TOKYO TECH
Pursuing Excellence

Mobile Communications Research Group
Tokyo Institute of Technology

2008 Annual Report

MCRG
Tokyo Tech

Contents

TOKYO INSTITUTE OF TECHNOLOGY

Leading the world in science and technology, Tokyo Institute of Technology continues to evolve.

Tokyo Institute of Technology, or Tokyo Tech in short, was founded by the Japanese Government, Department of Education, as the Tokyo Vocatioanl Shool in 1881, and then renamed Tokyo Kogyo Daigaku (Tokyo Institute of Technology), in 1929. Following a brilliant history and tradition spanning over 126 years, Tokyo Institute of Technology continues to evolve as one of the world leading science and technology universities of the 21st century.

To be recognized as one of the world-class science and technology universities, Tokyo Tech fosters world-class graduates, develops new frontiers of world-class knowledge, and benefit society through transfer of knowledge by having:

- Three Undergraduate Schools: School of Science, School of Engineering, School of Bioscience and Biotechnology
- Graduate Schools: Graduate School of Science and Engineering, Graduate School of Bioscience and Biotechnology, Interdisciplinary Graduate School of Science and Engineering, Graduate School of Information Science and Engineering, Graduate School of Decision Science and Technology, and Graduate School of Innovation Management.
- Other Research Laboratories.

Tokyo Tech is committed to the following missions:

1. Producing world-class graduates
2. Creating world-class knowledge
3. Contributing to society through the utilization of knowledge

Tokyo Tech seeks to maintain the highest standard in its every mission.

(Information resources:http://www.titech.ac.jp/ and 2006 profile of Tokyo Institute of Technology.)

Tokyo Tech Logo

The logo 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 part represents the Japanese character [大], which is the first character of 'university' (大学). This figure also symbolizes a swallow, which the Japanese regard a bird of good-luck.

Tokyo Tech

Over the years, Tokyo Institute of Technology or 東京工業大学 (*Tokyo Kogyo Daigaku*) in Japanese had been described in several short names both in English and Japanese. In 2002, the university officially adopted "Tokyo Tech" as the international and "東工大" (*Tokodai*) as the Japanese abbreviation.

School Color

In 2004, Tokyo Tech resolved that its school color would be royal blue, the color that stands for advancement and evolution.

Mobile Communications 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
   (Staff: Prof. Hiroshi Suzuki, Associate Prof. Kazuhiko Fukawa, and Assistant Prof. Satoshi Suyama)
2. System laboratory
   (Staff: Prof. Kiyomichi Araki, and Associate Prof. Kei Sakaguchi)
3. Propagation and Antenna laboratory
   (Staff: 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 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.

Environment of the weekly seminar

MCRG members

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

In the 2008 Open House, five invited lectures were held and we would like to take this opportunity to express our thanks and appreciation to Dr. Hitoshi YOSHINO of NTT DoCoMo, Dr. Ki-Ho KIM of Samsung Electronics, Dr. Shinichi NOMOTO of KDDI R&D Laboratories, and Prof. Masao NAKAGAWA (Keio University.) for their valuable contribution to the Open House.

Visit our website at http://www.mcrg.ee.titech.ac.jp/

Laboratory Introduction
&
Annual Report 2008

TAKADA LABORATORY

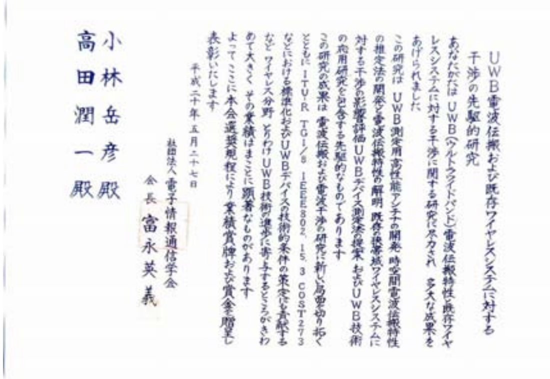
Professor Jun-ichi TAKADA

was born in Tokyo, Japan, in 1964. He received the B.E., M.E., and D.E. degrees from the Tokyo Institute of Technology in 1987, 1989, and 1992 respectively. From 1992 to 1994, he was a Research Associate at Chiba University. From 1994 to 2006, he was an Associate Professor at the Tokyo Institute of Technology, where he has been a Professor since 2006. He was also a part time researcher in National Institute of Information and Communications Technology from 2003 to 2007. He is currently the chair of IEICE Technical Committee on Software Radio, and the co-chair of Special Interest Group on Body Communications in European COST Action 2100 “Pervasive Mobile & Ambient Wireless Communications.” His current research interests are wireless propagation and channel modeling, cognitive radio, and application of wireless communication and information technology for regional/rural development. He is a member of IEEE, IEICE, ACES, ECTI Association Thailand, and JASID.

Assistant Professor Minseok Kim

Asst. Prof. Kim was born in Seoul, Republic of Korea. He received the B.S. degree in Electrical Engineering from Hanyang University, Seoul, Korea, M.E. and Ph.D. degrees in Division of Electrical and Computer Engineering, Yokohama National University (YNU), Japan in 1999, 2002 and 2005, respectively. He was with a startup company from 2005 and has experienced H/W and S/W development of various embedded system. 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. His research interests include digital signal processor implementation, raido propagation measurement, array signal processing, smart antenna system, software defined radio / cognitive radio. He is a member of IEEE and IEICE.

Awards of Takada Laboratory



UWB電波伝搬および既存ワイヤレスシステムに対する
干渉の先駆的研究

あなたがたはUWB(ウルトラワイドバンド)電波伝搬特性と既存ワイヤ
レスシステムに対する干渉に関する研究に尽力され　多大な成果を
あげられました
この研究は　UWB測定用高性能アンテナの開発　時空間電波伝搬特性
の推定法の開発と電波伝搬特性の解明　既存狭帯域ワイヤレスシステムに
対する干渉の影響評価UWBデバイス測定法の提案　およびUWB技術
の応用研究を包含する先駆的なものであります
この研究の成果は　電波伝搬および電波干渉の研究に新しい局面を切り拓く
とともに　ITU-R TG1/8　IEEE802.15.3　COST273
などにおける標準化およびUWBデバイスの技術的条件の策定にも貢献する
など　ワイヤレス分野とりわけUWB技術の進歩に寄与するところがきわ
めて大きく　その業績はまことに顕著なものがあります
よってここに本会選奨規程により業績賞牌および賞金を贈呈し
表彰いたします

平成二十年五月二十七日

社団法人電子情報通信学会
会長　富永英義

小林岳彦　殿
高田潤一　殿

Professor Takada won IEICE Achievement Award May 27, 2008

Kimtho won 2007 Young Investigator Award in Software Radio May 29, 2008

International Symposium on Antennas and Propagation

Certificate of
Best Student Paper Award

Awarded to
Yukiko Kishiki

Paper titled:
Improvement of 3D Ray Tracing Simulation in Microcell Environment by Introducing the Complex Radar Cross Section

In recognition of
Your excellent presentation

30 October 2008

Dau-Chyrh Chang
General Chair of ISAP 2008

International Symposium on Antennas and Propagation

Certificate of
Best Student Paper Award

Awarded to
Lawrence Materum

Paper titled:
Improved Multipath Clustering of a Small Urban Macrocellular MIMO Environment at 4.5 GHz

In recognition of
Your excellent presentation

30, October, 2008

Dau-Chyrh Chang
General Chair of ISAP 2008

Lawrence & Kishiki won ISAP'08 Best student paper award Oct. 30, 2008

Member of Takada Laboratory

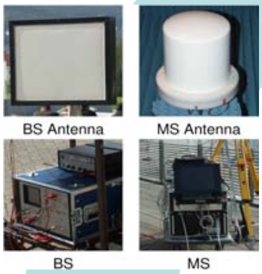
TAKADA LABORATORY

Recent Research Topics

Recent Research Topics

Channel Characterization and Modeling for Wireless Communication Systems

- Comparison of directional channel measurement and ray-tracing simulation in street microcell
- Application of radar cross section in ray-tracing for prediction of microcell propagation channels
- Frequency characteristic of propagation loss through foliage
- Spatio-temporal multipath clustering of wideband MIMO channel at the mobile station
- Scalable MIMO channel sounder architecture
- Performance evaluation of user terminal array antenna system
- Body area network (BAN) channel measurement and modeling
- Polarization properties of double directional channel



Channel sounding measurement campaign

Cognitive Radio and Software Defined Radio

- Performance analysis of cyclic detectors of OFDM signals
- Implementation issues of spectrum sensing in cognitive radio
- Spectrum sensing prototype implementation for ISDB-T signal
- Evaluation of open source software defined radio platform using GNU radio and USRP (universal software radio peripherals)

Instrumental Signal Processing

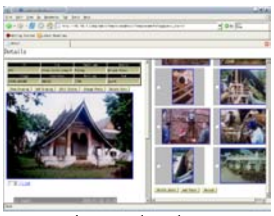
- UWB delay estimation
- Spherical harmonics modeling of directional channel
- Evaluation of EMC anechoic chamber

BAN channel measurement

GNU Radio Peripherals

ICT Applications for International Development

- ICT applications for sustainable development of world heritage site of Luang Prabang, Lao PDR
- ICT Applications for teacher training in rural schools of Mongolia



Heritage database

Local ICT center

VCD teacher training

Body Area Network Channel Measurement and Modeling

Introduction

As a growing interest in the body centric wireless communication technology has been taken in various applications including medical, health care and consumer electric industry for entertainment and etc., the body area network (BAN) has become more important to connect some devices around the human body. IEEE 802.15.6 BAN is currently discussing the standardization of body area network mainly for medical and health care applications. The most significant difference of BAN from existing wireless networks is that the radio propagation channel necessarily includes the human body itself, which plays an important role in radio propagation mechanism directly.

In wireless BAN channels on the body surface, some mutual interactions between body and antenna can occur. The transmitting signal usually arrives at the receiver with large propagation loss due to the absorption by the human body, impedance mismatch and the body movement. Therefore, this study is focusing on introducing a proper model for body interaction in body surface channel.

Dynamic BAN Channel Measurement

The body movement in channel fading is a primary factor and hence channel modeling must include the effect of movement. In this report, dynamic channel measurement results using a real-time channel sounding system which is suitable to capture the dynamic behavior of the human body are introduced. This is our original contribution on IEEE 802.15.6 standardization for dynamic channel model [*], where the dynamic channel behavior is statistically modeled by the path gain at various positions on the surface of the human body. The following figures shows a result that was measured by channel sounder at 4.5 GHz with the bandwidth of 120 MHz. Now we are trying to observe dependancies of human and frequency and plan to measure for further study.

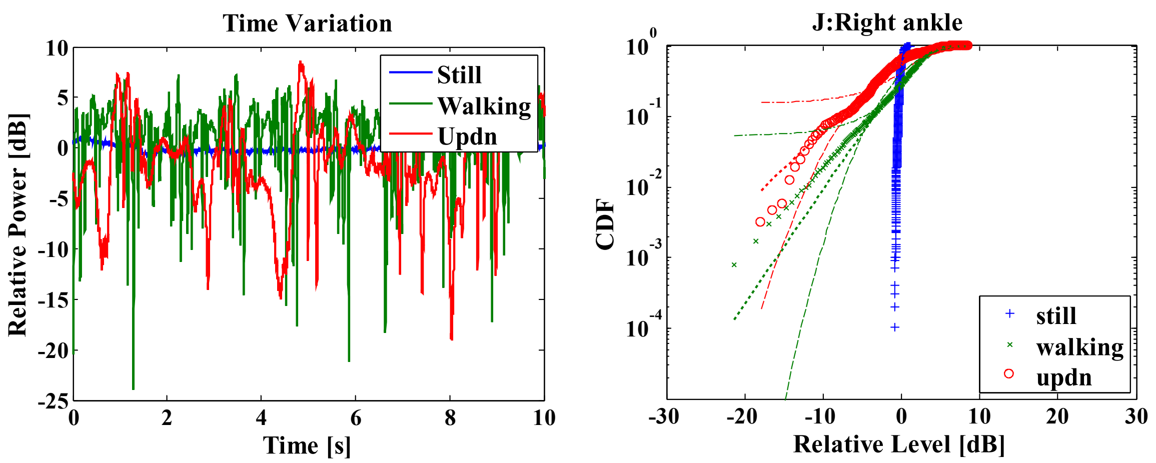


Figure: (a) Path gain variation in a movement scenario and (b) cumulative distribution of the path gain (dashed line : log-normal distribution fitting and dotted line: Weibull distribution fitting)

[*] M. Kim et al., "Statistical Property of Dynamic BAN Channel Gain at 4.5GHz," IEEE 802.15 Working Group for Wireless Personal Area Network, IEEE 802.15-08-0489-01-0006, July 2008 (Denver, Co, USA).

