AWCC
Advanced Wireless and Communication Research Center

Advanced Wireless & Communication Research Center

ACTIVITY REPORT 2017

The University of Electro-Communications

Message from the Director, Prof. Yasushi Yamao

Twelve 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.

Two 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 the new 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, higher accuracy and flexibility are required by for the innovated RF hardware. 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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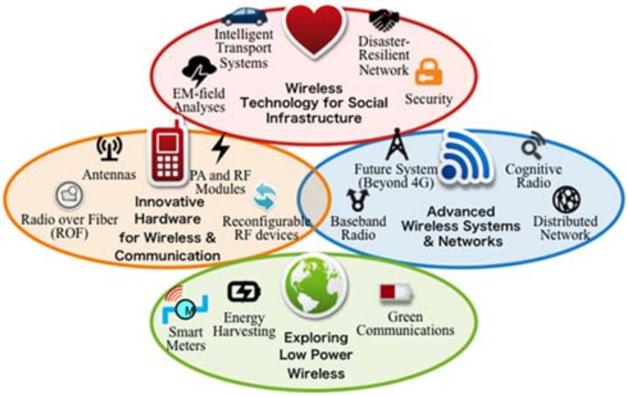
1. ABOUT AWCC

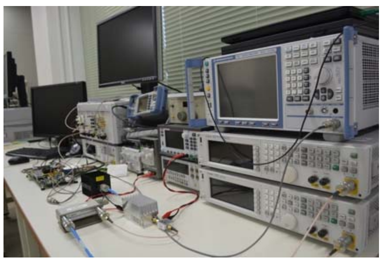
1.1. OVERVIEW



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, 16 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.

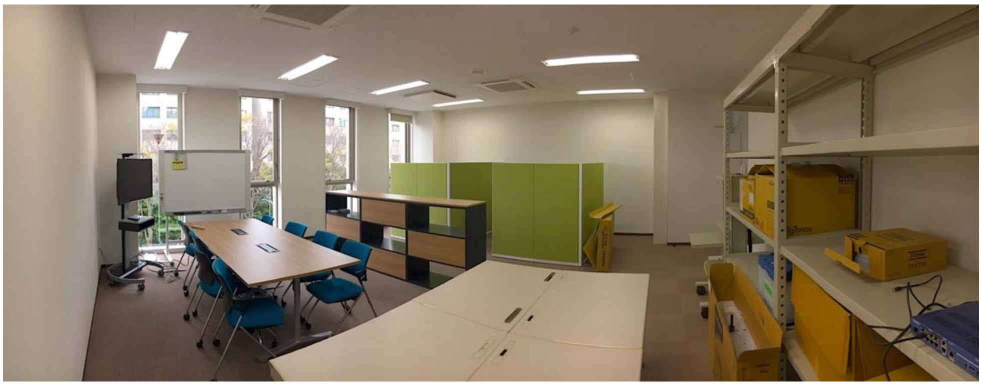
The AWCC organizes regular seminars and workshops with the highlight of 2014 being the "Tokyo Wireless Technology Summit" held in March 2014. The meeting focused on the next major phase of mobile telecommunications called 5th generation (5G) and attracted approximately 240 participants from all over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

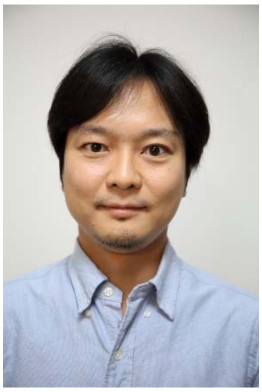
【Full time Prof. Takeo Fujii】

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 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. 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.

【Cooperative Professors from Industry】

Prof. Kunio Uchiyama (Hitachi Ltd.)

Prof. Yukihiko Okumura (NTT Docomo R&D)

Prof. Yoji Kishi (KDDI Research Inc.)

Prof. Isamu Chiba (Mitsubishi Research Institute Inc.)

Prof. Eisuke Fukuda (Fujitsu Laboratory Ltd.)

Prof. Hideki Hayashi (Softbank Corp.)

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, IoT)
Prof. Takeo Fujii (ITS, Radio Environment Analysis (REA), DPRN, Wireless security)
Prof. Takayuki Inaba (ITS, Rader)
Associate Prof. Koji Ishibashi (ITS)
Associate Prof. Koichi Adachi (IoT)

2.1.3. Major Research Outcomes in 2017

(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.)

Our laboratories have studied creating radio environment database for mobility environment of not only receivers but also transmitters. Figure 2.1-1 shows the system model. In order to construct and evaluate the proposed database, we had filed test in an actual V2V (Vehicle to Vehicle) environment during three days from Jan. 5th to 7th, 2017, by using three vehicles at the location of Chofu-shi and Mitaka-shi, Tokyo. Each vehicle had transceiver standardized as ARIB STD-T109 and the received power and location information were recorded. After the measurement campaign, we evaluated the accuracy of the proposed database by using Root Mean Squared Error (RMSE). First, the measurement data observed in the day 1 and day 2 are statistically averaged in each 2m, 5m, and 10m mesh on a SQL server and the averaged received power is obtained in each transmitter and receiver locations. The data observed in the day 3 are treated as the instantaneous received power, and we calculated RMSE from the difference between the averaged received power and the instantaneous received power. For the comparison, we evaluated the estimation accuracy by using fitted path loss model, ITU-R P.1411, Two-ray path loss, and Okumura-Hata model. Figure 2.1-2 shows the RMSE characteristics. The RMSE of the fitted path loss model, ITU-R P.1411, Two-ray path loss, Okumura-Hata model are 5.546 [dB], 5.670 [dB], 12.340 [dB] and 13.700 [dB], respectively. On the other hand, the RMSE of the proposed database are 4.241 [dB] at 2m mesh, 4.210 [dB] at 5m mesh and 4.489 [dB] at 10m mesh. From the above results, we can conclude that accurate received power can be predicted by using the measurement-based radio environment database in V2V communication systems. The proposed database will enable to improve the communication efficiency in future V2V communications.

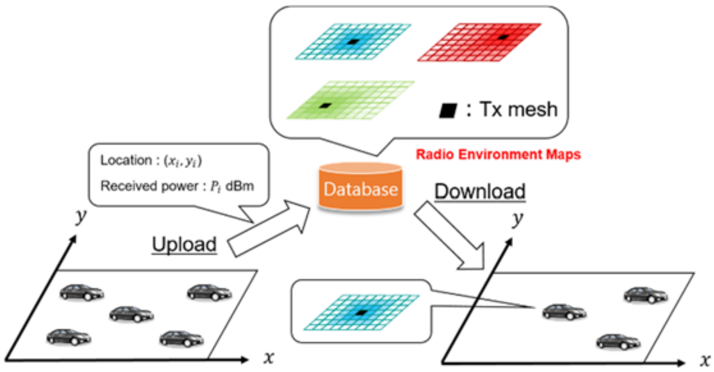


Figure 2.1-1 Radio environment database.

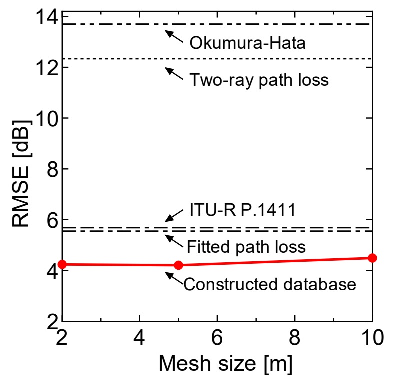


Figure 2.1-2 Mesh size versus RMSE.

[Multiple Antenna Successive Interference Cancellation for V2V Communication] (Fujii Lab.)

We have improved the reliability of V2V communications by using multiple antenna SIC (Successive Interference Cancellation). In V2V communications, broadcast CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) is adopted as an access control scheme to avoid collision. However, when communication traffic increases, multiple signals from multiple vehicles collide and thus communication reliability decreases. One of the solutions to this problem is simultaneous transmission and reception with SIC, which is widely studied as a technique to enable receivers to demodulate multiple signals from a mixed signal. However, SIC is not successful when the difference of the received power between signals in a mixed signal is small, e.g. when the hidden node problem occurs. In order to improve the SIC efficiency, we propose a SIC with multiple directional antennas that emphasizes the received power difference and thus improve the performance of SIC. We evaluate the proposed method through numerical simulation to show the improvement of reliability in V2V communication. Figure 2.1-3 shows a simulation scenario. Figu 2.1-4 shows t packet error ra From this figu we can confi that S efficiency multi-antenna systems improved 22%.

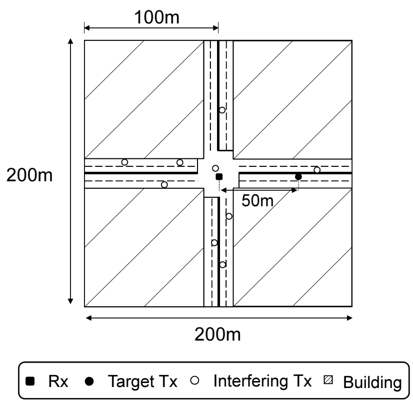


Fig. 2.1-3 Simulation model.

