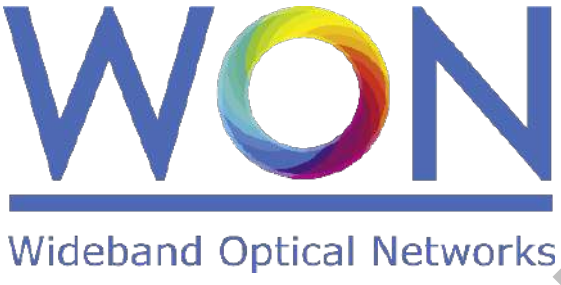

Wideband Optical Networks [WON]

Grant agreement ID: 814276

WP5 – Innovative personal career training

Deliverable D5.2 Network-wide training workshops held

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement 814276.

Document Details

Work Package	W5 – Innovative personal career training
Deliverable number	D5.2
Deliverable Title	Network-wide training workshops held
Lead Beneficiary:	Aston University
Deliverable due date:	30 June 2023
Actual delivery date:	30 June 2023
Dissemination level:	Public

Project Details

Project Acronym	WON
Project Title	Wideband Optical Networks
Call Identifier	H2020-MSCA-2018 Innovative Training Networks
Coordinated by	Aston University, UK
Start of the Project	1 January 2019
Project Duration	48 months
WON website:	https://won.astonphotonics.uk/
CORDIS Link	https://cordis.europa.eu/project/rcn/218205/en

WON Consortium and Acronyms

Consortium member	**Legal Entity Short Name**
Aston University	Aston
Danmarks Tekniske Universitet	DTU
VPIphotonics GmbH	VPI
Infinera Portugal	INF PT
Fraunhofer HHI	HHI
Politecnico di Torino	POLITO
Technische Universiteit Eidhoven	TUE
Universiteit Gent	UG
Keysight Technologies	Keysight
Finisar Germany GmnH	Finisar
Orange SA	Orange
Technische Universitaet Berlin	TUB
Instituto Superior Tecnico, University of Lisboa	IST

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ABBREVIATIONS

AIPT	Aston Institute of Photonic Technologies
BT	British Telecom
EID	European Industrial Doctorate
ESR	Early Stage Researcher
ETN	European Training Network
GA	Grant Agreement
H2020	Horizon 2020
IAB	Industrial Advisory Board
ITN	Innovative Training Network
ML	Machine Learning
OTAW	Open-to All Workshop
TSW	Transferable Skills Workshop
UCL	University City London
UWB	Ultra-wideband
WON	Wideband Optical Network
WP	Work Package

EXECUTIVE SUMMARY

Deliverable D5.2, titled "Network-wide training workshops held" is part of the Work Package 5 "Innovative personal career training" of the "Wideband Optical Networks" (WON) project. WON is a European Training Network funded by the European Commission under the Horizon 2020 MSCA Grant Agreement ID: 814276.

Coordinated by Aston University, the WON Consortium consists of world-leading groups working in the area of wideband optical networks, which have already made significant contributions to this booming field: eight academic institutions, namely: Aston University (UK); Politecnico di Torino (Italy); Fraunhofer HHI (Germany), Technical University Eindhoven (Netherlands), Technical University of Denmark – DTU(Denmark), Ghent University (Belgium) and five industrial companies: VPIphotonics GmbH (Germany), Infinera Portugal (Portugal), Keysight GmbH (Germany), Finisar (Germany) and Orange SA (France).

WON's main objective is to train Early Stage Researchers (ESRs) in the unexploited area of wideband optical networks in three main areas:

1. Network management and control plane algorithms
2. Design, prototyping, and testing of transceiver and in-line components
3. Digital signal processing techniques and system modelling

The project started on January 1, 2019, and ended on June 30, 2023.

WON's objectives were achieved through an innovative, multidisciplinary, inter-sectorial training programme delivered through the following mechanisms: i) training through research; ii) network-wide training events, including transferable skills workshops; iii) local training activities; and iv) a secondment program. This deliverable provides an overview of the network-wide training events organised by the project consortium in line with the Annex I Description of Work of the GA, including annual project workshops, open-to-all workshops and mini-symposia, Transferable Skills workshops and online training courses. Some training events were co-organised together with H2020 ITN projects coordinated by AIPT/Aston University, such as EID FONTE (GA 766155), EID REAL-NET (GA 813144), EID MOCCA (GA 814276).

There were some deviations in the schedule of events due to the withdrawal of two beneficiaries from WON following project amendments. Furthermore, the format of many events was changed to virtual and online due to the COVID-19 pandemic and various restrictions in place. It provided an incredible opportunity for the events' organisers to invite and engage with many high-calibre speakers and lecturers worldwide.

1 LIST EVENTS ORGANISED BY WON

Training Type	Title	Lead Beneficiary	Dates
WON Annual Workshops	WON Introduction Training	INF G (COR G)	18-19 November 2019
	1st Year WON Workshop	Aston	26 February 2020
	2nd Year WON Workshop	DTU, Aston	23 April 2021
	3nd Year WON Workshop	HHI	9 February 2022
	Final WON workshop	PoliTo	21-22 June 2022
Transferable Skills Workshops (TSW)	TSW 1	Aston	27-28 February 2020
	TSW 2	Aston	22-24 March 2021
	TSW 3	Aston	24-25 March 2022
Open-to All Workshops (OTAW)	OTAW 1 Machine learning applied to optical communication	DTU	7-8 September 2020
	OTAW 2 Modelling of photonic components and systems	HHI	7-8 February 2022
	OTAW 3 Current and future trends for optical communication systems	DTU	7-8 April 2022
Online courses	Online training course on silicon photonics	UG	5 November 2020
	Online training course on optimal design of wideband optical systems	PoliTo	5-6 July 2021
	Online training on design challenges for next generation optical networks	INF PT	
	Online training course on Wideband Optical Switches	TUE	8-9 November 2021
Mini-symposium	Numerical implementation of Bayesian filtering for signal equalization and demodulation:	DTU	28 October 2020
Intensive training course	Design and modelling of optical communication systems and photonic components	VPI, HHI, Orange	10-12 June 2020
ECOC Workshop	WON Special Event at ECOC 2021 Conference	All	13 September 2021
Additional training events organised and co-organised by the WON Beneficiaries (not covered in Deliverable 5.2)			
PhD course	PhD course "Optical Transport Network"	PoliTo	Jan-February 2021
Summer school	Lake Como School of Advanced Studies "Machine Learning in Photonics"	Aston	15-19 March 2021
Summer school	Summer School on AI for Optical Networks & Neuromorphic Photonics for AI Acceleration	HHI	6-10 September 2021

2 RECRUITED COHORT OF ESRs

ERS N	Name	Recruiting Beneficiary	PhD programme enrolment
ESR 1	Rasoul Sadeghi Yamchi	Politecnico di Torino	Politecnico di Torino
ESR 2	Thyago Monteiro Sá Pinto	Technical University of Denmark – DTU	Technical University of Denmark – DTU
ESR 3	André Luiz Nunes de Souza	Infinera Portugal	Instituto Superior Tecnico (IST), University of Lisboa
ESR 4	Bruno Vinicius de Araujo Correia	Politecnico di Torino	Politecnico di Torino
ESR 5	Elliot Peter London	Politecnico di Torino	Politecnico di Torino
ESR 6	Gabriele Di Rosa	VPIphotonics GmbH	Technical University Berlin, TUB
ESR 7	Caio Marciano Santos	Fraunhofer HHI	N/A
ESR 8	Pratim Hazarika	Aston University	Aston University
ESR 9	Yu Wang	Eindhoven University of Technology	Eindhoven University of Technology
ESR 10	Rafael Magalhães Gomes Kraemer	Eindhoven University of Technology	Eindhoven University of Technology
ESR 11	Aleksandr Donodin	Aston University	Aston University
ESR 12	Matheus Sena	Fraunhofer HHI	Technical University Berlin, TUB
ESR 13	Yaonian Cui	Fraunhofer HHI	N/A
ESR 14	Emadreza Soltanian	Ghent University	Ghent University

3 ANNUAL WORKSHOPS

3.1 Introduction Workshop

Date: 18-19 November 2019
Venue: Munich, Germany
Organiser: Coordinator Aston University and COR G INF G team, Dr Antonio Napoli
Participants: WON Consortium, newly recruited project's ESRs

Overview:

The primary objective of the workshop was to enhance interactions among the consortium members, specifically with the newly appointed ESRs (see the list below), providing them with opportunities to discuss research topics linked to the project. The two-day event incorporated scientific and training components strategically designed to familiarize ESRs with state-of-the-art technologies and specific research undertakings within every work package of WON. During the sessions, ESRs shared information about their educational backgrounds, accomplishments, achievements, and previous experience. They also presented their future plans, which complemented the overall understanding of the project's objectives and goals. Guided by the expertise of WON's Coordinators, Prof. Wladek Forysiak and Dr. Antonio Napoli, as well as the WP leaders and supervisors, the sessions facilitated open discussions on technical topics, helping the ESRs connect their individual research initiatives with the scientific outcomes of the WON project. Additionally, the Project Manager of WON presented an overview of the project, focusing on its alignment with the grant agreement GA. The presentation highlighted crucial project aspects such as the timeline, the schedule of network-wide training events, the secondment programme, and the consortium's plans for outreach and dissemination activities.

Agenda:

Day 1_18 November 2019

09:00-09:30 Welcome, Introductions
09:30-10:30 Project overview / Dr Antonio Napoli and Prof Wladek Forysiak
10:30-13:00 Presentations of the WON partners: different expertise within the project. ESRs talks
13:00-14:30 Lunch
14:30-16:00 Introduction to the projects. WPs breakdown
16:00-16:30 Break
16:30-18:00 Network training activities and communication /

Day 2_19 November 2019

09:00-09:30 Arrival
09:30-12:30 Technical discussions within the WPs. Divide work and prioritize synergies.
12:30-14:00 Lunch
14:00-15:00 Technical discussion & strategic planning session
15:00-17:00 Cross WP discussion. Conclusions. Closing.

The following ESRs, who started to work in the project, attended the Introduction Workshop:

ESR 1 Rasoul Yamchi Sadeghi
ESR 2 Thyago Monteiro
ESR 5 Elliot London
ESR 6 Gabriele Di Rosa
ESR 9 Yu Wang
ESR 10 Rafael Kraemer
ESR 11 Aleksandr Donodin
ESR 12 Matheus Sena
ESR 13 Yaonian Cui
ESR 14 Emadreza Soltani

ESR3, ESR4, ESR7, and ESR8 did not commence their positions in WON at the time of the workshop organisation due to various delays in the recruitment process. ESR4, Bruno Correia, and ESR8, Pratim Hazarika, delivered introductory presentations at the 1st-year workshop at Aston – please refer to section 3.2.

ESR3, André Luiz Nunes de Souza, joined the project in January 2021, and ESR7, Caio Marciano Santos, joined in September 2021.

Figure 1: WON Consortium at the Introduction Workshop, Munich, 2019

3.2 1st Year Workshop

Date:	26 February 2020
Venue:	Aston University, Birmingham, UK
Organiser:	Coordinator Prof Wladek Forysiak and Aston University team
Participants:	WON and REAL-NET Consortia

Overview:

The 1st year WON workshop was co-organised together with the REAL-NET Consortium. The main pupose of the event was to review the progress made by the project's team in the first year. The event was divided into three main sessions: i) presentations on the state of the art in WPs ii) talks of invited speakers, including two members of the WON Industrial Advisory Board (IAB); presentations of WON and REAL-NET ESRs on the progress and results achieved in the first year of the project.

Invited Speakers:

Lidia Galdino | Lecturer, Royal Academy of Engineering Research Fellow at UCL

Dr Lidia Galdino received M.Sc. and Ph.D. degrees in electronic and electrical engineering from the University of Campinas, Brazil, in 2008 and 2013, respectively. Dr Galdino commenced a lectureship and a Royal Academy of Engineering Research Fellowship in September 2018 on the topic of "Capacity-approaching, Ultra-Wideband Nonlinear optical Fibre Transmission System", and a co-investigated in the EPSRC TRANSNET programme grant. She previously worked as a Senior Research Associate on the EPSRC UNLOC programme grant. She is Associate Editor of Optical Fiber Technology and part of the Technical Programme Committee for IEEE Photonic Conference (IPC) and Associated Vice President of IEEE's Women in Photonic Dr Galdino was a co-recipient of the RAEng Colin Campbell Mitchell Award in 2015 for pioneering contributions to optical communications technology and named as one of the 2017 "Top 50 Women in Engineering under 35" by The Telegraph and Women in Engineering Society which features the U.K.'s top rising female stars of engineering.

Andrew Lord | BT Group | WON IAB external advisor

Andrew joined BT in 1985 after a BA in Physics from Oxford University. He has helped design a wide range of optical network systems and technologies, including long haul subsea and terrestrial DWDM networks. He has been responsible for optical fibre and systems specifications. He currently leads BT's optical core and access research including optical access, high speed transmission, Software Defined Networking and Quantum Communications. He has recently initiated BT's quantum research, with applications in areas such as secure communications, timing and sensing. He regularly speaks at conferences, sits on several organising committees, including ECOC and was Technical Program Chair for OFC 2015 and General Chair for OFC 2017. He is an associate Editor of Journal of Lightwave Technology, is Visiting Professor at Essex University, Senior Member of the IEEE and a Chartered Engineer with the IET. He is industrial chair of NDFIS (National Dark Fibre Infrastructure). He is a project manager of the EU Horizon 2020 project 'Metro-Haul' researching optical networks for 5G.

Ian McClean | Product Manager, II-VI Photonics | WON IAB external advisor

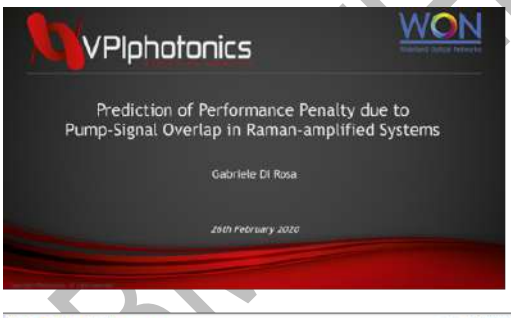
Ian McClean is Product Manager for II-VI Photonics in Paignton, UK, where he specialises in the development of ROADM products for optical networks. With 23 years of experience in optical amplifier design for Nortel Networks, Bookham Technology, and Oclaro, Dr. McClean is a respected leader in the field and has written multiple patents and papers on various technology aspects for optical components. He is a Chartered Engineer with the IET and serves as a PI for the IEC's standards working groups on optical amplifiers and dynamic modules. Dr. McClean is a member of the ECOC Technical Sub-Committee on Fibre, Fibre and Free Space Devices, and Fibre Amplifiers. He also serves as an External Industrial Adviser for the WON Industrial Advisory Board and the EE and PE post-graduate Industrial Steering Committee at Aston University. He obtained B.Eng. and M.Eng. degrees in Electronic & Electrical Engineering from the University of Bradford and holds a Ph.D. in Engineering focussing on II-VI thin-film semiconductor device development.

