Advanced Wireless & Communication Research Center

ACTIVITY REPORT 2019

The University of Electro-Communications

Message from the Director, Prof. Takeo Fujii

Advanced Wireless Communication Research Center (AWCC) of the University of Electro-Communications (UEC) was established in 2005 and the name was changed to "Advanced Wireless & Communication Research Center" in 2015. For the years, AWCC has been aiming and conducting four missions that are;

- Dedication to advanced research on wireless communications; offering more unique results.
- Education in graduate school for cultivating specialty in engineering; specialized and universal education in the area.
- Active collaboration / joint research with industries and government; transferring the outcomes to the society.
- Constant acquisition of competitive research funds; for self-supported operation.

The current vision of AWCC is "Ambient Wireless in Connected Community (AWCC)." AWCC intends to cover broader research area including not only wireless communications but also any promising aspects of "wireless" and "communications". As an academic institute, it is our mission to pursue basic research in science and technology. Toward the goals, AWCC will enhance its force and strengthen its presence in the world.

We are focusing the following four research sectors.

(1) Wireless Technology as Social Infrastructure

Wireless technologies will have more importance in the society as the base of safe, secure and smart life for the individual and the community. Intelligent Transport System (ITS) is one of the focused topics, anticipating the great demand for automated driving.

(2) Innovative Hardware for Wireless & Communication

Demands for broadband and high-capacity mobile communication systems are very strong, and 5G and beyond system is being developed in the world. The 5G and beyond system introduces new usage of frequency spectra called multi-band multi-access, which requires innovation in RF hardware to achieve higher-accuracy signal transmission with flexibility. Also, wireless power transfer is another hot and important topic.

(3) Advanced Wireless System & Networks

We have developed many fundamental technologies such as distributed dynamic multi-hop network, cognitive radio, fault-tolerant network operation, and radio environment-aware communications. From now on, we integrate the technologies and establish an ultimate wireless network design.

(4) Exploring Low Power Wireless

By reducing power consumption of wireless system dramatically, applications of wireless communications will spread wider than now. It will make all things connected in the world, realizing the word "IoT". Innovative low-power technologies are necessary to realize such a world.

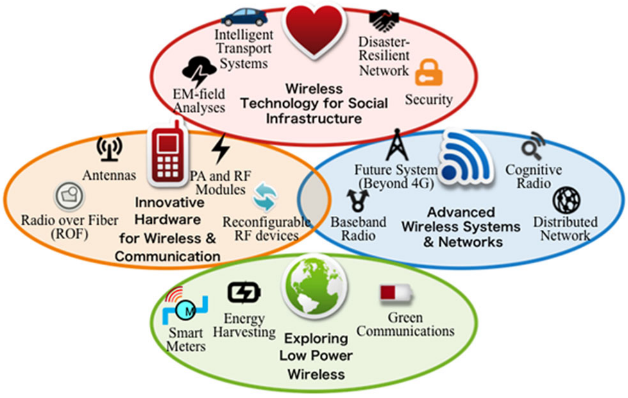
As the open research center to the society, AWCC would like to think together with people and contribute much in research and education of "wireless" and "communications". We hope your kind help and great understanding to AWCC.

藤井 威生

1 . ABOUT AWCC

1.1 OVERVIEW

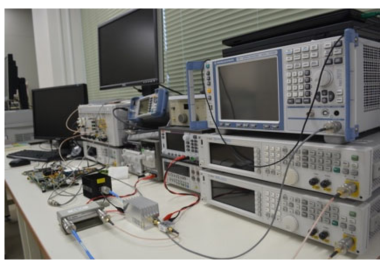
The Advanced Wireless Communication Research Center (AWCC) was launched in April 2005 with the aims of establishing a global hub for wireless communications; advancing education in wireless technology; industrial collaboration and technology transfer; and nurturing young engineers with strong emphasis on both theoretical and experimental aspects of wireless communications. In April 2015, the center was re-launched as the Advanced Wireless and Communication Research Center with the same abbreviation, AWCC, to enhance its remarkable range of activities over the previous ten years. With funding of approximately 1000 million yen over nine years, the center consists of 4 full time, 5 concurrent, 20 cooperative, and 6 visiting professors. In addition, there are 9 visiting professors from industry and more than 100 graduate students, post-doctoral and research fellows. The center actively contributes to academic societies and publishes more than 150 papers annually in top journals and proceedings of international conferences.



The AWCC organizes regular seminars and workshops with the highlight of 2014 being the “Tokyo Wireless Technology Summit” held in March 2014. The meeting focused on the next major phase of mobile telecommunications called 5th generation (5G) and attracted approximately 240 participants from all over the world.

1.2 FACILITIES

AWCC is located on the east-campus of the University of Electro-Communications in Chofu city, Tokyo near Shinjuku district in Japan. The center has opened with 10,441 square foot of modern research space containing a class room, two conference rooms, four research offices, and two experiment rooms with a wide range of instruments including FPGA development platforms, signal generators, vector network analyzers, spectrum analyzers, software defined radios, and so on. Also, it has extensive computer and network resources including high-speed workstations and personal computers which are integrated with resources of the Univeristy of Electro-Communications.



1.3 PEOPLE

【Director, Full-time Prof. Takeo Fujii】

Takeo Fujii was born in Tokyo, Japan, in 1974. He received the B.E., M.E. and Ph.D. degrees in electrical engineering from Keio University, Yokohama, Japan, in 1997, 1999 and 2002 respectively. From 2000 to 2002, he was a research associate in the Department of Information and Computer Science, Keio University. From 2002 to 2006, he was an assistant professor in the Department of Electrical and Electronic Engineering, Tokyo University of Agriculture and Technology. From 2006 to 2014, he has been an associate professor in Advanced Wireless Communication Research Center, The University of Electro-Communications. Currently, he is a professor in Advanced Wireless and Communication Research Center, The University of Electro-Communications. His current research interests are in cognitive radio and ad-hoc wireless networks. He received Best Paper Award in IEEE VTC 1999-Fall, 2001 Active Research Award in Radio Communication Systems from IEICE technical committee of RCS, 2001 Ericsson Young Scientist Award, Young Researcher's Award from the IEICE in 2004, The Young Researcher Study Encouragement Award from IEICE technical committee of AN in 2009, Best Paper Award in IEEE CCNC 2013, and IEICE Communication Society Best Paper Award in 2016. He is a member of IEEE and a fellow of IEICE.

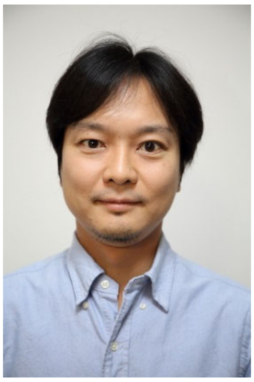
【Full-time Prof. Yasushi Yamao】

Dr. Yasushi Yamao received his B.S., M.S., and Ph.D. degrees in electronics engineering from Kyoto University, Kyoto, Japan, in 1977, 1979, and 1998, respectively. In 1979, he joined the Nippon Telegraph and Telephone Corporation (NTT) Laboratories, Japan, where his major activities included leading research on GMSK modulator /demodulator and GaAs RF ICs for digital mobile communications, and development of PDC digital cellular handheld phones. In 1993, he moved to NTT DoCoMo Inc. and directed standardization of high-speed paging system (FLEX-TD) and development of 3G radio network system. He also joined European IST research programs for IP-based 4th generation mobile communication. In 2005, he moved to the University of Electro-Communications as a professor of the Advanced Wireless Communication Research Center (AWCC). Prof. Yamao is a Fellow of the IEICE and member of the IEEE and IPSJ. He served as the Vice President of IEICE Communications Society (2003-2004), the Chairman of IEICE Technical Group on Radio Communication Systems (2006-2008), the Chief Editor of IEICE Communication Magazine (2008-2010), a Director of the IEICE (2016-2017) and the Vice Chairman of IEEE VTS Japan chapter (2009-2015). Now he is the Chairman of IEEE VTS Tokyo/Japan chapter

【Full-time Associate Prof. Koji Ishibashi】

Koji Ishibashi received the B.E. and M.E. degrees in engineering from The University of Electro-Communications, Tokyo, Japan, in 2002 and 2004, respectively, and the Ph.D. degree in engineering from Yokohama National University, Yokohama, Japan, in 2007. From 2007 to 2012, he was an Assistant Professor at the Department of Electrical and Electronic Engineering, Shizuoka University, Hamamatsu, Japan. Since April 2012, he has been with the Advanced Wireless Communication Research Center (AWCC), The University of Electro-Communications, Tokyo, Japan where he is currently an Associate Professor. From 2010 to 2012, he was a Visiting Scholar at the School of Engineering and Applied Sciences, Harvard University, Cambridge, MA. Prof. Ishibashi has contributed more than 80 articles to international journals and conference proceedings. His current research interests are signal processing, cooperative communications, RF energy harvesting, rateless coding, and information theory. He is a member of IEEE and IEICE.

【Full-time Associate Prof. Koichi Adachi】



Koichi Adachi received the B.E., M.E., and Ph.D. degrees in engineering from Keio University, Japan, in 2005, 2007, and 2009 respectively. From 2007 to 2010, he was a Japan Society for the Promotion of Science (JSPS) research fellow. From May 2010 to May 2016, he was with the Institute for Infocomm Research, A*STAR, in Singapore. Currently, he is an associate professor at The University of Electro-Communications, Japan. His research interests include cooperative communications and energy efficient communication technologies. He was the visiting researcher at City University of Hong Kong in April 2009 and the visiting research fellow at University of Kent from June to Aug 2009.

Dr. Adachi served as General Co-chair of the 10th and 11th IEEE Vehicular Technology Society Asia Pacific Wireless Communications Symposium (APWCS) and Track Co-chair of Transmission Technologies and Communication Theory of the 78th and 80th IEEE Vehicular Technology Conference in 2013 and 2014, respectively. He is an Associate Editor of IET TRANSACTION ON COMMUNICATIONS since 2015 and IEEE WIRELESS COMMUNICATIONS LETTERS since 2016. He was recognized as the Exemplary Reviewer from IEEE COMMUNICATIONS LETTERS in 2012 and IEEE WIRELESS COMMUNICATIONS LETTERS in 2012, 2013, 2014, and 2015. He was awarded excellent editor award from IEEE ComSoc MMTC in 2013.

【Concurrent Prof. Koichiro Ishibashi】

Koichiro Ishibashi has been a professor of The University of Electro-Communications, Tokyo, Japan since 2011. He received PH. D degree from Tokyo Institute of Technology in 1985. He joined Central Research Laboratory, Hitachi Ltd. in 1985, where he had investigated low power technologies for Super H microprocessors and high density SRAMs. From 2004 to 2011, he was in Renesas Electronics where he developed low power IPs mainly for mobile phone SOCs as a department manager.

He has presented more than 110 academic papers at international conferences including ISSCC, IEDM invited papers, and IEEE Journals. He was awarded R&D 100 for the development of SH4 Series Microprocessor in 1999. He is a member of IEICE and a Fellow of IEEE.

His current interests include design technology of low power LSI, and IoT applications using the low power LSIs. They include low power design technology using SOI devices and energy harvesting sensor networks.

【Concurrent Prof. Takayuki Inaba】

Takayuki Inaba received a B.S. degree from the Department of Physics, Tokyo Institute of Technology, in 1981, completed the M.E. program in physics in 1983. He received the Ph.D. degree in engineering from Tokyo Institute of Technology in 2001. Since April 2008, he has been with the University of Electro-Communications, where he is a Professor at the Department of Mechanical and Intelligent Systems Engineering, Graduate School of Informatics and Engineering. He has been engaged in research and development of radar signal processing, and adaptive array signal processing, and automotive radar systems. He is a senior member of IEEE. He is a recipient of the Telecommunications Advancement Foundation Award (32th), IEEJ Distinguished Paper Award (72th), 2014 IEEE AES Japan-chapter Best Paper Award, IEICE Communications Society Distinguished Contributions Award 2009, 2006 IEEE AES Japan-chapter Best Paper Award, and IEICE Communications Society Excellent Paper Award 2006. .