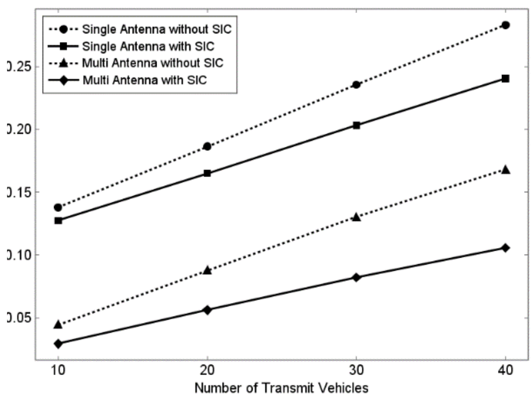
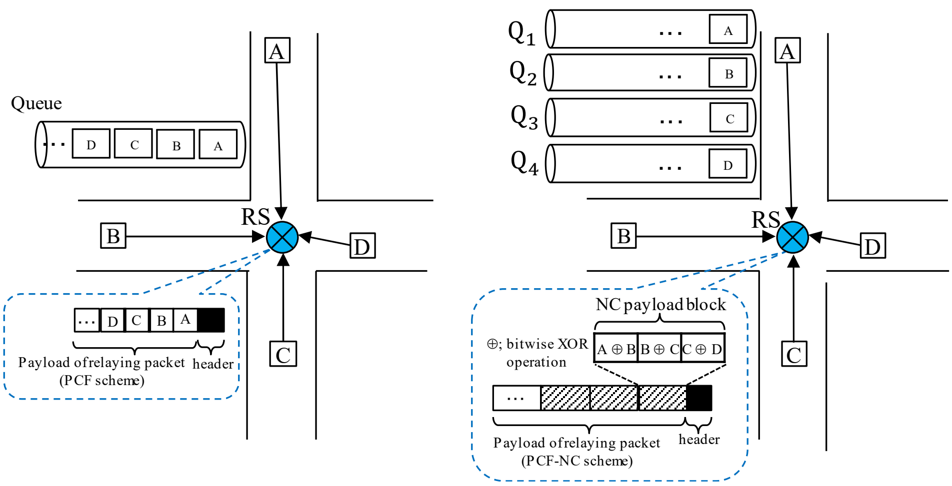


Fig. 2.1-4 Packet error rate performance.

[Network Coding Based Relay-Assisted V2V Communications] (Yamao Lab.)

A reliable vehicle-to-vehicle (V2V) communication is essential for safe and highly automated driving system. The use of roadside relay stations (RSs) has been studied to assist the V2V communication and improve its reliability. However, its improvement is limited by possible packet congestion at RSs. In order to mitigate the packet congestion at RSs, we proposed a network coding based payload concatenation forwarding with a payload sorting and selection algorithm (SR-V2VC/PCF-NC) shown in Fig. 2.1-5 (b). In the normal PCF scheme (a), RS stores the received V2V payloads in a single queue and concatenates payloads to generate a relaying packet. In the proposed PCF-NC scheme (b), all vehicle stations (VSs) are divided into G groups and payloads of VSs from each group are stored in the corresponding queue. For example, if a street-based grouping method is adopted, G can be set to the number of streets at the intersection. We consider an urban environment with multiple intersections as shown in Fig. 2.1-6. Fig. 2.1-7 shows the broadcast packet delivery rates (BPDRs) of the three V2V schemes. The former scheme, sectorized receiving V2V communication with payload combine forwarding (SR-V2VC/PCF) has improved BPDR up to 83% at the intermediate point by mitigating the effect of HT and compensating shadowing loss, compared with direct V2V communication (D-V2VC). However, the newly proposed SR-V2VC/PCF-NC scheme provides BPDR of higher than 90% for all locations of T-VS. This shows the effectiveness of the proposed scheme.



(a) PCF scheme (b) PCF-NC scheme

Fig. 2.1-5 Operations of normal PCF scheme and PCF-NC scheme using a street-based grouping method.

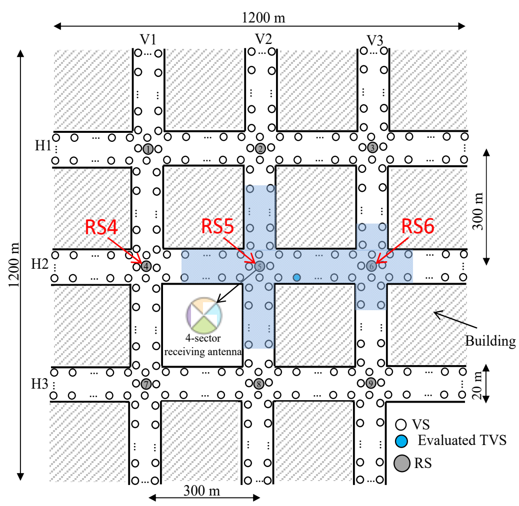


Fig. 2.1-6 Nodes layout of urban area for simulation.

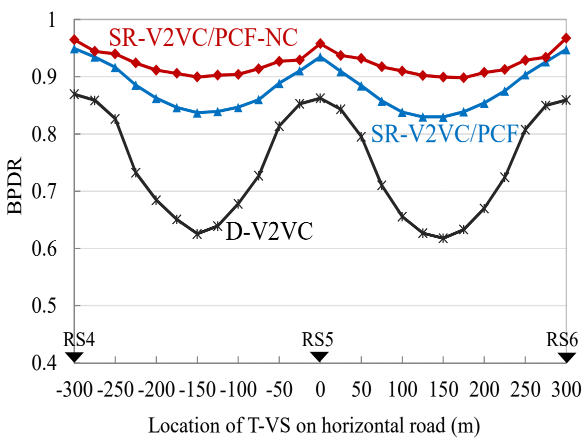


Fig. 2.1-7 Average packet delivery rate from VS

[Error Correcting Codes for Low-Latency Robust V2V Communications] (Koji Ishibashi Lab.)

We have investigated error correcting codes for *automated cooperative-driving systems*. In F.Y. 2015, we studied the decoding performance of various state-of-the-art error correcting codes, e.g., binary and non-binary *low density parity check* (LDPC) codes and signal codes. In F.Y. 2016, we proposed new LDPC-coded hierarchical modulation with backward compatibility to exchange additional safety information among vehicles. In F.Y. 2017, we proposed a practical information delivery protocol named asynchronous dissemination protocol based on distributed coding, in short ADDC. To further enhance the safety of automated driving systems, vehicles should know precise information around them such as road condition, lane information, and so on. Roadside units (RSUs) can be used to gather such information. However, it results in high cost to install a lot of RSUs to provide services everywhere. Wireless sensor networks (WSNs) is a judicious option to realize such services since sensors are much cheaper and much easier to be installed. Conventional studies have proposed transmission protocols which realize energy-efficient information distribution to moving vehicles by assuming that information packets to be transmitted are ideally shared among sensors, where the assumption is obviously impractical. As a practical protocol, we considered to utilize a beacon and short-period reception to form a partially-synchronized network to broadcast a new packet, so that new packets are efficiently shared among sensors with minimum overhead. Then, shared packets are broadcasted to vehicles using Luby-transform codes. Figure 2.1-6 depicts the packet loss rate (PLR) performance of ADDC and a conventional information delivery protocol named HEED, where the horizontal axis denotes the sleep probability of sensors. It is observed that ADDC achieves lower PLR than HEED when the sleep probability is small. The result confirms that roadside information can be delivered to automated driving vehicles, achieving high reliability.

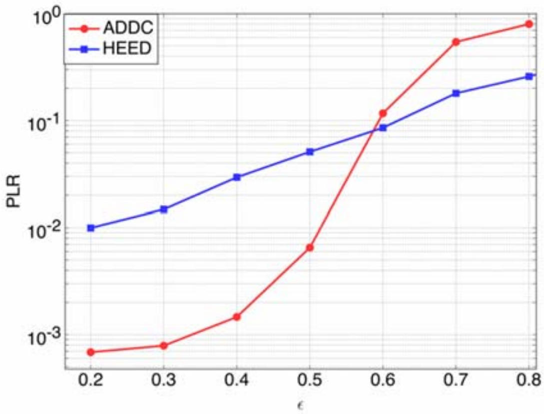


Fig. 2.1-6 Packet loss rate performance of ADDC and conventional HEED.

(B) Radar Signal Processing

[Vehicle Onboard Radar] (Inaba Lab.)

In the application of automotive radar, radar is expected to obtain the angle of the target. It is also hoped to be robust to mutual coupling between elements and to have a tolerance to the calibration errors that exists in the actual measurements. We proposed the angle estimation in the stepped multiple frequency CPC (SMFCPC) radar. The angle estimation method consists of the combination of 1-D Super Resolution (SR) and Blocking Matrix (BM) plus mono-pulse angle estimation. The method is expected to work in the situation where the targets have same velocity and are located on very close range which is comparable to the range resolution. Both random and bias errors of angle by proposed method are smaller than those of conventional method (2-D SR method) in the experiments. By proposed method, two targets could be identified in the cases where we could not separate the two targets by 2-D SR (Fig.2.1-7). The results also indicated that proposed method has a tolerance to the calibration errors that exists especially in antenna elements in the actual measurements.

We have been developing a method to improve the range resolution by expanding the transmission bandwidth by coherent signal processing using measured data of SMFCPC radar operated in separated bands (Fig.2.1-8). It is expected that this technique avoids the increase of a hardware load and the degradation of the detectable range, which generally become a problem by the expansion of the transmission bandwidth. We proposed the iterative range estimation method, which is Coherently Combining Sparse-Multiband processing (CCSM). We also show the simulation results using 8 separated frequency bands data where the two targets are separated with 0.042m that is equivalent to the range resolution of transmission bandwidth. Signal to Noise (S/N) ratio of observation data is set to be 30dB. The standard deviation of range estimations are also obtained as 0.003 for two targets (Fig.2.1-9).

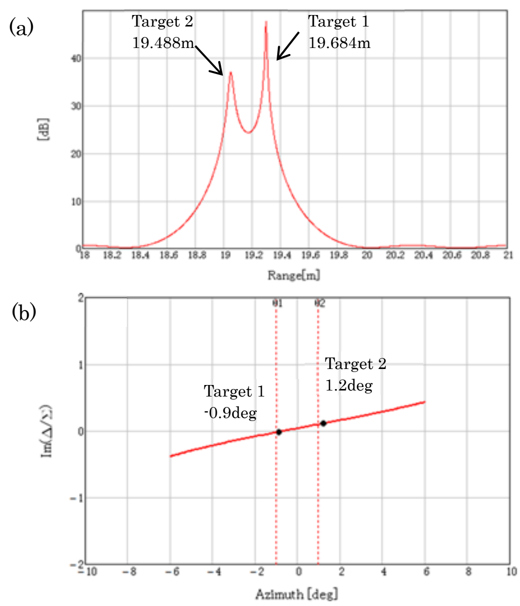


Fig.2.1-7 Range and angle estimation result ((a) Range estimation by 1-D SR, (b) Angle estimation by mono-pulse angle estimation).