Agenda:

08:45 – 09:15 Arrival, Opening

09:15 – 09:30	Introduction and News: Prof Wladek Forysiak, Aston, Dr Antonio Napoli, INF G/ COR G
09:30 – 10:30	Talks on the state of the art in WP Network management: planning and control – Dr Nelson Costa, INF PT Digital signal processing and system modelling – Dr Antonio Napoli, INF G
10:30 – 11:00	Coffee break
11:00 – 12:00	Talks on the state of the art in WP State of the art in amplifiers – Dr Ian McClean, II-VI Photonics State of the art of ultra-wideband modulators – Dr Gerrit Fiol, HHI
12:00 – 13:00	Lunch
13:00 – 14:30	Invited Talks (45 min each) The future of optical fibre communications: an operator's perspective – Prof Andrew Lord, BT State of the art in digital coherent transmission – Dr Lidia Galdino, UCL
14:30 – 15:00	Coffee break
15:00 – 16:30	ESRs talks on the progress: "Introduction" – Pratim Hazarika, Aston University "Theory and applications of models for nonlinear wideband optical transmission" – Bruno Correia, PoliTo "Prediction of Performance Penalty due to Pump-Signal Overlap in Raman-amplified Systems"– Gabriele Di Rosa, VPI "Network Performance Assessment with Uniform and Non-Uniform Nodes Distribution in C+ andrades vs. Fiber Doubling SDM Solutions" – Rasoul Sadeghi, PoliTo "Progress Update; Machine Learning for OLS Controllers, SPM Accumulation" – Elliot London, PoliTo "E, S, C and L-Band wavelength switching on a single device" – Rafael Kraemer, TUE
16:30 – 17:00	"Do's and don't's of an ESR – how to make the most of it", Md Asif Iqbal, Auro Perego, Aston
17:00 – 18.00	Discussion, ESR networking, closing

Snapshots of slides:



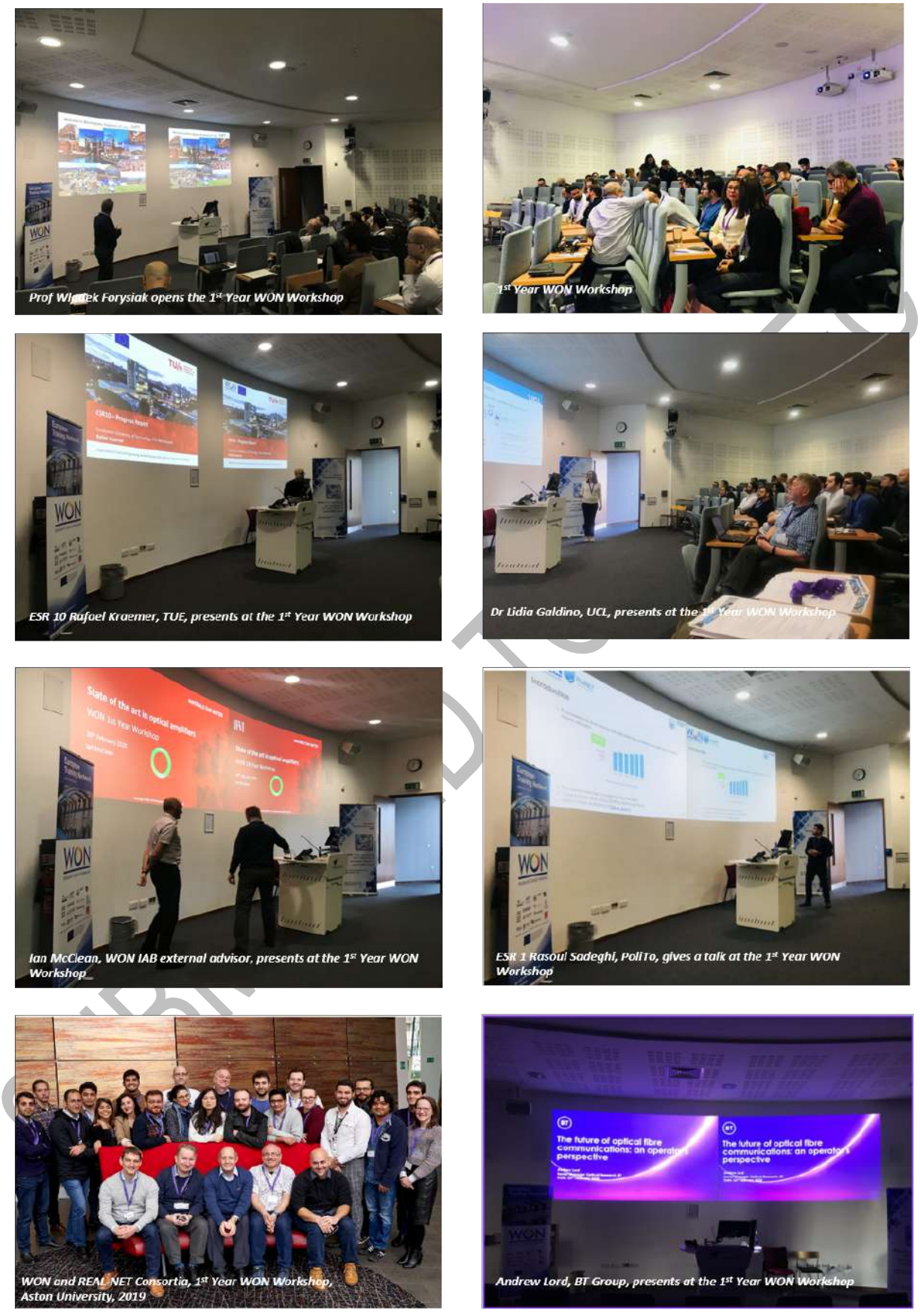


Figure 2: 1st Year WON Workshop, Aston University, 2020

3.3 2nd Year Workshop

Date: 23 April 2021
Venue: Virtually and online
Participants: WON Consortium

Overview:

The 2nd Year WON workshop was held virtually and online, due to the COVID-19 pandemic. Initially planned to be held at DTU, the Workshop was designated for a comprehensive day of technical presentations and updates, provided by the WP leaders and beneficiaries' leads, who reported on the accomplished progress made within each WP. The event was mainly built around technical presentations of ESRs, as well as their plans for the upcoming year, including preparation of secondment visits, publications strategies and participation in scientific conferences. After each presentation there was time for open discussion and Q&A sessions.

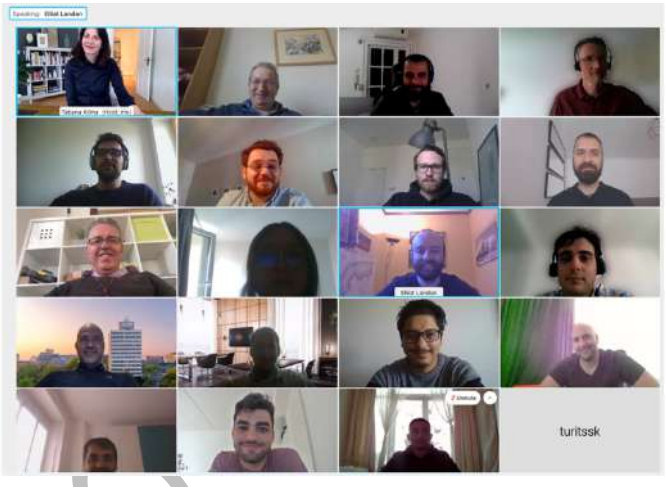


Figure 3: WON team at the 2nd Year Workshop, Virtually, 2021

Title of talks presented by ESRs at the Workshop:

- Performance Comparison of Translucent C-band and Transparent C+L-band Network – by Rasoul Sadeghi, PoliTo;
- Optical Frequency Combs Optimization using Metaheuristics algorithm – by Thyago Monteiro, DTU;
- First Steps and Future Plans – by Andre Souza, INF PT;
- Metaheuristic Applied to Optical Power Control for C+L+S-bands Network Performance – by Bruno Correia, PoliTo;
- Nonlinear noise generation through flex-grid, flex-rate LPs and leading impairments in wideband optical transmission – by Elliot London, PoliTo;
- Scientific progress update, results of the 2nd year – by Gabriele Di Rosa, VPI;
- Impact of Chromatic Dispersion in Discrete Raman Amplifiers on Coherent Transmission Systems – by ESR 8 Pratim Hazarika, Aston;
- Ultra-wide band (O to L) polymer TIR thermo-optic switch matrix – by Yu Wang, TUE
- Converged multi-band metro transport architecture for 5G and beyond and Impact of Cascaded Multi-Band 1x2 Photonic Integrated WSS in Metro-Access Networks – by Rafael Kraemer, TUE
- 4-channel E-band data transmission over 160 km of SMF-28 using bismuth-doped fibre amplifier – by Aleksandr Donodin, Aston
- Network monitoring through link discovery and the advantages of using C-band technology to enable multiband systems – by Matheus Sena, HHI
- InP based Multimode Interference (MMI) coupler with Sub-Wavelength Grating (SWG) structure – by Yaonian Cui, HHI
- Towards the Tunable narrow-linewidth III-V/Si Lasers by uTP – by Emadreza Soltanian, UG

3.4 3rd Year Workshop

Date:	9 February 2022
Venue:	Virtually and online due to COVID
Organiser:	Beneficiary Fraunhofer HHI, Dr Johannes K. Fischer
Participants:	WON Consortium

Overview:

The 3rd year WON workshop was organised by the beneficiary Fraunhofer HHI and was held virtually and online. The Fraunhofer HHI team had initially planned to host the workshop at their premises in Berlin following the OTAW II, which was collocated with the Workshop: ITG Expert Group KT 3.1 "Modeling and Simulation of Photonic Components and Systems". However, due to various restrictions related to the pandemic that were in place at that time, the decision was made to conduct both workshops virtually and online. Just like all WON annual workshops, the 3rd year workshop offered an opportunity for the ESRs to report on results with their research projects, specific project's tasks carried in the reported year, as well as progress with their PhD program. During their presentations, the ESRs showcased the technical results and provided summaries of their ongoing professional development, such as submitted and upcoming publications, outreach and science communication activities, and their plans for the next year aligned with their Career Development Plan. The workshop was also a platform for in-depth scientific discussions with the senior team – including WP leaders, supervisors, and co-supervisors. An external invited speaker, Jörg-Peter Elbers from ADVA, presented a talk about the future of optical fibre communications from a system vendor's perspective. ADVA Optical Networking SE is a European telecommunications vendor that provides network equipment for data, storage, voice and video services.

Agenda:

09:00 – 09:20 Welcome, Introduction and News – WON Coordinators
09:20 –09.40 Progress in the project WPs
WP1: Network management: planning and control – Dr Nelson Costa, INF PT
WP2: Digital signal processing and system modelling – Prof Vittorio Curri, PoliTo
WP3: In-line Components Design – Prof Wladek Forysiak, Aston
WP4: Transceiver components design – Dr Johannes Fischer, HHI
09:40 –10:20 Invited Talk: "The future of optical fibre communications: a system vendor's perspective" Jörg-Peter Elbers, ADVA
10:20 –10:40 Coffee break
10:40 –11:40 ESRs talks on the progress and results:

- "QoT Evaluation of Optical Line System Transmission with Bismuth-Doped Fiber Amplifiers in the E-Band" – Bruno Vinícius Correia, PoliTo
- "Optimal Spectral Usage and Energy Efficient S-to-U Multiband Optical Networking" – Rasoul Sadeghi Sadeghi, PoliTo
- "Raman and Power Optimization for Wideband Systems" – André Souza, INF PT
- "End-to-End Deep Learning in Multi-Band Optical Communication Systems – First Steps" –
- Caio Marciano Santos, HHI
- "DSP-based Link Tomography for Amplifier Gain Estimation and Anomaly Detection in C+L-band Systems" – Matheus Sena, HHI
- "Characterization, Monitoring, and Mitigation of the I/Q Imbalance in Standard C-Band Transceivers in Multi-band Systems" – Gabriele Di Rosa, VPI
- "Reinforcement Learning applied to Optical Frequency Combs" - Thyago Monteiro, DTU
- "50 Gbaud QPSK E-band Transmission Using Bismuth Doped Fiber Amplifiers" – Aleksandr Donodin, Aston
- "210 nm E, S, C and L Band Multistage Discrete Raman Amplifier" – Pratim Hazarika, Aston

- "Ultra-wide band (O to L) photonic integrated polymer cross-bar switch" – Yu Wang, TUE
- "Assessment of Lossless SOA-based Multi-band OADM Nodes in Metro-Access Networks" Rafael Kramer, TUE
- "Towards Narrow-Linewidth Widely Tunable III-V/SI Lasers" – Emadreza Soltanian, UG
- "Validation of Broadband MMI Design" – Yaonian Cui, HHI

16:40 – 17.40 Closing, Discussions, Questions

Snapshots of slides:

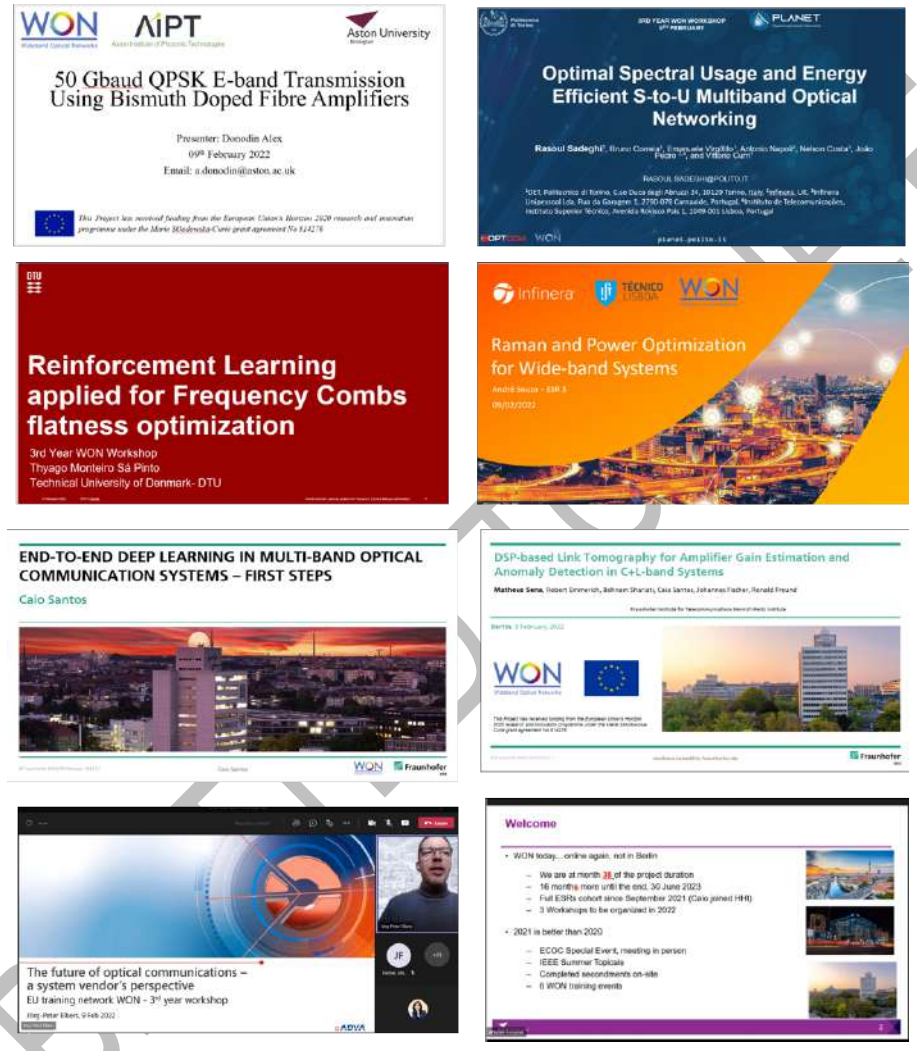


Figure 4: Snapshots from the 3rd Year Workshop, 2022

Invited Speaker:

Jörg-Peter Elbers | ADVA

As SVP of advanced technology, standards and IPR, Jörg-Peter Elbers is responsible for ADVA's technology strategy, new product concepts, standardization, and research. His interest areas comprise network and node design, efficient optical transmission, and programmable systems. Over his career, Jörg has authored and co-authored more than 100 technical publications, three book chapters, and 15 patents. He is a member of the IEEE, heads the VDE (German Association for Electrical, Electronic & Information Technologies) expert committee for optical communications and serves on the program committee of the Optical Fiber Communication Conference (OFC). He is a frequent reviewer of technical publications and serves on the board of the Networks and Photonics21 European Technology Platforms. Jörg joined ADVA in 2007 from Marconi (now Ericsson), where he was director of technology in the optical product unit. Prior to that, he worked at

Siemens Optical Networks and at Dortmund University. Jörg received his master's (diploma) and Ph.D (Dr.-Ing.) in electrical engineering from Dortmund University, Germany, in 1996 and 2000, respectively.

3.5 Final Workshop

Date:	21-22 June 2022
Venue:	Politecnico di Torino, Turin, Italy
Organiser:	Beneficiary PoliTo, Prof Vittorio Curri together with the Coordinator Aston University
Participants:	WON Consortium, external speakers and attendees

Overview:

The Final Workshop was organised by the beneficiary Politecnico di Torino, Prof Vittorio Curri and his team and was run for two days, on 21-22 June 2022, on the PoliTo campus in Turin, Italy. The workshop was open for researchers and students from the Department of Electronics and Telecommunications (DET) of PoliTo, IAB members of the project and WON associated partners. There were talks of invited speakers from academia and industry, such as Telecom Italia, Huawei, Infinera, etc., who gave presentations covering various WON and UWB topics. The workshop' sessions were broadcast online and were made available for a research community linked to the project.

