DIGITAL SIGNAL PROCESSING IN OPTICAL FIBER COMMUNICATION

WORKSHOP

OCTOBER 25, 2021

Projects REAL-NET and FONTE have received funding from the EU H2020 research and innovation programme under the Marie Skłodowska-Curie GA 813144 and GA 766115, respectively.

The workshop on Digital Signal Processing in Optical Fiber Communication will bring together researchers from the fields of fiber-optic transmission, digital signal processing (DSP) and machine learning, to discuss advances in digital communication over optical fiber. The focus is on equalization of channel impairments, hardware implementation of DSP algorithms and transceiver design based on neural networks. The workshop should promote interaction and collaboration among the participants from academia and industry.

TOPICS OF INTEREST

- Equalization in optical fiber communication
- DSP in fiber-optic transmission
- Hardware implementation of communication algorithms
- Transceiver design based on neural networks

ORGANISING COMMITTEE

- Mansoor Yousefi (TPT), chair of the workshop
- Sergei Turitsyn (AiPT)
- Antonio Napoli (Infinera)
- Erwan Pincemin (Orange)
- Pedro Freire (Aston, ESR's representative)

Workshop is jointly organised by projects **REAL-NET** and **FONTE**.

REAL-NET is an MSCA-ITN-EID collaborative European project, including AITP at Aston University, Telecom Paris at Institut Polytechnique de Paris, UPC, and the industry partners Infinera and Orange.

FONTE is an MSCA-ITN-EID collaborative European Industrial Doctorate, including AITP at Aston University, Telecom Paris at Institut Polytechnique de Paris, Technical University of Denmark (DTU), Delft University of Technology (TU Delft) and industry partner Nokia Bell Labs.

SPEAKERS

- **Sebastian Randel**, Karlsruhe Institute of Technology, "The role of digital signal processing in optical communications"
- **Laurent Schmalen**, Karlsruhe Institute of Technology, "End-to-end Optimization of Short-Reach Optical Communications Using Deep Learning"
- **Christian Häger**, Chalmers University, "Physics-Based Machine Learning for Fiber-Optic Communication Systems"
- **Marco Secondini**, Sant'Anna School of Advanced Studies, "New lower bounds on the capacity of optical fiber channels via optimized shaping and detection"
- **Sebastien Bigo**, Nokia Bell Labs France, "Brighter networks are smarter"
- **Alan Pak-Tao Lau**, The Hong Kong Polytechnic University, "Machine Learning for Fiber Nonlinearity Compensation"
- **Maxim Kuschnerov**, Huawei Munich, "Signal processing evolution for the 1.6Tb/s generation of data center networks"
- **Darko Zibar**, TU Denmark, *"Towards intelligence in photonic systems"*

AGENDA

Morning session

CEST-time: Brussels/Paris/Berlin; for the UK subtract 1 hrs (start 08:00)

- **9:00 – 9:15 Mansoor Yousefi, Welcome**
- **9:15 – 10:00 Sebastian Randel, "The role of digital signal processing in optical communications"**
- **10:00 – 10:45 Laurent Schmalen, "End-to-end Optimization of Short-Reach Optical Communications Using Deep Learning"**
- **10:45 – 11:00 Coffee break**
- **11:00 – 11:45 Marco Secondini, "New lower bounds on the capacity of optical fiber channels via optimized shaping and detection"**
- **11:45 – 12:30 Alan Pak-Tao Lau "Machine Learning for Fiber Nonlinearity Compensation"**

AGENDA

Afternoon session

CEST-time: Brussels/Paris/Berlin; for the UK subtract 1 hrs (start 13:00)

- **14:00 – 14:45 Darko Zibar, "Towards intelligence in photonic systems"**
- **14:45 – 15:30 Sébastien Bigo, "Brighter networks are smarter"**
- **15:30 – 15:45 Coffee break**
- **15:45 – 16:30 Christian Häger, "Physics-Based Machine Learning for Fiber-Optic Communication Systems"**
- **16:30 – 17:15 Maxim Kuschnerov, "Signal processing evolution for the 1.6Tb/s generation of data center networks"**

