Mobile Communications Research Group
Tokyo Institute of Technology

2015
ANNUAL REPORT

TOKYO INSTITUTE OF TECHNOLOGY

Contents

TOKYO INSTITUTE OF TECHNOLOGY

Overview

Tokyo Tech is the top national university for science and technology in Japan with a history spanning more than 130 years. The Institute has 3 schools with 23 departments, 6 graduate schools with 45 departments, and many research institutes spread over its Ookayama, Suzukakedai and Tamachi Campuses. Of the approximately 10,000 students, half of them are undergraduates and the other half are graduate students. International students number 1,200. There are 1,200 faculty and 600 administrative staff members. In the 21st century, the role of sci-tech universities has become increasingly important. Tokyo Tech continues to cultivate global leaders in the fields of science and technology and contributes to the betterment of society through its research focusing on solutions to global issues. The Institute's long-term goal is to become the world's leading sci-tech university.

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 2014-2015, http://www.titech.ac.jp)

Main building

Institute library

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. Propagation and Antenna Laboratory
(Prof. Jun-ichi Takada)
2. System Laboratory
(Associate Prof. Kei Sakaguchi, Assistant Prof. Gia Khanh Tran and Emeritus Prof. Kiyomichi Araki)
3. Signal Processing Laboratory
(Prof. Kazuhiko Fukawa)

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 2015

Takada Laboratory (http://www.ap.ide.titech.ac.jp)

Professor Jun-ichi Takada

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 currently belongs to the Department of International Development Engineering, Graduate School of Science and Engineering. 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, and information technology for regional/rural development. He is fellow of IEICE, senior member of IEEE, and member of Japan Society for International Development (JASID).

Assistant Professor Kentaro Saito

Assistant Professor Kentaro Saito was born in Kanagawa, Japan, in 1977. He received his B.E., M.E., and D.E. degrees from The University of Tokyo, Japan, in 2000, 2002 and 2008, respectively. He joined NTT DOCOMO, Kanagawa, Japan, in 2002. Since then, he has been engaged in the research and development of mobile communication systems, and the radio propagation. He joined Tokyo Institute of Technology, Japan in 2015. Since then, he has been engaged in the research of radio propagation for mobile communication systems. Dr. Saito is a Member of IEICE and IEEE.

Recent Research Topics

- MIMO Channel Studies for Microwave (11GHz)
  - MIMO Channel Parameter Estimation for Dense Multipath Component
  - Geometry-based Clustering Method from an Indoor Measurement
  - Channel Parameter Estimation, Channel Capacity Characteristics
- Channel Sounding for Future Heterogeneous Network: for Millimeter wave (60GHz)
- Diffuse Scattering Simulation from Rough Surfaces for Millimeter wave
- Hybrid T-Matrix Modeling of Electromagnetic Scattering from Foliage Structures
- Development of Simultaneous Measurement System for Dynamic WBAN Channel
- Space-Time Coding On Polarized Line-Of-Sight MIMO Transmission Channels
- Development of Directional Channel Sounder using USRP and GNU Radio
- Development of Channel Sounder Prototype for Distributed Wireless Networks.
- Fingerprint-based Localization of Unknown Emitters in Dense Urban Environments
- Public Broadband Mobile Communication System
- Wide Frequency Band Analysis of Multilayer Planar Electromagnetic Wave Absorber

Microwave (11GHz) MIMO Channel Study

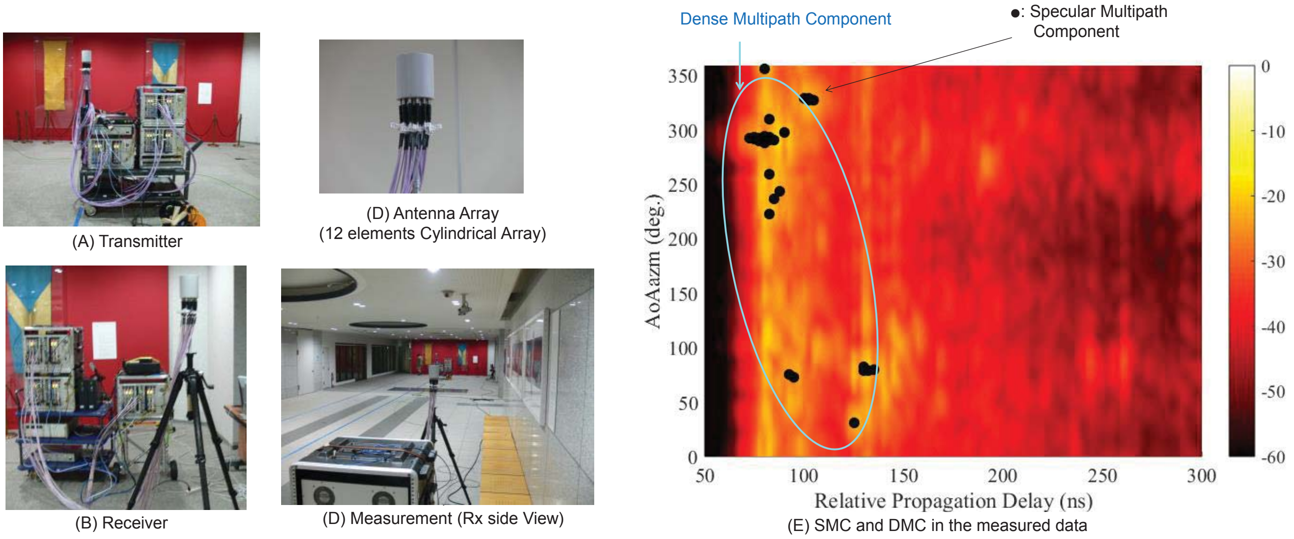
(The project was funded by Ministry of Internet Affiars and Communications in FY2009-2012.)

Overview

The demand for the data traffic in future mobile services has been increasing exponentially, and exploring new frequency bands above 5 GHz is an inevitable choice to accommodate such demand. However, the radio propagation channels properties at higher frequency bands have not been sufficiently justified from the view point of the requirements for current mobile data transmission. This work aims at the fundamental studies of radio propagation properties of 11 GHz with bandwidth of 400 MHz. We have developed a 24×24 multiple-input and multiple-output(MIMO) channel sounder system to exploit new frequency bands. The comprehensive indoor and outdoor environments have been conducted in 2012. Currently, the analysis and the modelling of double-directional properties of MIMO channel, the clarification of the radio propagation mechanism, the propagation parameter estimation method, and the eigen-structure of the channel are investigated ongoingly.

MIMO Channel Parameter Estimation

In the higher frequency bands, in addition to the higher propagation loss, the contribution of the diffuse scattering to the radio propagation becomes more significantly. The diffuse scattering is the irregular scattering from rough surfaces of floors, walls, ceilings, and pillars as well as the small structural object like furniture. Since it is known that the Multiple-Input Multiple-Output (MIMO) transmission performance is affected by the diffuse scattering, the clarification of the mechanism and the characteristics of diffuse scattering will be the important issue to design the new MIMO transmission scheme for the next-generation mobile communication system. In this research, the characteristics of diffuse scattering component were investigated in 11 GHz band. Dense Multipath Component (DMC) parameters of the diffuse scatter were estimated from measured data by using RiMAX algorithm. In the measurements, a strong DMC was observed due to the diffuse scattering from the floor and the ceiling. The result also showed that the DMC had the directional and the polarization dependencies, which were different from RiMAX DMC model. The measurement results will be utilized for the construction of the higher frequency band MIMO Channel Model.



(A) Transmitter

(D) Antenna Array (12 elements Cylindrical Array)

(B) Receiver

(D) Measurement (Rx side View)

(E) SMC and DMC in the measured data

Fig. 1. The Channel sounder overview and the power spectrum of measured data

Takada Labratory

Development of Geometry-based Clustering of the Double-Directional Wideband Multipaths from an Indoor Measurement [1],[2]

This work proposes the novel geometry-based clustering approach by utilizing the scattering points (SPs) as the input into a power weighted K-means clustering algorithm. The SPs are obtained by the measurement-based ray tracer which can estimate the single bounce and double bounce paths separately. In the conventional method, clustering is based on the similarity between multipath delays and angles which might create clustering results not corresponding to the interacting objects (IO) and thus not accurate. The proposed approach aims to solve this problem. In this method, single bounce and double bounce multipaths are clustered separately. Figure 5 shows the clustering results of single and double bounce multipaths and median eigen value comparison of the channel obtained from the proposed and conventional clustering and channel obtained from original estimated paths (measured). The results show that clusters are grouped based on IO and the eigen values from the proposed method is closer to the measured results indicating that it is more accurate than the conventional approach.

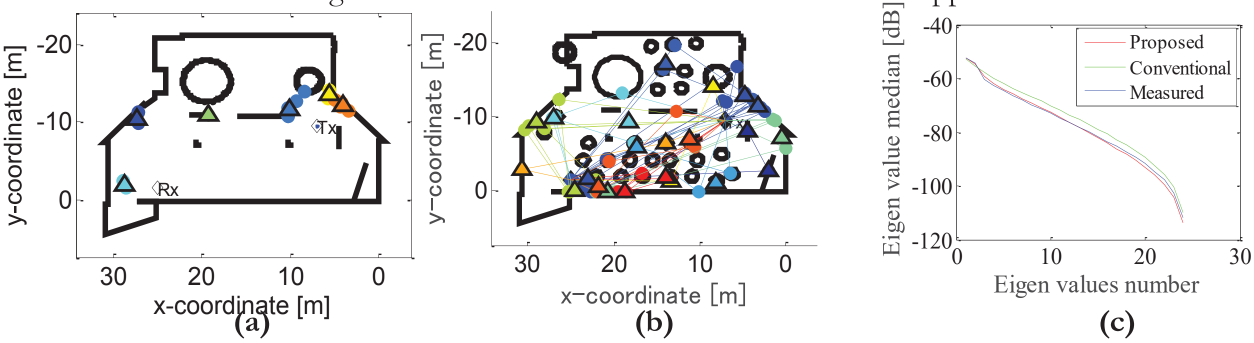
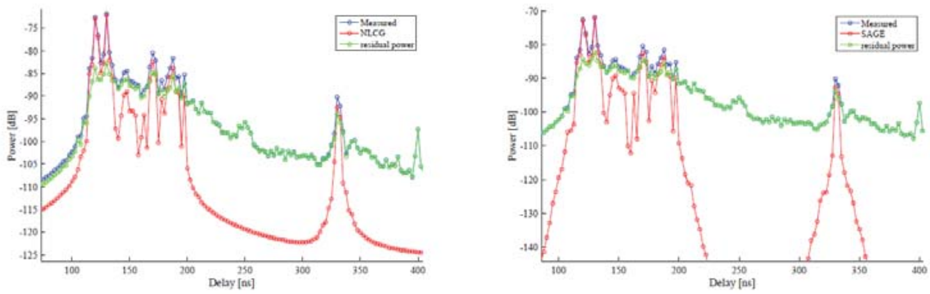


Fig. 1. Results ((a) single bounce clustering, (b) double bounce clustering, (c) eigen value)

NLCG-Based Estimation of Radio Channel Parameter

MIMO transmission is a powerful technique to improve the quality of wireless link transmission. Under this background, Takada lab is focusing on performance of 11GHz based MIMO transmission. To evaluate the performance accurately, MIMO channel model is required. Propagation parameters of channels need to be estimated when we attend to build such a channel model. However, conventional estimation method EM-SAGE is limited by resolution and huge computation. This work is to apply Non Linear Conjugate Gradient based algorithm in parameter estimation in order to improve the accuracy and convergence speed. Super-high accuracy parameters estimation algorithm will help us having better understanding of relationship between propagation environment and physical waves.



(a) Mesured DPS by NLCG (b) Mesured DPS by SAGE

Fig. 1. Measured data-based comparison of EM-SAGE and NLCG

Initial parameter setting in the propagation estimation based on EM/SAGE algorithm (Miyake)

SAGE algorithm is one of the propagation parameter estimation method from the MIMO channel measurement data. This algorithm is iterative algorithm which is known that the accuracy heavily depends on the initial parameters. Successive Interference Cancellation (SIC) parameter estimation is one of the initial parameters estimation methods. This algorithm, however, has searching problem and can't estimate the l-th path propagation parameter accurately when the l-th path propagation parameter differs greatly from (l-1)-th path propagation parameter. To solve the problem, in this paper, we proposed the SIMO-based initial parameter estimation method. In our proposal, MIMO channel matrix is decomposed into the set of SIMO channel matrices. Since SIMO channel matrices don't have Tx-side information, the dimension of parameter estimation problem is reduced from 5 to 3. The estimated SIMO parameters are then used as input to the correlation function. Then the remaining two parameters of correlation function are estimated. The figures show the subtraction result of estimated signal of simulation of conventional and proposed method. The simulation data is generated on the condition that SNR is 0 dB and the number of propagation path is 10.

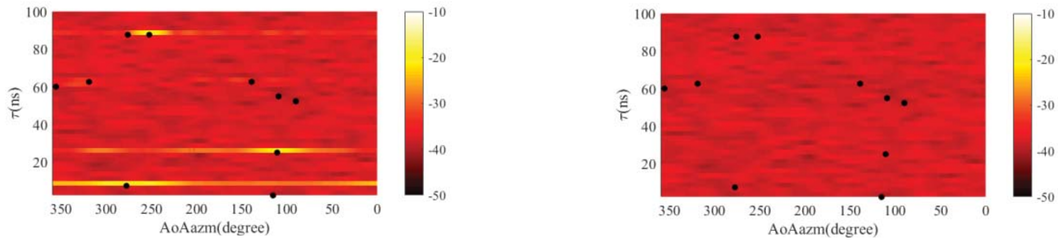
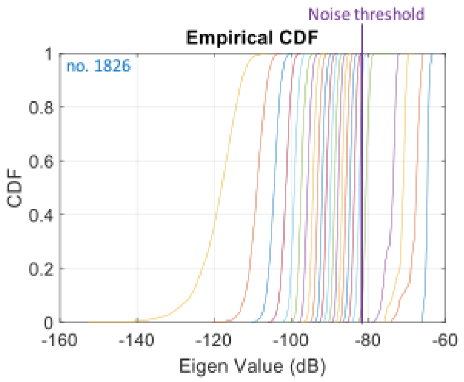


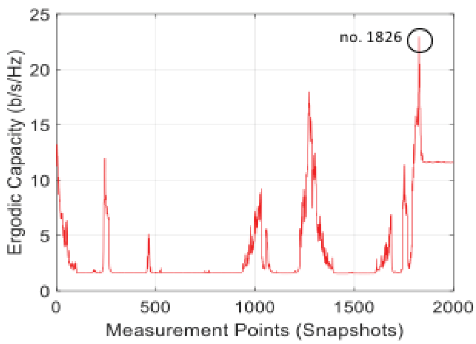
Figure Power spectrum subtraction result of conventional and proposed method

Wideband MIMO Eigenvalues and Channel Capacity in 11 GHz Band

The basic measure of wireless communication performance is the channel capacity. In Multiple-Input Multiple-Output (MIMO) system, capacity increasing due to multiplexing gain is considered as one of the precious technique in wireless research. Deploying MIMO system in the higher frequency for the next generation wireless system is a challenging topic. In this research, the MIMO propagation channel in 11 GHz band in the urban microcell environment in Ishigaki City, Okinawa is investigated by using wideband MIMO channel sounder developed by our laboratory.

