototype hardware of battery-less sensor consuming power of −4dBm and conducted an experiment to verify our proposed scheme. Fig. 18 and 19 show the experiment setup and received power distribution respectively. Fig. 19 shows that our proposed scheme (red line) can solve the standing-wave problem. Table 1 concludes the percentage of coverage for each scheme. The coverage of the proposed scheme achieves 99.3% to activate the battery-less sensor.

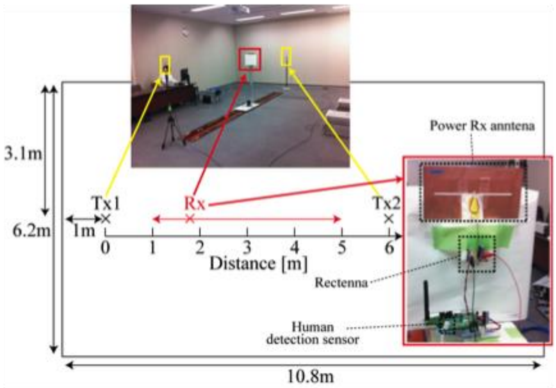


Fig. 18 Experiment setup

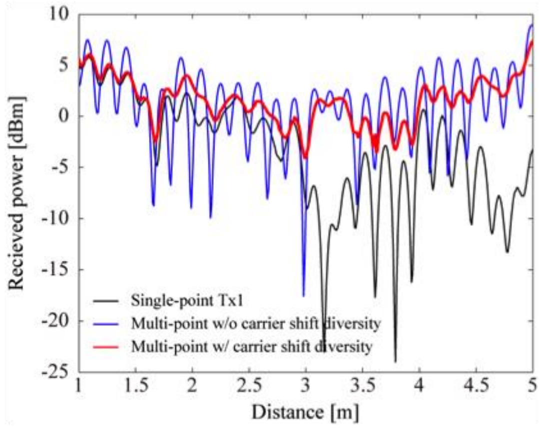


Fig. 19 Power distribution

Table 1 : Coverage of sensor activation

Single-point	Simple multi-point	Proposed multi-point
57.5%	89.6%	99.3%

Received Power Maximization Problem Under a Given Transmission System [24][40]

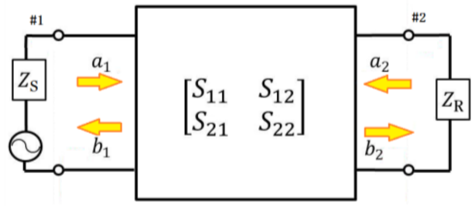


Fig. 20 System model

In recent years, wireless power transmission has been widely applied in low-power devices. As the consumption power in such devices is limited, efficient wireless power transmission is required. Despite being well investigated, conventional researches on transmission circuits only assume receiver with impedance value as a certain constant. In this study, we examine the relationship between receiving power and variable receiver impedance. As changing the power source or the transmission circuit is a difficult task, circuit design adapting to arbitrary power source or transmission circuit is necessary. For a fixed power source and transmission circuit, we attempt to maximize the receiving power by changing only the impedance value of receiver. We employ S-parameters for circuit parameters, and internal impedance of the power source. These parameters must be measured in advance. After that, the optimum impedance value of receiver can be derived. Because S-parameters change depending on the impedance value of receiver, it is necessary to check if a change of receiver impedance might affect S-parameters. Then the impedance of receiver needs to be selected for maximizing the received power. In our result, by using only internal impedance of power source and circuit parameters, we can find the optimum impedance of receiver. Moreover, by changing the internal impedance of power source to a limiting value, we interestingly find that the power source can be virtually treated as a constant voltage source or a constant current source.

Performance Evaluation Method for Body Area Network (BAN) [28]

BAN provides wide range applications including medical support, healthcare monitoring, and consumer electronics with increased convenience or comfort. In this system, propagation characteristics depend on transmitter/receiver position and human motion, therefore transmission performance is changed by these factors. We propose Nakagami-*m* fading model to represent these various situations and we analyze packet error rate under this fading model. Analysis specification is based on the IEEE802.15.6 standard. There are four combinations of transmit parameter. So, transmission performance is changed by difference of these parameters. Results show that average SNR which required to achieve packet error rate lower than 10% (required average SNR) depends on *m* parameter and transmit parameter. In BAN, the required average SNR when *m* =0.32 is larger than that when *m* = 22.69 by about 25dB. But if transmit parameter is changed, the required average SNR is also changed about 7dB. So, we can consider to take the best transmit parameter in order to achieve the required average SNR.

Table 2 Nakagami-*m* parameter

	m	Average SNR
Wrist	0.32	32.8 dB
Waist	22.69	37.2 dB

**Motion : Walking, TxPosition : Stomach*

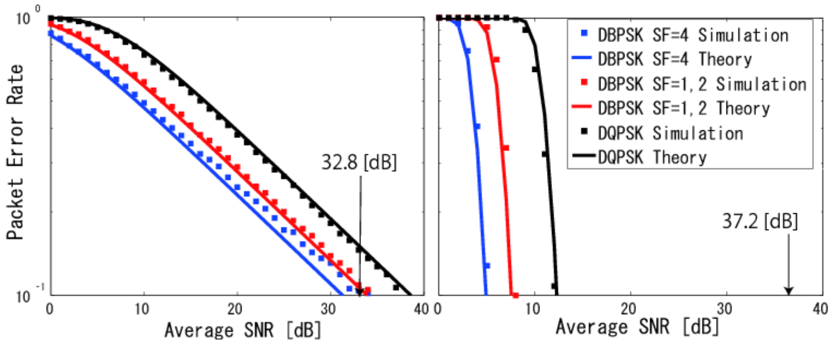


Fig. 21 Packet Error Rate (Left: *m* = 0.32, Right: *m* = 22.69)

Fading Channels on Inter-Vehicle Communications [27]

Inter-vehicle communication is expected to help drivers notice the existence of cars that are not in the sight of drivers by means of wireless communication and thus reduce the number of car accidents. In 2012, 700MHz bands were assigned to this system in Japan owing to its preferable propagation characteristics even in the Non-Line-of-Sight (NLOS) environments. We propose to formulate spatial distribution of received signal amplitudes based on measurement data inside a 1.8m grid at Nakakasai, Tokyo. This method employs Nakagami-*m* distribution whose parameter *m* is estimated by maximum likelihood estimation method. The estimated distribution is in good agreement with experimental data. In addition to the modeling, we conduct the analysis of packet error rates. Parameters for the analysis are based on the domestic standard called ARIB STD-T109. Results show that the average SNR required to achieve packet error rate lower than 5% deviates by about 5dB from that assuming Rayleigh fading channel.

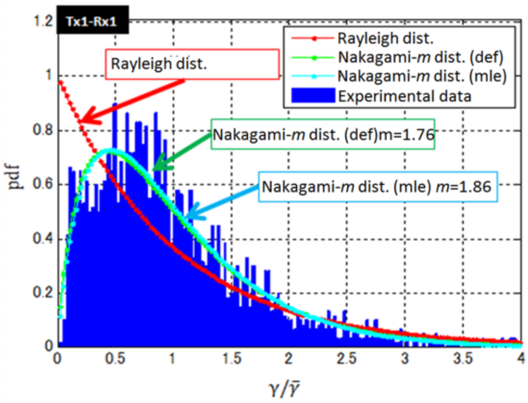


Fig.22 Spatial distribution of received power

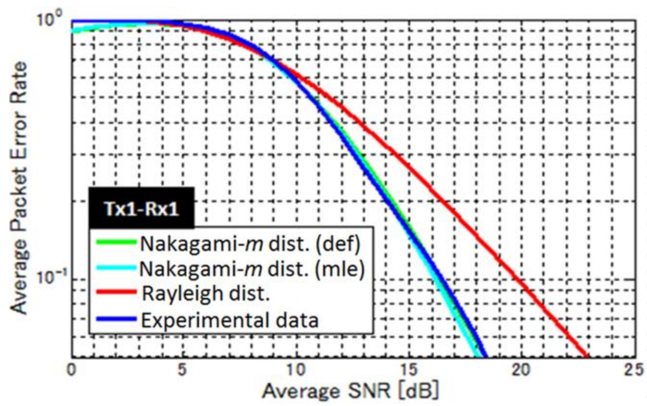


Fig.23 Average Packet Error Rate

ARAKI-SAKAGUCHI LABORATORY

Concurrent multi-band predistortion for wideband amplifier [17] [23] [30] [43] [45] [49]

In the recently developed Flexible Wireless System (FWS), the same platform needs to deal with different wireless systems. This increases nonlinear distortion in its wideband power amplifier (PA) because the PA needs to concurrently amplify multi-band signals. By taking higher harmonics as well as inter- and cross-modulation distortion into consideration, We propose a novel method that enables modeling of the PA amplifying dual-band signals and a design method for the dual-band predistorter.
Fig. 24 shows the nonlinear PA characteristic can be modeled when PA input power is between -30 dBm and -20 dBm and Fig. 25 shows our proposal predistorter can improve adjacent channel power ratio (ACPR) of dual-band OFDM signals.

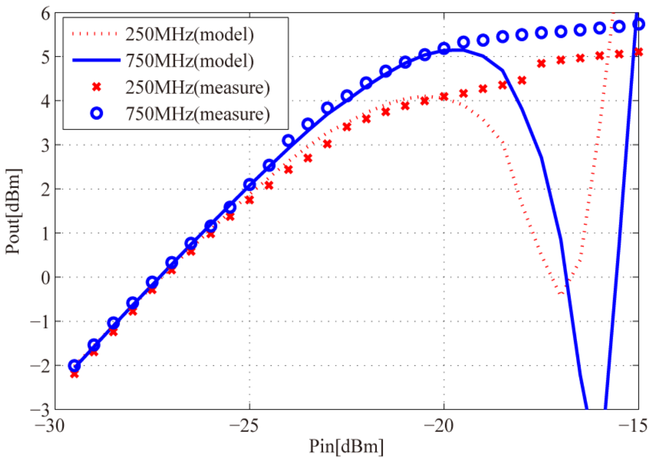


Fig. 24 Modeling for the nonlinear PA

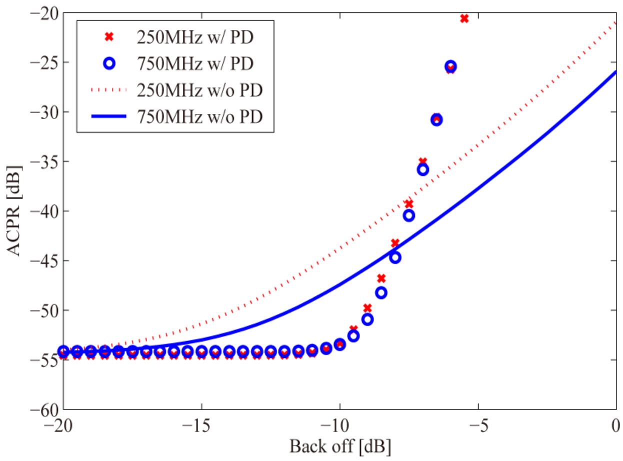


Fig.25 ACPR in dual-band OFDM system

Inter-carrier interference (ICI) reduction in OFDM system [37] [39]

The implementation of OFDM system has suffered with the problem of phase noise and frequency offset from local oscillator (LO). These problems destroy the orthogonaliy between subcarriers and causes inter-carrier interference (ICI) in OFDM transmission system. The self-cancellation is one of the famous methods to reduce ICI. However, the self cancellation technique has a big effect on bandwidth efficiency and the data rate. After self cancellation is implemented, bandwidth efficiency and data rate is reduced by a half. The new self-cancellation scheme splits subcarriers into several groups to reduce the ICI level. The propose method can gain the advantages of self-cancellation method without losing the bandwidth efficiency and the data rate. However, this idea cannot remove all ICI in OFDM system. Therefore, the other ICI reduction technique is applied after propose scheme which is extended Kalman filter (EKF).

