NTU GICE Newsletter
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In this issue

Technology Developed in GICE

Capacity of Broadcast Packet Erasure Channels with Single-User Delayed CSI

From Communication and Signal Processing Group

INTRODUCTION

We characterize the capacity region of the two-user broadcast packet erasure channel (PEC) with single-user delayed channel state information (CSI). More precisely, we assume one receiver does not provide its channel state to the other two nodes (the other receiver and the transmitter), while the other receiver reveals its state globally with unit delay. This is a hybrid CSI at the transmitter (CSIT) setting where the transmitter has the delayed CSI of one user but not the other. Characterization of such a capacity region of broadcast channel (BC) with single-user delayed CSI is open for years. In this work, we develop new achievability strategy and show that the capacity region, surprisingly, matches that of the broadcast PEC with global delayed CSI of both users. The key is proposing a new precoding strategy for the retransmission, so that interference from the feedback receiver can be aligned at the other receiver.

Feedback in Broadcast PEC

In a packet-based communication network, network, instead of the classic Gaussian channel, the network-coding-based approaches generally model each communication hop as a packet erasure channel (PEC) [1]. By sending back the ACKnowledgement (ACK) signal from each receiver to the transmitter, the system can achieve channel state feedback with acceptable overhead. The simple PEC abstraction not only allows tracing information-theoretic capacity with mathematical rigor and but also accelerates the transition from theory to practice. One prominent example is the Automatic Repeat reQuest (ARQ) and its variations, which is conceived by the point-to-point PEC capacity

(Continued on page 2)

GICE Honors

Prof. Soo-Chang Pei
110 Fellow of the Chinese Institute of Electrical Engineering

Prof. Ruey-Beei Wu
110 Fellow of the Chinese Institute of Electrical Engineering

Message from the Director

Hsi-Tseng Chou

Professor & GICE Director

Happy Chinese New Year! Wishing every happiness will always be with you. We have great news to share. Congratulations to Prof. Soo-Chang Pei and Prof. Ruey-Beei Wu for receiving 110 Fellow of the Chinese Institute of Electrical Engineering. They well deserve these highly competitive awards.

In this issue, we have Prof. Shih-Chun Lin sharing his recent research results on Capacity of Broadcast Packet Erasure Channels with Single-User Delayed CSI. Prof. Tian-Wei Huang shares his recent research results on Broadband CMOS RFICs for B5G/6G. We hope that you enjoy reading this issue.

Technology *(Continued from page 1)*

and have been incorporated into 5G mobile networks. In contrast to the point-to-point case where feedback cannot increase the capacity region, it was shown that delayed state feedback from both receivers are very helpful in the broadcast PEC [1][2]. The capacity region of the broadcast PEC compared to that without feedback is strictly enlarged.

Capacity of Broadcast PECs with Single-User Delayed CSI

All previous capacity results for broadcast PECs assumed that all receivers can provide delayed state feedback [1][2], while in 6G, the feedback capabilities may be heterogeneous for receivers. Thus we consider a two-user broadcast PEC with single-user delayed CSI, as in Figure 1. However, a negative result was revealed for BCs with continuous CSI [3], that is, single-user CSI will reduce the sum degrees-of-freedom (DoF), or high signal-to-noise ratio sum rate, when comparing with that of global delayed feedback. Here we not only characterize the whole capacity region of the two-user broadcast PEC with single-user delayed CSI, which, to our surprise, coincides with the one with delayed feedback from both receivers. Main difference of PEC to BC in [3] is now the CSI is discrete. This result is true not only for the case where there are two private messages but also for the one with an additional common message. The capacity-achieving opportunistic network coding comes as follows [4]. In the first two phases, the transmitter sends information bits intended for the two users, respectively, and determines the bits to be recycled in the third phase according to the CSI. In the third phase, by efficiently aligning the interference according to the single-user CSI feedback, each receiver can only decode its own recycled bits. More specifically, the achievability strategy for the case with private messages only is established by proposing a new precoding strategy for the recycled bits in the third (retransmission) phase of the three-phase opportunistic network coding scheme proposed by our group in [5]. The previous scheme only utilizes the CSI feedback in the retransmission phase. Meanwhile, our new precoding strategy fully utilizes the single-user delayed CSI feedback in the retransmission phase and dynamically adapts to it, which is the key to why we can further enlarge the achievable rate region and achieve the capacity. More specifically, in [5], the receiver that never feeds back its channel state needs to decode the recycled bits for both users.