MORE ABOUT TALKS AND SPEAKERS

SEBASTIAN RANDEL

Karlsruhe Institute of Technology

TALK TITLE: The role of digital signal processing in optical communications

Sebastian Randel received the Dr.-Ing. degree for his work on high-speed optical-time-division-multiplexed transmission systems from Technische Universitat Berlin, Berlin, Germany, in 2005. He is currently a Professor with the Karlsruhe Institute of Technology, Karlsruhe, Germany, where he is heading the Institute of Photonics and Quantum Electronics. From 2005 to 2010, he was a Research Scientist at Siemens Corporate Technology, Munich, Germany, where he led research and standardization activities in the fields of polymer- optical-fiber communication, visible-light communication, and optical access networks.

From 2010 to 2016, he was a Member of Technical Staff at Bell Laboratories, Holmdel, NJ, USA. In this role, he designed, tested, and implemented power-efficient DSP algorithms for high-performance coherent optical transceivers. He first demonstrated that a digital multiple-input multiple-output equalizer can fully compensate mode coupling in few-mode fibers. In 2014, he demonstrated dual-polarization coherent-optical 64-QAM transmission at a record-high symbol rate of 72 GBd enabled by advanced DSP algorithms. He has (co-)authored more than 200 publications in peer-reviewed journals and conference proceedings and has filed more than 30 patent applications. His current research is focused on densely integrated optical communication systems. He received the 2012 Best Paper Award from the IEEE/OSA Journal of Lightwave Technology. He serves as a Subcommittee Chair of the Optical Fiber Communication Conference 2018.

LAURENT SCHMALEN

Karlsruhe Institute of Technology

TALK TITLE: Physics-Based Machine Learning for Fiber-Optic Communication Systems

Laurent Schmalen is a full professor at Karlsruhe Institute of Technology (KIT) in Karlsruhe, Germany, where he heads the Communications Engineering Lab (CEL). From 2011 to 2019, he was a member of technical staff and department head at Nokia Bell Labs in Stuttgart, Germany. He joined Bell Labs after receiving his Ph.D. from RWTH Aachen University in Germany. His research topics include forward error correction algorithms and digital coded modulation schemes for high-speed optical communications. He received multiple awards for his research work, including the 2016 Journal of Lightwave Technology Best Paper Award, has more than 120 publications in journal and conference papers, has co-authored 4 book chapters and holds several patents.

ABSTRACT: Short reach optical fiber communications rely on the intensity modulation/direct detection (IM/DD) technology to enable simple and inexpensive solutions in many data center, metro and access network scenarios. IM/DD links are severely impaired by fiber dispersion as well as non-linearity and noise stemming from the low-cost transmitter and receiver hardware components. Thus, digital signal processing (DSP) is required for increasing the data rate and transmission reach of such systems. However, there is a lack of optimal, computationally feasible DSP algorithms for communication over the dispersive non-linear IM/DD channel. This necessitates the use of carefully chosen approximations to better exploit the data transmission potential over the optical links. The presentation discusses the application of artificial neural networks (ANN) and deep learning in the design and optimization of DSP modules for short reach optical IM/DD communication systems. The focus is on the implementation of fully learnable ANN transceivers, also known as auto-encoders, together with their experimental validation as well as novel techniques for equalization.

CHRISTIAN HÄGER

Chalmers University

TALK TITLE: Physics-Based Machine Learning for Fiber-Optic Communication Systems

Christian Häger is an assistant professor in the Communication Systems research group. He received the Dipl.-Ing. degree (M.Sc. equivalent) in electrical engineering from Ulm University, Germany, in 2011 and his Ph.D. degree in communication theory from Chalmers University of Technology, Sweden, in 2016. From 2016 until 2019, he was a postdoctoral researcher at the Department of Electrical and Computer Engineering at Duke University, USA. Since 2017, he is a postdoctoral researcher at the Department of Electrical Engineering at Chalmers University of Technology. His research interests include modern coding theory, fiber-optic communications, and machine learning. He received the Marie Sklodowska-Curie Global Fellowship from the European Commission in 2017.