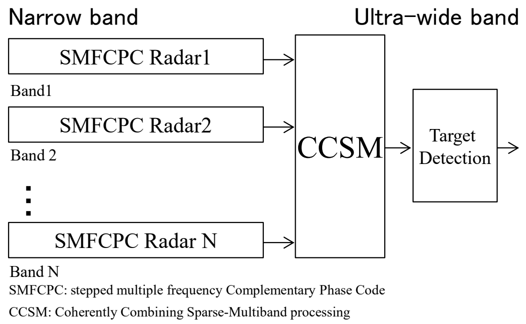


Fig.2.1-8 Concept of Coherently Combining Sparse-Multiband processing (CCSM) for a high resolution.

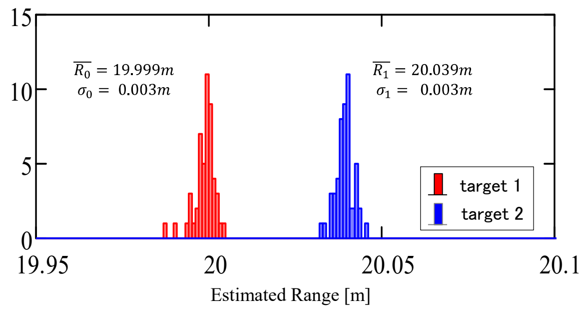


Fig.2.1-9 Concept of Coherently Combining Sparse-Multiband processing (CCSM) for a high resolution.

2.1.4. Funds

【Grants-in-Aid for Scientific Research】

1. Scientific Research A "Research on New Transmission Technologies based on Lattice Structures for Next-Generation Ultra-High Data-Rate Communications"
2. Y. Yamao, T. Fujii, T. Inaba, S. Obana, T. Ogitsu (Gunma Univ.)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

【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. "Development and monitor run test of the train speed meter of middle range radar"
   T. Inaba and M. Akita
2. "Research on Marine Radar signal processing"
   Y. Yamao
3. "Improvement in recognition rate of RF IDs"
   Y. Yamao
4. "Research on Communications Technology for Machine Tools"
   K. Adachi and Y. Yamao

【Other Funds】

1. Toyota Info-Technology Center USA Unrestricted Research Fund, "Reliable Vehicular Communications using SIC"
   T. Fujii
2. DENSO Corporation, "Comparative investigation of millimeter wave radar modulation for automotive", Academic consulting
   T. Inaba
3. Kyosan Electric Mfg. Co., Ltd., "Improvement of radar target detection performance", Academic consulting
   T. Inaba
4. DENSO Corporation, "Program of evaluation of automotive radar modulation", Patent Number 5704552), License agreement
   T. Inaba
5. DENSO Corporation, "Program of generation of interference data", Patent Number 5704552, License agreement
   T. Inaba
6. Kyosan Electric Mfg. Co., Ltd., "Program of target tracking", License agreement
   T. Inaba

2.2 Division of Advanced Hardware Research

2.2.1 Purpose of Research

Research and development of wireless information/power transmission hardware for next generation mobile phone 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. K.Wada	(Microwave circuits)
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 2017

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

[Concurrent Multi-Band High-Efficiency Low-Distortion Amplifier] (Ishikawa Lab.)

We have proposed and realized a novel power amplifier system to achieve high-efficiency low-distortion concurrent dual-band amplification for low SHF (4.5 GHz band) and high SHF (8.5 GHz band), where two harmonic reactive termination GaN HEMT amplifiers and two diplexer circuits are systematically combined to suppress harmonic signals and inter-modulation and cross-modulation signals. For high SHF amplifiers, novel 2-Watt class GaN HEMT chip and low loss alumina substrates have been newly introduced to improve the power efficiency at 8.5 GHz. As a result, a power added efficiency of 63% was achieved at 8.48 GHz. For low SHF amplifiers, to obtain the required wide bandwidth from 4.5 GHz to 4.9 GHz, two methods such as a band switched circuit technique using PIN diode, and a novel broadband fundamental/harmonic frequency matching technique. For the former, a fabricated GaN HEMT amplifier (Fig. 2.2.1) has achieved a maximum power-added efficiency of 57% and 66%, and a maximum drain efficiency of 62% and 70% at 4.6 GHz and 5.0 GHz, respectively, with a saturated output power of 38 dBm, for each switched condition.

As the second trial version using low loss alumina substrates, a total power amplifier system consisting of a low SHF 4-watt class GaN HEMT amplifier, a high SHF 2-Watt class GaN HEMT amplifier, and two diplexers have been fabricated and tested (Fig.2.2.2). A measured power added efficiency of 63% was achieved at 4.7 GHz and a measured power added efficiency of 60% was obtained at 8.24 GHz. Excellent distortion characteristics concerning harmonic frequencies, inter-modulation frequencies, and cross-modulation frequencies have been realized. These results show the validity of the proposed concurrent power amplifier system for 5G system applications.

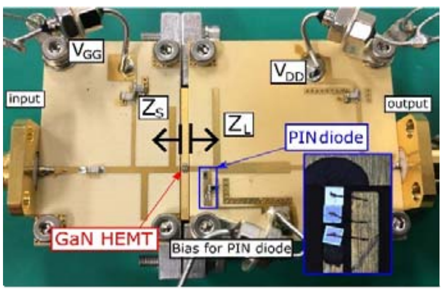


Fig. 2.2.1 A 4.5-/4.9-GHz band selective GaN HEMT HEMT high-efficiency power amplifier using PIN switches.

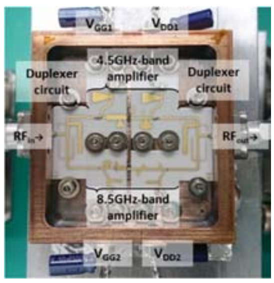


Fig. 2.2.2 Concurrent dual-band GaN HEMT power amplifier

[Dual-bad Reconfigurable Bandpass Filter]（Yamao Lab.）

For more flexible and efficient use of radio spectrum, reconfigurable RF devices will play an important role in the future wireless systems. In 5G, concurrent operation of multiple RF bands is considered including new SHF bands over wide frequency range. We developed an SHF concurrent dual-band bandpass filter (BPF) consisting of a low-SHF three-bit/eight frequencies (3.5–5GHz) reconfigurable BPF and a high-SHF (8.5GHz) BPF, shown in Fig. 2.2.3. It employs a direct parallel- connected configuration of the two BPFs without divider/combiner. Fig. 2.2.4 shows prototype BPF and measured S_{21}. The BPF can switch eight low-SHF passbands without affecting the high-SHF BPF performance. The low insertion losses below 2.0 dB are achieved for both low-SHF and high-SHF frequencies.

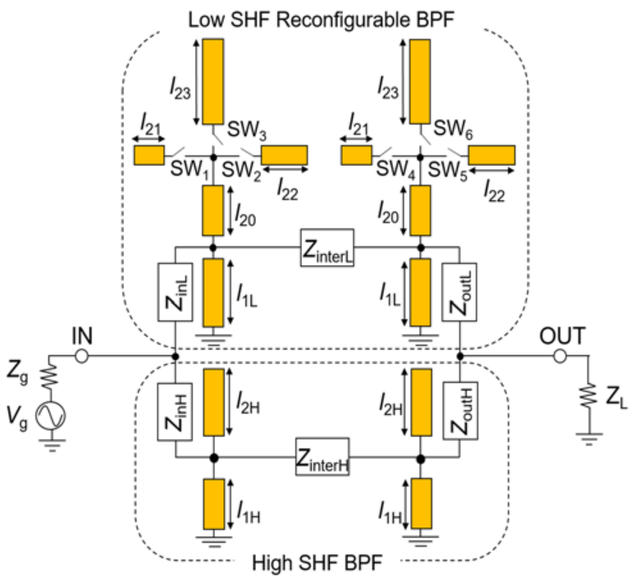
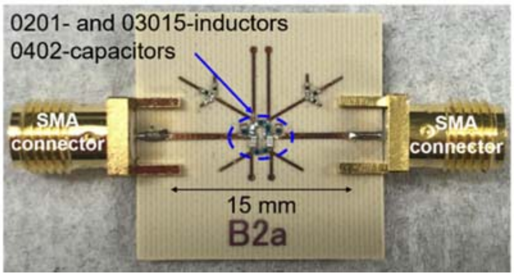


Fig. 2.2.3 Dual-band Reconfigurable BPF.



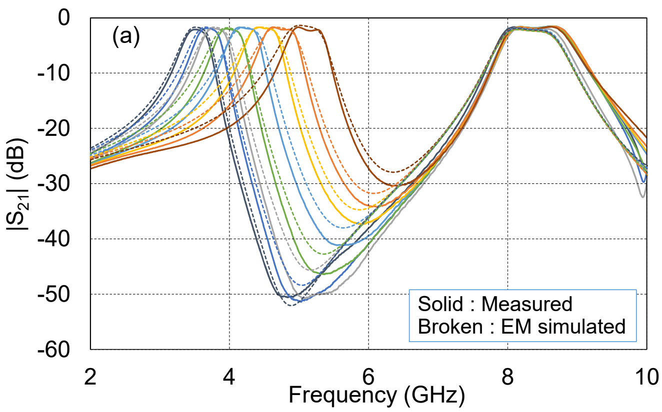


Fig. 2.2.4 Prototype Dual-band Reconfigurable BPF and measured S_{21}.

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

In the fifth-generation (5G) mobile communication systems, RF bandwidth becomes very wide to handle broadband signal transmission. A novel wideband digital predistortion (DPD) technique that enables a simpler feedback circuit is proposed. The proposed Spectrum-Folding Scalar Feedback (SF-SFB) method can reduce the number of analog to digital converter (ADC) to only one in baseband while keeping its compensation bandwidth same as the conventional method. DPD parameter determination algorithm has been modified to enable the scalar feedback. To compare the performance of the proposed and conventional techniques, computer simulations are conducted. The results show that they have the same performance in terms of adjacent channel leakage power ratio (ACLR) and error vector magnitude (EVM). Experiments using carrier-aggregated LTE signal with two component carriers are also conducted to validate the results. The proposed technique can provide high nonlinear compensation performance with lower circuit complexity.