By efficiently aligning the interference according to the single-user CSI feedback, each receiver in our scheme only decodes its own recycled bits, and the decoding burden is significantly reduced. Moreover, we propose a two-phase achievability strategy by merging two of the phases. This achievability also simplifies the design for the case with an additional common message. The detailed analysis please referred to [4].

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Technology *(Continued from page 2)*

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For more information please contact:
Signal and data processing for Cyber-physical system Lab (SCL)
Professor: Shih-Chun Lin
Email: sclin2@ntu.edu.tw

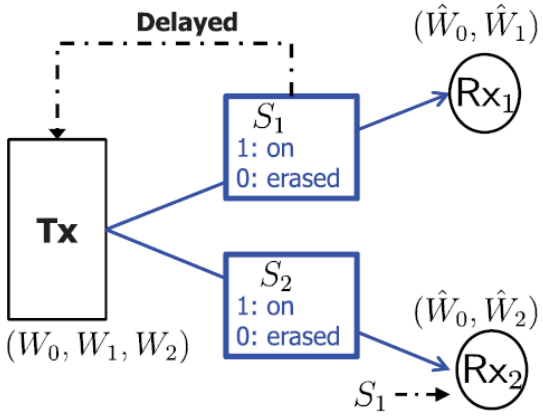

Figure 1 Broadcast PEC with single-user delayed CSI with a common message and two private messages, where a common message W_0 is targeted for both receivers and private message Wi is targeted for receiver i, i = 1, 2.

Broadband CMOS RFICs for B5G/6G

from Electromagnetics Group

INTRODUCTION

In 2021 Nokia achieved a new record for 5G data rate with 10 Gbps, which is twice the data rate of the previous year's record. At 28 GHz and 39 GHz, the combined modulation bandwidth is 800 MHz in Nokia's Over-The-Air (OTA) demo. Analog Pre-Distortion (APD) design was implemented in [1], [2] in order to increase the modulation bandwidth up to 1200 MHz or even 1600 MHz, as shown in Fig 1. To accelerate 5G Gigabit speed to achieve 6G extreme high data rate, e.g., Terabit, we will use three techniques (Fig 2): (1) broad bandwidth: NTU's 65% MMW broadband linearization in Fig. 3, to provide less power back-off, 3.7 dB, from OP1dB to 64-QAM linear output power [3], [4]. (2) High-order modulation: from 64QAM to 1024QAM or 4096QAM [5]. (3) MIMO or dual-polarization [6] can boost spectral efficiency at MMW/THz.

Ultra-broadband PA With Phase Linearization

An ultra-broadband power amplifier (PA) with AM-PM linearizer in 28-nm bulk CMOS process is presented [4]. Deep class AB bias is selected in order to raise power efficiency. To achieve wideband AM-PM linearization, a PMOS linearizer at power stage is introduced.
The S-parameters simulation and measurement results are shown in Fig. 4. The proposed linearized PA achieves a 3-dB gain bandwidth from 19.7 to 38.9 GHz (65.5% fractional bandwidth). The measured OP1dB is 12.7 ± 0.6 dB from 22 to 38 GHz, and the PAE is larger than 25% from 21 to 36 GHz. For 100MHz 64-QAM OFDM signal, this PA obtains a linear output power of 8.5/8.3/8.8-dBm under EVM of -25 dB with modulated PAE of 11.0/11.0/11.9% at 23/28/38 GHz, respectively.

Moreover, the measured back-off power from OP1dB to linear output power is 4.7/3.9/3.7 dB at 23/28/38 GHz.

