Advanced Wireless & Communication Research Center

ACTIVITY REPORT 2018

The University of Electro-Communications

Message from the Director, Prof. Yasushi Yamao

Thirteen years have passed since Advanced Wireless Communication Research Center (AWCC) was established in the University of Electro-Communications (UEC). 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.

Three years ago, AWCC created a new vision, “Ambient Wireless in Connected Community (AWCC)”, and changed its name to “Advanced Wireless & Communication Research Center”. With the new vision and name, 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 in AWCC.

(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 system is being developed in the world. The 5G 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

AWCC has 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.

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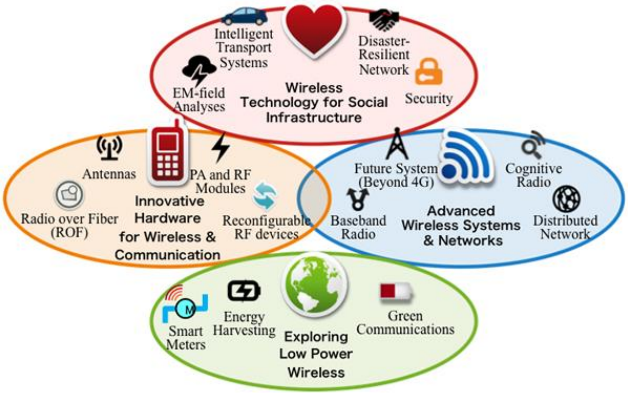
1 . ABOUT AWCC

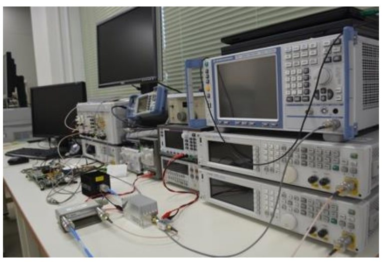
1.1 OVERVIEW



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.

Furthermore, the center will open a new remote research office in UEC Alliance Center from April 2017 to enhance joint research projects with industry and overseas universities. This remote office has a common discussion space with high-quality video conference system, an experiment space with general instruments, and two personal workspaces for visiting researchers. Moreover, its infrastructure is completely integrated with AWCC computing and network resources.

1.3 PEOPLE

【Director, 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

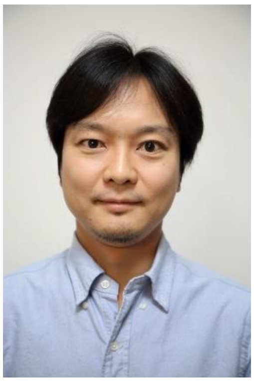
【Full time Prof. Takeo Fujii】

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 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 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.

【Concurrent Associate 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 an Associate 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.

【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.

【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. Isamu Chiba (Mitsubishi Research Institute Inc.)

Prof. Hideki Hayashi (Softbank Corp.)

Prof. Eisuke Fukuda (Fujitsu Laboratory Ltd.)

Prof. Yukitsuna Furuya (WiTLa)

Prof. Kenji Yoshida (GM Holdings Inc.)

2. Research Activities

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）
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 2018

(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 sufficient 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."

[Field Test of Creating Spectrum Environment Map for V2V Comminutions] (Fujii Lab.)

Connected and automated vehicles (CAVs) have attracted attention because CAVs are expected to revolutionize future transportation system. However, wireless connection has unstable reliability according to the surrounding environment like building geography and congestion. In order to solve the unstable wireless connection with low reliability, we have proposed using a spectrum database, which stores the radio status between the transmitter location and the receiver location. For example, if the received signal power of each link is stored at the database with transmitter and receiver location, the users can understand the link reliability before transmission. To create the database we utilize a common broadcast vehicle to vehicle communication (V2V) packet which includes transmitter location. Therefore, if the receiver can receive the packet, the locations of transmitter and receiver, received signal power can be collected. The collected data are uploaded to the spectrum database and radio environment map (REM) can be created as shown in Fig. 2.1-1. In order to proof of this concept, a field test is performed for obtaining the measurement data over V2V communication using three vehicles at UC Berkeley Richmond Filed Station. We utilize 5.9GHz band Dedicated Short Range Communications (DSRC) and different building environment fields are compared. The test sites is shown in Fig. 2.1-2 and the created REM can be shown in Fig. 2.1-3. From these figures, we can understand the different radio propagation due to building and can recognize the different reliability between two transmitter locations if the link is crossed at the center of loop.

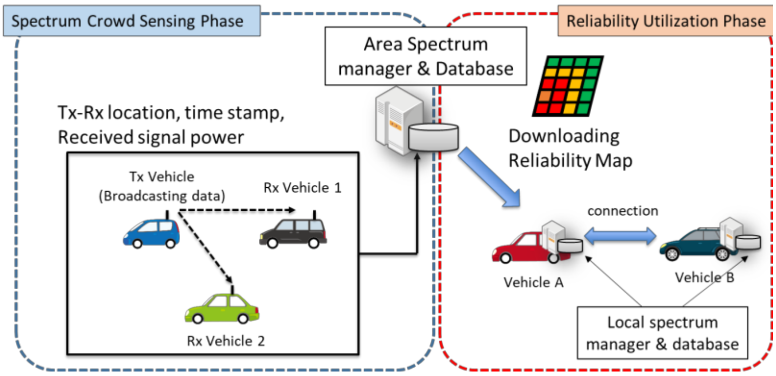


Figure 2.1-1 Concept of spectrum database with communication reliability.

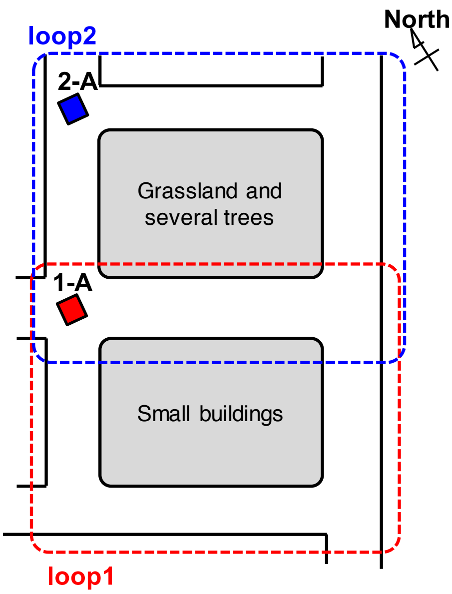


Figure 2.1-2 Field test site.

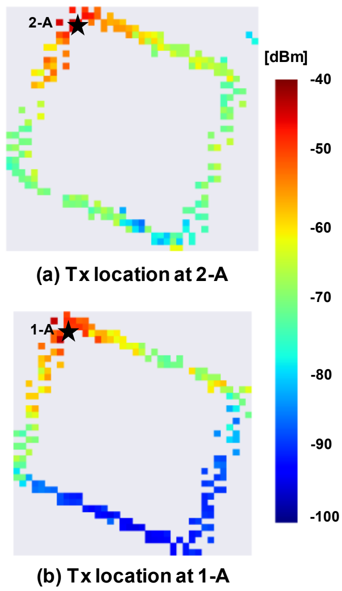


Figure 2.1-3 Received signal power map.

[V2I Multi-Hop Broadcast Communication by TC-BF Method] (Yamao Lab.)

A novel Infrastructure to Vehicle (I2V) multi-hop broadcast communication technique was proposed. The proposed Time-Controlled Broadcast Forwarding (TC-BF) method enables more efficient information delivery on the road compared to the existing broadcast packet forwarding schemes such as Flooding and Irresponsible Forwarding (IF) methods. The proposed forwarding method introduces priority control by differentiating transmission waiting time according to link distance and prohibits duplicate forwarding. The priority control according to link distance enhances longer distance forwarding and enables wider broadcast service area. During the waiting time, the waiting node monitors other nodes whether they forward the same packet or not. If no other node forwards the same packet, the node can forward the packet as the first forwarder. This is important to suppress unnecessary second forwarding by the shorter distance node after the longer distance node has completed forwarding. Packet delivery rate (PDR) and forwarding efficiency of the proposed scheme are evaluated by using computer simulations. Fig. 2.1-5 shows broadcast packet delivery rate (PDR) for 50 vehicle nodes on the straight road of 2 km. It is concluded that the TC-BF can reduce unnecessary forwarding and keep high PDR with extended communication range.

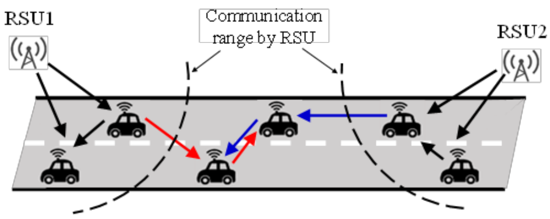


Fig. 2.1-4 Multi-hop road to vehicle broadcast communication.

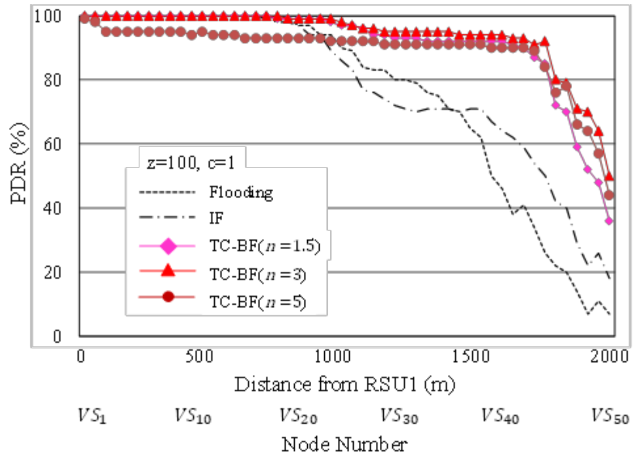


Fig. 2.1-5 Broadcast packet delivery rate (PDR) for 50 vehicle nodes on the straight road of 2 km.

[Propagation Loss Characteristic Analysis of V2V Communication for Right-Turn Accident Prevention Scenario] (Yamao Lab.)

One of the scenarios that is highly expected for V2V communication is right-turn collision prevention in intersections. In this scenario, however, there is a concern that a large vehicle waiting in an intersection frequently blocks the radio propagation path between a right-turn vehicle and a coming-though vehicle (Fig.2.1-6)). Therefore, study on the radio propagation for this scenario is essential to confirm the effectiveness of V2V communication. In this study, effect of surrounding buildings on large vehicle shadowing in intersection V2V communication has been analyzed by FDTD method (Fig.2.1-7). The result of FDTD analysis was compared with that of ray tracing in terms of propagation loss. Although the shadowing of large vehicles issues large attenuation, reflected waves from the surrounding buildings mitigate the propagation loss by 5-20 dB. The results of ray tracing analysis show smaller loss values by around 5 dB from that of FDTD. This error can be reduced by employing FDTD / Ray tracing hybrid technique.