Agenda:

WON FINAL WORKSHOP

Energy Centre, Politecnico di Torino (PoliTo), Turin, Italy

Time (CET; Rome, Paris, Berlin)

DAY 1 – 21 June 2022

08:30 – 09:00	Arrival
09:00– 09:15	Welcome & News: Prof Wladek Forysiak, Aston and Prof Vittorio Curri, PoliTo
09:15 – 10.00	Progress in Work Packages
	WP1: Network management: planning and control – Dr Nelson Costa, Infinera Portugal **WP2: Digital signal processing and system modelling** – Prof Vittorio Curri, PoliTo **WP3: In-line Components Design** – Assoc Prof Nicola Calabretta, TUE **WP4: Transceiver components design** – De Johannes Fischer, Fraunhofer HHI
10:00 – 10:15	Coffee break
10:15 – 10:55	Prof Pierluigi Poggiolini, Politecnico di Torino **Ultra-wideband transmission on NANF fibre: prospects and challenges**
10:55 – 11:35	Dr Antonio Napoli, Infinera Germany **Coherent in access/metro networks and the need for ultrawideband transmission**
11:35 – 12:00	Dr Alessio Ferrari, Huawei Paris Research Centre **The Huawei view on multi-band network**
12:00 – 13:15	Lunch
13:15 – 15:15	ESRs talks on the progress and results:
	• Bruno Vinícius Correia, Politecnico di Torino **Evaluation of C+L systems upgrades: Comparison between S- and E-bands** • Elliot London, Politecnico di Torino **NLI Generation in Disaggregated and Wideband Optical Network Architectures** • Rasoul Sadeghi Yamchi, Politecnico di Torino **Transparent vs Translucent Multi-band Optical Networking: Capacity and Energy Analyses** • André Luiz Nunes de Souza, Infinera Portugal **Recent advances in Raman and Power Optimization for Wideband Systems**
15:15 – 15:45	Coffee break
15:45 – 17:15	ESRs talks on the progress and results:
	• Gabriele di Rosa, VPIphotonics **Digital Optimization Techniques for Multi-Band Optical Communication Systems** • Matheus Sena, Fraunhofer HHI **Tx- and Rx-DSP Applications for Optical Multiband Systems** • Caio Marciano Santos, Fraunhofer HHI **Automated Dataset Generation and Next Steps Towards End-to-End Deep Learning in Optical Communication Systems**
17:15	Networking
20:00	Dinner

DAY 2 – 22 June 2022

08:45 – 09:00	**Arrival**
09:00 – 10:30	ESRs talks on the progress and results:
	• Emadreza Soltanian, University of Ghent **Towards the Narrow-Linewidth Widely Tunable III-V-on-Si lasers** • Yaonian Cui, Fraunhofer HHI **InP based building blocks in Mach-Zehnder Modulator** • Thyago Monteiro, Technical University of Denmark (DTU) **Spectral Shaping of Electro-Optical frequency Combs using Machine Learning Techniques**
10:30 – 11:00	**Coffee break**
11:00 – 13:00	ESRs talks on the progress and results:
	• Aleksandr Donodin, Aston University **Recent advances in Bismuth-doped fibre amplifiers for coherent transmission in E-band** • Pratim Hazarika, Aston University **Multistage Raman amplifier for ultra-wideband signal amplification** • Yu Wang, Eindhoven University of Technology (TU/e) **Novel ultra-wide band optical filters and switches** • Rafael Kraemer, Eindhoven University of Technology (TU/e) **Paths towards a multiband wavelength selective switch**
13:00 – 14:00	**Lunch**
14:00 – 14:40	Dr Erwan Pincemin, Orange **Multiband Optical Transport: An Opportunity to Increase Fiber Network Infrastructure Throughput for Service Providers**
14:40 – 15:20	Dr Nicola Sambo, Scuola Superiore Sant'Anna (SSSA) **Provisioning and control in multiband transparent networks**
15:20 – 16:00	Dr Emilio Riccardi, Telecom Italia **Disaggregation applied to the optical domain**
16:00 – 16:15	**Coffee break**
16:15 – 17:30	**Round table discussion**
18:00	**Closing**

Invited Speakers:

Erwan Pincemin |Senior R&D Engineer | Orange, France| WON IAB member

Erwan Pincemin graduated from Ecole Supérieure d'Optique (SupOptique), Orsay, France and received the M.S. degree in optics and photonics from Université Paris XI, Orsay, France. In 1997, he joined Alcatel Alsthom Recherche, Marcoussis, France where he worked on dispersion-managed solitons and optical regeneration for 40 Gbps WDM submarine transmission systems. In 2000, he was enrolled by France Telecom R&D, Lannion, France where he worked on high-speed optical terrestrial transmission systems at 10 Gbps and 40 Gbps. In Orange Labs, Lannion, France, he was in charge of research on 100 Gbps and beyond optical transmissions, including advanced modulations, coherent detection, digital mitigation of fiber impairments, and has also some key contributions on flexible optical networking in European FP7 FOX-C and CELTIC-Plus SASER projects. He has authored and co-authored more than 150 journal and conference papers and 27 patents. He was sub-committee chair of the Conference on Lasers and Electro-Optics (CLEO) Europe from 2015 to 2017 and was member of the Technical Program Committee of the Optical Fibre Communications Conference (OFC) from 2007 to 2010 and from 2017 to 2020. In WON, Dr Pincemin serves as a member of the IAB.

Pierluigi Poggiolini | Full Professor, Politecnico di Torino

Pierluigi Poggiolini received his M.S. degree "cum laude" in 1988 and his Ph.D. degree in 1993, both from Politecnico di Torino, Italy. From 1988 to 1989 he was with the Italian State Telephone Company research center CSELT, in Torino. From 1990 to 1995 he was a Visiting Scholar and then a Post-Doctoral Fellow at Stanford University. Since 1995 he has been with Politecnico di Torino and in 2010 he became a Full Professor of Optical Communications. He was an elected Member of the Academic Senate (2005-2010) and an elected Member of the Board of Directors (2016-2020) of Politecnico di Torino. He was Technical Co-Chair of the ECOC

conference in 2010. He has published over two hundred and seventy papers in leading journals and conferences. His papers have received more than 7000 citations. He is a co-author of two papers that have received the “Journal of Lightwave Technology Best Paper Award”. He is an OSA and IEEE Fellow. His current research interests focus on the modelling of non-linear fibre effects and on ultra-wide-band coherent transmission systems over both conventional and hollow-core fibres.

Alessio Ferrari| Huawei Paris Research Center

Alessio is a Research Engineer at the Huawei Paris Research Center, Optical Communication Technology Lab, where he has been conducting research activities in the field of optical network design and automation for the last 1,5 years. Alessio received his Master’s degree in Telecommunications engineering in PoliTo, with a thesis entitled “Physical layer aware open optical networking”. Alessio’s research interests include all aspects of optical communications and networking.

Nicola Sambo | Assistant Professor, Scuola Superiore Sant’Anna

Nicola Sambo received the Ph.D. degree from Scuola Superiore Sant’Anna (SSSA), Pisa, Italy, in 2009. Currently, he is an Assistant Professor at SSSA. His activity is focused on optical networks, ranging from the signal transmission to control plane, protocol analysis, and network design. He took part in several international projects, such as the EU HORIZON 2020 ORCHESTRA, in which he was a Work Package leader. Nicola achieved outstanding results in the field of optical communications and networking, (more than 3300 citations and h-index=30 with around 200 papers including more than 70 papers in top-level journals). He is a lecturer in the “Advanced optical networking” course on architecture, control, and management of optical networks at SSSA, in the PhD of Emerging Digital Technologies and the Photonic Integrated Circuits, Sensors and NETworks – PIXNET Erasmus Mundus Joint Master Degree.

Emilio Riccardi | Telecom Italia

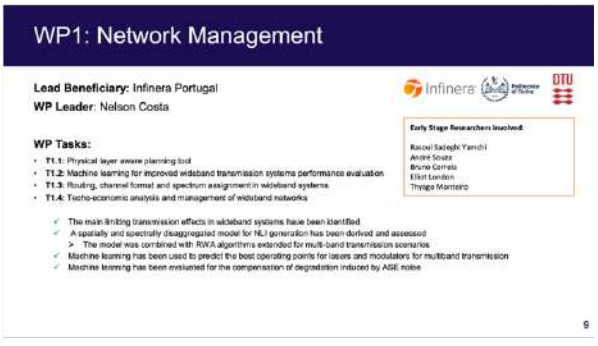
Emilio Riccardi received his graduate degree in theoretical physics from Universitat di Torino in 1991. He joined TIM (formerly CSELT and TIlab) in 1992 in the Optical Transmission Department. He is presently in the Technology Innovation Department of TIM. His current interest is dedicated to elastic optical networks and optical “white boxes” in an SDN ecosystem. He has been involved in several EU projects and currently leads the data plane Working Package of the Metro-Haul EU Horizon 2020 project. In WON, Emilio acts as a member of IAB.

Antonio Napoli | Infinera Germany

Received his Ph.D. degree from the Politecnico di Torino with a thesis on “Electronic equalization for advanced modulation formats”. Since 2006 he joined the R&D of Siemens COM. In 2007, he became a member of the established joint venture between Nokia and Siemens. In 2013, he joined Coriant, where he has been involved in EU project working on data plane activities, from Oct. 1st 2018, he is with Infinera. His research interests include DSP for optical bandwidth variable transponders from metro to long-haul network receivers, advanced modulation techniques, and wideband optical system design and modelling. In WON, Antonio serves as a member of the IAB as well as industrial mentor for some ESRs.

WPs Research Highlights:

Research highlights in technical WPs presented at the Final Workshop is available at the link below:
https://won.astonphotonics.uk/wp-content/uploads/sites/12/2022/10/WON-Final-Workshop_Day-1_General-Presentation.pdf



Snapshots of ESRs slides:

Figure 5: ESRs talks presented at the Final Workshop

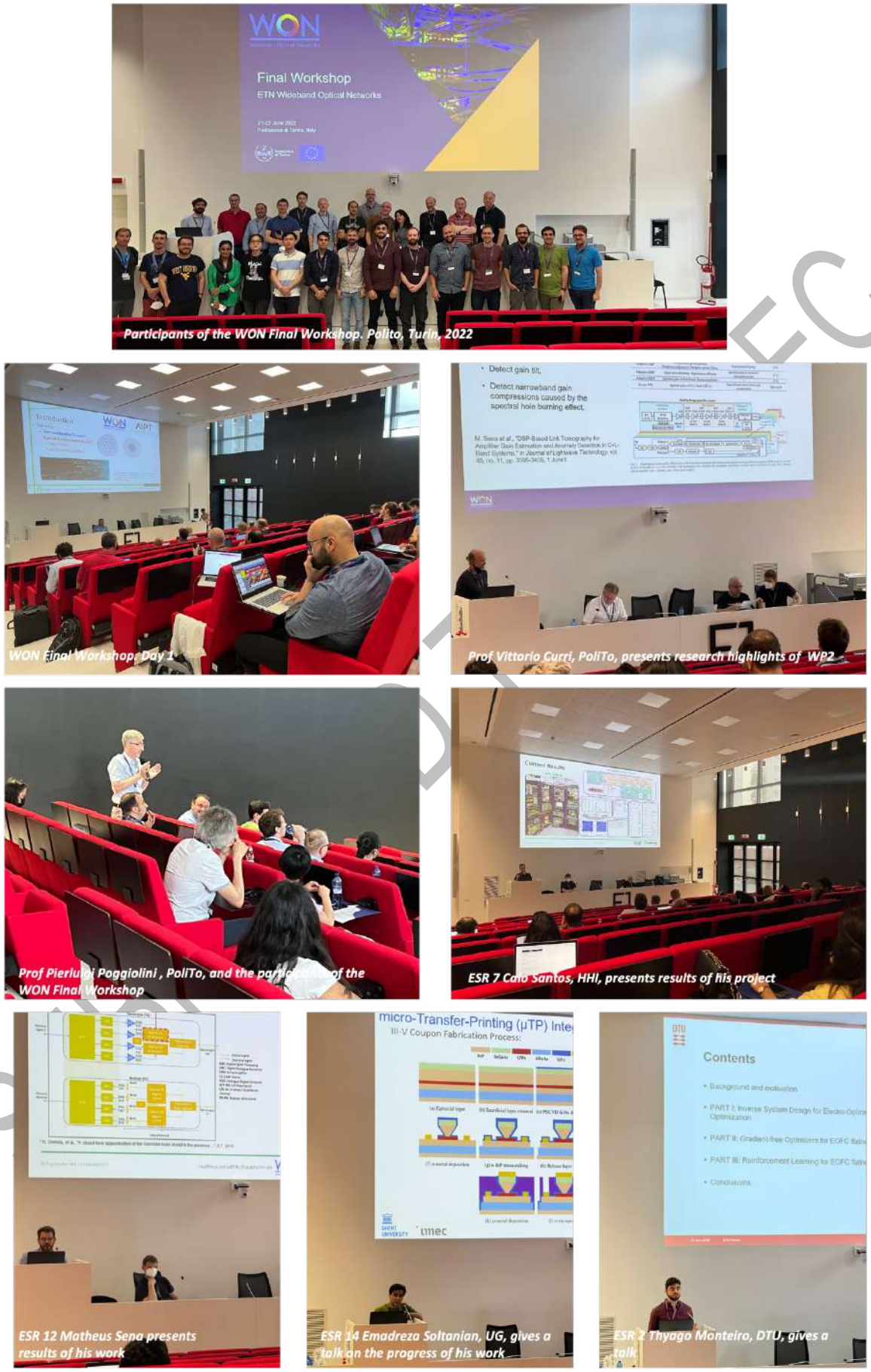


Figure 6: WON Final Workshop, PoliTo, Turin, 2022

4 TRANSFERABLE SKILLS WORKSHOPS (TSW)

4.1 Transferable Skills Workshop 1

Date: 27-28 February 2020
Venue: Aston University, Birmingham, UK
Participants: ESRs from WON and EID projects coordinated by Aston: REAL-NET, FONTE,MOCCA

Overview:

In collaboration with three EID projects coordinated by Aston University – FONTE, REAL-NET, and MOCCA – WON successfully organised the first of three planned Transferable Skills Workshops (TSW) for its ESRs. This comprehensive two-day training event took place at Aston University in Birmingham, UK, from February 27th to 28th, 2020, followed by al social and team-building event for all participants.The workshop covered a diverse range of essential topics, including scientific writing, open access principles, effective social media engagement, crucial communication and presentation skills, networking proficiency, and collaborative teamwork.

Agenda:

Day 1_27 February 2020

09:00 – 09:45 From idea to patent – Disciplining your practical ideas, Dr Gorkem Memisoglu
10:00 – 12:09 Engaging with the social media, Dr Annmarie Hanlon, Cranfield School of Management
12:00 – 12:45 How to write for “The Conversation” , Stephen Harris, The Conversation
12:50 – 13:30 Lunch at Conference Aston
13:40 – 14:30 IP presentation (Room: MB231) Dr Claire Howell, Aston University
14:30 – 15:30 How to write a great paper, Rachel Won, Nature Photonics
15:30 – 15:45 Coffee Break
15:45 – 16:30 Open Access, Hannah Hickman, Aston University
16:30 – 17:30 Scientific Writing, Srikanth Sugavanam, Aston University

Day 2_28 February 2020

Richard Fallon, The Marketing Engineer
09:00 – 10:30 Key communication skills
10:30 – 10:45 Coffee Break
10:45 – 13:00 How to create the perfect presentation
13:10 – 14:00 Lunch at Conference Aston
14:10 – 15:45 Session on Networking
15:45 – 16:00 Coffee Break
16:00 – 17:00 Session on Team Working
17:00 – 17:30 Closing

Speakers:

Annmarie Hanlon | Academic and Practitioner in Digital Marketing

Annmarie is an academic and practitioner in digital marketing strategy and the application of social media for business.Originally a graduate in French and Linguistics from University of London, Annmarie gained a Master’s in Business Administration, focusing on marketing planning. She studied for the Chartered Institute of Marketing Diploma for which she won the Worshipful Company of Marketors’ award for the best results worldwide. She subsequently gained a distinction for the Chartered Institute of Marketing’s E-Marketing Award and her PhD investigated social media marketing within organisations and she was awarded the Mais Scholarship. As Course Leader for Social Media Management on the International Executive MBA programme at the University of St Gallen, she planned, designed and delivered this intensive elective course.

Rachel Won | Internal Editor Nature Photonics

Rachel Won joined Nature Photonics in June 2006 from Aston University's Business Partnership Unit in Birmingham, UK where she worked as a Medici Fellow commercializing photonics research. She obtained her PhD in optical fibre sensing, microwave photonics and fibre nonlinearities as a member of Aston's Photonics Research Group. Prior to that, Rachel worked for Philips Optical Storage in Singapore as an Optics Engineer. She holds a Master's degree from Nanyang Technological University, Singapore and a Bachelor's degree from the National University of Malaysia. Rachel is based in London.

Dr Srikanth Sugavanam | Post-doctoral Research/EU Project Manager at Aston University

Srikanth Sugavanam is a post-doctoral research scientist/EU Project Manager at AIPT. He completed his PhD in 2015, specializing in the area of real-time intensity and spectral measurements of fiber laser dynamics. He has also worked in the areas of optical metamaterials, Raman fiber lasers, and random fiber lasers. His contributions have been featured in several international journals, including Nature Photonics and Nature Communications. Besides actively pursuing research, Srikanth fulfills the role of Programme Manager for the Marie S. Curie Postdoctoral Fellowship program, MULTIPLY, coordinated by Aston University.

Richard Fallom | Marketing Engineer for Professional Services

Richard obtained his Ph.D. in Electronic Engineering from Aston University in 1998. He subsequently joined British Airways as part of their Business Analyst graduate scheme. In this capacity, Richard served as a consultant bridging the gap between the operational aspects of the business and the IT department. His responsibilities included assembling business cases, translating customer needs into IT requirements, and devising new business processes to facilitate the efficient utilization of the new system. During his tenure at BA, he achieved the status of Qualified Facilitator with the International Association of Facilitators. He later assumed a senior position at Npower before embarking on his entrepreneurial journey in 2004. Since 2005, Richard has been actively engaged in assisting UCB students in developing employability skills. He has collaborated with BSEEN and NCGE graduate entrepreneurs and has been a frequent speaker at BCU. Additionally, he has delivered the Chartered Management Institute's Level 4 Diploma in Management to various companies in Birmingham.

Gorkem Memisoglu | MSCA postdoctoral Fellow

Gorkem is an experimental Physicist and former MSCA Postdoctoral Fellow in project MULTIPLY. She received her PhD in 2015 for her work on hybrid UV-A photodetector preparation and characterization. Having worked in industry for 6 years Gorkem is the inventor or co-inventor of 58 patent applications in both Europe and the US in a wide range of areas, including photonics, optoelectronic devices and consumer electronics.