Field measurement of 24 by 24 wideband MIMO utilizing cylindrical array antennas with 12-elements both transmitter (mobile station, height 3 m-height) and receiver (base station, 8 m-height) with 2048-subcarriers of 400 MHz bandwidth has been conducted for uplink communication scenario. The eigenvalues (snapshot no. 1826) and channel capacity is shown in the Figure. The total measurement points were 2000 snapshots in the area of 200 m^2.





Millimeter wave Channel Sounding for Future Heterogeneous Network: Outdoor urban pico-cell environment

One of the ways to meet the growing demand for higher data rates is to exploit the large amount of Spectral resources available in the millimetre wave frequency band. The unlicensed 60 GHz band with continuous bandwidths of more than 7 GHz is a very attractive candidate for use in the future heterogeneous cellular networks. The channel characteristics such as the directional properties in different environment is very important for the necessary use of techniques like beamforming and beam-steering. We developed a low cost double directional millimetre wave channel sounding system capable of carrying out measurement in out-door environments. Using the system we carried out a double directional channel sounding in a typical outdoor pico-cell environment, shown in fig.1 (left).

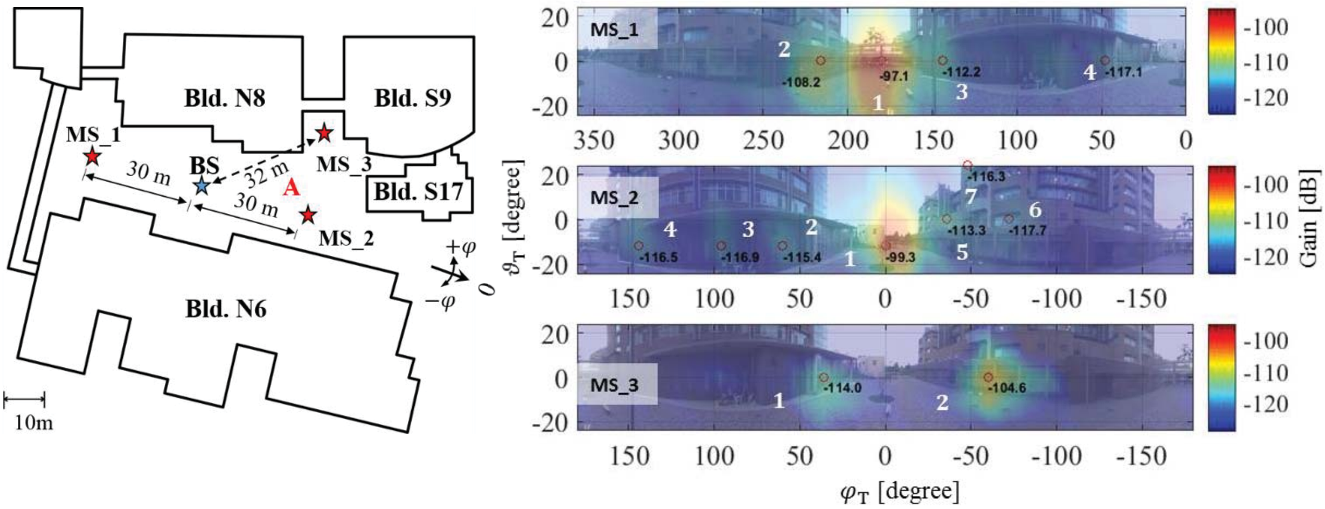


Figure 1. (Left) Outdoor pico-cell environment. (Right) Co-pol Angular power spectrum at BS

By analysing the measurement data we found the existence of cluster of paths other than the direct path in both line of sight (LOS; MS_1 and MS_2) and obstructed LOS (O-LOS; MS_3) cases. The co-polarized (**θ** - **θ**) angular power spectrum (APS) of the detected clusters and the corresponding scattering objects are shown in fig.1 (right). The corresponding measured rms angular spread in both elevation and azimuth angle are indicated in fig.2. The spread was relatively lower than what was found in the indoor environment. Such spread parameters will be useful in design of antennas, and for beam tracking algorithms.

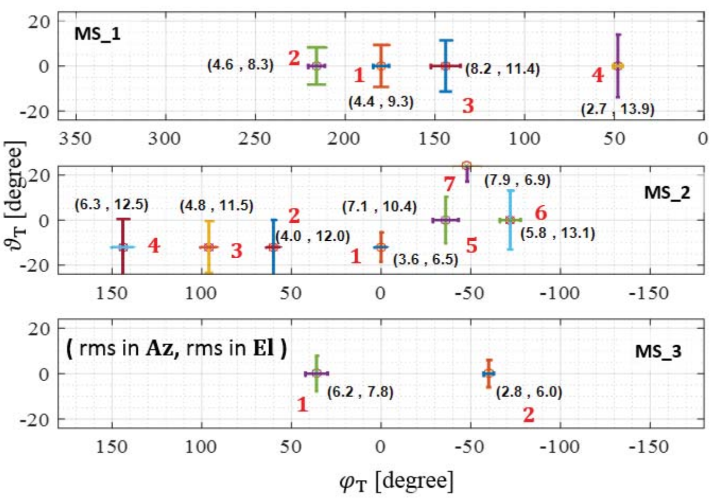


Figure 2. Measured angular spread (rms) of the clusters

Diffuse Scattering Simulation from Rough Surfaces in mmWave

As the demands for high speed wireless communications increase, the utilization of mmWave and scattering mechanism have become a topic of great interest. Physical Optics is an effective method to calculate electromagnetic fields of scattering. In this paper, we present the received power characteristics scattered from a random rough surface. We also discuss the appropriate integral area introducing Fresnel Zone. Figure 1 shows simulation setting. Rms height h is set as 1λ and correlation length l is set as 5λ. Figure 2 shows the result of the received power comparison in terms of the integral area. The indexes of S are defined by the number of fresnel integral area. Black line represent the received power from a flat surface by integral area of S1. The peak power of S1 is almost 20 dB less than S1-flat, and the power spread much wider than S1. More specific, rms angular spread of S1 is 12.09 degree while it is 3.85 degree in case of S1-flat. Regarding the integral area comparison, the peak received power difference between S3 and S4 is 2.04 dB, while it is 0.25 dB in case of S4 and S5. The difference is suddenly decreased after S4. For the future work, we are planning to conduct measurement campaign at 60 GHz to obtain angular and delay characteristics.

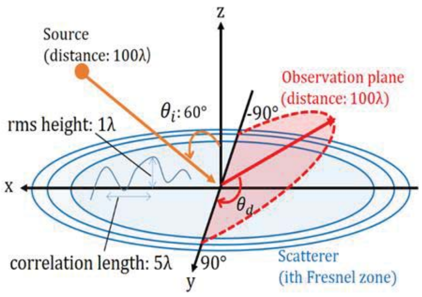


Figure 2 Simulation setting

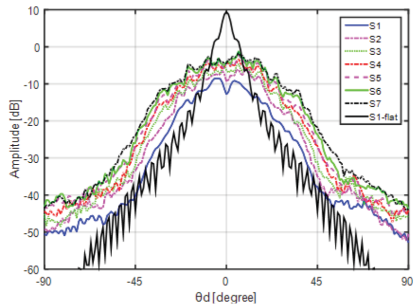


Figure 2 Received power (θ Component)

Hybrid T-Matrix Modeling of Electromagnetic Scattering from Simplified Foliage Structures

Foliage structures are one of the most dominant types of obstacle that is present in rural propagation environments. These foliage obstacles, with their leaves, branches, and trunks act as complex scatterers to the propagating radiowaves. Proper understanding of such interactions is necessary to predict their effects on radio systems operating in such environments. In this work, the leaves and branches are modeled as simplified geometric structures. The electromagnetic scattering from these simplified foliage elements are modeled using a proposed hybrid method of moments T-matrix. The T-matrix describes the electromagnetic scattering of an arbitrary scattering object in terms of the spherical wave expansion coefficients of the incident and scattered electromagnetic waves. We use the method of moments to evaluate the scattered fields from the arbitrary scatterer. The least squares solution to the T-matrix is then found from this incident and scattered field coefficients. The scattered fields from multiple structures can be found using a superposition approximation of the scattered fields from each of the individual foliage elements. Results show good agreement between the full method of moments results and the hybrid T-matrix approach, with a significant reduction in simulation time.

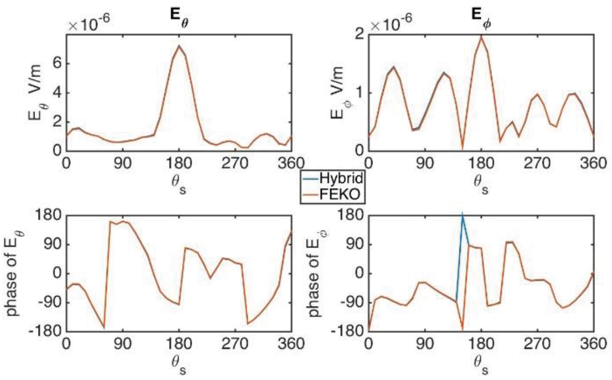


Fig. 1 Scattered fields from 30 random leaves

Takada Laboratory

Development of Simultaneous Measurement System of MIMO Channel Responses and Body Motion for Study of Dynamic WBAN Channel

Wireless Body area network (WBAN) is a wireless sensor network inside, on or around human body, and is expected to be utilized in medical and health-care applications. Dynamic behavior of radio propagation channel is important information for design and characterization of WBAN system. Various factors simultaneously influence the channel responses, such as position and orientation of antennas, electromagnetic interaction antenna and human body, and obstruction by human body itself. This paper reports the development of simultaneous measurement system of WBAN channel. Body motion information is utilized to synthesize numerical phantom for electromagnetic simulation via computer animation software. A 3x3 MIMO channel sounder is utilized to capture measurement result. And comparison between measurement and simulated channel responses is possible by using this system and example of navel-chest antenna link for walking motion is presented.

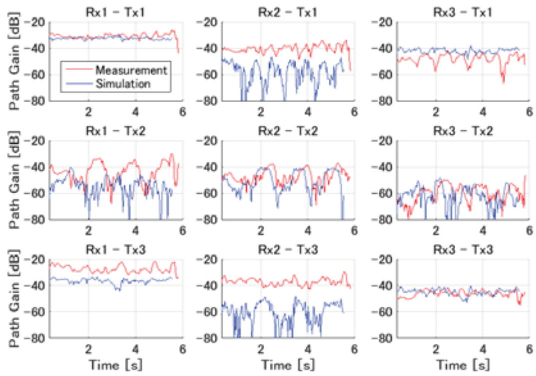
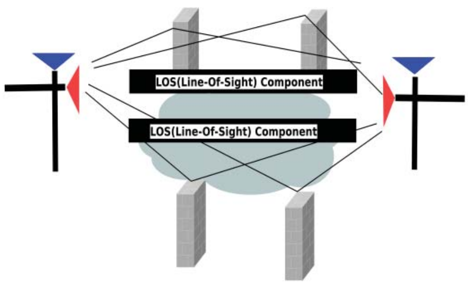
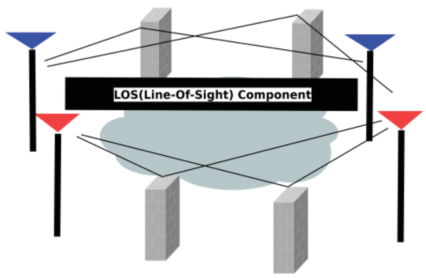


Fig 1: Comparison for navel-chest, walking motion

Space-Time Coding On Polarized and Non-Polarized Line-Of-Sight MIMO Transmission Channels

Recently, the use of multiple antennas at both transmitter and receiver sides appears as a solution to issues posed by the high demand of mobile communication system in increasing data rates, reliability of wireless transmission systems and the efficient usage of the spectrum. Even though the Multiple-Input Multiple-Output (MIMO) system has demonstrated its capacity to solve these problems, the performance degradation cannot avoided in the presence of strong line-of-sight (LOS) when the transmitter does not have any knowledge of the propagation channel. Performance is degraded due to the correlation caused by the LOS component.





Typical Co-located 2x2 MIMO system - Typical Spatially-Separated 2x2 MIMO system

Since orthogonal polarizations ideally may offer complete separation between channels of the propagation environment, therefore this research aims to analyze improvement of MIMO system in the LOS environment, through the use of co-located dual polarized and spatially separated antennas by employing the Space-Time Trellis Code.

Development of Directional Channel Sounder using USRP and GNU Radio

Channel sounding has long held importance for wireless communication system design. Recently, the directional property of the channel has been recognized as an important factor when evaluating the propagation channel. However, conventional channel sounding is high cost and a big workload. Therefore, our lab developed a channel sounding system using low cost hardware (USRPs) and free-software (GNU Radio). USRP purchased from Ettu Reseach is a reconfigurable hardware peripheral that provides a general purpose radio with high variety of RF board at various frequency bands (400~4400MHz). By conducting a comparison indoor channel sounding with VNA, the performance of this work is validated that it can achieve almost the same accuracy as VNA for measuring the directional property of the channel. Fig. 1 shows the double directional spectrum comparison between VNA and USRP. The clusters detected by VNA and USRP have a good agreement that validates the good performance of developed directional USRP channel sounder.

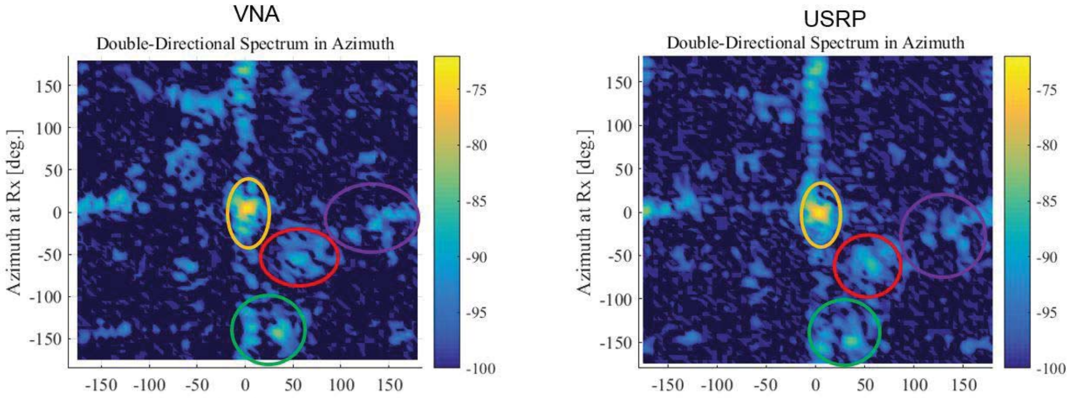


Fig. 1. Double Directional spectrum comparison between VNA and USRP

Development of Channel Sounder Prototype for Distributed Wireless Networks.

