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MCRG TITECH

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Mobile Communications Research Group

The Mobile Communications Research Group (MCRG) consists of 3 laboratories, namely Araki-Murata Laboratory, Suzuki-Fukawa Laboratory, Takada Laboratory, and cooperative laboratory of Ando-Hirokawa Laboratory. 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. Speakers from MCRG and external organizations are also invited to our weekly seminar to share their latest research results and achievements. For the fiscal year 2005, we would like to take this opportunity to express our thanks and appreciation to Dr. Kenta Umebayashi from Oulu University, Asst. Prof. Kouji Ishii from Kagawa University and Prof. Akira Matsuzawa from Tokyo Institute of Technology for their valuable contribution to our weekly seminar.

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

An annual Open House is also organized to promote the research in MCRG and also to provide an excellent opportunity for interaction between researchers in the field of mobile communications. Distinguished speakers from both the academia and industry are invited to give keynote speeches and panel discussions to contribute their views and visions for the future development of research in mobile communications.

In the 2005 Open House, a panel discussion titled "MIMO Technology Standardization and Remaining Research Topics" was held and we were honored to have Prof. Yoshio Karasawa from The University of Electro-Communications, Prof. Yasutaka Ogawa from Hokkaido University, Prof. Seiichi Sampei from Osaka University and Prof. Hiroshi Suzuki from MCRG as our distinguished panel members.

Laboratory Introduction
&
Annual Report 2005

ARAKI-MURATA LABORATORY

web site: http://www.mobile.ss.titech.ac.jp/araki-lab/

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 and Information Society of Japan.

Associate Professor Hidekazu Murata

Assoc. Prof. Murata (right) received B.S., M.S., and Ph.D. degrees in electronic engineering from Kyoto University, Kyoto, Japan, in 1991, 1993, and 2000, respectively. In 1993, he joined the Faculty of Engineering, Kyoto University. Since 2002, he has been an Associate Professor of Tokyo Institute of Technology, Tokyo, Japan. His current research interests include signal processing and its hardware implementation, with particular application to multihop radio networks. He received the Young Researcher's Award from the IEICE of Japan in 1997 and the Ericsson Young Scientist Award in 2000. Assoc. Prof. Murata is a member of the IEICE, IEEE and SITA.

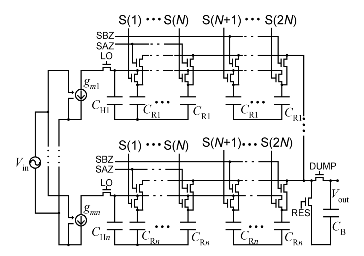
Assistant Professor Kei Sakaguchi

Asst. Prof. Sakaguchi was born in Osaka, Japan, on November 27, 1973. He received the B.E. degree in electrical and computer engineering from Nagoya Institute of Technology, Japan, in 1996, and the M.E. degree in information processing from Tokyo Institute of Technology, Japan, in 1998.

From 2000, he is an Assistant Professor at the Tokyo Institute of Technology. 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. His current research interests are in MIMO propagation measurement, MIMO communication system, and software defined radio. Asst. Prof. Sakaguchi is a member of IEICE and IEEE.

Members of Araki-Murata Laboratory.

ARAKI-MURATA LABORATORY



Direct Sampling Mixer

Research Topics

1
RFCMOS
Development and design of SDR transceiver based on CMOS.

2
POWER AMPLIFIER
Compensation techniques and development of multi-port power amplifier.

3
RF FILTERS
High performance filters with flexible and sharp response.

Future of Software Defined Radio

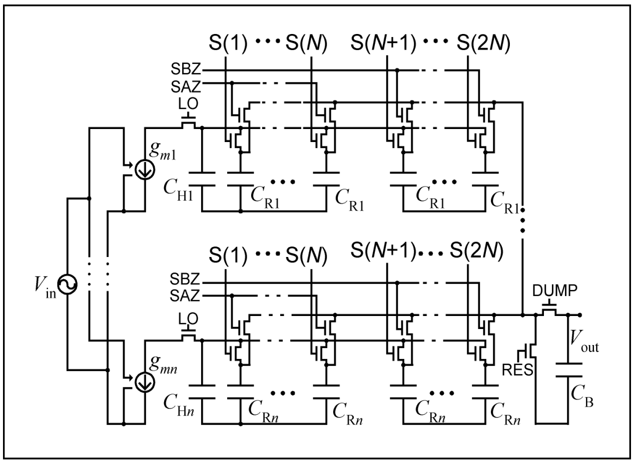
Digital RF Transceiver

Software defined radio (SDR) is of critical importance to the future of efficient and effective radio communication that must include interoperability between different protocols and standards with varying software, system and physical parameters.

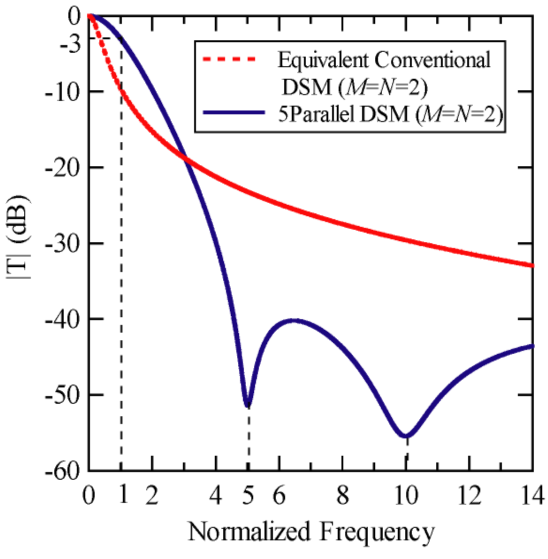
The transceiver is easily the toughest challenge for the realization of a true SDR system. The ideal transceiver must be able to respond smoothly to the rapidly changing protocols and transmit/receive signals operating at different frequencies and modulation techniques. This demanding requirement means that traditional RF design methods are insufficient and thus we are devoted to the research on digital RF transceiver which is widely recognized as an answer to the practical implementation of SDR.

Direct Sampling Mixer with Parallel Structure

As part of our research program, we focus on Direct Sampling Mixer (DSM) as a possible solution for the digital RF of SDR. DSM, as the name suggests, is a digital circuit that directly samples the RF signal, performs decimation and filtering to achieve its role as a mixer for up and down-conversion. However, the transfer function of DSM is only of first order and thus possesses poor skirt characteristics. To alleviate this problem, we propose a novel parallel architecture for DSM where the number of attenuation poles can be configured thus achieving excellent skirt characteristics



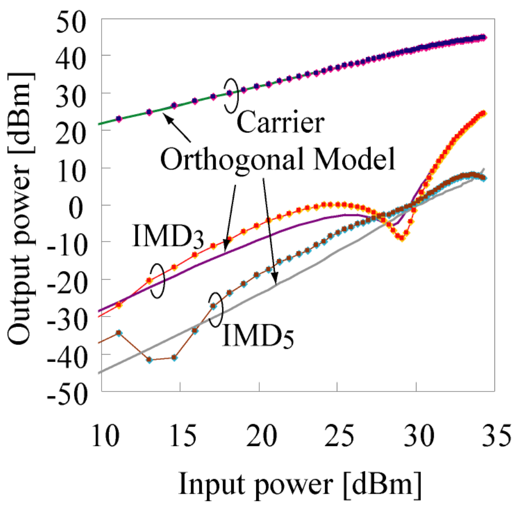
DSM with parallel architecture.



Frequency response of proposed DSM.