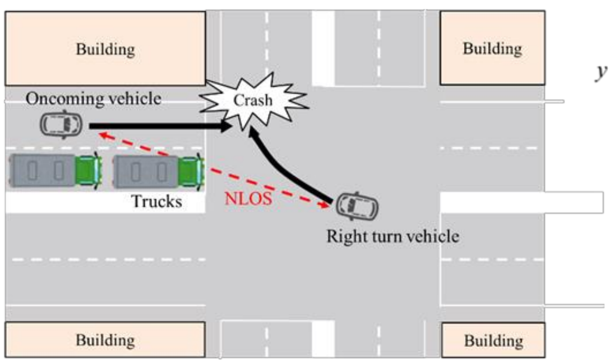


Fig. 2.1-6 Right-turn collision prevention scenario.

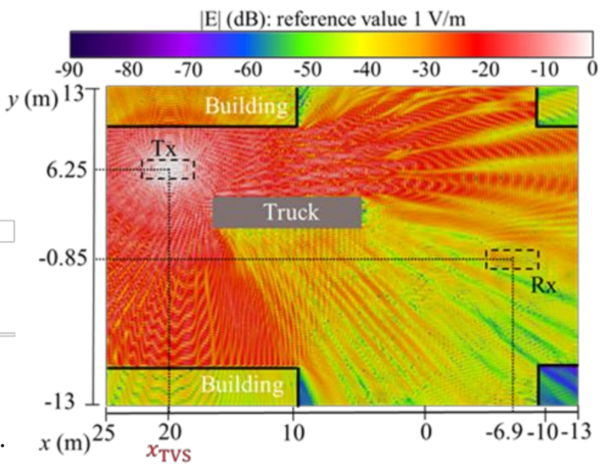


Fig. 2.1-7 Electric field strength map in intersection.

[Outage Probability Analysis of Sensor Nodes Served by an ULA Equipped UAV-BS](Adachi Lab.)

In 2017, we have proposed an unmanned aerial vehicle (UAV) with a uniform linear array antenna (ULA) has been proposed to tackle the high outage probability due to the low transmit power of sensor node (SN) and the existence of interfering SNs. However, the performance improvement had been evaluated by computer simulation only. This year, we have analytically evaluated the effectiveness of this method. The approach being used is to evaluate the possibility of the achievable signal-to-noise power ratio (SNR) or signal-to-interference plus noise power ratio (SINR) falls below a certain threshold which is called outage probability. For the tractable analysis, the positions of the desired SN and the interfering SN were fixed at certain locations. A tilt angle of the antenna arrangement is determined so that the antenna directivity of the array antenna towards the coverage area. The closed form expression of the outage probability for the proposed method is derived separately for the cases of no interfering SN and interfering SN. The analytical and the simulation results matched perfectly, which showed the derived outage probability expression is valid as shown in Fig. 2.1-8.

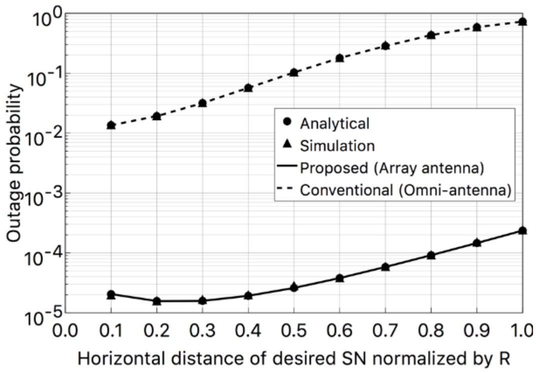


Fig.2.1-8 Outage probability function of distance to UAV

(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 Lab. also 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.2.1-9). These millimeter wave radars meet the specified low-power radio station standard of the millimeter wave in Japan. In recent years, the legal system for short range radar has been changed 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 radar modulation/demodulation method based on SMF modulation which adopts sparse-random frequency step sequence. The range-velocity ambiguity was mitigated by the sequence and the side-lobe due to the sparse-random frequency step sequence was subtracted by the signal processing of iterative signal subtraction and frequency estimation (Fig.2.1-10). The proposed method can detect the targets having different signal power with the resolution of ultra-wideband without ambiguity in both velocity and range profiles.

Fig. 2.1-9 Millimeter wave radar developed by Inaba Lab. of UEC

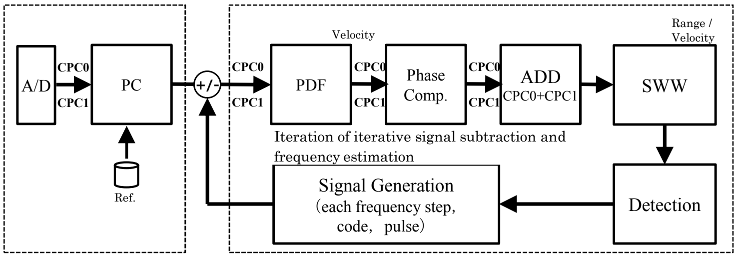


Fig.2.1-10 Block diagram of the signal processing of iterative signal subtraction and frequency estimation method in stepped multiple frequency CPC.

(C) RF-ID Communications

[Radio Propagation Analysis for 920MHz RFID on Metallic Storage Shelf] (Yamao Lab.)

Radio Frequency Identification (RFID) is one of the promising technologies of Internet of Things (IoT) that provides basis of the future economy and society. The RFID system consists of Reader/Writer (R/W) and RF tags. Recently passive RF tags are widely used because it is very small, needs no battery and low-cost. It is rapidly spreading in various area such as shops, factories, and public spaces including libraries. Since RFID technology depends on the radio propagation between R/W and RF tags, reliability of the communication is crucial. However, RFID is easily affected by the environment where RF tag is placed. In this study, radio propagation of 920MHz RFID on metallic storage shelf is analyzed by using Finite-Difference Time-Domain (FDTD) simulation. Experiments using a thin sheet-type RF tag on a cardboard box are conducted for verification of the analysis.

Simulated electric field strength created by the R/W antenna is shown in Fig. 2.1-11. As can be seen from the figure, standing waves are observed in the shelf. In the experiment, height pattern of the R/W received power caused by RF tag reflection was measured. The measured result is shown in Fig. 2.1-12, where blue line shows the received power and vertical broken lines represent null points in simulation. Communication failed when the received power is less than -60 dBm. Areas of communication failure and simulated null points match well. It is concluded that the standing waves severely affect the reliability of RFID communication.

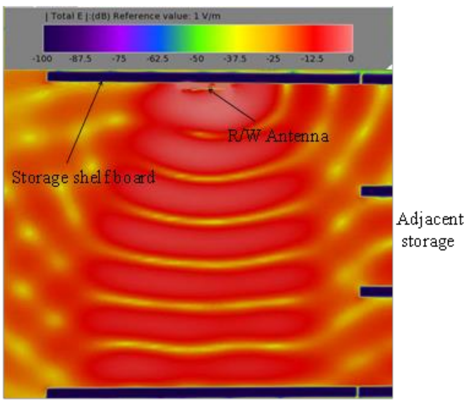


Fig.2.1-11 Electric field strength map in metal shelf.

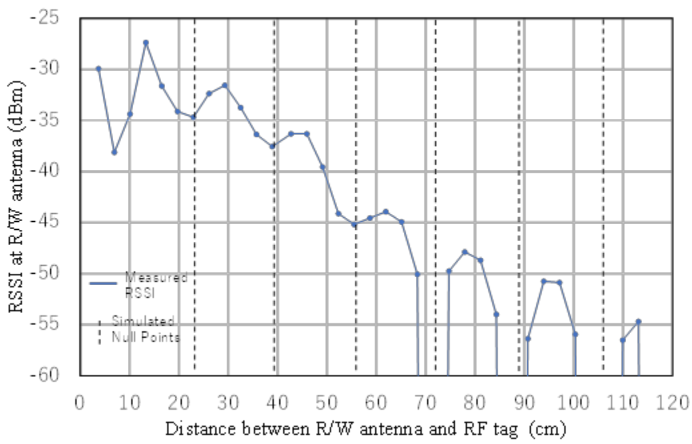


Fig.2.1-12 Measured height pattern of received power at R/W.

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 and M. Akita

【Cooperative Research】

1. "Research on Marine Radar signal processing"
   Y. Yamao
2. "Improvement in recognition rate of RF IDs"
   Y. Yamao
3. "Research on Communications Technology for Machine Tools"
   K. Adachi and Y. Yamao

【Other Funds】

1. DENSO Corporation, "Comparative investigation of millimeter wave radar modulation for automotive", Academic consulting
   T. Inaba
2. Kyosan Electric Mfg. Co., Ltd., "Parameter design for stepped multiple frequency CPC radar", Academic consulting
   T. Inaba
3. DENSO Corporation, "Program of evaluation of automotive radar modulation", Patent Number 5704552), License agreement
   T. Inaba
4. DENSO Corporation, "Program of generation of interference data", Patent Number 5704552, License agreement
   T. Inaba
5. Kyosan Electric Mfg. Co., Ltd., "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. K. Wada (Head of Division, Microwave circuits)
Prof. Koichiro Ishibashi (Low Power RF Devices, Sensor Networks)
Prof. Y. Yamao (Reconfigurable RF Circuit, Nonlinear Compensation)
Associate Prof. R. Ishikawa (Microwave/Millimeterwave Devices and Circuits)
Associate Prof. M. Matsuura (Wideband RoF Systems, Devices, Fibers and Integration)
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 2018

(A) Multi-Band Multi-Access Wireless Hardware for 5G System

[Low-/High-SHF-Band GaN MMIC Power Amplifiers] (Ishikawa Lab.)

For 5G communication systems, we have developed low- and high-SHF band GaN HEMT MMIC power amplifiers. For the low-SHF band, a fully integrated asymmetric Doherty power amplifier has been developed. To minimize the circuit size, a two-power-level impedance optimization method was applied instead of using a quarter-wavelength transmission line impedance inverter for load modulation in the Doherty amplifier. For this optimization, asymmetric configuration is required to realize optimum impedance conditions. In the actual design at a 4-GHz band on the MMIC, lumped circuit elements were used for all components (carrier/peaking amplifiers, a phase adjusting circuit, and an Wilkinson power divider). The 4-GHz-band GaN HEMT MMIC Doherty amplifier was designed and fabricated by using a 0.25-μm GaN/SiC HEMT process with a circuit area of 2320 by 1500 μm^2 (Fig. 2.2-1). The GaN HEMT MMIC Doherty amplifier exhibited a maximum drain efficiency of 56% and a maximum power-added efficiency (PAE) of 53% at 4.3 GHz, with a saturation output power of 36 dBm. In addition, PAE of 44% was achieved at 4.2 GHz on a 6-dB output back-off condition.