Distributed wireless networks (DWNs) e.g. wireless sensor networks in which the devices in the network are be able to communicate each other independently are suitable for implementing in agriculture because it is easy to be deployed in the agriculture filed without addition cost of infrastructure. To maximize the performance of such deployment in terms of reliability and energy consumption, the cooperative distributed algorithms e.g. partner selection are crucial. To implement such algorithms in DWNs, knowing the wireless channel model in distributed manner is essential. Although, traditional channel sounders were utilized by existing works to measure and construct the model for indoor distributed channels, it is difficult to implement such a system in large scale of outdoor distributed measurement such as agriculture field which requires the numerous transmitter and receiver nodes. Therefore, the well-suited channel sounder prototype for the outdoor DWNs is developed by adopting the standalone system which combines the free gnu radio software and the open source USRP hardware into a small and low-cost commercially available device called E100. The hardware customization of the E110 device to be the distributed channel sounder is developed and verified with VNA as reported in [1]. This work also adresses the problem regarding the synchronization and the protocol of the communications among the distributed nodes.

[1] Tossaporn Srisooksai and Jun-ichi Takada, "Development of Channel Sounder Prototype for Distributed Wireless Networks", IEICE Tech. Rep., vol. 115, no. 161, SR2015-32, pp. 95-102, July 2015.

Takada Laboratory

Fingerprint-based Localization of Unknown Emitters in Dense Urban Environments

Localization of unknown emitters is crucial in order to avoid interference to other radio systems. Conventional techniques such as multilateration and triangulation require line-of-sight (LOS) between the unknown emitter and receiver (Rx) sensors, thus are not reliable in dense urban areas. Furthermore, conventional fingerprint-based techniques, which is expected to perform well in NLOS environments, require that the unknown emitter's signal parameters such as bandwidth, frequency and transmit power match those of the localization system.

This research proposes a novel technique to localize unknown emitters in an urban environment by utilizing the cross-correlation of the channel impulse response (CIR) as location fingerprints. Training fingerprints are collected from many locations using several frequencies and bandwidths in the training phase, and are interpolated in the bandwidth (delay), frequency and spatial domains. Pattern matching is performed between the unknown emitters fingerprints and training fingerprints based on the minimum squared error criterion.

Performance of the proposed technique is evaluated through Monte Carlo simulations, and CIRs are obtained using ray-tracing in an urban environment modeled after Shinjuku station, Tokyo. Results show that the proposed technique is robust against a wide range of unknown emitter's parameters, and is able to achieve a median localization error of around 25 meters.

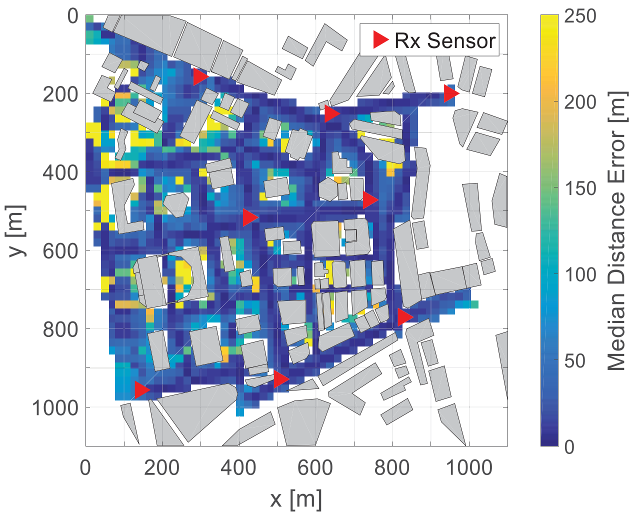


Fig. : Localization error for various unknown emitter locations

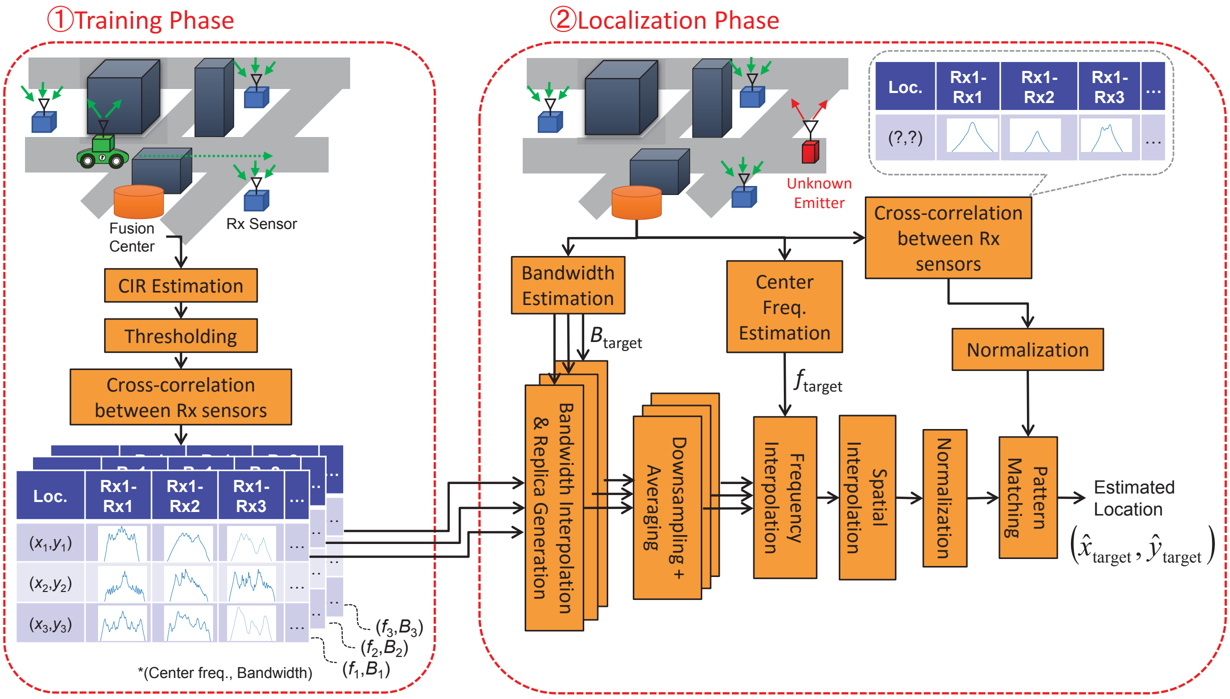


Fig. : Flowchart of proposed technique

Public Broadband Mobile Communication System

After digitization of analog TV broadcasting in Japan, a part of the VHF band (170-202.5 MHz) was allocated for public broadband mobile communication (PBB) system as shown in Fig. 1. The allocated bandwidth of 32.5 MHz was divided into 6 channels of 5 MHz each. The VHF band has suitable propagation characteristics to minimize the blind zones in complex terrain environments because the radio wave at this frequency band can easily sneak around obstacles. Therefore, the PBB system is expected to be a suitable flexible wireless communication system to share critical information using real time video streaming in disaster relief purpose. ARIB STD-T103 was standardized for the PBB system based on IEEE 802.16-2009. Recently, the PBB system as shown in Fig. 2 has been developed and evaluating to obtain propagation characteristics and system performance in various environments.

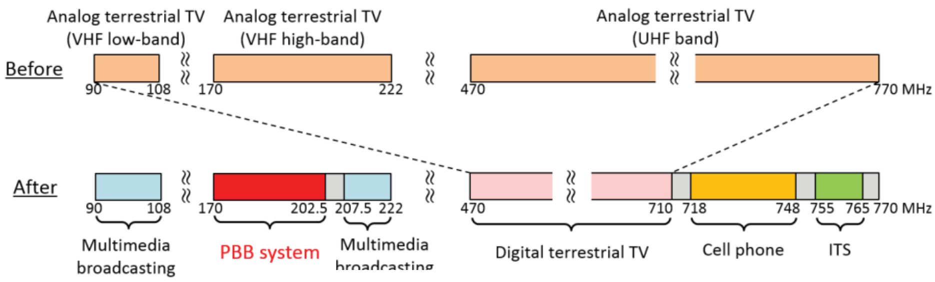
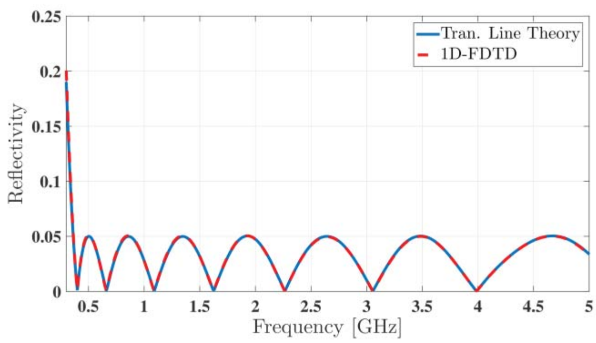


Fig. 1 Spectrum allocation plan

Fig. 2 PBB device

Wide Frequency Band Analysis of Multilayer Planar Electromagnetic Wave Absorber

To enable the FDTD analysis for the multilayer planar wave absorbers made of foamed polystyrene, the proper equation of its dielectric properties is needed. In this study, the multi-pole Debye dispersion function is utilized to reformulate the closed-form solution of its complex relative permittivity derived from the measurement data. The quadratic and exponential functions are proposed to represent for all Debye dispersion parameters in term of carbon content. Figure 1 shows the reflectivity of the eight-layer wave absorber evaluated by the 1D-FDTD technique and transmission line theory. As a result, good agreement between both techniques are obtained.



SAKAGUCHI LABORATORY

Associate Professor Kei Sakaguchi

Assoc. Prof. Kei Sakaguchi received the B.E. degree in electrical and computer engineering from Nagoya Institute of Technology, Japan in 1996, and the M.E. degree in information processing from Tokyo Institute of Technology, Japan in 1998, and the Ph.D. degree in electrical and electronic engineering from Tokyo Institute of Technology in 2006. From 2000 to 2007, he was an Assistant Professor at Tokyo Institute of Technology. Since 2007, he has been an Associate Professor at the same university. Since 2012, he has also joined in Osaka University as an Associate Professor, and since 2015, he has extra joined in Fraunhofer HHI in Germany as a Senior Scientist. He received the Young Engineering Awards from IEICE and IEEE AP-S Japan Chapter in 2001 and 2002 respectively, the Outstanding Paper Awards from SDR Forum and IEICE in 2004 and 2005 respectively, the Tutorial Paper Award from IEICE Communication Society in 2006, and the Best Paper Awards from IEICE Communication Society in 2012, 2013, and 2015. He a member of IEEE and IEICE.

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 Awards in Software Radio from IEICE SR technical committee in 2009 and 2012. His research interests are MIMO transmission algorithms, multiuser MIMO, MIMO mesh network, wireless power transmission, cooperative cellular networks, sensor networks, digital predistortion RF and mm-waves. He is a member of IEEE and IEICE.

Emeritus 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. From 1995 to 2014 he was 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.

Project researchers:

Yuyuan Chang, Ebrahim Rezagah Roya, Ehab Mahmoud Mohamed*

Doctor course students:

Yu Tao, Maehara Daiki, Hidekazu Shimodaira

Working doctor students:

Hiroyuki Kamata

Master course students:

Keita Sumi, Ryota Kosaka, Gento Matsushita*, Sayako Haze, Naofumi Abe, Ryosuke Kuniyoshi

Bachelor course students:

Hiroaki Ogawa

Researchers:

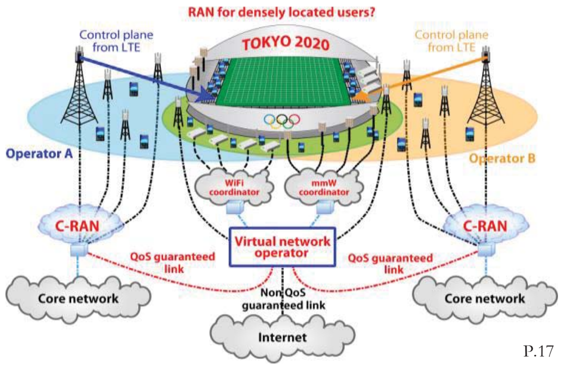
Masahiro Suneya

* : works at Osaka University

www.sakaguchi-lab.net

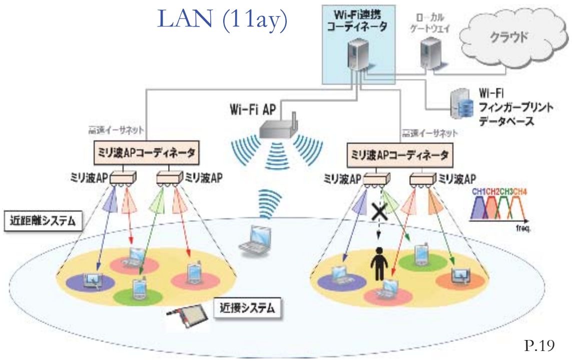
Sakaguchi Laboratory

Design and Standardization of 5G Cellular Network



P.17

Design and Standardization of mm-Wave Wireless LAN (11ay)



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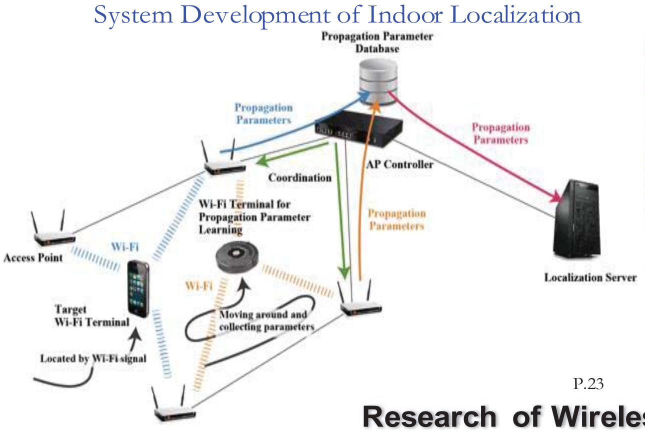
System Development of Indoor Localization



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System Development of Battery-less Sensor Network

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Research of Wireless Communication

Research Interests

Sakaguchi laboratory (originally Araki-Sakaguchi laboratory) has been researching in wireless technology, since 1995. Founded on wireless communication systems, the lab has been extended widely from theoretical analysis to hardware implementation, measurement system construction and empirical experiments and from domestic to international research collaboration. Moreover, not only academic works within the university, but also co-works with various famous industrial domestic/international companies have been conducted for developing new wireless applications and contributing to the next generation wireless system standards.