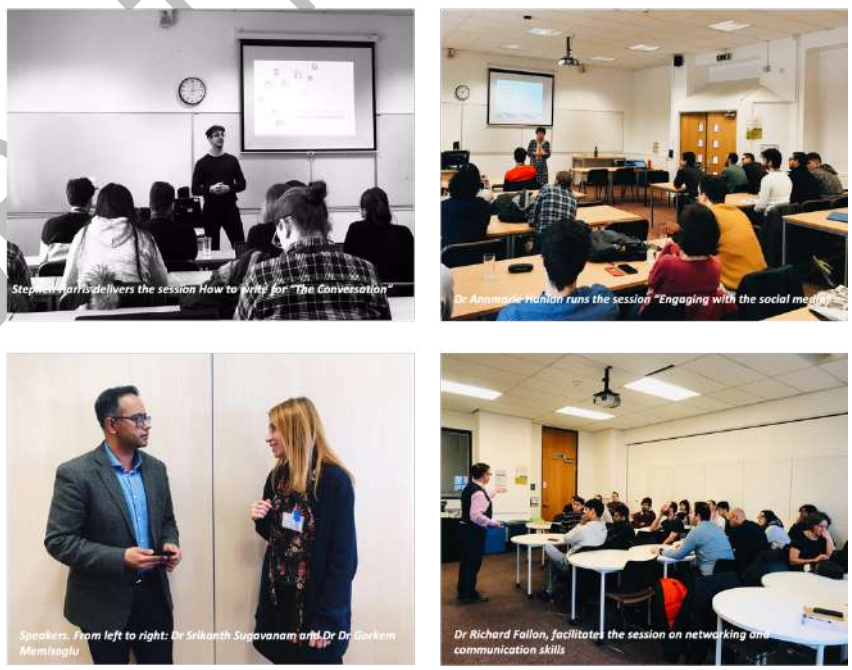


Figure 7: Transferable Skills Workshop at Aston, 2020

4.2 Transferable Skills Workshop 2

Date:	22-24 March 2021
Format:	Virtually and online
Participants:	ESRs from WON and EID projects coordinated by Aston: REAL-NET, FONTE,MOCCA

Overview:

Exploiting synergies with three additional Initial Training Networks coordinated by Aston Institute of Photonic Technologies at Aston University, the intense 3-day workshop was delivered by professional external facilitators providing interactive, targeted training. The event addressed ESRs from WON and other ITNs projects coordinated by AIPT, Aston, such as REAL-NET, MOCCA and FONTE, with a total of 28 ESRs for the first 2 days and 50 ESRs for the third day when projects MEFISTA and POST-DIGITAL joined the TSW2 workshop, representing further opportunities to interact with fellows MSCA students and build professional networks. Due to the coronavirus outbreak, the entire event was held online and remotely in an interactive format. The aim of this 3-day workshop was to give an overview of:

- Entrepreneurship – delivered by Scandinavia Stories (1 day)
- Project Management – delivered by Skillfluence (1 day)
- Science Communication (0.5 day)

Day 1: Entrepreneurship

The workshop on entrepreneurship, led by Warrick Harniess of Scandinavia Stories, aimed to equip ESRs with tools to apply their research output in innovative ventures. Warrick Harniess, the founder of Scandinavia Stories, specialises in marketing, communications and business start-up support, and has extensive experience teaching at renowned UK universities. His familiarity with the 'EntreComp: The Entrepreneurship Competence Framework' of the European Commission made him an ideal facilitator for this session. The workshop included six interactive group exercises that covered critical concepts. Warrick's skill in engaging the audience through personal experiences enhanced the learning experience. The day conveyed the critical concepts and centred around 6 interactive group exercises. As facilitator, Warrick has a natural ability to connect with the audience and to share personal experience, encouraged others to engage with the learning.

Agenda:

09:00 – 13:00 Session 1: Designing the Customer Experience
Introduction
Activity 1: Understanding Customers
Activity 2: Mapping the buying journey
Activity 3: Designing a brand and a business model
Presentations and discussion (60 minutes)

14:00 – 18:00 Session 2: Designing the Operating Model
Introduction
Activity 1: Creating the company value chain
Activity 2: Staffing the value chain
Activity 3: Preparing the pitches
Presentations and discussion

Day 2: Project Management

Facilitator: Dr Robin Henderson of Skillfluence [http://www.skillfluence.co.uk/]
Skillfluence specialise in transferable skills training that equips researchers to work with others, both inside and outside of academia. Skillfluence aims to help researchers maximise the social and economic impact of their academic work, but also to realise the value their skills and expertise could have on industry and society.
Dr Robin Henderson is a Higher Education consultant with a specific interest in enhancing institutional research capacity through developing researchers and research leaders. Through his work with over a dozen research

intensive universities he has a deep knowledge and understanding of the challenges academics and researchers face in undertaking world leading research and regularly works with PhD students, postdoctoral researchers and academic staff. Robin has a background in engineering, teaches project management modules at degree level and facilitates around 130 workshops each year with a mix of training (focussing on leadership and research management) and facilitation (focussed on the development of strategy and research themes). Robin is therefore uniquely qualified to provide Project Management training to our cohort of Photonics ESR/PhD students.The aim of this interactive workshop was to explore the practical application of project management to research projects. The ESRs worked through a project lifecycle exploring: i) how to work with collaborators and stakeholders to define project success; ii) how to effectively plan projects taking into account the iterative nature of research; iii) how to pre-empt issues and risk manage the project and iv) how to assess progress and resolve issues with the project. Throughout the workshop the students discussed how the same skills that can be applied within research can be applied to future projects both within and beyond academia with a variety of stakeholders including in industry, business start-up and public sector.

Agenda:

09:45-17:15	Project Management: Your PhD and Beyond

Day 3: SCIENCE COMMUNICATION

Facilitator: **Prof John Dudley** (University Bourgogne Franche-Comté)

John Dudley (PhD FOSA FEOS FIEEE FInstP FSPIE DSc h.c. Hon FRSNZ) is Professor at the University of Franche-Comté in Besançon, France and is particularly recognized for his contributions in ultrafast optical pulse metrology, nonlinear fiber optics, the study of nonlinear localized soliton structures, and especially broadband fiber supercontinuum generation. He has published extensively in peer-reviewed journals and received numerous accolades and awards for service to international scientific societies, and for initiatives in promoting international scientific outreach and the public communication of science. He is recipient of the American Physical Society Dwight Nicholson Medal for Outreach in 2017.
The aim of this session was to convey the importance and practicalities of effectively communicating science to different audiences, an essential skill for all researchers. This workshop and open discussion looked at what makes effective science communication to a variety of different audiences.
During the presentation of Prof John Dudley, two other ITNs joined the event (MEFISTA and POST-DIGITAL), scaling up the number of ESRs participating to 50.

Agenda:

10:00-12:00	Science Communication for ESRs

Post-Event Survey: To assess and if necessary improve the quality of the training provision, a Feedback Questionnaire was designed and distributed to all participants of TSW2 to provide confidential/ anonymous input. The completed questionnaires indicated a high level of satisfaction among the ESRs with the training content and delivery.

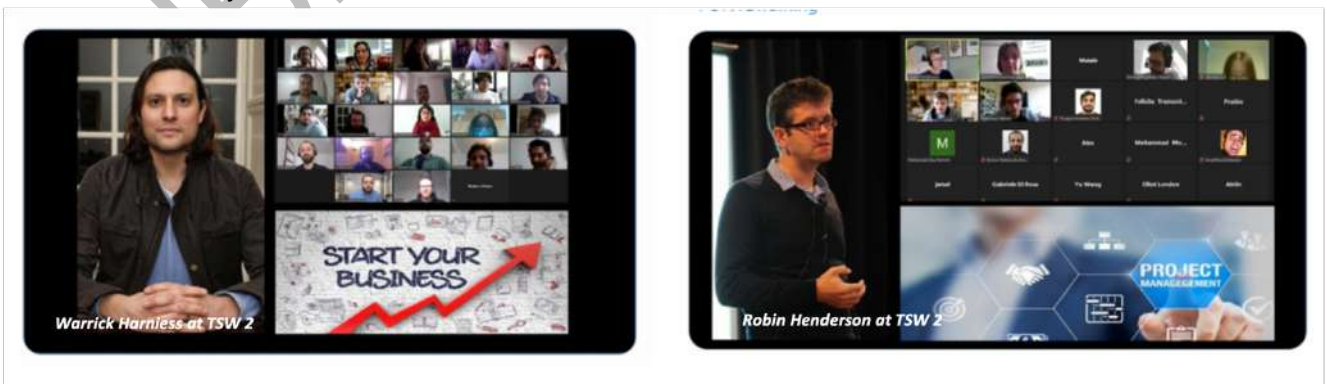


Figure 8: TSW 2 speakers and online sessions

4.3 Transferable Skills Workshop 3

Date:	24-25 March 2022
Format:	Virtually and online
Participants:	ESRs from WON and EID projects coordinated by Aston: REAL-NET, FONTE,MOCCA

Overview:

Transferable Skills Workshop 3 was focused on career planning, job market opportunities, CV preparation and development of the interview skills, with the aim to prepare ESRs for the next steps in their career after finishing PhDs. The aim of this 2-day event was to give an overview of the following main topics:

- Career Planning and the non-academic job market – delivered by Dr Sarah Blackford
- Career Paths – delivered by Prof Andrew Ellis, Prof of Optical Communications, Aston
- Funding opportunity after PhD – delivered by Paul Knobbs, Research Funding Manager, Aston
- CV's and interview skills – delivered by the training provider Skillfluence

Speakers:

Dr Sarah Blackford

Dr Sarah Blackford is a qualified higher education careers adviser (MA, Warwick University) and an honorary teaching fellow (Lancaster University) with a background in scientific research and publishing. A Senior Fellow of the Higher Education Academy (SFHEA), Sarah specialises in providing career development education to doctoral students and early career researchers and has been delivering career workshops and one-to-one coaching for over 20 years in research institutions, universities, EU consortia and doctoral training programmes. As a registered career practitioner with the Career Development Institute and the Association for Graduate Careers Services (AGCAS), Sarah adheres to a recognised ethical code of practice. http://biosciencecareers.org/about

Prof Andrew Ellis

Andrew Ellis received the B.Sc. degree in physics with a minor in mathematics from the University of Sussex, Brighton, U.K., in 1987. He received the Ph.D. degree in electronic and electrical engineering from The University of Aston in Birmingham, Birmingham, U.K., in 1997 for his study on all optical networking beyond 10 Gb/s. He previously worked for British Telecom Research Laboratories as a Senior Research Engineer investigating the use of optical amplifiers and advanced modulation formats in optical networks and the Corning Research Centre as a Senior Research Fellow where he led activities in optical component characterization. From 2003, he headed the Transmission and Sensors Group at the Tyndall National Institute in Cork, Ireland, where he was also a Member of the Department of Physics, University College Cork and his research interests included the evolution of core and metro networks, and the application of photonics to sensing.

Heather Livingston

Heather Livingston is an experienced trainer, facilitator and coach. She specialises in helping individuals and groups work positively towards effective career transition, change and development. Heather is a fully qualified Careers Adviser and member of the CDI (Career Development Institute) with 20 years career management experience across all sectors. She is skilled in developing and delivering workshops to help people successfully develop and progress in their careers with confidence and purpose.

Andy Ridgeway

Andy Ridgeway is Programme Leader of the MSc in Science Communication at UWE Bristol and a Fellow of the Higher Education Academy. One of his areas of research is Science journalism practices. Andy spent nearly 20 years as a journalist, including a spell as Deputy Editor of BBC Focus magazine. Prior to that, he worked in local newspapers as a Reporter and News Editor Andy continues to be a practicing journalist, writing predominantly for BBC Focus as well as New Scientist. He has also written for The Economist and Men's Health among other publications. As well as writing for and editing print publications, Andy has extensive experience of digital publishing, particularly on tablet computers. While editing BBC Focus's interactive iPad app, it was named specialist publication of the year twice at the Digital Magazine Awards (2011 and 2012). Andy was also

named Editorial Person of the Year in the BBC Magazines Awards for Excellence in 2010. Andy is a member of the judging team for the Max Perutz Science Writing Award run by the Medical Research Council (MRC).

Agenda:

Day 1_24 March 2022

09:00 – 12:00 Career Planning and non-academic job market, Dr Sarah Blackford
12:00 – 13:00 Break
13:00 – 15:30 Career Planning (continuation)
16:00 – 17:00 Science Journalism as a career

Day 2_25 March 2022

10:30 – 11:15 Career paths, Prof Andrew Ellis
11:30 – 12:30 Funding Opportunities after PhD, Paul Knobbs
14:00 – 17:00 CV's and Interview Skills, Heather Livingston

Figure 9: Participants of the TSW 3, virtual workshop, 2022

5 INTENSIVE TRAINING COURSE

Title:	Design and modelling of optical communication systems and photonic components
Date:	10-12 June 2020
Format:	Virtually and online
Organisers:	Beneficiaries VPIphotonics, Fraunhofer HHI and Associated Partner Orange
Participants:	WON ESRs

Overview:

From 10-12 June 2020, the Intensive Training Course on "Design and Modeling of Optical Communication Systems and Photonic Components" was held by the beneficiaries VPIphotonics, Fraunhofer HHI, and the project's associated partner Orange Labs (France). Originally designed to be conducted in-person for a five-day period, the course format needed to be changed due to the COVID-19 pandemic. To ensure the training could still take place, the consortium made the decision to shift the course to a virtual format, allowing for seamless implementation of the training program. During the course, WON ESRs were given training on the use of the VPIphotonics Design Suite and were provided with knowledge and skills to work with the HHI DSP library for the design, estimation, and evaluation of coherent communication systems. As part of the training, Dr Erwan Pincemin, a member of the WON IAB and Orange Labs, presented a lecture on "Capacity Growth through Multi-Band Amplified WDM Systems" in a highly-engaging presentation. For wider dissemination, the presentation was made publicly accessible via the WON website, ensuring that the knowledge shared during the course could reach a wider audience.

Agenda:

Day 1_10 June 2020:

08:40 – 09:00	Welcome and introductions
09:00 – 09:45	Capacity growth through Multi-BandAmplified WDM Systems, Dr. Erwan Pincemin (Orange)
09:45 – 10:00	Break
10:00 – 12:00	Itroduction to VPI Design Suite: VPI Instructor
12:00 – 13:00	Lunch break
13:00 – 15:00	Design of Coherent Digital Transmission Systems: VPI Instructor
15:00 – 17:00	Homework Exercises on your own

Day 2_11 June 2020

08:00 – 09:20	Homework (VPI instructor available)
09:20 – 09:50	Homework Q&A and wrap-up: VPI Instructor
09:50 – 10:00	Break
10:00 – 12:00	Digital Signal Processing for Coherent Optical Systems: HHI Instructor
12:00 – 13:00	Lunch break
13:00 – 17:00	Homework Exercises on your own

Day 3_11 June 2020

08:00 – 09:20	Homework (HHI instructor available)
09:20 – 09:50	Homework Q&A and wrap-up: HHI Instructor
10:00 – 12:00	Coded Modulation and FEC: VPI Instructor

Certificates of completion: upon successful completion of the course, all ESRs received the "Training Certificates", signed by the VPIphotonics General Manager.

Snapshots of slides:

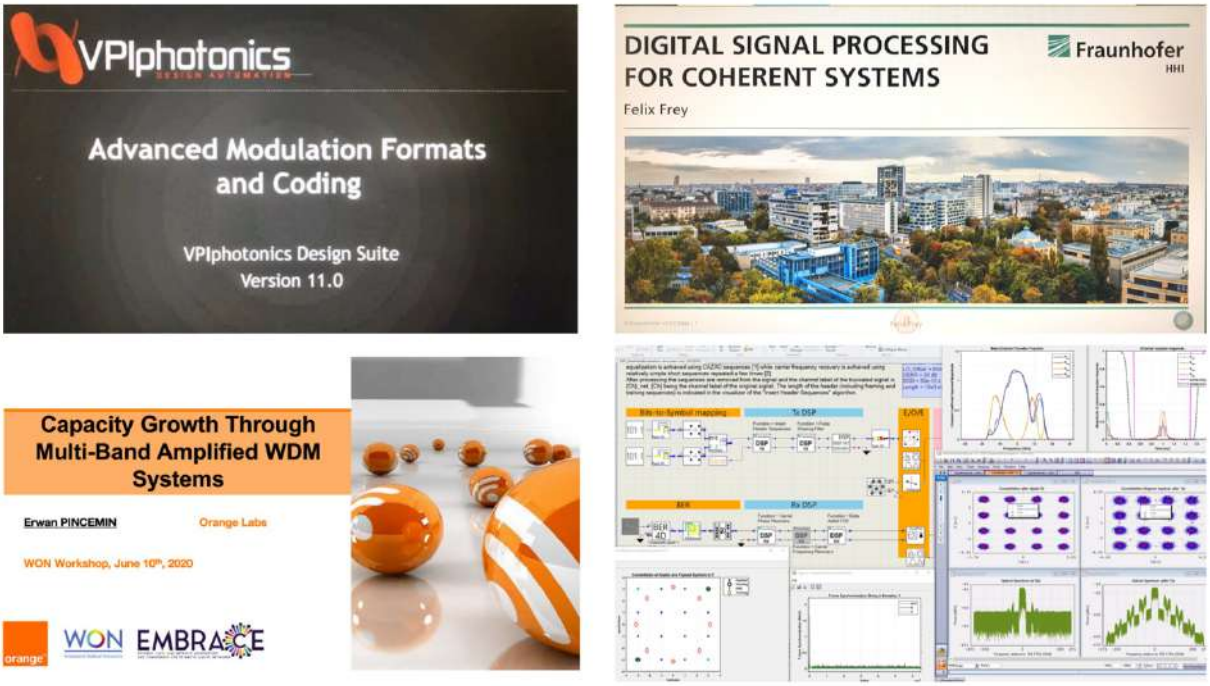


Figure 10: Lectures at the WON Intensive Training Course

6 OPEN-TO-ALL WORKSHOPS (OTAW) AND MINI SYMPOSIA

6.1 OTAW 1 "Machine Learning applied to optical communication"

Date:	7-8 September 2020
Format:	Virtually and online
Organiser:	Aston University and DTU
Participants:	ESRs from WON, FONTE, REAL-NET and MOCCA

Overview:

The aim of this training event was to facilitate all ESRs high-level discussions on research challenges on machine learning in optical communications.