For the high-SHF band, a GaN HEMT MMIC power amplifier has been designed at 28 GHz by using the same GaN MMIC process. The 0.25-μm process can save a cost due to a use of

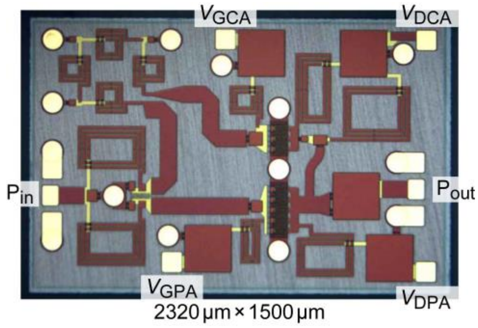


Fig. 2.2-1 4-GHz-band GaN HEMT MMIC asymmetric Doherty power amplifier

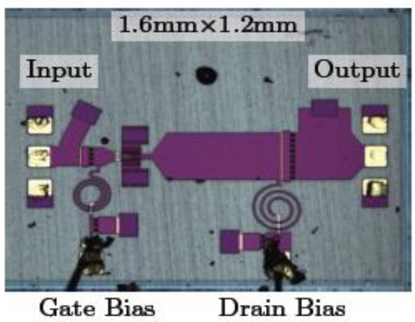


Fig 2.2-2 28GHz-band GaN HEMT MMIC power amplifier

on optical photolithography process, though a maximum oscillation frequency is not so high (about 50 GHz). A simple and wide-line-width layout design was performed so that circuit insertion loss became as low as possible (Fig. 2.2-2). The fabricated GaN HEMT MMIC amplifier exhibited a maximum drain efficiency of 26% and a maximum power-added efficiency (PAE) of 20% at 26.4 GHz, with a saturation output power of 26 dBm. These performances are applicable for actual wireless communication systems.

[Reconfigurable Bandpass Filter with Integrated Switch Array] (Yamao Lab.)

For the efficient use of frequency spectrum under multi-band operation in 5th generation mobile communication (5G), RF circuits that can flexibly switch multiple bands are important. Three-bit reconfigurable bandpass filters (BPF) have been proposed that can choose one of eight center frequencies in UHF or SHF bands. However, the RF switches employed for the frequency switching have been treated as ideal component and not studied in detail. In this study, we focus on the FET switches in the reconfigurable BPF for SHF band and analyze the influence of their parasitic elements on the performance of BPF. In order to reduce insertion loss of the BPF, a new gate width design method for RF switch array (SWA) is proposed. A 3-bit RF SWA is fabricated using 0.5 μm gate pHEMT process and installed in the prototype BPF with passband center frequency changeable from 3.5 to 4.64 GHz. The measured RF characteristic of the prototype is close to the result of circuit simulation.

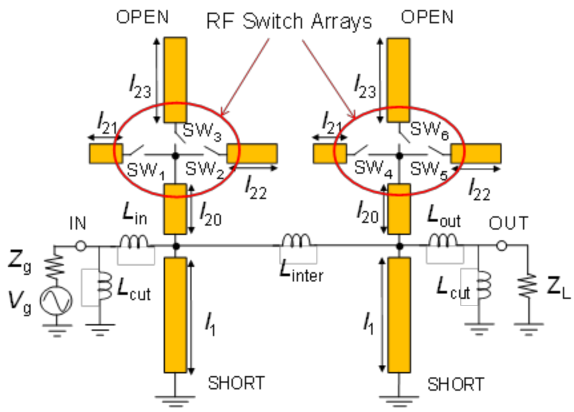
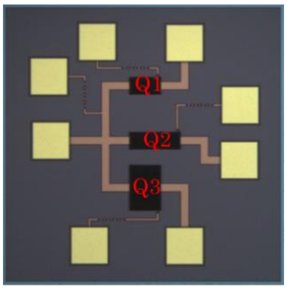
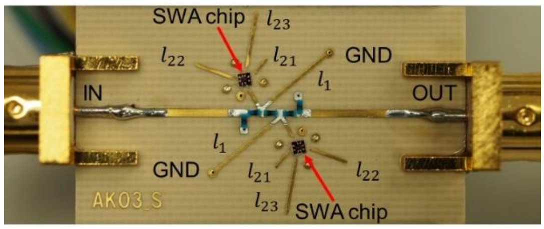


Fig. 2.2-3 Three-bit reconfigurable BPF with RF switch arrays.



0.7 mm × 0.7 mm

Fig. 2.2-4 PHEMT 3-bit switch array IC.



23 mm x13 mm

Fig. 2.2-5 Prototype BPF with PHEMT 3-bit switch arrays.

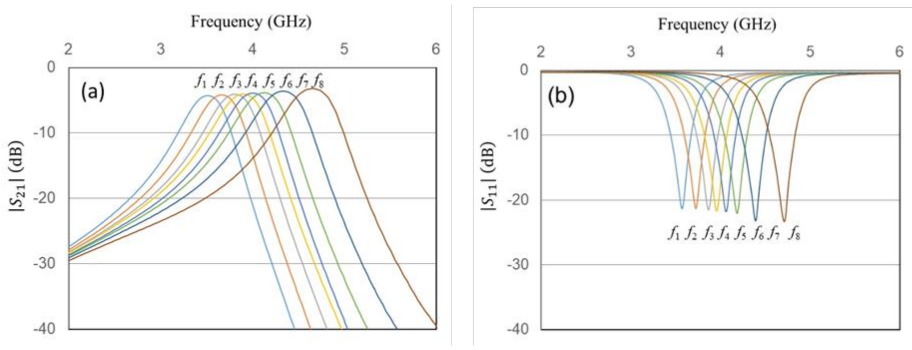


Fig. 2.2-6 Measured S parameters of prototype BPF, (a) S_{21}, (b) S_{11}.

[Band-Split Nonlinear Compensation Techniques for Wideband RF Signal] (Yamao Lab.)

A novel wideband digital predistortion (DPD) technique that can relax the requirement for sampling frequency is proposed. The proposed band-split parallel signal processing DPD can reduce the sampling frequency to the half of normal DPD while compensating all nonlinear terms and achieve the same compensation performance. After presenting the principle of the proposed scheme, the simulation results employing two-component carrier (2CC) LTE-A signal are presented that achieve ACLR of less than -50 dB and EVM of less than 2.5 %. The proposed DPDs with four-band and two-band splitting methods can decrease the sampling frequencies to the half and two thirds of the normal DPD, respectively.

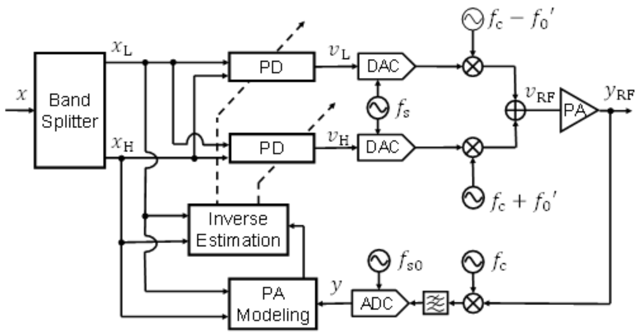


Fig.2.2-7 Block diagram of proposed DPD with band splitting method (Two-band splitting).

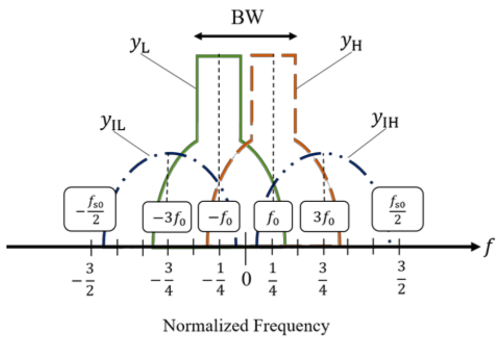


Fig. 2.2-8 Decomposed PA output spectra.

Table. 2.2-1 Required Sampling Frequency and Number of DACs.

	Four-band splitting DPD	Two -band splitting DPD	Conventional DPD
Required sampling frequency	$\frac{3}{2}BW$	$2BW$	$3BW$
Required number of DACs	4	2	1

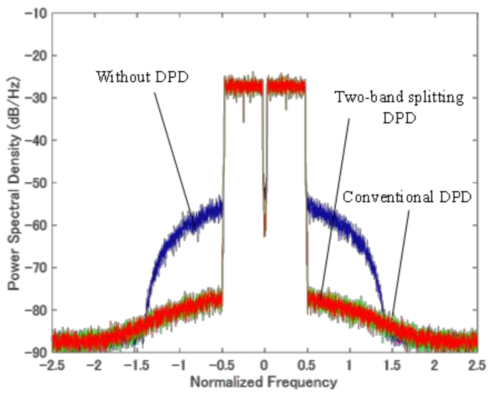


Fig. 2.2-9 PA output spectra with proposed DPD.

[Blind Nonlinear Compensation of RF Receiver Employing Folded-Spectrum Sub-Nyquist Sampling Technique] (Yamao Lab.)

Blind nonlinear compensation for RF receivers 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. Since nonlinear compensation circuits must handle intermodulation bandwidths that are more than three times the signal bandwidth, reducing the sampling frequency is essential for saving power consumption. We proposed a novel blind nonlinear compensation technique that employs sub-Nyquist sampling analog-to-digital conversion. Although outband distortion spectrum is folded in the proposed sub-Nyquist sampling technique,

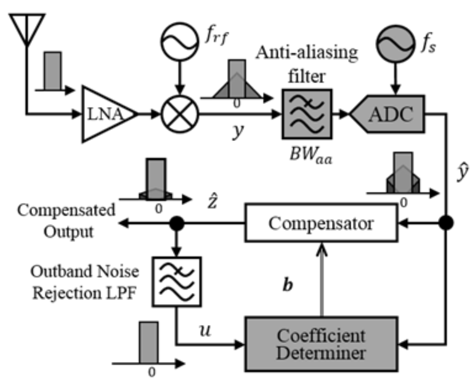


Fig.2.2-10 Proposed blind nonlinear compensation scheme with sub-Nyquist sampling technique.

determination of compensator coefficients is still possible by using the distortion power. Proposed technique achieves almost same compensation performance in EVM as the conventional compensation scheme, while reducing sampling speed of analog to digital convertor (ADC) to less than half the normal sampling frequency. The proposed technique can be applied in concurrent dual-band communication systems and adapt to flat Rayleigh fading environments.

