Enhanced Fronthaul for 5G and Beyond

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In the radio access network (RAN) infrastructure, fronthaul links territorially disperse remote units (RUs) to distributed units (DUs) in regular or open RAN. With the fifth generation (5G) rollout worldwide and the active research on technologies beyond 5G, fronthaul has become a critical part of RAN to balance throughput, delay, reliability, and security. Based on a group of Tier 1 operators' insights on 5G deployment, a recent technology analysis report expects the 5G fronthaul transmission market to reach more than US$2 billion in revenue by 2024, almost triple the current rollout.

Advanced applications of 5G and beyond require the fronthaul connection to support features such as high speed, ultra-low latency, traffic protection, and secure data privacy. Fronthaul plays an important role in network operations for macro and small cells, distributed antenna systems with RAN sharing, and evolution toward openness and virtualization of RAN. Network controller coordination of fronthaul access networks (FANs) and RAN is also an open topic.

This Special Issue (SI) promotes enhanced fronthaul technologies as an essential building block of the 5G and beyond RAN infrastructure. It presents the latest research endeavors, industry implementations, as well as standards development in the field of fronthaul. This SI also investigates the theoretical and practical challenges to encourage a joint effort from both academia and industry. After a rigorous review process, four articles have been accepted. They cover different aspects within this field.

Optical fiber is the primary solution of fronthaul. Advanced optical technologies are being actively developed in this direction. The first article, "WDM-PON for 5G Wireless Fronthaul" by Effenberger *et al.*, introduces China Telecom's trial of using wavelength-division multiplex passive optical network (WDM-PON) for 5G fronthaul. The trial demonstrates that the WDM-PON system can meet the 25 Gb/s rate required for 5G fronthaul. With 10 km fronthaul transport, the one-way system delay is around 56.2 μs, and the power budget reaches 24.97 dB. Typical fronthaul scenarios in the North America and Asia markets are further analyzed to resemble the 5G deployment diversity. The latest progress of WDM-PON standards in the International Telecommunication Union - Telecommunication Sector (ITU-T) is reviewed as a key industry effort of promoting the WDM-PON solution for 5G fronthaul.

The second article, "Point-to-Multipoint Coherent Architecture with Joint Resource Allocation for B5G/6G Fronthaul" by Fan *et al.*, proposes a flexible point-to-multipoint fiber architecture for 5G fronthaul based on optical coherent technologies. Coherent transceivers along with DSP are employed to facilitate subcarrier signal transmission between RUs and their associated DUs. A joint resource allocation algorithm is introduced to adjust wireless network resources such as modulation format, bandwidth, as well as launch power for the purpose of improving resource utilization efficiency. Simulation results illustrate that the proposal provides power saving with high bandwidth efficiency at increased transmission rate.

When fiber connection is neither feasible nor economically available, the wireless solutions for fronthaul come into play. The third article, "Wireless Fronthaul for 5G and Future Radio Access Networks: Challenges and Enabling Technologies" by Jiang *et al.*, investigates using millimeter-wave (mmWave) or higher bands for the 5G fronthaul transport. Challenges are overviewed based on the interfaces and requirements defined by industry groups such as the 3rd Generation Partnership Project (3GPP), Open RAN Alliance (O-RAN), and Small Cell Forum (SCF). Enabling technologies include fronthaul signal compression and optimizing line-of-sight multiple-input multiple-output (LOS-MIMO) transmission. Moreover, a deployment scenario using LOS-MIMO at 80 GHz is analyzed in detail. Experiments demonstrate robust and reliable performance to meet the high data rate demand of fronthaul.

The 5G network features a user-centric design with an open fronthaul interface between the RU and the DU. Some of the core and RAN functionalities are moved closer to the edge network. Fonthaul security is thus a critical issue. The last article, "Security Aspect of 5G Fronthaul" by Wong *et al.*, provides a thorough analysis of the fronthaul security vulnerabilities and threats. An overview of incremental improvements in the CPRI and eCPRI standards is provided with major security gaps being identified. Furthermore, necessary security enhancements are explored in multifold. First, the certificate enrollment procedure should consider signing the public key for RUs and DUs from different vendors. Second, the secure environment of a single 5G entity should be maintained in cases where the entity functions are split, virtualized, or implemented in different architectures. Third, the overall end-to-end security should be improved to fill the gaps of system vulnerability.