ABSTRACT:
Rapid improvements in machine learning over the past decade are beginning to have far-reaching effects. In this work, we propose a new machine-learning approach for fiber-optic systems in which signal propagation is governed by the nonlinear Schrödinger equation (NLSE). Our main idea is to exploit the fact that the popular split-step method for numerically solving the NLSE has essentially the same functional form as a "deep" multi-layer neural network; in both cases, one alternateslinear steps and pointwise nonlinearities. We demonstrate that this connection allows for a principled machine-learning approach by appropriately parameterizing the split-step method and viewing the linear steps as general linear functions, similar to the weight matrices in a neural network. The resulting physics-based machine-learning model has several key advantages compared to conventional "black-box" function approximators. For example, it allows us to easily examine and interpret the learned solutions in order to understand why they perform well.

MARCO SECONDINI

Sant'Anna School of Advanced Studies

TALK TITLE: New lower bounds on the capacity of optical fiber channels via optimized shaping and detection

Marco Secondini received the M.S. degree in Electrical Engineering from the University of Roma Tre, Rome, Italy, in 2000, and the Ph.D. degree from Scuola Superiore Sant'Anna, Pisa, Italy, in 2006. In 2005, he was a Visiting Faculty Research Assistant with the Photonics Group, University of Maryland Baltimore County, Baltimore, USA. Since 2007, he has been with Scuola Superiore Sant'Anna, where he currently serves as an Assistant Professor of Telecommunications. He served in the technical program committees of the OFC, the ECOC, the ACP, the GLOBECOM, and the ICC.

His research interests are in the area of optical fiber communications, with a special focus on information theoretical aspects, modulation and detection techniques, and fiber nonlinearity modelling. In this area, he has coauthored more than 120 papers in leading journals and conferences.

ABSTRACT:

Constellation shaping is a practical and effective technique to improve the performance of optical communication systems. Some recent works suggest that it could also be used to mitigate the impact of nonlinear effects, possibly increasing the information rate beyond the current limit dictated by fiber nonlinearity. This appealing idea is frustrated by the difficulty of designing an effective shaping strategy that take into account the nonlinearity and long memory of the fiber channel, as well as the possible interplay with other nonlinearity mitigation strategies. As a result, only little progress has been made so far, and both the optimal shaping distribution and the ultimate channel capacity remain unknown. In this work, we describe a novel technique to optimize the shaping distribution in a very general setting and large-dimensional space. In a simplified scenario, the proposed technique allows to study the asymptotic behavior of channel capacity at high power. In a more realistic WDM scenario, the technique can be combined with an improved (non-Gaussian) detection metric to estimate new capacity lower bounds.

SÉBASTIEN BIGO

Nokia Bell Labs France

TALK TITLE: Brighter networks are smarter

Sébastien Bigo graduated from the Institut d'Optique Graduate School, in 1992. In 1996, he received a PhD degree in physics for a work devoted to all-optical processing and soliton transmission. He joined Alcatel Research & Innovation (now Alcatel-Lucent Bell Labs) in 1993, while being a student at the University of Besançon, France. In 1997, he started studying high-capacity WDM terrestrial systems, and conducted large-scale demonstration experiments, at 10Gbit/s, 40Gbit/s, 100Gbit/s and 100Gbit/s channel rates. He is currently heading a research team devoted to optical networks. He has authored and co-authored more than 230 journal and conference papers, and 35 patent.

ABSTRACT:

The race to the Shannon limit is over. The race for automation is just starting. While optics is becoming pervasive in all segments of networks, innovations are shifting from capacity growth to operation simplification. Digital coherent optics collects a multiplicity of indicators which help eliminate over-dimensioning, proactively detect failures and correct failures instantaneously, while providing useful insight on the environment.