Recent Research Topics

5G cellular network architecture and overall evaluation [6][7][14][15][16][20][34]

Sakaguchi laboratory has proposed a comprehensive architecture of 5G (5th Generation) cellular networks with mm-wave access, where mm-wave smallcell BSs (SC-BS) and a conventional macro BS (macro-BS) are both connected to Centralized-RAN (C-RAN) to effectively operate the system by enabling power efficient seamless handover as well as centralized resource management including dynamic cell structuring to synergize the limited coverage of mm-wave access with high traffic user locations via user-plane/control-plane splitting.

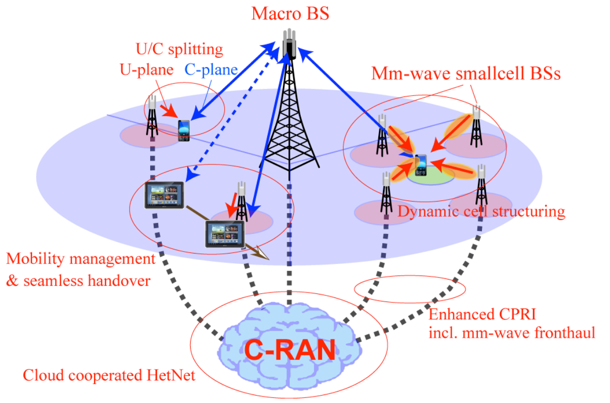


Fig. 1 5G cellular network architecture

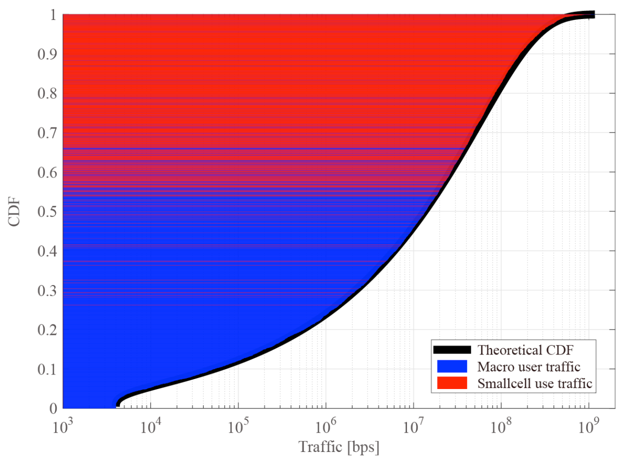


Fig. 2 – Association status

To prove the effectiveness of the proposed 5G cellular networks, a system level simulator was developed. A novel cell association algorithm mapping high-speed mm-wave access to users of high traffic demand was proposed to fulfill a requirement of 1000x traffic increase as shown in Fig. 2 and Table 1.

Table 1 Simulation Results

	HomoNet	HetNet
System rate	123.53 Mbps	195.40 Gbps
Average user rate	22.26 kbps	35.21 Mbps

Dynamic resource management framework [8][9][17][29]

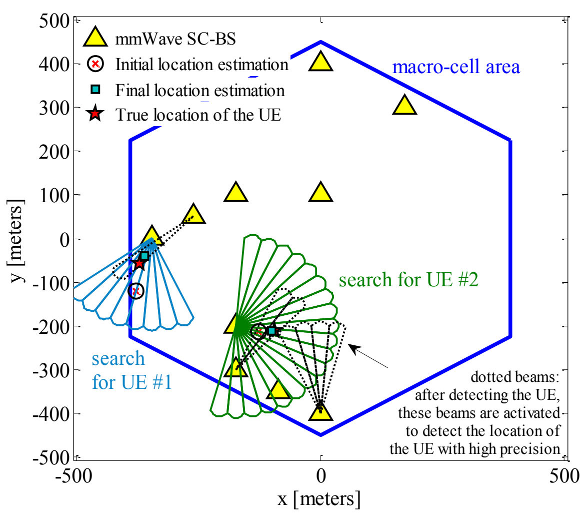


Fig. 3 Location-based cell/beam discovery alongside location estimation update

Dynamic cell structuring

Future heterogeneous networks (HetNets) are going to consist of cellular macro-BSs and various types of SC-BSs, each operating in microwave and/or millimeter bands. Cell discovery of mm-wave SC-BSs is a challenging issue because of the limited communication range. Here, a location-based cell selection scheme that takes into account the effects of inaccuracy of the location estimation is developed and evaluated. The proposed scheme selects the SC-BSs/beams according to the probability that they can reach the UE as seen in Fig. 3. This probability is dynamically calculated and updated during the search process to assure that at any step the SC-BS with

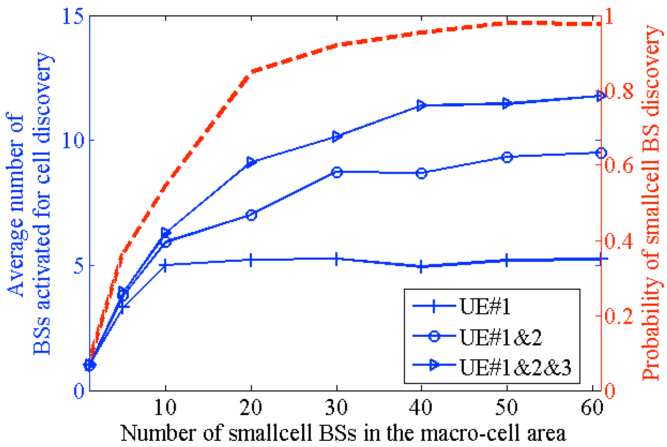


Fig. 4 - Average number of smallcell BSs activated for cell/beam discovery (blue lines) beside the probability of discovering at least one smallcell BS/beam for a UE (red line)

highest detection probability is selected.
In a recursive process, the estimated location of the UE is used to assign cell/beams to search for the UE and the search result is used to dynamically update the location estimation. This enables the C-RAN to obtain an accurate traffic map that can be used to apply further network optimization algorithms. The simulation results show a 30% reduction in the latency of this cell discovery compared to the conventional scheme. Furthermore, even more than 70% reduction in delay is possible if the proposed algorithm is extended to simultaneously select three SC-BSs with maximum joint probability of detection seen in Fig. 4.

Dynamic smallcell BSs ON/OFF

5G HetNet should support not only the conventional area traffic capacity but also network energy efficiency. Our dynamic resource management framework also deals with a joint optimization of user association and ON/OFF status of smallcell BSs for balancing the sum throughput and energy consumption trade-off presented in Fig. 5. We also develop a dynamic traffic model using realistic measurement data in metropolitan Tokyo, based on that the network can dynamically adapt to the variation in a cost-effective way. Numerical results show that our algorithm can effectively deactivate non-necessary BSs against dynamic variation of hourly traffic while improving users' satisfaction as compared to conventional homogeneous network. We also confirm the superiority of mm-wave smallcell HetNet against conventional microwave HetNet in terms of energy efficiency in bps/W as seen in Fig. 6.

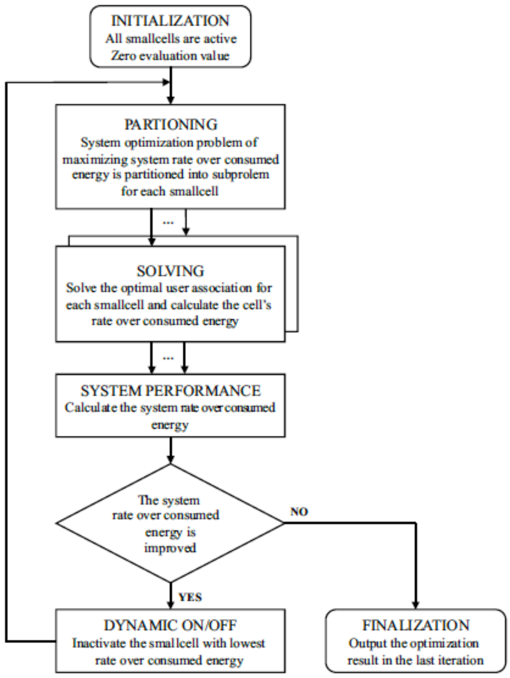


Fig. 5 – Dynamic ON/OFF algorithm for energy-efficient 5G HetNet

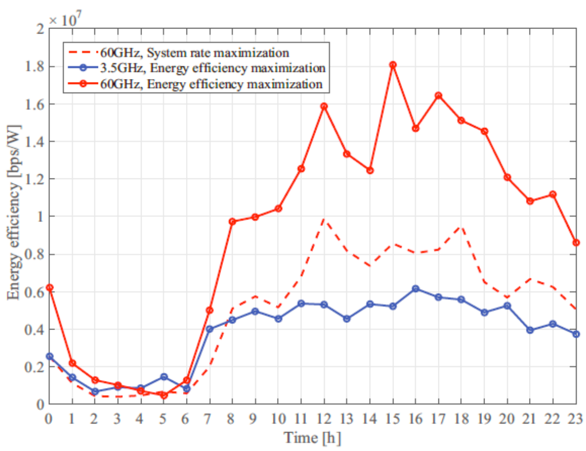


Fig. 6 – Energy efficiency performance of 5G HetNet in terms of bps/W

Wi-Fi/WiGig Coordination for Optimal WiGig Concurrent Transmissions [2][26][33]

Introduction

Wireless Gigabit (WiGig) access points (APs) using 60 GHz unlicensed frequency band are considered as key enablers for future Gbps WLANs. Due to its short range transmission with high susceptibility to path blocking, a multiple number of WiGig APs should be installed to fully cover a typical target environment. Towards that, we proposed a Wi-Fi/WiGig coordination to optimize WiGig transmissions in random access scenario using Wi-Fi assistance and location estimation using Wi-Fi RSS.

Proposed Coordinated Wi-Fi/WiGig WLAN

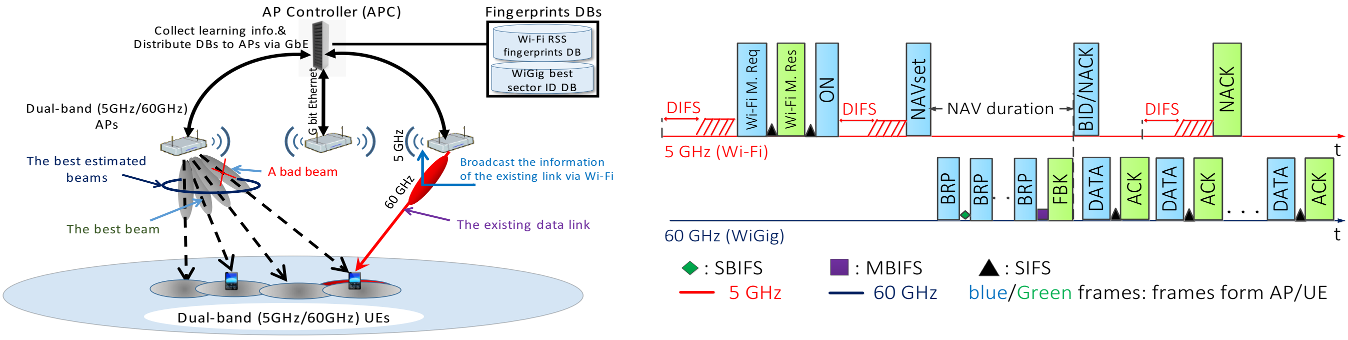


Fig.7 Proposed coordinated Wi-Fi/WiGig WLAN and dual band MAC protocol

Fig. 7 shows the system architecture of the proposed WLAN using Wi-Fi/WiGig tight coordination and the proposed dual band MAC protocol. In Fig. 7, multiple dual-band (5 and 60 GHz) APs are connected to an AP controller (APC) via gigabit Ethernet links. The APC works as a central coordinator that assists the establishment of WiGig concurrent links and acts as a gateway to connect the WLAN to the Internet. The wide coverage 5 GHz (Wi-Fi) band in Fig.7 is mainly used to associate the UEs to the WLAN and broadcasts the signaling information required for enabling optimal 60 GHz (WiGig) concurrent transmissions. To effectively estimate the best candidate APs and estimate their best and bad beam IDs, statistical learning is used using Wi-Fi RSS fingerprints.

Simulation Analysis

Figure 8 shows the total system throughput of the proposed coordinated Wi-Fi/WiGig WLAN and that of the IEEE 802.11ad DCF based WLAN. By using 8 APs, about 5-time increase in total system throughput is obtained using the proposed WLAN compared to using IEEE 802.11ad DCF WLAN. This comes from the optimality in establishing the WiGig concurrent links in random access scenarios of which function cannot be provided by IEEE 802.11ad DCF WLAN.

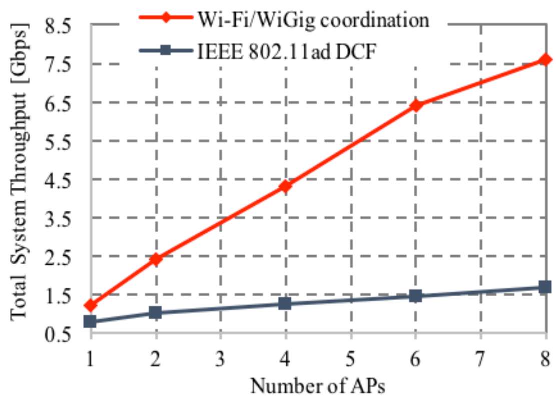


Fig.8 Total system throughput

Integrated Design of Ultra Broadband mm-Wave WLAN at 60 GHz [18][22][30][35][39][42]

Recently due to the increasing of data traffic, 60 GHz millimeter wave (mm-Wave) band has been considered because of its license-free and wide bandwidth for the fifth generation (5G) mobile network. The channel allocation is as shown in Figure 9 that the license free frequency band from 57 to 66 GHz is divided into 4 channels; and for each channel, 2 GHz band width allocated for broad band wireless applications. Here we employ multiple-input and multiple-output (MIMO) and multiuser MIMO (MU-MIMO) techniques with orthogonal frequency division multiplexing (OFDM) schemes to further improve the efficiency of the millimeter wave channel. By combine multiuser MIMO and OFDM, we propose optimal user scheduling method.

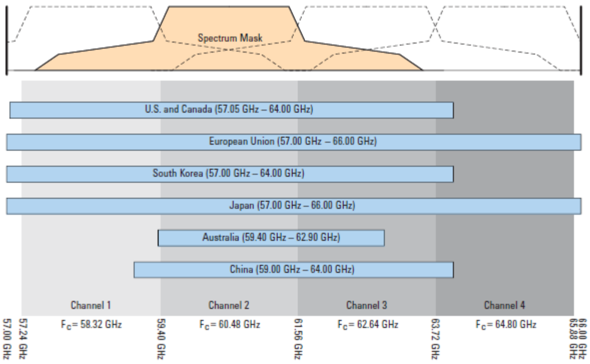


Fig. 9. 60 GHz band plan (from Agilent Technologies Application Note, "Wireless LAN at 60GHz–IEEE 802.11ad plained.")