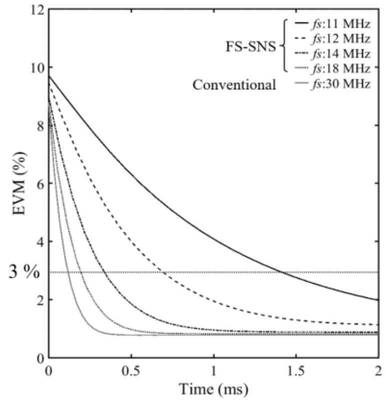


Fig.2.2-11 Simulated EVM convergence v.s. sampling frequency

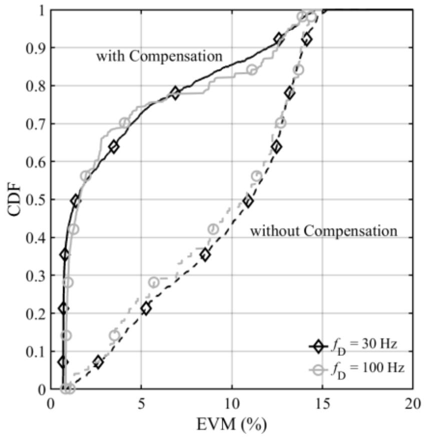


Fig.2.2-12 CDF of EVM for Rayleigh faded channel (f_D = 30,100 Hz).

(B) Long-Range OAM Communication Using Loop Antenna Arrays (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 a coaxial four loop-antenna-array system in which four OAM modes can be generated and separated to individual ports with more than 10-dB isolation, in last year. By adjusting relative RF connection positions for each loop antenna, and by placing a metal reflection plate behind the loop antenna array, isolation performances between loop-antenna communications were successfully improved. A performance for a long-range OAM communication with a distance of 90 cm was estimated by using paraboloids with accurate alignments for each component (Fig. 2.2.13). In a 5-GHz-band system, the measured transmission between antennas of the same radius was the maximum, and an excellent measured transmission isolation of more than 23.4 dB was obtained. In addition, in a 12-GHz-band system, the measured transmission isolation of more than 17.6 dB was obtained.

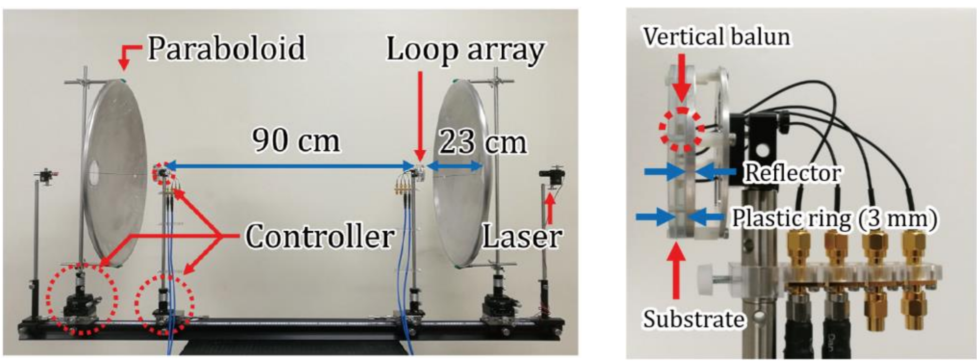


Fig. 2.2-13 Long-range OAM communication system using loop antenna arrays at 12-GHz band.

(C) **Photonic Analog-to-Digital Conversions (ADCs) for RoF systems (Matsuura Lab.)**

In this year, we have achieved 10-GSamples/s, 15-level optical quantization using red frequency chirp in a quantum-dot semiconductor optical amplifier (QD-SOA). To dramatically increase the quantization level, we have carefully adjusted the input signal power and the threshold for optical quantization. The input signal power required for the quantization is much lower than those of the previously reported photonic ADCs. The result shows the measured relationship between the normalized peak power of the input sampling pulse and the red-shifted frequency of the R-BPF when the peak power of the extracted sampling pulse exceeded a threshold for discriminating “0” or “1” level. As the red-shifted frequency was increased, the required peak power of the input sampling pulse was increased. As a result, we achieved 15-level quantization. Here, it should be noted that the threshold and the power injected into the QD-SOA of the input sampling signal were very important factors to determine the quantization performance. Therefore, we carefully optimized these parameters to obtain the best performance with a higher quantization level. In this experiment, the threshold was set to 0.25 to the highest peak power of the normalized output pulse train with a red frequency shift of 20-GHz, whereas the powers injected into the QD-SOA of the sampling pulse train and CW probe were set to −7.0 dBm and −2.0 dBm, respectively. In Fig. 2, the normalized peak power of 1.0 corresponded to the actual peak power of 8.4 mW. This means that the input sampling signal peak power required for the optical quantization was less than 8.4 mW, which was much lower than those of the previously reported photonic ADCs.

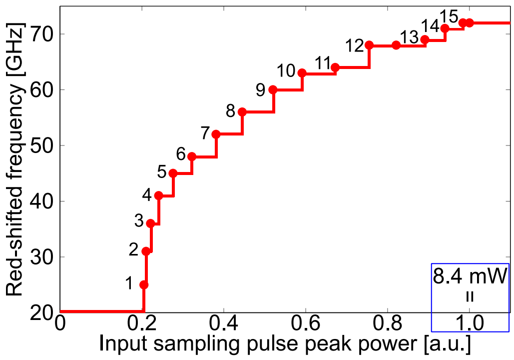


Fig.2.2.14 15-level quantization performance

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
3. Grant-in-Aid for Challenging Exploratory Research, “Research on 100 GSample/s Optical Quantization Using quantum-dot semiconductor optical amplifiers”
   M. Matsuura

【Commissioned Research】

1. Ministry of Internal Affairs and Communications (MIC) of Japan, "Research and Development for the realization of 5G mobile communication system"
   Y. Yamao, K. Honjo, R. Ishikawa, A. Saitou, Y. Takayama
2. MIC, SCOPE, "Research and Development for Super Multiplexing OAM Communication Using Loop Array Antennas,"
   A. Saitou, K. Honjo, R. Ishikawa

【Cooperative Research】

1. Taiyo Yuden Co., Ltd. "Study on OAM applications"
   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"
   K. Honjo, R. Ishikawa
4. MoDeCH Inc. "Millimeter wave circuit design"
   R. Ishikawa, K. Honjo
5. YAZAKI Corporation, "Analog and Digital Signal Transmission Using Multi-Mode Fibers"
   M. Matsuura

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

2.3.3 Major Research Results in 2018

[Multiband Hierarchical Ad Hoc Network with Wireless Environment Recognition] (Fujii Lab.)

Wireless ad hoc networks have attracted high attention to adapt to multi-hop networks such as wireless mesh networks, sensor networks, vehicle-to-vehicle (V2V) networks, and so on. Conventional wireless communications such as cellular networks and Wi-Fi networks are considered to optimize human-to-human communication. In recent years, on the other hand, wireless communication is not limited to human only communication due to the Internet of Things (IoT). In such an environment, how to treat the limited frequency bands to provide robust wireless networks and to satisfy users is a challenging issue. Wireless ad hoc network is preferable to adapt to such environment because it can generate wireless links with dynamic route only when necessary. Up to now, communication of wireless ad hoc network is assumed to use 2.4 GHz Industry-Science-Medical (ISM) bands. Such bands can use freely without any permission. Consequently, ISM bands always crowded for the sake of using wireless LANs, microwave ovens, and so on. From the viewpoint of users, on the other hand, the requirement of the system is different according to the service. Therefore, in this research, we focus on a method of band selection for wireless ad hoc networks that corresponds to multi-frequency. To obtain a high success rate of routing, high throughput, and high PDR, we proposed a Software Defined Network (SDN)-based routing scheme for multi-user environments. The system model is shown in Fig. 2.3-1. Fig. 2.3-2 shows the average throughput performance comparison between the result used SDN and not used one. From this figure, we can confirm that the proposed method can select frequency bands dynamically to achieve higher throughput.

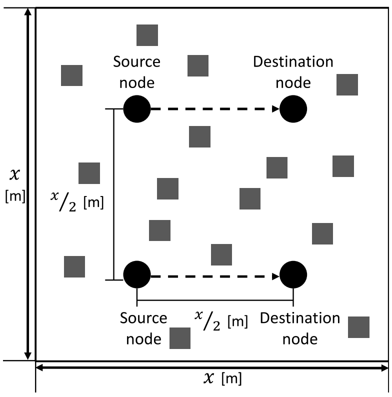


Figure 2.3-1 System model.

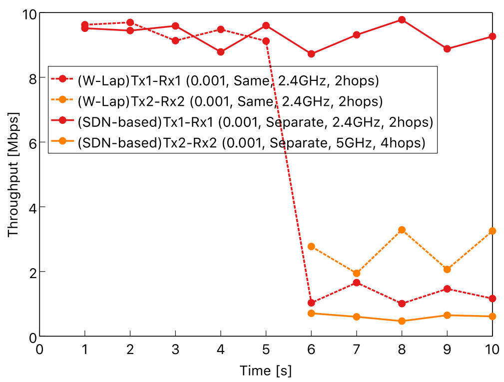


Figure 2.3-2 Average Throughput.

[Highly Accurate Prediction of Radio Propagation using Model Classifier] (Fujii Lab.)

In order to accurately recognize the radio environment, measurement-based spectrum database (MSD) has attracted attention. Radio environment is gathered by huge numbers of terminals and the database accumulates the datasets related to the locations of receivers. Then, the datasets are used to generate the statistical information such as radio environment map (REM). By using the REM, path loss and shadowing deviation can be estimated at arbitrary position. However, the conventional database stores the statistical radio information of each receiver location. Hence, the registered data size is enormous. In this research, to reduce the registered data size of MSD, we propose the MSD using model classifier. Figure 2.3-3 shows a concept of a model classifier in this research. In model classifier, K propagation models including path loss and shadowing are constructed. Then the database unifies the propagation model at the point where the shadowing characteristics are similar. By using model classifier, we can reduce the registered data size while accurately estimating the radio environment. To evaluate the proposed classifier, we used measurement datasets of a 3GPP cellular band in the real environment. This measurement was performed in Kudanshita Chiyoda-ku in Tokyo, Japan. Center frequency is 3.5GHz, transmission power is 29dBm and the amount of the datasets is 100,423. Figure 2.3-4 shows the result of RMSE between the estimated average received power and instantaneous received power. For the performance comparison, REM-based method and single path loss model-based method are evaluated. We can confirm that the proposed method can accurately estimate the radio environment while reducing the registered data size.