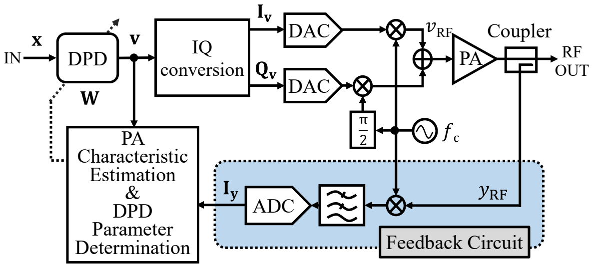


Fig.2.2.5 Proposed SF-SFB digital predistorter.

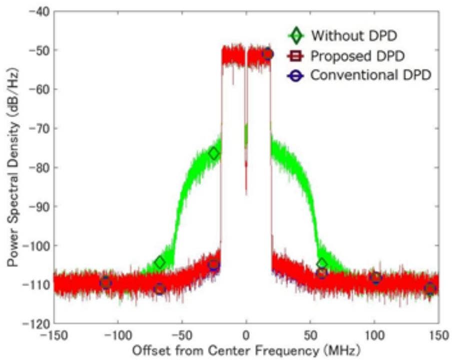


Fig. 2.2.6 Output Spectrum of two-carrier aggregated 20 MHz LTE

Table. 2.2.1 Required Number of ADC and Sampling rate.

	SF-SFB DPD	Conventional DPD	
		Quadrature detection	IF Conversion
ADC	1	2	1
Min. Sampling rate	BW	BW	> 2BW

(B) EVM evaluation on OAM Multiple Transmission System at 5.35 GHz (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. Using fabricated two coaxial loop antenna arrays with paraboloid reflectors, a four multiplex transmission experiment was carried out at a distance of 1.5 m and a frequency of 5.3 GHz. Moreover, by using the fabricated OAM antenna, an EVM evaluation was carried out for a 1-cm short-range OAM communication, as shown in Fig. 2.2.7. For the evaluation, a 64 quadrature amplitude modulation (QAM) signal with a symbol rate of 75 MSymbol/s was used

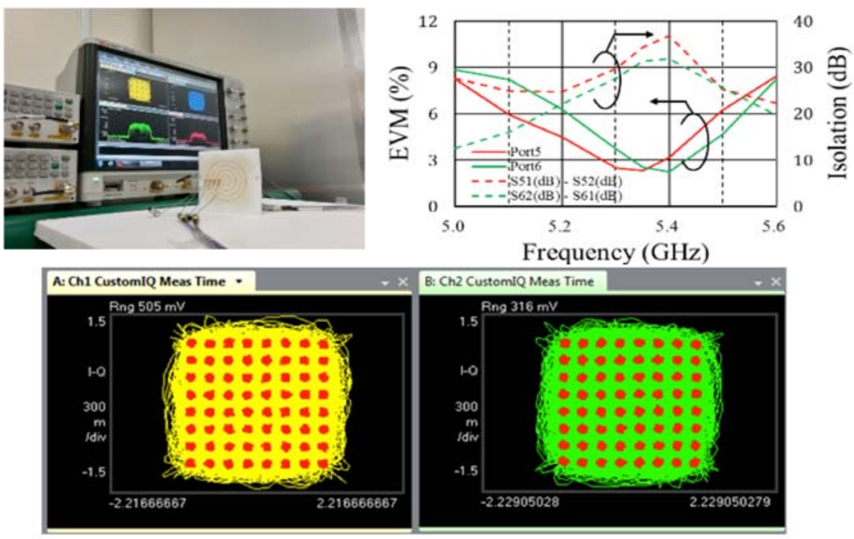


Fig. 2.2.7 EVM and constellation characteristics for a fabricated OAM antenna.

to estimate an error vector magnitude (EVM). Less than 3% EVM was achieved between 5.3 and 5.4 GHz where the transmission isolation was more than 30 dB. In addition, Good constellation characteristics were obtained, as shown in Fig. 2.2.7.

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

Analog-to-digital conversion (ADC) is an important function to convert an analog signal into a digital signal in any electronics and photonics systems. There are numerous applications, each with their corresponding resolution and sampling speed requirements. In particular, recent demand for ADCs includes ultrawide-bandwidth applications such as digital coherent communications. However, as ADCs in the electrical domain have significant bottlenecks such as sampling jitter, ADCs in the all-optical domain, so called photonic ADCs (PADCs), have attracted much attention as future ADCs with better quantization resolution and higher sampling speed performance.

Semiconductor optical amplifiers (SOAs), including quantum-dot SOAs (QD-SOAs) are attractive devices not only for optical amplification, but also for optical signal processing such as wavelength conversion and optical demultiplexing. As the gain change in these devices gives rise to refractive index changes, amplified signals experience temporal frequency chirp at the leading and trailing edges of the signal pulses. Until now, we have observed these unique frequency chirp properties induced by conventional SOAs and QD-SOAs, and shown that the peak value of the red frequency chirp, in that the frequency was temporally shifted to longer wavelength (red) side, had a strong dependence on the input signal pulse power. Moreover, it did not give rise to the pattern effect if the gain recovery time of the device was faster than the timeslot of data signals. Therefore, we concluded that the red frequency chirp property could facilitate intensity-to-frequency conversion and be applied to optical quantization for PADCs.

Until now, there have been many reports on optical quantization using nonlinear effects in optical fibers; such as soliton self-frequency shift, supercontinuum generation, self-phase modulation, and nonlinear fiber loop mirrors-based cross-phase modulation. Although the semiconductor-based, 4-level optical quantization has also been demonstrated using SOAs, the scheme consisted of cascaded optical logic gate circuits using SOAs. Since the speed is strictly limited by the accumulated gain recovery times of the cascaded SOAs, it will therefore be difficult to enhance the sampling speed. In addition, to increase the quantization level, a huge number of optical logic gates will be required.

In this year, we have proposed a novel PADC scheme using red frequency chirp in a SOA or QD-SOA. The actual scheme consists of a QD-SOA and multiple wave sharpers (WSs) located in parallel. We have investigated the quantization performance in detail. Moreover, we have successfully demonstrated 10-GSamples/s, 8-level optical quantization, for the first time.

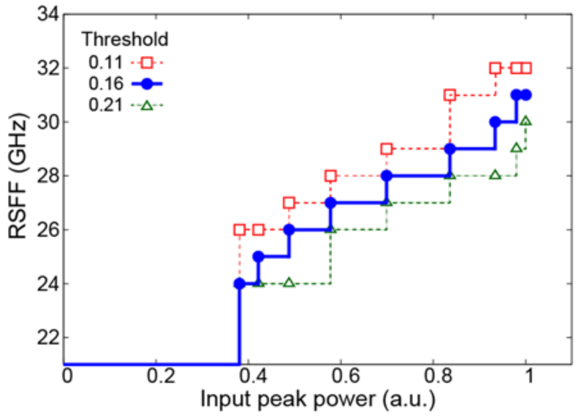


Fig. 2.2.8 8-level quantization performance

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 Post, Telecommunication and Internal Affairs, "Research and Development for 5G Mobile Phone System"
   Y. Yamao, K. Honjo, R. Ishikawa, A. Saitou, Y. Takayama
2. JST CREST, "Research on nW-Class Technology for Rectifier and Wireless Communication"
   Koichiro Ishibashi, R. Ishikawa, Koji Ishibashi"
3. MIC, SCOPE, "Research and Development for Super Multiplexing OAM Communication Using Loop Array Antennas"
   A. Saitou, K. Honjo, R. Ishikawa
4. 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

【Cooperative Research】

1. SoftBank Group Corp. "Low Power Consumption Amplifier"
   K. Honjo, R. Ishikawa
2. Sumitomo Electric Industries, Ltd. "MHz Harmonic Load-Pull Technique for GaN HEMT"
   K. Honjo, R. Ishikawa
3. MoDeCH Inc. "Millimeter wave circuit design"
   R. Ishikawa, K. Honjo
4. Cosel Co. Ltd. "EMI Technology for Switching Power Unit"
   K. Honjo, R. Ishikawa
5. "Research on Next generation Wireless Systems"
   Y. Yamao
6. YAZAKI Corporation, "Analog and Digital Signal Transmission Using Multi-Mode Fibers"
   M. Matsuura

【Other Funds】

1. SCAT Grant, "Optical Quantization Using Optical Frequency Shift in Quantum-Dot Semiconductor Devices"
   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（Division Leader, 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 2017

[Data Offset Calibration Method for Spectrum Database using Crowd Sensing] (Fujii Lab.)

In order to accurately estimate the radio environment for reliable communication, a measurement based spectrum database by using crowd sensing has been attracted attention. The measurement based spectrum database has to collect the huge amount of data from distributed wireless sensors. If the highly accurate measurement sensors like spectrum analyzer are used, the created database also has a good accuracy. However, the cost for setting measurement sensors is very expensive and it is difficult to realize in the realistic situation. Therefore, in this research, we focus on spectrum measurement by using communication terminals like smart phone wireless LAN terminal and on board unit of V2V (Vehicle to Vehicle) communications. However, the measurement data with these terminals contain individual measurement offset and errors. In order to compensate these offset and errors, we propose a measurement data offset calibration method using propagation parameter estimation and transmit power estimation using EM algorithm. The system model is shown in Fig.2.3-1. Here, the estimation is proceeded in the following steps; path loss factor is estimated by using least squares method, fading effect reduction by using averaging in a meshed area, transmission power estimation using EM algorithm, and offset component is estimated. Figure.2.3-2 shows the RMSE (Root Mean Square Error) performance comparison between the result before the calibration and that after the calibration.