【Concurrent Prof. Koji Wada】

Koji Wada received the B.E. and M.E. degrees from Kinki University, Osaka, Japan, in 1991 and 1995, respectively, and the Doctorate degree from Yamaguchi University, Yamaguchi, Japan, in 1999. From 1999 to 2004, he was a Research Associate with the Department of Electrical Engineering and Electronics, Aoyama Gakuin University, Kanagawa, Japan. From 2004 to 2015, he worked as an Associate Professor at the Department of Electronic Engineering, the University of Electro-Communications, Tokyo, Japan and he is Currently a Professor at the Department of Computer and Network engineering, Graduate School of Informatics and Engineering, the University of Electro-Communications. His research interests include resonators, filters, multiplexers, multiband circuits, tunable circuits, periodic structure, and metamaterial circuits. Dr. Wada is a member of the Institute of Electronics, Information and Communication Engineers (IEICE), Japan, Institute of Electrical Engineers of Japan (IEEJ), and Japan Institute of Electronics Packaging (JIEP).

【Concurrent Prof. Motoharu Matsuura】

Motoharu Matsuura received the Ph.D. degree in electrical engineering from the University of Electro-Communications, Tokyo, Japan, in 2004. In 2007, he joined the Department of Information and Communication Engineering at the University of Electro-Communications as an Assistant Professor. From 2010 to 2011, on leave from the university, he joined the COBRA Research Institute, Eindhoven University of Technology, Eindhoven, The Netherlands, as a Visiting Researcher, where he studied ultrahigh-speed optical signal processing using semiconductor-based devices. He is currently a Professor with the Graduate School of Informatics and Engineering, Department of Communication Engineering and Informatics, University of Electro-Communications. His research interests include optical signal processing, photonic subsystems, and radio-over-fiber transmission systems. He is the author or coauthor of more than 180 papers published in international refereed journals and conferences. He received the Ericsson Young Scientist Award in 2008, the FUNAI Information Technology Award for Young Researcher in 2009, and the Telecommunication System Technology Award of the Telecommunications Advancement Foundation in 2011. He is a member of IEEE, OSA, and IEICE.

【Concurrent Associate Prof. Ryo Ishikawa】

Ryo Ishikawa received the B.E., M.E., and D.E. degrees in electronic engineering from Tohoku University, Sendai, Japan, in 1996, 1998, and 2001, respectively. In 2001, he joined the Research Institute of Electrical Communication, Tohoku University, Sendai, Japan. In 2003, he joined the University of Electro-Communications, Tokyo, Japan. His research interest is the development of microwave compound semiconductor devices and related techniques. He was the recipient of the 1999 Young Scientist Award for the Presentation of an Excellent Paper of the Tohoku Chapter, Japan Society of Applied Physics.

【Visiting Professors】

Prof. Kazuhiko Honjo, Ph.D.

Prof. Yoichiro Takayama, Ph.D.

Prof. Akira Saito, Ph.D.

Prof. Masashi Hayakawa, Ph.D.

Prof. Hiroshi Suzuki, Ph.D.

Prof. Mitsuo Makimoto, Ph.D.

Prof. Giuseppe T. F. de Abreu, Ph.D

【Cooperative Professors】

Prof. Nobuo Nakajima, Ph.D.

Prof. Haruhisa Ichikawa, Ph.D.

Prof. Kazuo Ohta, Ph.D.

Prof. Sadao Obana, Ph.D.

Prof. Toshihiko Kato, Ph.D.

Prof. Naoto Kishi, Ph.D.

Prof. Tetsuro Kirimoto, Ph.D.

Prof. Kazuo Sakiyama, Ph.D.

Prof. Fengchao Xiao, Ph.D.

Prof. Xi Zhang, Ph.D.

Prof. Cong-Kha Pham, Ph.D.

Associate Prof. Manabu Akita, Ph.D.

Associate Prof. Yoshiaki Ando, Ph.D.

Associate Prof. Hiroyuki Kasai, Ph.D.

Associate Prof. Toshiharu Kojima, Ph.D.

Associate Prof. Hisa-Aki Tanaka, Ph.D.

Associate Prof. Kazuki Nishi, Ph.D.

Associate Prof. Wu Celimuge, Ph.D.

Assistant Prof. Satoshi Ono, Ph.D.

Assitant Prof. Katsuya Suto, Ph.D.

【Cooperative Professors from Industry】

Prof. Kunio Uchiyama (Hitachi Ltd.)

Prof. Yukihiko Okumura (NTT Docomo R&D)

Prof. Yoji Kishi (KDDI Research Inc.)

Prof. Terunao Soneoka (NTT-AT)

Prof. Akinori Taira (Mitsubishi Research Institute Inc.)

Prof. Hiroyuki Tsuji (NICT)

Prof. Hideki Hayashi (Softbank Corp.)

Prof. Eisuke Fukuda (Fujitsu Laboratory Ltd.)

Prof. Yukitsuna Furuya (WiTLa)

Prof. Kenji Yoshida (GM Holdings Inc.)

2.1 Division of Wireless Technologies as Social Infrastructure

2.1.1 Purpose of Research

Wireless technologies will have more importance in the society as the base of safe, secure and smart life for individuals and community. Various types of machine to machine communication such as sensors, IoT devices and vehicular communications will spread in the society taking little notice but support safety and secureness of society, as well as creating more comfortable and smarter life. The goal is to develop such technologies.

2.1.2 Research Staffs and Their Specialties

Prof. Yasushi Yamao（Head of Division, ITS, RF-ID, Radar)
Prof. Takeo Fujii（ITS, Radio Environment Analysis (REA), DPRN, Wireless security）
Prof. Takayuki Inaba（ITS, Rader)
Associate Prof. Koichi Adachi (Drone)

2.1.3 Major Research Outcomes in 2019

(A) Intelligent Transport System (ITS)

Advance technologies for Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communications towards automated driving are studied. Since Vehicular communications are conducted in fully distributed environments, wireless communication techniques for such environments are pursued. This work was supported by the Ministry of Internal Affairs and Communications (MIC) of Japan under the Strategic Innovation Promotion (SIP) program during physical years 2014 to 2016, MIC-1, "Development of V2V and V2I Communication Technologies necessary for Automated Driving Systems".

On the other hand, in order to realize fully automated driving, it is not enough by studying only vehicular communication issues, but necessary to discuss and collaborate with the researchers who study automated vehicle control and stand-alone sensors on the vehicles. Therefore, we established a project with related members to such subjects and collaborate on the Grants-in-Aid for Scientific Basic Research A, "Basic Research for Integrated Automated Driving System combining Stand-Alone Sensors and Cooperation by vehicle communications."

[V2V Packet Delivery Ratio Estimation based on Spectrum Database considering Packet Collision by using Positions and Density of Vehicles] (Fujii Lab.)

V2V communication is expected as one of the technologies to realize connected and automated driving. However, it is difficult to know the radio environment accurately in V2V communication and the method for avoiding packet collision and estimating radio environments is required. The measurement-based spectrum database (MSD) is one of the methods to estimate radio environments. The conventional method using the MSD can estimate radio environment with high accuracy by creating packet delivery ratio (PDR) maps. However, in that method, the accuracy of PDR maps is expected to be deteriorated significantly if the vehicle density changes between creating and using the maps. This paper proposes the method for correcting PDR maps considering packet collision by using positions and the density of vehicles. Furthermore, we analyze the proposed method by computer simulation.

We propose a method for estimating PDR considering packet collision by using positions and density of vehicles. This method corrects a PDR by multiplying the PDR not considering packet collision by the probability that packet collision does not occur. The PDR considering collisions of the packets from the transmitting vehicle to the receiving vehicle is found by

$$PDR'(\boldsymbol{C}_{\mathrm{Tx}}, \boldsymbol{C}_{\mathrm{Rx}}) = PDR_{\boldsymbol{C}_{\mathrm{Tx}}, \boldsymbol{C}_{\mathrm{Rx}}} \times PH(\boldsymbol{C}_{\mathrm{Tx}}, \boldsymbol{C}_{\mathrm{Rx}}) \;, \quad (1)$$

where $\boldsymbol{C}_{\mathrm{Tx}}$ and $\boldsymbol{C}_{\mathrm{Rx}}$ are the meshes of the transmitting and the receiving vehicle, $PDR_{\boldsymbol{C}_{\mathrm{Tx}}, \boldsymbol{C}_{\mathrm{Rx}}}$ and $PH(\boldsymbol{C}_{\mathrm{Tx}}, \boldsymbol{C}_{\mathrm{Rx}})$ are the PDR not considering packet collision and the probability that the hidden collision does not occur when one vehicle transmits packets at $\boldsymbol{C}_{\mathrm{Tx}}$ and another vehicle receives at $\boldsymbol{C}_{\mathrm{Rx}}$.

In order to evaluate the performance of the proposed method, computer simulations using the C++ programming language are executed. Fig. 2.1-1 shows the layout of the simulation scenario. Each street of the crossroads has 5 m width and 215 m length. Fig. 2.1-2 shows the $\mathrm{PDR}_{\mathrm{No-Collision}}$ map, Fig. 2.1-3 shows $\mathrm{PDR}_{\mathrm{Simulation}}$ and Fig. 2.1-4 shows the $\mathrm{PDR}_{\mathrm{Proposed}}$ map. The simulation results show that the proposed method can estimate PDR more accurately than the method not considering packet collision.

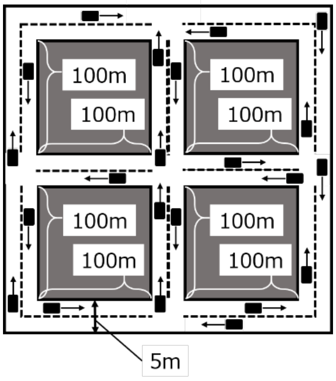


Fig. 2.1-1. The layout of simulation scenario

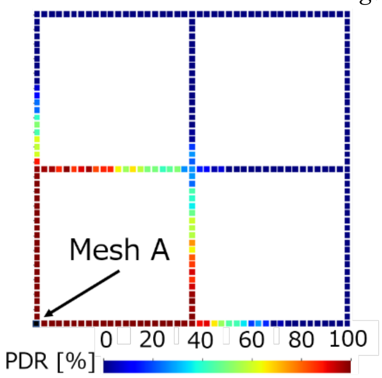


Fig. 2.1-2. $\mathrm{PDR}_{\mathrm{No-Collision}}$ map when the vehicle transmits packets at the mesh A

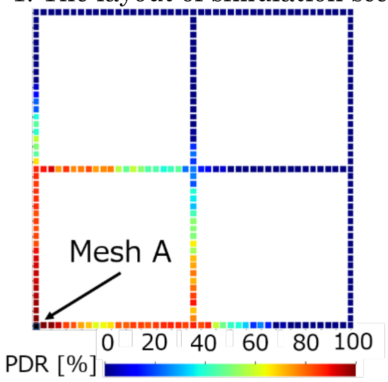


Fig. 2.1-3. $\mathrm{PDR}_{\mathrm{Simulation}}$ map when the vehicle transmits packets at the mesh A

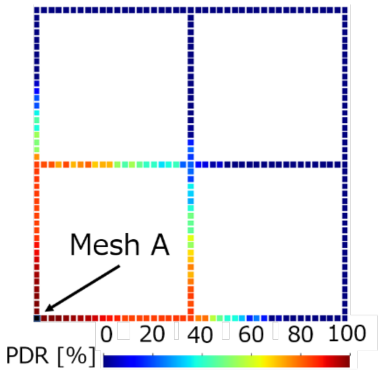


Fig. 2.1-4. $\mathrm{PDR}_{\mathrm{Proposed}}$ map when the vehicle transmits packets at the mesh A

[ULA Equipped UAV-BS for Low Power Wireless Networks] (Adachi Lab.)