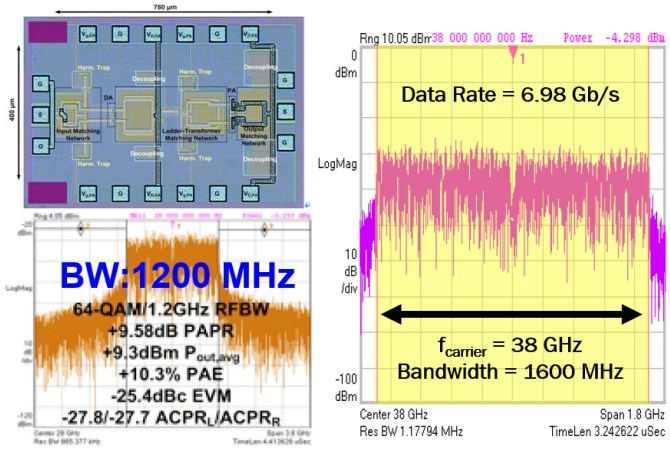

Fig. 1. Modulation bandwidth of 1200 MHz and 1600 MHz can be achieved by utilizing APD design

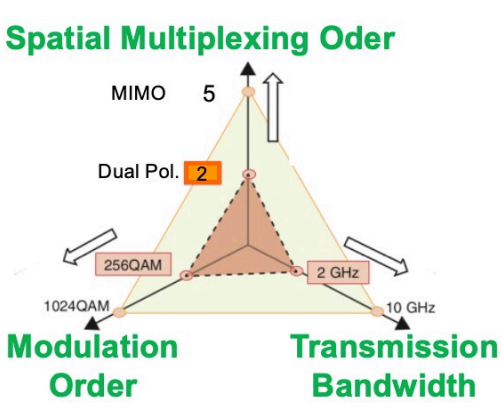

Fig. 2. Approaches to achieve 6G extreme high data rate

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Technology *(Continued from page 3)*

CLASS-F POWER AMPLIFIER WITH 4096-QAM OFDM

A Ka-band 28-nm CMOS power amplifier (PA) has been proposed for B5G MMW high-speed applications. Under low supply voltage, 0.9-V, this PA achieves 22.5 dB of measured gain, 37% Peak PAE and 12.3dBm OP1dB at 28 GHz. Fig 5 shows the measured and simulated S-parameters of the proposed PA.

Fig. 6 shows the comparison between gain and PAE for 64-QAM modulation test under -25 dB EVM, the gain and PAE performance is superior in these works. Fig 7 shows the measurement result of the PA under 64/1024/4096 QAM.

60 GHZ DUAL POLARIZATION RECEIVER

A dual-polarization antenna with high spectral efficiency for transmission application distance at 60 GHz is presented. The dual-polarization antenna is integrated with the receivers through flip chip on the LTCC substrate at 60 GHz. The receiver front-end composes of a low noise amplifier and demodulator fabricated in 65-nm CMOS process. Fig 8 shows the diagram of the module. The conversion gain is higher than 14 dB and the noise figure is lower than 6 dB from 57 to 66 GHz. The total data rate of the proposed system's spectral efficiency is up to 12 bit/s/Hz for wireless measurement and the EVM is below 5.5 %.