The Guest Editors thank all the authors for submitting their work, the anonymous reviewers for their insightful comments, and the Editor-in-Chief and *IEEE Wireless Communications* staff members for their strong support. Due to space limitations, many papers could not be published in this SI. We anticipate reading them in other publications. We hope that the readers enjoy this SI.

Biographies

Yuanqiu Luo [SM] (yuanqiu.luo@futurewei.com) received her Ph.D. degree in electrical engineering from the New Jersey Institute of Technology, Newark. She is currently a director of Optical Access Standards in Futurewei Technologies, USA. She has been heavily involved in the R&D effort of access networks for over 15 years. She is the Editor of IEEE Standard 802.3cp (Highspeed BiDi). She was a Clause Editor of IEEE

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Philippe Chanclou [M] (philippe.chanclou@orange.com) received his Ph.D. and Habilitation degrees from Rennes University, France, in 1999 and 2007, respectively. He joined the R&D facilities of France Telecom in 1996 where he worked on research of active and passive optical telecommunications functions for access networks. In 2000, he joined the University of ENST-Bretagne (now IMT Atlantique) as a senior lecturer where he was engaged in research on optical switching and optical devices using liquid crystal for telecommunications. During 2001 to 2003, he participated in the foundation of Optogone Company. In 2004, he joined Orange Labs where he was engaged in research on the next generation optical access networks. He is now manager of the Fixed Access Networks team. This team is active in delivery, anticipation, standardization, and research concerning FTTx topics for Home (Passive Optical Network), Enterprise (Passive Optical LAN), and Antenna (including the transport of radio access network interfaces "xhaul": backhaul, midhaul, fronthaul). Dr. Chanclou is a Senior Member of SEE and a member of SFO. He received the SPIE Rudolf Kingslake Medal and Prize in 2007.

Knud Erik Skouby (skouby@es.aau.dk) is a professor and founding director of the Center for Communication, Media and Information (CMI) technologies, Aalborg University-Copenhagen — a center providing a focal point for multi-disciplinary research and training in applications of CMI. His research areas include techno-economic analyses, development of mobile/ wireless applications and services, and regulation of telecommunications. He is a project manager and partner in a number of international, European, and Danish research projects. He has served on a number of public committees within telecom, IT, and broadcasting. He also served as a member of the Boards of professional societies, organizing boards, and evaluation committees, and as an invited speaker at international conferences. He has published a number of Danish and international articles, books, and conference proceedings papers. He is the Editor-in-Chief of the *Nordic and Baltic Journal of Information and Communication Technologies*, the Chair of WGA in the Wireless World Research Forum, and the past Department Chair of IEEE Denmark.

Hong Zhao (zhao@fdu.edu) is a professor of electrical and computer engineering at Fairleigh Dickinson University, New Jersey. Her research focuses on various aspects of broadband communications and computer security including network traffic/performance/security analysis and modeling, and hardware Trojan detection. She serves as Associate Editor of the *Journal on Multidimensional Systems and Signal Processing*, and Editor of the *Journal of Computing and Information Technology*. She also serves as the Vice Chair of the IEEE North Jersey Section. She has been a TPC member, Symposium Co-Chair, technical paper reviewer, and book reviewer for IEEE conferences, journals, magazines, and book publishers. She served as a Board Chair of the Wireless and Optical Communication Conference (2017–2018). She received the AFRL VFRP award in 2014–2016, the AFOSR SFFP award in 2017–2019, the Visiting Professor Award from the Ministry of Science and Technology Taiwan in 2015, and The 2015 IEEE Region 1 award for Outstanding Support for the Mission of the IEEE, MGA, REGION 1 and Section.

Kota Asaka (kota.asaka.mg@hco.ntt.co.jp) received B.S. and M.S. degrees in electrical engineering from Waseda University, 1996 and 1999, respectively, and a Ph.D. degree in physics from Kitasato University in 2008. In 1999, he joined NTT Photonics Laboratories, where he engaged in research on several photonics integrated circuits and low-cost optical subassemblies for access networks. Since 2012, he has been with NTT Access Service System Laboratories, where he is engaged in R&D of next-generation optical access networks. He has contributed to several standardization organizations, such as IEC SC86C/WG4, ITU-T Q2/SG15, FSAN, and BBF. His recent activities focus on the development of disaggregation technologies in access systems including contributions to the SEBA project at ONF.