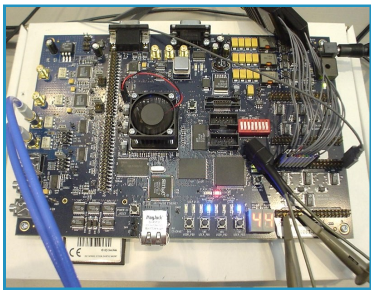
Compensation for Non-linear Distortion in Power Amplifiers

Recently, low-distortion characteristics are desired for power amplifiers used in digital radio communication systems. In particular, the influence of intermodulation distortion (IMD) including memory effect is significant as a source of out-of-band interference. Thus, there is a need to study and model the transfer characteristics of IMD. The transfer characteristics of IMD and that of our proposed model are shown below and we can see that the match is excellent. As part of our research effort, we will next examine the spectrum characteristics of a modulated wave in the presence of IMD.



Transfer characteristics of IMD.

4
RECONFIGURABLE RF
Architecture and hardware development of pure software-based RF circuits.



Research Topics

1
TRANSMISSION
Cooperative relaying, radio resource management, ARQ control, adaptive modulation, equalization and synchronization.

2
FIELD TRIALS
Performance evaluation of cooperative wireless multihop networks in urban area.

Next Generation Wireless Communication Technology

Wireless Cooperative Networks

Recently, mobile multihop wireless communication systems have received a lot of attention as a key technology in next generation wireless networks. Multihop wireless networks are formed by multihop capable radio equipments which can be fixed or even mobile. In these networks, the communication between any two radio stations can either be direct or relayed through intermediate stations in cases where the direct communication is not reliable. Benefits of multihop communications include overcoming dead-spots and reduction of transmit power, capacity gain and so on.

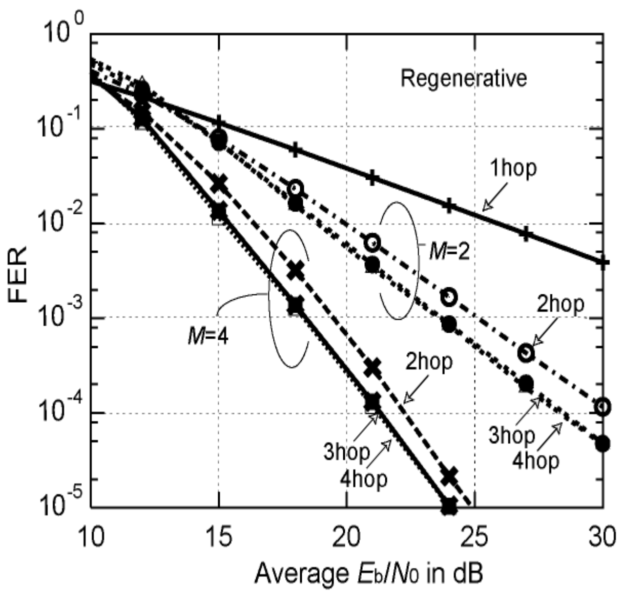
Diversity in Multihop Networks - Cooperative Relaying

In mobile multihop wireless networks, diversity technique is important since channels between mobile terminals may suffer from effects of fading and the source terminal normally communicates with the destination terminal through several relay channels. Several diversity techniques have been developed in order to mitigate the fading effects by using copies of the signal which pass through uncorrelated fading channels.

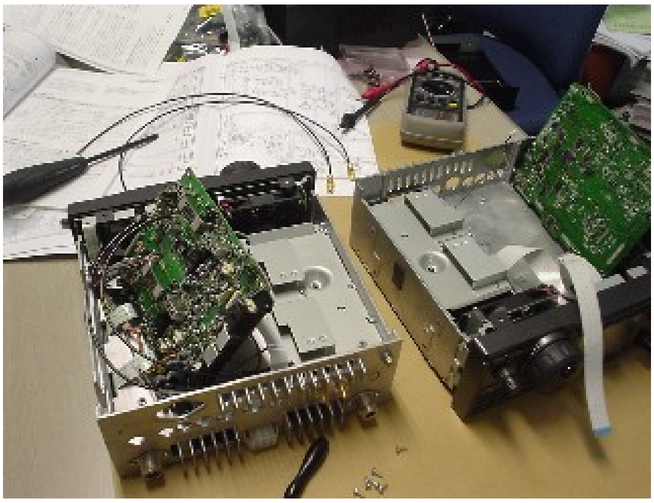
Space-time coding (STC) has been proposed as a transmit diversity technique exploiting multiple transmit antennas, which provides diversity gain by introducing temporal and spatial correlation on the signals transmitted from different antennas.

STC is attractive since it provides diversity gain without feedback and multiple receive antennas. However, generally it is undesirable to apply an advanced signal processing technology using multiple antennas to the mobile terminal due to the size and cost limitations. A new way of exploiting spatial diversity using a collection of distributed antennas has recently been proposed. This form of space diversity is referred to as ``cooperative diversity'' or ``cooperation diversity'' because terminals share their resources.

In this research, we consider multihop communications in cases where the number of hops is more than two and we develop space-time block coded cooperative relaying scheme in both non-regenerative and regenerative manner and evaluate end-to-end frame error rate (FER) performance of multihop communications. We show by computer simulations that space-time coded cooperative relaying scheme provides almost full spatial diversity gain. It is also shown that frame error rate is more improved as the number of hops increases. As far as the authors knowledge, this unique phenomenon has not been reported previously.



FER performance of multihop cooperative wireless networks.



1.3GHz transceivers for field trials.

3
IMPLEMENTATION
Implementation of baseband and
IF signal processing techniques
using FPGA and other devices.

4
ITS
Radio transmission techniques for ITS vehicle-to-vehicle communications.

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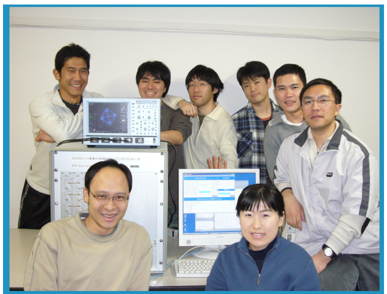


Research Topics

1
MIMO SOFTWARE DEFINED RADIO
Development of software-based testbed for evaluation of MIMO systems.

2
MIMO CHANNEL MEASUREMENT
Extensive and thorough study of MIMO propagation characteristics.

True Wireless Broadband Communication

MIMO Technology

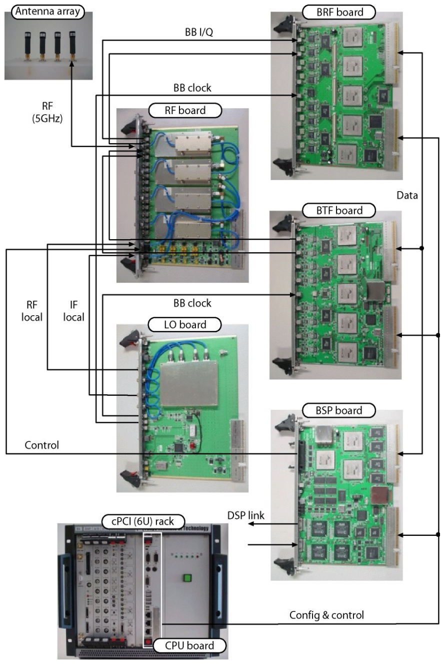
Multi-Input Multi-Output (MIMO) system creates a new dimension of transmission through the spatial modes of the MIMO channel on the same time-frequency slot, thus promising an exciting increase in the spectral efficiency. By tapping on the different spatial signatures inherent in a wireless channel, MIMO systems are able to exploit the multipath propagation environment rather than just mitigating the fading effects as in conventional systems.