ALAN PAK-TAO LAU

The Hong Kong Polytechnic University

TALK TITLE: Machine Learning for Fiber Nonlinearity Compensation

Alan Pak Tao Lau obtained the B.A.Sc. in Engineering Science (Electrical Option) and M.A.Sc. in Electrical and Computer Engineering from the University of Toronto in 2003 and 2004 respectively. He worked on source coding techniques for wireless communication systems utilizing multiuser diversity for his masters' thesis research. He then obtained the Ph.D. degree in Electrical Engineering at Stanford University in 2008. He is the recipient of numerous government awards during his post-graduate study at Stanford University. He also worked at NEC Labs America in 2006 as a research associate in the Optical Networking Division. His current research interests include system designs and signal processing techniques for coherent fiber-optic communication systems and multi-mode fiber communication systems. He joined the Electrical Engineering Department at the Hong Kong Polytechnic University as an Assistant Professor in Fall 2008.

ABSTRACT:
In this talk, we will review Machine Learning applications for fiber nonlinearity compensation, additional insights gained by machine learning and new coding platforms to combine optical communications DSP and Machine Learning algorithms.

MAXIM KUSCHNEROV

Huawei Munich

TALK TITLE: Signal processing evolution for the 1.6Tb/s generation of data center networks

Maxim Kuschnerov is a Director of the Optical and Quantum Communications Laboratory at Huawei:
– Manager of the optical research lab at the Munich Research Center
– Member of the CTO Office of the Transmission & Access Product Line
– Leading research activities covering data center networks and interfaces, coherent optical communication for data center interconnect/metro/edge, optical switching, next generation access, quantum key distribution.

ABSTRACT:
Future optical interconnects for data center connectivity will evolve to and beyond 1.6Tb/s, although the technology might see some fundamental shifts depending on the limitations of direct detection receivers and the abilities of coherent optics. In this talk, the evolution of short reach interconnects is discussed with respect to modulation, synchronization, equalization and FEC with an emphasis on power consumption, interoperability and cost. The role of deep learning will be shown in the context of DSP design, evaluating the proper infliction point into commercial transceiver architectures. Paths beyond Moore’s law will be discussed, addressing innovation at component, module and system level.

DARKO ZIBAR
TU Denmark

TALK TITLE: Towards intelligence in photonic systems

Darko Zibar is Associate Professor at the Department of Photonics Engineering, Technical University of Denmark and the group leader of Machine Learning in Photonics Systems (M-LiPS) group. He received M.Sc. degree in telecommunication and the Ph.D. degree in optical communications from the Technical University of Denmark, in 2004 and 2007, respectively. He has been on several occasions (2006, 2008 and 2019) visiting researcher with the Optoelectronic Research Group led by Prof. John E. Bowers at the University of California, Santa Barbara, (UCSB).

At UCSB, he has been working on topics ranging from analog and digital demodulation techniques for microwave photonics links and machine learning enabled ultra-sensitive laser phase noise measurements techniques. In 2009, he was a visiting researcher with Nokia-Siemens Networks, working on clock recovery techniques for 112 Gb/s polarization multiplexed optical communication systems. In 2018, he was visiting Professor with Optical Communication (Prof. Andrea Carena, OptCom) group, Dipartimento di Elettronica e Telecomunicazioni, Politecnico di Torino working on the topic of machine learning based Raman amplifier design. His resresearch efforts are currently focused on the application of machine learning technqiues to advance classical and quantum optical communication and measurement systems. Some of his major scientific contributions include: record capacity hybrid optical-wireless link (2011), record sensitive optical phase noise measurement technique that approaches the quantum limit (2019) and design of ultrawide band arbitrary gain Raman amplifier (2019). He is a recipient of Best Student paper award at Microwave Photonics Conference (2006), Villum Young Investigator Programme (2012), Young Researcher Award by University of Erlangen-Nurnberg (2016) and European Research Council (ERC) Consolidator Grant (2017). Finally, he was a part of the team that won the HORIZON 2020 prize for breaking the optical transmission barriers (2016).

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