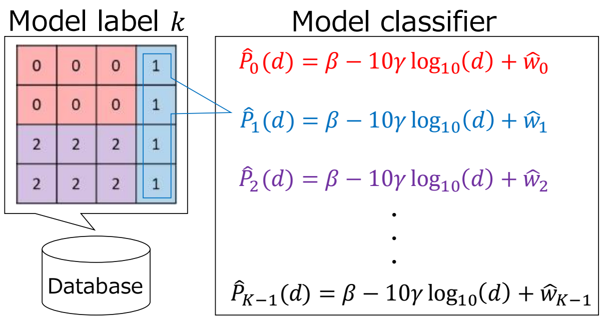


Fig. 2.3-3 Concept of a model classifier

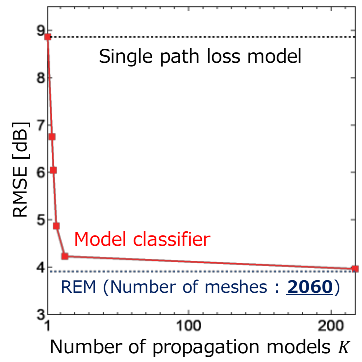


Fig. 2.3-4 RMSE characteristics

[Radio and Computing Resource Allocation for Minimizing Total Processing Completion Time in Mobile Edge Computing] (Adachi Lab.)

Due to the ever increasing interest in mobile applications and services, the concept of mobile edge computing (MEC) has emerged. Due to the proximity between mobile user (MU) and MEC server located at base station (BS), i.e., the edge of radio access network (RAN), MEC can realize low-latency mobile application. For MEC, MU and MEC server need to exchange tasks using limited radio resources. Furthermore, when multiple MUs possess tasks, MEC server has to handle multiple tasks. Thus, the radio and computing resources need to be allocated to MUs by taking into account the wireless channel condition and the computing power of MUs and MEC server. In this research, we proposed a radio resource and computing

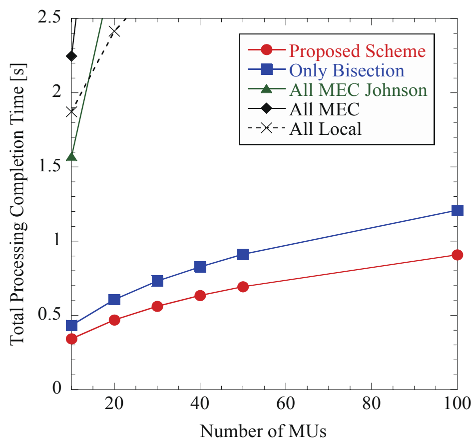


Fig.2.3-5 Total processing completion time as a function of number of MUs.

resources allocation scheme in order to minimize the total processing completion time of all the tasks. Each task is assumed to be divided into local task and offload task. Local task is computed by each MU whilst offload task is computed by a MEC server. We first formulated the optimization problem to minimize the total processing completion time of all tasks. For the formulated optimization problem, we developed a two-step radio and computing resources allocation scheme which iteratively performs bisection search method and Johnson's algorithm. Fig. 2.3-5 shows the total processing completion time of the proposed scheme and the existing schemes. The figure clearly shows that up to 25% total processing completion time reduction is achieved by the proposed scheme compared to the conventional schemes.

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

The management of mutual interference is essential in Internet-of-Things (IoT) era due to densely deployed wireless nodes. Some standards of Low Power Wide Area (LPWA) adopt Carrier Sense Multiple Access / Collision Avoidance (CSMA/CA) as a random access scheme. It allows the wireless nodes to access the channel while avoiding such mutual interferences using carrier sensing. However, the wireless node may not be able to carrier sense the other wireless nodes' communication due to the radio environment such as large pathloss between them. Therefore packet collision may happen and this results in the packet delivery rate (PDR) degradation. This problem is severer in LPWA network due to its wide coverage and the low transmit power of wireless nodes. In order to avoid such packet collision, we have proposed an orthogonal resource allocation scheme using powerful machine learning technique, e.g., reinforcement learning. This scheme learns the surrounding radio environment of each wireless node and allocates the wireless resources to wireless nodes so that that allocation can improve the PDR performance. For the reward of reinforcement learning, the number of successfully received packets at the Fusion Center (FC) is adopted since it is obtainable at the FC without any explicit feedback from wireless nodes. Due to the strong correlation between the number of successfully received packets and PDR, it is possible to improve the PDR performance. Under the LoRaWAN network, the numerical evaluation has been conducted. Fig. 2.3-6 shows the process of learning. As it can be seen from the figure that the PDR performance improves as the learning progresses. The cumulative distributeion function (CDF) of PDR is shown in Fig. 2.3-7. The figure clearly shows that the proposed scheme can improve PDR performance compared to random resource allocation. For example, 10% PDR value can be improved by 22 % compared to random allocation scheme. It indicates that the proposed scheme can improve PDR performance of wireless nodes with poor channel condition.

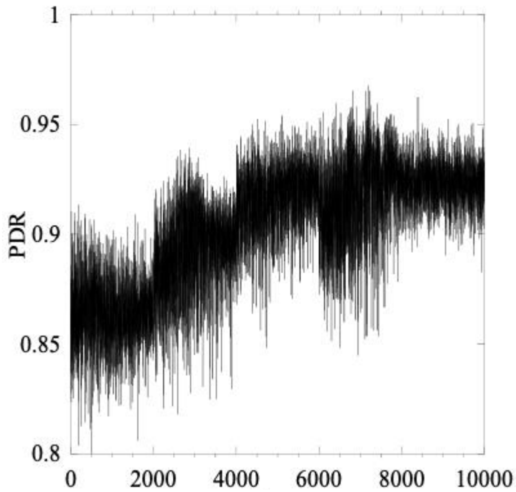


Fig.2.3-6 Process of Learning.

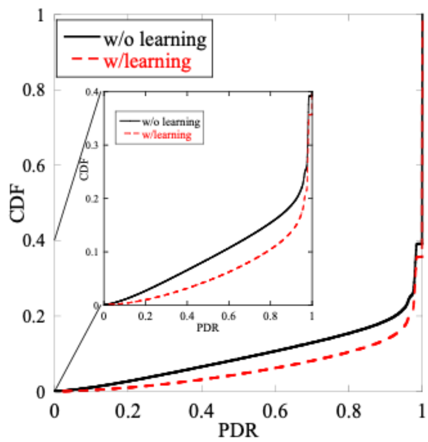


Fig. 2.3-7 PDR Performance of proposed method

[Random Access Protocols for Massive Users] (Koji Ishibashi Lab.)

Future wireless communication would accommodate massive number of devices, as represented by Internet-of-Things (IoT). In order to realize efficient data transmission of large number of devices, designing the transmission protocol of devices 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 an efficient random access protocol, namely frameless ALOHA with multiple base station cooperation. Multiple base stations are exploited to cooperatively retrieve transmitted packets, while devices transmit their packets using transmission probabilities. We have theoretically optimized transmission probabilities to maximize the achievable throughput. Upon the optimization, our proposed scheme achieves remarkable throughput performance. While frameless ALOHA with multiple base station cooperation can start the packet retrieval process only from collision-free time slots, ZigZag decoding has been proposed as a technique to retrieve two colliding packets. In 2018, we have then proposed ZigZag decodable frameless ALOHA, where frameless ALOHA protocol is modified so as to fully exploit ZigZag decoding. As shown in Fig. 2.3-8, ZigZag decodable frameless ALOHA outperforms the original frameless ALOHA in whole thresholds on packet loss rate (PLR). Those results have been already published in IEEE journals.

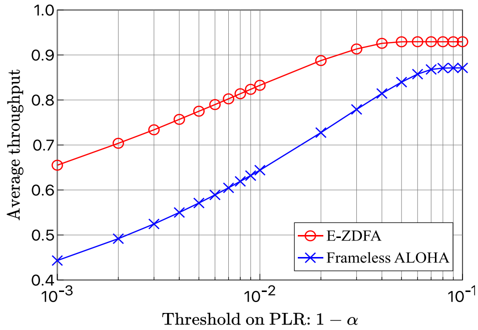


Fig. 2.3-8 Throughput of ZigZag decodable frameless ALOHA.

[Low-Complexity Detector for Frame-Theoretic 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 *5G and beyond*. 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 this end, frame-theoretic NOMA exploiting full resources of the system has been proposed in the literature. However, the dense use of resources results in the high complexity of the detection. To reduce the complexity, we proposed the low-complexity detector based on Gaussian belief propagation (GaBP) and also the design of the precoder enhancing the performance of GaBP. Figure 2.3-9 shows bit error rate (BER) performances of conventional detection for frame-theoretic NOMA systems and proposed approaches (GaBP and GaBP. As obvious from the figure, our proposed approach enhances the BER performance with even lower complexity.

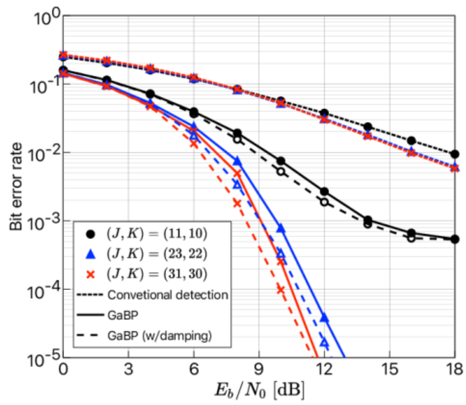


Fig. 2.3-9 BER performances of several detection techniques.

[Compressed-Sensing-Aided Subcarrier IQ Index Modulation] (Koji Ishibashi Lab.)]

In current wireless communication systems, orthogonal frequency division multiplexing (OFDM) is employed. Recently, the combination of OFDM and index modulation, namely subcarrier index modulation (SIM) has been proposed. SIM utilizes a part of subcarriers so that information bits are conveyed via not only classical constellations but also patterns of active subcarriers. Although a minimum Euclidean distance (MED) increases thanks to this transmission scheme, SIM has a superiority against OFDM only in low bandwidth efficiency. To this end, we have proposed *compressed-sensing-aided subcarrier in-phase/quadrature-phase index modulation* (CS-SIQIM). CS-SIQIM can enhance both the detection performance and the bandwidth efficiency by applying compressed sensing to subcarrier in-phase and quadrature-phase index modulation. We further proposed the use of aggregate-compression in CS-SIQIM, called AC-SIQIM, so as to improve the performance of the signal reconstruction. Figure 2.3-10 shows bit error rate (BER) performance of our proposals compared with OFDM where their transmission rates are set 1.25 [bits/s/Hz]. As seen in the figure, the improvement of our proposed approach is more than 2 dB at BER=10^{-4}.