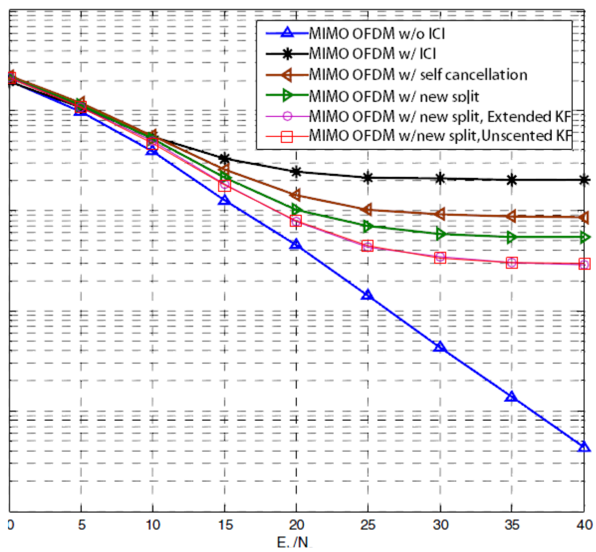


Fig. 26

Distributed Power Control Network [16][23][38]42][51]

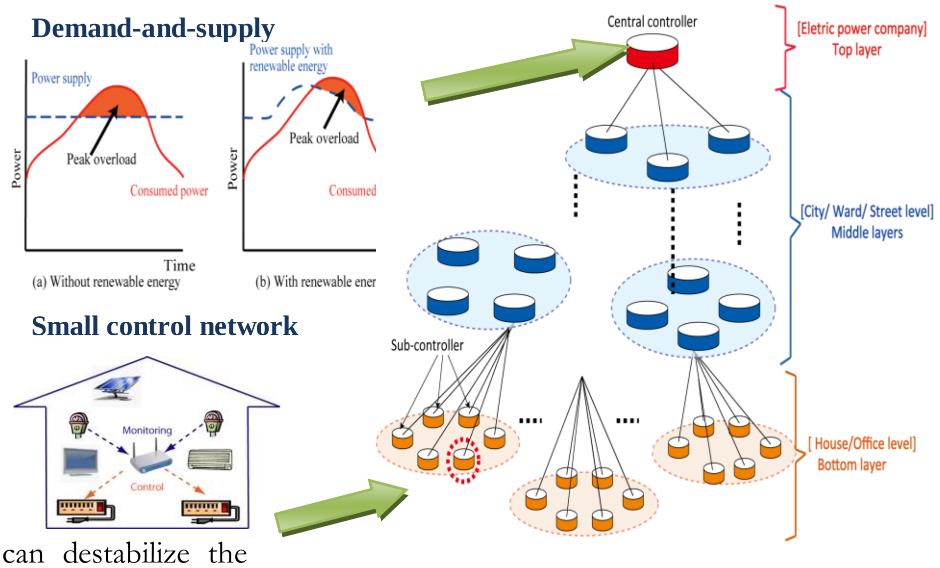


Fig.27 Hierarchical Distributed Control Network

Demand and supply power balancing is an essential method to operate power delivery system and prevent blackouts caused by power shortage. The difficulty of its implementation is the complicated architecture of both power grid and communication grid of the huge number of geographically distributed electric entities, which leads to long network delay and can destabilize the power control system when Demand Response strategy is conducted. Instead of the traditional centralized control network where long latency of data collection occurs, we proposed a new architecture of hierarchical distributed power control network which is scalable regardless of the network size. It's shown in Fig.27.

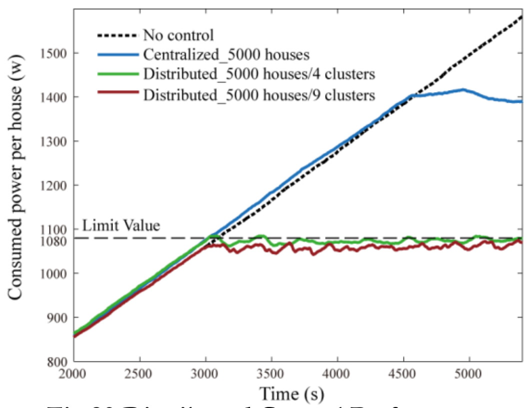


Fig.28 Distributed Control Performance

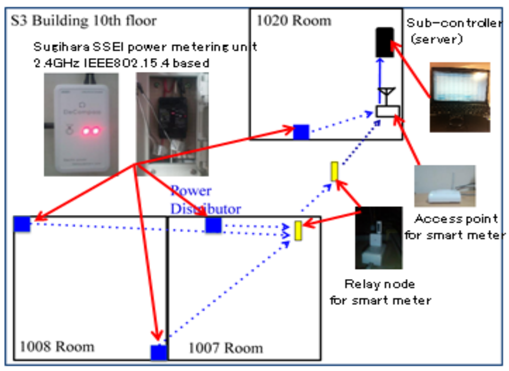


Fig.29 Distributed Control Performance

In the proposed network, the sub-controllers are introduced to divide the system into smaller distributed clusters where low-latency local feedback power control loops are conducted to guarantee local control stability. Thus the sub-controllers require only the knowledge of its cluster load instead of the load profiles of all other clusters, and can execute the power control process in parallel.

Numerical simulations in a realistic scenario of up to 5000 consumers show the effectiveness of the proposed scheme to achieve a desired 10% peak power saving under the communication delay induced from using IEEE802.15.4g standard wireless protocol. The result is shown in Fig 28. From the result, it was also shown that the proposed control network is effective for power system with distributed renewable energy sources.

In addition, a small scale power control system for green building test-bed, shown in Fig 29, is implemented to demonstrate the potential use of the proposed scheme for power saving in real life.

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 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 of the Institute of Electronics, Information, and Communication Engineers (IEICE) of Japan, and of IEEE. He received the Paper Award in 1995, 2007, and 2009, and received the award of IEICE Fellow in 2006, and the IEICE Achievement Award in adaptive space signal processing for mobile communications in 2009.

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 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, 2009, and 2012, 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 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. Assist. Prof. 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 IEICE in 2005, the Best Paper Prize from the European Wireless Technology Conference (EuWiT) in 2009, and the Paper Award from IEICE in 2012.

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, 10 Gbps super high-bit rate mobile communications, and millimeter wave. 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
    - Factor graph
    - MMSE detection avoiding noise Enhancement
  - Adaptive blind method for heterogeneous streams
  - Soft decision-directed channel estimation (SDCE)

- *MIMO-OFDM system optimization*
  - BER improvement
    - Minimum BER (MBER) precoding
  - PAPR reduction
    - Block diagonalization with selected mapping (BD-SLM)
    - Partial transmit sequence (PTS)
  - Joint BER and PAPR improvement
    - Eigenmode transmission with PAPR reduction
  - Relaying system improvement
    - Amplify-and-Forward (AF) / Decode-and-Forward (DF) switching

- *super high-bit rate mobile communications*
  - 8×16 MIMO multi-Gbps systems

Multiple Access

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

- *Access scheme*
  - IDMA with iterative detection
  - Random packet collision solution

Modulation and Demodulation for Cognitive Radio

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

Millimeter Wave 10 Gbps

- *Phase noise compensation*
- *I/Q imbalance compensation*
- *Real zero coherent detection*

In-House Simulator Design and Implementation

- *FPGA on-board system simulators*
- *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.

Iterative MAP Receiver Employing Forward Channel Estimation via Message Passing for OFDM over Fast Fading Channels [1]

In OFDM system, the optimal receiver is one based on the maximum a posteriori (MAP) criterion. An ideal receiver of this kind, however, would involve prohibitive computational complexity because it would need to perform channel estimation for all hypothetical transmitted signal sequences. To avoid such complex computation task, a suboptimal receiver utilizing the expectation-maximization (EM) algorithm shown in Fig. 1 is one of the solutions. The EM algorithm, which approximates the MAP estimation in an iterative manner, involves feasible computational complexity and has been widely used to track time-varying channels. A conventional EM-based receiver performs the channel estimation which uses the Kalman filter and employs the differential model as the process equation of the filter.

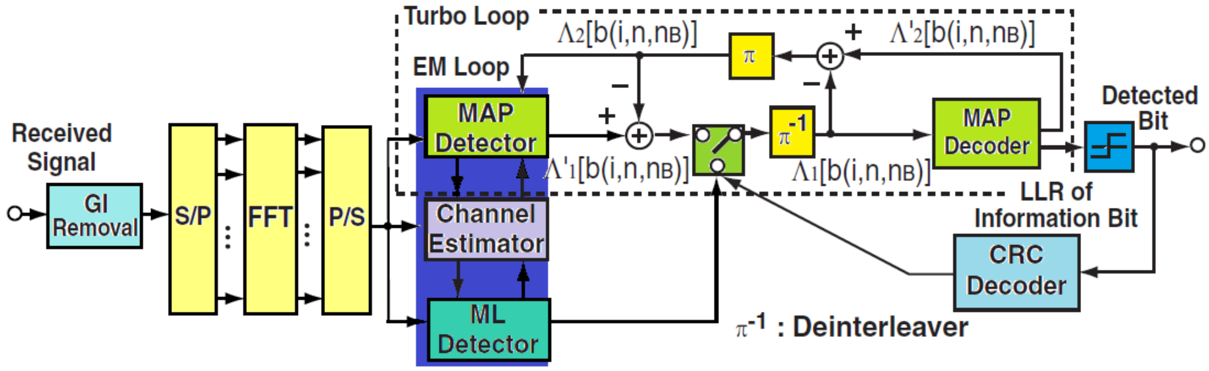


Fig. 1. Structure of a suboptimal OFDM receiver

For further improvement of the accuracy of the channel estimation, this paper proposes a new joint signal detection, channel decoding, and channel estimation using the differential model as the process equation of the Kalman filter. The joint processing employs two new message passing algorithms on factor graphs. The first proposed algorithm modifies the iterative channel estimation of the original EM algorithm by removing information on a targeted subcarrier. This method, which is referred to as the channel estimation with subcarrier removal, can avoid the repetitive use of incorrectly detected signals for the channel estimation and thus can improve the accuracy of the channel estimation. The second proposal is referred to as partial turbo processing, which performs symbol-by-symbol channel decoding, and then the soft demodulator and the MAP decoder iteratively exchange extrinsic information on the targeted symbol as the a priori probability before the processing of the next symbol. Owing to this process, the current channel estimate, which is more accurate due to the decoding gain, can be used as the initial channel estimate for the next symbol.