MIMO Research Group

The MIMO research group consisting of 4 bachelor (3 from Tokyo University of Science), 5 master, and 3 doctor course students, was managed by Assistant Professor Kei Sakaguchi in 2005/2006. Research topics of the MIMO group can be broadly categorized into three areas, namely MIMO hardware development, MIMO propagation and MIMO transmission systems.

MIMO Software Defined Radio

A 5GHz band MIMO software defined radio was developed for the purpose of research and development of future MIMO systems. A schematic diagram of the system is shown on the right. The MIMO SDR composes of RF board, LO board, Tx front end board, Rx front end board, and a DSP board. A variety of MIMO-OFDM systems can be implemented on the developed hardware by rewriting the software running on the reconfigurable devices such as the DSP, FPGA and CPU.



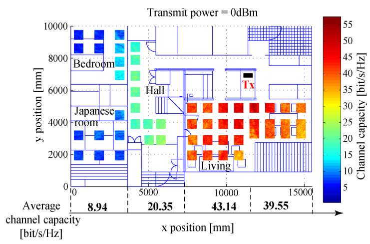
MIMO SDR architecture.

For instance, we have developed a MIMO-OFDM transmission system and real-time channel measurement system using the developed MIMO SDR testbed.

MIMO Channel Measurement

Channel measurement based on a 4x4 MIMO-OFDM system at 5GHz band was conducted in a residential home environment within an area of 15m by 10m including two rooms, a hallway, living and dining areas in a model house with over 55,000 snapshots. From the measured broadband MIMO capacity, we concluded that MIMO system can greatly increase the area coverage compared to conventional system especially at areas near to the transmitter where a high SNR is expected. Computer simulations using measured channel data were also performed to compare the realistic performance of MIMO-OFDM systems with various detection methods.

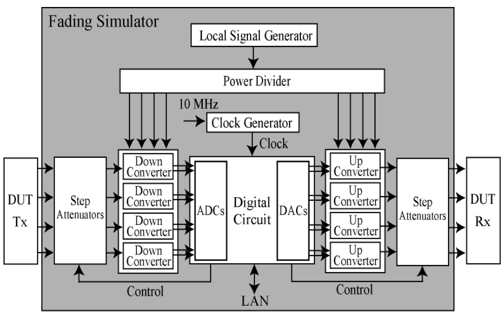
Model house used for measurements.



Measured 4x4 MIMO capacity.

MIMO Fading Simulator

Multipath channel characteristics as well as antenna configurations are both important factors in determining wireless system performance. Field tests in a mobile environment are considerably expensive. Therefore, MIMO fading simulator (FS) with a standard MIMO channel model is indispensable when developing products of MIMO systems. Our MIMO FS prototype implements a set of channel models developed by working group 11 of IEEE Standards Committee which is based on tapped delay line model and Kronecker model. The hardware platform supports up to 4x4 RF I/O.



MIMO fading simulator .

3
MIMO FADING SIMULATOR
Development and design of cost efficient RF fading simulator for MIMO systems.

4
MIMO TRANSMISSION SYSTEM
Proposal of robust and spectral efficient MIMO systems.

5
IQ IMBALANCE COMPENSATION
Robust and efficient IQ imbalance compensation scheme for MIMO-OFDM systems.

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

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

Assistant Professor Satoshi Suyama
received the B.S. degree in electrical and electronic engineering and the M.S. degree in information processing from Tokyo Institute of Technology, Tokyo, Japan, in 1999 and 2001, respectively. Since 2001, he has been an Assistant Professor in the Department of Communications and Integrated Systems at the Tokyo Institute of Technology. He is currently interested in various applications of the adaptive signal processing to radio signaling: turbo equalization, interference cancellation, and channel estimation for OFDM, MC-CDMA, and MIMO-OFDM. He is also interested in FPGA and DSP based simulators for radio signal processing. Prof. Suyama is a member of the Institute of Electronics, Information, and Communication Engineers (IEICE) of Japan. He received the Young Researchers' Award from the IEICE in 2005.

SUZUKI-FUKAWA LABORATORY

Subcarrier-Phase Hopping MIMO-OFDM Transmission with Phase Pattern Control for PAPR Reduction

SPH-SDM for PAPR Reduction

I. Introduction

The MIMO-OFDM technology has attracted much attention in wireless communications because it can realize more reliable and higher bit-rate transmission systems.

The subcarrier phase hopping for space division multiplexing (SPH-SDM) has been recently proposed in order to increase the frequency diversity gain via channel coding in MIMO-OFDM. The MIMO-OFDM transmitter, however, has to handle the signal waveform with the high peak power, and it requires the sufficient backoff for linear power amplification, which results in lower power efficiency. This report introduces a MIMO-OFDM transmission scheme that combines the subcarrier phase hopping for space division multiplexing (SPH-SDM) with an enhanced selected mapping (ESLM).

II. SPH-SDM with ESLM

A block diagram of an SPH-SDM transmitter employing ESLM is shown in Fig.1. Information bits are divided into M data streams, and encoded by a channel code, and after interleaving the coded bits, the transmitter maps them into a modulation signal at each subcarrier. Next, it carries out the subcarrier phase hopping (SPH) for the modulation signals of all streams. In SPH-SDM with ESLM, U phase matrices of all subcarriers are prepared as the phase patterns for the peak reduction, and then a ESLM controller selects an optimum phase pattern that can minimize the peak power for every symbol.

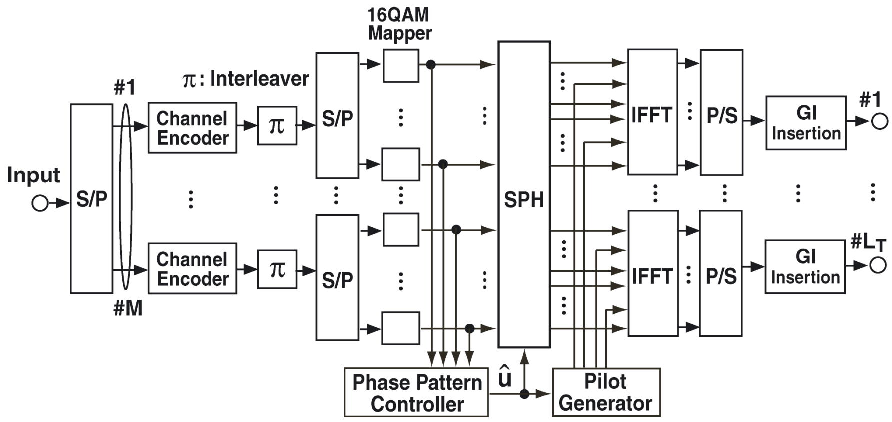

Fig.1 SPH-SDM transmitter employing ESLM

ESLM controller first performs SPH to the inputted modulated signals. Next, the quantized-IFFT, which reduce the complexity of the conventional IFFT, generates a quantized time-domain signal from the modulation signals with SPH, and the peak detector selects the optimum pattern u by comparing the peak powers of U patterns.

III. Computer Simulation

Computer simulation to verify the performance of SPH-SDM employing ESLM was conducted, which follows the 5GHz WLAN specification. Quantized level is set to Q = 16 which reduce the number of multiplications to almost 1/3 of the conventional IFFT Q=64. Fig2. shows an example of the IQ constellation of the transmitted signal of the conventional MIMO-OFDM and SPH-SDM with ESLM. This figure shows that the peak power is reduced by employing SPH with ESLM. Concretely, this scheme improve CCDF performance by increasing the phase pattern U and can achieve PAPR of 7.2 dB when U=256.