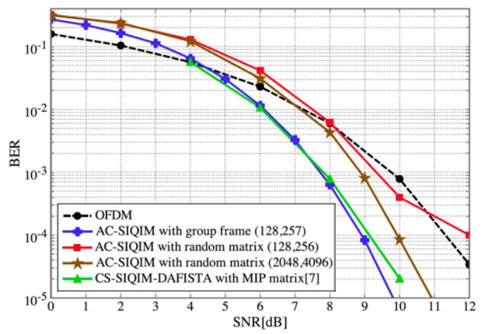


Fig. 2.3-10 BER performances of the proposed SIQIMs and OFDM.

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

Power-over-fiber (PWoF) is an attractive approach not only to delivery optical power using optical fibers but also to simplify the power supply system of remote antenna units (RAUs) for radio-over-fiber (RoF)-based mobile networks. If the power required for RAUs can be fully supplied from a central station (CS) using RoF links, the networks does not require conventional public power lines and batteries. In addition, as the power supply system of the RAUs is centralized in the CS, it is easier to control the power supplied to each RAU, according to the temporary traffic load of each RAU.

We have proposed PWoF systems using double-clad fibers (DCFs) consisting of a single-mode (SM) core and an inner cladding; the SM core is used for RoF data transmission, while the inner cladding with a much larger core area than SM cores is used for optical power feeding. We also have demonstrated the RoF transmission experiments with 60-W PWoF feed using a 300-m DCF. Moreover, we have achieved the good bidirectional transmission performances of up to 1-km DCF link, and significant influence on the link length has never been observed.

In this year, we demonstrate up to 150-W PWoF feed with bidirectional RoF transmission using a 1-km DCF link, and evaluate the signal transmission performances. To the best of our knowledge, this is the highest optical power feeding demonstration of simultaneous power and data transmission experiments over a single optical fiber. The result shows the error vector magnitude (EVM) penalties to the back-to-back signal of the downlink/uplink transmitted signals when the received electrical signal power was set to –30 dBm. The obtained EVM penalties were less than 0.04%, and there was no significant increase in the EVM value even if the optical feed power was increased up to 150 W. Moreover, the

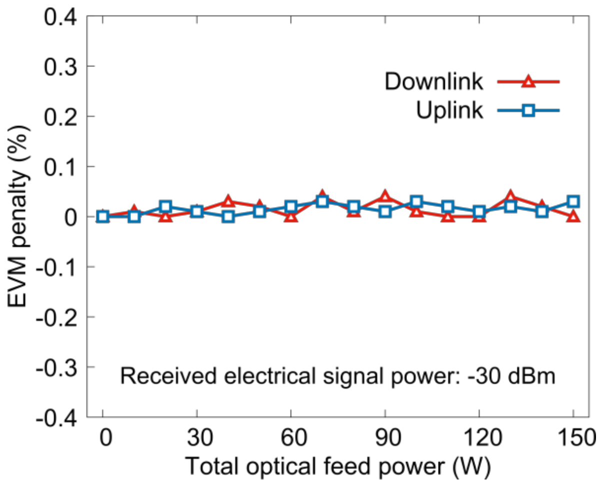


Fig. 2.3-11 EVM penalties to back-to-back signal of downlink/uplink transmitted signals into a 1-km DCF link while changing total optical feed power when received electrical power was set to – 30 dBm.

result was almost the same performance as those of the previous bidirectional transmission experiment under the 60-W feeding using a 300-m DCF link.

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. Challenging Exploratory Research "Research on 100 GSamples/s Optical Quantization Using Quantum-Dot Semiconductor Optical Amplifiers"
   Motoharu Matsuura
8. Scientific Research C "Research on New Multiple Access Control Technologies based on Multi-Dimensional Graph Structure for Massive Users"
   Koji Ishibashi
9. 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)
10. Scientific Research A "Research on analog factor graph for large MIMO systems"
    Koji Ishibashi (PI belongs to other organization)

【Commissioned Research】

1. MIC SCOPE "Augmented Learning of Wireless Communication Environment for Forwarding Frequency Spectrum Sharing"
   Koichi Adachi (PI belongs to other organization)
2. MIC SCOPE JP-EU Joint Research "5G Enhanced Mobile Broadband Access Networks in Crowded Environments (5G-Enhance)"
   Takeo Fujii, Koji Ishibashi, Koichi Adachi
3. MIC SCOPE "Non-orthogonal multiple access technique based on frame theory for 5G"
   Koji Ishibashi (PI belongs to other organization)

【Other Funds】

1. KDDI Research, Joint Research Fund, "Radio Propagation Modeling based on Database of Measurement Data"

Takeo Fujii

2. Fujitsu, Joint Research Fund, “Prediction of Mobile Terminal”
   Takeo Fujii, Koichi Adachi
3. KDDI Research, Joint Research Fund, “Interference Prediction and Resource Management based on Database of Measurement Data”
   Koichi Adachi
4. 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 2018

[Development of RF Energy Harvesting System] (Prof. Koichiro Ishibashi)

RF energy harvesting technology which can be inevitable for future Trillion Sensor Universe has been investigated in the Low Power Wireless division. In this year we try to harvest the energy from 950MHz 3G and 4G cell phone base station by the circuit of cross couple rectifier circuit on 65nm SOTB technology (Fig. 2.4-1). With the system shown in Fig. 2.4-2, average power of 500nW and average voltage of 700mV has been obtained (Fig. 2.4-3).

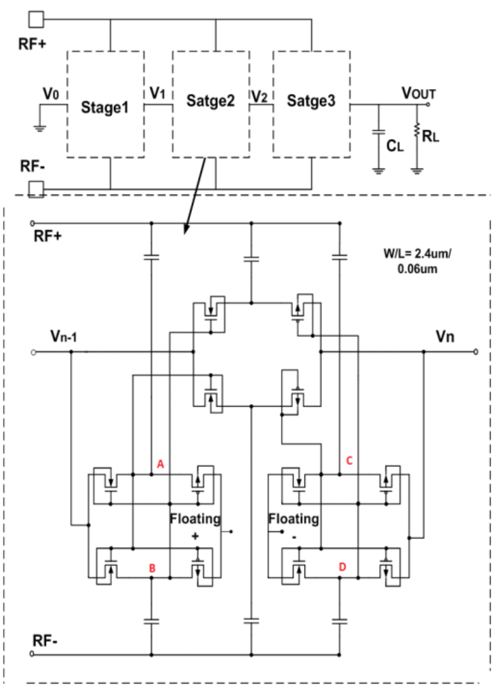


Fig. 2.4-1 Circuit of cross couple rectifier with DTMOS on 65nm SOTB technology.

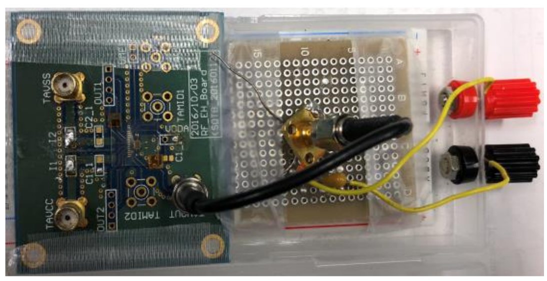


Figure 2.4-2 RF Energy harvesting System.

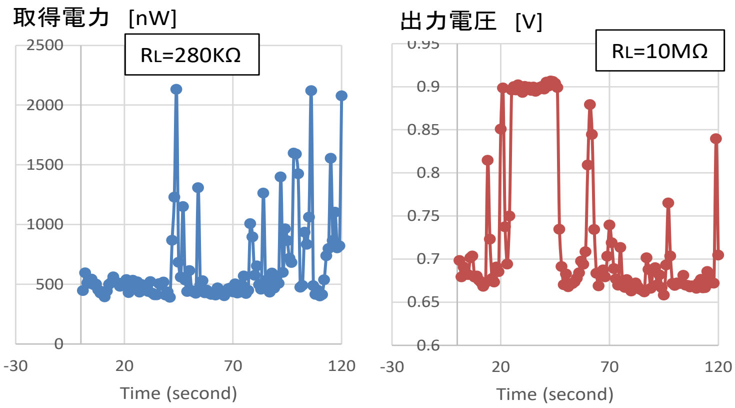


Figure 2.4-3 Output power and voltage from environmental RF energy of 950MHz for cell phones.

Design of Protocol for Wireless-Powered Communication System]（Prof. Koji Ishibashi）

Due to recent advances in Internet-of-Things (IoT), wireless devices operating with extremely low-power supply are highly desired. To this end, wireless-powered communication system (WPCS) harvesting energy from RF signals can be considered as the best candidate enabling the system with extremely-low power consumption. When radio frequency (RF)-chain is used in WPCS, devices can achieve higher bandwidth efficiency while suffering from higher power consumption. On the other hand, unless RF-chain is used, the energy consumption significantly drops while the resulting bandwidth efficiency is significantly limited since the system cannot use digital modulations such quadrature amplitude modulation (QAM).

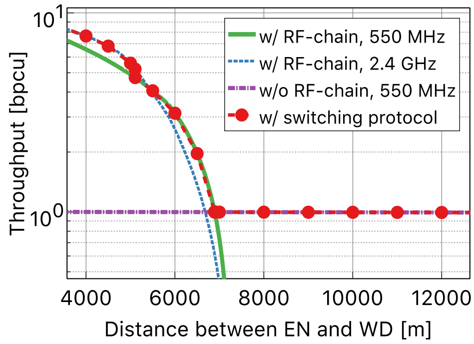


Figure 2.4-4: Throughputs of different communication schemes with and without RF-chain.

To leverage this trade-off, we proposed the simple switching protocol which enables each device to independently select appropriate communication scheme and frequency band. Figure 2.4-4 shows throughput performances of the device without switching and switching where two frequency bands, namely 550MHz and 2.4GHz, are available. From the figure, our protocol achieved the highest throughput over the almost whole distance.

[MHz-Band Multi-Harmonic Active Source-Pull for RF Rectifier Design]（Ishikawa Lab.）

A MHz-band multi-harmonic active source-pull technique has been developed for a GHz-band high-efficiency rectifier design. An active load-pull technique is usually used for a high-efficiency amplifier design. This method has been successfully diverted to the rectifier design by carefully considering an optimum-source-impedance estimation at the fundamental frequency existing an input source signal. In addition, an intrinsic nonlinear resistance as a rectifying element with an operation frequency of a GHz band can be directly extracted by the MHz-band measurement, due to negligible parasitic reactance elements. The MHz-band measurement system can be constructed with low cost (Fig. 2.4-5), in comparison with apparatuses for GHz-band measurements. An example of the active source-pull for a GaAs HEMT at 10 MHz is shown in Fig. 2.4-6. In the measurement, harmonics up to the fifth-order were adjusted to estimate a high-efficiency operation.