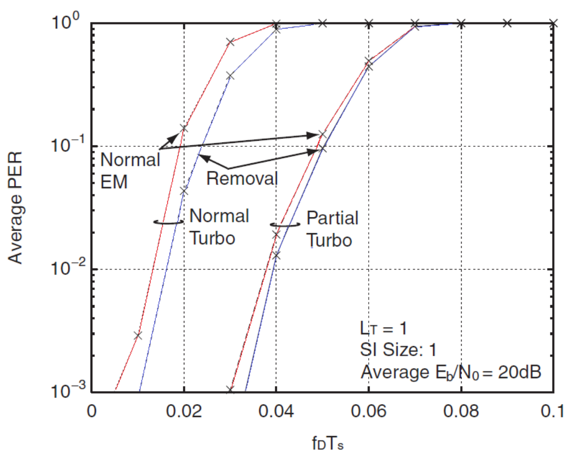


Fig. 2. PER performance versus $f_D T_S$ with $L_T = 1$

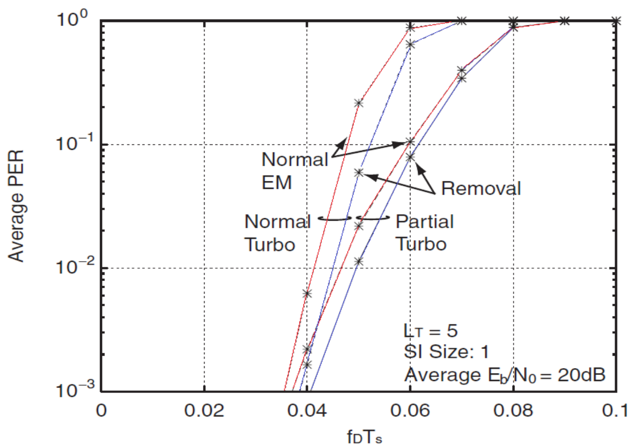


Fig. 3. PER performance versus $f_D T_S$ with $L_T = 5$

Computer simulations under 16-path Rayleigh fading channels with exponential decay have demonstrated that the proposed MAP receiver can achieve excellent PER performance. **Fig. 2** and **Fig. 3** show the average packet error rate (PER) performances versus the maximum Doppler frequency with turbo iteration (LT) = 1 and 5, respectively. In both the graphs, the average E_b/N_0 was set to 20 dB. Even with LT = 1, the combination of the subcarrier removal and the partial turbo processing can achieve PER of 1.3 x 10^{-2} with $f_D T_S$ = 4.0 x 10^{-2}, whereas the PER of the channel estimation by the original EM algorithm with conventional turbo processing is nearly equal to 1.0. Although this difference becomes small with L_T = 5, the improvement of PER by the combination of the subcarrier removal and the partial turbo processing is considerable. The combination can achieve PER of almost 1.0 x 10^{-2} with $f_D T_S$ = 5.0 x 10^{-2}, whereas the receiver employing the channel estimation by the original EM algorithm and the conventional turbo processing achieves only 2:1 x 10^{-1}.

Packet Error Rate Analysis Using Markov Models of Signal-to-Interference Ratio for Mobile Packet Systems[2]

The packet error rate (PER) is one of the most important factors to characterize packet transmissions on mobile radio channels. To evaluate the PER, link-level simulations involving upper-layer protocols have been conducted, but they require a great deal of computational time. One method for reducing the computational time is to apply Markov models that represent the link-level process.

The conventional Markov models assume flat-fading channels and focus on the SNR. In wideband cellular systems, however, frequency-selective fading should be considered. In addition, co-channel interference affects the throughput performance more severely than noise does, because the received power remains almost constant owing to wide frequency-bands and major systems such as direct spread-code division multiple access (DS-CDMA) systems are interference-limited. Thus, a packet error analysis based on the signal-to-interference ratio (SIR) over the frequency-selective fading channels is preferable to that based on SNR over the flat-fading channels.

With the aim of evaluating the PER of interference-limited packet transmission, this study theoretically derives Markov models of the time-varying SIR over frequency-selective fading channels. In the derivation, we assume only the open-loop transmit-power-control, which cannot sufficiently track the fluctuating SIR. The derived Markov models are also applicable to the ad-hoc network, where both transmitters and receivers move around (this mobility is referred to as "double mobility"). The state and state transition probabilities are obtained from both the LCR and AOD of the SIR. Further, the PER is evaluated from one of the Markov models for a finite time interval. In addition, this study provides a detailed signal model, discusses a relation between the LCR of the SIR and that of the SNR, and compares the analytical results of the PER with those obtained by computer simulations.

In the following discussions, two typical cases are considered: (i) Equal Average Power (EAP), (ii) Unequal Average Power (UAP).

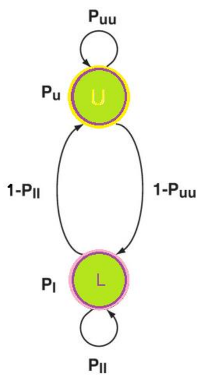


Fig. 4 Infinitesimal time-interval Markov

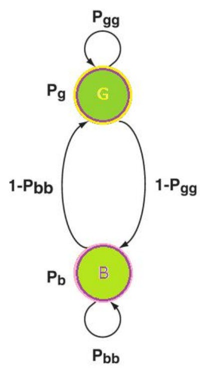


Fig. 5 Finite time-interval Markov model

Let us construct a new Markov model of the SIR for the infinitesimal period *dt*. The model is illustrated in **Fig. 4**; the propagation conditions are classified into two states. The states U and L the channel conditions for which the SIR is greater than and smaller than or equal to λ_{th} at a certain *t*, respectively. These states are observed at *kdt*, where *k* is an integer. The period *dt* is set so short that state transitions can occur at most only once during the time interval *dt*. The probabilities of these are P_u and P_l. P_{uu} and P_{ll} are the transition probabilities from State U to State U and from State L to L, respectively. The model for an infinitesimal time interval can be extended to one for a finite time interval, *T*. The Markov model is illustrated in **Fig. 5**; States G and B represent the channel conditions the SIR to remain greater than and smaller than or equal to λ_{th} during *T*, respectively. P_g and P_b are the probabilities of States G and B, respectively. P_{gg} and P_{bb} are the probabilities of the state transitions State G to State G and from State B to State B, respectively.

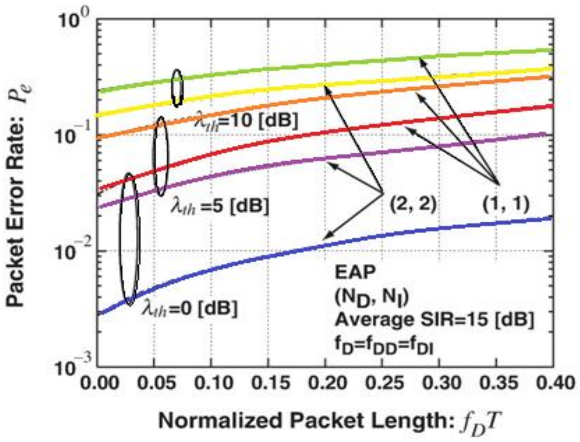


Fig. 6 Packet error rate for the EAP condition: P_e

Fig. 6 shows a plot of the PER performance versus the normalized packet length f_DT under the EAP condition, where $f_D = f_{DD} = f_{DI}$. f_{DD} and f_{DI} are the maximum Doppler frequencies of the desired and interfering signals, respectively. The average SIR is set to 15 dB and λ_{th} is specified as a parameter. As the packet length increases, the PER performance degrades owing to the fading fluctuations. However, s desired and interfering signal propagation paths, N_D and N_I, increase, the PER improves owing to the diversity effect.

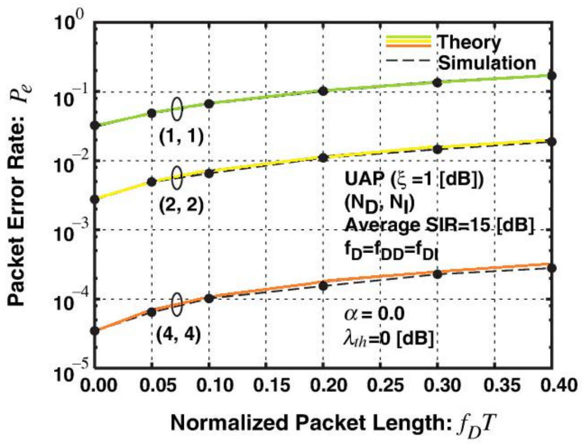


Fig. 7 Packet error rate for the cellular system (α = 0.0) under the UAP condition (ξ = 1 dB): P_e

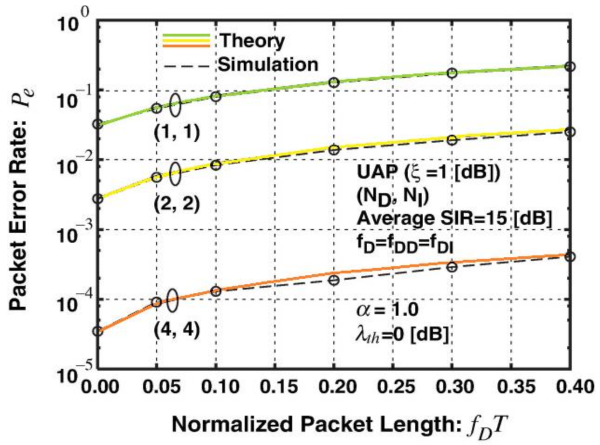


Fig. 8 Packet error rate for the ad-hoc network (α = 1.0) under the UAP condition (ξ = 1 dB): P_e

Fig. 7 and **Fig. 8** compare the theoretical PER with that obtained by computer simulations under the UAP condition for path power ratio (dB), ξ = 1 dB. This is the case where $f_D = f_{DD} = f_{DI}$, the average SIR is 15 dB, and λ_{th} is 0 dB. a = 0 in **Figs. 7**, whereas a = 1.0 in **Fig. 8**. Therefore, **Fig. 7** corresponds to cellular systems while **Fig. 8** corresponds to ad-hoc networks. The simulations assume that the propagation paths are statistically independent and follow the Rayleigh distribution. They were generated on the basis of the Jakes model. One run of the simulations investigates 100 consecutive packets and each packet is composed of 200 symbols. The SIR is evaluated at each symbol timing and compared with λ_{th}. The number of simulation runs was set to 16×10^3. When $\xi = 1$ dB, the simulation results agree with the theoretical ones very well.