Agenda:

Day 1_7 September 2020

08:20 – 08:30	Opening
08:30 – 10:30	Prof Darko Zibar, DTU FOTONIK, Departmenr of Photonics Engineering Title: Introduction to ML and neural networks in particular
10:30 – 10.45	Break
10:45 – 12:45	Continuation of the Prof Darko Zibar's talk
12:45 – 14:00	Break
14:00 – 15:00	Dr Morteza Kamalian-Kopae, Research Associate, Aston University Title: Machine learning-based equalisation in fiber-optic communication
15:00 – 15:15	Break
15:15 – 16:15	Dr Milad Sefidgaran, Postdoctoral fellow at Telecom Paris. Title: Information theory of the optical fiber

Day 2_8 September 2020

13:20 – 13:30	Opening
13:30 – 14:30	Prof David Saad, Professor in mathematics, Aston University
14:30 – 14:45	Break
14:45 – 15:45	Dr Jelena Pesic & Dr Matteo Lonardi, Nokia bell labs Title: Will ML mitigate the extra cost of increase in capacity
15:45 – 16:00	Break
16:00 – 17:00	Prof Nathan Kutz, University of Washington
17:00 – 17:10	Closing

Speakers:

Prof Darko Zibar | DTU FOTONIK

Darko Zibar is a 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 resrearch 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).

Prof David Saad | Professor in Mathematics, Aston University

David Saad holds the 50th Anniversary Chair of Complexity Physics at Aston University, Birmingham UK. He received a BA in Physics and a BSc in Electrical Engineering from the Technion, Haifa, Israel (1982), an MSc in Physics (1987) and a PhD in Electrical Engineering (1993) from Tel-Aviv University. He joined the Physics Department at the University of Edinburgh in 1992 and Aston University in 1995. His research, published in over 200 journal and conference papers, focuses on the application of methods from statistical physics and Bayesian statistics to a range of fields, which include neural networks, error-correcting codes, multi-node communication, network optimisation, routing, noisy computation, epidemic spreading and advanced inference methods.

Dr Morteza Kamalian-Kopae | Research Associate at Aston University

Morteza Kamalian-Kopae received his BSc in electrical engineering from Isfahan University of Technology, Isfahan, Iran, his MSc in communication engineering from Yazd University, Yazd, Iran, and his PhD in electrical engineering from Aston University, Birmingham, UK. Since graduation, he has been with Aston Institute of Photonic Technologies (AIPT) as a research fellow working on nonlinear Fourier transform, in particular, for periodic solutions of the nonlinear Schrödinger equation. His research interests include signal processing in optical communication, analysis of nonlinear dynamics, and wireless communication systems.

Dr Milad Sefidgaran | Department of Communications and Electronics Télécom ParisTech Paris, France

Milad Sefidgaran obtained his BSc and MSc in Telecommunication from University of Tehran in 2007 and Sharif University of Technology in 2009, respectively. Then, he pursued his research on information theory and received his PhD from Telecom ParisTech in 2013. Between 2013 and 2015 he worked as postdoctoral associate at Telecom Paris and Sharif University of Technology. Later, he joined some Telecom companies as ZTE corporation and Huawei technologies. He is now working as postdoctoral researcher at Telecom Paris, since May 2019. His main research interests are information theory, optical fibers, wireless networks, and cellular technologies.

Dr Jelena Pesic |Systems Integration Specialist at Nokia Business Group, ION IP Optical Networks

Jelena Pesic obtained her MSc degree at the University of Belgrade. Later she moved to France where in 2011 she obtained the Phd in Optical Network at the Université Bretagne Sud. Later, she worked as postdoctoral research at Telecom Paris, from 2011-2013, and at Inria, from 2013 to 2014. In 2014 Jelena joined Nokia Bell Labs as research engineering. Since Jun 2020 she is working as Systems Integration Specialist at Nokia Business Group, ION IP Optical Networks WDM technical expertise on the basis of the Nokia IP Transport product portfolio Research engineer in Nokia Bell labs OSA Ambassador (The Optical Society of America).

Prof Nathan Kutz | University of Washington

Professor Kutz was awarded the B.S. in Physics and Mathematics from the University of Washington in 1990 and the PhD in Applied Mathematics from Northwestern University in 1994. Following postdoctoral fellwoships at the Institute for Mathematics and its Applications (University of Minnesota, 1994-1995) and Princeton University (1995-1997), he joined the faculty of applied mathematics and served as Chair from 2007-2015.

Dr Matteo Lonardi | Nokia Bell Labs

Dr. Matteo Lonardi obtained his BSc in Computer Engineering in 2012, his MSc in Communications Engineering in 2016 and his PhD in Information Technology (Optical Communications) at the Università degli Studi di Parma. Later he worked as researcher at the Unversità deli Studi di Parma, investigating the assessment, estimation, and monitoring of performance in dynamic modern optical communication systems developed to fight the expected capacity shortage. In March 2018 Matteo joined the Nokia Bell Labs as visiting researcher. Since November 2019 he is working as Research Engineer at Nokia Bell Labs.

6.2 Mini-Symposia "Numerical implementations of Bayesian filtering for signal equalization and demodulation"

Date:	28 October 2020
Format:	Virtually and online
Organiser:	Aston University
Participants:	ESRs from WON, FONTE, REAL-NET and MOCCA

Overview:

The mini-symposia was co-organised together with other H2020 ITN coordinated by AIPT: FONTE, REAL-NET, MOCCA, MEFISTA and POST-DIGITAL. The aim of this mini-symposia is to facilitate high-level discussions on research challenges of Bayesian filtering implemented in telecommunication applications.

Agenda:

09:20 – 9:30	Opening remarks, Prof Sergei Turitsyn, Aston University
09:30 – 10:30	Simo Särkkä, Aalto University, Finland Title: Introduction to Bayesian Filtering
10:30 – 10.45	Break
10:45 – 11:45	Prof Darko Zibar, DTU Title: Application of Bayesian filtering for laser and frequency comb noise characterization
11:45 – 12:00	Break
12:00 – 13:00	Prof Laurent Schmalen, Karlsruhe Institute of Technology (KIT) Title: Bayes' Theorem and the BCJR Algorithm – Swiss Army Knife for Communication Engineers
13:00 – 14:00	Break
14:00 – 15:00	Dr Hou-Man Chin, DTU Title: Bayesian filtering for quantum communication
15:15 -16:15	Assoc Prof Zhe Chen, School of Medicine; New York University, USA Title: Bayesian filtering: history, new tools and applications
16:15 – 16:30	Closing

Speakers:

Prof Darko Zibar | DTU FOTONIK

See the biography provided in 5.1

Simo Särkkä | Aalto University

Simo Särkkä is Associate Professor in Sensor informatics and medical technology at Department of Electrical Engineering and Automation (EEA), Aalto University. Simo received his Master of Science (Tech.) degree in engineering physics and mathematics, and Doctor of Science (Tech.) degree in electrical and communications engineering from Helsinki University of Technology, Espoo, Finland, in 2000 and 2006, respectively. Currently, he is an Associate Professor in Aalto University, Technical Advisor of IndoorAtlas Ltd., and an Adjunct Professor with Tampere University and LUT University. He is also a Fellow of European Laboratory for Learning and Intelligent Systems (ELLIS), and he is the leader of AI Across Fields (AIX) program and AI for Health SIG in Finnish Center for Artificial Intelligence (FCAI). From 2000 to 2010 he worked with Nokia Ltd., Indagon Ltd., and Nalco Company in various industrial positions related to telecommunications, positioning systems, and industrial process control. From 2010 to 2013 he worked as a Senior Researcher with the Department of Biomedical Engineering and Computational Science (BECS) at Aalto University, Finland, and also held the position of Academy Research Fellow for 2013-2018.His and his group's research interests are in multi-sensor data processing systems with applications in location sensing, health and medical technology, machine learning, inverse problems, and brain imaging. He has authored or coauthored around 150 peer-reviewed scientific articles and his books "Bayesian Filtering and Smoothing" and "Applied Stochastic Differential Equations" along with the Chinese translation of the former were recently published via the Cambridge University Press. He is a

Senior Member of IEEE, member of IEEE Machine Learning for Signal Processing committee, and serving as a Senior Area Editor of IEEE Signal Processing Letters.

Prof Dr.-Ing Laurent Schmalen | Karlsruhe Institute of Technology (KIT)

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 Aachen, 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.

Dr Hou-Man | DTU

Hou-Man is a Postdoctoral Research Fellow working on Machine Learning aided DSP for CV-QKD, system performance ,simulation and verification. Previously an Early Stage Researcher in the Marie Curie ICONE Initial Training Network Fellow Hou-Man worked on the design of next generation optical networks at Orange Polska as a part of the ITN, investigating provisioning strategies to enable greater network capacity throughput. He also has an interest in digital signal processing for compensation of signal impairments due to optical fibre and component properties. Hou-Man's work was been in the area of optical networks, specifically the design and implementation of optical networks incorporating cognitive flexible transceivers. Most recently he is investigating the provisioning of optical links with respect to link deviations from the ideal design in anticipation of increased network dynamics due to technologies such as flexgrid, elastic optical networking and software defined networking being a key component of next generation optical networks. Hou-Man has extensive laboratory experience from the implementation of 10 Gbit/s OOK and BPSK channels to more advanced coherent DP-QPSK and DP-16QAM up to 35 Gbaud using both lab equipment and commercially available products. He designed the experimental test setups used at UCL and implemented the automation required to perform measurements of very large data sets and visited Ciena Corporation in Ottawa to avail of their comprehensive laboratory facilities to perform DWDM measurements using the latest available commercial modems as a continuation of his work in UCL. Hou-Man's specialties are: Digital Signal Processing; Optical measurements and lab work; Experimental design; Measurement automation; Troubleshooting and debugging of complex optical transmission systems.

Assoc Prof Zhe (Sage) CHEN | New York University School of Medicine (NYUSOM)

Zhe (Sage) CHEN is a principal investigator at New York University School of Medicine (NYUSOM), where Ihe direct the Computational Neuroscience, Neuroengineering and Neuropsychiatry (CN3) Laboratory. He is also a faculty member of the Training Program of Computational Neuroscience at NYU and an affiliated faculty member of the Neuroscience Institute at NYUSOM. Zhe is a computational neuroscientist and an electrical engineer. His work has focused on using statistical/biophysical modeling, computational statistics, and machine learning methods to help understand representations of neuroscience data, to decipher important neural circuit mechanisms of targeted brain circuits, such as the hippocampus, prefrontal cortex, and motor cortex of rodents and non-human primates. In collaboration with experimental neuroscientists, his team has developed real-time brain-machine interfaces to conduct closed-loop neuroscience experiments, such as detecting acute pain signals for acute pain signals for pain neuromodulation, and decoding animal's trajectory paths during off-line memory reactivation. Finally, Zhe has been gradually building his research portfolio along the direction of computational psychiatry and translational neuroscience, aiming to bridge the gap between animal and human research. Zhe's current and future research directions focus on the intersection of computational and systems neuroscience, neural engineering, and data science.

6.3 OTAW 2 “Modeling of photonic components and systems”

Date:	7 February 2022
Format:	Virtually and online
Organiser:	Fraunhofer HHI
Participants:	ESRs from WON, and other researchers from (46 participants in total)

Overview:

The Workshop was collocated with the Workshop: ITG Expert Group KT 3.1 “Modeling and Simulation of Photonic Components and Systems” and organised by the Fraunhofer HHI team led by Dr Johannes K. Fischer, Head of Digital Signal Processing Group at HHI. Once a year, representatives of the relevant industrial companies as well as of universities and research institutes active in the field of optical communications technology meet in workshops for an intensive exchange of experience.

Agenda (speakers and titles of the talks presented):

- Exact component parameter agnostic QoT estimation in optical networks using different machine learning techniques, *Alexandr Langolf,* Kiel University Christian-Albrechts-Universität zu Kiel
- ML Model Design for QoT Estimation – Public Datasets, Data Visualization and Data Quality Evaluation *Geronimo Bergk,* Fraunhofer Heinrich Hertz Institute
- Variational-Autoencoder Equalizer, *Vincent Lauinger,* Karlsruhe Institute of Technology
- Learning a Nonlinear Pulse Shaping by a γ-lifted Training, *Tim Uhlemann,* University of Stuttgart
- Deep Learning Based Modelling of Short Reach Optical Link for Modulation Format Optimization, *Shuagnxu Li,* Huawei
- On Shortening Multi-Solitons Using the Continuous NFT Spectrum, *Sander Wahls*, Delft University of Technology
- Performance Requirements for Optical Frequency Comb Generators as Optical Power Supplies in Coherent SDM/DWDM Links, *Christoph Füllner,* Karlsruhe Institute of Technology
- Optical Bistability in Silicon Nitride Ring Cavities with Thermo-optic Effect, *Menglong He*, Technische Universität Dresden
- Simulation and design of integrated cavity tunable mode-locked laser, *Jiaxing Dong,* VPIphotonics
- Time adaptive probabilistic shaping for combined optical/THz links , *In-Ho Baek* Fraunhofer HHI
- Modeling SNR and sensing range of an OTDR for POF, *Simon Dengler,* POF Application Center – Nuremberg Institute of Technology

Figure 11: OTAW 2 “Modeling of photonic components and systems”

6.4 OTAW 3 "Current and future trends for optical communication systems"

Date:	7-8 April 2022
Format:	Hybrid format (online and on-site at DTU)
Venue:	DTU, Lyngby, Denmark
Organisers:	DTU team led by Prof Darko Zibar and Aston University team

Overview:

Free and Open-to All 2-day workshop on machine learning, artificial intelligence and nonlinear fourier transform in fiber optical communication, was held at the Technical University of Denmark 7-8 April 2022 (incl online participation). Addressing both current and future trends, this workshop was particularly suited for PhD students and ESRs working in the fields of Photonics and Fiber Optical Communications. Featured sessions covered:

1. Practical Implementation and Network Applications of Nonlinear Fourier Transform
2. Machine Learning Methods for Ultra-Wide Band Systems
3. Machine Learning and Artificial Intelligence Applied to Multiband Optical Communication.

High profile speakers from both Industry and Academia include Antonio Napoli (Infinera Germany), Jelena Pesic (Nokia), Sander Wahls (TU Delft), Laurent Schmalen (KIT), Marija Furdek (Chalmers), Andrea Carena (PoliTO), Alan PT Lau (HKPU), Michael Galili (DTU), Stanislav (Stas) Derevyanko (Ben Gurion University), Marco Secondini (SSSA), and Cristian Antonelli (University of L'Aquila) among others. Main organisers: Darko Zibar/Francesco Da Ros (both DTU) and Sergei K. Turitsyn (AIPT).

Agenga:

Day 1_7 April 2022

Session 1: Practical implementation and network applications of Nonlinear Fourier Transform

09:00 – 09:05	Darko Zibar, Technical University of Denmark Welcome and Opening Remarks
09:05 – 09:40	Sander Wahls, Delft University of Technology Title: Pulse shaping in the nonlinear Fourier domain
09:40 – 10:15	Marco Secondini, Scuola Superiore Sant'Anna (SSSA) Title: To NFT, or not to NFT, different ways of dealing with fiber nonlinearity
10:15 – 10:50	Alan Pak Tao Lau The Hong Kong Polytechnic University Title: Multi-symbol DSP techniques for discrete eigenvalue transmissions based on NFT
10:50 – 11:05	Break
11:05 – 11:40	Stas Derevyanko, Ben Gurion University of the Negev Title: Channel models and spectral efficiency limits for optical fiber transmission systems employing the Nonlinear Fourier Transform
11:40 – 12:15	Morteza Kamalian-Kopae Aston University Title: Noise in the nonlinear Fourier domain

Session 2: ML methods for Ultra-Wide Band systems

13:30 – 14:05	Antonio Napoli, Infinera Germany Title: Coherent-based point-to-multipoint optical networks: potentialities, challenges and benefits
14:05 – 14:40	Cristian Antonelli, University of L'Aquila Title: Modeling of Multiple-Mode Propagation in Fibers for Space-Division Multiplexing
14:40 – 15:15	Michael Galili, Technical University of Denmark Title: Compensation of Nonlinear Signal Distortion using Optical Phase Conjugation
15:15 – 15:30	Break

15:30 – 16:05	Andrea Carena, Politecnico di Torino Title: ML models for the abstraction of photonic components in UWB systems
16:05 – 16:40	Thomas Bradley, Eindhoven University of Technology Title: High Capacity Data Transmission with Space Division Multiplexing
16:40 – 17:15	Anastasiia Vasylchenkova, University College London Title: Analytical models for quality of information estimation in the ultrawideband transmission

Day 1_8 April 2022

Session 3: ML and AI applied to MB optical communication

09:00 – 09:35	Jelena Pesic, Nokia Title: Will Machine Learning mitigate the extra cost of increase in capacity?
09:35 – 10:10	Marija Furdek, Chalmers University of Technology Title: Monitoring optical network security with machine learning
10:10 – 10:45	Marc Ruiz, Universitat Politècnica de Catalunya Title: Opportunities and challenges of AI-based autonomous operation in MB scenarios
10:45 – 11:00	Break
11:00 – 11:35	Laurent Schmalen, Karlsruhe Institute of Technology Title: Autoencoders in Optical Communications – From Modulation Format Optimization to Blind Equalization
11:35 – 12:10	Boris Krasnov, Eindhoven University of Technology Title: End-to-end deep learning for communication over dispersive nonlinear channels
12:10 – 12:45	Mehran Soltani, Technical University of Denmark Title: Spatial and spectral power evolution design using machine learning-enabled Raman amplification
14:00 – 17:00	Guided tour of the DTU Laboratories Facilities with workshop participants and DTU members

Figure 12: DTU workshop: participants and statistics

Figure 13: DTU Workshop: on-site participants and speakers

The organisers of the workshop created a stand-alone website for the handling registration and dissimilation of the event: https://dtu-workshop.astonphotonics.uk and published a workshop booklet containing all information in one place, including schedule, list of speakers and abstracts of their talks (see Appendix 1).