In wireless sensor networks (WSNs), high outage probability is one of the major problems due to the low transmit power of sensor node (SN) and interference among SNs. Instead of a fixed ground base station (BS), the use of an unmanned aerial vehicle (UAV) as a BS has been attracting attention. This is because UAV-BS can be deployed at an arbitrary place, so it can avoid SNs from transmitting with high power. However, interference among SNs still exists. In order to avoid such interference, we have previously proposed rotational angle division multiple access (RADMA) for UAV-BS with a uniform linear array antenna (ULA). In RADMA, virtual sectors are created by RADMA and SNs within each virtual sector transmit at each time. Thus, interference among SNs can be avoided. This year, we have first theoretically evaluated the performance improvement brought by RADMA under low power wide area (LPWA) scenario. Then, a simple trajectory design to cover wide communication area is developed. The analytical and simulation results perfectly match with each other, as shown in Fig. 2.1-5. Thus, it confirms the validity of the derived closed-form expression. By combining a trajectory design of UAV-BS and RADMA, the outage probability of WSN can be significantly reduced. Fig. 2.1-6 shows packet loss ratio of the conventional method and RADMA with the proposed trajectory design as a function of the number of SNs, *K*. As can be seen from the figure, the proposed method can suppress the packet loss even when the number of nodes is large.

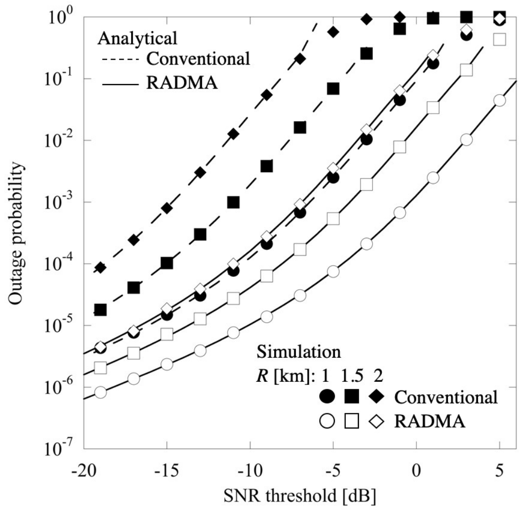


Fig. 2.1-5 Outage probability performance.

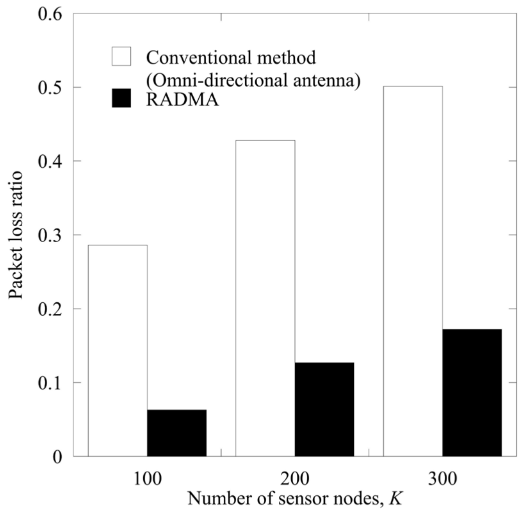


Fig. 2.1-6 Packet loss ratio performance.

(B) Radar Signal Processing

[Vehicle Onboard Radar] (Inaba Lab.)

We have proposed stepped multiple frequency (SMF) modulation. The unique radar modulation/demodulation method can achieve a high range resolution and a long-range detection performance by a narrow receiver bandwidth compared to transmitting bandwidth. That is why this method has long range detection performance. Stepped multiple frequency CPC modulation proposed by Inaba Laboratory made it possible to obtain the extremely low range side-lobe by the short code length in CPC pulse compression. Authors have developed the millimeter wave radar using stepped multiple frequency CPC (Fig.2.1-7). These millimeter wave radars meet the specified low-power radio station standard of the millimeter wave in Japan. In recent years, Japanese radio wave laws for short range radar has been modified for use of the ultra-wide bandwidth of 4 GHz in 79 GHz band. The advantage of this method itself must be more remarkable for use of the ultra-wide bandwidth. On the other hand, SMF modulation suffer from the deterioration of the detectable velocity accompanied by expansion of transmission bandwidth, since it adopts the transmission sequence of switching the frequencies in time-division. In the case of use of ultra-wide bandwidth of 4GHz, we also face not only the velocity ambiguity but the range ambiguity problem, since the frequency steps also must be sparse for keeping the number of pulse repetitions. We proposed the sparse frequency division radar, in which the sparse frequency steps are designed for obtaining good side-lobe characteristics by less frequency steps without range-Doppler ambiguity. The target signals are obtained by the signal processing of iterative signal subtraction and frequency estimation (Fig.2.1-8). These proposed methods can detect the targets having different receiving signal level of power among them with the resolution of ultra-wideband without ambiguity in both velocity and range profiles.

Fig. 2.1-7 Millimeter wave radar developed by Inaba Lab. of UEC

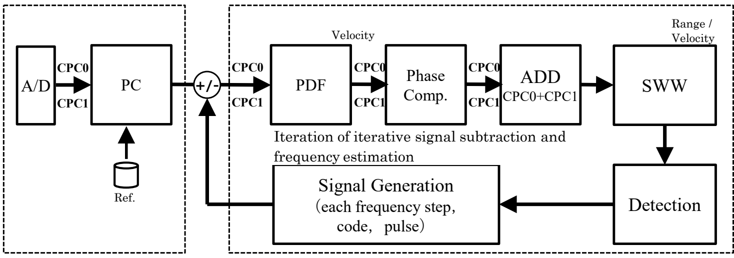


Fig.2.1-8 Block diagram of the signal processing of iterative signal subtraction and frequency estimation method in stepped multiple frequency CPC.

[High Dynamic Range DSP Chirp Radar Transceiver] (Yamao Lab.)

Automotive and marine radars require high dynamic range and high resolution to identify multiple targets. We propose a novel digital signal processing (DSP) radar transceiver implementation design that consists of a multi-bit quadrature Δ-Σ modulator transmitter and a mismatched filter receiver (Fig.2.1-9). It can achieve high dynamic range with moderate oversampling frequency while relaxing the requirement for digital-to-analog converter (DAC) resolution. The simulation results for a linear FM chirp radar signal show that the proposed transceiver with 3-bit DACs can achieve high dynamic range of more than 75 dB in range pulse response. The performance of the proposed transceiver has been validated also by experiments (Fig. 2.1-10).

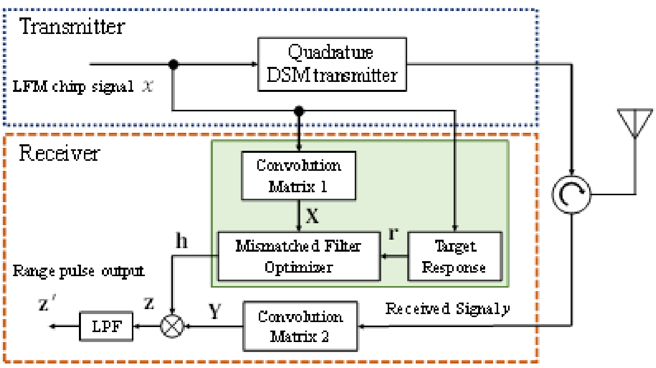


Fig. 2.1-9 Proposed DSP radar transceiver.

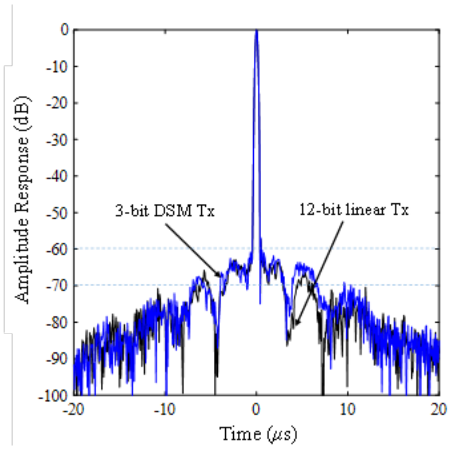
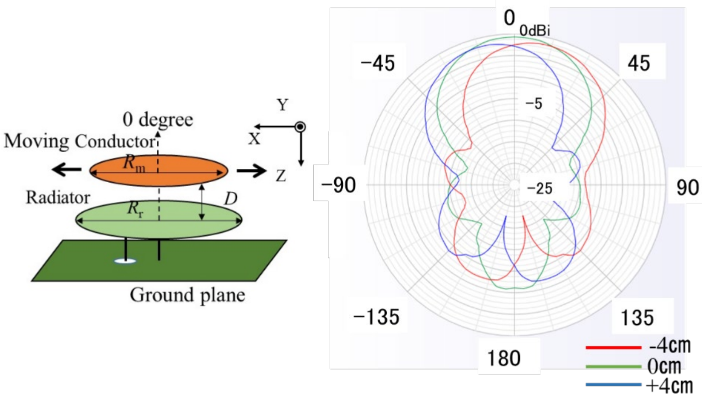


Fig. 2.1-10 Measured range pulse outputs with mismatched filter.

(C) RF-ID Communications

[Read Accuracy Improvement by R/W Beam Scanning and Repeated Transmission for 920 MHz RFID] (Yamao Lab.)

Radio Frequency Identification (RFID) has been expected as a promising solution that bring about revolution in the supply chain management. One of the important scenarios is that an RFID system is used for identifying goods in shops and warehouses. For achieving good read accuracy, however, it is necessary to understand indoor radio propagation environment with surrounding materials that reflect radio waves and generate standing waves. In this study, we analyze RFID read success rate in metal shelf environment through FDTD simulation. In order to reduce the read error, we propose a reader/writer (R/W) beam scanning and repeated transmission scheme with a moving conductor. By displacing the conductor in the vicinity of R/W antennas, directivity of R/W antenna changes as shown in Fig. 2.1-11, which causes dynamic change of multipath propagation structure between R/W antenna and RF tag. As a result, receiving power null position caused by the standing waves is moved and read accuracy can be improved by repeated transmission and selection combining (Fig. 2.1-12). It is confirmed from the simulations and experiments that the read success rate is greatly improved by the proposed scheme.



(a) Configuration (b) Directivity change

Fig. 2.1-11 R/W antenna with a moving conductor.

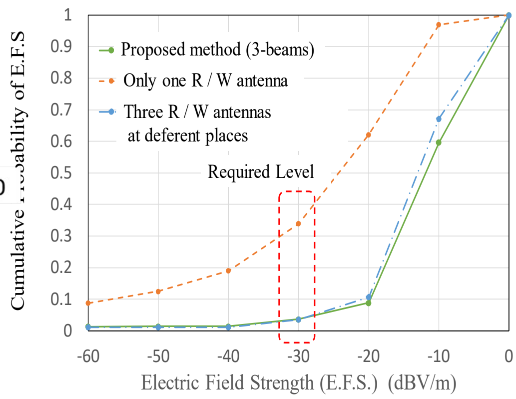


Fig. 2.1-12 Cumulative distribution of E.F.S. in the storage shelf area

2.1.4 Funds

【Grants-in-Aid for Scientific Research】

1. Scientific Research A "Basic Research on Automated Driving System by Integrating Autonomous Sensing and Cooperative Information Sharing Technologies"
   Y. Yamao, T. Fujii, T. Inaba, S. Obana, T. Ogitsu (Gunma Univ.)
2. Fund for the Promotion of Joint International Research (Fostering Joint International Research) "Research on Advanced Wireless Vehicle Networks with Learning Spectrum Environment for Cooperative Self Driving"
   T. Fujii
3. Scientific Research C "Research on Energy Efficient Wireless Communications Network Using UAV-BS"
   K. Adachi

【Commissioned Research】

1. Strategic Information and Communications R&D Promotion Program (SCOPE), “R & D of Ultra-wide band coherent radar technology”
   T. Inaba, Y. Yamao and M. Akita

【Cooperative Research】

1. “Research on improvement in recognition rate of RF IDs”
   Y. Yamao
2. "Research on communications technology for machine tools"
   K. Adachi and Y. Yamao

【Other Funds】

1. “Parameter design for stepped multiple frequency CPC radar”, Academic consulting
   T. Inaba
2. “Analysis program of stepped multiple frequency CPC”, License agreement
   T. Inaba

2.2 Advanced Hardware Research Division

2.2.1 Purpose of Research

Research and development of wireless information/power transmission hardware for next generation mobile communication base stations and terminal devices

2.2.2 Research Staffs and Their Specialties

Prof. Y. Yamao	Reconfigurable RF Circuit, Nonlinear Compensation
Prof. Koichiro Ishibashi	Low Power RF Devices, Sensor Networks
Prof. M. Matsuura	Wideband RoF Systems, Devices, Fibers and Integration
Prof. K.Wada	Microwave Filters and Their Applications
Associate Prof. R. Ishikawa	Microwave/Millimeterwave Devices and Circuits
Visiting Prof. K. Honjo	Microwave Engineering, Semiconductor Devices
Visiting Prof. Y. Takayama	Microwave Power Amplifier Systems
Visiting Prof. A. Saitou	Electro-Magnetic Wave Engineering, Antennas

2.2.3 Major Research Outcomes in 2019

(A) Multi-Band Multi-Access Wireless Hardware for 5G System
[High-efficiency GaN HEMT Doherty Power Amplifier] (Ishikawa Lab.)