60 GHz OFDM Experimental System Employing Decision-Directed Phase Noise Compensation

Wireless personal area network (WPAN) systems in 60 GHz millimeter-wave band have been extensively studied. A single-chip RF-CMOS ICs based on the silicon (Si) technology for the 60 GHz WPAN transceiver have been developed to reduce power consumption and cost. However, it is difficult to realize a frequency synthesizer with sufficiently low-level phase noise that can tune four channels of 2 GHz bandwidth in the 60 GHz band on the RF-CMOS ICs. On the other hand, it is well known that OFDM with the multi-level QAM is much sensitive to the phase noise. In order to alleviate this impairment, decision-directed phase noise compensation (DD-PNC) embedded in OFDM demodulator shown in **Fig. 9** was proposed and proven to be effective by computer simulation. In this paper, 60 GHz OFDM experimental system employing DD-PNC to baseband (BB) demodulation processing is proposed and tested to verify the practicality of the DD-PNC in real-world application.

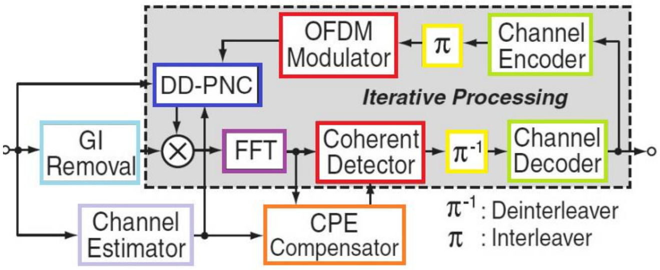


Fig. 9. OFDM demodulation employing DD-PNC

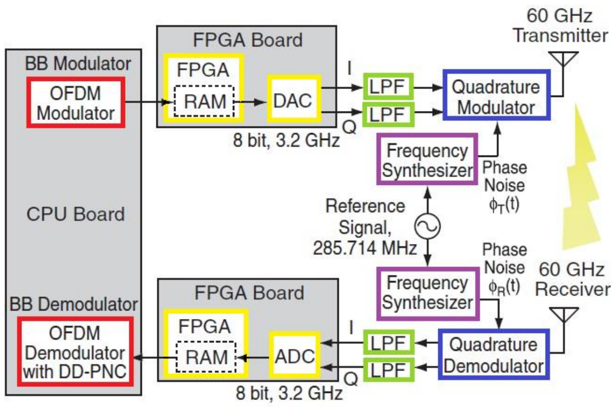


Fig. 10. 60 GHz OFDM experimental system

Fig. 10 shows the 60 GHz OFDM experimental system to evaluate the performance of DD-PNC. It consists of the BB signal processing circuit and the commercial 60 GHz single-chip VμbIQ transceiver which includes the frequency synthesizer with PLL-VCO. **Fig. 11** shows the BB circuit which is composed of a CPU board and two FPGA boards with ADC or DAC, and a compact PCI box. Two DAC chips of Maxim MAX196938 with 8-bit resolution and 3.2 GSPS (samples per second) or two ADC chips of National Semiconductor ADC083000 with 8-bit resolution and 3.2 GSPS are loaded in the FPGA board. Each FPGA board mounts two FPGA chips of Xilinx Virtex-5 LX110T.
The BB OFDM modulation and demodulation software, which are written by the floating-point C programming language, are installed in the CPU board. The transmitted packet generated on CPU is transferred and stored into the memory inside FPGA, and then DAC outputs it as inphase/quadrature (I/Q) component of the analog BB signal. Note that FPGA outputs the same signal to DAC repeatedly until the transmitted signals are updated.

The analog BB signals through low path filter (LPF) are inputted to the 60 GHz transmitter. 60 GHz radio frequency (RF) signal is transmitted from the 60 GHz transmitter to the receiver as shown in **Fig. 12**. BB received signals through LPF are sampled by ADC and are transferred into CPU via FPGA. Finally, CPU performs the OFDM demodulation processing with DD-PNC. Hence, the OFDM modulation and demodulation processing are performed in the offline mode, and their FPGA implementation is the future work.

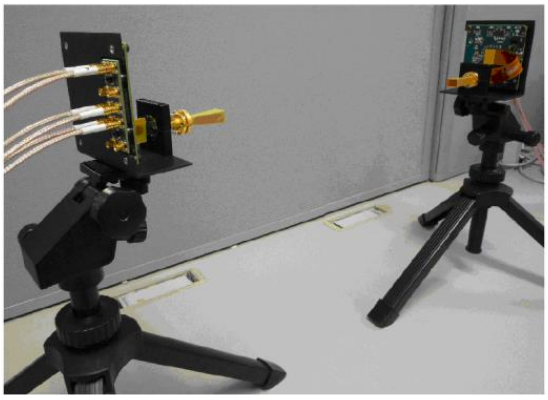


Fig. 11. BB circuit of OFDM experimental system

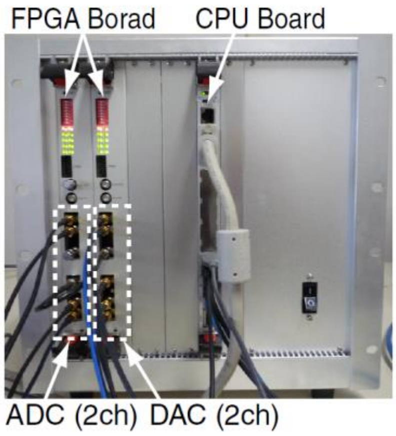


Fig. 12. 60 GHz transceiver of OFDM experimental system

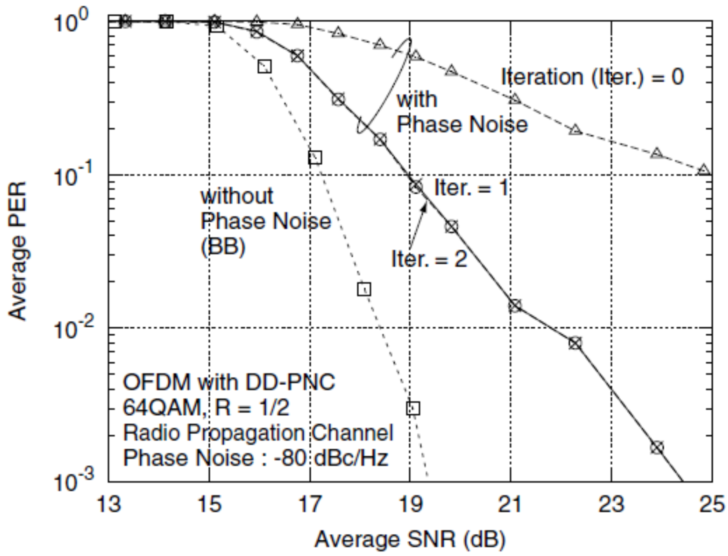


Fig. 13. Measured PER performances with OFDM/64QAM

The experimental results from the proposed experimental system which consists of both the BB signal processing circuit including ADC and DAC with 8-bit and 3.2 GSPS and the commercial 60 GHz transceiver is shown in **Fig. 13**. With 64QAM and coding rate (R) = 1/2 (2.96 Gbps), one iteration of the OFDM demodulation processing with DD-PNC can achieve packet error rate (PER) = 10^{-2} at the received SNR = 21.8 dB, even when the phase noise level is -80 dBc/Hz at 1 MHz offset.

10 Gbps 8x8 MIMO-OFDM Broadband Experimental System for 11 GHz Band Super High Bit-Rate Mobile Communications[5]

Sophisticated mobile terminals such as smartphone are rapidly growing a demand for high bit-rate transmission. For verifying the super high bit-rate mobile communications by experiments, the 5 Gbps 4x4 MIMO-OFDM experimental system has been developed , while an experimental system supporting 10 Gbps bit-rate has never existed.

SUZUKI-FUKAWA LABORATORY

This paper presents a 10 Gbps 8x8 MIMO-OFDM experimental system that consists of baseband (BB) circuits supporting the signal bandwidth of 400 MHz and 11 GHz band radio frequency (RF) circuits. The enhanced BB circuits employ newly developed 800 MHz-sampling ADC circuits and the RF circuits are expanded to eight channels. The experimental system employs a BB calibration method that compensates for different phases of clock signals provided into ADCs by using an interpolation filter and a RF calibration method that copes with IQ imbalance. Moreover, laboratory experiments are conducted to evaluate the performances of the experimental system. This paper shows that the 8x8 MIMO-OFDM experimental system can achieve 10 Gbps throughput.

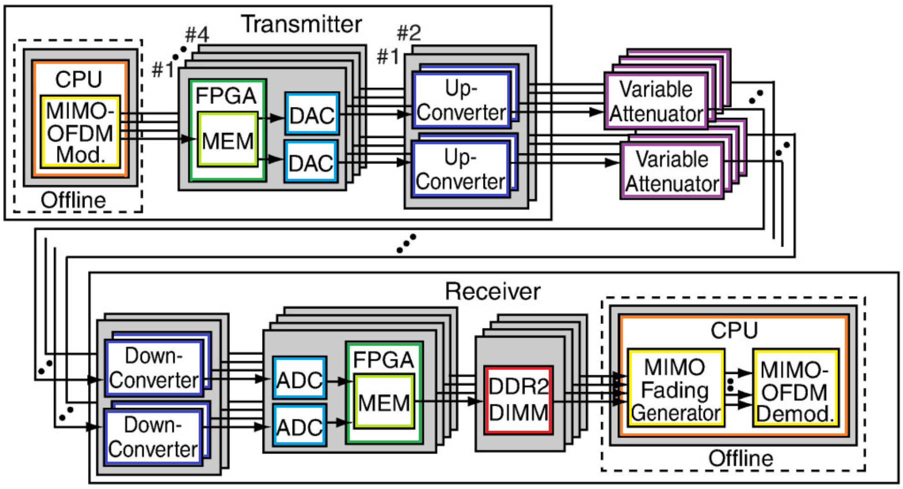


Fig. 14. 11 GHz band 8x8 MIMO-OFDM experimental system

A basic structure of the 11 GHz band 8x8 MIMO-OFDM experimental system is shown in **Fig. 14**. The MIMO-OFDM transmitter consists of a CPU board that performs the MIMO-OFDM transmission processing, FPGA boards with 800 MHz sampling DACs, and 11 GHz band transmit RF circuits. A MIMO-OFDM transmitted signal with 400 MHz bandwidth that CPU generates in the offline mode is transferred and stored into the memory (MEM) inside FPGA, and then DAC repeatedly outputs a BB signal from FPGA in real-time. The transmit RF circuits up-convert the BB signal, which is band-limited by lowpass filter (LPF), to a 11 GHz modulated signal. The modulated signal is input into receive RF circuits through the variable attenuator. The MIMO-OFDM receiver is composed of the receive RF circuits, the FPGA boards with ADCs, memory boards with DDR2 DIMM, and the CPU board. The input signal of the receive RF circuit is down-converted to the BB signal. After band-limiting it by LPF, the BB signal, which ADC samples at the sampling frequency of 800 MHz, is transferred and stored into DDR2 DIMM via MEM inside FPGA in real-time. The CPU board periodically reads the sampled BB signals from DDR2 DIMM, and performs the MIMO-OFDM reception processing in the offline mode.