Figure 14: DTU Workshop website

7 ONLINE TRAINING COURSES

7.1 Online training course on silicon photonics

Date: 5 November 2020
Format: Virtually and online
Organisers: Photonics Research Group at Ghent University, Prof Gunther Roelkens
Participants: WON ESRs

Overview:

The workshop consisted of six presentations, each lasting about 50 minutes, focusing on the basics of silicon photonics and its applications in datacom/telecom. These sessions were part of ePIXfab's 5th edition of the Silicon Photonics Summer School, held in June 2020. The presentations were recorded during this online event. After each session, an interactive Q&A segment was included, allowing participants to raise questions, which were addressed by the UG beneficiary lead, Prof Gunther Roelkens. This format was designed to offer an engaging and insightful learning experience

What is silicon photonics?

- Basic topics covering silicon photonics science and technology
- State-of-the-art in silicon photonics
- Latest technological trends and access routes for silicon photonics

What are the new advances made in silicon photonics?

- New methodologies for silicon PIC design
- Developments made in laser integration for silicon PICs
- Integration of electronics with silicon PICs

Where silicon photonics can be deployed?

- High-speed optical transceivers
- Microwave photonics, LiDARs, and quantum applications
- Life-science and sensors market

Speakers and presentations:

Speaker, affiliation	Title of the lecture
Prof. Roel Baets Ghent University-imec, Belgium	Introduction to silicon photonics
Prof. Andrea Melloni Politecnico di Milano, Italy	Passive Silicon Photonics: from basics to circuits
Dr.Laurent Vivien C2N, CNRS, Uni. Paris-Sud, Uni. Paris Saclay, France	High-speed Modulators in Silicon Photonics
	High-speed Detectors in Silicon Photonics
Prof. Gunther Roelkens Ghent University – imec, Belgium	Transfer printing for silicon photonics
Prof. Ajey Jacobs University of Southern California	Monolithic electronic-photonics integration

7.2 Online training on design challenges for next generation optical networks

Date: 5-6 July 2021
Format: Virtually and online
Organisers: Prof Vittorio Curri (Politecnico di Torino) and Dr João Pedro (Infinera Portugal)
Participants: WON ESRs

Overview:

This two-day short course provided an overview of the remarkable evolution over the last three decades of optical networking, from an infrastructure of 2.5G/10G point-to-point links to large scale mesh deployments with reconfigurable light paths at 400G and beyond. It then discussed optical transmission and the fundamental need for its proper abstraction for optimized network planning. The increasingly relevant role of SDN in transport networks was explained, and the main capacity planning problems that underpinned each new major roll-out of new or additional capacity were highlighted. Finally, the course offered insights into the perspectives of an autonomous optical transport with advanced monitoring of in-field characteristics combined with self-optimization capabilities.

Speakers and presentations:

- Prof Vittorio Curri, Politecnico di Torino
- Dr João Pedro, Infinera Portugal

Speaker, affiliation	Title of the lecture
Dr João Pedro	How we got here: A brief history of optical transport networks
	Planning of Transport Networks
	Capacity planning / network optimization
Prof Vittorio Curri	Optical transport modeling and design
	Software-defined optical transport optimization and control
	Autonomous and cognitive optical networking

Snapshots of slides:

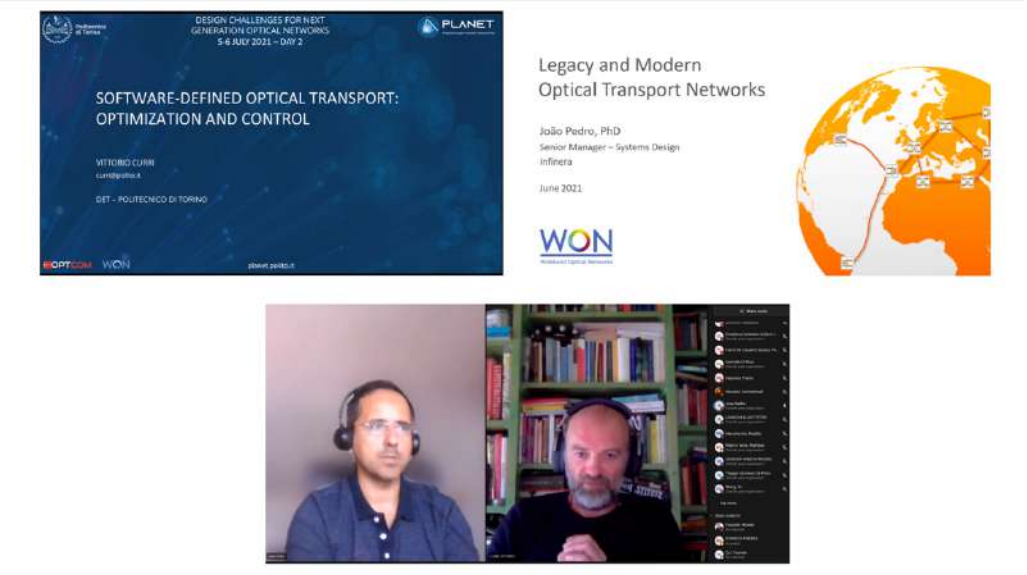


Figure 15: Dr Joao Pedro and Prof Vittorio Curri deliver the WON online training course, 2021

7.3 Online training course on Wideband Optical Switches

Date: 8-9 November 2021
Format: Virtually and online
Organisers: Assoc Prof Nicola Calabretta (Eindhoven University of Technology, TUE)
Participants: WON ESRs

Overview:

This two-day short course discussed the evolution and implementation of Photonic switches in optical networks, spanning from short-distance communication in data centres to long-haul optical communications. It provided an overview of the different switched network paradigms and techniques, considering circuit as well as burst/packet-switched networks and associated wideband optical switching technologies. Reconfigurable add/drop multiplexer (ROADM) architectures that were commercially deployed in the optical networks were discussed. At the heart of the ROADM operation, the course covered wavelength selective switch (WSS) operation and technologies. Finally, the course offered insights into the perspectives of WSS in advanced communications, such as SDM and multimode transmission systems, as well as WSS for ultra-wideband transmission from the O-band to the L-band.

Speakers and presentations:

Speaker, affiliation	Title of the lecture
Prof Nicola Calabretta, TUE	Photonic switches in optical networks
	Optical switching technologies
	ROADM architectures
Prof Dan Marom Hebrew University of Jerusalem, Israel	Wavelength selective switch technologies
	Wavelength selective switches for advanced optical systems
Dr Nicholas Fontaine Nokia Bell Labs, USA	Wavelength selective switches for ultra-wideband transmission,

Snapshots of slides:

8 WON Special Event at ECOC Conference 2021

Date: 13 September 2021
Format: Bordeaux, France
Organisers: WON Consortium

Overview:

The WON Consortium was invited to organise a Special Event on Wideband Optical Network at the ECOC 2021, the largest conference on optical communication in Europe. Wideband Optical Networking has emerged as a topic of great global interest in recent years addressing near to mid-term requirements. Systems based on Wideband Technology are attractive to end-users because they leverage the massive investment in the single mode optical fibre plant already deployed in millions of km worldwide, by potentially making use of the whole low-loss transmission window, from ~1250nm to ~1650nm. This approach provides a cost-effective and green solution to increasing capacity, when compared to solutions requiring the deployment of new fibre cables. Many research challenges remain, however, such as the availability of highly integrated wideband optical components and sub-systems, bandwidth allocation, spectral power management, and the impact of the Raman effect in such high bandwidth systems. The workshop took place on 13th September, and began with an introduction to the WON project, its context and highlights from its work packages, followed by a series of short “lightning presentations” from the ESRs focusing on their specific research subjects, and conclude with an extended external presentation on the current state-of-the- art in Wideband Optical Networks research from Dr Ben Puttnam of NICT, Japan. See Appendix II.

Agenda:

- Wladek Forysiak, Aston University: Introduction to ETN "Wideband Optical Networks"
- Vittorio Curri, Politecnico di Torino: Overview of WP1 - Network management: planning and control, and WP2 - Digital signal processing and system modelling
- Johannes K. Fischer, Fraunhofer HHI: Overview of WP3 - In-line components design, and WP4 - Transceiver components design
- Elliot London, Politecnico di Torino: Nonlinear interference generation in wideband and disaggregated optical networks
- Bruno Correia, Politecnico di Torino: Impact on quality of transmission of launch power choice for wide-band scenarios
- Rasoul Sadeghi, Politecnico di Torino: Comparison of Transparent C+L Band Network versus -band Translucent Upgrade
- Aleksandr Donodin, Aston University: Bismuth-doped fire amplifier as a promising solution for multi-band transmission networks
- Pratim Hazarika, Aston University: Multistage Raman amplifier for ultra-wideband signal amplification
- Rafael Kraemer, Technology University or Eindhoven: Multi-band wavelength selective switching in metro networks
- Yu Wang, Technology University of Eindhoven: Ultra-wide band (0 to L) integrated polymer TIR thermo-optic switch matrix
- Emadreza Soltanian, Ghent University – IMEC: Micro-transfer-printing integration of III-V-on-Si to realize SOs and tunable lasers
- Thyago Monteiro Sá Pinto, Technical University of Denmark: Optical Frequency Combs Optimization using Evolutionary Algorithms
- Yaonian Cui, Fraunhofer HHI: Broadband In based Mach-Zehnder Modulator
- Matheus Sena, Fraunhofer HHI: Enabling cognitive transceivers for multiband operation
- Gabriele Di Rosa, VP|photonics: Wavelength-Dependency of Standard -Band Transceivers Performance in Multiband Systems
- Andre Souza, Infinera-Portugal: Going beyond C+L-band Transmission: Accurate and Scalable Quality of Transmission Estimation and its applications
- Benjamin Puttnam, National Institute of Information and Communications Technology: Extending transmission window and data-rates in SMF and low spatial-channel count DM fibres

Figure 16: WON Special Event at ECOC 2021

A dedicated workshop booklet containing abstracts of the talks was created and published on the WON website. To ensure wider accessibility, the booklet was also disseminated through the project's social media channels, Twitter and LinkedIn. This allowed for increased visibility among the research community and facilitated the dissemination of the valuable information presented during the workshop. See Appendix II

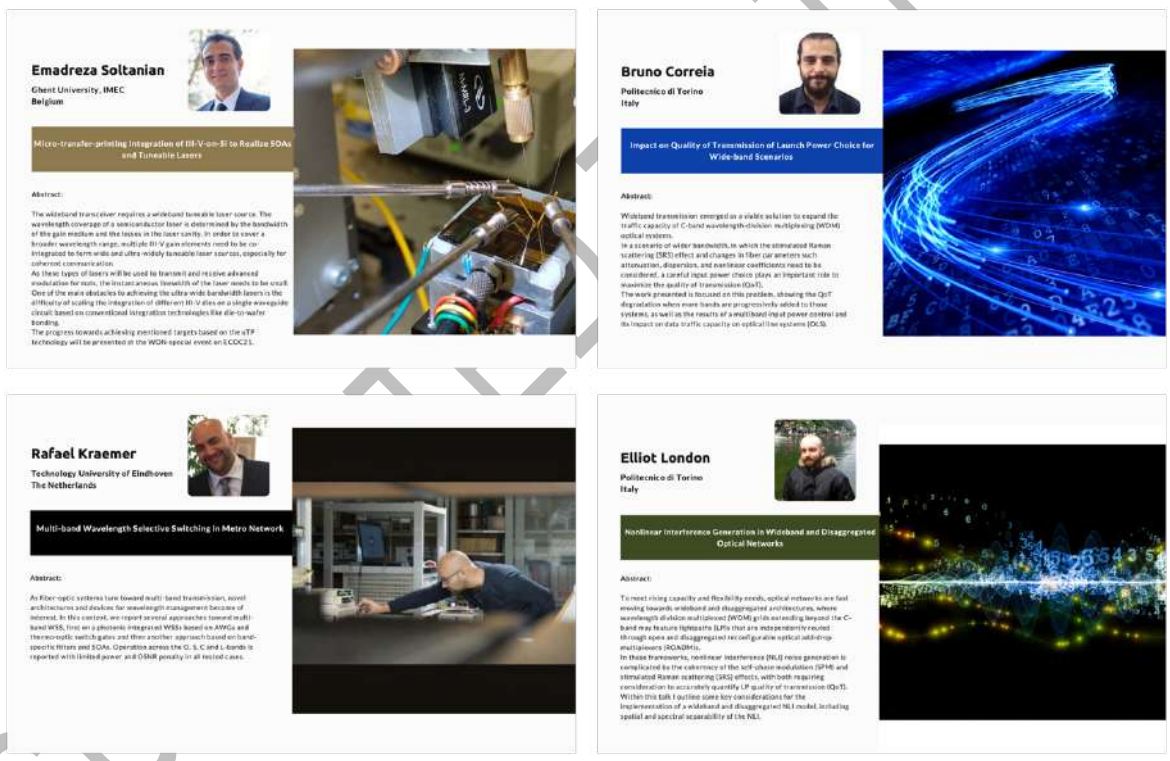


Figure 17: Booklet of abstracts. WON Special Event,2021

9 SOCIAL MEDIA INTERACTION AND POST EVENT ACTIVITIES

WON and its members used social media platforms, such as Twitter and LinkedIn, to advertise project events and workshops with the goal of reaching out to a wider research community and advancing the dissemination of WON activities. These channels regularly featured visual content like banners showcasing the WON logo, the EC emblem, as well as acknowledgment of MSCA funding and the GA number coupled with relevant posts. Below, you can find Figures 15 and 16 which illustrate some examples of these posts.
All presentations delivered during the training events were gathered from speakers and shared with WON ESRs confidentially via dedicated, time-limited download links or shared BOX folders. This made the presentations accessible to the ESRs while ensuring security and confidentiality of the presented materials.