In recent years, the greater sophistication and diversity in wireless communication systems have become remarkable, hence further improvements in performance of wireless transmitters in the base stations are required. Power amplifiers are an important device, which greatly affect distortions for signals and power consumption. A peak-to-average power ratio (PAPR) of recent digital wireless signals is large as more than 6 dB. A PAPR of 9 dB is often considered in 4G and 5G OFDM (Orthogonal Frequency Division Multiplexing) / QAM (Quadrature Amplitude Modulation) systems. In such systems, power efficiency at large output power back off levels dominates a total power consumption of the amplifiers than that in saturation levels. Thus, high efficiency characteristics are required for wide dynamic range in the amplifiers, where a special attention should be paid on the efficiency at large output back-off (OBO) power level. For this issue, we have developed a harmonic-tuned high-efficiency GaN HEMT Doherty power amplifier (DPA) without a quarter-wave transformer. The output matching circuits in the fabricated DPA were designed based on the dual-RF-input-power-level impedance optimization method instead of one with a quarter-wave transformer for load modulation. In addition, optimum harmonic reactive termination conditions to achieve high efficiency were maintained in the load modulation for both carrier and peaking amplifiers. The fabricated DPA achieved a maximum drain efficiency of 67% and a maximum power-added efficiency (PAE) of 61% with a saturation output power of 40 dBm at 4.7 GHz. Furthermore, in a 7-dB back-off condition, a drain efficiency of 66% and a PAE of 60% were obtained, which were comparable to the saturated output power efficiencies and had excellent back-off performance. In addition, a maximum drain efficiency of 60 and a PAE of 55 % were achieved at a 7-dB OBO between 4.68 and 4.74 GHz. (Fig. 2.2.1)

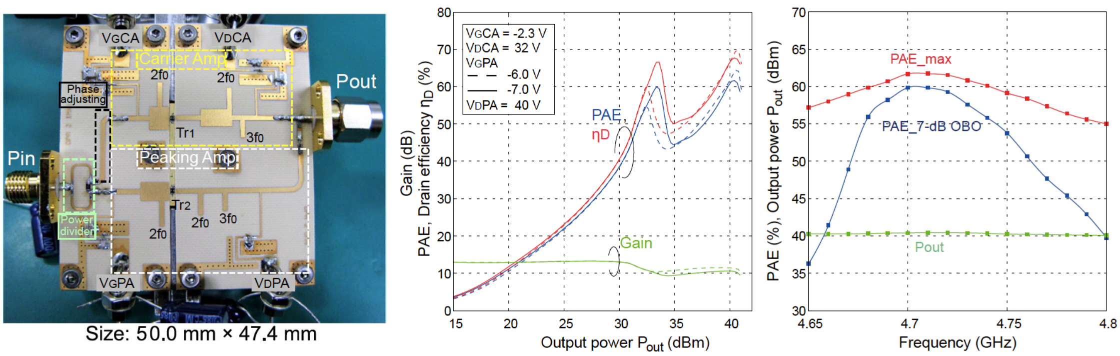


Fig. 2.2.1 Fabricated harmonic-tuned high-efficiency GaN HEMT Doherty power amplifier, and its characteristics

[Compact Reconfigurable Bandpass Filter with pHEMT Switched Capacitor Array ICs] (Yamao Lab.)

For more efficient use of radio spectrum in 5th generation mobile communication (5G) and beyond, reconfigurable RF circuits that can flexibly change multiple bands are promising. Three-bit reconfigurable bandpass filters (BPFs) have been proposed that employs reconfigurable resonators with branch-line switching structure. However, from the view point of actual implementation, the transmission lines that form branch-lines restrict the circuit size and increase complexity. In this study, we design a new reconfigurable resonator with a switched capacitor array (SCA) and apply it to 3-bit reconfigurable BPF in SHF band. After analyzing the influence of parasitic capacitance of the RF switches, a 3-bit SCA is designed using 0.5-µm gate pHEMT process including MIM capacitors. Prototype BPF is fabricated for selecting center frequencies from 3.3 to 4.44 GHz. The measured RF characteristic of the prototype is almost same as that of transmission line design, while reducing circuit size remarkably.

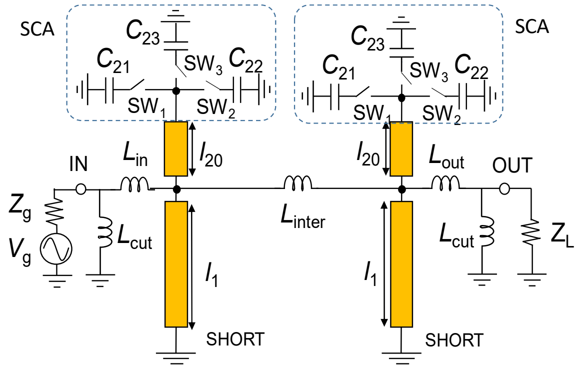
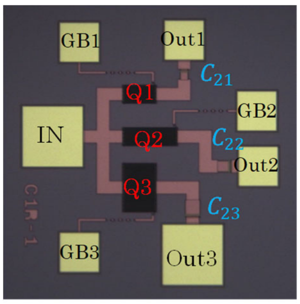


Fig. 2.2.2 Three-bit reconfigurable BPF with switched capacitor arrays.



0.7 mm × 0.7 mm

Fig. 2.2.3 PHEMT 3-bit switched capacitor array IC.

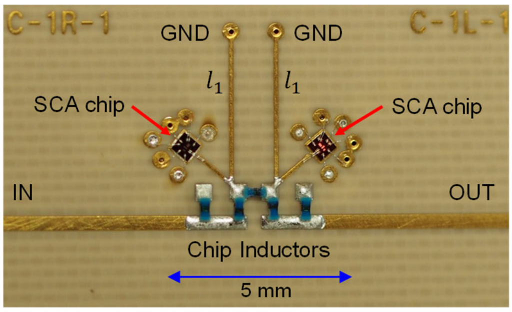
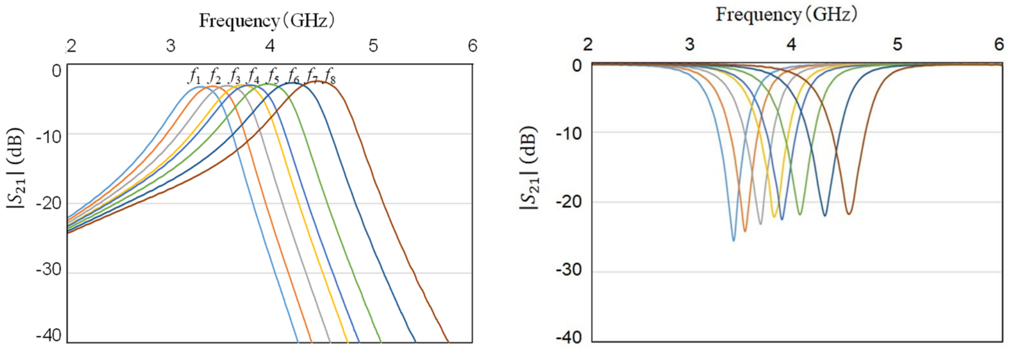


Fig. 2.2.4 Prototype BPF with PHEMT 3-bit SCA ICs.



(a) S_{21} (b) S_{11}

Fig. 2.2.5 Measured S parameters of the prototype SCA BPF.

[Blind Nonlinear Compensation of Tandem Nonlinearity Caused by Transmitter and Receiver (Yamao Lab.)

Nonlinear compensation for RF circuits is an important research topic in 5G mobile communication, in which higher level modulation schemes are employed more often to achieve high capacity and ultra-broadband services. Transmitters and receivers in 5G systems are required to cover broad bandwidth and achieve high-accuracy signal transmission. This study proposes a novel blind nonlinear post-compensation technique (Tandem Nonlinearity Post Compensation; TNLPC) that improves received EVM by eliminating whole nonlinearities caused by transmitter and receiver after receiving the signal. The total nonlinear characteristic is modelled using a tandem polynomial and the proposed post-compensator determines the inverse characteristic of the tandem nonlinearity without knowledge of sending signal. The simulation results employing LTE-A signal with 256 QAM modulation show that the proposed method can efficiently suppress nonlinearity and achieve EVM of less than 2 %.

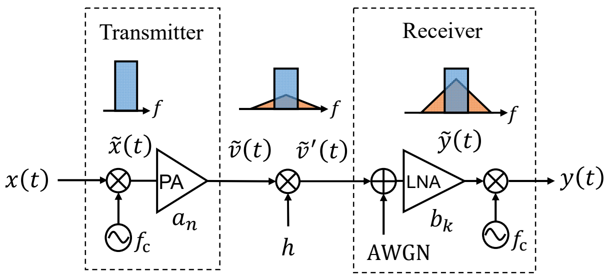


Fig.2.2.6 Tandem nonlinearity model of transmitter and receiver.

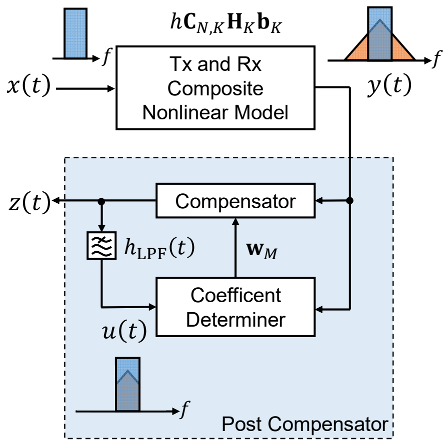
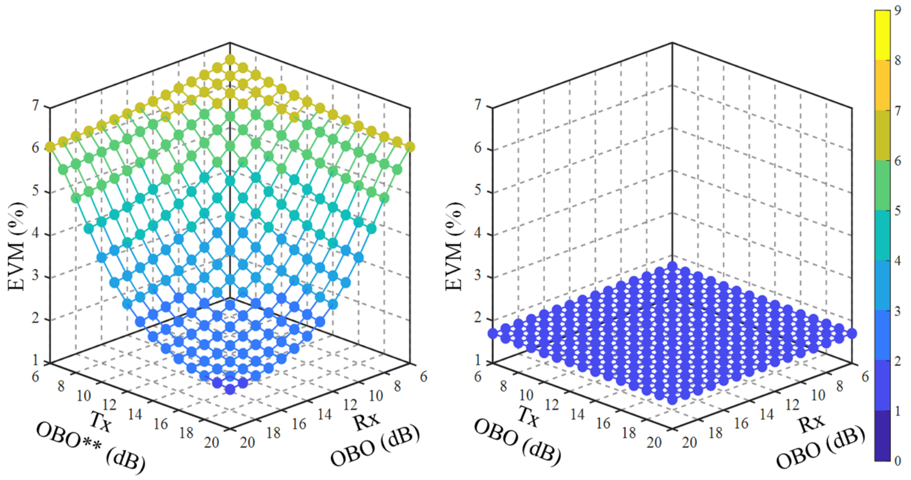


Fig.2.2.7 Block diagram of TNLPC.