Body Area Network Channel Measurement and Modeling

TAKADA LABORATORY

Modeling of non-specular scattering for the prediction of microcell environment

Modeling of non-specular scattering for the prediction of microcell environment

Introduction

In microcell environment, the dominant propagation mechanisms are not only from reflections and diffractions from buildings but can also come from non-specular scatterings. Propagation prediction tools such as ray-tracing algorithms which calculate only reflections and diffractions are hence not enough to completely predict the channel. To address this issue, an implementation called polygon meshed physical optics (polygon meshed PO) is used.

Measurement Scenario and Data Processing

To know the actual propagation channel, wideband measurement was performed inside TiTech university campus. With antenna arrays on both the transmit and receive sides, wideband double-directional channel characteristics such as azimuth-delay power spectrum can be obtained after applying the beamforming and match filtering.

Results and Discussion

Ray-tracing simulation (Raplab) can predict the arrival of strong signals due to specular. After incorporating polygon mesh PO with Raplab, the second peak can be observed. These metallic objects have effects in the propagation channel

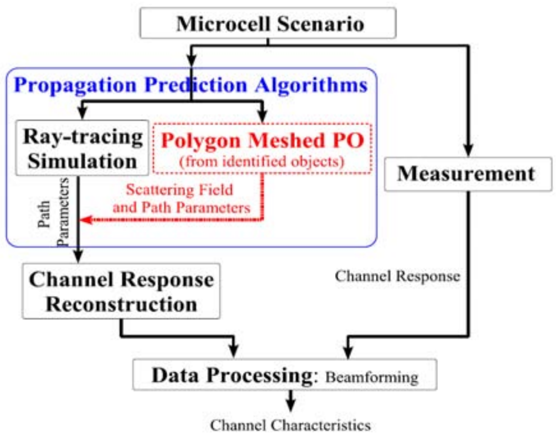


Fig.1 : Outline of this approach taken to investigate non-specular scattering

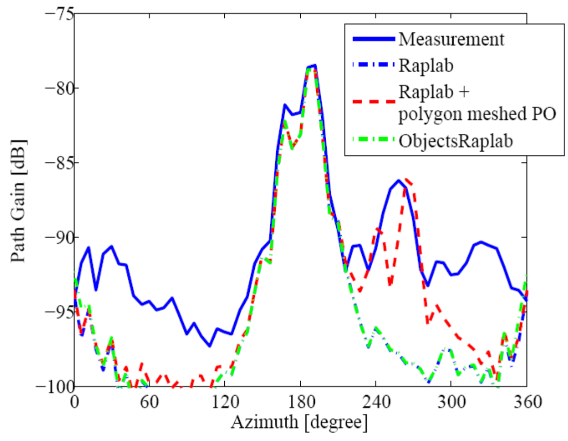


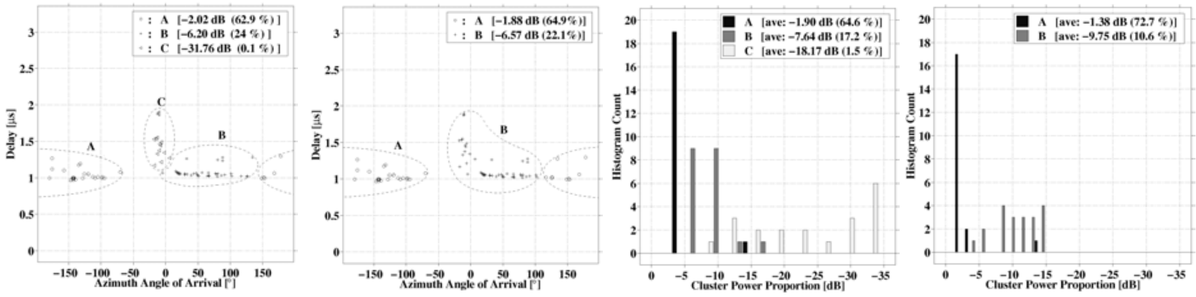
Fig.2:Comparison of azimuth spectrum among four cases

Conclusion

Comparison of measurement and simulation results reveals that small metallic objects cause non-specular scattering and affect the propagation channel. These objects can be predicted by the proposed polygon meshed PO in cooperation with ray tracing.

Multipath Clustering of a Small Urban Macrocell at 4.5 GHz

Understanding multipath clusters includes identifying them in a satisfactorily accurate way. However, as large data sets from channel sounding have made the manual identification of clusters cumbersome, the use of clustering algorithms has been a resort. Using a ML multidimensional estimation, path parameters such as the time delay, direction of departure and arrival, and complex polarimetric path weights were extracted from channel sounding results of small urban macrocell at 4.5 GHz. Clusterization was performed using K-means clustering with Simulated Annealing. The best number of clusters was determined by Average Rank Aggregation.

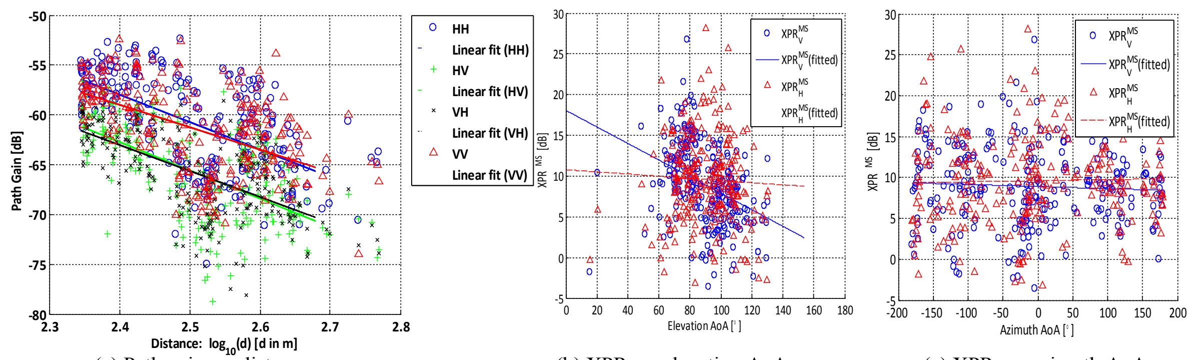


(a) Two clusters (b) Three clusters (c) Entire route; two clusters (d) Entire route; two clusters

Results considering the cluster power and the number of clusters.

Cluster Polarization Analysis of a Small Macrocell

Utilization of polarization diversity in multi-antenna systems has attracted a lot of attention in order to make the mobile terminal compact. Polarization path gain, cross-polarization ratio (XPR), and co-polarization ratio (CPR) characteristics of a small macrocell as influenced by delay, azimuth and elevation angle of arrival (AoA) were investigated. Analysis was done cluster-wise since the goal was to examine degree of depolarization due to dominant multipath mechanisms. The results indicate that HH polarization path gains decay faster than their VV counterparts. The analysis of the behavior of XPR and CPR shows that they are affected by elevation AoA, whereas delay and azimuth AoA do not show any significant impact.



(a) Path gain vs. distance (b) XPR vs. elevation AoA (c) XPR vs. aximuth AoA

Examples of the polarization characteristics (Path gain, XPR at MS)

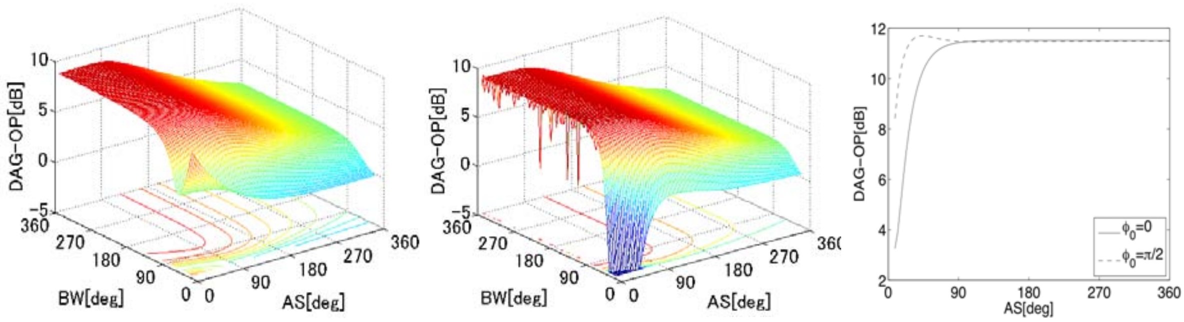
TAKADA LABORATORY

Impact of APS on the Diversity Antenna Gain & UWB Delay Estimation

Impact of Angular Power Spectrum (APS) on the Diversity Antenna Gain

In the multipath environment, the classical parameters to evaluate antenna systems such as directivity and efficiency are not sufficient for evaluation of the performance of the antenna system. The propagation channel should be considered for appropriate evaluation. The so far proposed antenna evaluation models are too simple and unrealistic. We have proposed a simple model using multi-antenna diversity technique to examine the influence of angular power spectrum on the performance evaluation of array antennas in various environments.

We evaluated performance of the unidirectional APS on the direction diversity and space diversity. The figures show the effect of APS on diversity antenna gain for AoA=0[deg] and AoA=90[deg] for direction diversity and space diversity cases. The conclusion is, the unidirectional APS does not have the same behavior as unidirectional APS, when the angular spread is very small, so the omnidirectional APS cannot be used instead of unidirectional APS.



UWB Delay Estimation

Ultra wide band systems have a potential to realize accurate ranging. Threshold based time of arrival based ranging is attractive due to its simplicity. In the conventional threshold based methods, the threshold value is obtained based on noise level.

We introduce a noise level independent threshold, which is postulated on the fact that power of first arrival path (FAP) decreases as transmitter to receiver (Tx-Rx) distance increases. Consequently the threshold value for detecting FAP is Tx-Rx distance dependent (DD). Received samples are then compared to the respective threshold values. The algorithm can be formulated as:

$$\tau_{\text{FAP}} = kT, \quad k = \arg\min_{n} ((z[n] > \xi(nT))$$

where T is the sampling period, $\xi(nT)$ is the threshold value and $z[n]$ is received UWB signal. Figure 1 shows the basics of the proposed method. Figure 2 compared the variance of ranging error of noise based threshold ranging with those obtained from the proposed method. Variance of ranging error decreases in all channels using DD threshold. Moreover this approach is independent from any prior knowledge of the noise level. Important advantage of the proposed method is in using the standard path-loss model.

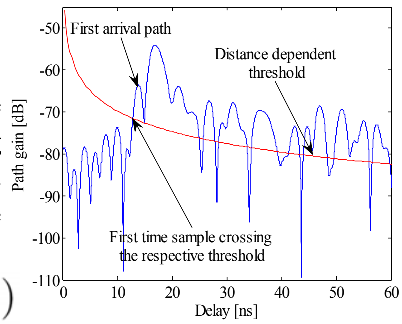


Fig. 1.

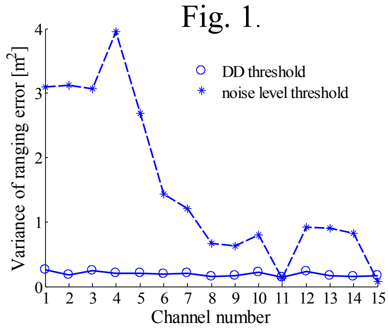
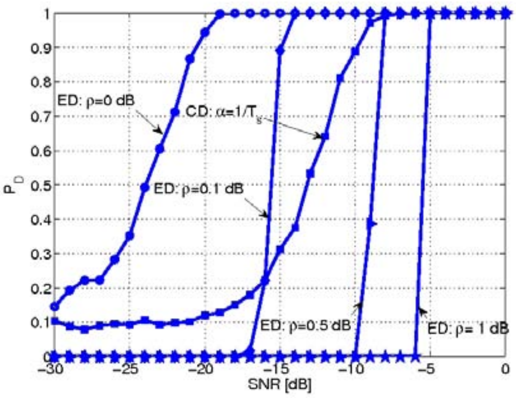


Fig. 2.

Cyclic Detector vs. Energy Detector

Cyclic detector is performed by searching the periodicity of the primary signal while the energy detector is performed by computing the received signal power. The test statistic of cyclic and energy detectors can be defined as follows

$$\mathcal{T}_{\mathrm{IS}}^{\alpha_k}[l] = \sum_{k=1}^{N_\alpha} w_k \mathcal{T}^{\alpha_k}[l] \qquad Z_{\mathrm{ED}} = \sum_{n=0}^{N-1} x[n]x^\star[n]$$



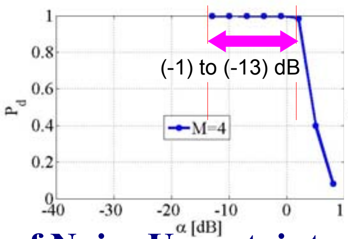
The absent and the present of the signal is defined by comparing the test value with a detection threshold . The detection threshold is calculated for a specified probability of false alarm.