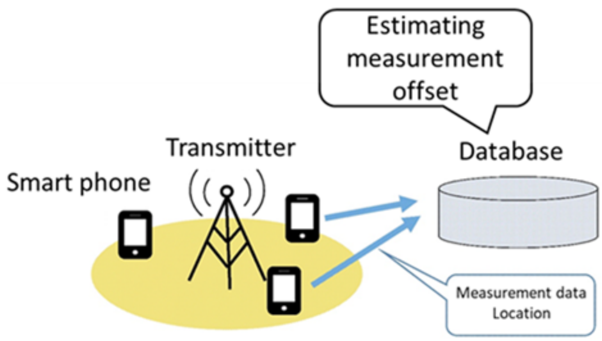


Figure 2.3-1 System model

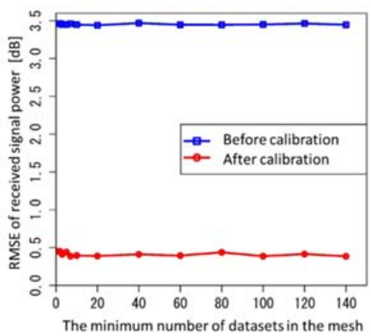


Figure 2.3-2 RMSE of received signal power.

[Mesh Clustering Method for Measurement based Spectrum Database] (Fujii Lab.)

In order to recognize the spectrum environment for spectrum sharing, measurement based spectrum database has attracted attention. The measurement based spectrum database collects the measurement received power data from communication terminals and statistical values like averaged received power are stored by spatial divided meshes. The small size of mesh can improve the accuracy because locality of the spectrum information can be stored. However, small mesh dramatically increases the total data size of storage. In this research, to decrease the consumed storage size of spectrum database, we propose a mesh clustering methods my using k-means algorithm and Gaussian mixture model (GMM) algorithm. Figure 2-3-3 shows a concept of a mesh clustering considered in this research. Multiple meshes are clustered and the stored datasets are stored in each cluster instead of each mesh. The total data size can be reduced because the number of clusters is less than the number of meshes for supporting the same size area. We derive the simulation results by using the measurement data transmitted from road side unit of a vehicle to infrastructure (V2I) communication system located at Odaiba, Tokyo. The parameters of communication method are OFDM with 10MHz bandwidth at 760MHz. Figure 2-3-4 shows the results of route mean square error (RMSE) of the measurement power compared with the conventional mesh data with different mesh size (10m and 1m) in the area of 100m square. The number of database data of 10m and 100m mesh are 100 and 10000, respectively. From this results, we can confirm that the performance of RMSE can be reduced by using proposed clustering methods with smaller number of data.

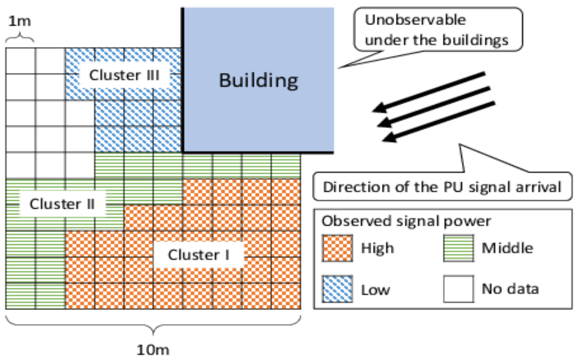


Fig. 2.3-3 Concept of a mesh clustering

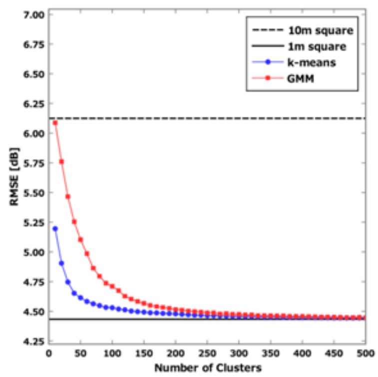


Fig. 2.3-4 RMSE of V2I system.

[Received Power Threshold and Reply Timing Controlled Reactive Routing Scheme] (Yamao Lab.)

Most of reactive ad hoc routing schemes establish a route by using route request (RREQ) and route reply (RREP) messages. In actual wireless environments, however, route construction with this method is not always successful, nor is the established route stable. This paper analyses two issues that prevent stable route establishment. They are the packet collision of RREQ/RREP and the decrease of channel correlation between RREQ/RREP. In order to overcome these problems, an improved reactive routing scheme is proposed that employs received threshold and reply timing control. The route construction performance for the proposed scheme is evaluated by network simulation. The simulated results show that the proposed scheme can improve route construction probability under fading environment with a small increase of route construction delay.

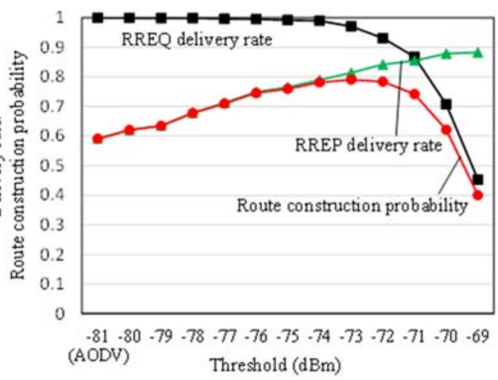


Fig. 2.3-5 RREQ/ RREP delivery rates and Rout Construction Probability.

[Machine Learning Based Resource Allocation Scheme] (Adachi Lab.)

The demand for larger capacity in wireless communications is fast growing due to the rapid spread of multimedia communications and social networking services. Furthermore, the emerge of M2M communications for IoT adds more demand for larger capacity. Many wireless nodes need to share the limited resources while achieving desired QoS. In order to achieve it, it is mandatory to handle the deterioration of signal due to the channel and the mutual interference between wireless nodes by means of advanced techniques such are resource scheduling and spatial beamforming. However, these techniques require the accurate channel state information (CSI), which needs to be fed back from wireless nodes to the network controller. In order to avoid the explicit CSI feedback, machine learning based resource allocation has been vigorously studied. In this project, we focus on CSMA/CA, which is one of the random access schemes that allow the wireless nodes access the channel while avoiding such mutual interferences. However, if carrier sense mechanism does not work, the packet collision may happen and this results in the degradation of the packet delivery rate (PDR). We have propose an orthogonal resource allocation scheme using machine learning. Whether the two wireless nodes are in the hidden terminal relationship is an unobservable information from the network controller. Thus, by using the machine learning approach, the wireless controller makes a guess of the unobservable information from the observable information such as wireless node locations. Based on the estimated unobservable information, the wireless controller assigns orthogonal resources to the wireless nodes that are in the relationship of hidden terminal. As shown in Fig. 2.3-6, numerical evaluation elucidates that the proposed scheme can improve the PDR performance by 15% compared to the system without resource allocation.

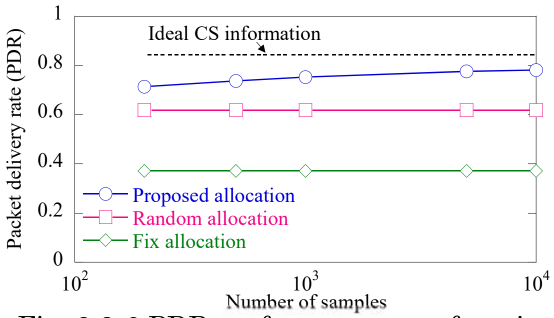


Fig. 2.3-6 PDR performance as a function of number of training samples.

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

Slotted ALOHA system employing successive interference cancellation, named coded ALOHA, has been studied as an efficient random access scheme which achieves remarkably high throughput performance. Frameless ALOHA is a recently-proposed coded ALOHA scheme, where users are given a transmission probability with which they transmit their packet. Frameless structure brought by probabilistic transmission enables automatic adaptation to the channel traffic. Most of conventional coded ALOHA schemes are designed only considering medium access control (MAC) layer, but not physical (PHY) layer. However, PHY layer should significantly affects the throughput performance; for instance, capture effect enhances throughput performance in practice. In 2017, we proposed a received-power-aware design of transmission probability for frameless ALOHA. In this scheme, users with low received-power are given higher transmission probability than users with high received-power. Specifically, users with low received-power

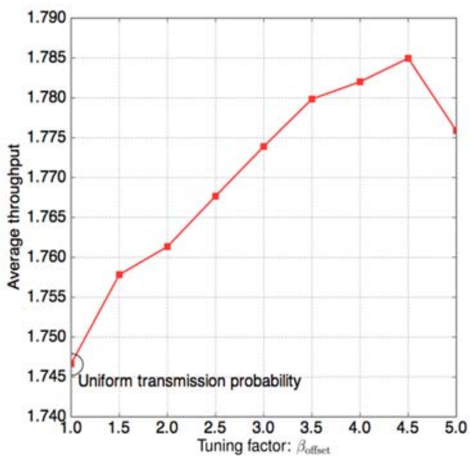


Fig. 2.3-7 Throughput of coded frameless ALOHA.

increases their transmission probability by a given offset. Figure 2.3-7 shows throughput performance of our proposed scheme. It is revealed that received-power-aware design can outperform the conventional frameless ALOHA which is designed by MAC-layer based analysis. Besides this new random access protocol, we proposed a general analysis of frameless ALOHA with base-station cooperation and Zig-Zag decodable contention resolution diversity slotted ALOHA (ZD-CRDSA) to further enhance the throughput performance. Those results have been already submitted to IEEE journals and IEEE conferences.

[Simple Message-Passing MIMO Detector based on QR-Decomposition] (Koji Ishibashi Lab.)

Multi-input multi-output (MIMO) technique is a undoubtedly key enabler to support massive wireless data traffic in next generation wireless systems such as 5G and beyond. The recent rise of massive MIMO gains more attention to effective detection of MIMO signals because of its inherent high complexity. Although belief propagation (BP) and Gaussian BP (GaBP) have been actively studied in the literature as efficient detection techniques. They suffer from inferior performances to maximum likelihood detector (MLD) because loopy structure of factor graphs. In 2016, we proposed QR-decomposed generalized belief propagation (QR-GBP) to improve the performance while its complexity is comparable to MLD. In 2017, we have proposed a new simple message-passing MIMO detector based on QR-decomposition named Edge-reduced QR-GBP (ER-QR-GBP). This detection method can be considered as the reduced version of original region graph constructed from the QR-decomposed channel matrix while its complexity is significantly lower than original QR-GBP and MLD. Meanwhile the resulting calculation is mathematically identical to the MLD. Figure 2.3-8 shows bit error rate (BER) performances of original BP with damping, MMSE-SIC, QR-GBP, QR-decomposed BP (QR-BP) with damping, MLD, and proposed approach (ER-QR-GBP) where the number of transmitting and receiving antennas is 8, respectively. As obvious from the figure, the performance of our proposed approach is identical to MLD while its complexity is lower than the MLD.