(a) without TNLPC (b) with TNLPC

Fig. 2.2.8 EVM without or with nonlinear compensation.

(B) 8-channel Multiplexing OAM Communication using Loop Antenna Arrays with Resistors (Ishikawa Lab.)

We have demonstrated that the electro-magnetic wave propagation occurs with a single orbital angular momentum (OAM) mode when a current distribution of the azimuth angle ϕ-direction for a circular loop antenna conductor contains only one Fourier expansion coefficient. This condition almost retains at the loop-antenna conductor length of $n\lambda$ (n is the integer). Based on this principle, we have successfully developed an 8-channel multiplexing OAM communication using double-layer coaxial 4 loop-antenna arrays adjusted with port azimuths of the loop antennas by $\pi/2m$, where m is magnetic quantum number. In this system, current distributions are scrutinized for the arrays, and the unique scattering of the OAM waves by the feeding coaxial cables is confirmed to undermine the orthogonality for the OAM waves. Induced interference waves could be reduced by implementing resistors at the antinodes of the current on the antennas of the orthogonal port azimuth. The signal wave was not affected, because the position of the resistor became the node where the antenna was stimulated. With the configuration, 8-element arrays were designed and fabricated, and the simulated and measured improved signal to interference ratios (SIRs) for the communication distance of 3 cm were better than 6.8 dB and 9.7 dB at 5.21 GHz. The measured SIR for the antenna with the resistors were better by 6.2 dB than that for the antenna without the resistors. (Fig. 2.2.9)

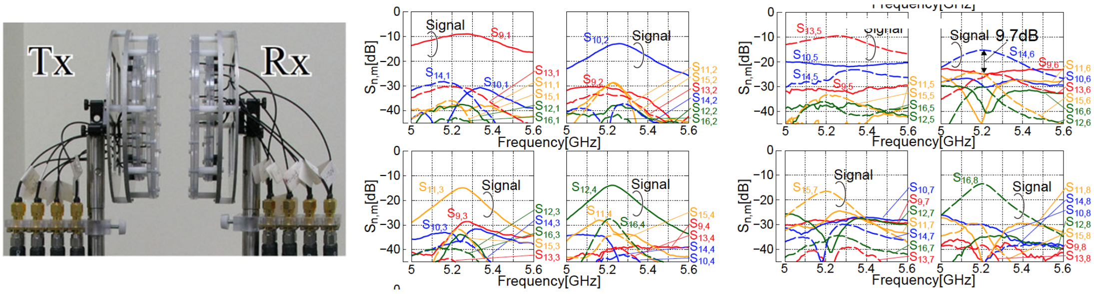


Fig. 2.2.9 Constructed 8-channel multiplexing OAM communication system using loop antenna arrays with resistors, and its characteristics

(C) Photonic Digital-to-Analog Conversions (DACs) for RoF Systems (Matsuura Lab.)

In this year, we present a photonic digital-to-analog conversion (DAC) technique based on blue-chirp spectral slicing using a semiconductor optical amplifier (SOA). Because the gain change in an SOA leads to a refractive-index change based on the change in intensity of the input data signal, probe signals experience a dynamic frequency shift to a shorter-wavelength side called blue-chirp. After passing through the SOA, the probe signals corresponding to the logic level of the input digital signal are extracted by filtering only the blue-chirp component of the probe signals using rectangular-shape filters. In this study, we demonstrate a 10-Gb/s, 2-bit photonic DAC from a 10-Gb/s digital signal with various data patterns to a four-level amplitude signal assuming an analog signal. In addition, we evaluate the resolution performance of the photonic DAC in terms of differential and integral nonlinearities and effective number of bits.

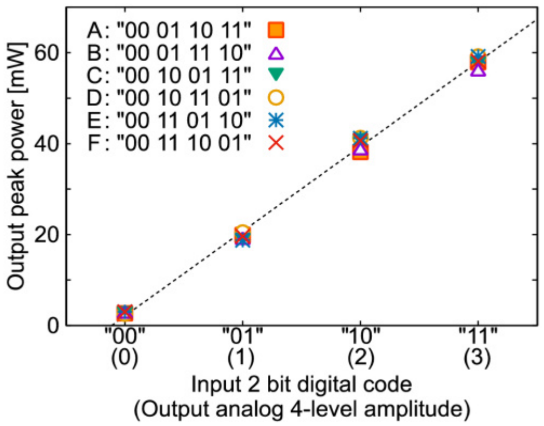


Fig.2.2.10 Relationship between input 2-bit digital code and output peak voltage of each corresponded pulse for different input data patterns.

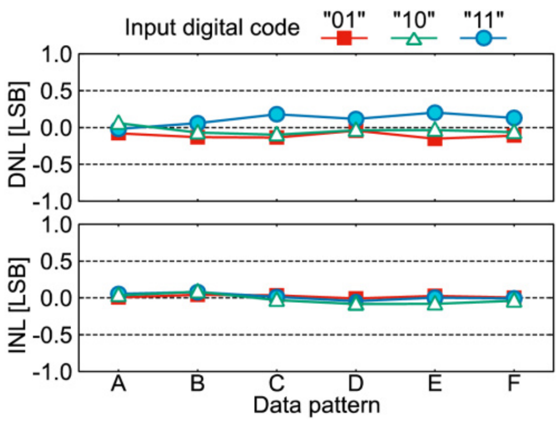


Fig.2.2.11 (a) Differential nonlinearity (DNL) and (b) integral nonlinearity (INL) for input digital codes.

To evaluate the conversion performance of the photonic DAC, we measured the output peak voltage of the converted pulse trains. Figure 2.2.10 shows the relationship between the input digital code and output peak voltage of the converted pulse trains. The obtained output peak voltage increased linearly with respect to the input digital code. On the other hand, we observed the peak voltage differences of the converted pulse trains for each input data pattern.

To assess the resolution performance of the photonic DAC, we calculated the differential nonlinearity (DNL) and the integral nonlinearity (INL) from the transfer functions, as shown in Fig. 2.2.11. The DNL was defined as the maximum deviation from one least significant bit (LSB), which was the smallest increment of a DAC output between two consecutive levels, whereas the INL was defined as the maximum deviation of the input/output transfer function from the best-fit line, as shown with the dotted line in Fig. 3. The absolute values of the DNL and the INL were up to 0.20 and 0.08 LSB, respectively. All the DNL and the INL values were from −0.5 to 0.5 LSB, which offered a no-mission code to the presented 2-bit photonic DAC.

2.2.4 Funds

【Grants-in-Aid for Scientific Research】

1. Grant-in-Aid for Scientific Research (C),"Microwave OAM Antenna" (A. Saitou)
2. Grant-in-Aid for Scientific Research (C),"Reconfigurable RF Switch Based on a Meta-material Technique" (H. Mizutani, K. Honjo)

【Commissioned Research】

1. MIC, SCOPE, "Research and development of personal area high-speed and large-capacity wireless communication and wireless power transmission module" (R. Ishikawa, K. Honjo, Y. Takayama, A. Saitou, H. Suzuki)

【Cooperative Research】

1. Taiyo Yuden Co., Ltd. "Study on OAM applications" (-10/2019)
   R. Ishikawa
2. RF device technologies Inc. "Study on novel devices and its evaluation methods for wireless communications"
   R. Ishikawa
3. SoftBank Group Corp. "Low power consumption amplifier"
   R. Ishikawa
4. Japan Space Systems. "Technical evaluation of high-efficiency power transfer section related to "Research and development project for high efficiency wireless power transfer in space solar power systems"
   R. Ishikawa
5. Mebius Inc., Tokyo Metropolitan Industrial Technology Research Institute, "Development of High-Accuracy mm-Wave Radar Signal Measurement System Targeting Autonomous Driving and Its Application to Frontend-End Circuit of Interference-Tolerant Radar"
   Y. Yamao

2.3 Division of Creating Advanced Wireless Systems

2.3.1 Purpose of Division

R&D of Advanced Wireless Systems and Networks contributing to development of society by sustainable technologies of wireless systems

2.3.2 Research Staffs and Their Specialties

Prof. Takeo Fujii (Division Leader, Future NW, Cognitive Radio, Distributed NW)
Prof. Yasushi Yamao (Future NW, Distributed NW)
Prof. Motoharu Matsuura (Future NW)
Associate Prof. Koichi Adachi (Future NW)
Associate Prof. Koji Ishibashi (Future NW, Distributed NW)

2.3.3 Major Research Results in 2019

[Signal Power Prediction considering Structure Information via Neural Network] (Fujii Lab.)
Recently, a measurement-based signal power map is considered as the accurate prediction method of radio propagation. The map has the average signal power in each mesh. The traditional method of radio propagation estimation utilizes empirical propagation models, such as the Okumura-Hata model. The empirical propagation models have been used for designing the coverage of cellular systems since they can estimate median path loss with a few parameters and less computational complexity. Almost all of these models were not designed for estimating shadowing. The measurement-based signal power map can help the accurate prediction for the components of path loss and shadowing when the mesh size is enough small and the data size is enough large. However, the construction cost of the map is too expensive to predict wide-area radio propagation. Therefore, the alternative method for accurate prediction or the method for support the map is needed. On the other hand, machine learning becomes popular because a computer became a higher performance and a lower cost than before. Then, Neural Network (NN), which is one of machine learning, has been used for a study well as the alternative method for various expressions. In this study, we tried to predict the radio propagation including not only the path loss component but also the shadowing component considering the structure information. As an initial study, the image of the building place was used as the structure information. Fig. 2.3-1 shows the concept of our study. A few information, which is the road width, the distance from the buildings and the direction of the road, were extracted from the picture as input variables for the NN. We performed the prediction of radio propagation using NN and regression considering the structure information. Fig. 2.3-2 shows the RMSE of the prediction result. We can confirm that the structure information and NN help a higher accurate prediction of radio propagation.

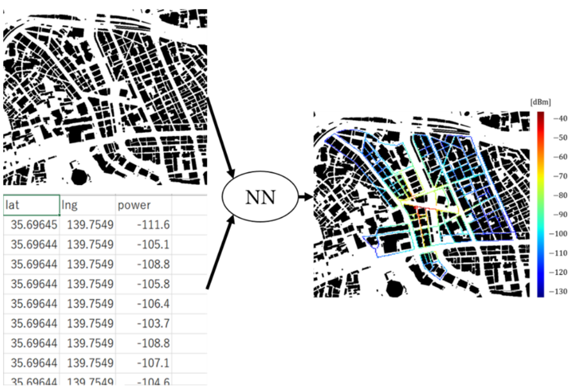


Fig. 2.3-1 Concept of the radio propagation considering structure information via NN.

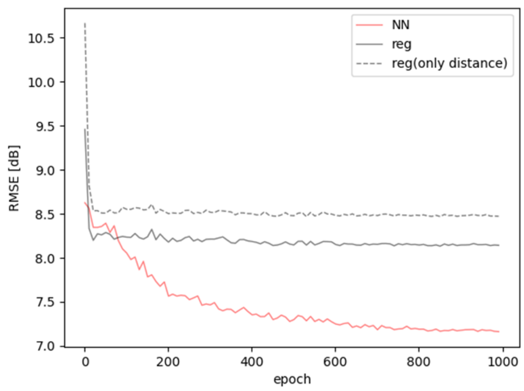


Fig. 2.3-2 RMSE characteristics.

[Adaptive Band and Power Control for Spectrum Shared Mobile Systems] (Fujii Lab.)

In this research, to realize spectrum sharing in private 5G environment, we propose an algorithm that utilizes spectrum band divide allocation and power control in cooperation with measurement-based spectrum database. Figure 2.3-3 shows the system model of the database. The radio environment information such as the received signal power of the own cell and the interference cell, the spectrum band, the Cell ID, etc., which are observed from the mobile devices is stored in the database. From the data sets, the average Signal-to-Interference plus Noise power Ratio (SINR) is derived for each square mesh, and the probability distribution of the mesh with the lowest average SINR is estimated and the cell edge throughput is derived. In the proposed method, from the estimated probability distribution and throughput, the throughput can be maximized by utilizing an algorithm that combines power control and spectrum band divide allocation to satisfy the permissible outage probability and the lower limit of throughput.