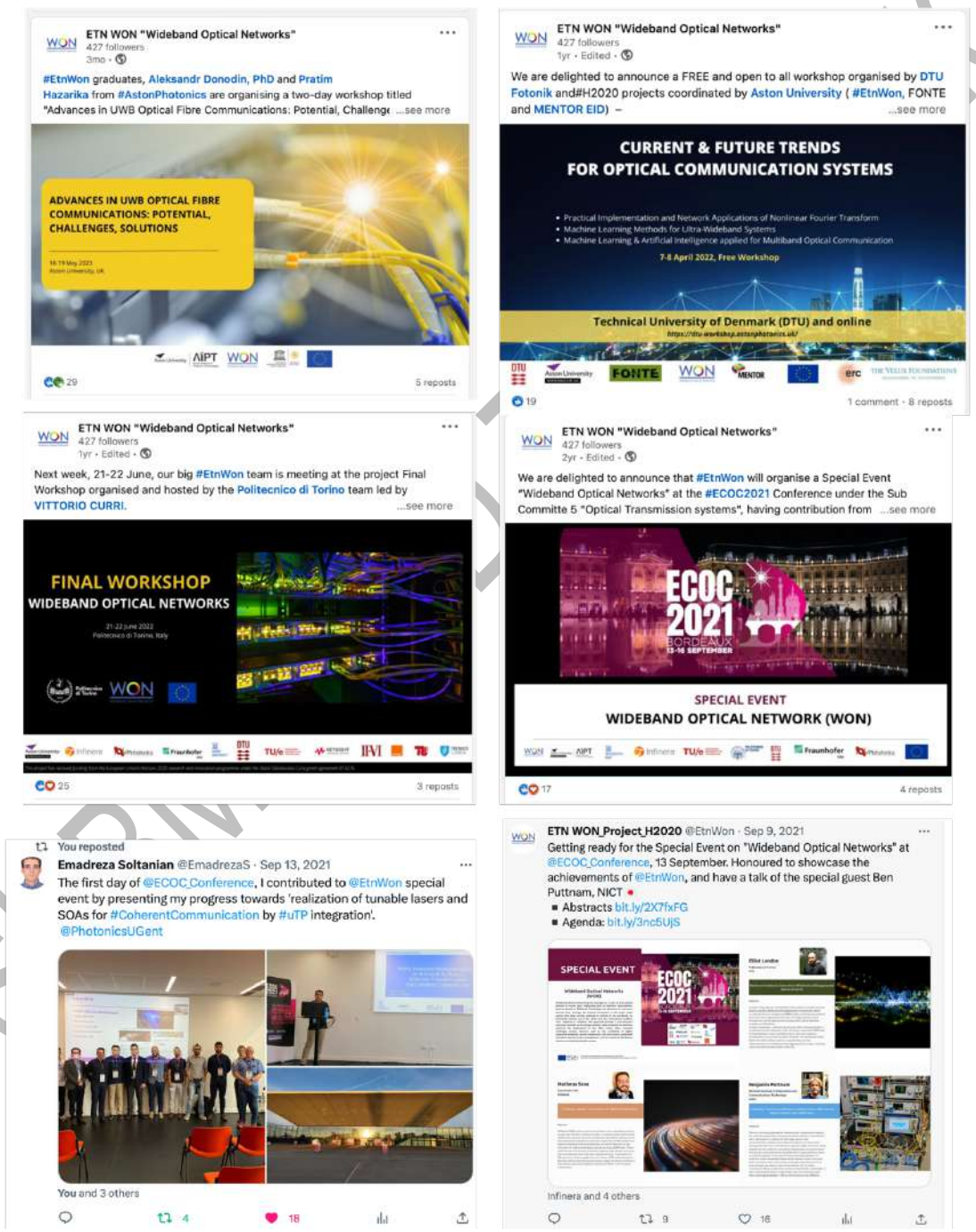


Figure 18: WON Social Media and events advertisement

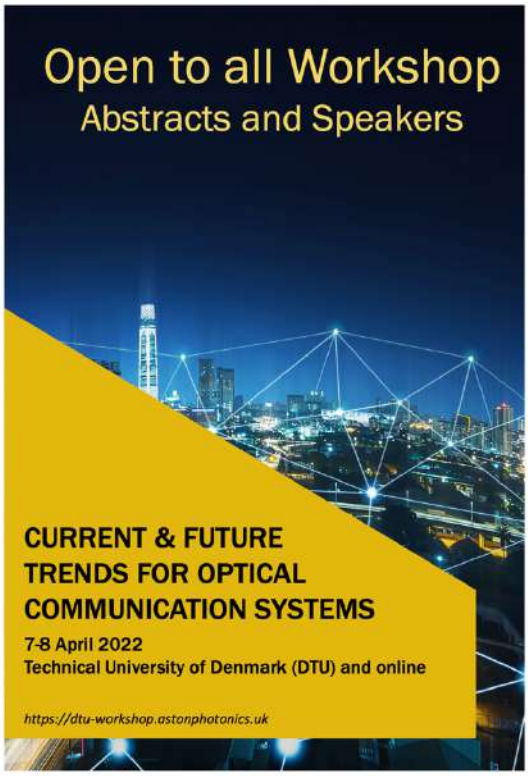
10 DEVIATIONS FROM THE GA

Due to the late recruitment in the WON project, the Consortium reschedule all main network-wide training events by approximately five months. This adjustment was undertaken to guarantee the involvement of all ESRs, who gained substantial benefits from these events.
Following the termination of two beneficiaries from the project the courses listed below were cancelled and (or) reorganized:

- Online course on digital pre-distortion techniques for modern optical transponders – was cancelled due to the withdrawal of the beneficiary Coriant Germany from the WON project.
- Online course on optimal design of wideband optical systems was postponed due to termination of the beneficiary University of Peloponnese and was combined with the online course on network planning and delivered together by PoliTo and ING PT teams as described in section 6.2.
- The planned webinar on test & measurement solutions for coherent systems, originally planned to be hosted by the Associated Partner Keysight, was canceled due to a lack of available resources within the team to manage the training event.

11 APPENDIX I

OTAW III “CURRENT & FUTURE TRENDS FOR OPTICAL COMMUNICATION SYSTEMS”.
Workshop booklet



The main organisers of this workshop are **Prof. Darko Zibar & Dr. Francesco Da Ros** of the Technical University of Denmark and **Prof. Sergei Turitsyn**, director of the Aston Institute of Photonic Technologies at Aston University (UK) together with collaborative research projects they coordinate. These are in particular projects FONTE, WON and MENTOR, who have received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 766115, 814276 and 956713; the European Research Council (H2020-EU CoG FRECOM; 771878) and the Villum Fonden /Villum Young Investigator Project VYI OPTIC-AI (29344).

Additional co-organisers of the event are projects REAL-NET, POST-DIGITAL, MOCCA, MEFISTA and MULTIPLY, who have received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement 813144, 860360, 814147, 861152 and 713694 respectively.

Session 1: Practical Implementation and Network Applications of Nonlinear Fourier Transform

Pulse shaping in the nonlinear Fourier domain

Sander Wahls
Delft University of Technology

Sander Wahls received a Diplom degree in mathematics from TU Berlin in 2007, and a doctorate in electrical engineering (summa cum laude) from the same university in 2011. He is currently an associate professor with ius promovendi at the Delft Center for Systems & Control at TU Delft. Before joining TU Delft in 2014, Sander spent two years as a Postdoctoral Research Fellow in the Department of Electrical Engineering at Princeton University. His research is focused on system theory and signal processing for nonlinear systems, currently in the areas of integrable systems, nonlinear Fourier transforms and their application in engineering problems. He received the 2015 Johann-Philipp-Reis Award for his work on fast nonlinear Fourier transforms. In 2016, the European Research Council (ERC) awarded him a Starting Grant on the same topic. Since 2021, he is serving on the ECOC Subcommittee "Techniques for digitally enhancing optical communication". He is a Senior Member of the IEEE.

Abstract:
In recent years, many new fiber-optic transmission schemes based on nonlinear Fourier transforms (NFT) have been proposed. The time domain characteristics of the pulses generated by these schemes can differ significantly. Pulse shapes have a considerable impact on spectral efficiency. We therefore survey existing NFT-based transmission schemes in this talk, and discuss the different possibilities to control the pulse shapes that they offer.

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TU Delft

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Session 1: Practical Implementation and Network Applications of Nonlinear Fourier Transform

To NFT, or not to NFT, different ways of dealing with fiber nonlinearity

Marco Secondini
Scuola Superiore Sant'Anna

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 Associate Professor of Telecommunications. He also collaborates with the Photonic Networks & Technologies National Lab of the CNIT in Pisa. He served in the technical program committees of the Optical Fiber Communication Conference (OFC), the European Conference of Optical Communication (ECOC), the Asia Communications and Photonics Conference (ACP), the Global Communications Conference (GLOBECOM), and the International Conference on Communications (ICC). He currently serves as an Associate Editor for IEEE Transactions on Communications. 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:
Fiber nonlinearity limits the performance of current optical fiber communication systems. In this talk, we review different approaches that can be followed to mitigate the impact of fiber nonlinearity. In particular, we focus on the idea that fiber nonlinearity can be avoided, or at least reduced, by properly shaping the waveforms that are transmitted through the optical fiber. To this aim, we consider two rather different approaches, namely, constellation shaping and nonlinear frequency division multiplexing. The former acts at a symbol level, optimizing the constellation in a high-dimensional space to minimize fiber nonlinearity. The latter acts at a waveform level, using the nonlinear Fourier transform to perform modulation and demodulation in the nonlinear spectrum domain, where fiber propagation is linear. Pros and cons of the two techniques are discussed, exploring their potential and limits.

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SCUOLA SUPERIORE SANT'ANNA PISA

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Session 1: Practical Implementation and Network Applications of Nonlinear Fourier Transform

Multi-symbol DSP techniques for discrete eigenvalue transmissions based on NFT

Alan Pak Tau Lau
The Hong Kong Polytechnic University

Alan PT LAU received his B.A.Sc in Engineering Science (Electrical Option) and M.A.Sc. in Electrical and Computer Engineering from University of Toronto in 2003 and 2004 respectively. He obtained his Ph.D. in Electrical Engineering at Stanford University in 2008 and has joined the Hong Kong Polytechnic University where he is now an Associate Professor. His research covers system characterization, performance monitoring, digital signal processing and machine learning applications of various optical communication systems and networks. He collaborates extensively with industry and serves in technical program committees of major conferences in Optical Communications.

Abstract:
For discrete eigenvalue transmissions (or soliton transmissions), one seeks to encode as much information as possible in each degree of freedom and shorten the distance between neighboring pulses to increase the overall bit rate. However, such attempts would result in nonlinear inter-symbol interference (ISI) across multiple symbols and significantly degrade transmission performance. We hereby demonstrate analytically and experimentally that one can considerably improve soliton transmission performance by intentionally allowing neighboring solitons to interact and collide during propagation and exchange positions at the receiver followed by standard NFT processing. This can be achieved by designing neighboring solitons' eigenvalues λ to have opposite signs in the real part while the magnitude $|\Re(\lambda)|$ is optimized for a given transmission distance so that neighboring transmitted pulses would have swapped their timing positions at the receiver. We further investigated joint modulation of discrete eigenvalue λ and b -coefficents $b(\lambda)$ and developed a suite of multi-symbol digital signal processing (DSP) techniques to exploit the statistical correlations between the continuous and discrete eigenvalues and b -coefficents to mitigate nonlinear distortions and improve detection performance. We jointly modulate λ with 16-QAM and $b(\lambda)$ with 16-APSK and experimentally demonstrate 64 Gb/s (net 54 Gb/s) over 1200 km with the proposed multi-symbol DSP algorithms.

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Session 1: Practical Implementation and Network Applications of Nonlinear Fourier Transform

Channel models and spectral efficiency limits for optical fiber transmission systems employing the Nonlinear Fourier Transform

Stas Derevyanko
Ben Gurion University of the Negev

Stanislav (Stas) DEREVYANKO is a theoretical physicist by training and has spent most of his career looking at nonlinear and/or disordered systems. From high energy beams scattering in a disordered medium to Shannon informational capacity of the modern day optical fibre communications scientists and engineers have to look at and describe the systems that are affected both by nonlinearity and noise. While the area of high power and high signal-to-noise ratio is studied by the nonlinear physics (with many achievements to its credit) the opposite limit deals with fully disordered systems and/or incoherent pulses and is the subject of the general theory of disordered systems. The grey area in between, when both signal and noise contribute equally to the dynamics of the system remains one of the main challenges for both physicists and engineers.
Most of his current research activities deal with the interplay of nonlinearity and disorder in one way or another. From optical telecommunications to thermalization in coupled waveguides and from information theory to machine learning – they all have one thing in common: they are enormous fun!.

Abstract:
In this talk I will outline recent developments in the field of theoretical modelling of NFT-channels limited by the amplifier spontaneous emission. The two main problems currently facing NFT-based transmission are signal-noise interaction due to the loss of integrability and low spectral efficiency due to the need for the burst mode transmission. With respect to the former I will show that the sources of signal distortion at the receiver are twofold: a direct ASE noise component and the so-called processing noise of purely deterministic nature. For the popular b-modulation NFT scheme the developed theory of the ASE noise component shows that the noise power spectral density goes to zero at high values of input power so the dominating signal distortion at high power is the processing noise.

With regard to the ways of increasing the spectral efficiency I will show that by using more efficient nonlinear spectral carriers (like Gauss-Hermit waveforms) one can significantly improve the time-bandwidth product of the NFT bursts and reach spectral efficiencies that are competitive with the conventional values at the same propagation distances.

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Session 1: Practical Implementation and Network Applications of Nonlinear Fourier Transform

Noise reduction techniques in the nonlinear Fourier domain

Morteza Kamalian-Kopae
Aston University

Morteza KAMALIAN-KOPAE received his BSc in electrical engineering from Isfahan University of Technology, Isfahan, Iran, his MSc in communication engineering from Yazd University, Yazd, Iran, and his PhD in electrical engineering from Aston University, Birmingham, UK. Since graduation, he has been with Aston Institute of Photonic Technologies (AIPT) as a research fellow working on nonlinear Fourier transform, in particular, for periodic solutions of the nonlinear Schrödinger equation. His research interests include signal processing in optical communication, analysis of nonlinear dynamics, and wireless communication systems.

Abstract:
Nonlinear Fourier transform provides us with the analytical relation between the input and output of the optical fibre link. This is what is required to find the capacity of fibre as the most important communication channel of modern data networks. An important part of this analytical model is the stochastic distribution of the received signal which is corrupted by random noise. In this talk, I will discuss some mathematical tools to explore noise and its representation in the Fourier domain and how we can quantify its impact in the NFT framework.

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Session 2: ML methods for Ultra-Wide Band systems

Coherent-based point-to-multipoint optical networks: potentialities, challenges and benefits.

Antonio Napoli
Infinera Germany

Antonio NAPOLI received his Ph.D. degree from the Politecnico di Torino with a thesis on "Electronic equalization for advanced modulation formats". Since 2006 he joined the R&D of Siemens COM, where he was initially working on EDFA transient suppression for long and ultra-long-haul optical networks. In 2007, he became a member of the established joint venture between Nokia and Siemens, named Nokia Siemens Networks, where he was working on cutting-edge projects on robust and tolerant design of optical communications systems at 100 Gb/s and 400 Gb/s. In particular, he was involved in the design and development of future DSP-based coherent receivers for next-generation optical communication systems. In 2013, he joined Coriant, where he has been involved in EU project working on data plane activities, such as for example in the EU FP-7 IDEALIST project. From Oct. 1st 2018, he is with Infinera. His research interests include DSP for optical bandwidth variable transponders from metro to long-haul network receivers, advanced modulation techniques, and wideband optical system design and modelling.

Abstract:
A paradigm shift in optical communication networks is proposed, with the introduction of a new ecosystem of devices and components with the capability of transforming current point-to-point optical networks (with their entailed, limiting, electrical aggregation) into flexible, scalable and cost-effective point-to-multipoint networks. In the new architecture, which better aligns with the hub-and-spoke traffic patterns observed in today's metro and access network segments, interoperability across a variety of transceivers operating at different speeds is achieved using individually routed, digitally generated subcarriers. The first comprehensive demonstration of the technical feasibility of the proposed point-to-multipoint architecture based on digital subcarrier multiplexing is presented, along with the remarkable cost savings and simplification of the network it enables.

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Session 2: ML methods for Ultra-Wide Band systems

Modeling of Multiple-Mode Propagation in Fibers for Space-Division.

Cristian Antonelli
University of L'Aquila
CV here

Abstract:
This talk will review the main concepts involved in the modelling of propagation in fibers for space-division multiplexed transmission, with focus on modal dispersion and nonlinear interference, as well as the interplay between them.

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UNIVERSITÀ DEGLI STUDI DI L'AQUILA

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Session 2: ML methods for Ultra-Wide Band systems

Compensation of Nonlinear Signal Distortion using Optical Phase Conjugation.

Michael Galili
Technical University of Denmark

Michael GALILI (Member, IEEE) was born in Aabenraa, Denmark, in 1977. He received the M.Sc. degree (Eng.) in applied physics from the Technical University of Denmark (DTU), Kgs. Lyngby, Denmark, in 2003 and the Ph.D. degree in optical communications and signal processing from DTU Fotonik in 2007. He is currently an Associate Professor and Scientific Coordinator with the Research Center Silicon Photonics for Optical Communication (SPOC). He is the author or coauthor of more than 300 peer-reviewed journal and conference publications and he is teaching and supervising students at bachelor's, master's, and Ph.D. level. His research interests include optical transmission and signal processing for telecommunication, nonlinear integrated devices for optical processing and advanced optical switches for datacom systems.

Abstract:
We will discuss our recent work on compensation of fibre nonlinearity using optical phase conjugation. This technique allows for some degree of compensation of optical nonlinearities accumulated during fibre transmission by implementing optical phase conjugation at a symmetric position with respect to the accumulation of nonlinearities. In this way nonlinear phase rotation accumulated during one part of the propagation may be compensated by nonlinear phase rotation affecting the conjugated field in a later part of the propagation.
We will discuss span configurations in transmission links to improve the performance of compensation. We will also discuss optical pre- or post-compensation using lumped compensation schemes as well as efforts to achieve compensation in few-mode fibre transmission.

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DTU

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Session 2: ML methods for Ultra-Wide Band systems

ML models for the abstraction of photonic components in UWB systems

Andrea Carena
Politecnico di Torino

Andrea CARENA is Full Professor in the Optical Communication Group of Dipartimento di Elettronica e Telecomunicazioni at Politecnico di Torino, Italy. He received the M.Sc. and Ph.D. degrees in electronic engineering from Politecnico di Torino, Torino, Italy, in 1995 and 1998, respectively. He is currently an Associate Professor at the Optical Communication Group, Dipartimento di Elettronica e Telecomunicazioni, Politecnico di Torino. His research interests include physical layer design optical communication systems: coherently detected systems, digital coherent receiver design, digital signal processing techniques for advanced modulation formats, digital nonlinearity mitigation, Nyquist-WDM for Terabit Superchannel implementation, algorithm for computer simulation of fiber propagation, and a particular emphasis on fiber nonlinearities modeling. He co-authored more than 200 scientific publications. In 2014 and 2015, he received the IEEE/OSA "JOURNAL OF LIGHTWAVE TECHNOLOGY" Best Paper Award.

Abstract:
In recent years data traffic has seen an extraordinary growth driven by a continuous increase in the number of connected devices and the development of new bandwidth hungry applications. To improve the capacity of optical networks, a promising solution is the adoption of Ultra-Wide-Band (UWB) systems expanding the fiber bandwidth beyond the standard C-band. In this context, the introduction of a software-defined networking (SDN) paradigm is a viable solution to deliver flexibility and dynamic reconfigurability to the network. To implement SDN in UWB networks it is required the full abstraction and virtualization of each network element as it allows operations coordinated by a centralized network controller. This objective can be reached by defining simple but accurate models for all components. This talk presents an approach based on the application of Machine Learning (ML) techniques and it focus on two network elements: the photonic switch and the Raman amplifier.