Block error rate (BLER) performances were first measured by the 10 Gbps 8x8 MIMO-OFDM RF/BB experimental system. One OFDM symbol was treated as one block, and the channel coding was performed by one block unit. **Fig. 15** shows the measured BLER performances. For comparison, both simulation results and results measured by the BB experimental system are also plotted. It is shown that the RF/BB experimental system can limit SNR degradation at BLER = 10^{-2} to 0.4 dB compared to the simulation results and the BB experimental results. In addition, the turbo detection can drastically improve BLER by increasing the number of iterations, and two iterations can improve

8 dB at BLER = 10^{-2}. Next, throughput performances that are calculated from the BLER performances are examined in **Fig. 16**. They are compared with the simulation results, and the maximum number of iterations was set to four. It is found that the throughput performances converge by three iterations of the iterative processing in addition to the initial processing, and that three iterations can achieve 10 Gbps throughput at SNR = 15.9 dB even in the 11 GHz RF laboratory experiments.

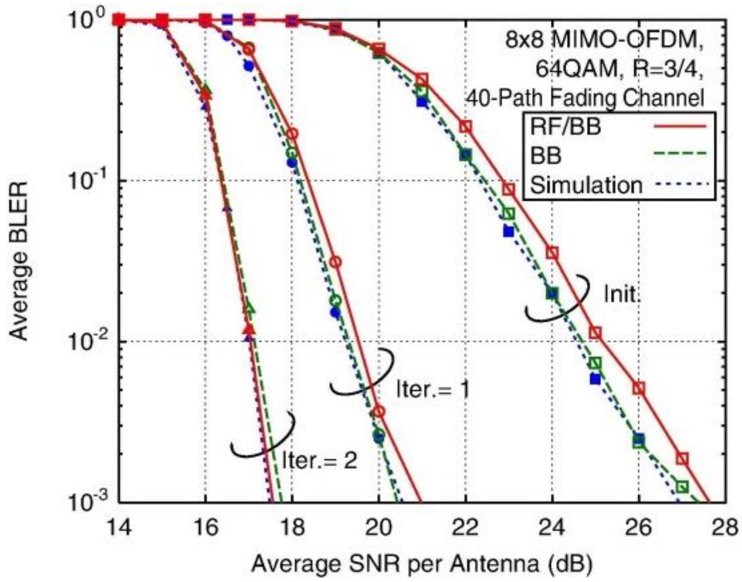


Fig. 15. Average BLER performance of 10 Gbps 8 *x* 8 MIMO-OFDM

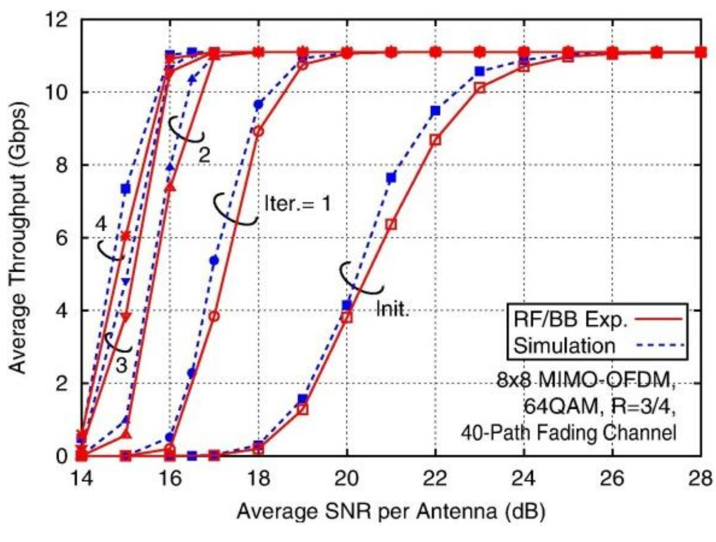


Fig. 16. Throughput performance calculated from average BLER

CONTRIBUTIONS

TAKADA LAB

Transactions and Letters

[1] Minseok Kim, Yohei Konishi, Jun-ichi Takada, and Boxin Gao, "Automatic IQ Imbalance Compensation Technique for Quadrature Modulator by Signle-Tone Testing," IEICE Transactions on Communications, vol. E95-B, no. 5, pp. 1864-1868, May. 2012.

[2] Norrarat Wattanamongkhol, Warakorn Srichavengsump, Pisit Vanichchanunt, Robithoh Annur, Jun-ichi Takada and Luncharkorn Wuttisittikulkij, "Analysis of Effect of User Misbehaviors on the Reservation-Based MAC Protocols in Wireless Communication Networks," IEICE Transactions on Communications, vol. E95-B, no. 9, pp. 2794-2806, Sept. 2012.

[3] Minseok Kim, and Jun-ichi Takada, "Characterization of Wireless On-Body Channel Under Specific Action Scenarios at Sub-GHz Bands," IEEE Transactions on Antennas and Propagation, vol. 60, no. 11, pp. 5364-5372, Nov. 2012.

[4] Minseok Kim, Jun-ichi Takada, and Yohei Konishi, "A Novel Scalable MIMO Channel Sounding Technique and Measurement Accuracy Evaluation with Transceiver Impairments," IEEE Transactions on Instrumentation and Meassurements, vol. 61, no. 12, pp. 3185-3197, Dec. 2012.

[5] Minseok Kim, Yuta Maruichi, and Jun-ichi Takada, "Parametric Method of Frequency-dependent I/Q Imbalance Compensation for Wideband Quadrature Modulator," IEEE Transactions on Microwave Theory and Techniques, vol. 61, no. 1, pp. 270-280, Jan. 2013.

[6] Katsuyuki Haneda, Afroza Khatun, Marzieh Dashti, Tommi Laitinen, Veli-Matti Kolmonen, Jun-ichi Takada, and Pertti Vainikainen, "Measurement-Based Analysis of Spatial Degrees-of-Freedom in Multipath Propagation Channels," IEEE Transactions on Antennas and Propagation, vol. 61, no. 2, pp. 890-900, Feb. 2013.

International Conferences

[7] Yousuke Naruse, and Jun-ichi Takada, "Efficient Channel Estimation Method for MIMO Antenna Selection Systems Exploiting Temporal Correlation of Channel," 75th IEEE Vehicular Technology Conference (VTC 2012-Spring), May 2012 (Yokohama, Japan).

[8] Takahiro Aoyagi, Minseok Kim, and Jun-ichi Takada, "Characterization of electrically small antenna in proximity to human body towards antenna deembedding in body area network channel modeling," COST IC1004 5th Management Committee and Scientific Meeting, TD(12)05014, Sept. 2012 (Bristol, UK).

[9] Minseok Kim, Yohei Konishi, Yuyuan Chang, and Jun-ichi Takada, "Measurement Results of Wideband Indoor MIMO Channel at 11 GHz," COST IC1004 5th Management Committee and Scientific Meeting, TD(12)05029, Sept. 2012 (Bristol, UK).

[10] Yuyuan Chang, Yohei Konishi, Minseok Kim, and Jun-ichi Takada, "Indoor Wideband 8 x 12 MIMO Channel Analysis in an Exhibition Hall with Presence of People," COST IC1004 5th Management Committee and Scientific Meeting, TD(12)05030, Sept. 2012 (Bristol, UK).

[11] Jan Jarvelainen, Katsuyuki Haneda, Mikko Kyro, Veli-Matti Kolmonen, Jun-ichi Takada, and Hiroaki Hagiwara, "60 GHz Radio Wave Propagation Prediction in a Hospital Environment Using an Accurate Room Structural Model," COST IC1004 5th Management Committee and Scientific Meeting, TD(12)05049, Sept. 2012 (Bristol, UK).

[12] Yohei Konishi, Minseok Kim, Yuyuan Chang, and Jun-ichi Takada, "Development of Versatile MIMO Channel Sounder for Double Directional and Multi-link Channel Characterizations at 11GHz," COST IC1004 5th Management Committee and Scientific Meeting, TD(12)05051, Sept. 2012 (Bristol, UK).

[13] Yew Siang Poong, Shinobu Yamaguchi and Jun-Ichi Takada, "Elucidating Initial Perceptions of Mobile Learning to Promote World Heritage Site Preservation Awareness in Luang Prabang, Lao P.D.R.," accepted for presentation in 11th International Workshop on Internationalisation of Products and Systems (IWIPS), Sept. 2012 (Bangalore, India; canceled).

[14] Hung V. Le, Jun-ichi Takada, Mir Ghoraishi, Chaymaly Phakasoum, Koshiro Kitao, and Tetsuro Imai, "Analysis of Angular Spread Characteristics of Mobile Radio Wave Dispersion through Foliage, "2012 International Symposium on Antennas and Propagation (ISAP 2012), pp. 315-318, Nov. 2012 (Nagoya, Japan).

[15] Yuyuan Chang, Yohei Konishi, Minseok Kim, and Jun-ichi Takada, "Calibration Techniques for Fully Parallel 24 X 24 MIMO Sounder," 2012 International Symposium on Antennas and Propagation (ISAP 2012), pp. 331-334, Nov. 2012 (Nagoya, Japan).

[16] Yohei Konishi, Yuyuan Chang, Minseok Kim, Yuta Maruichi, Pham Hue Van, and Jun-ichi Takada, "Multi-link Indoor MIMO Measurements at 11 GHz using Scalable Wideband Channel Sounder," 2012 International Symposium on Antennas and Propagation (ISAP 2013), pp. 335-338, Nov. 2012 (Nagoya, Japan).

[17] Jun-ichi Naganawa, Minseok Kim, and Jun-ichi Takada, "On Point Source and Observation Modeling for Path Loss Calculation Using FDTD Method," 2012 International Symposium on Antennas and Propagation (ISAP 2013), pp. 983-986, Nov. 2012 (Nagoya, Japan).

[18] Jan Jarvelainen, Katsuyuki Haneda, Mikko Kyro, Veli-Matti Kolmonen, Jun-ichi Takada, and Hiroaki Hagiwara, "60 GHz radio wave propagation prediction in a hospital environment using an accurate room structural model," 2012 Loughborough Antennas and Propagation Conference (LAPC 2012), Nov. 2012 (Loughborough, UK).

[19] Takahiro Aoyagi, Minseok Kim, and Jun-ichi Takada, "Analyses of propagation and antennas for wireless body area network channel modeling in Tokyo Tech," 2012 International Conference on Engineering, Applied Sciences, and Technology (ICEAST 2012), Nov. , 2012 (Bangkok, Thailand).

[20] Michifumi Miyashita, and Jun-ichi Takada, "Influence of Multi-rate Control Function to End-to-End Latency of Multi-hop Wireless LAN," 27th International Conference on Information Networking (ICOIN 2013), Jan. 2013 (Bangkok, Thailand).

[21] Takahiro Aoyagi, Jun-ichi Takada, and Minseok Kim, "Characterization of an Electrically Small Antenna in Proximity to Human Body by Multipole Technique," COST IC1004 6th Management Committee and Scientific Meeting, TD(13)06040, Feb. 2013 (Malaga, Spain).

[22] Katsuyuki Haneda, Afroza Khatun, Marzieh Dashti, Tommi Laitinen, Veli-Matti Kolmonen, Jun-ichi Takada, and Pertti Vainikainen, "Measurement-Based Analysis of Spatial Degrees-of-Freedom in Multipath Propagation Channels," COST IC1004 6th Management Committee and Scientific Meeting, TD(13)06056, Feb. 2013 (Malaga, Spain).