Figures 2.3-4 and 2.3-5 show the simulation results. From Fig. 2.3-4, the proposed method shows a higher average throughput than the conventional method (power control only). From Fig. 2.3-5, it can be confirmed that the permissible outage probability is satisfied.

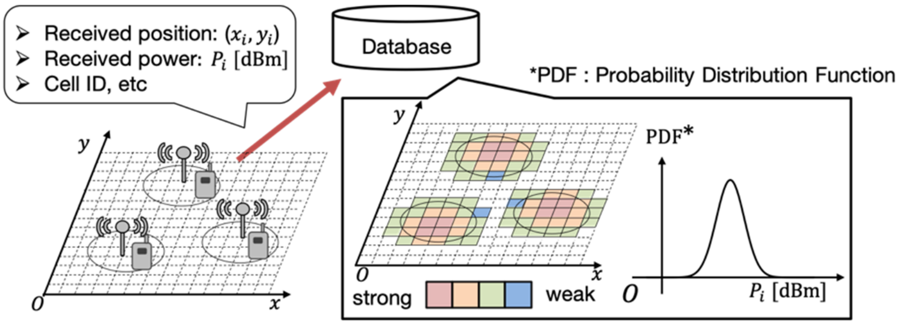


Fig. 2.3-3 System model of the database.

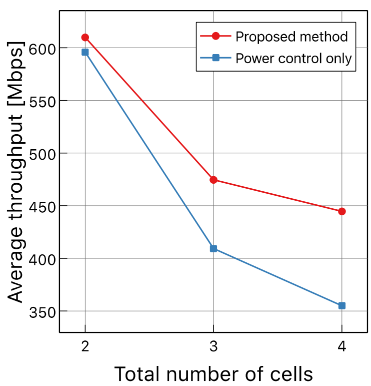


Fig. 2.3-4 Average throughput.

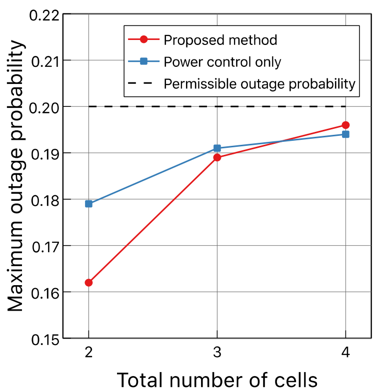


Fig. 2.3-5 Maximum outage probability.

[Radio and Computing Resource Allocation for Mobile Edge Computing] (Adachi Lab)

In this research, we tackle the user scheduling problem for multi-user mobile edge computing (MEC) (or multi-access edge computing) systems. MEC system enables real-time processing of users' tasks. This is realized by exchanging information between users and MEC server, which is located at the edge of radio access network (RAN). The MEC server is required to process the tasks offloaded from users. Thus, it is necessary to appropriately allocate not only radio resource but also computing resource at the MEC server. Different from legacy wireless communication systems, task uploading, task processing, result downloading need to be considered during scheduling. We consider the scenario where there are two types of users, i.e., MEC users and legacy users. The objective of MEC users is to complete the task processing within a deadline while that of legacy users is to maximize the throughput. In such an environment, two different objectives should be balanced. In this research, we propose a scheduling metric to balance the two objectives. The computer simulation results elucidate that the proposed scheduling metric can balance the throughput performance of legacy users (Fig. 2.3-6 (a)) and the outage probability of MEC users (Fig. 2.3-6 (b)).

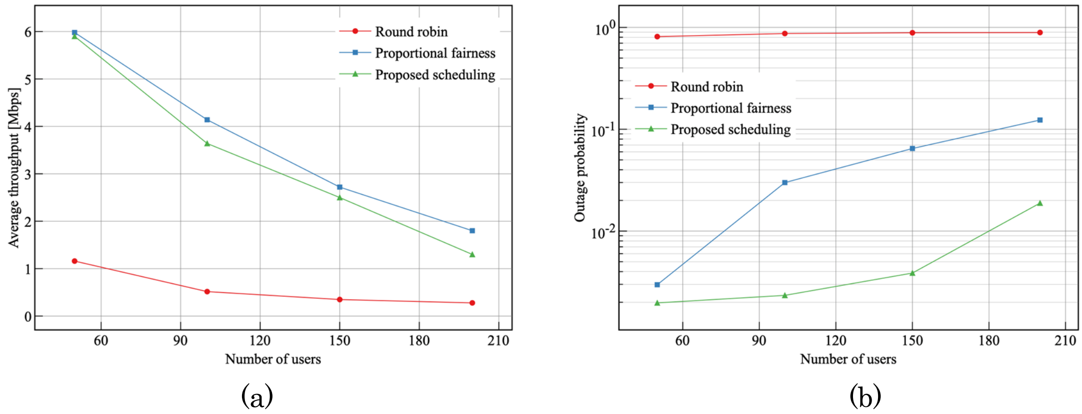


Fig. 2.3-6 Performance of the proposed scheduling strategy (a) Throughput performance of legacy users (b) Outage probability of MEC users.

[Q-Learning Based Resource Allocation in LPWA] (Adachi Lab.)

Low power consumption communication is becoming more important due to the emerge of the Internet-of-Things (IoT). Long-range wide area network (LoRaWAN) is one of the promising network architectures for low power wide area networks (LPWANs). However, due to the simple medium access control (MAC) protocol of LoRaWAN, packet collision happens more frequently as the network size becomes larger. To tackle the packet collision problem, we have proposed a machine learning based resource allocation scheme. In a realistic scenario, multiple systems share the same frequency band. Thus, the performance of the system may be severely degraded by inter-system interference. In this work, we propose an inter-system interference state change detection for efficient use of limited frequency resources. The proposed detection scheme utilizes a density ratio estimation and requires neither any prior knowledge nor information about the other system. In order not to require training data, pseudo training data and test data are generated. Once the change of the inter-system interference state is detected, the frequency channels are reassigned to LoRaWAN nodes by relearning. The performance evaluation considering the LoRaWAN network has been conducted. As can be seen from Fig. 2.3-7 (a) that the proposed scheme can successfully detect the change of the inter-system interference state, which results in higher

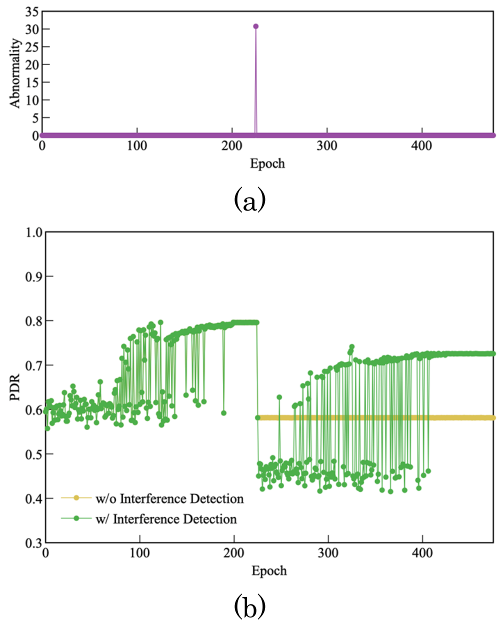


Fig. 2.3-7 Performance of the proposed resource allocation scheme (a) Detection of inter-system interference state change (b) PDR performance.

value of abnormality. In the proposed scheme, rearning of channel allocation is carried out once such high abnormality is detected. By carrying out relearning of the channel allocation, the proposed scheme can improve the packet delivery rate (PDR) performance compared to the system without detection as shown in Fig. 2.3-7 (b).

[Grant-Free Access for Massive Users] (Koji Ishibashi Lab.)

Future wireless communication such as Beyond 5G and 6G would accommodate massive number of devices, as represented by Internet-of-Things (IoT). In order to realize efficient low-latency data transmission of large number of devices, designing multiple access schemes is crucial. While conventional grant-based access schemes, e.g., time division multiple access (TDMA), can achieve highly-efficient transmission via resource allocation for devices, such allocation causes a large overhead in the presence of massive number of users, which results in the degradation of the throughput performance. To this end, we have proposed two efficient random access schemes: 1) grant-free non-orthogonal multiple access (GF-NOMA) employing multiple measurement vector approximate message passing (MMV-AMP), 2) coded slotted ALOHA with ZigZag decoder. In GF-NOMA scheme, a multi-antenna base station (BS) receives transmitted symbols, while devices are randomly activated to transmit their pilot and data symbols, which are multiplied by their unique non-orthogonal sequences. Then, the BS estimates the active users and the transmitted data symbols via our proposed algorithms based on MMV-AMP. Fig. 2.3-8 shows the symbol error rate (SER) performance of GF-NOMA with our proposed receivers named Boosted AMP and MMV-AMP and demonstrates that our proposals outperform the conventional scheme, namely BSASP. Moreover, we have proposed ZigZag decodable coded slotted ALOHA (ZDCSA) and enhanced ZDCSA (E-ZDCSA) as schemes which apply ZigZag decoding before and after successive interference cancellation, respectively. Both schemes can retrieve a larger number of colliding packets than the conventional coded slotted ALOHA scheme and yield superior throughput performance as shown in Fig. 2.3-9. Those results have been already published in IEEE journals.

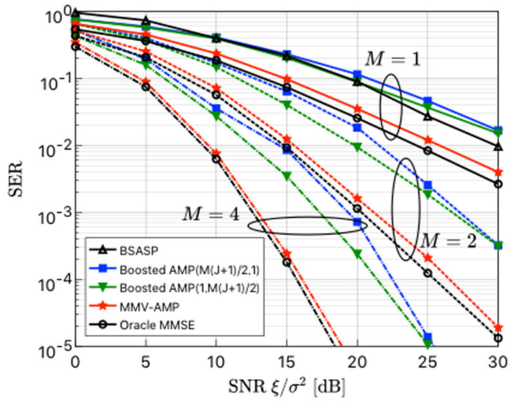


Fig. 2.3-8 SER performance of GF-NOMA schemes.

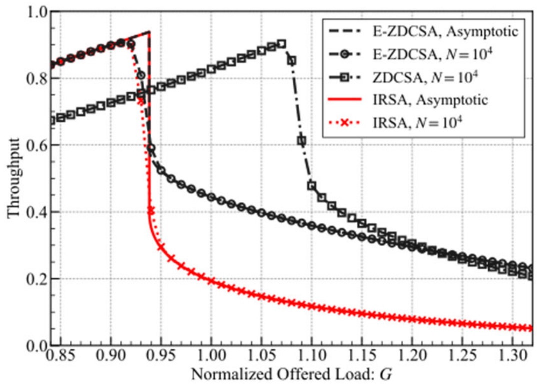


Fig. 2.3-9 Throughput performance of ZDCSA and E-ZDCSA.

[Frame-Theoretical Design of Massively Concurrent NOMA] (Koji Ishibashi Lab.)

Non-orthogonal multiple access (NOMA) is a promising enabler to support massive users in the next-generation of wireless systems such as Beyond 5G and 6G. Recently, NOMA schemes based on sparse multiplexing such as sparse code multiple access (SCMA) have gained much more attention since each user-data can be detected by a low-complexity message passing algorithm (MPA). However, users cannot exploit overall available resources of the system since the sparse use of recourses is necessary to use MPA. To improve the achievable rate, we proposed a frame-theoretical design of NOMA exploiting full resources of the system. However, the dense use of resources results in the high complexity of the detection. To this end, we also proposed an efficient detector based on tree search. Figure 2.3-10 shows the achievable sum-rate of our proposed NOMA (MC-NOMA) and conventional approaches (PDMA and SCMA) in downlink scenarios. As obvious from the figure, our proposed approach outperforms both SCMA and PDMA across the SNR range. Those results have been already published in IEEE journals.