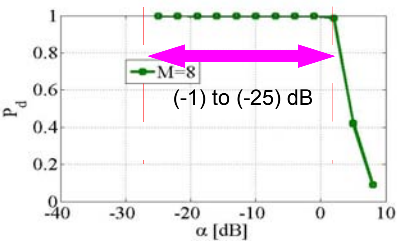
- If the noise power is exactly known, the energy detector performs better than that of the cyclic detector.
- If the effect of the noise uncertainty is considered, the performance of the energy detector is highly degraded.
- For example, if an error of the noise power is about 1 dB, the energy detector cannot detect the signal.
- Therefore, the energy detector is not robust to noise uncertainty while the cyclic detector is.

Effect of Quantization and Noise Uncertainty on the Performance of Energy Detector for CR System

Effect of Quantization

ADC is an inseparable part of any receiver. So, the effect of quantization (including clipping) in detection performance should be considered.

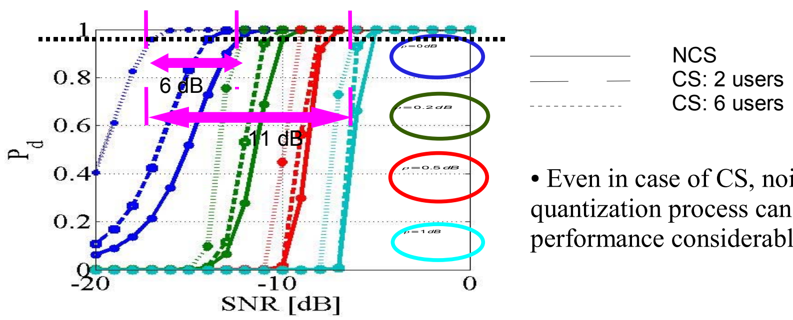




- The range of for acceptable performance depends on M.
- Even with slight increase in , the performance will be drastically affected because of clipping.

Effect of Noise Uncertainty

Thermal noise due to change in temperature, calibration error etc. give rise to noise uncertainty in the system. So, the effect of noise uncertainty (with quantization effect) should also be considered in the detection performance.



- Even in case of CS, noise uncertainty and quantization process can affect the detection performance considerably.

Cyclic Detector vs. Energy Detector & Effect of Quantization on the Performance of Energy Detector

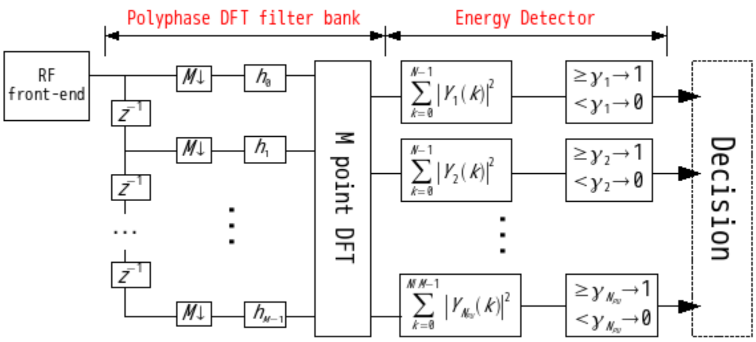
TAKADA LABORATORY

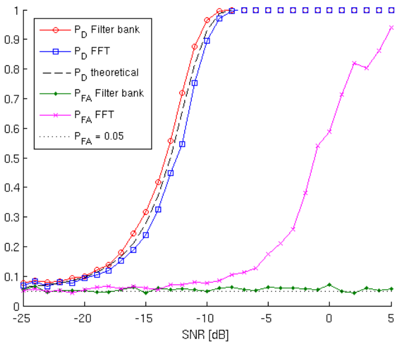
Spectrum sensing by DFT filter bank & Implementing a channel sounder with GNU Radio

Spectrum sensing by DFT filter bank

Spectrum sensing is an important and challenging task in realization of cognitive radios. We propose new sensing architecture for multi-channel environment based on polyphase DFT filter bank followed by energy detectors. The advantage of filter bank is that it enables implementation of M bandpass filters in order to suppress energy leakage from neighboring channel with just one cost of low-pass filter, therefore performance improvement is expected compared to conventional architecture with relatively low cost addition.

We evaluated performance of the proposed architecture by theoretical analysis and simulation. As a result, the proposed architecture show improved Probability of Detection and significantly suppressed Probability of false alarm at high SNR. We also investigated implementation cost by introducing number of multipliers as cost index.





Implementing a channel sounder with GNU Radio

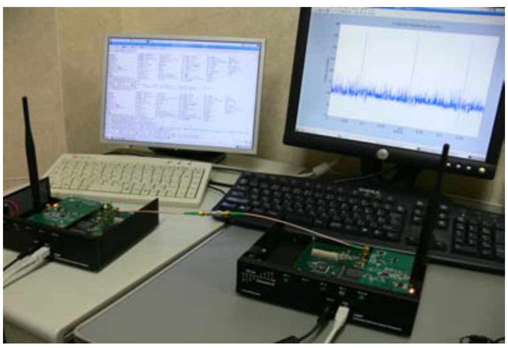


Figure 1

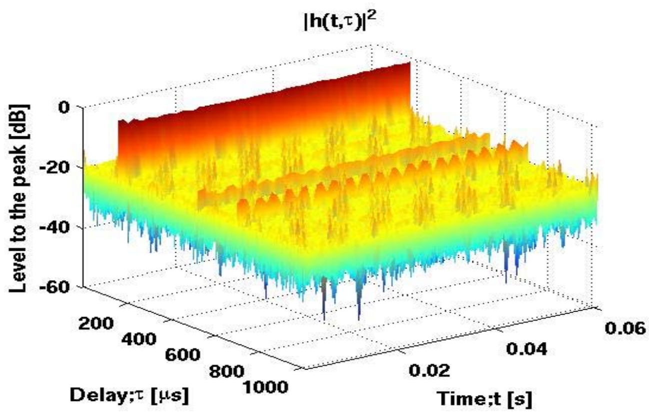


Figure 2

We have been researching about the possible uses of a low cost open source software based software radio platform called GNU Radio. The GNU Radio software works in conjunction with low cost hardware called Universal software radio (USRP), shown in Fig 1. We have subsequently used this system to do channel sounding measurements in line of sight (LOS) and non-line of sight indoor conditions (NLOS). Shown in Fig 2 is a snapshot of the obtained impulse response for NLOS condition. Our channel sounding demonstration shows that the GNU Radio is a promising low cost candidate for this purpose

Introduction of GIS to promote Sustainable Development of World Heritage Site: Luang Prabang, Lao PDR

Introduction

GIS (Geographical Information System) is a system which captures, stores, analyzes, manages and presents data which are linked to geo locations. Poor planning of GIS can lead to failure cases due to high expenses and lack of human resources. Luang Prabang of Lao PDR (Figure 1 and 2), a World Heritage is facing rapid building construction due to high increase of tourist and development pressure. This report describes the collaboration with Local Heritage Office (La Maison du Patrimoine, MdP) to develop a feasible GIS prototype to analyze the impact caused by illegal construction on the historical urban landscape. The trend and severity of illegal construction in the past is highlighted in Figure 3.

Fig 1. Map of Luang Prabang
Source: Texas University Library, (2007)

Fig 2. Luang Prabang landscape
Source: ICT Center, (2006)

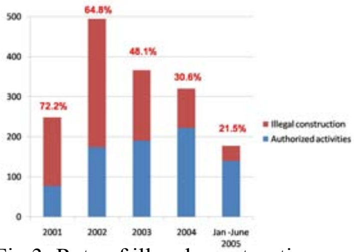


Fig 3. Rate of illegal construction (2001 – June 2005)
Source: MdP Construction Report, (2001 – 2005)

Development of GIS Prototype

Feasible introduction of GIS is essential to effectively reflect local needs and continuously utilized by local officials. Needs assessment was conducted to study the needs local from 11 government departments and identified the crucial components to be incorporated into the prototype (Figure 4). One of the major challenges faced is the adequate and updated data on the buildings built. Hence, current work in developing prototype is to build databases for authorized and unauthorized buildings. The buildings are monitored in accordance preservation regulations.

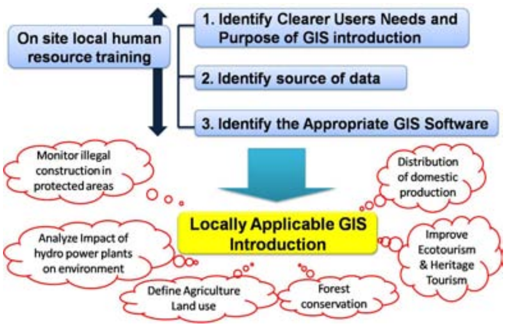


Fig 4. Pre-requisite for development of GIS Prototype
Source: JASID 19th Conference, (2008)

ARAKI SAKAGUCHI LABORATORY

Professor Kiyomichi Araki

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

Associate Professor Kei Sakaguchi

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

Wireless System Laboratory

Digital RF

-Direct Sampling Mixer

- Nonlinear distortion [31]
- Multi-rate system design[13]
- Low Noise design[4]

-Digital processing for nonlinear amplifier

- Analysis of distortions[12]
- Adaptive modulation [18]
- Polar modulation [13]

-MIMO system with parasitic and switchable antenna element

- Antenna configuration[35]
- Parasitic element control

Distributed MIMO

- Base station Cooperation

MIMO Cellular Networks

- Fractional base station cooperation cellular network[11,47]
- Cell planning for base station cooperation [42,43]
- Cooperative scheduling for fractional base station cooperation [47]

-MIMO relay networks

- 2-way MIMO multi-hop relay[26,30]
- 2-D MIMO network coding [9,37]
- Distributed Power control for MIMO relay networks[44]

System Development

- CMOS-IC implementation of direct sampling mixer[33]
- Prototype hardware for MIMO relay networks at 950 Mhz band [15,22]
- 4x4 MIMO fading simulator for LTE, Mobile Wi-MAX, and 802.11n W-LAN[39]
- MIMO terminal antenna design using spherical mode expansion[36,40]

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ARAKI SAKAGUCHI LABORATORY

Characteristic improvement of Direct Sampling Mixer

Characteristic improvement of Direct Sampling Mixer

Recently, RF circuits have been migrated to deep-submicron CMOS processes. The Direct Sampling Mixer (DSM) is friendly with CMOS technology since it consists of MOS switches and capacitors. Moreover, DSM is one of essential elements in Software Defined Radio (SDR) receiver. Down-conversion and finite-impulse-response (FIR) anti-aliasing filtering are done by charge-sampling along with decimation. Infinite-impulse-response (IIR) channel selection filtering is provided by charge sharing in a discrete charge domain. These operations have reconfigurability, and can reduce power consumption and cost of manufacturing in SDR receiver. In other words, DSM is appropriate for the SDR receiver. However, there are still some problems. We have been improved them from several ways.

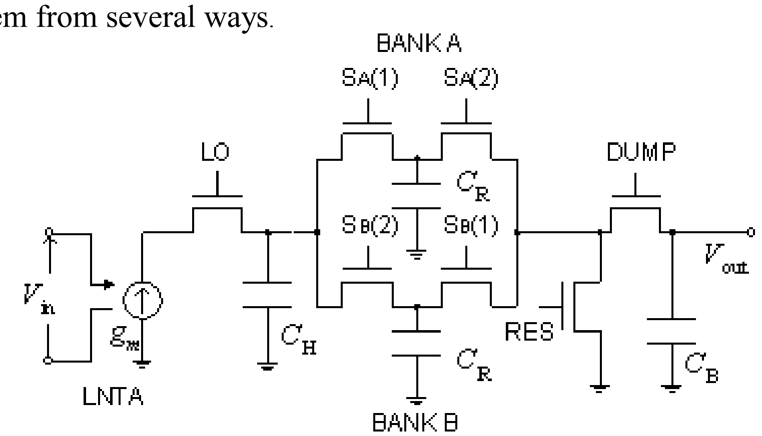


Fig.1 Direct sampling mixer

Harmonic-Rejection DSM

In the DSM, frequency conversion could be achieved by switching mixer. Frequency conversion based on switching is equivalent to multiplying received signal by rectangular signal. Although high conversion gain and proper noise characteristics could be achieved, odd order harmonics act as the interference and deteriorate the demodulation accuracy since rectangular wave contains the odd order harmonic components. Some quadrature harmonic rejection mixers were proposed, however, larger circuit size and more power consumption are needed. These can be solved by using shared transconductance amplifier between IQ-path.

Furthermore, we applied this harmonic rejection mixer to DSM and fabricated its prototype by utilizing TSMC 0.18µm process.