[23] Karma Wangchuk, Minseok Kim, and Jun-ichi Takada, "Cooperator Selection in 2.4GHz On-body Wireless Body Area Network,"7th International Symposium on Medical ICT (ISMICT 2013), Mar. 2013 (Tokyo, Japan).

[24] Akinori Fujie, Jun-ichi Naganawa, Minseok Kim, Takahiro Aoyagi, and Jun-ichi Takada, " Voxel Model Construction by Kinect for Propagation Channel Simulation," 7th International Symposium on Medical ICT (ISMICT 2013), Mar. 2013 (Tokyo, Japan).

Domestic Conferences

[25] Minseok Kim, Yohei Konishi, YuYuan Chang, and Jun-ichi Takada, "Development of Wideband Scalable 24x24 MIMO Channel Sounder at 11 GHz," IEICE Technical Report, vol. 112, no. 29, RCS2012-28, pp. 37-42, May 2012.

[26] Minseok Kim, Yuta Maruichi, and Jun-ichi Takada, "Frequency-dependent I/Q Imbalance Compensation for Wideband Quadrature Modulator using Sub-band Circuit Parameter Estimation," IEICE Technical Report, vol. 112, no. 55, SR2012-2, pp. 9-16, May 2012.

[27] Miao Yang, and Jun-ichi Takada, "Extrapolation of Whole Sphere Data From Incomplete Antenna Measurement," IEEE Instrumentation & Measurement Society Japan Chapter, 2nd Student Workshop, IEEE_IM-S12-01, May, 2012.

[28] Pham Hue Van, Minseok Kim, Jun-ichi Takada, "Impact of I/Q Channel Skew on Radio Channel Sounding," IEEE Instrumentation & Measurement Society Japan Chapter, 2nd Student Workshop, IEEE_IM-S12-16, May, 2012 (in Japanese).

[29] Sho Kobayashi, Minseok Kim, Jun-ichi Takada, "Developement of UWB Multichannel Radio Channel Measurement System for BAN," IEEE Instrumentation & Measurement Society Japan Chapter, 2nd Student Workshop, IEEE_IM-S12-15, May, 2012 (in Japanese).

[30] Kazuhiro Kamiyama, and Jun-ichi Takada, "Study on the Actual Condition of Pregnant Women in a Mountainous Region of Nepal through the Pregnant Women Project," JASID 13th Spring Conference, June 2012.

[31] Shotaro Yano, Seregelen Ika Sukhbaatar, Shinobu Yamaguchi, and Jun-ichi Takada, "Introduction of Scratch into Mongolian Primary Education - Case Study for 3 Provinces," JASID 13th Spring Conference, June 2012 (in Japanese).

[32] Yew Siang Poong, Shinobu Yamaguchi, and Jun-ichi Takada, "Introducing mobile learning for promoting World Heritage Site preservation awareness: Assessment of mobile usage behavior of undergraduate students in Luang Prabang," JASID 13th Spring Conference, June 2012.

[33] Tetsuro Okumura, Jun-ichi Takada, and Shinobu Yume Yamaguchi, "Development of Knowledge Management System to Promote Knowledge Transfer: Evaluating Evernote Service in the World Heritage Site of Luang Prabang, Lao PDR," JASID 13th Spring Conference, June 2012.

[34] Yanran Liu, Minseok Kim, Jun-ichi Takada, Takahiro Kishi, Junko Suzuki, and Satoshi Suzuki, "Contact-less Heartbeat Detection Method by using Microwave," IEICE Technical Committee on Medical ICT, June 2012.

[35] Jun-ichi Naganawa, Minseok Kim, Jun-ichi Takada, "Development of BAN Simulation Environment using FDTD method on multi-GPUs," IEICE Technical

Committee on Medical ICT, MICT2012-5, June 2012.

[36] Yohei Konishi, Yuyuan Chang, Minseok Kim, Yuta Maruichi, Pham Hue Van, and Jun-ichi Takada, "Multi-link Indoor MIMO Measurements at 11 GHz using Scalable Wideband Channel Sounder," IEICE Technical Report, vol. 112, no. 132, RCS2012-90, pp. 91-95, July 2012.

[37] Yuyuan Chang, Yohei Konishi, Jiyun Shen, Minseok Kim, and Jun-ichi Takada, "Analysis for Wideband 8 × 12 MIMO Indoor Measurement at 11 GHz Frequency with Presence of People," 2012 IEICE Society Conference, B-1-9, Sept. 2012.

[38] Minseok Kim, Yohei Konishi, Yuyuan Chang, and Jun-ichi Takada, "Chracterization of Wideband Indoor MIMO Channel at 11 GHz," 2012 IEICE Society Conference, B-1-10, Sept. 2012.

[39] Azril Haniz, Minseok Kim, and Jun-ichi Takada, "Proper Selection of Parameters for Spectral Correlation Density Computation," 2012 IEICE Society Conference, B-17-20, Sept. 2012.

[40] Michifumi Miyashita, and Jun-ichi Takada, "End-to-End Latency Reduction of Multi-hop Wireless LAN," IEICE Technical Committee on Reliable Robust Radio Control Workshop, Oct. 2012.

[41] Jun-ichi Naganawa, Minseok Kim, and Jun-ichi Takada, "Path Loss Simulation for Body Area Network using FDTD Method," IEICE Technical Report, MW2012-110, Utsunomiya, Oct. 2012 (in Japanese).

[42] Sho Kobayashi, Minseok Kim, and Jun-ichi Takada, "Development of measurement system for Body Area Network by UWB," IEICE Technical Report, MW2012-111, Utsunomiya, Oct. 2012 (in Japanese).

[43] Yang Miao and Jun-ichi Takada, "Antenna Pattern Reconstruction Using Spherical Waves For Spherical Antenna Measurement," IEICE Technical Report, MW2012-105, Utsunomiya, Oct. 2012.

[44] Karma Wangchu, Minseok Kim, and Jun-ichi Takada, "On-body Multilink Radio Channel Measurement for Cooperative Transmission," IEICE Technical Report, MICT2012-12, Nagoya, Oct. 2012.

[45] Orgilmaa Luvsandash, Shotaro Yano, Sergelen Sukhbaatar, Shinobu Yamaguchi, and Jun-ichi Takada, "Analysis on ICT use to Promote Student Centered Approach: Case of Scratch software program," JASID 23rd National Conference, 2-2, Dec. 2012.

[46] Jun-ichi Takada, "Research and Practice of 'International Development and Engineering' - Activities of Study Group -," JASID 23rd National Conference, 16-3, Dec. 2012 (in Japanese).

[47] Junko Onodera, Shinobu Yamaguchi, and Jun-ichi Takada, "Current Status of ICT Use in Primary Education in Mongolia - Case Study of Bayankhongor Province," JASID 23rd National Conference, 22-1, Dec. 2012 (in Japanese).

[48] Kenta Yokoi, Jun-ichi Takada, and Shinobu Yume Yamaguchi, "Application of Virtual Reality (VR) Panorama for Townscape Monitoring in the World Heritage Site of Luang Prabang," JASID 23rd National Conference, Poster-3, Dec. 2012.

[49] Yew Siang Poong, Shinobu Yamaguchi, and Jun-ichi Takada, "Promoting World Heritage Site Preservation Awareness: Gender Differences on Mobile Learning Perceptions," JASID 23rd National Conference, Poster-4, Dec. 2012.

[50] John Auxillos, Orgilmaa Luvsandash, Shinobu Yamaguchi, and Jun-ichi Takada, "ICT Use in Primary Education: The Case of the One Laptop Per Child Initiative in Mongolia," JASID 23rd National Conference, Poster-11, Dec. 2012.

[51] Yuyuan Chang, Yohei Konishi, Minseok Kim, Jiyun Shen, Yasuhiro Oda, and Jun-ichi Takada, "Analysis of Field Measurement with Wideband MIMO Sounder at 11 GHz Frequency," IEICE Technical Report, vol. 112, no. 384, AP2012-153, pp. 167-172, Jan. 2013.

[52] Munenori Matsumoto, Yuji Sugimoto, Ichiro Shigetomi, and Jun-ichi Takada, "A Method of Analysis the MIMO performance in Consideration of a Vehicle Condition," 2013 IEICE General Conference, Mar. 2013.

[53] Jun-ichi Takada, "New Trend of UWB Regulation in Japan," 2013 IEICE General Conference, Mar. 2013 (in Japanese).

[54] Jiyun Shen, Yuyuan Chang, Yasuhiro Oda, Minseok Kim, Jun-ichi Takada, "Outdoor Propagation Experiment on 24 24 MIMO at 11GHz Frequency for Super High Bit-Rate Mobile Communications," 2013 IEICE General Conference, Mar. 2013 (in Japanese).

[55] Yuyuan Chang, Minseok Kim, Jiyun Shen, Yasuhiro Oda, and Jun-ichi Takada, "Measurement Result of Microcell Environment with MIMO Sounder at 11 GHz for Super High Bit-Rate Mobile Communication Systems," 2013 IEICE General Conference, Mar. 2013.

[56] Minseok Kim, Yohei Konishi, Yuyuan Chang, and Jun-ichi Takada, "Indoor Channel Capacity of Dual-polarized 24 x 24 MIMO System at 11 GHz for Super High Bit-Rate Mobile Communication," 2013 IEICE General Conference, Mar. 2013.

[57] Jun-ichi Takada, Minseok Kim, Yuyuan Chang, Yohei Konishi, "Development of 24 × 24 Channel Sounder for for Super High Bit-Rate Mobile Communication Systems," 2013 IEICE General Conference, Mar. 2013 (in Japanese).

Articles

[58] Minseok Kim, Azril Haniz, "GNU Radio Open Source Software Defined Radio Platform," Journal of IEICE, vol. 96, no. 1, pp. 52-57, Jan. 2013 (in Japanese).

[59] Jun-ichi Takada, "Usage of TV White Space in Japan," Journal of IEICE, vol. 96, no. 2, pp. 111-116, Feb. 2013 (in Japanese).

Books

[60] Mir Ghoraishi, Jun-Ichi Takada and Tetsuro Imai, "Radio Wave Propagation Through Vegetation," in Wave Propagation / Book 2, Yi Zheng, Ed., Rijeka, Croatia: InTech, 2013, ch. 6, pp. 155-174.