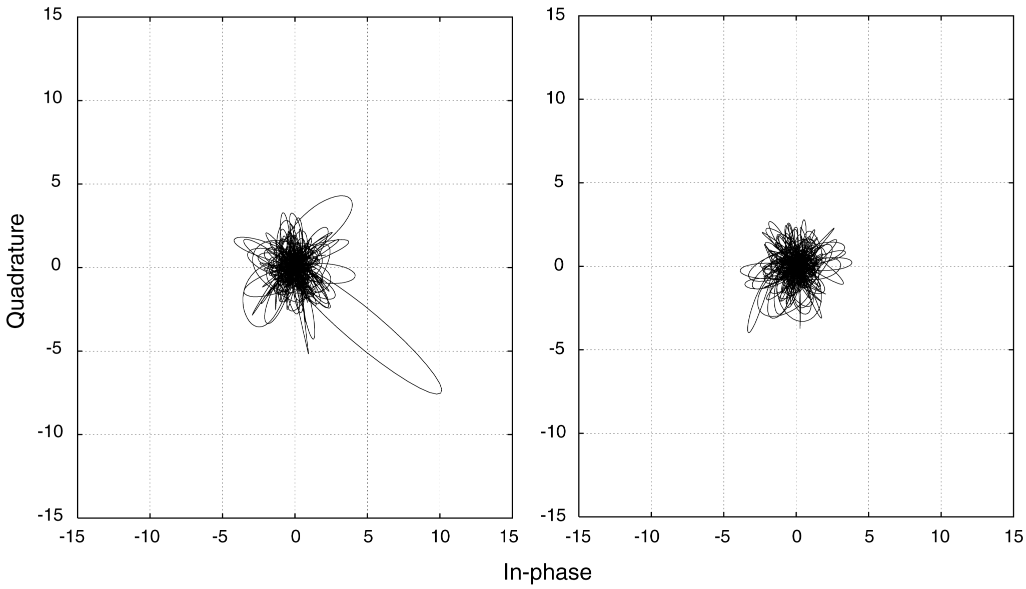

Fig.2 IQ constellation of conventional MIMO-OFDM and SPH-SDM

References [23], [27]

An OFDM Turbo Equalizer Cancelling ISI and ICI in Multipath Environments with Large Delay Spread

Iterative Processing of Channel Estimation, MAP Detection and MAP Decoding for ISI and ICI Cancellation

I. Introduction

OFDM is one of the most promising techniques in multipath fading channels. However, OFDM suffers from both the inter-symbol interference (ISI) from the adjacent OFDM symbols and the inter-carrier interference (ICI) within the same symbol, if the maximum propagation delay is greater than the guard interval (GI). To overcome this degradation, an OFDM turbo equalizer (TE), namely an iterative processing of equalization and decoding shown in Fig.1, has been proposed. It can equalize both ISI and ICI by employing the turbo processing with decoder outputs and use the CRC decoder output for judging whether they continue the iterative processing, which generally needs too many iterations especially in low SNR conditions. This report presents a novel OFDM turbo equalizer that controls the number of iterations by exploiting the replica error of the received signal. Furthermore, to improve an accuracy of the channel estimation, soft decision directed channel estimation (SDCE) is employed in the iterative processing.

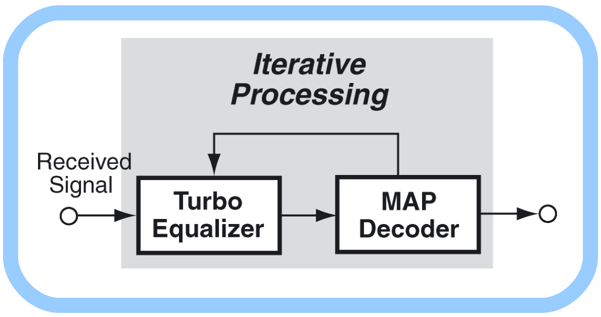

Fig.1 Principle of the turbo equalizer

II. TE employing iteration control and SDCE

Fig.2 shows a block diagram of TE, which consists of SDCE, an ISI canceller, an ICI canceller, an optimal detection filter, a MAP detector, and a MAP decoder. TE iterates the SDCE and the cancellation of both ISI and ICI by using log likelihood ratio (LLR) that the decoder produces. The optimal detection filter linearly combines the signal components on the MMSE criterion, and it carries out DFT simultaneously. In the initial processing, TE suppresses ICI only by the optimal detection filtering and copes with ISI by the decision feedback equalization. In addition, to reduce the numerical complexity, an simplified TE (STE) that performs the coherent detection (CD) for initial processing has been proposed.

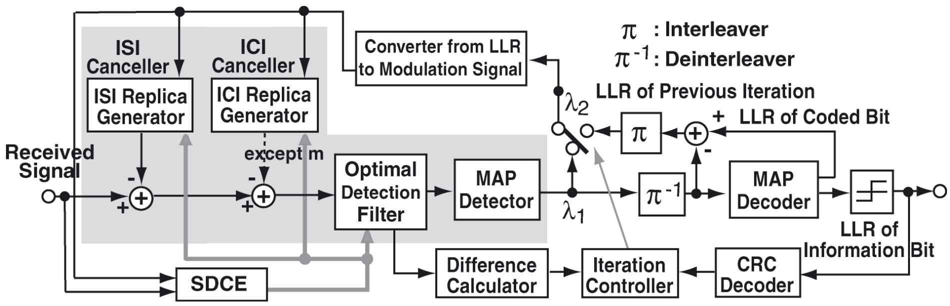

Fig.2 Block diagram of the receiver

Besides the judgement concerning the CRC decoder output, the next iteration of TE employing the iteration control will be carried out if a squared error between the received signal and its replica is greater than a threshold. This is because the replica error is used as the metric of the maximum likelihood estimation, and indicates whether TE can correct the bit errors in the next iteration.

III. Performance Evaluation

In order to verify the effectiveness of TE with iteration control, computer simulations were conducted, which follows the WLAN specification. It is assumed that the maximum delay is almost time of GI duration. The threshold for controlling the iteration was previously optimized by computer simulation. Fig.3 shows average PER performance and average numbers of the iterations. It demonstrates that both TE and STE can achieve better performance than CD, and that the average number of the iterations of the new method is reduced to 1/3 of the conventional one without performance degradation. This clarifies that the iteration control can greatly reduce power consumption and latency of the reception processing.