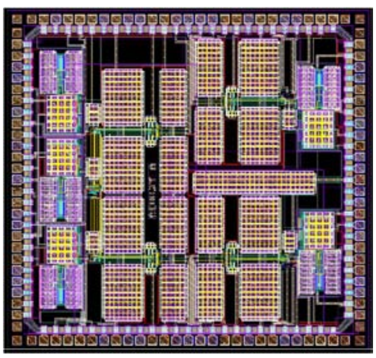


Fig.3 Layout pattern

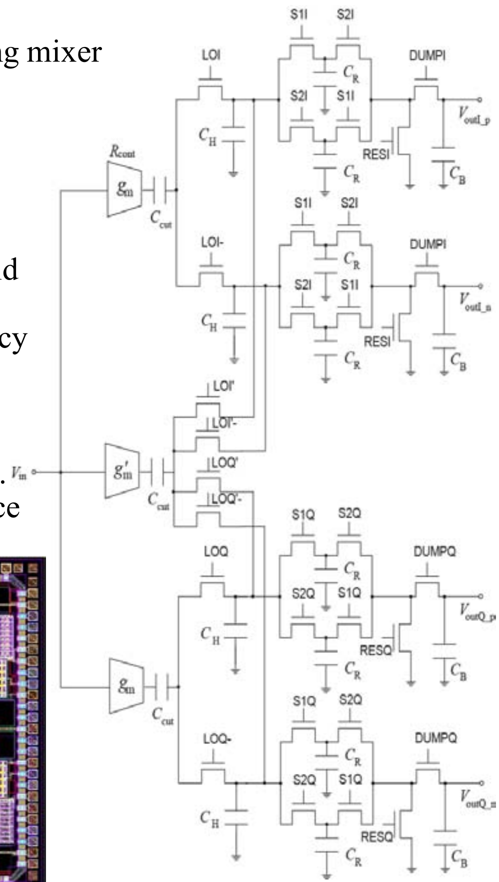


Fig.2 Quadrature harmonic rejection DSM

Polyphase Structure of Switched Capacitor Networks

A novel polyphase structure of switched capacitor networks in the DSM is proposed. Utilizing this structure, we can obtain a higher order filtering which enables us to create an attenuation pole at an arbitrary position close to DC frequency after down-conversion by changing capacitance ratios and clock frequencies. Therefore, an excellent attenuation characteristic against adjacent blockers can be achieved without introducing any additional transconductance amplifiers (TA) which are huge active elements and thus inevitably boost power consumption. On the other hand, since aliasing problem still remains, it is needed to utilize a tunable bandpass pre-filter prior to charge sampling in the analog domain for anti-aliasing.

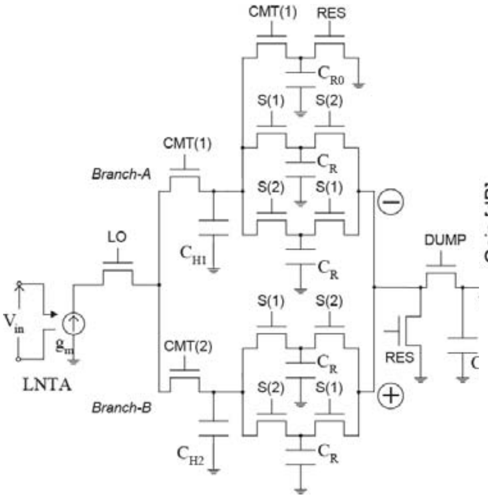
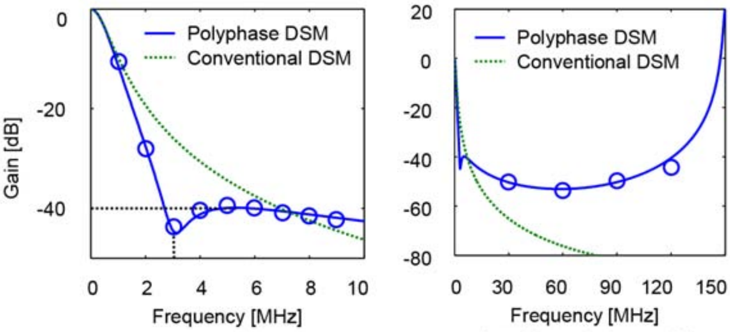


Fig.4 Schematic Diagram



(a) Near Attenuation Poles Characteristic

(b) Wide Band Characteristic

Fig.5 Frequency Characteristics

The Design of Low Distortion MOS Switches

Design guideline of low distortion MOSFET in Direct Sampling Mixer is introduced by analytical modeling and calculation. There are two distortion factors in MOSFET which are the saturation of drain current and switching error by source potential. The difference of these distortions is clarified, and what parameters in MOSFET causing each distortion are shown. From these results, low distortion MOSFET is designed and the method which improves distortions from switching error is shown. These figures show that two types of distortion are improved by low distortion design and offset voltage.

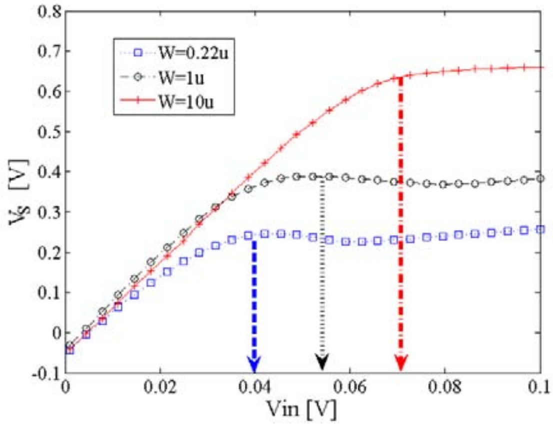


Fig.6 Saturation vs Gate-width performance

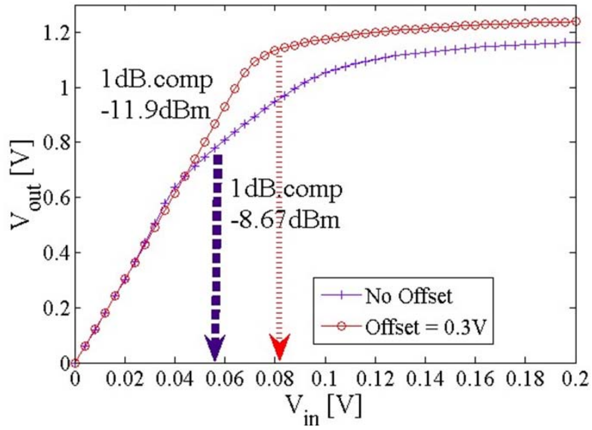


Fig.7 Saturation vs Offset performance

ARAKI SAKAGUCHI LABORATORY

Adaptive MIMO using parasitic and switchable antenna elements

Adaptive MIMO using parasitic and switchable antenna elements

Recently, Multiple-Input Multiple-Output (MIMO) system has been well studied and implemented to the actual communication systems. In addition to that, the combination of the MIMO technology and analog adaptive array can be beneficial in enhancing channel capacity without increase of number of transmitters or receivers. We focus on configure the parasitic antenna elements as analog array to achieve the adaptive MIMO system.

Parasitic antenna elements

When the directivity of receive antenna is steered to the direction of the propagated radio wave, the channel capacity can be improved. Yagi-Uda array antennas are ones of the traditional methods of steering directivity. However, their electrical characteristic and directivity are designed beforehand. In other words, such design cannot be changed adaptively. To solve this problem, many adaptive beamforming techniques have been proposed. One of the methods is using unfeeded parasitic antenna elements which are terminated by reactance.

Distribution of max $\tilde{S}_{RT}$

We consider the SISO system with 1 parasitic antenna element is placed at receiver. In this system the components of S matrix are scalar, and the lossless condition of the parasitic antenna elements is $|\Gamma_P| = 1$. Under this condition, the maximum value of $\tilde{S}_{RT}$, which denotes the channel response improved by using a parasitic antenna element is calculated as follow:

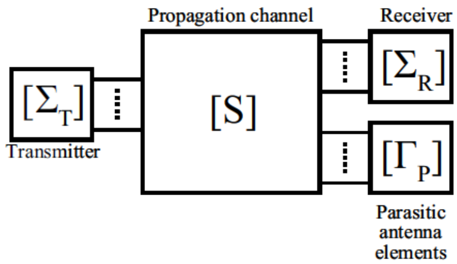


Fig.1 Tandem of channel, transmitter, receiver and parasitic antenna elements

$$\max\left|\tilde{S}_{RT}\right| = \left|S_{RT} + \frac{S_{PP}^{*} S_{RP} S_{PT}}{1-\left|S_{PP}\right|^{2}}\right| + \frac{S_{RP} S_{PT}}{1-\left|S_{PP}\right|^{2}}$$

where S_{RT} and S_{PT} are the random variables corresponding to radio channels, and S_{RP} and S_{PP} are the fixed S parameters at receiver.

From the equation above we can derive the probability density function of $\max\left|\tilde{S}_{RT}\right|$ and the Fig. 2 and Fig. 3 shows the simulation result. These results show the improvements in channel capacity.

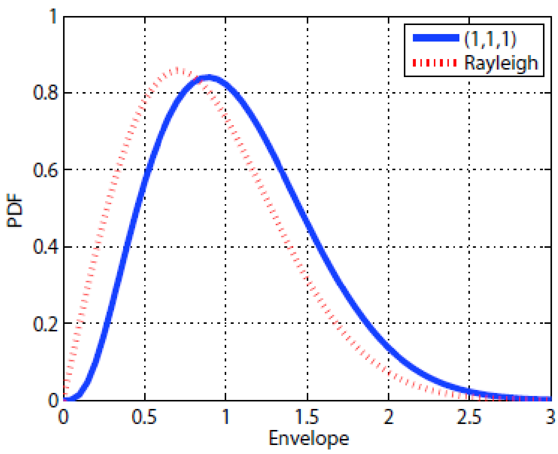


Fig. 2 PDF of max $\tilde{S}_{RT}$

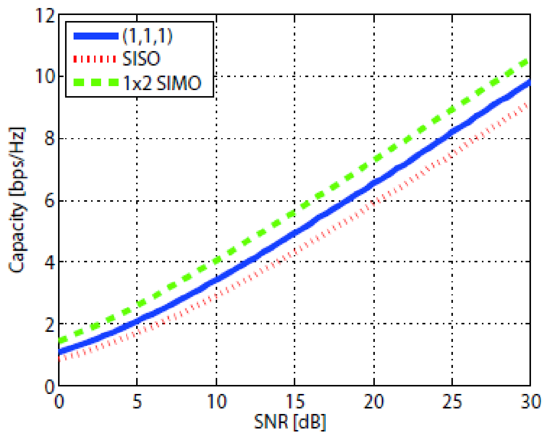


Fig. 3 Capacity using a parasitic antenna element

A Design of Power-Controllable Class-E Amplifier with Variable Capacitors

Polar modulation is a new modulation method suitable for digital transmitter in wireless communication because both amplitude modulation and phase modulation are accomplished by nonlinear amplifiers. This transmitter require digital power-controllable amplifier, and conventional architectures have trade-off between efficiency, size and bandwidth. We present a practical design of new power-controllable Class-E amplifier using π-matching circuit with variable capacitance in Fig.1. This architecture takes advantage of the high efficiency even for a wide range of output power. We study the optimum design of Class-E PA suitable for this architecture and variable capacitors designed of MOS varactor. As a result of ADS simulation in Fig.2, higher power efficiency can be maintained for a wide range of output power than switch-array method.

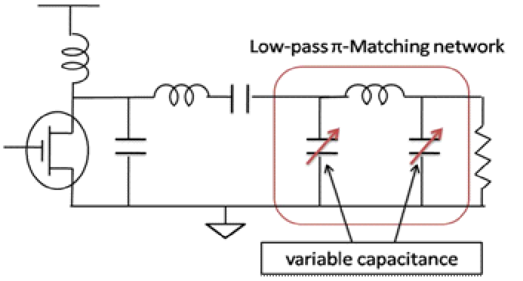


Fig.1 The proposed design of amplifier

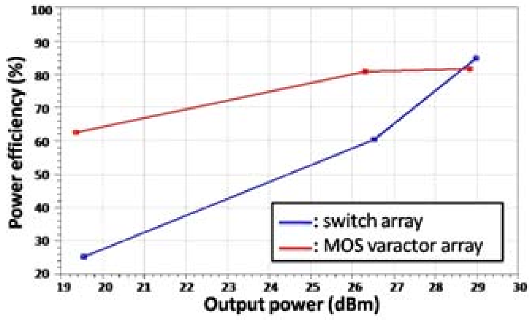


Fig2 Comparison of power efficiency

Predicting Nonlinear Distortions in Power Amplifier for a Complex Gaussian Process

Nonlinear distortion in power amplifiers (PAs) generates spectral regrowth in amplifiers' output, which causes adjacent channel interference and the error vector for the digitally modulated signal. We developed a close-form expression for the PA output autocorrelation function with a complex Gaussian input signal. The PA's nonlinearity is modeled as a complex power series from the measured amplitude-to-amplitude (AM-AM) and amplitude-to-phase (AM-PM) characteristics. PA's memory effects are assumed not to be present in this discuss. We derived explicit formulas for evaluating the adjacent channel power ratio (ACPR) and the error vector magnitude (EVM) in nonlinear power amplifiers. These analytical methods allow us to predict ACPR and EVM value without running time-domain simulations; they also can give instructive information for the PAs design to satisfy the requirements in communication systems.