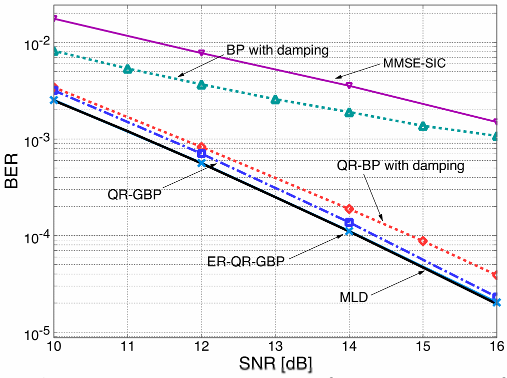


Fig. 2.3-8: BER performances of several MIMO detection techniques.

[Lattice Codes based on Repeat-Accumulate Codes] (Koji Ishibashi Lab.)

Signal codes have been proposed as a feasible lattice coded modulation, which can operate channel encoding and generate suitable modulated signal for AWGN channel by signal processing filters. However, the conventional signal codes cost high-decoding complexity. For this problem, we have proposed a new signal code called *repeat-accumulate signal code* (RASC), where low-complexity sum-product decoder can be used to decode original signals. We have also proposed Monte-Carlo density evolution (MC-DE) for RASC since an asymptotic behavior of signal codes has not been investigated. Figure 2.3-9 shows symbol error rate performance of RASC compared with the conventional turbo signal codes. Based on MC-DE, the

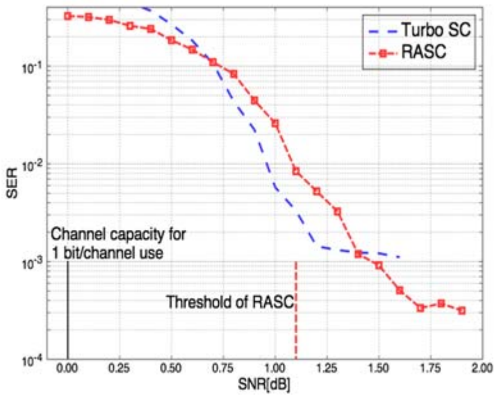


Fig. 2.3-9 SER Performance of RASC compared with the conventional turbo signal codes. 1000 symbols are used for transmission.

optimum filter coefficient can be found and its noise threshold is close about 1 dB to the channel capacity. From our computer simulations, although the decoding complexity of RASC is quarter or less than that of turbo signal codes, the optimized RASC can close to the conventional turbo signal codes about 0.2 dB in waterfall region. In addition, RASC can achieve better performance in error floor region.

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

In future optical access networks, convergence of wired and wireless will provide multiple services and simpler optical network management. For wired services, such as Fiber-to-the-Home (FTTH), optical access systems based on passive optical networks using conventional digital signals are widely employed. On the other hand, as for wireless services, radio-over-fiber (RoF) is an indispensable technology for transmitting RF signals into fiber links between central office (CO) and remote antenna units (RAUs). Although digital signals are widely used in the current RoF systems, the use of analog signals has a high potential for improving the data capacity of RF signals and simplifying the configuration of RAUs.

In general, electrical power supply systems, which use external batteries and public power lines, are required to drive remote units (RUs), such as optical network units (ONUs) and RAUs, for optical access networks. However, as the number of RUs will dramatically increase in near future, the capital and operating expenditures for the RUs will increase further, and simpler and cost-effective management for RUs will be required. Power-over-fiber (PWoF) is one of the potential solutions for these problems because the use of PWoF enables centralization of the overall power supply system in the CO. Recently, we have reported a PWoF transmission technique using double-clad fibers (DCFs), which consisted of a single-mode (SM) core and a multimode (MM) inner cladding. We have achieved good transmission performance with negligible power penalties in the bidirectional RoF transmission and the optically controlled beam steering system. However, these demonstrations were based on single-channel, analog signal transmission. In addition, the feed light was not yet converted into the electrical power, which is required for driving RUs in actual systems.

In this year, we have demonstrated multichannel analog and digital signal transmission with a 60-W feed PWoF using a DCF, for future optical access networks. To obtain the electrical power required for driving an RU, multiple high power photovoltaic converters (PPCs) with a maximum input power of up to 10-W were employed. After investigating the performance of the PPCs, we have evaluated the multichannel transmission performance with electrical power delivery by the 60-W feed PWoF, in terms of error-vector magnitude (EVM) of the analog signal and bit-error-rates (BERs) of the digital signals. As a result, we have successfully achieved good transmission performances of the analog and digital signals under 60-W feed PWoF.

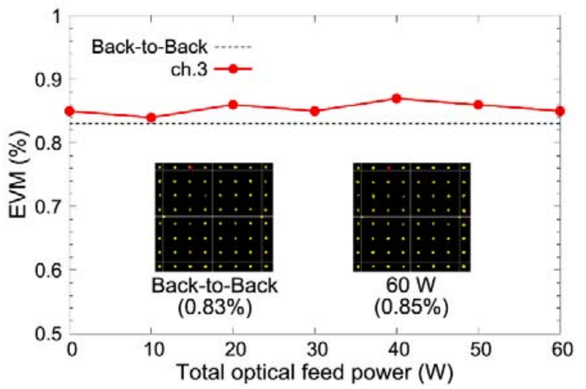


Fig. 2.3-10 EVM characteristics of ch.3 as a function of total optical feed power.

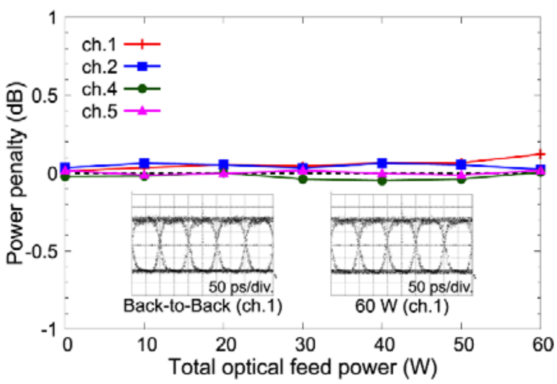


Fig. 2.3-11 Power penalties to the back-to-back signal of received digital signals at all digital signal channels.

2.3.4 Funds

【Grants-in-Aid for Scientific Research】

1. Scientific Research B “Research on Self Organized Propagation Model Generation based on 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 User Centric Wireless Communication using Traffic Estimation and Environmental Cognition based on User Preference”
   Takeo Fujii (PI belongs to other organization)
4. 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)
5. Scientific Research B “Research on Advanced Wireless and Wired Harmonized SDN”
   Takeo Fujii (PI belongs to other organization)
6. Scientific Research C “Research on New Multiple Access Control Technologies based on Multi-Dimensional Graph Structure for Massive Users”
   Koji Ishibashi
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)
9. Scientific Research B “Research on Optically Powered Radio-over-Fiber systems”
   Motoharu Matsuura
10. Challenging Exploratory Research “Research on 100 GSamples/s Optical Quantization Using Quantum-Dot Semiconductor Optical Amplifiers”
   Motoharu Matsuura

【Commissioned Research】

1. MIC SCOPE “Augmented Learning of Wireless Communication Environment for Forwarding Frequency Spectrum Sharing”
   Koichi Adachi (PI belongs to other organization)

【Other Funds】

1. Support Center for Advanced Telecommunication Technology Research, Foundation “Research on optical quantization using optical frequency shift in quantum-dot semiconductor device”
   Motoharu Matsuura
2. KDDI Research Unrestricted Research Fund, “Future Mobile Communications”
   Takeo Fujii

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 investing 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.

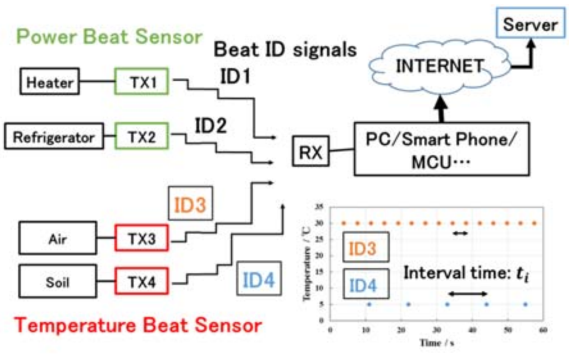
2.4.2 Research Staffs and Their Specialties

Prof. Koichiro Ishibashi (Head of Division, Low-power devices)
Prof. Yasushi Yamao (Smart meters)
Prof. Takeo Fujii (Smart meters)
Associate Prof. Motoharu Matsuura (Radio over Fiber)
Associate Prof. Koji Ishibashi (Green network and communication theory)
Prof. Kunio Uchiyama (Application systems)

2.4.3 Major Research Outcomes in 2017

[Development of Beat Sensors] (Prof. Koichiro Ishibashi)

IoT Beat Sensors was proposed in 2015, where data acquired by sensors are transmitted as interval times of ID signal (Fig. 2.4-1, 2.4-1-2). In 2017, we have successfully developed DC current Beat Sensors, and Illumination Beat Sensors, as well as temperature and AC power Beat Sensors. We have shown such many advantages of the Beat Sensors as low cost, low power, small size and so on. The data recovery algorithm was also developed in 2017, thereby obtaining substantially longer communication range of the Beat Sensors by 5 times as compared to the conventional IoT sensors (Fig. 2.4-2).