Proportional Fair User Scheduling Algorithm with RF Beamforming

In mm-Wave wireless systems, due to the large path loss and straightness property the applications are limited to line of sight communication environments. Beamforming is a useful technology for mm-Wave systems and suitable for the realization of multiuser system and mitigation of interference from or toward other system. On the other hand, user scheduling for the MU-MIMO systems can increase the system capacity effectively; however, the fairness among the users should be considered. To consider not only the improvement of system rate, but also the fairness among uses, we propose a proportional fair user scheduling with RF beamforming. Here, we propose a modified SUS (Semi- orthogonal User Selection) method; in where, we decide the first user with the capacity-based criteria multiplied with the proportional fair factor. In the selection of the other users, we only consider the correlation of channels of the selected users. For evaluating the proposed algorithm, we conducted the simulation with a small meeting room channel model, which is obtained from the raytracing approach and propagation analysis. By using the proposed algorithms, although, the capacity decreases, the users with different signal to noise power ratio (SNR) have almost the same latencies, as shown in Figure 10; and the optimal number of users for the proposed scheduling is twelve as shown in Figure 11.

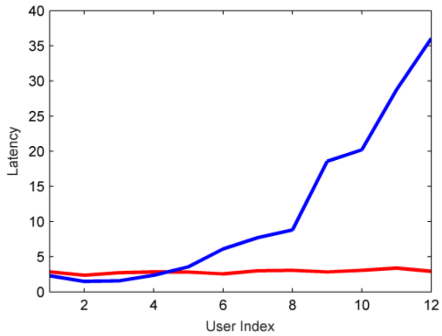


Fig. 10. Latency of users

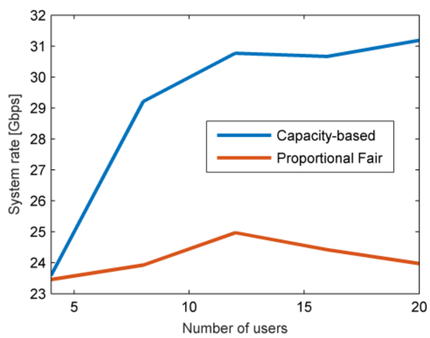


Fig. 11. System rate

Wireless Sensor Network

Wireless energy transmission, LED control system, WiFi localization [3] [10] [11] [13] [19] [26] [33] [36] [40] [41]

Wireless sensor networks (WSNs) are expected to be employed for many kinds of applications. In this research we focus on power supplying problem of sensor nodes, localization systems and LED light control system. Especially, we employ two different approaches for the localization system based on i.e. IR sensors and WiFi signal. Details on our developments and experiments are presented as follows.
Limited lifetime of the sensor node has long been an issue in WSNs. In order to deal with the problem, we proposed a wireless grid in which a large number of sensor nodes distributed in indoor environments can be simultaneously activated by multi-point wireless energy transmission with carrier shift diversity (MPCSD) which can realize seamless supply of energy by allocating different frequencies to the multiple energy transmitters compared with simple multi-point scheme (MP) in which multiple transmitters employ the same frequency.

In Japan, annual lighting energy consumption accounts for 16% of national energy consumption. As an application of WSNs, we focus on an LED light control system based on user's occupancy and environment luminance level. Owing to the proposed wireless energy transmission, multiple sensors can be freely deployed, compared to conventional systems, in which sensors have to co-locate with LED lights on the ceiling due to their power source. By using sensing data from the multiple battery-less IR sensors with overlapped coverage, user's location and motion is tracked by a maximum likelihood algorithm. The light control scheme mainly focuses on reducing office's lighting energy consumption and satisfying user's luminance requirement. For references, WiFi fingerprinting based localization technique can also be employed as another approach of localization, in which location

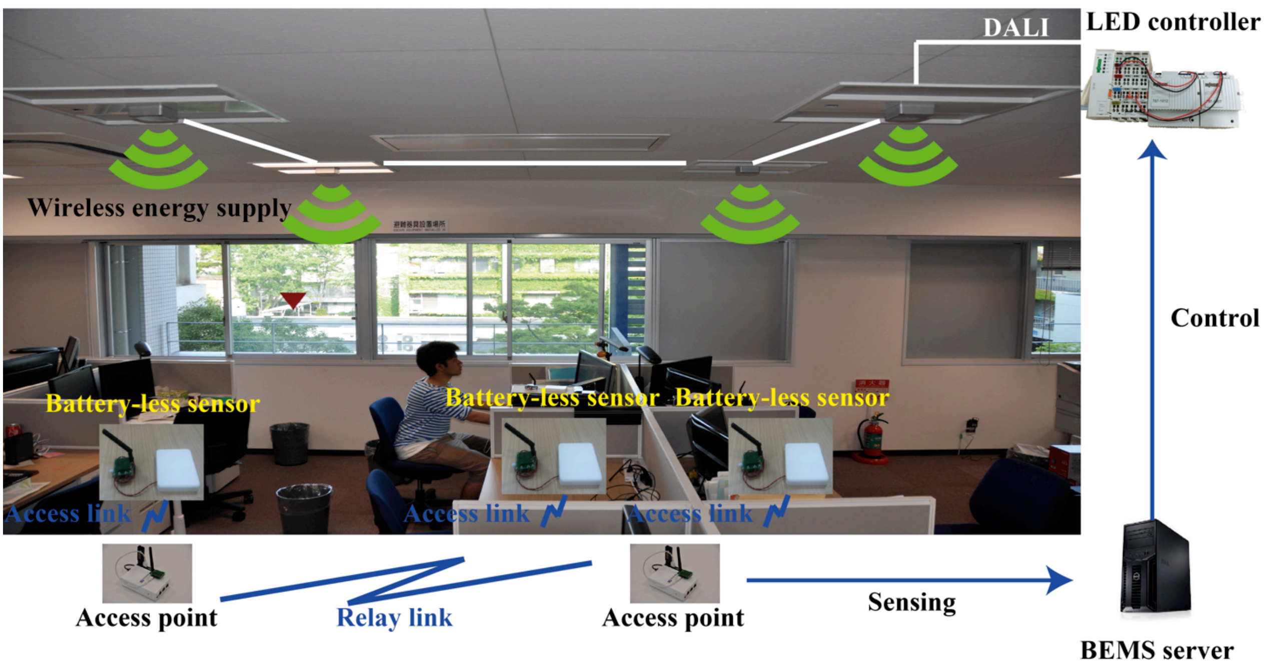


Fig. 12 Developed LED control system using battery-less sensor network.

dependent propagation parameters, e.g. RSSI (Received Signal Strength Indicator) and Received Signal Phase Difference (RSPD), are treated as "fingerprint" of location, and location is identified by its pre-learning and pattern-matching like fingerprint authentication.

As an example of wireless grid applications, LED light control system using battery-less human detection sensor is developed in an indoor office environment as shown in Fig. 12. Multiple wireless energy transmitters are embedded in all the LED ceiling lights to easily introduce the system. Battery-less sensor nodes are deployed on the desk to perform human detection. The sensing data is collected by the BEMS server and is employed to reduce the consumed power of LED lights. To evaluate the developed system, we conduct an experiment to verify the sensor activation and the power saving. In the experiment of wireless energy transmission system, the DC received power and the activation possibility are measured at the height of desks as shown in Fig. 13 (a). The result shows that MPCSD can seamlessly supply energy as shown in Fig. 13 (c) compared with MP as shown in Fig. 13 (b). In addition, the coverage of MP and MPCSD are 93.6% and 100% respectively. In the lighting

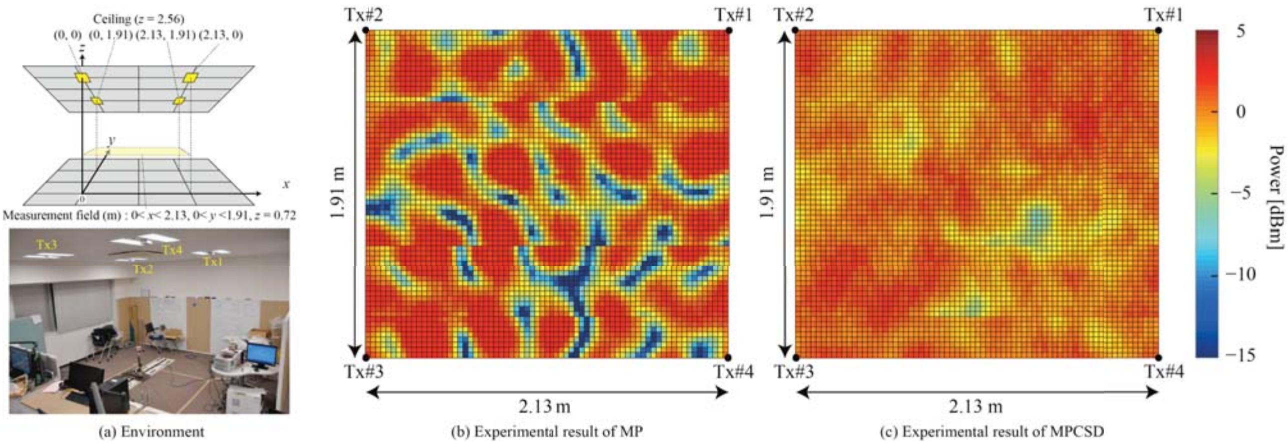


Fig. 13 Experimental results of activation status.

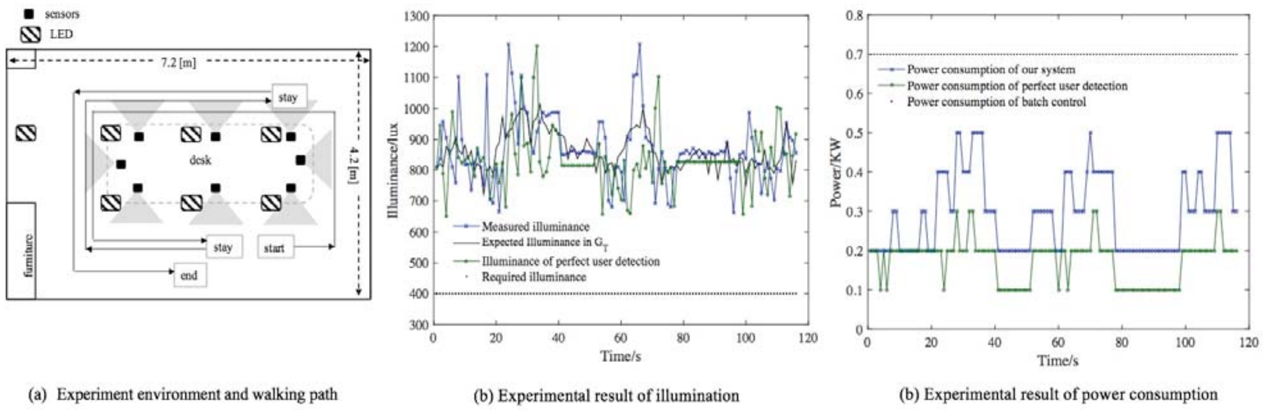
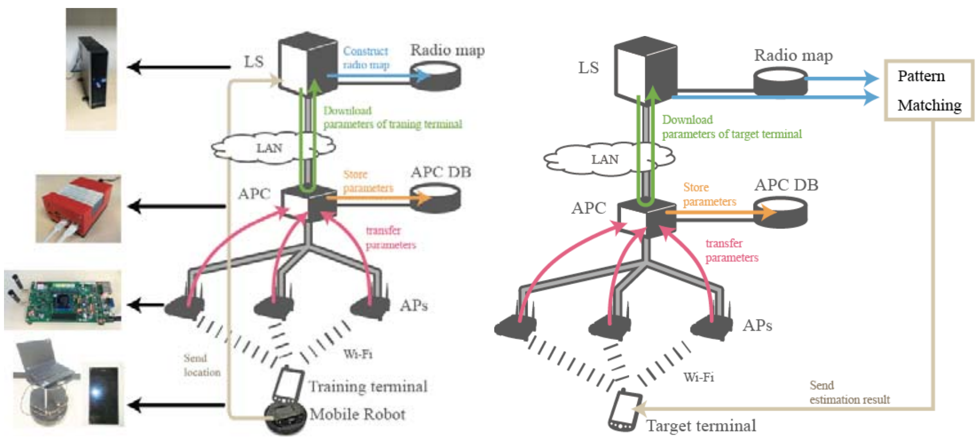


Fig. 14 Experimental results of lighting control.

control experiment, the test user walks in the office, as shown in Fig. 14(a). Meanwhile he records the luminance by a handheld luminance meter, and the lighting power consumption is also recorded by a power-logger. The results, in Fig. 14 (b) and (c), show that this LED light control system reduces the energy consumption significantly by 57%, compared to batch control scheme, and satisfies user's luminance requirement with 100% probability.

We also develop the Wi-Fi localization system using fingerprinting technique, as shown in Fig. 15, which is divided into pre-learning and estimation phases. At pre-learning phase, the training terminal on the mobile robot sends signals and information of its location to APs. The APs convert the received signals into the propagation parameters and then transfer them to AP controller (APC). APC receives and stores them in the database. Localization server (LS) downloads them from the APC database and constructs radio map by the information of the locations. At estimation phase, a target terminal sends signals to APs. As with the same as the pre-learning phase, LS receives the propagation parameters from the APs. Then, LS estimates the location of the target terminal by pattern matching with the parameters and radio map. We also evaluate the localization performance of the fingerprints by an indoor experiment. The experimental parameters, environment and results are shown in Tab.2, Figs. 16 and 17 respectively. In the experiment, the mobile robot moves along the movement path in both pre-learning and estimation phase. The results verify that our proposed fingerprinting scheme using both RSSI and phase information achieves 1 m of estimation error at 50% of median value.



Pre-learning phase

Estimation phase

Fig. 15 Developed Wi-Fi localization system.

Tab. 2 Experimental parameters.

Wi-Fi Standard	802.11a
Center Freq.	5.0 GHz
AP Num.	3
Antenna Num.	2

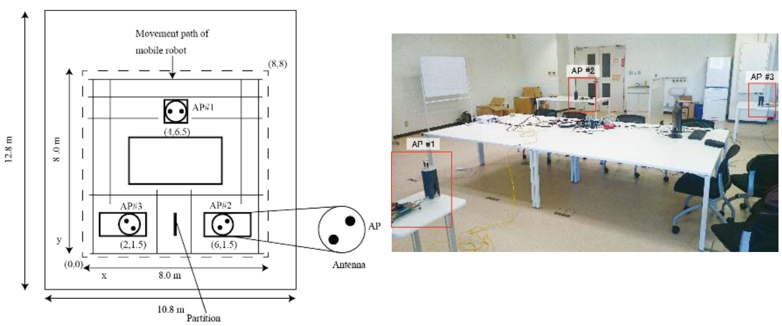


Fig. 16 Experimental environment (8 x 8 m).