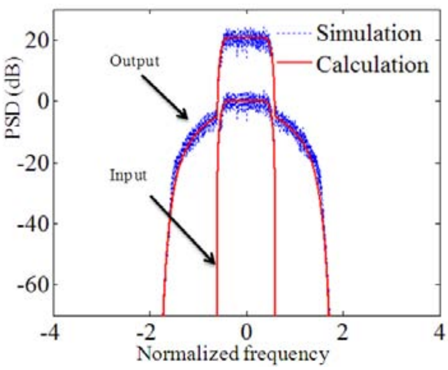


Fig.1 Spectral Characteristics

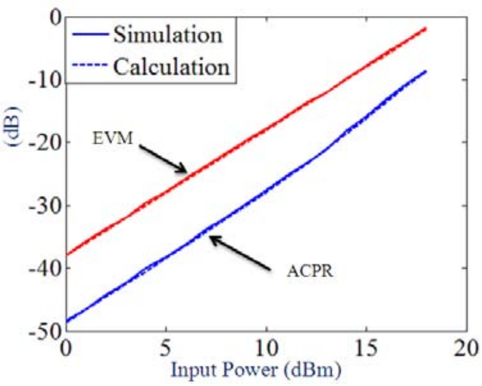


Fig.2 ACPR and EVM Characteristics

ARAKI SAKAGUCHI LABORATORY

Fractional Base Station Cooperation Cellular Network

Fractional Base Station Cooperation Cellular Network

Introduction

In modern cellular systems, high-rate communication is performed using MIMO transmission by a single Base Station (BS). This method is able to improve the transmission rate when the user is close to the BS (cell-inner user). However the rate severely degrades when the user is located at middle of two BSs (cell-edge user). Base Station Cooperation (BSC) MIMO is anticipated to alleviate the interference at the cell-edge. However, it has minimum impact on cell-inner users and increases the complexity of the network .

Fractional Base Station Cooperation Cellular Network (FBSC-CN)

The research project on Fractional Base Station Cooperation Cellular Networks was started in 2008 by the MIMO group of the Araki-Sakaguchi laboratory.

FBSC-CN is a cellular network in which a combination of single-BS MIMO, or non-cooperative transmission (NCT) and BSC MIMO, or BSC Transmission BSCT() is performed in order to achieve the gains both at the cell-inner and cell-edge with limited complexity.

The spectral efficiency of both single BS MIMO and BSC MIMO are dependent on the received signal strengths from the cooperating base stations and non-cooperating base stations. When the user terminal is midway two or three base stations, BSC-MIMO gives higher spectral efficiency by reducing inter-cell interference. However, when the user is closer to base stations, single BS MIMO may be more spectrally efficient and is less complex. In an FBSC-CN, the network selects which among single BS MIMO and BSC MIMO gives the higher spectral efficiency based from the received signal strength. Then, it uses the appropriate transmission method. Simulation results in Figure 2 show that FBSC-CN gives the best overall spectral efficiency and is less complex than BSC MIMO.

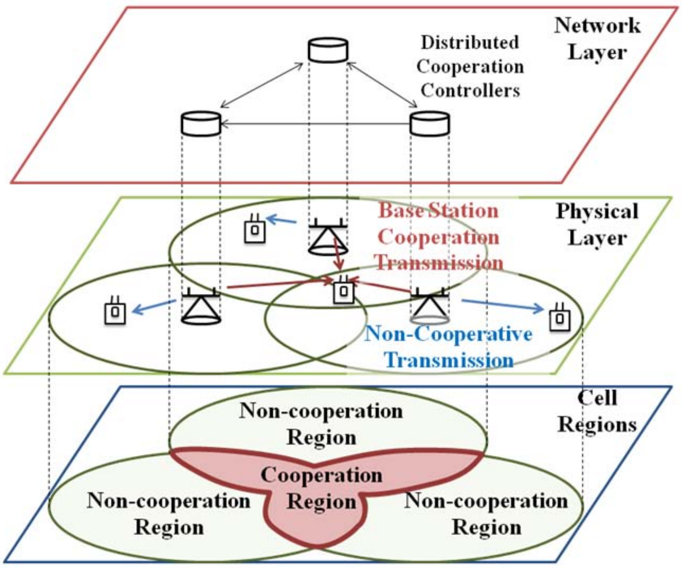


Fig. 1 Fractional Base Station Cooperation

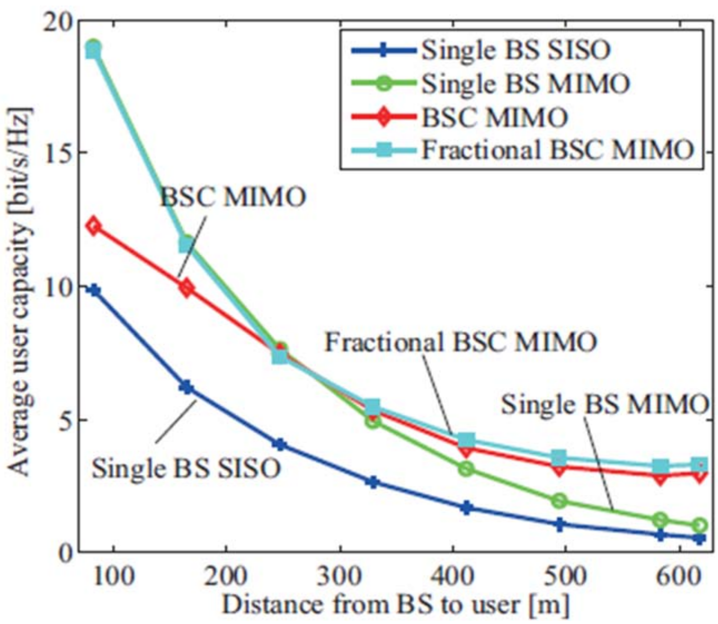


Fig.2 User Capacity vs. Distance

FBSC-CN Procedure

In FBSC-CN, the network performs either non-cooperative transmission (NCT) or BSC transmission (BSCT) for each user. The selected method is determined by the local base station from the information gathered by the user terminal based from its received signal strengths from the local BS, adjacent-cooperating BSs and far-non-cooperating BSs. The procedure is shown in Fig. 3. Multi-cell channel estimation and BSCT is performed when the adjacent-cooperating BSs are available. Through distributed cooperation, cell-edge interferences between cooperation clusters are avoided, thus yielding best capacity.

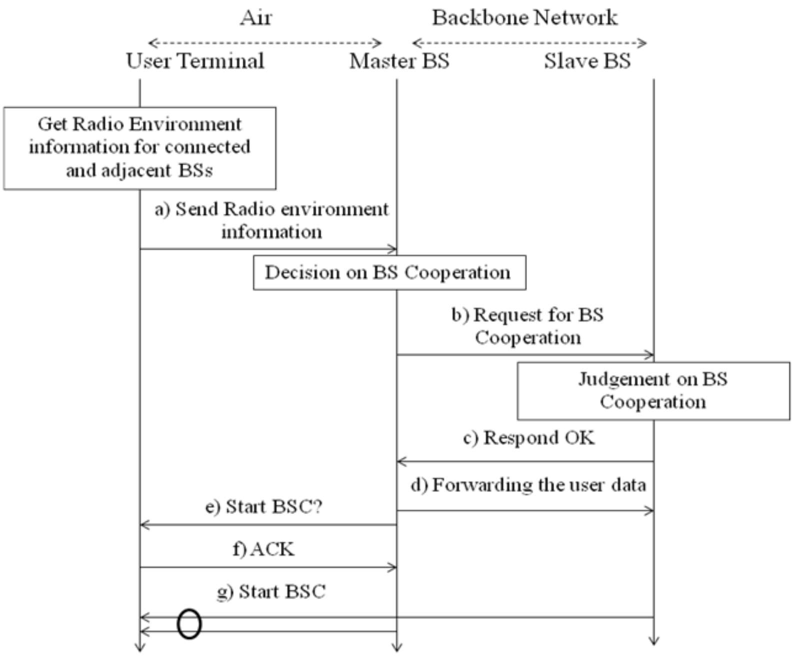


Fig.3 Fractional Base Station Cooperation Procedure

Cell Planning for FBSC-CN

Under FBSC-CN, two types of geographic regions within a cell are formed according to the chosen transmission scheme of users inside the region. These are cooperation regions and non-cooperation regions, shown on the first figure on the previous page.

We propose a cell region partition scheme for FBSC under fundamental BSCT and NCT schemes based on the predicted received signal strengths from the cooperating and non-cooperating base stations, and the MIMO channel model. This cell partitioning is considered to determine the cell plan design as shown on figure 4.

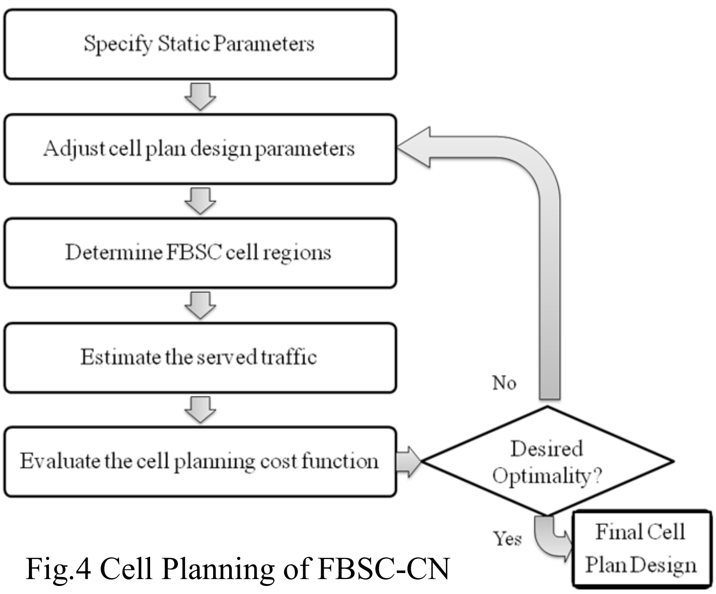


Fig.4 Cell Planning of FBSC-CN

Depending on the combination of specific BSCT and NCT schemes, the site-to-site distance and the cell layout, it is possible that either the cooperation region or non-cooperation region occupies the whole cell area. In such case, fractional cooperation is not applicable and the site-to-site distance is either too large or too small. We develop methods of finding the range of site-to-site distances where fractional base station cooperation is applicable.

ARAKI SAKAGUCHI LABORATORY

MIMO two-way network

MIMO Two-Way Network

Wireless mesh network (WMN) consisting of mesh routers and mesh clients has been achieving much more attention in recent years as there are more demands for WMN applications, namely wireless sensor networks, public wireless access networks, plant control systems, etc. The advantages of WMN are its ability to form a flexible network topology, robustness and wide area coverage owing to multi-hop relay property. In the mesh network which is used as a backbone network, mesh nodes are almost fixed, well power supplied and equipped with multiple antennas. MIMO technologies including Space Time Block Coding become indispensable R&D items to enhance diversity against wireless impediments and increase channel capacity to support high data rate mesh network.

MIMO Two-Way transmission

Since there are multiple transmission links in a network, multiple access interference occurs, and it degrades throughput performance of the network severely. Multi-channel strategy or Carrier Sense Multiple Access (CSMA) has been commonly introduced to avoid multiple access interference so far. However, these schemes are not appropriate for high traffic mesh networks, since it is based on FDMA or TDMA based schemes. In our proposed MIMO two-way transmission, the interference signals are cancelled by using transmit and receive antenna weights, and forward and backward links are spatially multiplexed.

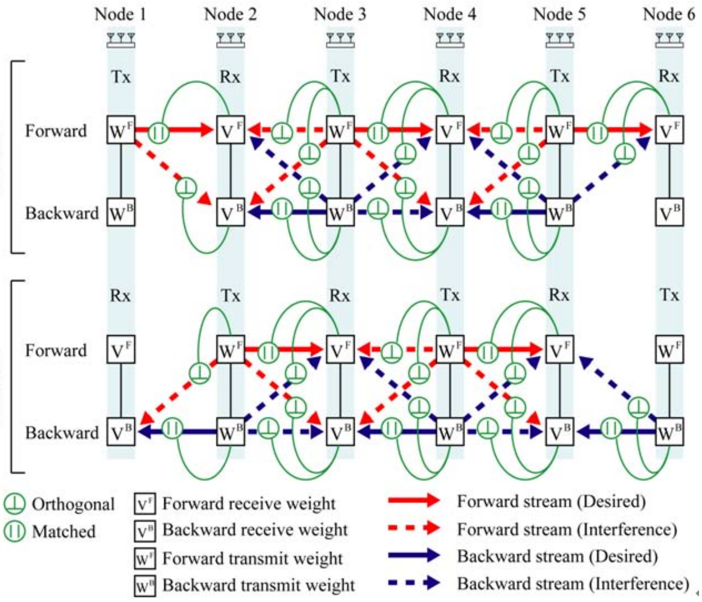


Fig.1 MIMO two-way transmission

2D MIMO Network Coding

The MIMO two-way transmission in 1D mesh topology can also be realized by MIMO network coding. The forward and backward information flows are combined using network coding at relay node, and then broadcast both to the forward and backward links. MIMO multiple access and network decoding are performed at receiver side for separation of information flows.