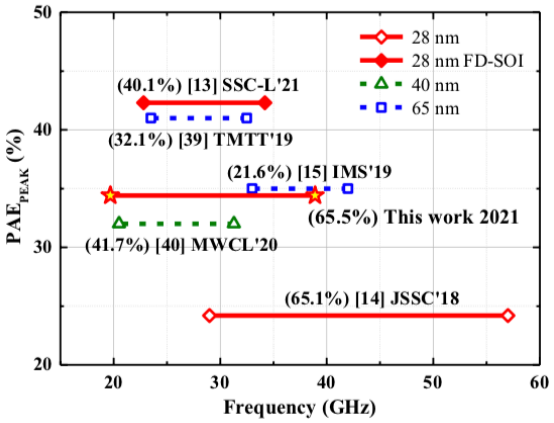


Fig. 3. 5G mm-Wave linearized CMOS PAs whose PAEPEAK vs. 3-dB BW

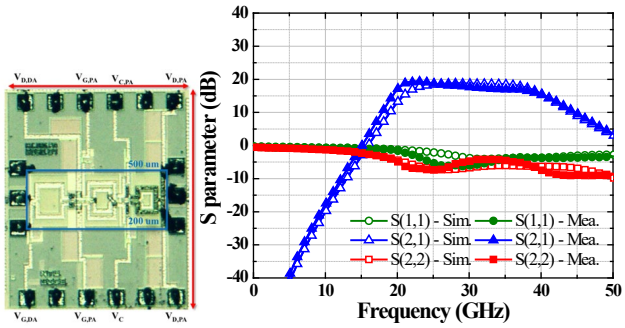


Fig. 4. Chip photo and measured S-parameters of the ultra-broadband PA.

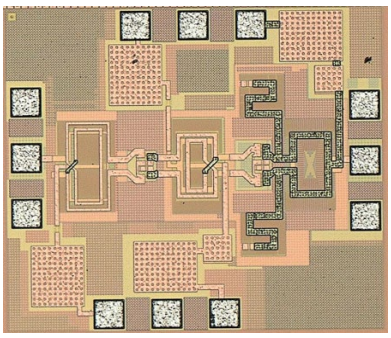


Fig. 5. 28-nm CMOS chip photo of the Class-F PA

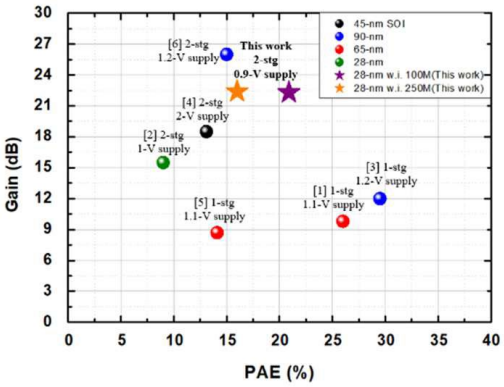
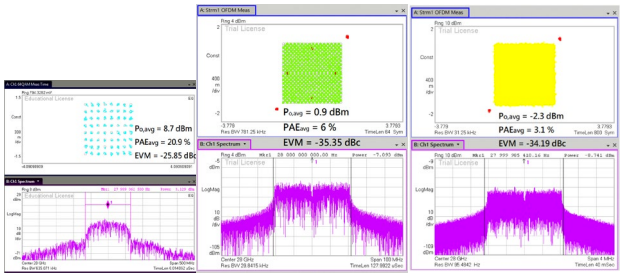


Fig. 6. Comparison for 64-QAM modulation test under -25 dB EVM between gain and PAE with the published Ka-band PA.



(a) (b) (c)

Fig. 7. Measurement result of the Class-F PA under (a) 64-QAM (b) 1024-QAM (c) 4096-QAM

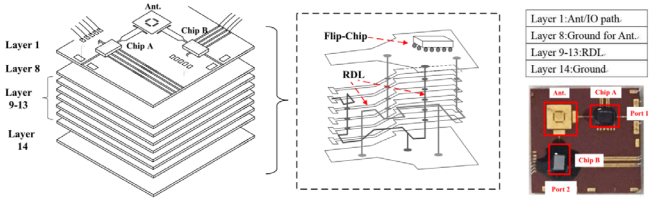


Fig. 8. The dual-polarization receiver module diagram

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Technology *(Continued from page 4)*

CONCLUSION

In this manuscript, different approaches to achieve extreme high data rate are discussed. An ultra-broadband power amplifier with over 65% fractional bandwidth and only 3.7 dB back-off from OP1dB to linear is presented.A 2-stage Class-F power amplifier with only 3.7 dB back-off from OP1dB to linear is presented. The Class-F PA can achieve over 20% PAE and 21dB gain with low supply voltage (0.9 V) and 2-stage topology. A 60 GHz receiver utilizing dual polarization to improve spectral efficiency is presented. The measured spectral efficiency can be up to 12 bit/s/Hz with 64 QAM modulation.