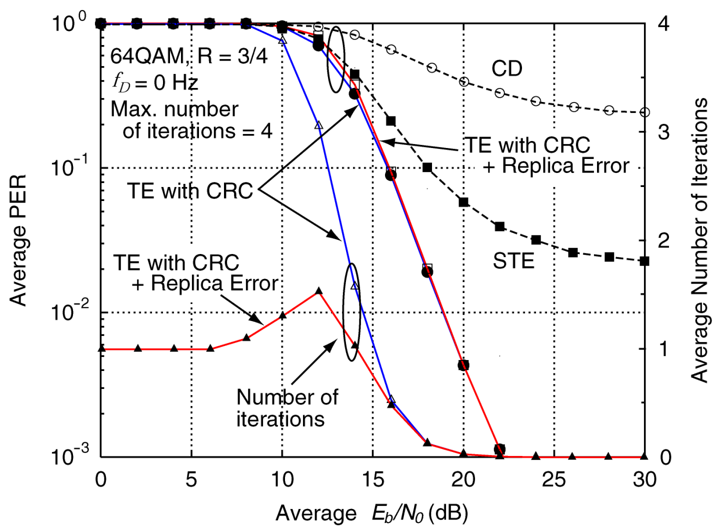

Fig.3 PER performance and the number of iterations

References [19], [29]

Precoding Method MIMO-OFDM Transmission Using Minimum BER Criterion

Minimized BER MIMO Precoding for MLD Reception

I. Introduction

MIMO-OFDM is one of the most promising techniques to realize the high bit-rate and spectral efficient transmission. To improve the performance of MIMO-OFDM transmission, a precoding which is based on linear processing is used at the transmitter. Since the conventional MIMO precoding methods assume linear reception, they can approximately minimize the BER of the MMSE-based linear receiver. However, the conventional methods do not increase the Euclidean distance between a pair of channel-distorted replicas of transmitted signals, and then can not minimize the BER of the maximum likelihood detection(MLD). This reports presents the precoding scheme to minimize the BER for MLD, which controls linear parameters of the precoding by minimizing the upper bound of BER based on the pairwise error.

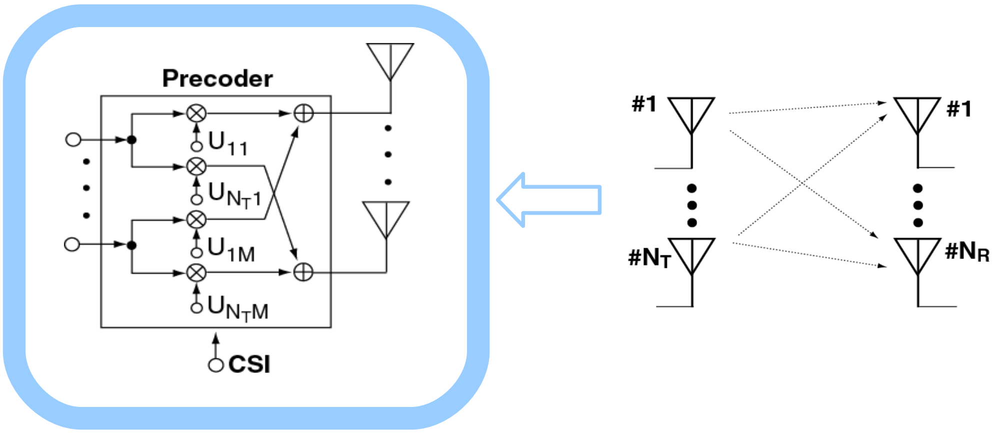

Fig.1 MIMO precoder

II. Precoding to minimize BER for MLD

Fig.2 shows the block diagram of the transmitter employing the precoding. Information bits are divided into each subcarrier of each antenna streams, and the transmitter maps them into a modulation signal. Next, it carries out the linear precoding, which maximize the Euclidean distance between a pair of channel-distorted replicas of transmitted signals at the receiver employing MLD, based on the channel frequency response and received CNR. Concretely, the linear parameter of this precoder is optimized by the steepest descent method as to minimize the upper bound of BER based on the pairwise error under the constant power constraint.

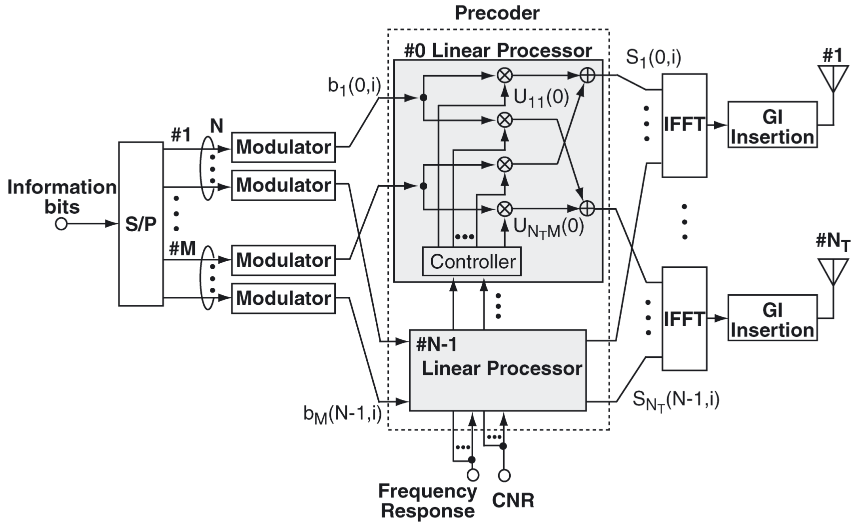

Fig.2 block diagram of the transmitter

III. Computer simulation

In order to verify the effectiveness of this precoder (MBER precoder), computer simulations were conducted, which follows the 5 GHz WLAN. The channel estimates and noise power was assumed to be kanown at the receiver and transmitter. Fig.3 shows the BER performance of the MBER and MMSE precoder when the number of the received antenna is set to 2 and transmit antenna to 2, 3, 4 respectively. The MBER precoder gain 6.9dB, 3.6dB, 2.3dB from MMSE precoder at average BER =10^{-3} for each antenna. For single carrier transmission, which also employs this precoder, over the flat Rayleigh fading channel, the gain was 13dB.

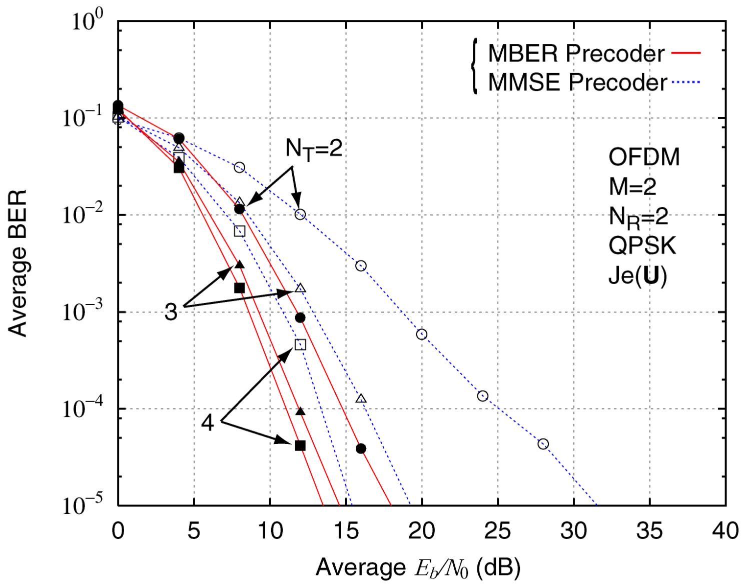

Fig.3 PER performance

An FPGA-board Simulator for MIMO-OFDM

FPGA Simulator for MIMO-OFDM Transmission

I. Introduction

The software defined radio (SDR) has attracted much attention because it can easily handle different wireless systems only by changing installed softwares. For researching SDR with highly complex radio signal processing, a reconfigurable on-board simulator that can effectively evaluate novel algorithms in real time is necessary. This topic presents an FPGA-board simulator for 2 x2 MIMO-OFDM transmission employing the subcarrier phase hopping (SPH-SDM).

II. FPGA Simulator for MIMO-OFDM

The simulator is implemented on an FPGA board shown in Fig.1, which consists of six FPGA chips of Xilinx VirtexII Pro (7 mega gates and 328 multipliers per chip). It employs 16-bit fixed-point processing, and can simulate real time MIMO-OFDM transmission including fading and noise generation available at baseband digital interface. Main parameters follow the WLAN standards, except that the bandwidth can be adjusted by the board clock frequency and that the modulation and coding scheme (MCS) is fixed to only QPSK with the code rate 1/2. A long preamble of the packet transmitted from each antenna is multiplexed in the time domain in order to simplify the channel estimation. The simulation can select one of two MIMO detection scheme: the maximum likelihood detector (MLD) and the MMSE detector (MMSED). Actual layout of this simulator is shown in Fig.2.