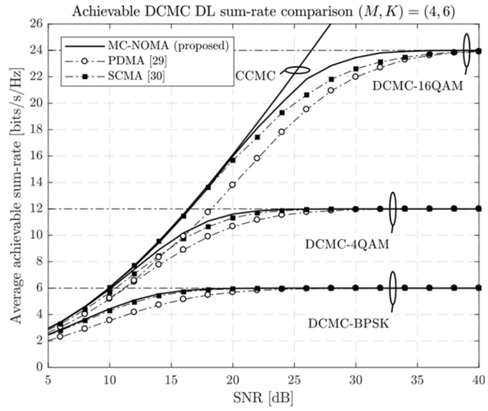


Fig. 2.3-10 Achievable sum-rate of several NOMA schemes.

[Blockage-Aware Robust Beamforming for mmWave Communications] (Koji Ishibashi Lab.)]

The utilization of high-frequency bands, including millimeter-wave bands, is essential for future mobile communications with high data-rate. In such communications, the system throughput can be significantly improved by beamforming, which performs interference management and resource allocation among users based on channel state information (CSI). However, it is significantly difficult to obtain the perfect CSI due to a huge burden of the estimation process with a large number of antennas. In addition, unpredictable path-loss may be caused by sudden blockages due to vehicles and human bodies. To deal with these impediments, a robust design against CSI errors is necessary. Although robust beamforming techniques considering channel estimation errors have been investigated in the literature, the sudden blockage has not been considered yet. We hence proposed a robust beamforming considering the channel estimation error and blockage loss. Figure 2.3-11 shows the cumulative distribution functions (CDF) of the instantaneous signal to interference plus noise ratio (SINR) of the conventional and proposed methods. When the required SINR of the system is 11 dB, the conventional method achieves the required SINR with a probability of 39%, while the proposed method achieves it with a probability of 96%. Thus, the proposed method can achieve more reliable communication than the conventional method.

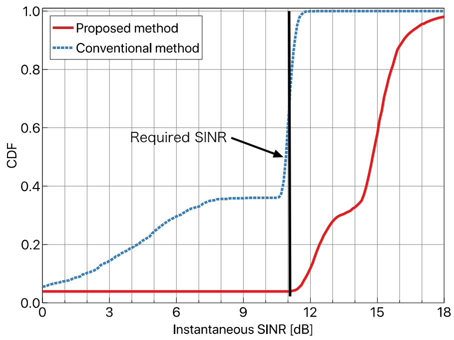


Fig. 2.3-11 CDF of the instantaneous SINR of the conventional and proposed methods.

[Optically powered transmission systems for optical access networks] (Matsuura Lab)

Optical access systems are expected to play an important role in supporting multiple wired and wireless internet services in future communication networks. In particular, radio-over-fiber (RoF) is an essential technology for transmitting radio-frequency (RF) signals into fiber links between a central office (CO) and remote antenna units (RAUs), as well as for providing broadband mobile communications. A reduction in the cell size of RAUs is required to support higher data rates for RF signals, and a large number of RAUs should be installed, especially in densely populated areas. Therefore, it is important to provide cost-effective installation, operation, and maintenance of RAUs. Power-over-fiber (PWoF) is a simple way to simultaneously transmitting optical data and power into the same optical fiber. In RoF networks, PWoF is effectively used not only to deliver the power required for driving RAUs from a CO, but also to centralize the power source in the CO. Although it is well known that the power transmission efficiency (PTE) of PWoF is lower than that of conventional electrical power lines, we believe that PWoF is an attractive approach to reducing overall network power consumption.

In this year, we demonstrate a PWoF feed with up to 150-W of power using a 1-km double-clad finer (DCF). To show the feasibility of the PWoF system, we investigate the bend performance and temperature characteristics of the DCF link. We also evaluate data and power transmission performance under the 150-W PWoF feed in the DCF link.

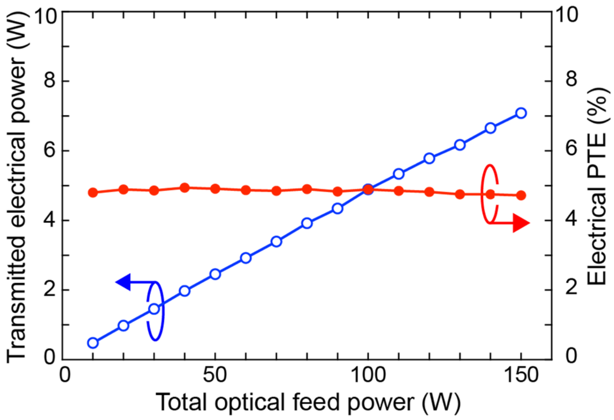


Fig. 2.3-12 Transmitted electrical power and PTE as a function of total optical feed power.

To evaluate the electrical power supply capability of the PWoF system, we measured the electrical PTE, which is defined as the power ratio between the four high-power laser-diode (HPLD) outputs and the total electrical power converted by the six PPCs. The result is shown in Fig. 2.3-12. As the total optical feed power increased, the converted electrical power increased linearly, whereas the PTE was almost constant regardless of the total optical feed power. Power linearity and the constant PTE are quite useful in the control of supplied power according to the temporary traffic load of each RAU. In the 150-W optical feed, the total transmitted electrical power was 7.08 W. The calculated average PTE was approximately 4.84%. If we were to use photovoltaic power converters (PPCs) with a higher O/E conversion efficiency, the PTE would be further improved.

2.3.4 Funds

【Grants-in-Aid for Scientific Research】

1. Scientific Research B "Research on Spectrum Sharing among Multiple Systems based on Correlation of Wireless Environment using Crowd Sensing"
   Takeo Fujii
2. Scientific Research Fostering Joint International Research "Research of Advanced V2X Network based on Wireless Environment Learning for realizing Cooperated Autonomous Vehicles"
   Takeo Fujii
3. Scientific Research B "Research on Information Passing between Sensing Information Space and Physical Space for Dense Wireless Sensor Network"
   Takeo Fujii (PI belongs to other organization)
4. Scientific Research B "Research on Advanced Wireless and Wired Harmonized SDN"
   Takeo Fujii (PI belongs to other organization)
5. Scientific Research Fostering Joint International Research Type B "Research of Smart Spectrum using Multi-dimensional Wireless Environment Recognition based on Learning"
   Takeo Fujii (PI belongs to other organization)
6. Scientific Research B "Research on Optically Powered Radio-over-Fiber systems"
   Motoharu Matsuura
7. Scientific Research A "Research on New Transmission Technologies based on Lattice Structures for Next-Generation Ultra-High Data-Rate Communications"

Koji Ishibashi (PI belongs to other organization)

8. Scientific Research A “Research on analog factor graph for large MIMO systems”
   Koji Ishibashi (PI belongs to other organization)

【Commissioned Research】

1. MIC “Dynamic Spectrum Sharing among Different Radio Services”
   Takeo Fujii, Koichi Adachi
2. MIC “Highly-Reliable Wireless Access Technology for Advanced 5G Networks”
   Koji Ishibashi
3. MIC SCOPE “Augmented Learning of Wireless Communication Environment for Forwarding Frequency Spectrum Sharing”
   Koichi Adachi
4. MIC SCOPE JP-EU Joint Research “5G Enhanced Mobile Broadband Access Networks in Crowded Environments (5G-Enhance)”
   Takeo Fujii, Koji Ishibashi, Koichi Adachi
5. MIC SCOPE “Unified IoT Monitoring System for Improving Spectrum Efficiency”
   Takeo Fujii (PI belongs to other organization)

【Other Funds】

1. The Telecommunications Advancement Foundation Research Grant, “Adaptive Base Station Operation Based on Machine Learning”
   Koichi Adachi

2.4 Division of Exploring Low Power Wireless

2.4.1 Purpose of Division

This division is aiming at low power wireless device technologies and application systems, which become fundamentals for future wireless communication systems. We are investigating such low power wireless technologies as super low power LSI design, energy harvesting technology, power transfer technology by optical fiber, as well as low power networks by theoretical approach. We also create new wireless application systems using the low power wireless technologies.

2.4.2 Research Staffs and Their Specialties

Prof. Koichiro Ishibashi（Head of Division, Low-power devices）

Associate Prof. Koji Ishibashi (Green network and communication theory)

Associate Prof. Ryo Ishikawa (RF energy harvesting)

Prof. Motoharu Matsuura (Radio over Fiber)

Prof. Takeo Fujii (Smart meters)

2.4.3 Major Research Outcomes in 2019

[Development of RF Energy Harvesting System from Environment RF signal]（Prof. Koichiro Ishibashi Lab）

RF energy harvesting technology which could be inevitable for future Trillion Sensor Universe has been investigated in the division of Exploring Low Power Wireless. We have been investigating to harvest the energy from environmental RF signal so that every sensor nodes at environment can operate everywhere and every time.

Nowadays cell phone base stations everywhere people are living transmit RF signals. We try to harvest the 950MHz cell phone RF signals with 15MHz BW at OFDM modulation as shown in Fig. 2.4.1. The rectenna system was designed to have enough BW for receiving the wide BW at OFDM, and it is composed of a dipole antenna with matching network, a cross couple rectifier circuit on 65nm SOTB technology. The system shown in Fig. 2.4.2, is placed in a laboratory room of UEC to receive the environmental RF signal, and harvests power of 2.77uW has been obtained (Fig. 2.4.3). This is the highest power ever reported from environment RF signal of -20dBm input power.

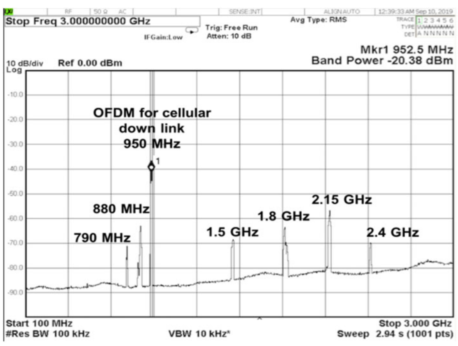


Figure 2.4.1 Environment RF spectrum

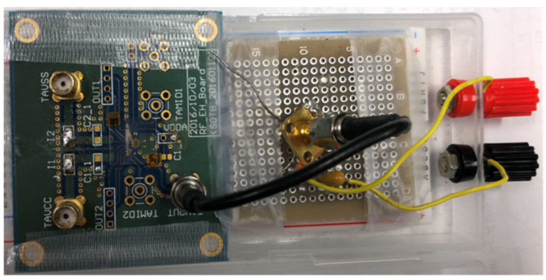


Figure 2.4.2 RF Energy harvesting System

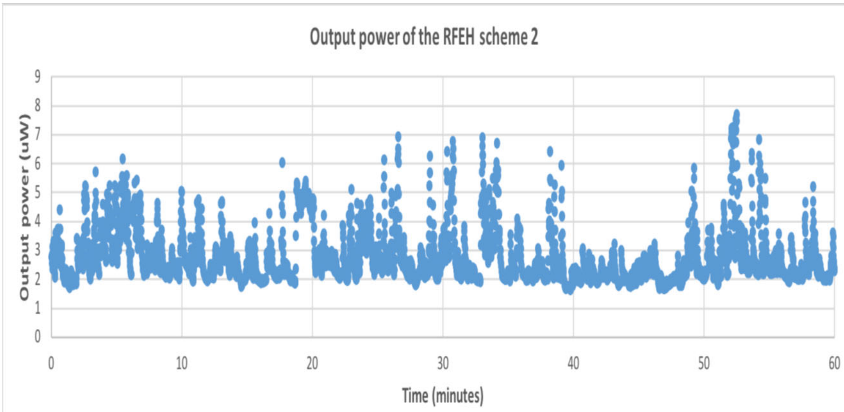


Figure 2.4.3 Harvested DC power for 60 min

[Ambient OFDM Pilot-Aided Backscatter Communications] (Koji Ishibashi Lab.)