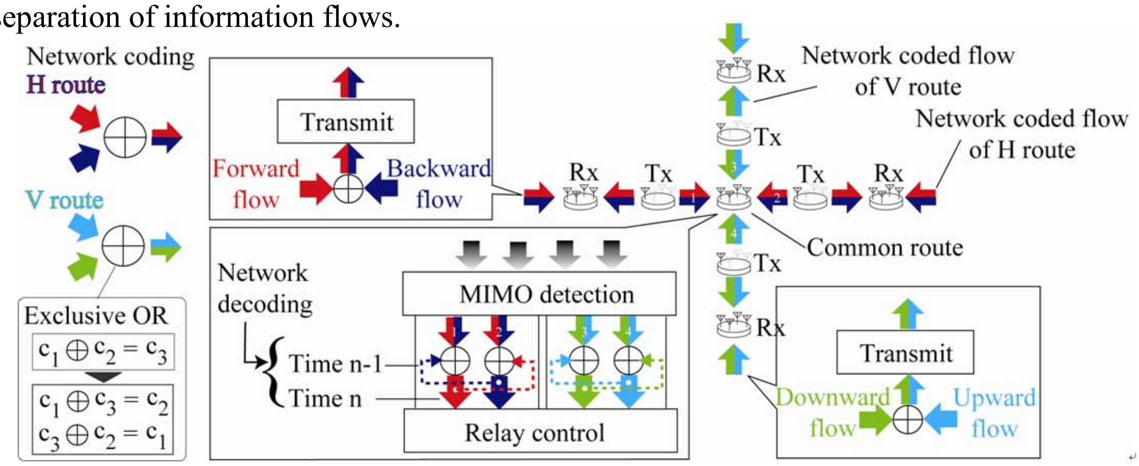


Fig.2 Algorithm of 2D MIMO network coding

The extension to 2D mesh topology becomes necessary for a more flexible mesh network. We establish 2D MIMO network coding based on 1D MIMO network coding for several typical topologies i.e. cross topology, rotary topology and tree topology. In general, there are four simultaneous information flows in these topologies: the forward, backward, upward and downward information flows. 1D MIMO network coding is applied to the forward and backward information flows, and the upward and downward information flows independently. At the common nodes of all information flows, two network coded flows are spatial multiplexed and broadcast to forward, backward, upward and downward links.

Furthermore, owing to freedom of antennas, the proposed MIMO network coding algorithms can be combined with STBC broadcast to achieve transmit diversity, or interference-aware transmit beam-forming to suppress long-distant interference for further throughput improvement. Also, three different centralized and decentralized power control schemes are proposed to apply in 1D and 2D mesh topologies to compensate for link imbalance due to non-equidistant mesh node placement, thus improve capacity performance at bottlenecks of mesh network.

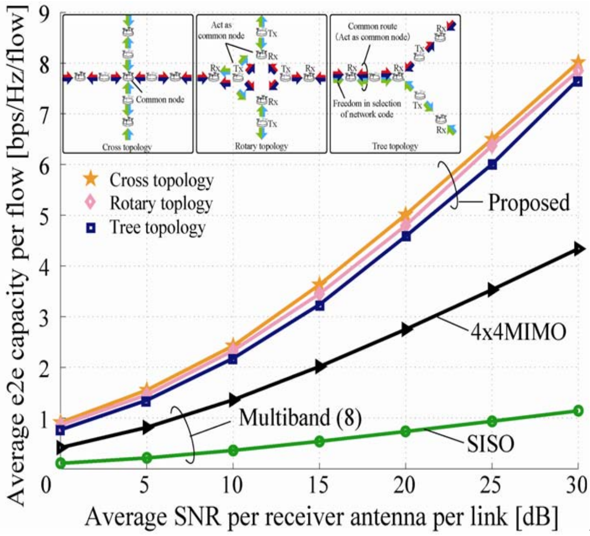


Fig.3 Performance of proposed schemes

COGNITIVE MIMO MESH RELAY NODE AT JAPANESE 950MHz BAND

For experimental evaluation and realization of the MIMO mesh network, we develop cognitive MIMO mesh relay nodes at Japanese 950MHz band. This prototype hardware consists of a baseband (BB) board which is equipped with an FPGA for signal processing, four digital-to-analog converters (DAC) and four analog-to-digital converters (ADC); a radio frequency (RF) board in which four transmitter and receiver circuits are implemented; four antennas and a CPU (PC). Fundamental technologies of physical layer of MIMO mesh network which are network synchronization scheme, RF calibration scheme, FFT based carrier sense and spectrum sensing scheme for cognitive radio are evaluated using this hardware. Finally, we challenge to realize the MIMO mesh network in indoor and outdoor propagation environment.


Fig.4 Overview of cognitive MIMO mesh relay node.

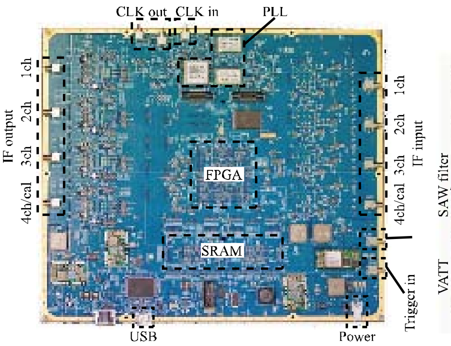


Fig.5 Baseband board of cognitive MIMO mesh relay node

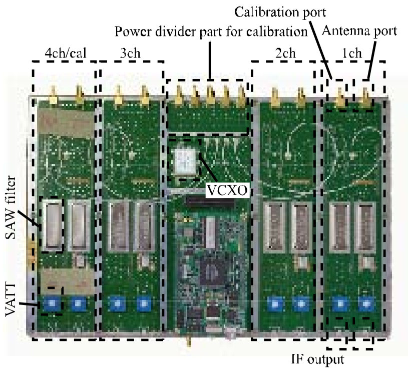


Fig.6 RF board of cognitive MIMO mesh relay node

SUZUKI FUKAWA LABORATORY

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

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Suzuki Fukawa Laboratory

Our Research Interests

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

Research Topics in Recent Five Years

Transmission System

- *MIMO detection and CSI estimation*
  - Suboptimal MLD
    - EM algorithm with factor graphs
    - MMSE detection avoiding noise enhancement
  - Adaptive blind method for heterogeneous streams [3]
  - Soft decision-directed channel estimation (SDCE)
- *MIMO-OFDM system Optimization*
  - BER improvement
    - Subcarrier phase hopping (SPH)
    - Minimum BER (MBER) precoding [2], [4], [5]
  - PAPR reduction
    - Enhanced selected mapping (ESLM)
    - Partial transmit sequence (PTS)
  - Joint BER and PAPR improvement
    - SPH-SLM
    - Eigenmode transmission with PAPR reduction [11], [13]
  - Relaying system improvement
    - Amplify-and-Forward (AF) / Decode-and-Forward (DF) switching [18]

Multiple Access

- *Interference mitigation*
  - Spatial filtering [1], [8], [19]
  - MBER precoding for cochannel interference environment [20], [22]
- *Access scheme*
  - IDMA with iterative detection [9], [21]
  - Random packet collision resolution

Modulation and Demodulation for Cognitive Radio

- *Gaussian multicarrier (GMC)* [7], [12], [14]
- *SSB*

RF Impairment Compensation

- *Phase noise compensation* [6], [10], [15], [16], [23], [24]
- *I/Q imbalance compensation*
- *Real zero coherent detection*

In-House Simulator Design and Implementation

- *FPGA on-board system simulators*
- *4X4 MIMO fading simulators*

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

MAP Receiver with Spatial Filters for Suppressing Cochannel Interference in MIMO-OFDM mobile communications [1], [8]

The MIMO-OFDM system is attractive for future mobile communications because of its high spectral efficiency. Recently, there have been many investigations that apply MIMO-OFDM in the multiple access. In the multiple access, careful design of the MIMO-OFDM system is necessary in order to mitigate the cochannel interference (CCI) that significantly degrades system performance. Joint processing between spatial filtering (SF) and signal detection is one of the most effective methods to alleviate the degradation caused by CCI. Fig. 1 shows the system model when SF is applied to the uplink communication.

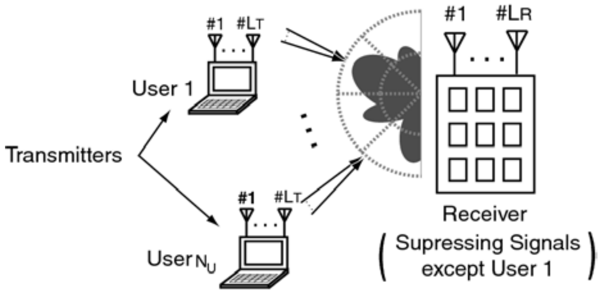
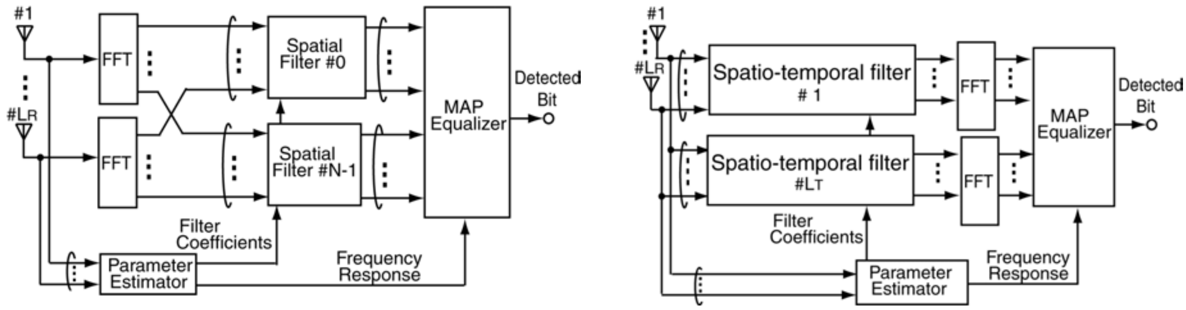


Fig. 1 System model of uplink communication with SF



(a) postFFT-type SF **(b) preFFT-type STF**

Fig. 2 Two conventional methods for implementing SF

There are two methods for implementing SF. One is to use SF posterior to FFT and estimates the filter coefficients in the frequency domain, which is referred to as postFFT-type SF as shown in Fig. 2 (a). Another is to use spatio-temporal filtering (STF) prior to FFT and estimates the filter coefficients in the time domain, which is referred to as preFFT-type STF as shown in Fig. 2 (b). The postFFT-type SF has high potential to suppress CCI given that there are large number of preambles for filter coefficient estimation. On the other hand, when there are only limited number of preambles for filter coefficient estimation, the preFFT-type STF is more effective than the postFFT-type SF. Therefore, we propose a maximum *a posteriori* probability (MAP) receiver making a switch from preFFT-type STF into postFFT-type SF as shown in Fig. 3. First, preFFT-type STF detects transmitted signals. With decision errors, the receiver switches from preFFT-type STF into postFFT-type SF. PostFFT-type SF can improve accuracy of its parameter estimation by using detected signals as preamble symbols. Thus, the proposed receiver can perform more reliable signal detection than that with only preFFT-type STF or that with only postFFT-type SF.

Computer simulations following the IEEE 802.11a standard were conducted over a MIMO fading channel to evaluate the performance of the proposed scheme. An uplink single cell system with one desired and one interfering users, both employing

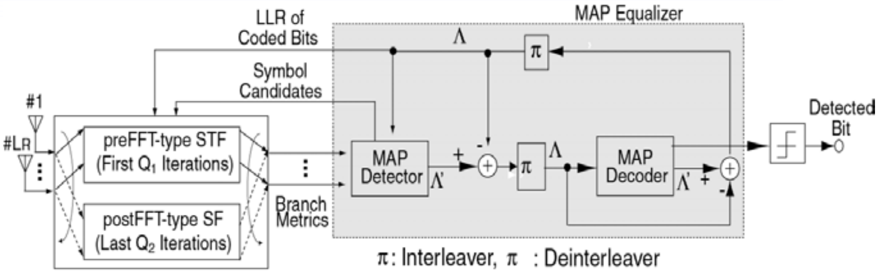


Fig. 3 Proposed MAP receiver with preFFT-type STF / postFFT-type SF switch

QPSK, is assumed. The base station (receiver) has three antennas and each user terminal (transmitter) has two antennas. Fig. 4 shows an average BER performance when the direction of arrival (DOA) difference between the desired and interfering users is 60°, and each DOA is Gaussian distributed with standard deviation 4°. The average carrier to interference ratio (CIR) was set to 0 dB and the normalized Doppler frequency was set to 6.0 x 10^{-3}. The proposed scheme outperforms both conventional schemes when it performs 3 iterations of preFFT-type STF followed by 3 iterations of postFFT-type SF.