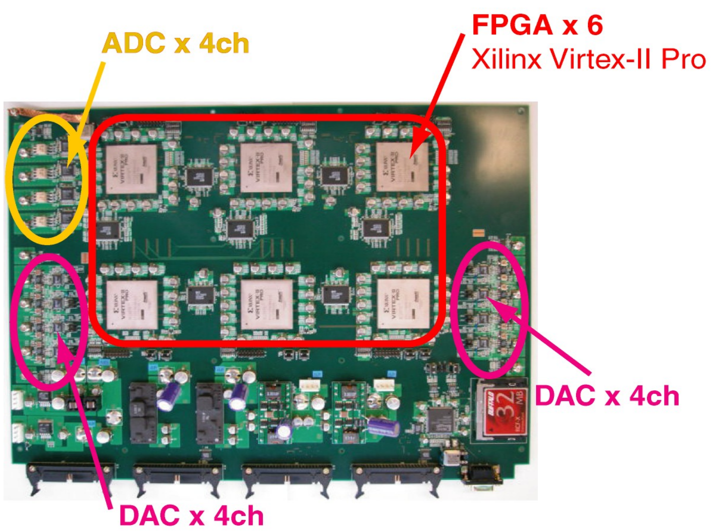

Fig.1 Multi-FPGA-Board with multi-ADC/DAC

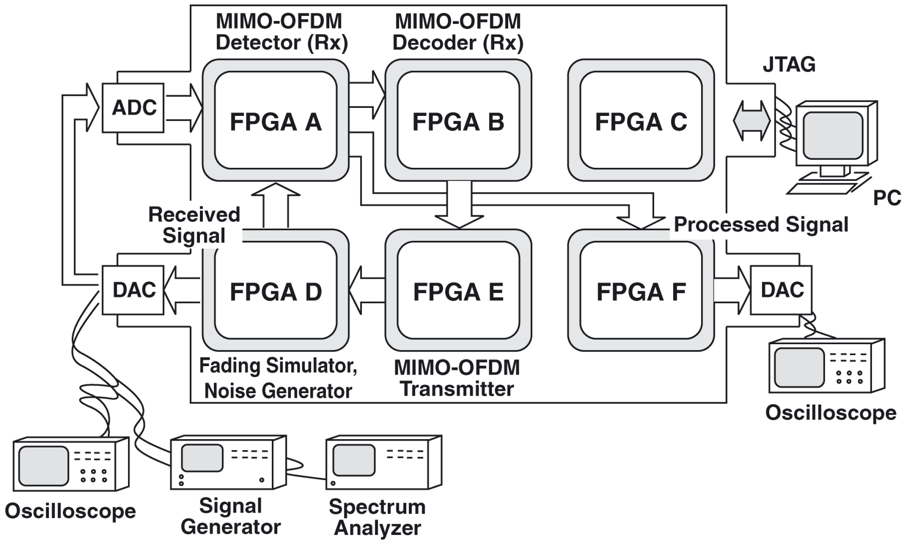

Fig.2 Simulator implementation on the multi-FPGA board

III. Performance Evaluation

Both the transmit and receive modules of 2 x 2 MIMO-OFDM with SPH consume almost 20% (8.4 mega gates) of the total resources on the FPGA board. Fig.3 shows average packet error rate (PER) performance of the simulator. In this figure, the results obtained by the floating-point computer simulations are also plotted for comparison. This figure verifies the validity of the implementation, and it demonstrates that SPH-SDM can improve the performances of both MMSED and MLD.

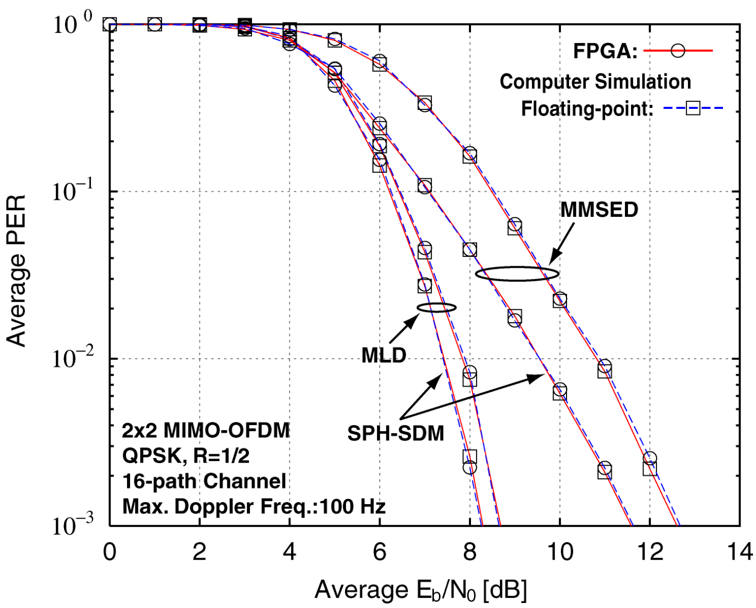

Fig.3 PER performance

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TAKADA LABORATORY

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Members of Takada Laboratory.

TAKADA LABORATORY

Introduction

We study the wireless communications and the applied radio instrumentations. As well, we involve in the international development projects. Many different approaches are taken, such as fabrication and prototyping, field measurement, lab experiments, computer simulation, and field work. Many joint researches are ongoing with industry, research institutions, and other universities.

Recent Research Topics

Radiowave propagation and channel characterization

- Measurement and modeling of microscopic scattering phenomena in micro- and pico-cell environments
- Multipath parameter estimation and modeling based on maximum likelihood estimation
- UWB double directional channel measurement and modeling in short range indoor environment
- Spatio-temporal channel measurement and modeling for adaptive array and MIMO transmission

Antennas

- Adaptive antenna impedance matching proximity to human body
- Analog RF adaptive array antenna using varactors
- Spatial fading emulator
- Evaluation of UWB transmission considering waveform distortion due to antenna
- Miniaturization of wrist watch antenna
- Evaluation of antenna calibration for precise angle of arrival estimation

Signal processing and applications

- Radio surveillance system utilizing independent component analysis
- Direction of arrival estimation based on amplitude-only array output
- Realtime telemetry system for monitoring of wild animals
- MIMO transceiver implementation using software radio approach

International development projects

- Sustainable development management in the World Cultural Heritage areas
- Radpidly deployable rural communication systems for regional development

In the succeeding pages, we show some detailed discussion of our works. For more details, visit our website at http://ap.ide.titech.ac.jp/

Investigation of the Bragg Scattering of UWB Signal from the Window Blind

In indoor and outdoor propagation environments, the non-specular scattering at the walls are often not negligible. Bragg scattering may not be negligibly small for the periodic walls such as brick walls, metallic shutters and blinds. In particular, its frequency dispersive property may influence the transmission property of the UWB system. This study investigates the Bragg scattering of the UWB signal from the window blind. Moreover, we discusses the range of the Bragg scattering theoretically for the experimental condition. Also, to compare the difference between the periodic surface and a flat surface, 2 experiment setups were made.

Bragg Scattering

Bragg's law defines a diffraction relationship between the wavelength of an incoming ray and the period of the periodic structure [1] as shown in Fig 1.