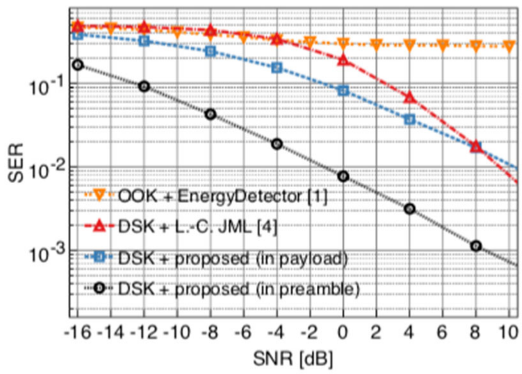


Fig. 2.4.4 SER of the conventional methods and proposed methods.

In the era of *internet-of-things* (IoT), a huge number of battery-driven wireless devices will be installed, so that this would result in a tremendously high cost to replace their batteries. As a promising scheme to transmit the information with ultra-low-power, ambient backscatter communication (AmBC) has gained considerable attention. In previous studies, AmBC has been implemented based on on-off keying (OOK) which can transmit the information with surprisingly low power, but the data rate and bandwidth efficiency are limited by using both a low-path filter and an energy detector. To solve this problem, we have proposed AmBC system employing the structure of ambient orthogonal frequency-division multiplexing (OFDM) signals and delay-shift keying (DSK), which intentionally adds the propagation delay to the ambient signals to transmit data. Figure. 2.4.4 shows the symbol error rates (SER) of the conventional methods and proposed methods. In the region of low signal-to-noise power ratio (SNR), our proposed methods can achieve the lower SER than the conventional methods. It indicates that our proposed methods can realize a highly reliable communication with low complexity demodulation and eliminating the estimation error of the backscatter signals.

[Low-power high-efficiency GaAs HEMT rectifier at 2.45-GHz band]（Ishikawa Lab.）

By rapid progress of wireless communications, many radio frequency (RF) signals now surround us in our environment. To effectively use environmental electro-magnetic waves, RF energy harvesting technology is a promising candidate. In RF energy harvesting, a rectifier or a rectenna is a key device for generating DC power from RF signals. Since the RF signals are usually very low in power, a sensitive rectifier is required. For this issue, we have developed an enhancement-mode GaAs pHEMT rectifier. The enhancement-mode GaAs HEMT was suitable for the rectifier operation due to its moderate gate-drain feedback capacitance, a strong nonlinearity, and a large transconductance. The gate-drain capacitance generates a sufficient gate-switching signal for a very low input power. The fabricated enhancement-mode GaAs pHEMT rectifier exhibited an RF-to-DC conversion efficiency of 24% for a –30 dBm input power at 2.41 GHz. In addition, RF-to-DC conversion efficiencies of 58, 63, and 63% were achieved at –15, –8, and –3 dBm RF input powers, respectively, when the gate bias voltage was controlled. (Fig. 2.4.5)

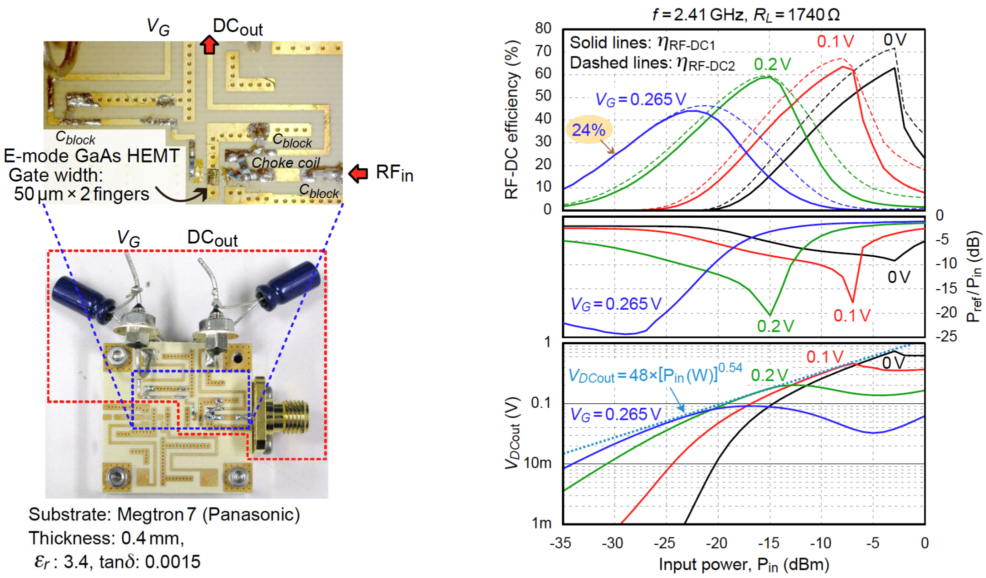


Fig.2.4.5 Fabricated enhancement-mode GaAs pHEMT rectifier, and its characteristics

[Simultaneous RF and Baseband Signal Transmission over a Multimode Fiber]（Matsuura Lab）

In this year, we present a simultaneous radio-frequency (RF) and high-speed baseband signal transmission using an electrically superimposed method over a graded-index silica multimode fiber (GI-MMF). To show the feasibility of the method, we experimentally demonstrate simultaneous transmission of electrically superimposed 28-GHz RF and 28-Gbit/s 4-level pulse amplitude modulation (PAM-4) baseband signals at a wavelength of 850 nm over a 50-m GI-MMF. Moreover, to evaluate the scalability of the method, we demonstrate simultaneous transmission of dual-channel, electrically superimposed 28-GHz RF and 14-Gbit/s non-return-to-zero on-off keying baseband signals at 850 nm and electrically superimposed 14-GHz RF and 14-Gbit/s PAM-4 baseband signals at 1550 nm over the 50-m GI-MMF. These results show that the presented method is useful for effectively utilizing the transmission band of transmitters and existing short-reach transmission systems.

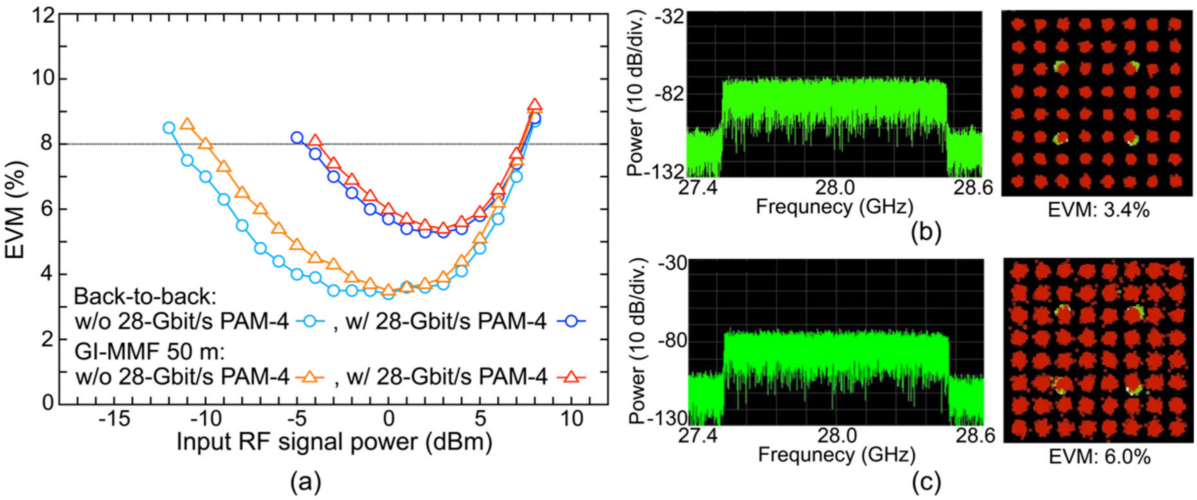


Fig. 2.4.-6 (a) EVM characteristics of back-to-back and transmitted 28-GHz RF signals over 50-m GI-MMF while varying input RF signal power to the laser. (b) Electrical signal spectrum and constellation of back-to-back signal without 28-Gbit/s PAM-4 signal when input RF signal power was 0 dBm. (c) Electrical signal spectrum and constellation of transmitted signal over 50-m GI-MMF with 28-Gbit/s PAM-4 signal when input RF signal power was +3 dBm.

Fig. 2.4.-6 (a) shows the error-vector magnitude (EVM) characteristics of the back-to-back and transmitted 28-GHz RF signals over the 50-m GI-MMF, while varying the input RF signal power to the laser. The dashed line shows the EVM value of 8%. For 64-QAM signals, the EVM value needs to be less than 8%. Here, the peak-to-peak voltage of the PPG output was set to 800 mVpp. In both cases, it could be observed that the signal quality of the RF signal was degraded by superimposing the 28-Gbit/s PAM-4 baseband signal. The electrical power penalties between with and without the baseband signal of the back-to-back and transmitted signals at the EVM of 8% (dotted line) were approximately 7.0 dB and 6.0 dB, respectively. The dynamic ranges of the back-to-back and transmitted signals with the 28-Gbit/s PAM-4 baseband signals at the EVM of 8% were 12.0 dB and 11.0 dB, respectively. Figs. 2.4-x (b) and (c) show the electrical signal spectra and the constellations of the back-to-back signal without the 28-Gbit/s PAM-4 signal and the transmitted signal over the 50-m GI-MMF with the 28-Gbit/s PAM-4 signal. These signals had high signal-to-noise ratios (SNRs) and good signal constellation diagrams.

[Adaptive Sensor Selection considering Spatial Data Correlation for Wireless Sensor Network]（Prof. Takeo Fujii）

In wireless sensor networks, the power of each sensor node (SN) is limited because a SN is battery-powered devices. So the method for realizing long-life network is needed. When an observation object has spatial correlation, sensor selection is valid. In the sensor selection, a fusion center makes some SNs active and the other sleep. The data of sleeping SNs can be estimated by data of other SNs exploiting spatial correlation of observation values and power consumption in the network reduces. The purposes of this study are to realize the long-life network and keep data accuracy highly. We propose the sensor selection scheme based on the interpolation accuracy and the number of selection. The number of selection shows power consumption of a SN. The system model is shown in Fig.2.4.7. In the proposed method, active SNs are selected by weighting the normalized interpolation accuracy and number of selection. We evaluate the proposed method through numerical simulation to show the number of selection and the data accuracy. The observation values are the actual temperature data we observed. Fig.2.4.8 shows the data accuracy. The proposed method is less error than k-means. Use smaller weight, the data accuracy is improved. Table 2.4.1 shows the number of selection. Use bigger weight, SNs are selected fairly. Therefore, the energy consumption is distributed and the network lives longer.

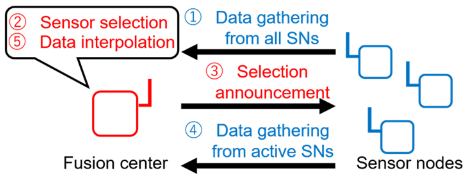


Fig. 2.4.7 System model.

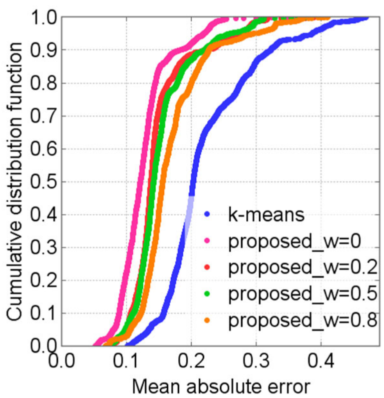


Fig.2.4.8 Gathered data accuracy.

Table 2.4.1 the number of selection.

	k-means	Proposed W=0	Proposed W=0.2	Proposed W=0.5	Proposed W=0.8
Min	13.47	4.47	21.80	22.70	23.30
Max	32.57	39.20	25.80	24.40	24.10

【Cooperative Research】

1. “Scavenging nW RF energy using Super Steep Transistor and Meta-Material Antenna,” On JST/CREST “Scientific Innovation for Energy Harvesting Technology” (Koichiro Ishibashi, Ryo Ishikawa, and Koji Ishibashi)
2. “Optimization of Smart-Meter Networks” (Koji Ishibashi and Takeo Fujii)

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特許

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