ARAKI-SAKAGUCHI LAB

Transactions and Letters

[1] Kim Min Jee, Gia Khanh Tran, Kei Sakaguchi, Kiyomichi Araki , “Performance Comparison between Open Loop and Closed Loop MIMO-OFDM Schemes using Analytical Approach”, IEICE Trans. Commun., Vol. E95-B, Nov 2012

[2] N. Lertwiram, P. Popovski, K. Sakaguchi, “A Study of Trade-Off Between Opportunistic Resource Allocation and Interference Alignment in Femtocell Scenarios”, IEEE Wireless Commun. Letters, Vol. 1, No. 4, pp. 356 – 359, Aug. 2012

[3] Jaeho Jeong, G. K. Tran, K. Araki, “Optimal Low Noise Single Front-end MIMO Receiver System with Parasitic Antenna Element”, IEICE Trans. Electron. Vol. E95-C. No. 10. IEICE, Oct 2012

[4] Yohei Morishita, Noriaki SAITO, Koji Takinami, Kiyomichi Araki, “Design of a Direct Sampling Mixer with a Complex Coefficient Transfer Function”, IEICE Trans. Electron., Vol. E-95C. No. 6. pp. 999-1007, Jun 2012

[5] N. Lertwiram, G. K. Tran, K. Mizutani, K. Sakaguchi, K. Araki , “Performance Analysis of MIMO Relay Network via Propagation Measurement in L-shaped Corridor Environment”, IEICE Trans. Commun.. Vol. E95-B. No. 04, Apr 2012

[6] G. K. Tran, S. Tajima, R. Ramamonjison, K. Sakaguchi, K. Araki, S. Kaneko, N. Miyazaki, S. Konishi, Y. Kishi, “Study on Resource Optimization for Heterogeneous Networks”, IEICE Trans. Commun., Vol. E95-B, No. 04, Apr 2012

International Conference

[7] Yohei Morishita, Kiyomichi Araki , “Nonlinear Analysis of MOS FET Passive Mixers as a Function of Local Signal”, APMC2012, Dec. 2012

[8] Daisuke Matsuo, Roya Rezagah, Gia Khanh Tran, Kei Sakaguchi, Kiyomichi Araki, Shoji KANEKO, Noriaki Miyazaki, Satoshi Konishi, Yoji KISHI, “Shared Remote Radio Head Architecture to Realize Semi-Dynamic Clustering in CoMP Cellular Networks”, IEEE GLOBECOM 2012 Workshop on Multicell Cooperation, Dec 3, 2012

[9] Kei Sakaguchi, “Enabling technologies for green by wireless – smart grid & battery-less sensor networks,” Advanced Wireless Communications Workshop, I2R & IEEE VTS Singapore Chapter, Nov. 21, 2012.

[10] Kentaro Sano, Gia Khanh Tran, Masahiro Watanabe, Kei Sakaguchi, Kiyomichi Araki, Daisuke Hayashi, Toshihiro Yamaguchi, Shintaro Arata , “Multi-sensor Location Estimation for Illegal Cell-phone Use in Real-Life Indoor Environment”, IEEE ICCS 2012, Nov 21, 2012

[11] Gia Khanh Tran, Kei Obara, Alden Ho, Kiyomichi Araki , “Theoretical analysis of ICI reduction methods due to phase noise and frequency offset in OFDM systems”, IEEE ICCS 2012, Nov 21, 2012

[12] Kei Sakaguchi, “[Keynote speech] Basestation cooperation (CoMP) is ready for standardization & deployment,” URSI ISSSE 2012, Potsdam, Germany, Oct. 4th, 2012.

[13] Daiki Maehara, G. K. Tran, K. Sakaguchi, K. Araki, T. Miyamoto, M. Furukawa, “Experimental Study on Multi-point Wireless Energy Transmission at 950MHz Band”, IEEE ISSSE 2012, Oct 3, 2012

[14] Hidekazu Shimodaira, Gia Khanh Tran, Tajima Shinichi, Kei Sakaguchi, Kiyomichi Araki, Noriaki Miyazaki, Shoji KANEKO, Satoshi Konishi, Yoji KISHI , “Optimization of Picocell Locations and Its Parameters in Heterogeneous Networks with Hotspots”, IEEE PIMRC2012, Sep 9, 2012

[15] Vutha Va, Keiichi Mizutani, Yutaro Kida, Kei Sakaguchi, Kiyomichi Araki, and Takehiro Miyamoto, “Experiment on MIMO Two-Way Relaying using Transmit Beamforming”, in Proceeding of IEEE PIMRC 2012, pp. 719-724, Sep. 2012

[16] Kei Sakaguchi, Ky Nguyen, Daiki Maehara, Gia Khanh Tran, Kiyomichi Araki, “Design of distributed power control networks to realize smart grid,” IEEE VTS APWCS 2012, Kyoto, Japan, Aug. 23th, 2012.

[17] Ikuma Ando, Gia Tran Khanh, Kiyomichi Araki, Takayuki Yamada, Yo Yamaguchi, Takana Kaho, "Design of Multi-band Predistorter and Modeling for Multi-band Power Amplifier", 2012 Thailand-Japan MicroWave (TJMW2012), Aug 2012

[18] Ikuma Ando, Yuyuan Chang, Kei Sakaguchi, Kiyomichi Araki , "Theoretical Analysis and Improvement of User Scheduling for MU-MIMO System Employing Block Diagonalization", 2012 Asia Pacific Wireless Communications Symposium (APWCS 2012), Aug 24, 2012

[19] Kei Sakaguchi "Indoor Wireless Grid to enable Battery-less Sensor Networks" Wireless Technology Park (WTP), July, 5th, 2012.

[20] Rindranirina Ramamonjison, Gia Khanh Tran, Kei Sakaguchi, Kiyomichi Araki , "Distributed Optimization of Transceiver Weights in MIMO Two-way Multihop Networks", IEEE VTC2012-Spring, May 2012

[21] Yutaro Kida, Keiichi Mizutani, Gia Khanh Tran, Takehiro Miyamoto, Kei Sakaguchi, Kiyomichi Araki , "Network synchronization scheme for scalable two-way multi-hop network employing MIMO network coding", IEEE VTC2012-Spring, May 2012

[22] N. Lertwiram, G. K. Tran, K. Sakaguchi, K. Araki, "Relay Placement of Two-Way Multi-Hop Relay Network with Power Adaptation in a Realistic Shadowing Environment", IEEE VTC2012-Spring, May 2012

Domestic Conferences

[23] Ikuma Ando, Gia Khanh Tran, Kiyomich Araki, Takayuki Yamda, Takana Kaho, Yo Yamaguchi, "Modeling for Wideband Power Amplifier on simultaneously Amplifying Single Carrier signals for User-centric Wireless Networks", IEICE General Conference, Proc. of IEICE General Conference, Mar. 2013.

[24] Hisashi Sakakibara, Gia Khanh Tran, Kiyomichi Araki, "Received power maximization problem under a given transmission system", IEICE General Conferences, B-1-9, Mar, 2013

[25] Yinpei Miao, Gia Khanh Tran, Kiyomichi Araki, "MIMO receivers with parasitic antenna," Proc. of IEICE General Conference, B-1-214, Mar, 2013

[26] Ryosuke Iwata, Va Vutha, Kei Sakaguchi, Kiyomichi Araki, "Prototype for MIMO Cognitive Radio with Transmit/Receive Beamforming", IEICE General Conference, Mar. 2013

[27] Kohei Matsumoto, Gia Khanh Tran, Kiyomichi Araki, "Simplified Method of Average Packet Error Rate Calculation in Fading Environment", IEICE General Conference, Gifu University, Gifu, Mar. 2013

[28] Keisuke Hirota, Gia Khanh Tran, Kiyomichi Araki, "Packet Error Rate Analysis of Body Area Networks", IEICE General Conference, Mar. 2013

[29] Jaeho Jeong, Gia Khanh Tran and Kiyomichi Araki, "A study of matching circuit on a lossy condition for compact symmetrical MIMO receiver," Proc. of IEICE General Conference, B-1-207, Mar, 2013

[30] T. Yamada, I. Ando, G. K. Tran, K. Araki, K. Kaho, Y. Yamaguchi, K. Uehara, "Performance Evaluation of Digital Predistortion for Simultaneously Amplifying Two Single Carrier Signals on Dual-band in User-centric Wireless Network," IEICE General Conference, Mar. 2013.

[31] K. Yasui, D. Matsuo, K. Sakaguchi, S. Sampei, "Inter Cluster Interfere Cancellation Systems with using Shared RRH in Cooperative Base Station Systems," Proc. Of IEICE General Conference, B-5-62, Mar, 2013

[32] Y. Kuki, N. V. Ky, Y. TAO, K. Sakaguchi, S. Sampei, "Proposal of Control Layer for realizing Distributed Control Networks," Proc. Of IEICE General Conference, AS3-2, Mar, 2013

[33] R. Akai, K. Sakaguchi, S. Sampei, D. Maehara, "Prototype of Battery-less Sensor Network Drived by Wireless Energy Transmission," Proc. Of IEICE General Conference, B-17-26, Mar, 2013

[34] T. Ishihara, D. Sugimura, K. Sakaguchi, S. Sampei, "Optimal Base Station Antenna Design for Robust Multi User-MIMO Systems," Proc. Of IEICE General Conference, B-5-9, Mar, 2013

[35] Hidekazu Shimodaira, Gia Khanh Tran, Kei Sakaguchi, Kiyomichi Araki, Satoshi Konishi, Noriaki Miyazaki, "Diamond Cellular Network -- Combination of Small Power Basestations and CoMP Cellular Networks", IEICE Technical Report, Feb 27, 2013.

[36] Roya Rezagah, Daisuke Matsuo, Gia Khanh Tran, Kei Sakaguchi, Kiyomichi Araki, Satoshi Konishi, Noriaki Miyazaki , "Large Scale Cooperation in Cellular Networks with Non-uniform User Distribution", IEICE Technical Report, Feb 27, 2013.

[37] Thitapha Chanpokapaiboon, Takayuki Inoue, and Kiyomichi Araki, "Inter carrier interference reduction of OFDM system with a novel self-cancellation scheme", IEICE Technical Report, Feb 27, 2013

[38] Van Ky Nguyen, Yusuke Kuki, Tao Yu, Gia Khanh Tran, Kiyomichi Araki, Kei Sakaguchi, Seiichi Sampei, Demonstration of micro-smartgrid for peak power control, RRRC2012, Jan 11, 2013.

[39] Takayuki Inoue, Kei Obara, Gia Khanh Tran, Kiyomichi Araki, Oscillator phase noise incurred ICI analysis and its reduction method for OFDM system at

millimeter wave, RCS, Jan 31, 2013

[40] Hisashi Sakakibara, Khanh Tran Gia, Kiyomichi Araki , "Transmission power optimization problem", WPT, Dec 2012

[41] Kei Sakaguchi, "[Requested Talk] Optimal antenna configuration for multi-user MIMO to be robust against channel variation," IEICE Technical Report, AP2012-99, RCS2012-166, Nov. 15, 2012.

[42] Van Ky Nguyen, Yusuke Kuki, Tao Yu, Gia Khanh Tran, Kiyomichi Araki, Kei Sakaguchi, Seiichi Sampei , "Distributed Power Control Network Utilizing Home-gateway", RRRC2012, Oct 2012

[43] Ikuma Ando, Gia Khanh Tran, Kiyomichi Araki, Takayuki Yamada, Takana Kaho, Yo Yamaguchi , "Analysis of OFDM signals on simultaneously amplifying multi-band signals", IEICE Society Conference 2012, Sep 12, 2012

[44] Jaeho Jeong, Gia Khanh Tran, Kiyomichi Araki , "A design of self noise matching circuit for compact MIMO system", IEICE Technical Report. 2012-09-MW, Sep 27, 2012

[45] Ikuma Ando, Gia Khanh Tran, Kiyomichi Araki, Takayuki Yamada, Takana Kaho(Saito), Yo Yamaguchi, Evaluation of a predistorter for OFDM signals on simultaneously transmitting multi-band signals, IEICE Technical Report. 2012-09-MW, Sep 27, 2012

[46] Kei Sakaguchi, "[Panel] We can change from our technical committee of SR," IEICE Technical Report, SR2012-25, Jul. 26th, 2012.