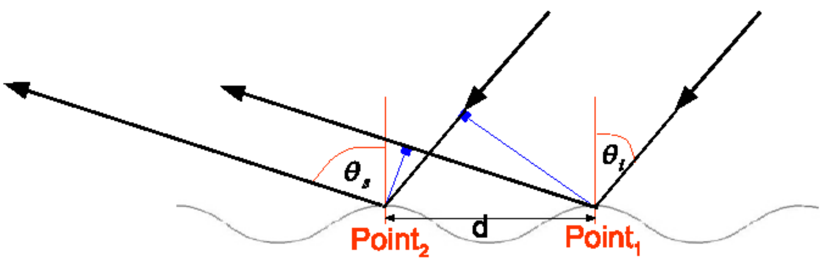


Figure 1: Bragg Scattering Illustration

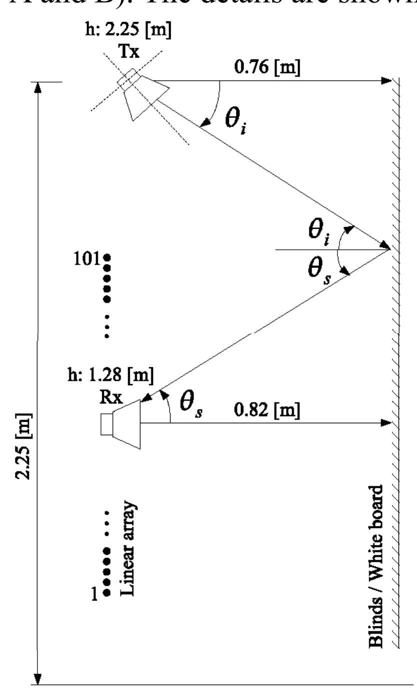
Bragg scattering equation is expressed below:

$$\begin{aligned} n\lambda &= d\sin\theta_i - d\sin\theta_s \\ \theta_s &= \arcsin(\sin\theta_i - \frac{n\lambda}{d}) \end{aligned}$$

where n is the order of reflection, d is the interplanar spacing, i is the index for incidence angle and s is for the reflection.

Experiment setup

Figure 2 shows the measurement setup of these experiments. The measurements have been performed with a vector network analyzer to determine the complex radio channel transfer function $H(f) = S_{21}(f)$. Some indispensable parameters are shown in Table 1. The Tx antenna was mounted on a pole and its position was fixed. While the Rx antenna was mounted on the arm of the scanner to measure the DOA. To compare what's the difference between the periodic surface and the flat surface, we measured 2 experiments (Cases A and B). The details are shown in Figs. 3.



θ_i: Incident angle
θ_s: Scattered angle

Figure 2 Experiment Setup

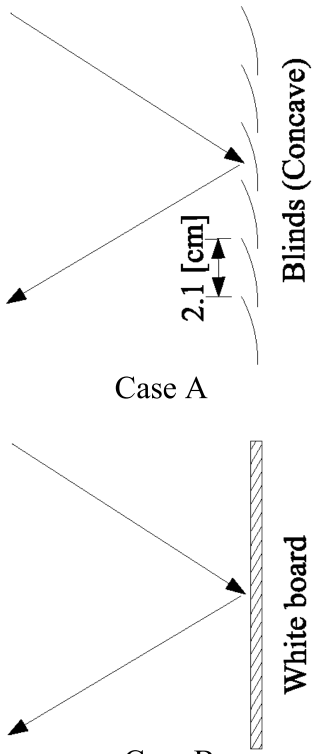


Figure 3 Target Objects

Bandwidth	3.1 to 10.6 [GHz]
Frequency sweeping points	751
Spatial sampling in the Rx position	101 points in vertical linear array whose element spacing is 1 [cm]
Power spectrum	DOA (θ_s) and frequency.
Type of antennas	Double-ridged guide horn
Polarization	Vertical-Vertical
Calibration	Function of VNA
IF bandwidth of VNA	100 [Hz]
SNR at receiver	about 50 [dB]

Table 1 Specifications of the experiment

Simulation and Experiment results

For data processing, Beamforming and Windowing function (Hanning) were used. Figs. 4 and 5 show the results of simulation and experiment respectively. We can find that Bragg scattering in case A appeared consequently for frequencies greater than 8 [GHz]. For case B, no Bragg scattering appeared since the reflection object is a flat surface. The specular reflection and LOS regions appeared in both cases.

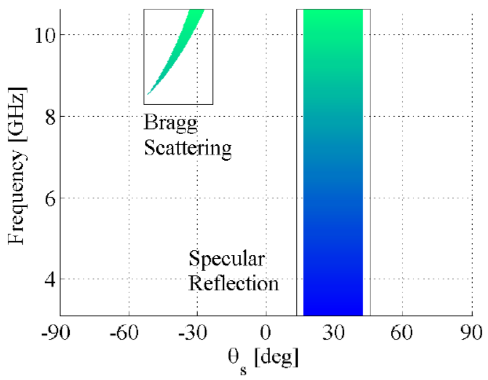
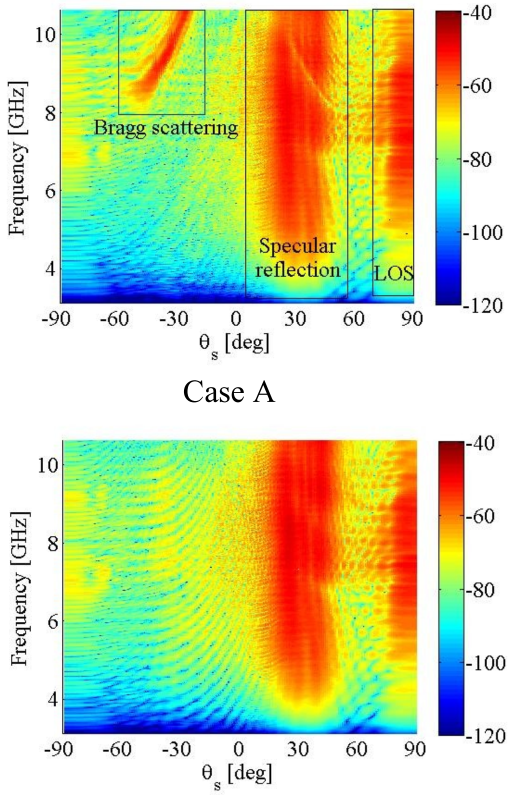


Figure 4 Theoretical Simulation



Case A

Case B

Figure 5 Angular frequency spectrum

Conclusion

UWB Bragg scattering experiments and its characteristics are shown. The results of these experiments correspond with the theoretical value. It verified that the frequency dispersive effects of UWB cannot be ignored.

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Verification of Kronecker MIMO Channel Model in a NLOS Macrocellular Environment

Based on the measurement in a NLOS macrocellular environment [1], the applicability of Kronecker MIMO channel model is verified. Two cases of polarization transmissions are investigated, i. e. , the horizontal polarized (HP) and vertical polarized (VP) ports at both transmitter (Tx) and receiver (Rx).

Measurement and Capacity calculation

From the measurement, 58 points with distance between adjacent 2 points of 10 m. are considered. 4 antenna ports at Tx and Rx are selected according to Fig. 1 to form a 4×4 MIMO matrix, $\mathbf{H}$. By shifting a column at Rx and a row at Tx, we have 48 combinations at each measurement point and in total 2784 different scenarios are obtained. The detection threshold of 10 dB above the noise floor is used. The capacity of equal power allocation is calculated as

$$C = \log_2 \det \left(\mathbf{I}_{4\times 4} + \frac{\mathrm{SNR}}{4} \mathbf{H}\mathbf{H}^H \right),$$

where $\mathbf{I}_{4\times4}$ is the identity matrix and average SNR is set at 5 dB. Only scenarios where we can detect impulse responses for all 16 channels are used for validations.