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For more information please contact:
Professor: Tian-Wei Huang
Email: tihuang@ntu.edu.tw

Activities

2022 Taiwan Telecommunications Annual Symposium:
(1) 2022 National Symposium on Telecommunications
(2) 2022 Electromagnetics Workshop- A Bridge to the Future
(3) 2022 Taiwan Workshop on Information Theory and Communication

The 2022 Taiwan Telecommunications Annual Symposium was held at the international conference hall in 「the Tsai Lecture Hall」, National Taiwan University, during Jan.24-27, 2022. The workshop was organized and hosted by the Graduate Institute of Communication Engineering, National Taiwan University. The co-organizers include the Chinese Microwave Association, Taiwan Association of Intelligent Information and Communication Technology, Engineering Technology Promotion Platform of Ministry of Science and Technology, Department of Electrical Engineering of NTU, IEEE APS Taipei Chapter,

Fig. 1. Attendees from「ROC Air Force Academy」

(Continued on page 6)

Activities *(Continued from page 5)*

IEEE APS Tainan Chapter, IEEE ComSoc Taipei Chapter, IEEE ComSoc Tainan Chapter, IEEE CRFID Taipei Chapter, IEEE EMC Taipei Chapter, IEEE ITSoc Taipei Chapter, IEEE ITSoc Tainan Chapter, IEEE MTT Taipei Chapter, and IEEE MTT Tainan Chapter.

The Annual Symposium comprised three workshops: the "2022 National Symposium on Telecommunications", the "Electromagnetics Workshop- A Bridge to the Future," and the "2021 Taiwan Workshop on Information Theory and Communications". NST 2022 provided topics as: Electromagnetic, Communication, Signal Processing, and Networking, and cooperated with the Ministry of Science and Technology to display the project achievement of a year. Due to the impact of the COVID-19 epidemic, the posters were presented on Whova online platform. As electromagnetic (EM) application develops and wireless communication technology evolves, it has become apparent that the advancement and growth of these fields require close collaboration between academia and industry. The Electromagnetics Workshop--A Bridge to the Future was therefore founded to create a channel between industry and academia in Taiwan. The 2021 Taiwan Workshop on Information Theory and Communications promoted information exchange between researchers in Taiwan in information theory and communications. The workshop provided a platform to connect scholars and students working on information theory and communications in Taiwan.

Internationally renowned scholars were invited to share new research results and technologies in communications and information theory.

Due to the rapid development of 5G on wireless technologies in recent years, future 6G wireless systems are demanded. Based on the extreme densification of the network infrastructure, scientists are dedicated to the research of higher frequency bands that reaching above 100 GHz and even up to 140 GHz. The central theme for telecommunications includes 6G THz applications, low-orbit satellites (LEO), 3DIC process integration, PCB layout, biomedical sensing systems, Internet of Things (IoT), autonomous areas including drones, crewless vehicles, UWB Wi-Fi, etc. For the extreme capacity of these applications, researchers aim to achieve a peak data rate of more than 400 Gbps or even 800 Gbps in the future.

Fig. 2. Prof. Hsi-Tseng Chou (National Taiwan University), a co-host of the symposium

Fig.3. Prof. Hsuan-Jung Su (National Taiwan University), a co-host of the symposium

Fig. 4. Prof. Ruey-Beei Wu at the opening of the event

Fig. 5. Prof. Tzong-Lin Wu, Associate Dean of the College of Electrical Engineering and Computer Science, at the opening of the event

(Continued on page 7)

Activities *(Continued from page 6)*

This four-day (Jan.24-27, 2022) event offered

1. Keynote speeches.
2. Special research project of the Ministry of Science and Technology published.
3. Distinguished Lecture Speech by Taiwan Electromagnetic Industry-University Alliance.
4. New Knowledge of Electromagnetic Industry Technology.
5. Electromagnetic Technology Dialogue.
6. B5G/6G Technology Dialogue.
7. National Telecom Seminar of Best Paper.
8. Rising Star.
9. Symposium on Telecommunications.
10. The Ministry of Science and Technology's Outstanding Young Scholars Research Program was published.
11. IT-Comm Talk.
12. Ministry of Science and Technology Columbus Project Published.

Several categories of topics in electromagnetism were presented. Some of the notable ones:

Scholars

[1] " Electromagnetic Perspective of Hemodynamic Vascular Waves in Human Arterial System, " Prof. Ching-Kuang C. Tzuang, National Taiwan University, Taiwan.