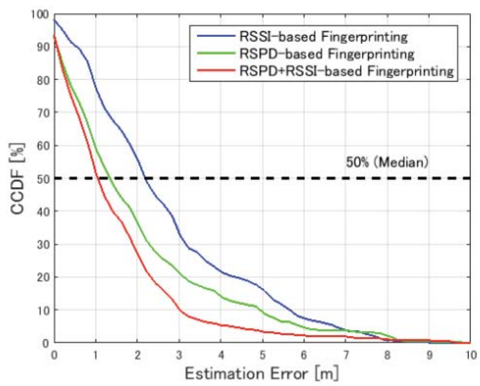


Fig. 17 Experimental result.

FUKAWA LABORATORY

Website: http://www.radio.ce.titech.ac.jp

Professor Kazuhiko Fukawa

received the B.S. and M.S. degrees in physics, and the Dr. Eng. degree in electrical and electronics engineering, all from Tokyo Institute of Technology, Tokyo, Japan, in 1985, 1987, and 1998 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, and an Associate Professor at the Tokyo Institute of Technology, from 2000 to 2014. Since 2014 March, he has been a Professor at the Tokyo Institute of Technology. Prof. Fukawa is a member of IEEE. He received the Paper Award from IEICE in 1995, 2007, 2009, and 2012, the Best Paper Prize from the European Wireless Technology Conference (EuWiT), and the Achievement Award from IEICE in 2009.

Researcher Yuyuan Chang

was born in 1975. He received the B.E. degree from Department of Control Engineering and the M.E. degree from Department of Electrical Control Engineering, National Chiao Tung University, Hsinchu, R.O.C. (Taiwan), in 1997 and 1999, respectively, and another M.E. and the D.E. degree from Electrical and Electronic Engineering Department, Tokyo Institute of Technology, Tokyo, Japan, in 2007 and 2011, respectively. He served in Industrial Technology Research Institute, Hsinchu, R.O.C. (Taiwan), from 2000 to 2005. He has been with Tokyo Institute of Technology from 2011 as a research fellow. His research interests include multi-user MIMO systems, user scheduling algorithm, MIMO sounder and millimeter wave wireless systems. He is a member of IEICE and received the Best Paper Award of IEICE Communications Society in 2013.

Our Research Interests

At 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.

Adaptive Codebook Precoder Employing Kalman Filter for Time-Varying MIMO Channels [1]

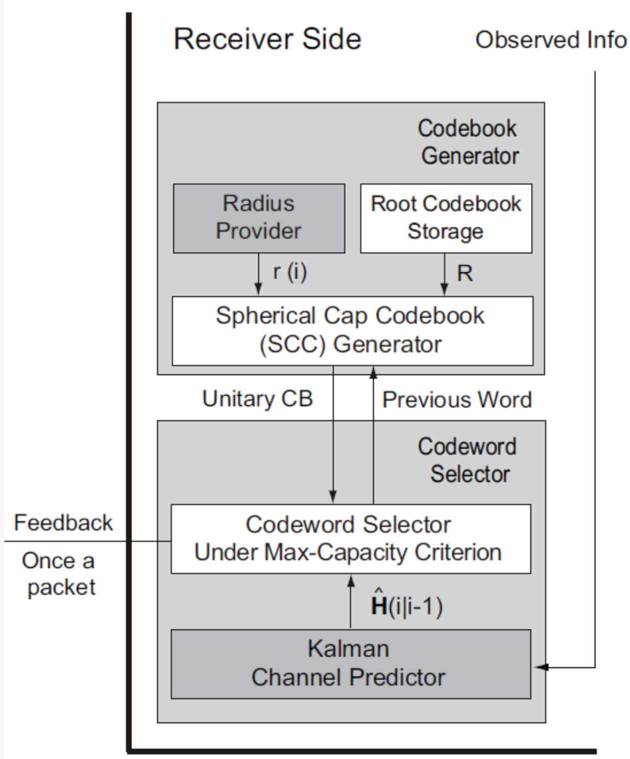


Figure 1 A block diagram of codebook generator and codeword selector on the receiver side

Multiple-input multiple-output (MIMO) is a promising technique to increase the channel capacity. Linear precoding for the MIMO system is a simple technique that can enhance the capacity furthermore. A MIMO transmitter should know the channel state information (CSI) in order to operate the precoding. In the case of a time division duplex (TDD) system in which the uplink and downlink channels share the same frequency, the transmitter can exactly know the CSI owing to the channel reciprocity. However, in the case of a frequency division duplex (FDD) system in which the uplink and downlink channels use different frequencies, the downlink CSI estimated by the receiver should be fed back to the transmitter. Schemes to feed the quantized CSI back to the transmitter have been investigated in the literature, but require a large amount of feedback information. To reduce the feedback, the codebook based precoding scheme has been proposed, in which the receiver selects a suitable precoding matrix from a predetermined set of precoding matrices, called the codebook, and feeds the index of the selected matrix back to the transmitter. For instance, time invariant codebooks have been adopted in the LTE standard. Furthermore, an adaptive codebook has been investigated for time-varying MIMO channels. The codebook is adaptively updated by exploiting temporary or spatial correlation of the MIMO channels so that it can fit the channels better and can improve performance with the same or even smaller codebook size. As one of the adaptive codebook schemes, the spherical cap codebook (SCC) that differentially quantizes the channel direction, which is the optimal non-waterfilling precoding matrix. This scheme sets the center of the codebook to a previously selected codeword, and controls a radius of the cap-style codebook in the Grassmann manifolds that is related to the statistics of the chordal distances between the center and the current channel direction. It has been shown that this scheme can drastically increase the channel capacity over slow fading channels. The radius of the cap at every update time is offline calculated under different fading conditions, which requires exact information on the maximum Doppler frequency, f_D. In a practical system with feedback delay, the transmitter uses outdated precoding matrices, which may degrade the performance. Selecting a precoding matrix on the basis of the predicted CSI can alleviate the degradation. An autoregressive (AR) model of the channel is often used for the channel prediction. In order to determine parameters of the AR model, exact information on f_D is necessary.

Fig. 1 shows a structure of the codebook generator and codeword selector on the receiver side. The SCC generator needs a pre-defined root codebook $\mathcal{R} = \{\mathbf{R}_1, \ldots, \mathbf{R}_{2^B}\}$, the previously selected codeword $\mathbf{F}(i-1)$ and cap's radius $r(i)$ in order to update the codebook $\mathcal{F}(i)$. This method differentially tracks the channel direction $\mathbf{V}_M(i)$, which is also known as the optimal non-waterfilling precoder. Here, $\mathbf{V}_M(i)$ is the first M columns of the N_t-by-N_t right singular matrix $\mathbf{V}(i)$ of $\mathbf{H}(i)$, and the singular value decomposition of $\mathbf{H}(i)$ is given by $\mathbf{H}(i) = \mathbf{U}(i)\mathbf{\Sigma}(i)\mathbf{V}^{\mathrm{H}}(i)$, where $\mathbf{U}(i)$ is the N_r-by-N_r left singular matrix and $\mathbf{\Sigma}(i)$ is an N_r-by-N_t diagonal matrix, whose diagonal elements are equal to the singular values of $\mathbf{H}(i)$ and are allocated in descending order. The k-th codeword in the updated codebook for the i-th feedback is generated by adding perturbation to the previous precoder and then projecting the result onto the N_t-by-M unitary space:

$$\mathbf{F}_k(i) = proj\left[\sqrt{1-\bar{r}^2(i)}\mathbf{F}(i-1) + \bar{r}(i)\mathbf{R}_k\mathbf{F}(i-1)\right]$$

where $\bar{r}(i) = r(i)/\min\{\sqrt{M}, \sqrt{N_t - M}\}$ is the normalized radius, the N_t-by-N_t unitary matrix $\mathbf{R}_k$ is the k-th codeword in the root codebook R, and $proj(\cdot)$ denotes the Gram-Schmidt column orthonormalization operation, which guarantees that codewords lie in the N_t-by-M unitary space. Given an N_t-by-M complex matrix $\mathbf{A}$, $proj(\mathbf{A})$ returns the first M columns of the left singular matrix of $\mathbf{A}$. The updated codebook focuses on a spherical cap centered by the previous precoder with radius $r(i)$ being a chordal distance metric in the N_t-by-M unitary space.

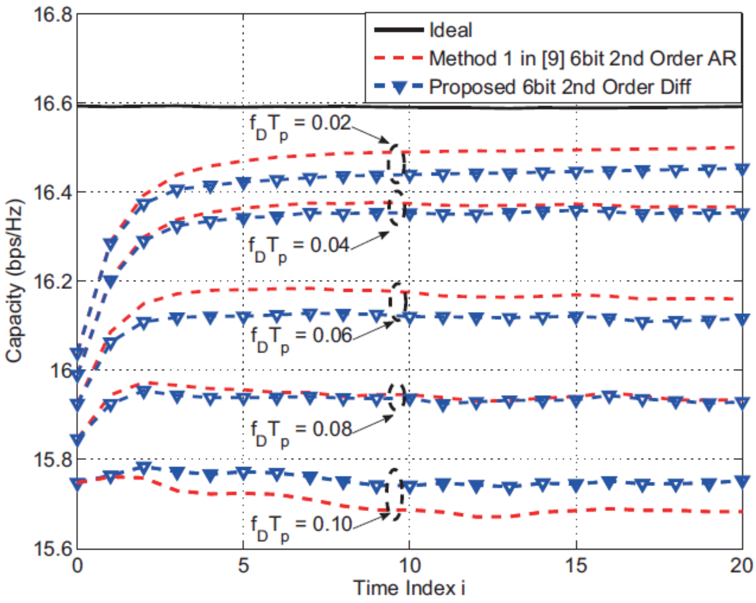


Figure 2 Capacity versus update time ($N_r = N_t = 4, M = 2, B = 6$, SNR=20 dB and the channels are generated as first order Gauss-Markov process)

Fig. 2 shows the achievable capacity versus update time when the channels were generated as the first order Gauss-Markov process. It can be seen that the proposed self-adaptive scheme improves the system throughput in the same way as the conventional scheme does. The capacity of the proposed scheme is almost the same as that of conventional schemes when $f_DT_p = 0.04, 0.08$, is inferior to the conventional scheme when $f_DT_p = 0.02, 0.06$, and better when $f_DT_p = 0.10$. The performance degradation is caused by the value of $r(1)$ and the discrete value of Δ_l. Also, since the Kalman prediction based on the AR model has the knowledge of f_D, its accuracy is higher than the prediction based on the differential model. When the channel varies fast, i.e., f_DT_p = 0.10, the local focus area of the conventional scheme may fail to cover almost all the channel direction $\mathbf{V}_M(i)$, while the proposed scheme can adjust its focus area size at each realization, which provides better performance.

In this study, an adaptive codebook precoding scheme for time-varying MIMO channels with feedback delay has been proposed. The proposed scheme updates its codebook on the basis of the SCC approach. In contrast with the conventional radius calculation for SCC, the proposed scheme does not need additional feedback of the cap radius or offline radius calculation, but only adapts the radius according to a previously selected codeword. In addition, the Kalman filter using the differential model as its process equation is employed to predict MIMO channels and select a suitable codeword from the codebook. Since the Kalman filter does not require information on the maximum Doppler frequency f_D, the proposed scheme that is a combination of the selfadaptive SCC and the Kalman filter can work well even when f_D is not exactly known. Computer simulations under 4×4 MIMO channels with 2 data streams and a 6-bit codebook have demonstrated that when the first order Gauss-Markov process is used as the channel model, the proposed scheme can improve the system capacity in the same way as the conventional schemes does, which needs exact information on f_D in contrast with the proposed scheme. When Jake's model is used as the channel model, is has been shown that the proposed self-adaptive SCC can still provide considerable capacity gain, while the conventional scheme cannot maintain the good performance.

Intercell-Interference Cancellation and Neural Network Transmit Power Optimization for MIMO Channels [2]

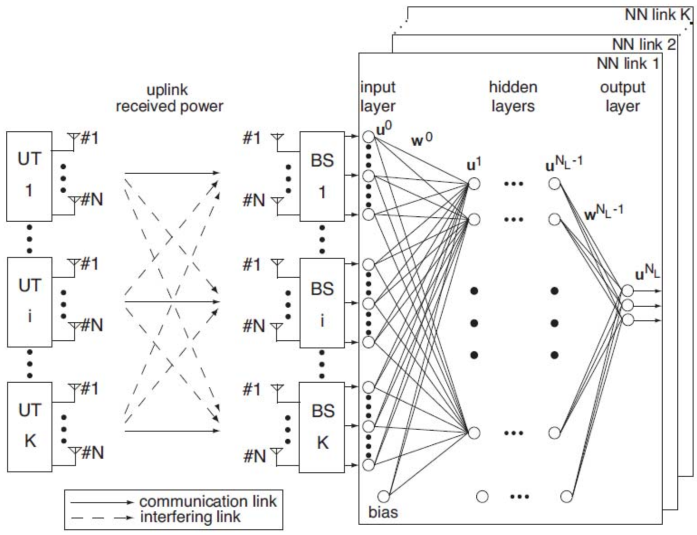


Figure 3 Neural network structure for power control

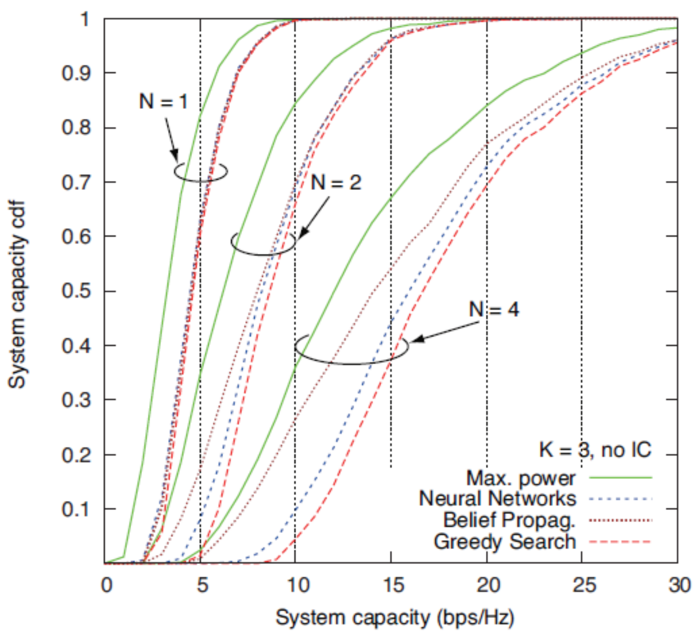


Figure 4 Network capacity cdf by various power control schemes

Cellular systems are expected to employ compact sized base stations (BSs) such as femtocell, also known as Home e Node B (H(e)NB) in order to increase the capacity in the long term evolution (LTE) systems. In contrast with the conventional system design, small cells are arranged in an unplanned manner inside the service area. The small cells may generate strong interference due to overlapping coverage among cells, which deteriorates the overall network capacity. To cope with this problem, intercell interference management (IIM) is inevitable.