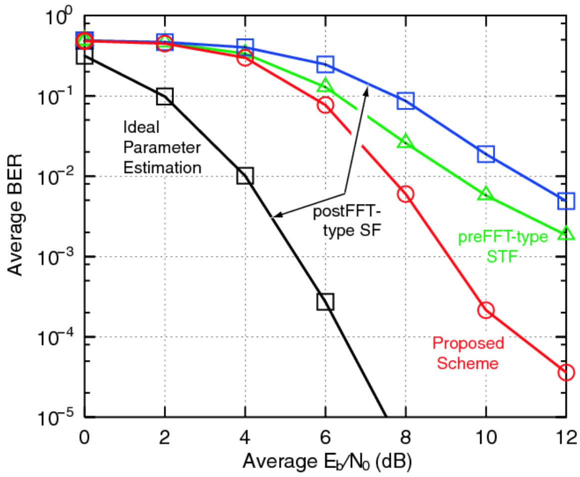
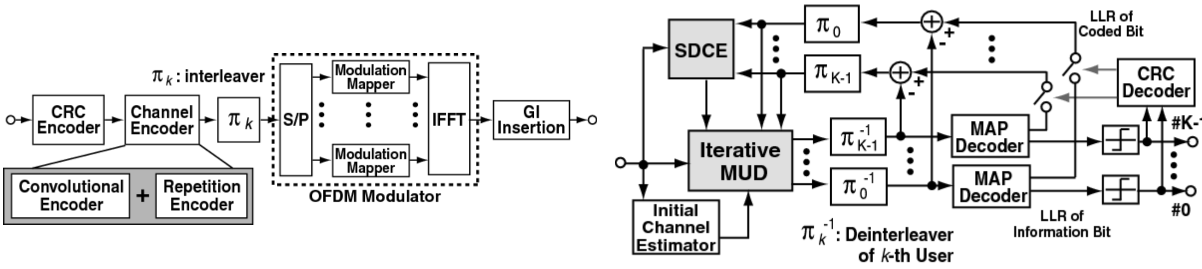


Fig. 4 Average BER performance

Performance of Iterative Multiuser Detection with Channel Estimation for MC-IDMA [9]

Recently, interleave-division multiple access (IDMA) and multicarrier interleave-division multiple access (MC-IDMA), which is called OFDM-IDMA, has been proposed as one of the promising radio access techniques that can improve spectral efficiency of mobile communication systems beyond 3G and 4G. They employ both a low-rate channel code and an individual chip interleaver for each user, which enable the receiver to use a low-complexity iterative multiuser detector (MUD). Since MC-IDMA alleviates ISI by the OFDM technique and cancels multiple access interference (MAI) by the IDMA technique, MC-IDMA is known to outperform normal MC-CDMAs. However, performance of MC-IDMA employing channel estimation has not sufficiently been investigated and the comparison of MC-IDMA and chip-interleaved (Chip-IL) MC-CDMA, which improves frequency diversity of normal MC-CDMAs, has not been made yet. Therefore, our research aims to clarify the effectiveness of our proposed MC-IDMA receiver employing a soft decision-directed channel estimation (SDCE) and to make a comparison with time-spread (TS), frequency-spread (FS), and Chip-IL MC-CDMAs.

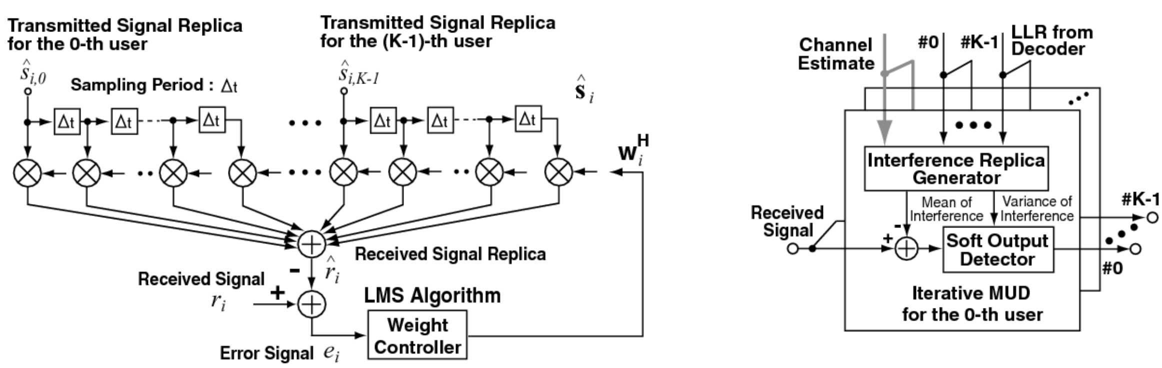


(a) Transmitter for k-th user **(b) Receiver**

Fig. 5 Proposed uplink MC-IDMA system

Fig. 5 shows (a) a transmitter for the k-th user and (b) a receiver of the proposed uplink MC-IDMA system. The transmitter implements the low-rate channel coding by cascading the convolutional encoder with the repetition encoder. Then, it permutes the encoded bits by the individual interleaver π_k for the k-th user and maps them into modulation signals. At the receiver, it first performs channel estimation using the preamble. After that, it performs the signal detection in an initial process. At the end of the initial process, the CRC decoder detects a decision error from LLR of the information bit. If there is an error, the receiver shifts from the initial process to the iterative one. Otherwise, the detection process for the corresponding users terminates. In the iterative process, the channel vector $\mathbf{w}_i$ is first updated by SDCE using the LMS algorithm as shown in Fig. 6 (a). Then, the updated channel estimate is used for the iterative MUD process as shown in Fig. 6 (b). The receiver repeats the iterative process until the number of iterations exceeds a predetermined threshold or CRC does not detect any decision errors.

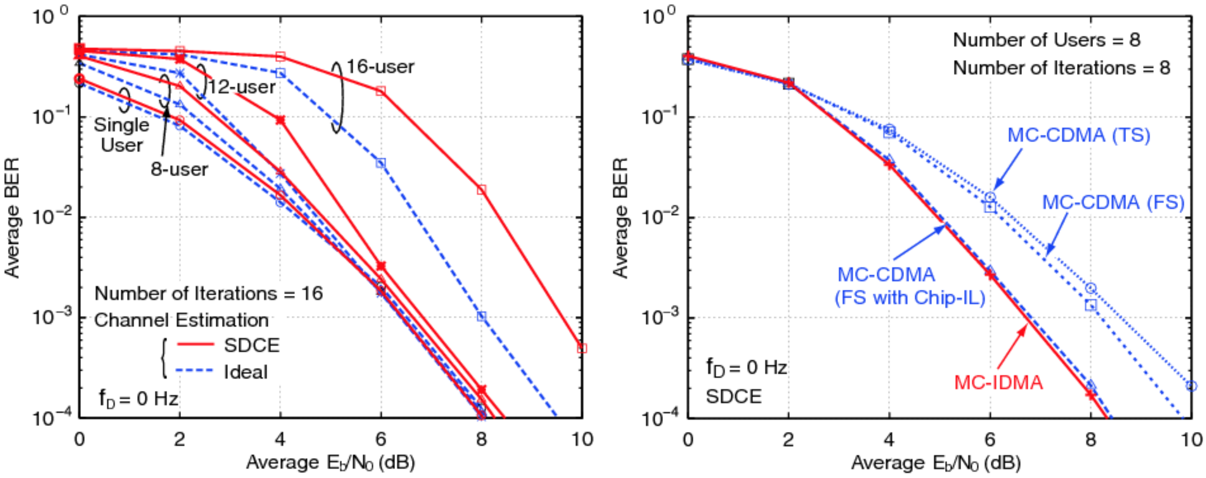
Computer simulations were conducted to verify the effectiveness of the MC-IDMA system with SDCE. The FFT point was 256, and the modulation scheme was QPSK. The convolutional code with coding rate R_c = 1/2 and the repetition code with coding rate R_r = 1/8 were employed. The random interleaver was used, and



(a) SDCE using LMS algorithm **(b) Iterative MUD**

Fig. 6 Functions of iterative process

the Max-Log-MAP algorithm was employed for the MAP decoding. The channel was subject to 16-path Rayleigh fading with an exponential decay. The maximum Doppler frequency f_D was set to 0 Hz. Fig. 7 (a) shows average BER performances of MC-IDMA with SDCE at different number of users K. MC-IDMA with SDCE can limit the degradation of E_b/N_0 at BER = 10^{-3} to 0.4 dB when $K \leq 12$. On the other hand, Fig. 7 (b) shows the performance comparison between MC-IDMA and the three MC-CDMAs. MC-IDMA is superior to FS and TS, and can achieve almost the same BER as Chip-IL MC-CDMA. However, it has been known that the complexity of iterative MUD in MC-IDMA is much lower than that of Chip-IL MC-CDMA.



(a) MC-IDMA with SDCE **(b) MC-IDMA vs. three MC-CDMAs**

Fig. 7 Average BER performances

OFDM Modulation with Gaussian Shaping and Its FPGA Transceiver [7]

Future wireless communication systems require higher spectral efficiency and more sophisticated spectrum management. Especially, the cognitive radio requires a transmission technique that does not cause inter-system interference. OFDM transmission, however, cannot control such interference sufficiently because its spectrum has considerable amount of sidelobes. On the other hand, Gaussian shaped OFDM (GS-OFDM), which replaces the rectangular pulse by the Gaussian one for pulse shaping of the OFDM symbol, can reduce the sidelobes to sufficiently low level. By nulling few subcarriers, GS-OFDM can generate a deep spectral dip in any frequency bands, which indicates a possibility of effective interference management. However, it cannot maintain the orthogonality among symbols and subcarriers due to the Gaussian pulse, which results in inter-symbol-and-subcarrier interference (ISCI). Hence, the GS-OFDM receiver needs an iterative interference canceller (IIC) to cancel ISCI, and the feasibility of hardware implementation of the transceiver should be studied. We investigate the GS-OFDM transmission technique and presents the results of its FPGA implementation.

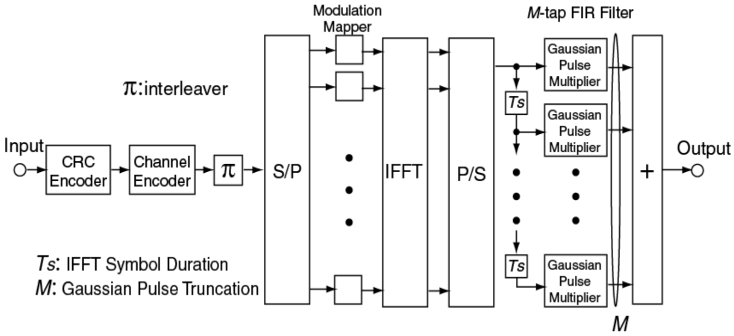


Fig. 8 GS-OFDM transmitter

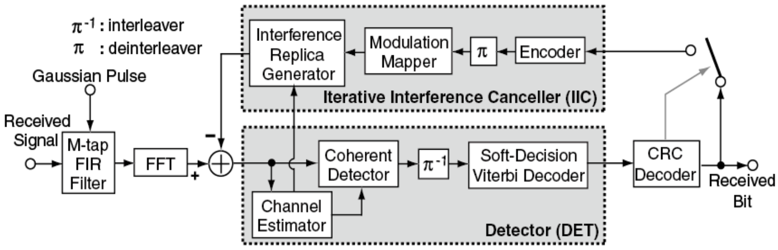


Fig. 9 GS-OFDM receiver

Fig. 8 shows the GS-OFDM transmitter. The processes before IFFT are similar to those of OFDM. In addition, GS-OFDM performs Gaussian waveform shaping by convoluting IFFT outputs of M symbols with Gaussian pulse. Fig. 9 shows the GS-OFDM receiver. A detector (DET) consists of a channel estimator, a coherent detector with soft outputs, deinterleaver, and the soft decision Viterbi decoder (SDVD). In the initial process, DET detects the received signals from FFT outputs. If the CRC decoder detects any decision errors, the receiver shifts the initial process to an iterative one. In the iterative process, IIC regenerates the ISCI component from the decoded bits and subtracts it from the received signal before performing another signal detection by DET. The receiver repeats the iterative process until the number of iterations exceeds a predetermined threshold or no decision error is detected.