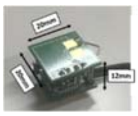


Fig. 2.4-2 Temperature Beat sensor

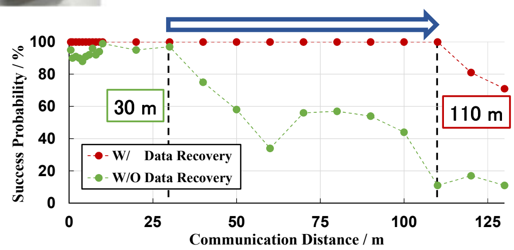


Fig. 2.4-1 Beat sensor concept Fig. 2.4-3 Long communication range by data recovery

[Vital Data Acquisition by Doppler Rada]

The non-contact measurement of the respiration rate (RR) and heart rate (HR) using a Doppler radar has been done. In this study, we propose a time-domain peak detection algorithm for the fast acquisition of the RR and HR within a breathing cycle (approximately 5 s), including inhalation and exhalation. The time domain peak-detection algorithm, based on the Doppler radar, exhibited a significant correlation coefficient of HR of 0.92 and a correlation coefficient of RR of 0.99, between the ECG and respiration band, respectively.

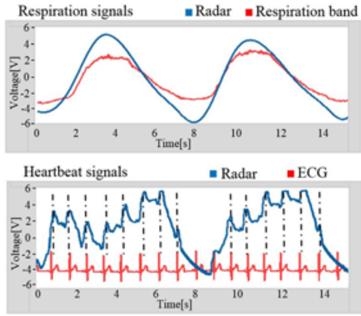


Figure 2.4-3　RR and HR acquired by Radar

[Low-Power MAC Protocol for Energy Harvesting Sensor Networks]（Prof. Koji Ishibashi）

Undoubtedly, a key enabler of *Internet-of-Things* (IoT) is *wireless sensor networks* (WSNs), which autonomously and continuously gather environmental information from everything with wireless communication capability. Using energy harvesting technologies, perpetual network is not a fairy-tale anymore. However, due to the limitation of sensor-size, typical energy harvesters cannot generate sufficient amount of electricity to run sensors with existing wireless protocols for sensor networks such as ZigBee.

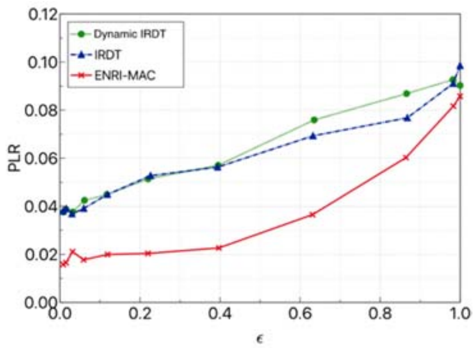


Figure 2.4-4: PLR performances of various MAC protocols.

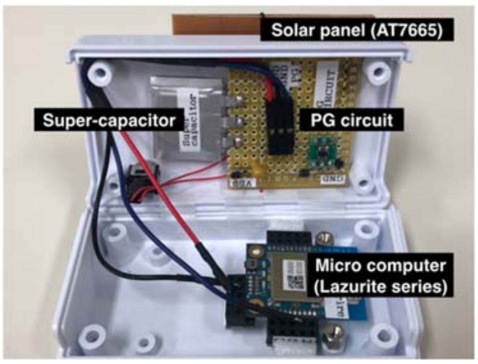


Figure 2.4.5: Fabricated sensor node with EH capability.

To overcome this inherent difficulty, we proposed a novel medium access control (MAC) protocol named energy-neutral receiver-initiated MAC (ENRI-MAC). In this protocol, each sensor adaptively changes its own intermittent interval depending on its average harvested energy and the number of neighboring nodes. Figure 2.4.3 shows the the packet loss rate (PLR) of the proposed protocol, conventional one with fixed intermittent interval (IRDT), and conventional IRDT with dynamic intermittent-interval. As obvious from figure, the proposed protocol decreases PLR by half compared with the conventional protocol.

Figure 2.4.5 shows our fabricated sensor node with EH capability and multi-hop capability. We conducted experiments with this fabricated node and confirmed that the PLR of our system is zero after the transmission of 200 packets whereas that of conventional system is 10%. These results were presented at IEEE CCNC conference.

[Wireless Sensor Network with Collision Resolution using Cloud Cooperation in Random Access Network]（Prof. Takeo Fujii）

As the Internet of Things (IoT) gets more popular, the study of wireless sensor networks (WSNs) attracts more attention. WSNs consist of sensor nodes (SNs), observe the information around, and fusion centers (FCs), gather the data from each SN. The application of IoT requires a lot of SNs to manage the data from them. However, increasing the number of SNs may degrade the quality of service (QoS), since the resources used in the communications between SNs and FCs are finite. In our research, we propose a random access network adapting three types (inter-slot, intra-slot and inter-FCs) of successive interference cancellation and network Multiple-Input and Multiple-output method to enlarge the capacity of the network. We assumed an environment in which multiple FCs are regularly and SNs are randomly located at 200×200["m"] as shown in Fig. 2.4-6. The simulation results in Fig. 2.4-7 show that the proposed method can increase the number of SNs which can send the data without degrading the QoS.

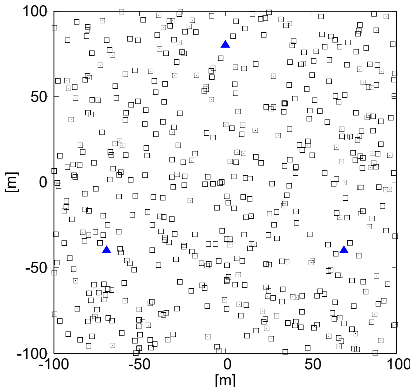


Fig. 2.4-6 Node position model.

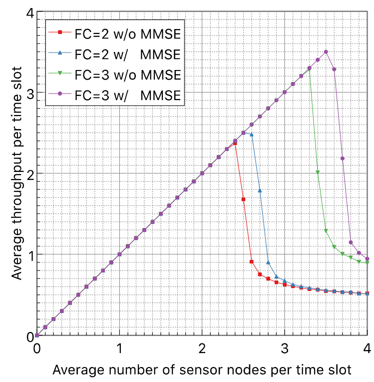


Fig. 2.4-7 Simulation results.

[Optically Powered RoF Systems for Future Optical Access Networks]（Matsuura Lab）

Power-over-fiber (PWoF) is a simple way to simultaneously transmit optical data and power into optical fibers. In radio-over-fiber (RoF) networks, the use of PWoF is effectively used to centralize the required power source in a central station (CS) and to deliver the feed light with optical data signals in the same cables. As optical fibers are nonconductive power lines, unlike electrical cables, PWoF is also useful for preventing lightning damage for the CS. In addition, a few research groups have shown that the introduction of sleep mode power control of remote antenna units (RAUs) offers up to 60% energy saving in the mobile networks. Therefore, if we are able to control the delivered power according to the data traffic in the link via PWoF, the overall power in the network will be more efficiently reduced. On the other hand, as the electric power required for driving a conventional femto-cell-type RAU is at least several watt-classes, single-mode fibers (SMFs), which are most popular and widely used for optical fiber communications, are not suitable for PWoF links. This is because simultaneous optical data signals and feed light transmission in its small core area strictly limits the available feed light power.

Multimode fibers (MMFs) are also widely used for optical fiber communications and are practical candidates for PWoF links, because MMFs are pre-existing fibers without requiring a large-scale deployment of new fibers, and have core area, which is much larger than that of the SMFs. However, owing to the differential delay in the MMFs, it is difficult to increase the transmission speed of MMF links. This is called “modal dispersion.” To solve this problem, a number of approaches have been reported so far. In particular, center-launching (CL) and offset-launching (OL) techniques, which adjust the beam launching position of the input optical signal into the MMF core, are widely used to restrict the modal excitation to either higher- or lower-order propagation modes.

In this year, we present a novel method to simultaneously mitigate modal dispersion and feed light crosstalk of the optical data signals by using a combination of CL and OL techniques in a conventional MMF. In this scheme, the CL technique is used for propagating the feed light into lower-order modes in the MMF, while the OL technique is used for propagating optical data signals into higher-order modes and mitigating the modal dispersion in the MMF. Moreover, the different modal excitations and propagations play an important role in mitigating the crosstalk between the signal and the feed light. Although the optical data signals and the feed light are not completely separated in space, the different modal propagation is effective in mitigating the crosstalk. To show the feasibility, we have successfully demonstrated downlink and uplink RoF transmissions with around 10-W feed PWoF over a conventional 4-km MMF, for the first time, to the best of our knowledge.

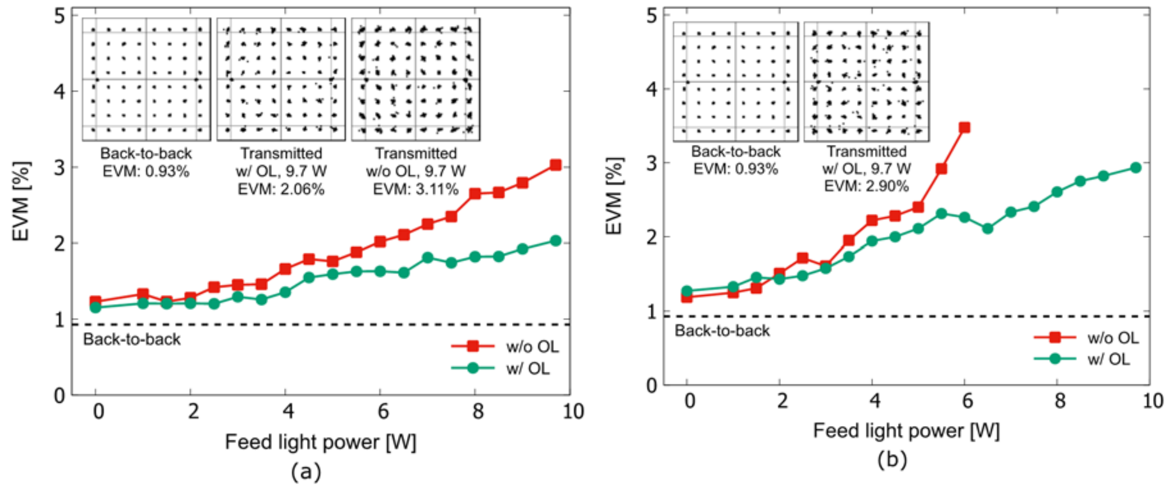


Fig. 2.4-8 : EVM characteristics of downlink transmitted signals without (w/o) and with (w/) OL technique as a function of feed light power after (a) 2 km and (b) 4 km transmissions. Insets show constellations of back-to-back and transmitted signals w/o and w/ OL technique.