[2] " From Millimeter-wave to Sub-Terahertz Frequencies: The Importance and Challenges of Antenna-in-Package (AiP) Technologies," Prof. Hsi-Tseng Chou, National Taiwan University, Taiwan.

[3] "Capacity of Discrete-Memoryless Two-Way Channels with Symmetry Properties," Prof. Jian-Jia Weng, National Taiwan Ocean University, Taiwan.

[4] " Neuromorphic and Distributed Bayesian Learning," Prof. Osvaldo Simeone, King's College London, UK.

[5] "Robust, Secure and Private Cache-aided Linear Function Retrieval, " Prof. Daniela Tuninetti, University of Illinois Chicago, USA.

Industry

[1] " MediaTek's Vision on 6G Technology Trends and Cellular/Satellite Convergence", MediaTek Inc., Hsinchu, Taiwan.

[2] " Towards the Metaverse, mmWave Commercial Sailing," Auden Tech. Corp., Hsinchu, Taiwan.

This symposium invited major scholars and industry experts to present their studies and share research ideas, including forward-looking research and development in telecommunications. At the same time, manufacturers of related industries are invited to give keynote speeches and demonstrations. Moreover, this symposium encourages young scholars to enhance their research inspiration for electromagnetic technology development. A horizontal and vertical development bridge between industry, government, academia, and research is expected to be established.

Fig. 6. The exhibition area where attendees and vendors could discuss

Fig. 7. Attendees at Conference Hall (Day 1)

Corner of Student News

Student life in Taiwan

Article by Poh Yuen Chan

It's been more than a year since arrived in this beautiful island. My journey in Taiwan so far has been blessed with wonderful and caring people. While it's not an easy decision to depart from home to pursue my postgraduate's study for years without going home under the unprecedented pandemic, the support and encouragement from family and friends had motivated me take up the challenge.

Adapting to a fast-paced environment in Taipei is not easy and requires the strongest wills to get through part and parcel of everyday life. Nevertheless, getting used to it is just a matter of time as with other highs and lows, especially when most of the people are nice and have understanding of my situation and even offer to help me when in needs. Furthermore, the transportation in Taipei is so efficient and covers most of the city, allowing me explore the beauty of Taipei in the morning or at night with different kinds of excitement and sensation. Tasting Taiwanese street food can be found in almost everywhere at affordable price for my craving.

I have joined the Wireless IoT Lab of Professor Ruey-Beei Wu. I have enhanced my knowledge on vertical and horizontal wise of IoT concept further with relevant courses under the guidance and supervision from him and his team. Prof. Wu is a very dedicated and knowledgeable professor, who always provides me with direction and instils the right attitude of researching. Seniors at lab are very caring and understanding, whenever I come across a problem, they will analysis the issues and provide alternative workarounds to get going.

Certainly, taking up postgraduate study at a foreign environment as an international student is not an easy task, as not only academic has to be synchronised with the syllabus here especially fundamentals and practical experience gained previously, but cultural differences and season changes are also having to be dealt with. For example, the temperature in my country is hot and humid throughout the entire year, but in Taipei it is more humid and therefore frequent cleaning of mold becomes a necessity.

Nevertheless, relatively chill and windy climate does make the environment cosier for outdoor adventures.

Even though most of my time here in NTU has been packed with research, I would find time to enjoy every moment like dinner gathering and birthday celebration with friends and seniors.

As I believe this journey would be a once in a lifetime experience and every moment should be cherished no matter ups or downs. As the saying goes you reap what you sow.

Fig. 1. Birthday cake for Prof. Wu

National Taiwan University
Graduate Institute of
Communication Engineering

No.1, Sec.4, Roosevelt Road,
Taipei 10617, Taiwan

Phone
+886-2-3366-3075

Fax
+886-2-2368-3824

E-mail
gicenewsletter@ntu.edu.tw

Visit us at:
http://www.comm.ntu.edu.tw

Editor in Chief
Prof. Shih-Chun Lin

Editor
SHU-TING HSU