The results of the FPGA implementation of the GS-OFDM transceiver are shown below. Fig. 10 shows the transmitted signal spectrum. Spectral attenuation of 40 dB was realized by nulling three adjacent subcarriers. Fig. 11 shows IQ constellations after coherent detection, (a) without IIC and (b) with IIC. IIC enables a clear observation of 16QAM constellation and the results confirm the significant effectiveness of IIC.

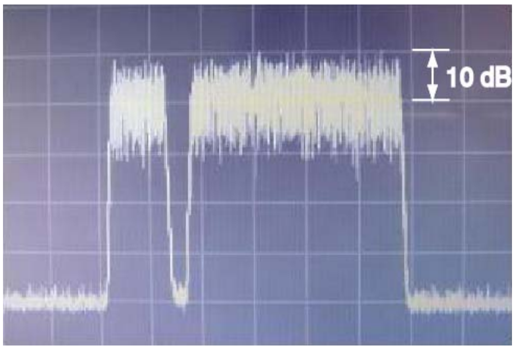
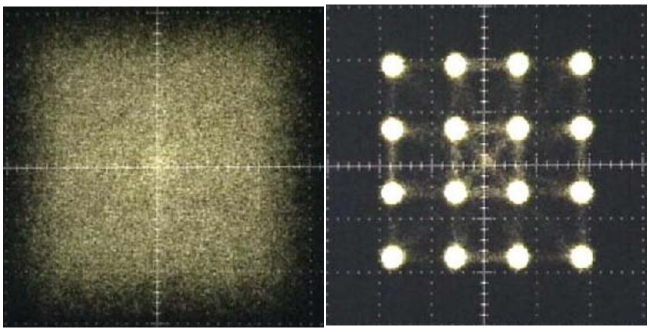


Fig. 10 Measured spectrum



(a) Without IIC **(b) With IIC**

Fig. 11 16QAM constellations

Decision Directed Phase Noise Compensator for Millimeter-Wave OFDM Systems [6]

Wireless personal area network (WPAN) systems in millimeter-wave 60 GHz band have been extensively studied, and 60-GHz WPAN standardization in IEEE 802.15.3c investigates both the single carrier and OFDM transmissions. It is well known that OFDM is sensitive to the carrier frequency offset and the phase noise because of narrowband multicarrier transmission. In the high bit-rate OFDM transceiver based on the single-chip Si RF-CMOS IC, the relatively large phase noise in the phase locked loop (PLL) synthesizer as shown in Fig. 12 degrades transmission performance severely.

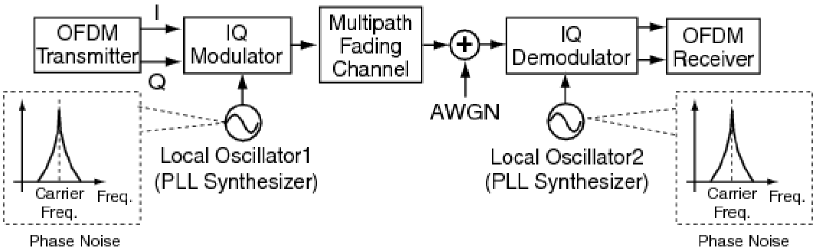
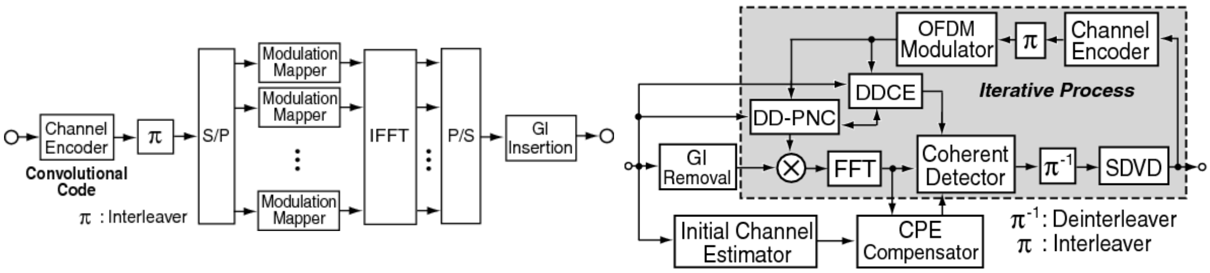


Fig. 12 Phase noises in OFDM transmission

Some phase noise compensation techniques for OFDM have been previously proposed such as compensation of the common phase error (CPE) which induces a common phase shift at all subcarriers and MMSE-based phase noise compensation by deconvolving the inter-subcarrier interference (ICI) caused by the phase noise. However, these techniques do not consider the degradation of the channel estimation due to the phase noise and their numerical complexities are very large, which make them unsuitable for high bit rate transmission. Therefore, we proposes a low-complexity OFDM receiver that iterates decision-directed phase noise compensation (DD-PNC) and decision-directed channel estimation (DDCE) by exploiting an output of the channel decoder. Fig. 13 shows block diagrams of (a) an OFDM transmitter and (b) the proposed receiver employing DD-PNC and DDCE.

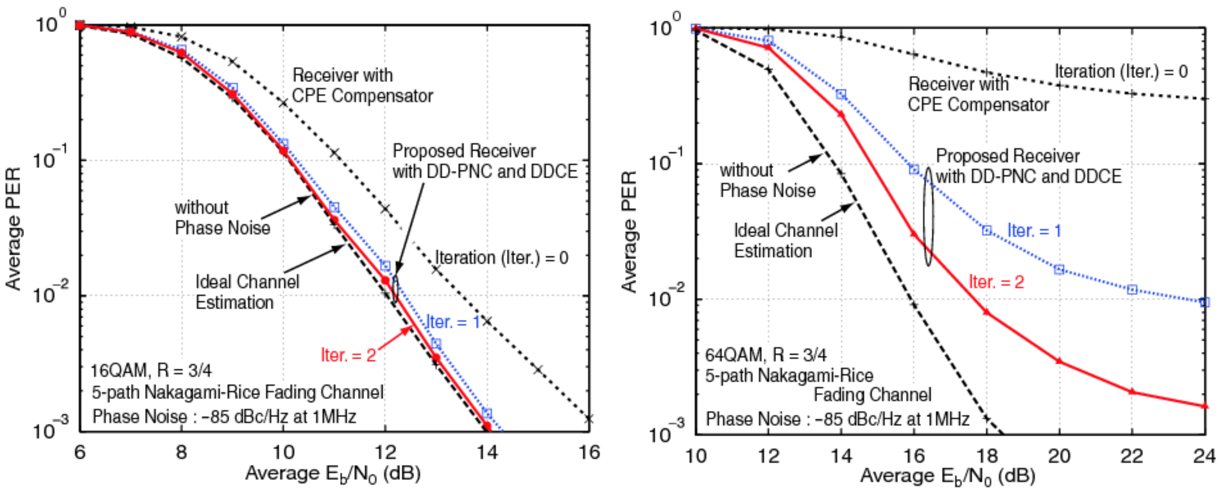


(a) Transmitter **(b) Proposed receiver**

Fig. 13 OFDM system model

The receiver iterates the phase noise compensation, channel estimation, and signal detection by exploiting an output of the channel decoder. In the initial process, an initial channel estimator (ICE) first estimates channel impulse response and then a CPE compensator estimates the mean of the phase noise, CPE, during one OFDM symbol by using pilot subcarriers. Next, the coherent detector provides soft output using the estimated CPE. After deinterleaving the soft output, a soft-decision Viterbi decoder (SDVD) is performed. If a decision error is detected from the decoded bits, the receiver shifts the initial process to an iterative one. In the iterative process, the OFDM modulator first generates a transmitted signal replica from the output of SDVD. Next, DD-PNC recursively estimates the phase noise using the replica, and then removes the estimate from a time-domain received signal. Moreover, DDCE also estimates the channel impulse response using the compensated signal. After that, the compensated signal is detected by the coherent detector. The receiver repeats the iterative process until the number of iterations exceeds a predetermined threshold or no decision error is detected.

Computer simulations were conducted to verify the effectiveness of the proposed receiver. The OFDM transmission parameters almost follow the IEEE 802.15.3c standard with the modulation being 16QAM or 64QAM. The subcarrier spacing was 5 MHz and the FFT point was 512. The convolutional code with the constraint length 7 and the coding rate R = 3/4 was employed. The channel model was 5-path Nakagami-Rice fading with Ricean factor K = 10 dB. The power spectral density (PSD) of the phase noise was the one-pole/one-zero model proposed in IEEE 802.15.3c with the level of –85 dBc/Hz at 1 MHz offset. Fig. 14 shows average PER performances of (a) 16QAM and (b) 64QAM. With 16QAM, the performance of the proposed receiver, which iterates DD-PNC and DDCE twice, is close to the ideal one. On the other hand, two iterations of the proposed receiver can significantly reduce the PER degradation from the ideal performance when 64QAM is employed.



(a) 16QAM **(b) 64QAM**

Fig. 14 Average PER performances

Contributions

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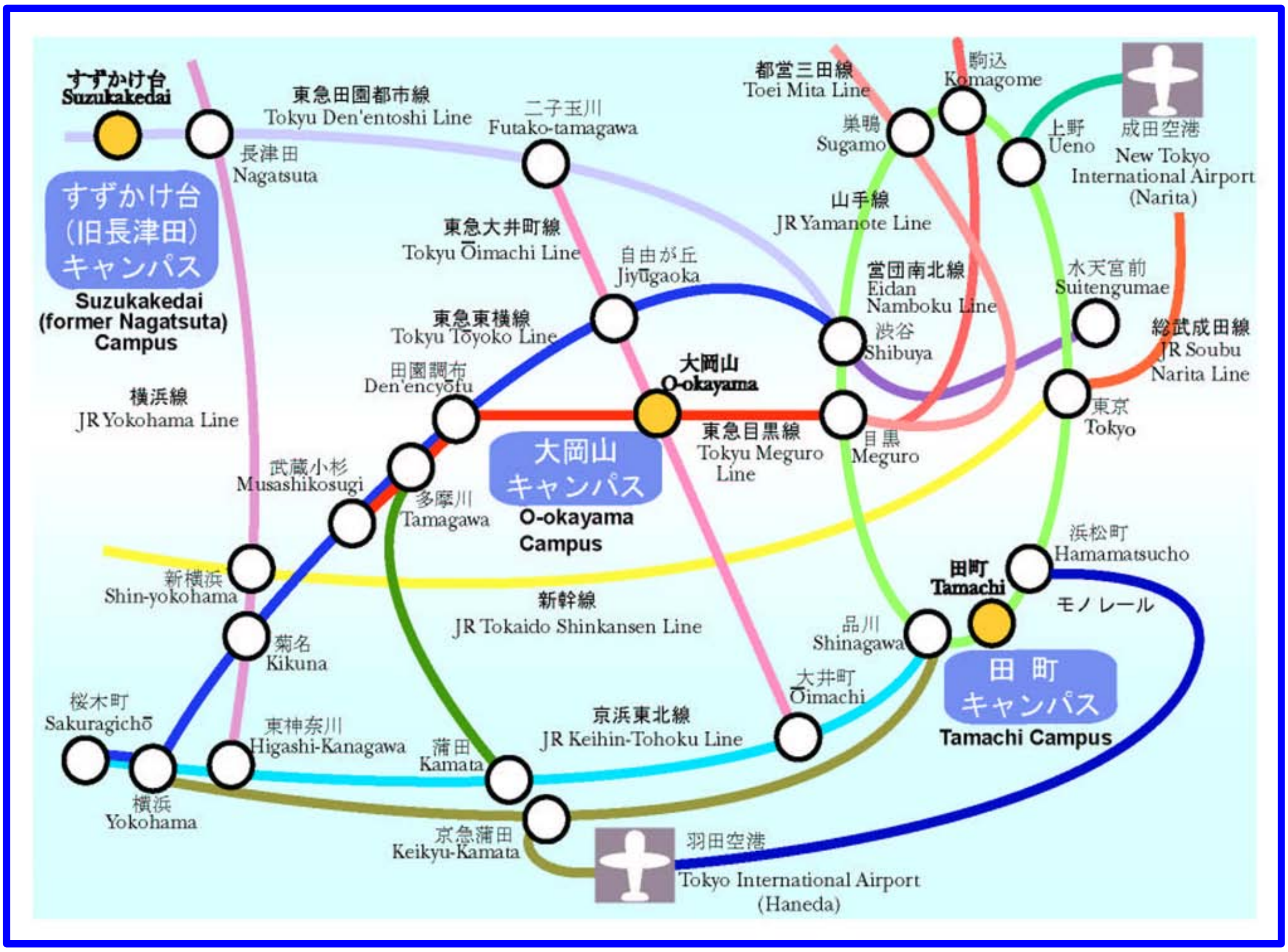

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