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 (The University of Electro-Communications), J. Ida, S. Makino, and K. Itoh (Kanazawa Institute of Technology).

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

3 Scientific Research B "Research on Optically Powered Radio-over-Fiber systems"
Motoharu Matsuura

【Cooperative Research】

1 "Researches on Energy Harvesting Power and its Application to Low-Power Data-Centric Sensor Network Systems,"
Koichiro Ishibashi, Koji Ishibashi, and Cong-Kha Pham

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

3. List of Publications in F.Y. 2017

Journal Papers with Referees

【1】 Le Tien Trien, Koichi Adachi, and Y. Yamao, “Network Coding Based Payload Concatenation for Relay-Assisted V2V Communications”, IEICE Trans. Commun. Express (Early Access).

【2】 Rei Hasegawa, Keita Katagiri, Koya Sato, and Takeo Fujii, “Low storage, but highly accurate measurement-based spectrum database via mesh clustering,” IEICE Trans. Commun., vol.E101-B, no.10, Oct. 2018 (in press).

【3】 征矢隼人, 田久修, 白井啓一朗, 太田真衣, 藤井威生, 笹森文仁, 半田志郎, “コグニティブ無線における低複雑かつ高精度な占有率と遷移率測定法,” 信学論(B), vol.J101-B, no.2, pp.133-145, Feb. 2018. (DOI: 10.14923/transcomj.2017GTP0010).

【4】 Le Tien Trien, Koichi Adachi, and Yasushi Yamao, “Packet Relay-Assisted V2V Communication with Sectorized Relay Station Employing Payload Combining Scheme”, IET Commun., vol.12, no.4, pp.458-465, Feb. 2018.

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【6】 Koya Sato, Kei Inage, and Takeo Fujii, “Frequency correlation of shadowing over TV bands in suburban area,” Electron. Lett., vol.54, no.1, pp.6-8, Jan. 2018. (DOI: 10.1049/el.2017.2164).

【7】 Tatsuya Ohtsuki and Motoharu Matsuura, “Wavelength conversion of 25-Gbit/s PAM-4 signals using a quantum-dot SOA,” IEEE Photon. Technol. Lett., vol.30. no.5, pp.459-462, Jan. 2018.

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【9】 Hayao Kuboki and Motoharu Matsuura, “Optically powered radio-over-fiber system based on center- and offset-launching techniques using a conventional multimode fiber,” OSA Optics Letters, vol.43, no.5, pp.1057-1070, 2018.

【10】 Jun Enomoto, Ryo Ishikawa, and Kazuhiko Honjo, “Second Harmonic Treatment Technique for Bandwidth Enhancement of GaN HEMT Amplifier With Harmonic Reactive Terminations” IEEE Trans. Microw. Theory Technol., vol.65, no.12, pp.4947-4952, Dec. 2017.

【11】 G. Sun, N. V. Trung, T. Matsui, K. Ishibashi, Tetsuo Kirimoto, Hiroki Furukawa, Le Thi Hoi, Nguyen Nguyen Huyen, Quynh Nguyen, Shigeto Abe, Yukiya Hakozaki, “Field evaluation of an infectious disease/fever screening radar system during the 2017 dengue fever outbreak in hanoi, vietnam: a preliminary report,” Elsevier Journal of Infection, vol.75, no.6, pp.593-595, Dec. 2017.

【12】 Shigeru Hiura and Ryo Ishikawa, "Electrothermal Transient Analysis of GaN Power Amplifier With Dynamic Drain Voltage Biasing," IEEE Microw. Wireless Compon. Lett., vol.27, no.11, pp.1019-1021, Nov. 2017.

【13】 小菅義夫, 古賀禎, 宮崎裕己, 呂暁東, 秋田学, 稲葉敬之, "高距離，高ドップラー分解能レーダにおける複数反射点目標の速度位置推定", 信学論(B), vol.J100-B, no.11, pp.923-933, Nov. 2017.

【14】 Tsukasa Yasui, Ryo Ishikawa, and Kazuhiko Honjo, "GaN HEMT DC I-V Device Model for Accurate RF Rectifier Simulation," IEEE Microw. Wireless Compon. Lett., vol.27, no. 10, pp.930-932, Oct. 2017.

【15】 本城和彦, 高山洋一郎, "マイクロ波半導体回路研究の黎明期 -立体回路から平面トランジスタ回路へ-（招待論文）," 信学論(C), vol.J100-C, no.10, pp.390-399, Oct. 2017.

【16】 Xu Zhu and Takeo Fujii, "Modulation classification for cognitive radios using stacked denoising autoencoders." Int. J. Satell. Commun. Network., vol.35, no.5, pp.517-531, Sep./Oct. 2017 (DOI: 10.1002/sat.1202).

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【19】 小菅義夫, 古賀禎, 宮崎裕己, 呂暁東, 秋田学, 稲葉敬之, "距離和とドップラー和を観測値とするマルチスタティックレーダによる位置及び速度推定," 信学論(B), vol.J100-B, no.8, pp.558-568, Aug. 2017.

【20】 Koji Kakinuma, Mai Ohta, Osamu Takyu, and Takeo Fujii, "Fusion center controlled MAC protocol for physical wireless parameter conversion sensor networks (PHY-C SN)," IEICE Trans. on Commun, vol.E100-B, no.7, pp.1105-1114, Jul. 2017. (DOI: 10.1587/transcom.2016SCP0008).

【21】 Manh Duy Luong, Ryo Ishikawa, Yoichiro Takayama, and Kazuhiko Honjo "Microwave Characteristics of an Independently Biased 3-stack InGaP/GaAs HBT Configuration," IEEE Trans. Circuits Syst. I, Reg. Papers, vol.64, no.5, pp.1140-1151, May 2017.

【22】 Tomokazu Moriyama, Taiki Nakayama, and Takeo Fujii, "Intermittent interval feedback design for multi-stage wireless sensor networks," Mobile Networks and Applications, Apr. 2017. (DOI: 10.1007/s11036-017-0859-0).

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【24】 H. Kawabata, K. Ishibashi, S. Vuppala, and G. Abreu, "Robust Relay Selection for Large-Scale Energy Harvesting IoT Networks," IEEE J. Internet of Things, vol.4, no.2, pp.384-

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【1】 Daisuke Kamiyama, Akira Yoneyama, and Motoharu Matsuura, “Multichannel analog and digital signal transmission with watt-class electrical power delivery by means of power-over-fiber using a double-clad fiber,” in Proc. OFC 2018, M2K.7, San Diego, USA, Mar. 2018.

【2】 Hayao Kuboki and Motoharu Matsuura, “Modal dispersion and feed light crosstalk mitigations by using center- and offset-launching for optically-powered radio-over-multimode fiber systems,” in Proc. OFC 2018, Th2A.62, San Diego, USA, Mar. 2018.

【3】 Yusuke Shirasaki, Osamu Takyu, Takeo Fujii, Tomoaki Ohtsuki, Fumihito Sasamori, and Shiro Handa, “Consideration of security for PLNC with untrusted relay in game theoretic perspective,” in Proc. IEEE RWS2018, Jan. 2018.

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【10】 Hayato Soya, Osamu Takyu, Keiichiro Shirai, Fumihito Sasamori, Shiro Handa, Mai Ohta, and Takeo Fujii, “Modified Rendezvous Scheme with Inferring Access Channel Probability of Slave by Master,” in Proc. IEEE ICOIN 2018, Chiang Mai, Thailand, Jan. 2018.

【11】 Tetsuya Noguchi, Osamu Takyu, Fumihito Sasamori, Shiro Handa, Takeo Fujii, and

Tomoaki Ohtsuki, "Transmit Control for Secure Information Sharing in Untrusted Relay with Two Antennas," in Proc. IEEE ICOIN 2018, Chiang Mai, Thailand, Jan. 2018.

【12】 Ryo Kurosawa, Osamu Takyu, Fumihito Sasamori, Shiro Handa, Mai Ohta, and Takeo Fujii, "Experimental Study of Signaling with IFDMA Modulation and Nonlinear Amplifying for Recovering Access Channel Mismatch," in Proc. IEEE ICOIN 2018, Chiang Mai, Thailand, Jan. 2018.

【13】 Yuki Kada and Yasushi Yamao, "Dual-Band SHF Reconfigurable Bandpass Filter Using λ/4 Microstrip Resonators and Chip Inductor Coupling," in Proc. of IEEE RWS2018, MO3B-1, Jan. 2018.

【14】 Shuichi Obayashi and Takeo Fujii, "An OTA measurement setup considering human body shadowing effect for indoor millimeter link in specific floor environment," in Proc. IEEE CAMA2017, Dec. 2017.

【15】 Toshiyuki Shizuoka, Osamu Takyu, Mai Ohta, and Takeo Fujii, "Multiband Hierarchical Ad Hoc Network with Wireless Environment Recognition," in Proc. APSIPA ASC 2017, Kuala Lumpur, Malaysia, Dec. 2017.

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【20】 Masahiro Hayashi and Yasushi Yamao, "Received Power Threshold and Reply Timing Controlled Reactive Routing Scheme for Reliable Ad Hoc Network," in Proc. APMC2017, P2-N12, Dec. 2017.

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【22】 Alice Maruyama, Yoichiro Takayama, Ryo Ishikawa, and Kazuhiko Honjo, "Linearity Improvement for Single-GaN HEMT Dual-Band Power Amplifier in Concurrent Operation Mode," in Proc. 2017 Asia Pacific Microwave Conference, THP1-P.12, Nov. 2017.

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【3】 本城和彦, "マイクロ波増幅器の基礎（基本原理から最新の話題まで）", Microwave Workshops 2017, FR1A-1, Dec. 2017.

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