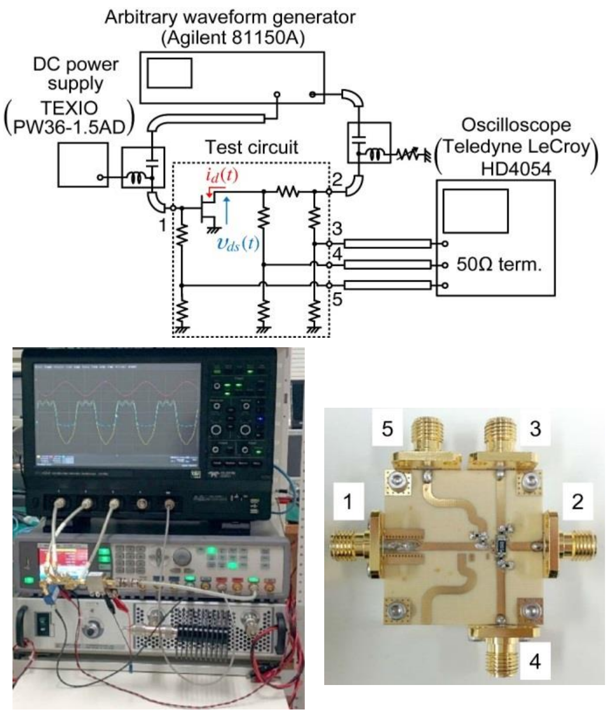


Fig. 2.4-5 MHz-band multi-harmonic active source-pull measurement system for estimating an intrinsic nonlinear resistance in a rectifying element

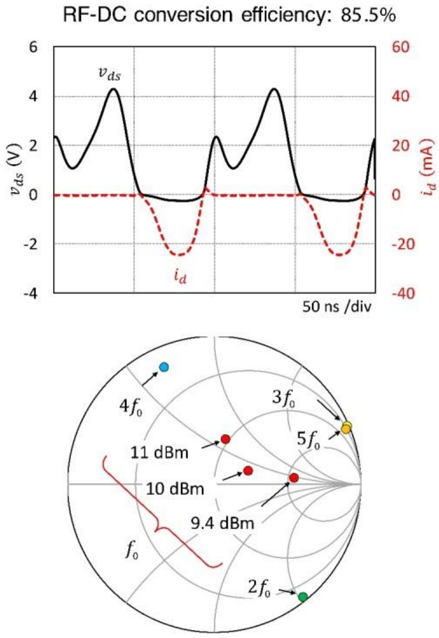


Fig 2.4-6 Example of the active source-pull for a GaAs HEMT at 10 MHz. Upper Fig.: votage and current waveforms, and lower Fig.: estimated source impedances

[Optically Powered RoF Systems for Future Optical Access Networks] (Prof. Motoharu Matsuura)

Power-over-fiber (PWoF) is an attractive technique to deliver the electric power required for any remote units using optical fibers. In radio-over-fiber (RoF) networks, it is useful for transmitting the electric power generated at a central office (CU) to remote antenna units (RAUs) using RoF links and centralizing the power supply system at the CU. Then, since each RAU does not require public power supply systems, it is much easier to install and manage many RAUs. For these applications, we have reported several PWoF technique using multimode fibers (MMFs) and double-clad fibers (DCFs).

In current situations, the electric power for RAUs is always fully supplied regardless of the actual mobile data traffic. In terms of power saving for RAUs, it is important to effectively use the electric power by controlling the supply power, corresponding to the mobile traffic. Indeed, a few research groups have reported the importance of sleep mode for RAUs and shown that the 60% power saving of RAUs could be achieved.

In this year, to show the availability of the dynamic power control of RAUs for PWoF systems, we evaluate the frequency response of a photovoltaic power converter (PPC). The result shows the frequency characteristics of the PPC we used. The cut-off frequency, which is defined as the frequency at which the PPC output decreases by 3 dB from the output at the flat level, was approximately 2.7 MHz.

The rise time calculated from the cut-off frequency was 0.13 μs. In our assumed application, the power control time is based on the traffic change caused by the variation of the number of mobile users in the cell area of each RAU. Therefore, the obtained rise time is enough to apply to the dynamic power control of RAUs for PWoF systems.

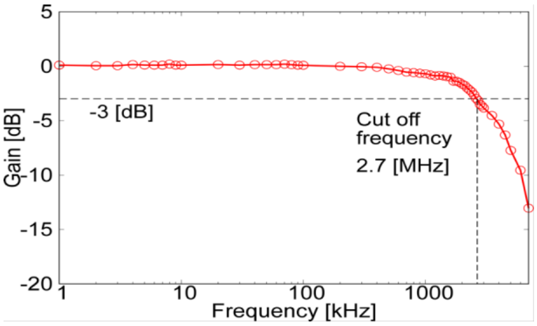


Fig. 2.4-7 : Frequency characteristics of PPC.

[Spectrum Sharing exploiting Spectrum Database for LPWA] (Prof. Takeo Fujii)

In order to utilize low-power devices distributed over very large areas, LPWA(Low Power, Wide Area) has attracted attention. LPWA technologies can realize low-power and low-cost because their simple network topology and protocol. Moreover, they enable long-distance communication using spread spectrum, ultra-narrow band modulation and other technologies. However, in many LPWA systems (e.g., LoRaWAN and Sig-Fox), communication with large number of nodes becomes collision because large number packets is transmitted with a certain fixed duty cycle. In this research, to reduce interference between other systems and to avoid transmission collision in LoRaWAN, we propose an adaptive algorithm for setting duty cycle of LoRaWAN. The system model is shown in Fig.2.4-8. Our method checks the surrounding nodes at gateway and adaptive duty cycle is informed to the nudes using ACK. The proposed system uses Spectrum Database for recognizing the surrounding spectrum environment to decide duty cycle. The final duty cycle of each node is updated to reduce the collision among the same LoRaWAN system. We evaluate the proposed method through numerical simulation to show the interference time ratio toward other systems and the packet loss rate in LoRaWAN. Figure 2.4-9 shows the average interference time ratio. Figure 2.4-10 shows the average packet loss rate. From these figures, we can confirm that the proposed method guarantees an acceptable interference time ratio and the packet loss rate.

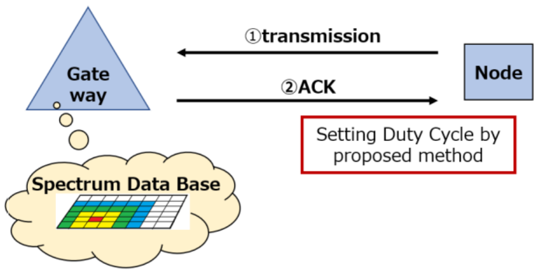


Fig. 2.4-8 System model.

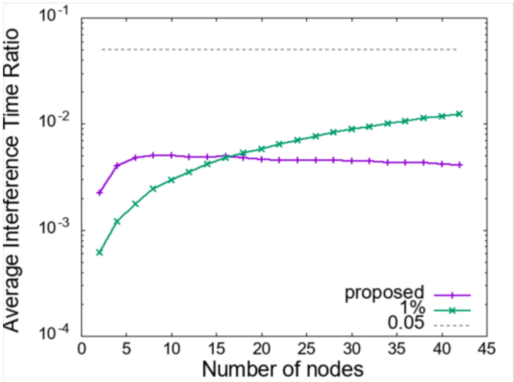


Fig. 2.4-9 Average interference time ratio.

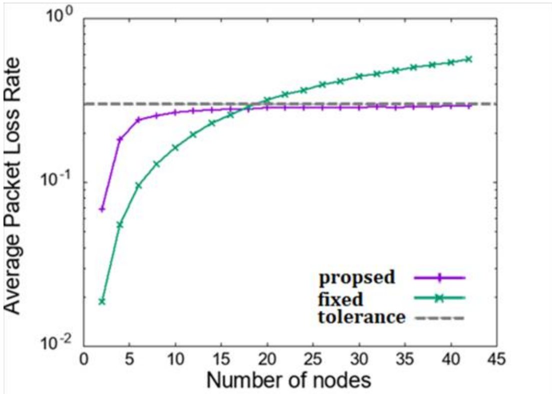


Fig. 2.4-10 Average packet loss rate.

2.4.4 Funds

【Commissioned Research】

1. JST/CREST Scientific Innovation for Energy Harvesting Technology
"Scavenging nW RF energy using Super Steep Transistor and Meta-Material Antenna,"
Koichiro Ishibashi, Ryo Ishikawa, and Koji Ishibashi, (J. Ida, S. Makino, and K. Itoh (Kanazawa Institute of Technology)).
2. Grant-in-Aid for Challenging Exploratory Research," Ultra-fast photonic A/D conversion using quantum-dot semiconductor optical amplifiers,"
M. Matsuura

【Cooperative Research】

1. "Optimization of Smart-Meter Networks"
Koji Ishibashi and Takeo Fujii

３． List of Publication in F.Y.2018

Journal Papers with Referees

【1】 D. Kamiyama, A. Yoneyama, and M. Matsuura, “Multichannel data signals and power transmission by power-over-fiber using a double-clad fiber,” IEEE Photon. Technol. Lett., vol. 30, no. 7, pp. 646-649, Apr. 2018.

【2】 T. Mori, J. Ida, S. Momose, K. Itoh, K. Ishibashi and Y. Arai, “Diode characteristics of a super-steep subthreshold slope PN-Body tied SOI-FET for energy harvesting applications,” IEEE J. Electron. Devices Soc., vol. 6, pp. 565-570, Apr. 2018.

【3】 K. Katagiri, K. Sato, T. Fujii, “Crowdsourcing-assisted radio environment database for V2V communication,” Sensors, vol. 18, no. 4, p. 1183, Apr. 2018.

【4】 R. Yazawa and M. Matsuura, “Optically powered drone small cells using optical fibers,” IEICE Electron. Express, vol. 15, no. 10, 20180371, May 2018.

【5】 H. Hoshino, T. Okada, and M. Matsuura, “Photonic analog-to-digital conversion using red frequency chirp in a semiconductor optical amplifier,” OSA Opt. Lett., vol. 43, no. 10, pp. 2272-2275, May 2018.

【6】 H. Soya, O. Takyu, K. Shirai, M. Ohta, T. Fujii, F. Sasamori, S. Handa, “Fast rendezvous scheme with a few control signals for Multi-Channel Cognitive Radio,” IEICE Trans. Commun., vol. E101-B, no. 8, pp. 1589-1601, Jul. 2018.