[47] Namzilp Lertwiram, Gia Khanh Tran, Kei Sakaguchi, Kiyomichi Araki , "Practical Relay Node Placement for MIMO Two-way Relay Networks in a U-Shaped Corridor Environment", IEICE Technical Report. 2012-07-SR, Jul 27, 2012

[48] Hidekazu Shimodaira, Gia Khanh Tran, Kei Sakaguchi, Kiyomichi Araki, Noriaki Miyazaki, Shoji KANEKO, Satoshi Konishi, Yoji KISHI , "Optimal Picocell Deployment in Heterogeneous Networks with Hotspots", IEICE Technical Report. 2012-07-SR, Jul 27, 2012

[49] Takayuki Yamada, Ikuma Ando, Gia Khanh Tran, Kiyomichi Araki, Takana Kaho(Saito), Yo Yamaguchi, Kazunori Akabane, Kazuhiro Uehara , "A Study on a Digital Predistortion for Multi-Band Multi-Signal Transmission of Flexible Wireless System", IEICE Technical Report. 2012-07-SR, Jul 27, 2012

[50] Ikuma Ando, Gia Khanh Tran, Kei Sakaguchi, Kiyomichi Araki, "User scheduling in MU-MIMO system considering codebook design and interference among users", RCS2012, May 18, 2012

[51] Van Ky Nguyen, Daiki Maehara, Namzilp Lertwiram, Gia Khanh Tran, Kei Sakaguchi, Kiyomichi Araki , "Hardware Demonstration on Distributed Electric Power Control Network", IEICE Technical Report. SR2012, May 2012

[52] Kei Sakaguchi, "[Requested Talk],Green wireless -Supply & control of energy via wireless communications -" IEICE Technical Report, Apr. 19th, 2012.

[53] Doppo Sugimura, Maki Arai, Kei Sakaguchi, Kiyomichi Araki, Takayuki Sotoyama, Masayuki Hoshino, "Optimization of Base Station Antenna Directivity for Base Station Cooperation Cellular Systems", RCS2012-20, Apr 2012

[54] Therdkiat Aphichartsuphapkhajorn, Yuyuan Chang and Kiyomichi Araki, "User Scheduling Algorithm with User grouping for Multi-user MIMO Downlink System utilizing Block Diagonalization," IEICE Technical Report. 2012-12-NS, Feb 24th. 2012

SUZUKI-FUKAWA LAB

Transactions and Letters

[1] K. Muraoka, K. Fukawa, H. Suzuki, and S. Suyama, "Iterative MAP receiver employing forward channel estimation via message passing for OFDM over fast fading channels," IEICE Trans. on Communi., vol.E95-B, no.5, pp.1770-1783, May 2012.

[2] K. Fukawa, H. Suzuki, and Y. Tateishi, "Packet-error-rate analysis using Markov models of signal-to-interference ratio for mobile packet systems," IEEE Trans. on Vehic. Technol., vol. 61, no. 6, pp. 2517-2530, July 2012.

International Conference

[3] S. Suyama, H. Fukuda, H. Suzuki, and K. Fukawa, "11 GHz band 4 x 4 MIMO-OFDM broadband experimental system for 5 Gbps super high bit-rate mobile communications," IEEE 75th Vehic. Tech. Conf. in Yokohama, Japan, pp.1-5, May 2012.

[4] K. Muraoka, K. Fukawa, H. Suzuki, and S. Suyama, "Iterative MAP channel estimation based on factor graph for OFDM mobile communications," IEEE 75th Vehic. Tech. Conf. in Yokohama, Japan, pp.1-5, May 2012.

[5] S. Suyama, H. Fukuda, H. Suzuki, and K. Fukawa, "10 Gbps 8x8 MIMO-OFDM broadband experimental system for 11 GHz band super high bit-rate mobile communications," Inter. OFDM-Workshop 2012, pp. 115-120, Aug. 2012.

Domestic Conference

[6] T. Tandai, H. Suzuki, K. Fukawa, and S. Suyama, "Hybrid backoff retransmission control in slotted non-persistent CSMA," IEICE Technical Report, RCS2012-34，May 2012.

[7] M. Harada, K. Fukawa, H. Suzuki, and S. Suyama, "MMSE precoding using the second-order statistics of channels for multiuser MIMO communications," IEICE Technical Report, RCS2012-38, May 2012.

[8] M. Harada, K. Fukawa, H. Suzuki, and S. Suyama, "channel block diagonalization using the second-order statistics of multiuser MIMO communication channels," IEICE Technical Report, RCS2012-39, May 2012.

[9] S. Suyama, H. Fukuda, H. Suzuki, and K. Fukawa, "10 Gbps 8x8 MIMO-OFDM RF/BB experimental system for super high bit-rate mobile communications," IEICE Technical Report, RCS2012-40, May 2012.

[10] S. Suyama, H. Fukuda, H. Suzuki, and K. Fukawa, "8x8 MIMO-OFDM experimental system employing software defined radio architecture for super high bit-rate mobile communications," IEICE Technical Report, SR2012-7, May 2012.

[11] D. Shin, S. Suyama, H. Suzuki, and K. Fukawa, "10 Gbps millimeter-wave OFDM experimental system with decision-directed phase noise compensation and its performances," RCS2012-62，June 2012.

[12] H. Suzuki, " Modulation and demodulation techniques for realizing 10 Gbit/s mobile communication systems," Wireless Technology Park 2012 E, July 2012.

[13] S. Suyama, H. Fukuda, H. Suzuki, and K. Fukawa, "11 GHz band 10 Gbps 8x8 MIMO-OFDM experimental system for super high bit-rate mobile communications," IEICE Society Conf., B-5-29，Sep. 2012.

[14] M. Takahashi, S. Suyama, H. Suzuki, and K. Fukawa, "FPGA design of 10 Gbps 8x8 MIMO-OFDM transmission processing for super high bit-rate mobile communications," IEICE Society Conf., B-5-30，Sep. 2012.

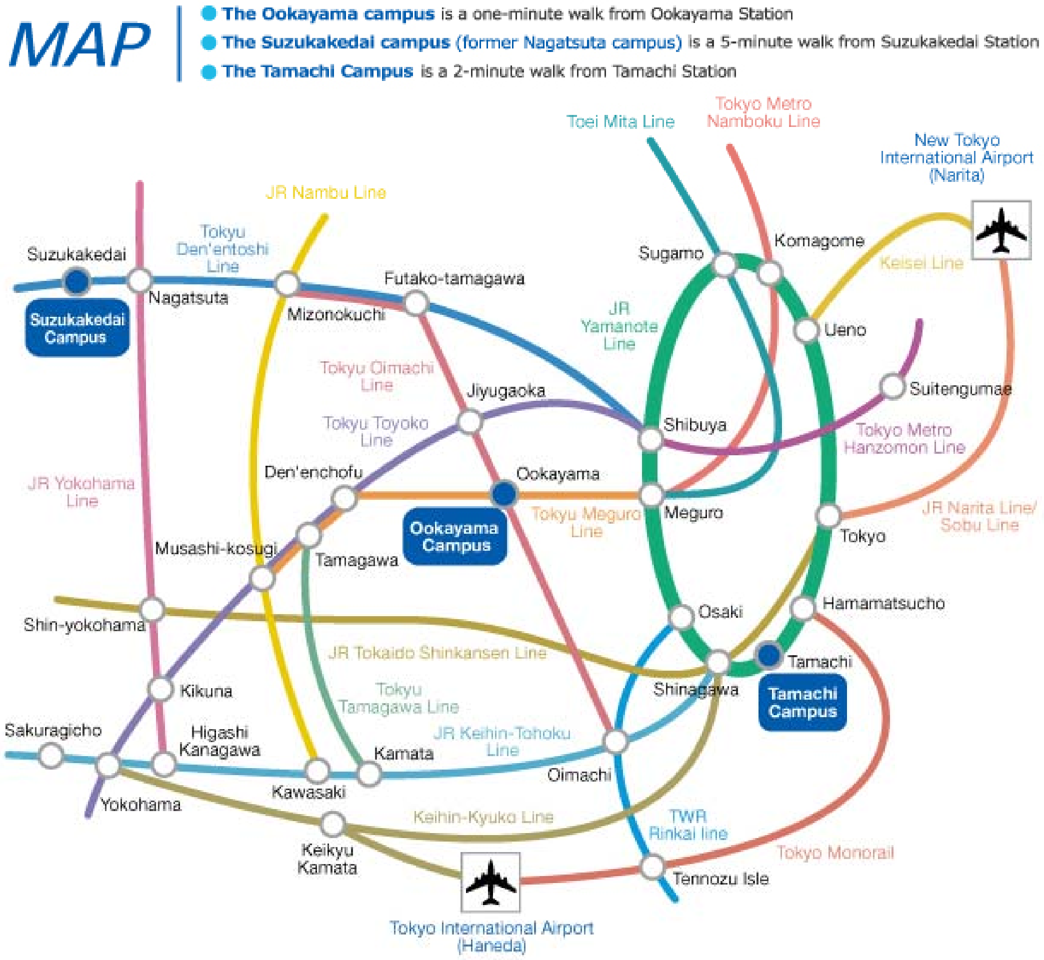
[15] H. Ichihara, S. Suyama, H. Suzuki, and K. Fukawa, "FPGA design of simplified turbo detector for super high bit-rate mobile communications," IEICE Society Conf., B-5-31，Sep. 2012.

[16] M. Harada, K. Fukawa, H. Suzuki, and S. Suyama, "MMSE precoding to avoid feedback of CSI for multiuser MIMO communications," IEICE Society Conf., B-5-50，Sep. 2012.

[17] M. Harada, K. Fukawa, H. Suzuki, and S. Suyama, "Approximate channel block diagonalization avoiding feedback of CSI for multiuser MIMO communications," IEICE Society Conf., B-5-51，Sep. 2012.

[18] D. Shin, S. Suyama, H. Suzuki, and K. Fukawa, "Millimeter-wave 60 GHz band 10 Gbps OFDM experimental system with decision-directed phase noise compensation," IEICE Society Conf., B-5-96，Sep. 2012.

Access information



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

Editorial Committee
Karma Wangchuk (Takada Lab.)
Roya Rezagah (Araki-Sakaguchi Lab.)
Supakiat Pattichart, Micheal Andri Wijaya (Suzuki-Fukawa Lab.)

Tokyo Institute of Technology http://www.titech.ac.jp
Mobile Communications Research Group http://www.mcrg.ee.titech.ac.jp/index.html
2-12-1 Ookayama, Meguro-ku, Tokyo 152-8550, JAPAN