Model Validation

Frobenious norm error between full channel correlation matrices of

$$\mathbf{R} = E\{\mathrm{vec}(\mathbf{H})\mathrm{vec}(\mathbf{H})^H\}$$

and Kronecker assumption is calculated. The expectation operator, $E\{\bullet\}$ is taken over the frequency bins of 385. The averages of the norm errors for the VP and HP are found to be 21.8% and 22.8 %, respectively.

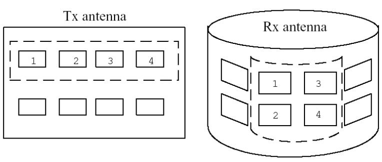

Figure 1: Selected MIMO configurations.

Capacity Comparison

Figures 2 and 3 show the average capacity from the measurement data and that from the Kronecker model. For both polarizations, it is clear that the Kronecker model tends to underestimate the average capacity in NLOS macrocellular environment as also shown in [2] and [3] for indoor and outdoor-to-indoor environments, respectively. Artifacts created by the Kronecker product reduce the average capacity when only certain multipaths connect between Tx and Rx. The averages of absolute error in average capacity for the VP and HP are about 6.6 %.

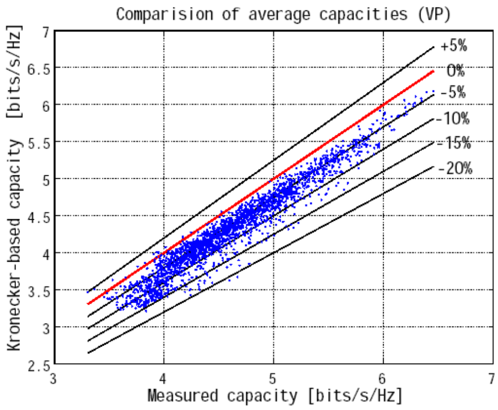

Figure 2: Comparison of average capacities for VP antennas.

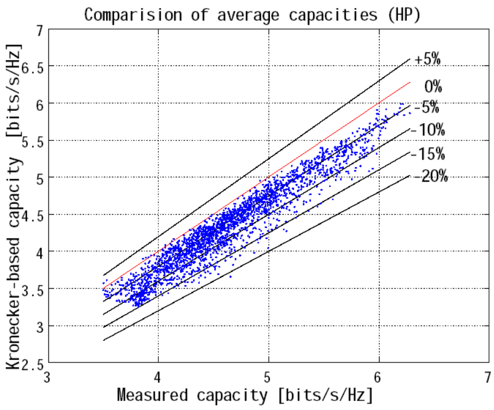

Figure 3: Comparison of average capacities for HP antennas.

Conclusion

The applicability of Kronecker model to the MIMO system in a NLOS macro-cellular environment was shown. We found that the predicted capacity when applying the model to the MIMO systems tends to be underestimated.

Acknowledgment

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RF Combining Diversity Antennas

Performance Evaluation for RF-Combining Diversity Antenna Configured with Variable Caps

High quality transmission is desired for mobile communications applications. However, mobile systems are often used under non-line-of-sight multipath environment where the performance is degraded due to fading and interference. Although the adaptive array antenna (AAA) is a useful technique to alleviate fading and interference, its realization in digital signal processing requires A/D and D/A converters, RF transmitters and receivers of the same number as the antenna elements so that it is difficult to implement on mobile terminals in terms of power consumption, cost and size.

On the other hand, the electronically steerable passive array radiator (ESPAR) antenna can perform the signal processing in space by using variable-capacitance devices controlled electronically. Comprehensive studies have been reported for diversity and co-channel interference suppression and so on [1]. Especially, for diversity scheme, the directional diversity that the directivity is changed by switching the bias voltage of varactor diode, has been proposed. However, the ESPAR antenna is fed only on one element and the other elements are excited by mutual coupling. Therefore, there is no flexibility for the layout of elements.

An RF adaptive array antenna (RF-AAA) configured with variable capacitors for mobile systems (Figs. 1 and 2) was proposed in [2]. This system is equipped with reactance control circuits (RCCs), which are configured with variable capacitors, and a common matching circuit. Advantages of this structure are that signals are detected only by one receiver and therefore the hardware architecture is quite simple. In this system, the power-combining ratios and phase values of received signals are changed by the RCCs in RF when signals received at antennas are combined.

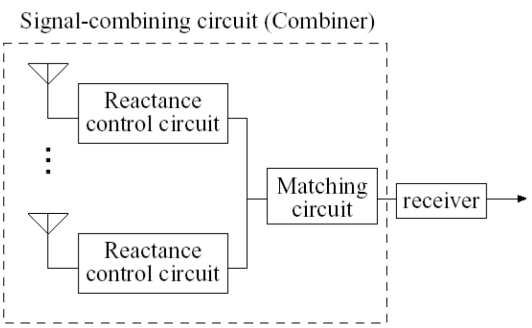

Figure 1: Configuration of proposed antenna system.

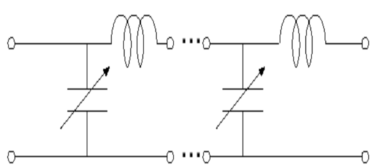

Figure 2: Reactance control circuit

Diversity Antenna Gain

Diversity antenna gain (DAG) evaluates the total performance including the antenna and propagation environment. If the fading is slow, the outage probability is a good criteria to measure the link quality. DAG-OP is defined as the gain of SNR at a specific outage probability with respect to a reference antenna under the same propagation environment [3] represented as

$$F = \frac{\Gamma_{\text{div}}}{\Gamma_{\text{ref}}}$$

where the numerator is the SNR at a specific outage probability for the diversity reception case and the denominator is the SNR at the same outage for the reference antenna, which is a single half-wave dipole antenna in this case.

Cumulative Probability

Figure 3 illustrates the cumulative probabilities of output SNR for the 2-branch and 4-branch RF-diversity antennas (RF-DAs), selection combining (SC), equal gain combining (EGC) and maximal ratio combining (MRC). Furthermore, Table 1 indicates the DAG-OPs which satisfy the outage probability of 5 percent. It is obvious that the RF-DA provides higher performance than SC.

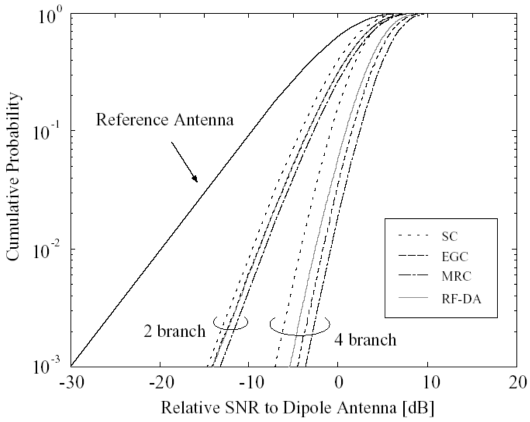

Figure 3: Cumulative probabilities

Table 1: DAG-OP (Outage probability 5%)

	SC	EGC	MRC	RF-DA
2 branch	6.8	7.7	8.3	7.7
3 branch	9.5	11.2	12.0	10.9
4 branch	10.9	13.3	14.2	12.6

(Unit : dB)

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