One of the most common methods for IIM is the intercell interference coordination (ICIC). Over the past years, various ICIC schemes have been proposed. Besides the ICIC schemes, interference cancellation (IC) is a promising technique to cope with interference-limited networks.

In scientific literature, a power control scheme using the belief propagation (BP) message passing algorithm has been proposed. The BP algorithm evaluates marginal probability distributions of BS power levels so as to maximize a network objective utility function. During the optimization process, rounds of message exchange between BSs and user terminals (UTs) are carried out over the air. The nature of iterative computation in the BP scheme makes it unsuitable for real systems, especially time-varying networks.

Let us consider a network of multiple-input multiple-output (MIMO) systems as shown in Fig. 3, where the numbers of BSs and UTs are equal to K. BSs and UTs are equipped with N antennas. BSs, which constitute small cells, and UTs are randomly distributed in the service area. All BSs are connected over a backhaul to an IIM equipment that receives channel state information (CSI) from BSs and that optimizes transmit power levels of BSs for ICIC. CSI is assumed to be perfectly estimated. UT requests to access the BS that provides the strongest average received power. One BS exclusively communicates with one UT. Synchronization between BSs and UTs are assumed to be perfect.

Fig. 4 shows CDFs of capacities of the four algorithms when $N = 1,2,4,\ K = 3$, and no IC is employed on the UT side ($\varphi_i = \emptyset$ or $M = 0$). As for neural networks (NN), 2-layer NN with 200 hidden nodes is used. The capacity increases along with N, the number of MIMO streams. Both the curves of

NN and BP are close to each other, and approaching the performance bound in a high capacity region. BP and NN algorithms degrade as N increase, where NN algorithm achieves the minimum capacity loss, especially in the MIMO case.

Iterative Reception Employing Sparse Channel Estimation for OFDM Systems [3]

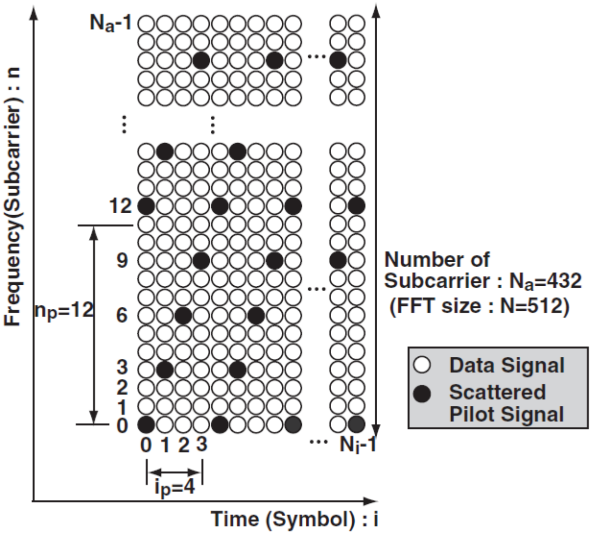


Figure 5 Allocation of SP signals

OFDM, which can realize high speed and reliable transmission over multipath fading channels, is practically employed in the integrated services digital broadcasting-terrestrial (ISDBT), the downlink of long term evolution (LTE) and other mobile communication systems. Since the receiver in ISDB-T moves rapidly, the channel fluctuates fast due to the Doppler effect and the channel estimation accuracy deteriorates significantly. In addition, since there are not many delayed paths in real propagation environments, most of the taps of the channel impulse response (IR) have small absolute values and are negligible. These channels become frequency selective and sparse. In order to alleviate the deterioration of the channel estimation accuracy in the fast fading environment, the iterative channel estimation scheme with the tap selection and the least mean squares (LMS) algorithm utilizing the log-likelihood ratio (LLR) output from the channel decoder has been studied.

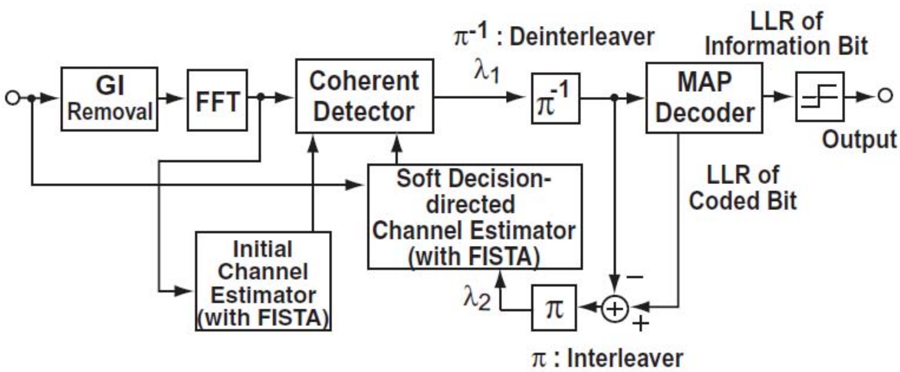


Figure 6 A block diagram of the proposed OFDM receiver

On the other hand, the sparse optimization methods have been actively studied in the fields of signal processing and applied mathematics in recent years, and many mathematical methods of which estimation performance is guaranteed have been proposed. Moreover, channel estimation schemes that employ the sparse optimization method like compressed sensing have been investigated, and they have superior performance to conventional least squares methods. In this paper, the sparse optimization method with L1-norm regularization, called fast iterative shrinkage-thresholding algorithm (FISTA) is employed for the channel estimation. FISTA estimates the channel using the scattered-pilots (SPs) inserted as in Fig. 5 in several symbols, in the initial process. Then, for further improvement of the channel estimation accuracy, FISTA estimates the channel again using the replicas of transmitted signals that are generated from the LLR output of the decoder, in the iterative process.

Fig. 6 shows a block diagram of the proposed OFDM receiver employing the sparse channel estimation. The proposed receiver is an enhanced version of the conventional OFDM receiver. The sparse optimization method is employed in ICE and SDCE and thus the adaptive tap selector is unnecessary. ICE estimates IR by FISTA using SPs, and SDCE also updates the estimate of IR by FISTA using the replicas of the transmitted signals.

Computer simulations are conducted under the condition of ISDB-T with the SP-OFDM signal. It is shown that the proposed scheme achieves excellent BER performance in a sparse and fast fading channel environment. In order to maintain the good BER performance of scattered-pilots OFDM in fast sparse fading environments, the sparse optimization method with L1-norm regularization, called fast iterative shrinkage-thresholding algorithm (FISTA) was applied to the channel estimation of the proposed receiver. The proposed receiver estimates the channel impulse response by FISTA using SPs of several symbols in the initial process. Furthermore, when any errors are detected, the receiver generates replicas of transmitted signals by using LLR that MAP decoder provides. Then, the receiver improves BER performance by repeating procedures of SDCE, the coherent detector and the MAP decoder. For evaluating the performance of the proposed scheme, computer simulations following ISDB-T with SP-OFDM were conducted. It was shown that the proposed scheme acquires about 3 dB average E_b/N_0 gain at the average BER of 10^{-4}, and can maintain the average BER of 10^{-3} up to $f_D T_s$ of 0.14 when average E_b/N_0 is 10 dB. It was also demonstrated that the proposed scheme achieves significant improvement compared with the conventional scheme.

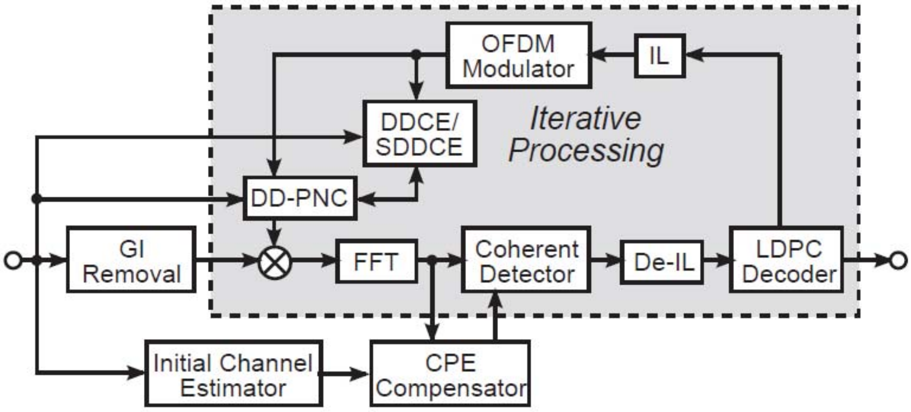


Figure 7 A block diagram of the OFDM iterative receiver

Iterative Receiver for Millimeter-Wave OFDM Systems: Evaluation of High Doppler Shift by Dynamic Channel Model [4]

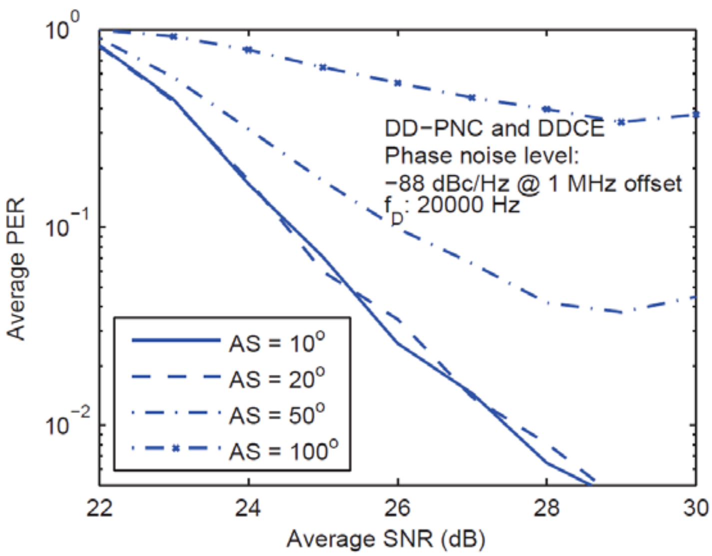


Figure 8 PER performance of DD-PNC and DDCE

Millimeter-wave (mm-wave) wireless systems using 60 GHz band have been extensively studied. Specifically, wireless personal area network (WPAN) standard, IEEE 802.15.3c, has also employed 60 GHz WPAN with orthogonal frequency division multiplexing (OFDM). Mmwave OFDM system can achieve as high data rate as multiple giga bits per second (Gbps). However, it is highly sensitive to the carrier frequency offset and the relatively large phase noise from the phase locked loop (PLL) synthesizer. An iterative receiver scheme, proposed in our previous works, employs decision directed phase noise compensation (DD-PNC) and decision directed channel estimation (DDCE), thus can effectively reduce the effects of the phase noise. In addition, the performance of the proposed scheme with low density parity check (LDPC) coding and decoding also has been demonstrated by a 10 Gbps mm-wave OFDM experimental system.

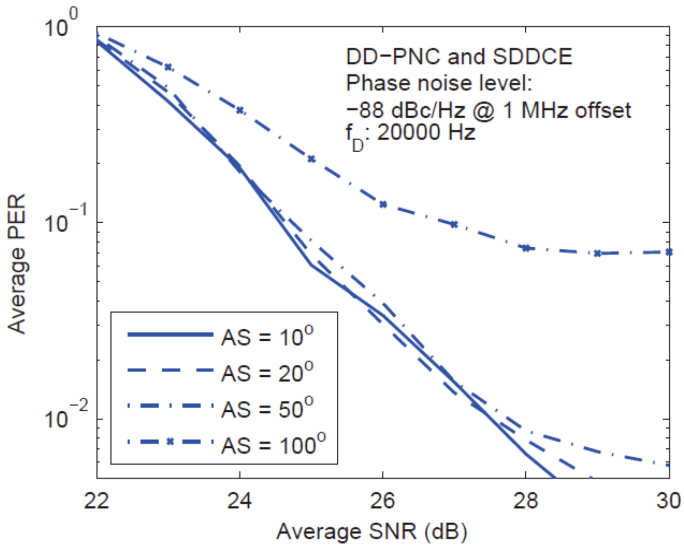


Figure 9 PER performance of DD-PNC and SDDDCE

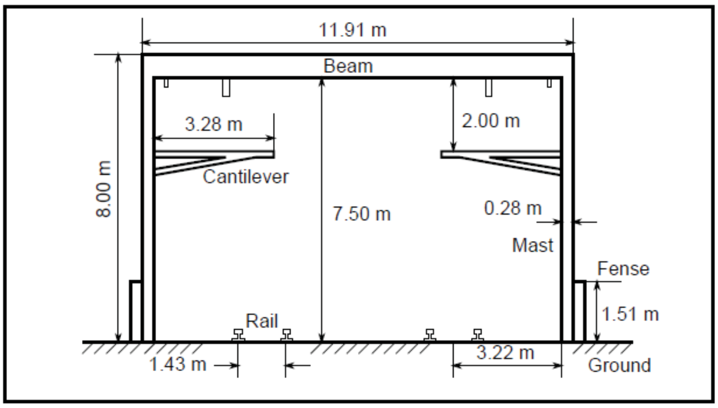


Figure 10 The front view of the HST environment

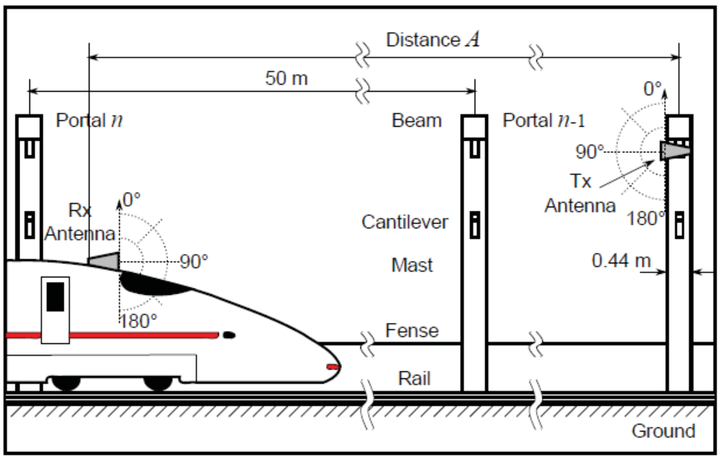


Figure 11 The side view of the HST environment

Fig. 7 shows the block diagram of the proposed iterative receiving process employing DD-PNC and DDCE. In the initial process, the ICE first estimates the channel impulse response (IR) and transfer function (TF) with the second preamble; then the CPE compensator estimates the mean of the phase noise including the effect of Doppler shift during one OFDM symbol by using pilot subcarriers. Then, the coherent detector provides soft decision of the coded bits with the estimated CPE and TF. After deinterleaving (De-IL) the soft decisions, the channel decode is conducted with the LDPC decoder. If the decision error is detected from the decoded bits by the parity check matrix of the LDPC decoder, the initial process is shifted to the iterative process. In the iterative process, the OFDM modulator first generates a transmitted signal replica with the LDPC decoded bits. Next, DD-PNC recursively estimates the phase noise including the effect of Doppler shift by the least mean square (LMS) algorithm with the replica; and then the received signal is compensated with the estimated phase noise. Moreover, DDCE using the compensated received signal to get the accuracy improved channel information that will be used in the next iteration. After that, the coherent detection is carried out for the compensated signal. The iterative process is repeated until the number of iterations exceeds a predetermined threshold or no decision error is detected.