【7】 V. Nguyen, R. Ishikawa, and K. Ishibashi, “83nJ/bit Transmitter Using Code-Modulated Synchronized-OOK on 65nm SOTB for Normally-Off Wireless Sensor Networks,” IEICE Trans. Electron., vol. E101-C, no. 7, pp. 472-479, Jul. 2018.

【8】 L. T. Trien and Y. Yamao, “Information Delivery Delay Reduction by Relay-Assisted Broadcast Transmission for ITS V2V communications,” IEICE Trans. Fundamentals, vol. E101-A, no. 9, pp. 1290-1297, Sep. 2018.

【9】 小菅義夫, 古賀禎, 宮崎裕己, 呂暁東, 秋田学, 稲葉敬之, “ドップラー観測値を併用するTDOAにおける速度推定精度の改善,” 信学論(B), vol. J101-B, no. 10, pp. 857-866, Oct. 2018.

【10】 R. Hasegawa, K. Katagiri, K. Sato, and T. Fujii, “Low storage, but highly accurate measurement-based spectrum database via mesh clustering,” IEICE Trans. Commun., vol. E101-B, no. 10, pp. 2152-2161, Oct. 2018.

【11】 K. Mashimo, R. Ishikawa, and K. Honjo, “4.5-/4.9-GHz-band selective high-efficiency GaN HEMT power amplifier by characteristic impedance switching,” IEICE Trans. Electron., vol. E101-C, no. 10, pp. 751-758, Oct. 2018.

【12】 Y. Kada and Y. Yamao, “Design of Dual-Band SHF BPF with Lower Band Reconfigurability and Direct Parallel-Connected Configuration,” IEICE Trans. Electron., vol. E101-C, no. 10, pp. 775-783, Oct. 2018.

【13】 F. Sakai, M. Makimoto, and K. Wada, “Near-field chipless RFID tag system using inductive coupling between a multimode resonator and detection probes,” IEICE Trans. Online, [Advance Publication] Released: Oct. 15, 2018.

【14】 S. Ogata, K. Ishibashi, and G. T. F. de Abreu, “Optimized Frameless ALOHA for Cooperative Base Stations with Overlapped Coverage Areas,” IEEE Wireless Commun., vol. 17, no. 11, pp. 7486-7499, Nov. 2018.

【15】 H. Liu, X. Zhu, T. Fujii, “A new classification-like scheme for spectrum sensing using spectral correlation and stacked denoising autoencoders,” IEICE Trans. Commun., vol. E101-B, no. 11, Nov. 2018.

【16】 松浦基晴, “【招待論文】無線基地局のための光ファイバ給電技術,” レーザー研究, vol. 46, no. 12, pp. 688-692, Dec. 2018.

【17】 小野哲, 和田光司, “チップキャパシタ結合型共有共振器を用いた小型ダイプレクサの設計と試作,” 信学論(C), vol. J101-C, no. 12, pp. 479-488, Dec. 2018.

【18】 S. Oshima, T. Oshima, T. Numao, and K. Wada, “A Design Method of Compact Lumped-Element Matching Circuits for Diplexers using SAW filters,” Trans. Japan Inst. of Electron. Packaging, vol. 11, E17-015-1, Dec. 2018.

【19】 F. Sakai, M. Makimoto, and K. Wada, “Design and Detection of Chipless RFID Tags Using Stepped Impedance Resonators with Short-circuited, Ends,” Trans. Japan Inst. of Electron. Packaging, vol. 11, E18-001-1, Dec. 2018.

【20】 S. Ono and K. Wada, “Unloaded quality factor for hairpin resonator affected by conduction and radiation losses on K-band,” Trans. Japan Inst. of Electron. Packaging, vol. 11, E18-002-1, Dec. 2018.

【21】 渡辺一宏, 秋田学, 稲葉敬之, “ELD-STAP と多周波ステップ CPC 方式による車載前方監視レーダにおけるクラッタ抑圧,” 信学論(B), vol. J101-B, No.12, pp. 1093-1106, Dec. 2018.

【22】 小菅義夫, 古賀禎, 宮崎裕己, 呂暁東, 稲葉敬之, “レーダと受信時刻を観測値とする複数パッシブレーダのデータ融合,” 信学論(B), vol. J102-B, No.1, pp. 23-31, Jan. 2019.

【23】 O. Takyu, K. Shirai, M. Ohta, T. Fujii, “Insertion and data tracking with frequency offset for physical wireless parameter conversion sensor networks,” Sensors, Feb. 2019.

【24】 M. Matsuura and G. Ito, “Selective amplitude-level regeneration based on blue-chirp spectral slicing using QD-SOAs,” OSA Opt. Express, vol. 27, no. 3, pp. 3030-3038, Feb. 2019.

【25】 K. Kimura and Y. Yamao, “Bandwidth-Efficient Blind Nonlinear Compensation of RF Receiver Employing Folded-Spectrum Sub-Nyquist Sampling Technique,” IEICE Trans. Commun., vol. E102-B, no. 3, pp. 632-640, Mar. 2019.

【26】 S. Ogata and K. Ishibashi, “Application of ZigZag Decoding in Frameless ALOHA,” IEEE Access, vol. 7, no. 1, pp. 39528-39538, Mar. 2019.

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【28】 M. Takai and K. Ishibashi, “Repeat-Accumulate Signal Codes,” IEEE Trans. Commun. Early Access, 2019

【29】 O. Takyu, K. Shirai, M. Ohta, T. Fujii, “Adaptive channel assignment with predictions of sensor results and channel occupancy ratio in PhyC-SN,” IEEE Access., Early Access, 2019

【30】 K. Sato, K. Inage, T. Fujii, “Modeling the Kriging-aided spatial spectrum sharing over log-normal channels,” IEEE Wireless Commun. Lett., Early Access 2019.

International Proceedings with Referees

【1】 O. Takyu, S. Fujii, M. Ohta, T. Fujii, S. Handa, F. Sasamori, “Channel assignment based on predictions of sensing result and channel occupancy rate in PhyC-SN,” in Proc. IEEE WCNC Workshop Smart Spectrum 2018, Barcelona, Spain, Apr. 2018.

【2】 M. Akita, T. Inaba, “Angle Estimation using Super Resolution and Blocking Matrix in Stepped Multiple Frequency Complementary Phase Code Radar,” in Proc. RadarConf’18, Apr. 2018.

【3】 M. Machida, R. Ishikawa, Y. Takayama, and K. Honjo, “GHz-band high-efficiency rectifier design based on MHz-band multi-harmonic active source-pull technique,” in Proc. IEEE MTT-S Int. Microw. Symp. Digest, Philadelphia, USA, pp. 1134-1137, Jun. 2018.

【4】 R. Yazawa and M. Matsuura, “Flight demonstration of power-over-fiber drone for airborne base stations,” in Proc. OECC 2018, 4A1-4, Jeju, Korea, Jul. 2018.

【5】 N. Tajima, A. Yoneyama, D. Kamiyama, and M. Matsuura, “Over 1-km power-over-fiber using a double-clad fiber for bidirectional RoF systems,” in Proc. OECC 2018, 4A4-2, Jeju, Korea, Jul. 2018.

【6】 T. Okada, H. Hoshino, and M. Matsuura, “10-GSample/s, 15-level optical quantization using frequency chirp in a quantum-dot SOA,” in Proc. OECC 2018, P1-26, Jeju, Korea, Jul. 2018.

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【8】 T. Ohata, K. Ishibashi and G. Sun, “Continuous Cuffless Systolic Blood Pressure Monitoring Scheme Using PPG Sensor and Doppler Radar,” in Proc. EMBC’2018, Hawaii, USA, Jul. 2018.

【9】 X. Yang, K. Ishibashi and G. Sun, “Dengue Fever Detecting System Using Peak-Detection of Data from Contactless Doppler Radar,” in Proc. EMBC’2018, Hawaii, USA, Jul. 2018.

【10】 D. Manyvone, R. Takitoge, and K. Ishibashi “Wireless and Low-Power Water Quality Monitoring Beat Sensors For Agri and Acqua-Culture IoT Applications,” in Proc. ECTI-COM2018, Chang Rai, Thailand, Jul. 2018.

【11】 K. Ishibashi and S. Takahashi, “A 375 nA Input Off Current Schmitt Triger LDO for Energy Harvesting IoT Sensors,” in Proc. ISVLSI 2018, Hong Kong, pp. 187-190, Jul. 2018.

【12】 H. Sanada, T. Kawata, R. Aizawa, T. Fujii, “Routing redundancy reducing method for U-Bus Air using cloud cooperation,” in Proc. ICUFN 2018, Prague, Czech Republic, Jul. 2018.

【13】 M. Ohta, K. Adachi, N. Aihara, O. Takyu, T. Fujii, “Measurement experiments on 920 MHz band for spectrum sharing with LoRaWAN,” in Proc. IEEE VTC2018-Fall, Chicago, USA, Aug. 2018.

【14】 Y. Aoki, T. Fujii, T. Ide, “Time series analysis of multiple primary user environment using HMM-based spectrum sensing,” in Proc. IEEE VTC2018-Fall, Chicago, USA, Aug. 2018.

【15】 M. Ohta, K. Adachi, N. Aihara, O. Takyu, and T. Fujii, “Measurement experiments on

920 MHz Band for Spectrum Sharing with LoRaWAN," in Proc. VTC2018-fall, Aug. 2018.
【16】 Y. Kikuchi and Y. Yamao, "Propagation Loss Characteristic of V2V Communication for Right-Turn Accident Prevention Scenario," in Proc. PIERS2018, Toyama, Aug. 2018.
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【2】 M. Matsuura, “Power-over-fiber for radio-over-fiber-based distributed remote antenna systems,” in Proc. CLEO-PR 2018, Th4F.2, Hong Kong, Aug. 2018.

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【4】 K. Ishibashi, R. Takitoge, and D. Manyvone, “Beat Sensors for Long Life IoT Applications,” in Proc. EuroSciCon Conf. 3D Printing Wireless Technol. 2018, Lisbon, Sep. 2018.

【5】 T. Fujii, “Smart Spectrum Management for V2X,” in Proc. IEEE DySPAN 2018, Seoul, Korea, Oct. 2018.

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【4】 松浦基晴, “信号と電力の同時伝送を目的とした光ファイバ給電,” 2019 信学総大, CI-3-2, Mar. 2019.

Tutorials

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【2】 松浦基晴, “無線基地局のための大電力光ファイバ給電技術,” 日本工業出版光アライアンス, vol. 30, no. 2, pp. 15-18, Feb. 2019.

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【2】 レ・ティエン・チエン, 山尾泰, “市街地環境での中継アシスト車車間通信における情報配信遅延の低減効果,” 信学技報, RCS2018-17, Apr. 2018.
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Other Academic Activities

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Awards

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