On the other hand, applications of mm-wave to high mobility wireless communication scenarios such as high speed trains (HSTs) have been discussed in the literature. In HST scenarios, not only phase noise but also Doppler shift should be considered. In this paper, we evaluate the iterative scheme with DD-PNC and DDCE in the HST environment by using a dynamic multipath channel model. Computer simulations show that the proposed scheme can reduce not only the effects of phase noise but also that of the Doppler shift, when angle spread (AS) of channel is small. However, when AS becomes larger, it is demonstrated that the performance of the proposed scheme degrades.

For alleviating the degradation, we modify DDCE into a symbol by symbol manner, symbol-DDCE (SDDCE) that improves the performance remarkably.

In Figs. 8 and 9, we show the PER performances of the receiver with DDCE and SDDCE, respectively, in a much severe situation that f_D is 20000 Hz. In Fig. 8, when AS is 10° or 20° the DDCE still keeps good PER performance; however, when AS is larger than 50°, the performance degrades. On the other hand, in Fig. 9, when AS is smaller than 50°, the SDDCE keeps much better PER performance than DDCE.

Propagation Analysis with Ray Tracing Method for High Speed Train Environments at 60 GHz [5]

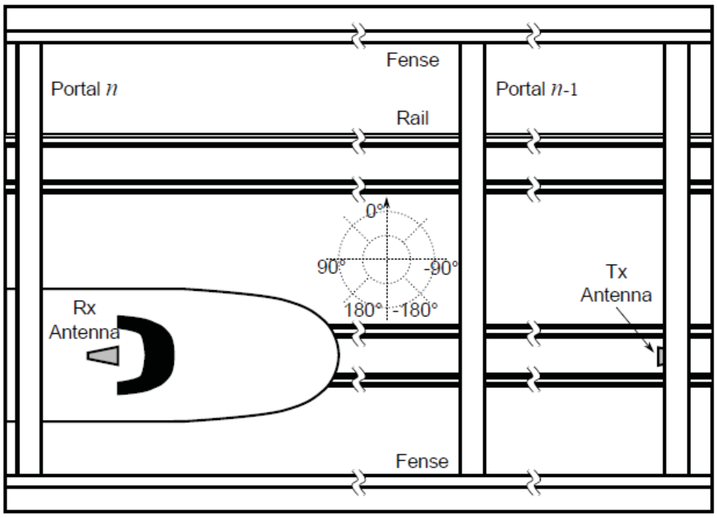


Figure 12 The top view of the HST environment

Millimeter-wave (mm-wave) wireless systems using 60 GHz band have been extensively studied. Specifically, wireless personal area network (WPAN) standard, IEEE 802.15.3c, has also employed 60 GHz WPAN with orthogonal frequency division multiplexing (OFDM). The mm-wave OFDM system can achieve as high data rate as multiple giga bits per second (Gbps). However, it is highly sensitive to the carrier frequency offset and the relatively large phase noise from the phase locked loop synthesizer. On the other hand, applications of mm-wave to high mobility wireless communication scenarios such as high speed trains (HSTs) have been discussed in the literature. In the HST scenarios, not only phase noise but also Doppler shift should be considered. Our proposed iterative phase noise compensation method was evaluated with a dynamic channel model with high Doppler shift.

Table I Average number of clusters

Section	A. 20 to 100 m	B. 102 to 200 m	C. 202 to 300 m
Aver. No. of clusters	2.61	5.02	7.08
Section	D. 302 to 400 m	E. 402 to 500 m	F. 20 to 500 m
Aver. No. of clusters	8.96	9.92	6.87

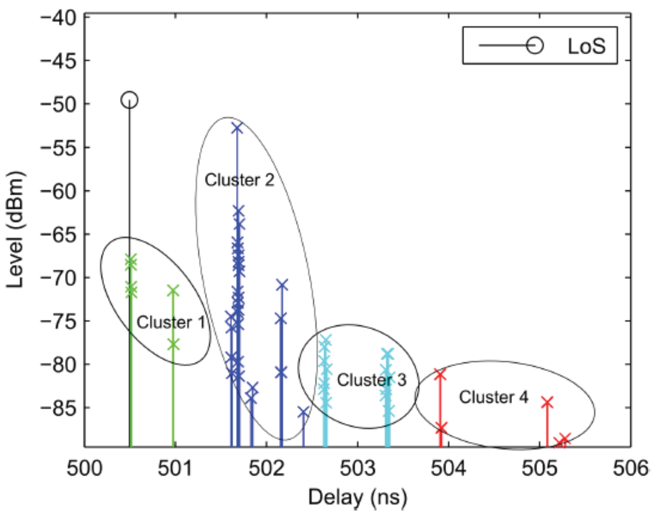


Figure 13 Power delay profile (distance A: 150 m)

The efficacy of the iterative method, employing symbol level decision directed channel estimation (SDDCE), was demonstrated with a dynamic channel model. However, parameters of the channel model need to be obtained further for the HST environments.

In this paper, we construct a linear HST environment, and analyse the propagation characteristics of the HST scenario with a ray tracing method at 60 GHz band. With the simulation, we obtain the received power, the K factor of the Rician model, delay spread, and angular spread characteristics of the HST environment. We also complete the dynamic channel model with the obtained statistical parameters, which can simulate the dynamic channel fluctuation due to the Doppler shift.

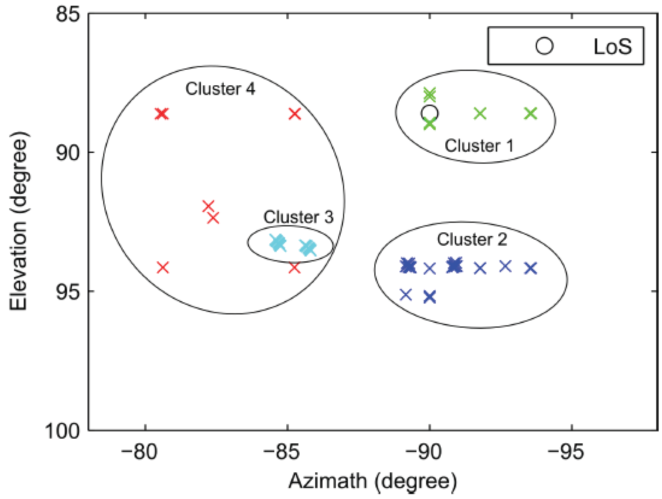


Figure 14 AoA plot (distance D: 150 m)

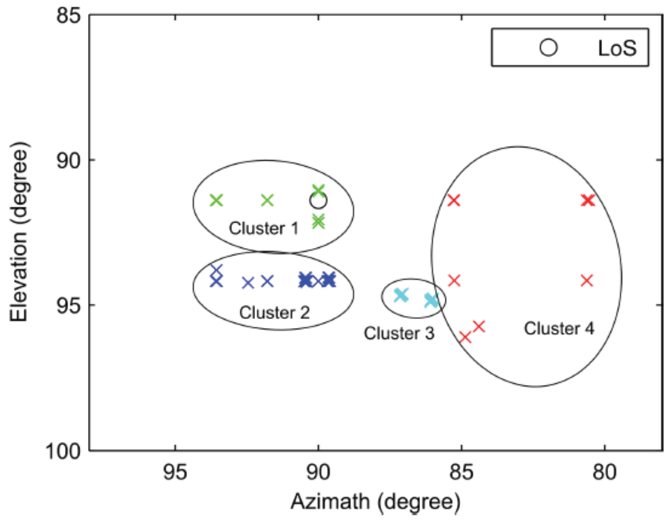


Figure 15 AoD plot (distance A: 150 m)

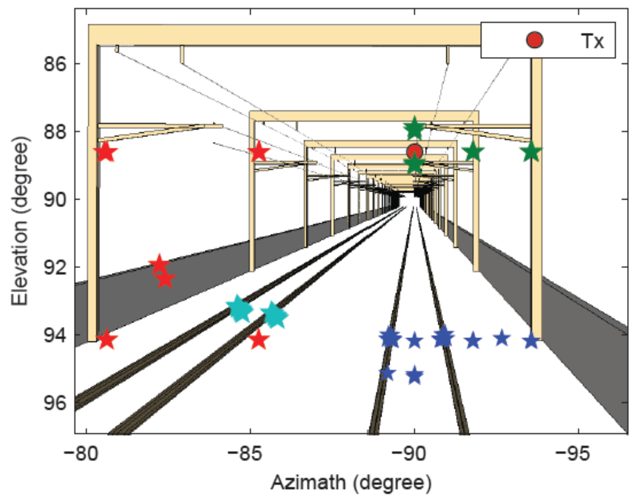


Figure 16 The arrived waves looked from the received antenna (distance A: 150 m)

Figs. 10, 11 and 12 show a considered linear HST environment including one transmitter (Tx) and one receiver (Rx). The front view of the HST environment is shown in Fig. 10, in where an overhead line portal consists of two masts, two cantilevers and one beam is shown; and there are also two sets of rails and two fences in this environment. The material of the portal and the rails is steel, and that of the fences and ground is concrete. Fig. 11 shows the side view of the HST environment, where the intervals between the portals are all 50 m, and the distance between the Rx antenna and the portal equipped with Tx antenna is defined as A. The angle coordinates in Fig. 11 indicate the elevation angles of the Tx and Rx antennas. Tx and Rx antennas have directivity and the tilt angles of the Tx and Rx are set to point to each other when A = 500 m. Fig. 12 shows the top view of the HST environment, where the angle coordinate indicates the azimuth angle of the Tx or Rx antenna; and the moving direction of the train is set toward −90°. The propagation simulation is conducted at every 2 m point in the interval A = 2 to 500 m with ray tracing simulator, RapLab. It is noted that the body of train is not included in the propagation simulation. We get the information of paths of each point, and for simplifying the analysis, we let 300 time delay shortest paths remain. From the remained paths, we select the paths that have the received powers are larger then the threshold that set as 40 dB lower than the maximum received power of path at the point; but when the threshold is smaller than −100 dBm, it is set as −100 dBm. It has been confirmed that the selected paths contain almost the power of the remained paths. The maximum and average numbers of selected paths are 190 and 98.0, respectively.

Table I shows the resulted average number of clusters in different distance section of A. The example of clustering results are shown in Figs. 13, 14, 15 and 16, that are the power delay profile, AoA and AoD plots at the point A = 150 m, where the NLoS paths are grouped into 4 clusters. We also plot the AoA onto the picture looked from the Rx antenna, and the clustering results is considered reasonable in geometric optics sense.

CONTRIBUTIONS

TAKADA LAB

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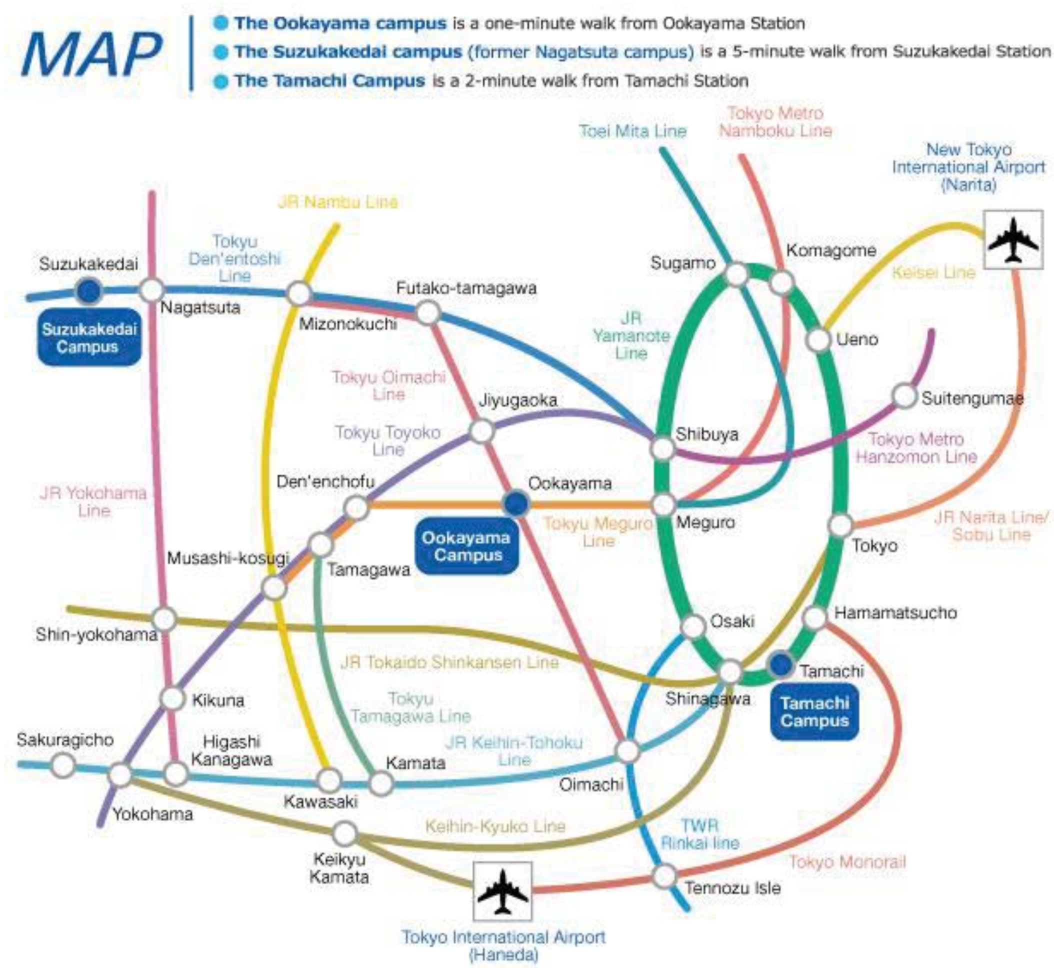

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2-12-1 Ookayama, Meguro-ku, Tokyo 152-8550, JAPAN