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Politecnico di Torino

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Session 2: ML methods for Ultra-Wide Band systems

High Capacity Data Transmission with Space Division Multiplexing.

Thomas Bradley
Eindhoven University of Technology

Thomas BRADLEY is a senior researcher in the High Capacity Optical Transmission Lab of the Electro-Optical Communications Group at the Institute for Photonics Integration, TU/e. His current research lies in two key areas of fibre optic sensing and quantum communications. The development of novel optical fibres and fibre post processing techniques can be exploited to support novel optical fibre sensors and advances in quantum communications. He has authored and co-authored several high impact publications in Nature Photonics, Optics Express and has several prestigious post deadline papers at leading optical communications conferences

Abstract:
There is current and ongoing exponential growth in internet traffic. Such scaling requires an exponential increase in the amount of single mode fibre deployed to support this traffic and which combined with the approach of the Shannon capacity limit requires the development of novel technology to address this challenge. Space division multiplexing (SDM) using few mode, multi-core and/or few mode multi-core fibres have potential for ultra-high capacity data transmission. Here, I present our work in developing SDM technology and characterisation tools for ultra-high capacity data transmission. In addition, I present an emerging technology, Hollow Core Fibres as a potential revolutionary technology for low latency high-capacity data transmission.

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TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

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Session 2: ML methods for Ultra-Wide Band systems

Analytical models for quality of information estimation in the ultrawideband transmission.

Anastasiia Vasylchenkova

University College London

Anastasiia Vasylchenkova is currently a Leverhulme Trust Research Fellow in Optical Networks Group at University College London, running a research project on the analytical modelling of ultrawideband optical communication. She received her BSc and MSc in nuclear physics from Kharkiv National University, and a PhD from Aston University, Birmingham, UK, for her research within the nonlinear Fourier transform approach for optical communications. Her research interests include fibre optics, nonlinearity mitigation, analytical modelling and transmission system design.
Anastasiia is an experienced educator in STEM, educational events manager and designer, Fellow of the Higher Educational Academy. She is holding the role of the President International Physicists' Tournament, leading the work of the executive team. Beyond this, she has 10 years of volunteering experience for STEM and photonics communities, including engagement through SPIE, IEEE, and OSA. She is a Committee Member and Publicity Officer of the IEEE Photonics UK and Ireland Photonics Chapter, and a Chair-elect of the OSA Optical Communication Technical Group.

Abstract:
The optimisation and design of optical transmission systems involve multiple factors and interplay between noise sources, fibre nonlinearity and dispersions. For ultrawideband systems, the total number of parameters scales with the number of channels, and the optimisation appears to be computationally challenging. To compensate for it, one can apply analytical models for the quality of transmission estimation. Those can give the statistically averaged value of the signal to noise ratio, being an effective and accurate tool instead of full-scale signal transmission simulations. In the talk, I will cover the advantage that the Gaussian noise model and its generalisation to account for interchannel Raman scattering can bring to the analysis and optimisation of the transmission systems.

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UCL

Session 3: ML and AI applied to MB optical communication

Will Machine Learning mitigate the extra cost of increase in capacity?

Jelena Pesic

Nokia France

Jelena PESIC received a Ph.D. in Optical Networks from the University of South Brittany in collaboration with France Telecom–Orange Labs, France, in 2012. She received a best paper award at the IEEE ONDM conference in 2011. After her PhD Jelena joint Telecom Bretange as Post-doctoral Research Engineer and later INRIA, where she worked on the European project SASER. After moving to Alcatel–Lucent (now Nokia) Bell Labs in 2014, she focused on dynamic elastic networks dimensioning and techno-economic studies. Her main areas of research interest include intelligent optical networks, including core and metro networks. Jelena was selected OSA Ambassador in 2018.
She is currently working at Nokia as Systems Integration Specialist, with ION IP Optical Networks WDM technical expertise on the basis of the Nokia IP Transport product portfolio.

Abstract:
Machine learning has become an exciting subject in optical networks for both industry and academia. Its success reflects the growing need for network adaptation to changing circumstances (e.g., traffic, topology, or even user preferences). Moreover, challenges in optical networ ks are becoming more critical as we think about their evolution towards future scenarios with more data traffic, such as 5G networks, IoT, and others. Tomorrow's optical networks are a complex domain asking for very high capacity networks that also need to save the cost per bit. In this talk, we will try to explore machine learning for optical networks in light of its enormous technical capabilities as well as its potential to reduce costs.

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Session 3: ML and AI applied to MB optical communication

Monitoring optical network security with machine learning

Marija Furdek

Chalmers University of Technology

Marija Furdek works in the research unit Optical Networks. Her expertise lies in optical network design and optimization, with an emphasis on physical-layer security and resilience. She strives to develop secure, cognitive and autonomous communication networks. As (co)PI and WP/task leader, Marija participated in several Swedish and international scientific projects with collaborators from industry and academia. She co-authored 90+ scientific publications in international journals and conferences, 5 of which received best paper awards. She is a Senior Member of IEEE and OSA.

Abstract:
Optical networks are critical infrastructure vulnerable to a range of physical layer attacks that can degrade a multitude of services in the upper network layers. Despite recent progress, a framework for cognitive security management is not established yet. In this talk, we will discuss the challenges related to attack prevention, detection, and recovery. The focus will be placed on supervised, unsupervised and semi-supervised learning techniques that have promising performance in detecting known as well as novel attack types. The main challenges related to accuracy, scalability, interpretability and practical deployment of ML-based security diagnostics procedures will be reviewed, and ways of addressing these challenges will be examined.

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CHALMERS UNIVERSITY OF TECHNOLOGY

Session 3: ML and AI applied to MB optical communication

Opportunities and challenges of AI-based autonomous operation in MB scenarios

Marc Ruiz

Universitat Politècnica de Catalunya

Marc RUIZ received the M.Sc. degree in Statistics and Operations Research in 2009 from the Universitat Politecnica de Catalunya (UPC). In 2009 he joined the Advanced Broadband Communications Center (CCABA) to start his pre-doctoral research, receiving the PhD degree (with honors) in Computer Science in 2012 from the Computers Architecture Department (DAC) at UPC. He is currently working as a post doctoral researcher with the CCABA. His research interests include optimization and data analytics for next generation 5G networks. He has developed part of his work in the framework of past FP-7 European research projects such as DICONET, STRONGEST, IDEALIST, and GÉANT. Currently, he is working on the H2020 5G-PPP METRO-HAUL project, covering several topics on network planning and data analytics for metro optical networks. Moreover, he has participated in various national funded projects.

Abstract:
After the success of the first focused and standalone 5G trials, the beyond 5G (B5G) era already started, becoming the mainstream of academic and industry-driven research for next-generation networks. Future B5G networks must be able to operate with massive small-cell deployments and end-to-end connectivity in support of heterogeneous use cases with very different requirements in terms of bandwidth, latency and reliability. The availability of Multi-Band transmission, as well as other key technologies such as pluggable optics, will also lead to a complete redesign of the optical transport network. This also includes the control and management planes, that need to fully support autonomous network operation based on AI/ML algorithms, zero-touch networking and intent-based networking paradigms.
In this talk, we will review recent research contributions focused on AI/ML-based autonomous networking for several use cases including real time and near-real time operation. In addtion, analysis of the challenges and opportunities for future research applied to the foreseen optical transport technologies and networking paradigms will be introduced.

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Autoencoders in Optical Communications – From Modulation Format Optimization to Blind Equalization

Laurent Schmalen
Karlsruhe Institute of Technology

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 Aachen, 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:
In the recent years, machine learning techniques have proven to be indispensable tools for designing communication systems. One particularly popular technique is the concept of auto-encoders. In this talk, we will introduce the concept of auto-encoders and show how they can be used in two distinct ways to optimize the physical layer of optical communication systems. In particular, we show how to design higher order constellations that are tailored to channels exhibiting laser phase noise by using a novel differentiable blind phase search algorithm. As a second application, we use the concept of variational auto-encoders to design novel blind equalizers for coherent optical communications compensating linear impairments. The proposed algorithm jointly carries out equalization and performs a channel estimation, which is useful for providing information to higher network layers.

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Karlsruher Institut für Technologie

End-to-end deep learning for communication over dispersive nonlinear channels

Boris Karanov
Eindhoven University of Technology

Boris KARANOV is a post-doctoral research member of the Signal Processing Systems Group at the Eindhoven University of Technology with research focused on the application of deep learning for digital signal processing in optical fibre communications. He received his PhD from University College London, London, U.K., and Nokia Bell Labs, Stuttgart, Germany His Ph.D. research focused on developing new coding and detection methods for communication over the nonlinear dispersive optical fibre channel using deep learning. In 2018, Boris was a recepient of the Nokia "Most innovative AI solution" award for pioneering work in the field of machine learning applications to communication systems.

Abstract:
Deep learning, allowing the approximation of any nonlinear function, finds an increasing application in the digital signal processing modules of communication systems. Often, a specific transmitter or receiver function, such as coding, modulation or equalization, is optimized using deep learning. Moreover, deep learning and neural networks allow to design a complete communication system by carrying out the optimization in a single process spanning from the transmitter input to the receiver output. Such systems, implemented as a single deep neural network, have the potential to achieve the optimal end-to-end performance and recently gained popularity in communication scenarios, where the optimum pair of transmitter and receiver or optimum processing modules are not known or prohibitive because of complexity. In low-cost optical fiber systems based on intensity modulation and direct detection (IM/DD), the joint effects of chromatic dispersion and square-law photodiode detection render the communication channel nonlinear with memory. Such systems are particularly suitable for deep learning-based signal processing due to absence of optimal algorithms as well as complexity constraints. We discuss how end-to-end deep learning can be implemented in the low-cost fiber system and compare their performance and complexity with classical designs.

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Spatial and spectral power evolution design using machine learning-enabled Raman amplification

Mehran Soltani
Technical University of Denmark

Mehran SOLTANI received his B.Sc. and M.Sc. degrees in electrical engineering, communications systems from Amirkabir University of Technology; Tehran, Iran. His M.Sc. thesis (2020) was entitled "Learning-based Estimation and Detection in OFDM Systems", addressing deep learning methods for channel estimation and signal detection in OFDM systems. He joined the *Machine Learning in Photonic systems* group at the Department of Photonics Engineering, DTU, in July 2020. His PhD, under the supervision of Prof. Darko Zibar, focuses on signal power evolution design using machine learning-based Raman amplification. His research interests include machine learning and signal processing applied to optical and wireless communication systems.

Abstract:
Raman amplification is one of the key technologies in improving the performance of fiber optic communication systems. In this talk, I will present our machine learning framework on Raman amplifier design for shaping the signal power evolution over the frequency and fiber distance. The proposed framework adjusts the Raman pump power values to obtain the desired two-dimensional (2D) profiles using a convolutional neural network (CNN) followed by the differential evolution (DE) technique. The CNN learns the mapping between the 2D profiles and their corresponding pump power values. Nonetheless, its performance is not accurate for designing 2D profiles of practical interest, such as a 2D flat or a 2D symmetric (with respect to the middle point in fiber distance). To adjust the pump power values more accurately, the DE fine-tunes the power values initialized by the CNN to design the proposed 2D profile with a lower cost value. The results assert the very good performance of the proposed CNN-assisted DE framework utilized in designing 2D flat and symmetric power profiles defined over the whole C-band. Furthermore, the proposed DE with the CNN initialization provides higher accuracy with lower variance compared to the randomly initialized DE optimization.

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12 APPENDIX II

WON Special Event at ECOC 2021. Workshop booklet

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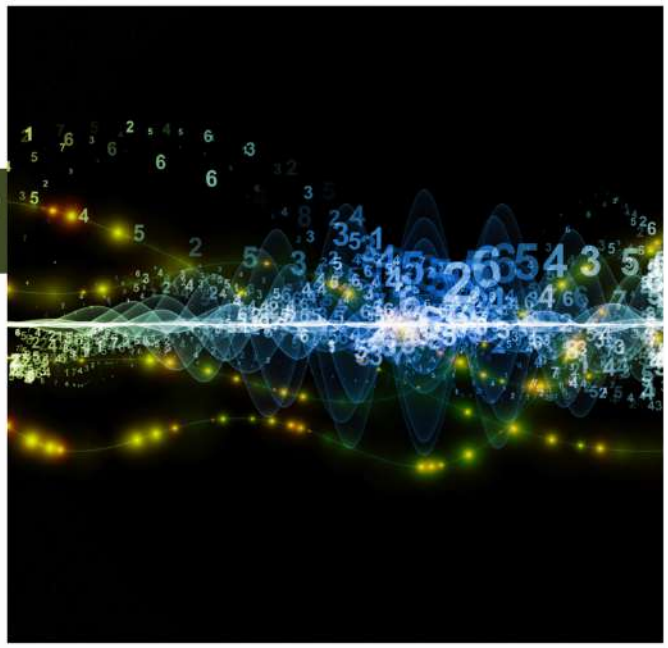

Nonlinear Interference Generation in Wideband and Disaggregated Optical Networks

Abstract:

To meet rising capacity and flexibility needs, optical networks are fast moving towards wideband and disaggregated architectures, where wavelength division multiplexed (WDM) grids extending beyond the C-band may feature lightpaths (LP)s that are independently routed through open and disaggregated reconfigurable optical add-drop multiplexers (ROADM)s.
In these frameworks, nonlinear interference (NLI) noise generation is complicated by the coherency of the self-phase modulation (SPM) and stimulated Raman scattering (SRS) effects, with both requiring consideration to accurately quantify LP quality of transmission (QoT). Within this talk I outline some key considerations for the implementation of a wideband and disaggregated NLI model, including spatial and spectral separability of the NLI.

Bruno Correia

Politecnico di Torino
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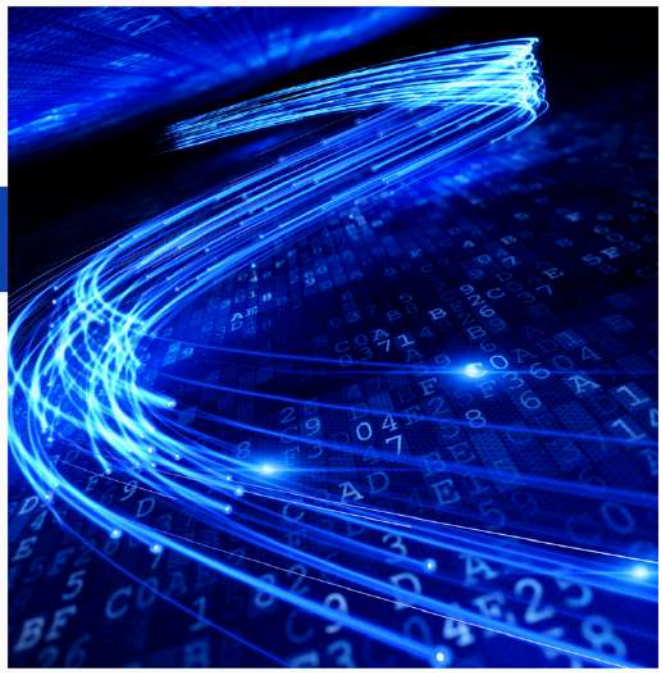

Impact on Quality of Transmission of Launch Power Choice for Wide-band Scenarios

Abstract:

Wideband transmission emerged as a viable solution to expand the traffic capacity of C-band wavelength-division multiplexing (WDM) optical systems.
In a scenario of wider bandwidth, in which the stimulated Raman scattering (SRS) effect and changes in fiber parameters such attenuation, dispersion, and nonlinear coefficients need to be considered, a careful input power choice plays an important role to maximize the quality of transmission (QoT).
The work presented is focused on this problem, showing the QoT degradation when more bands are progressively added to those systems, as well as the results of a multiband input power control and its impact on data traffic capacity on optical line systems (OLS).

Rasoul Sadeghi

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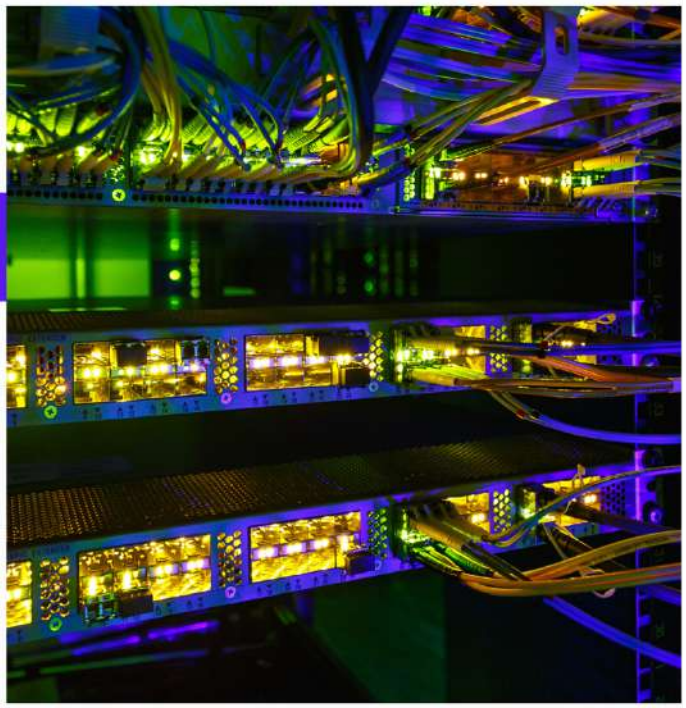


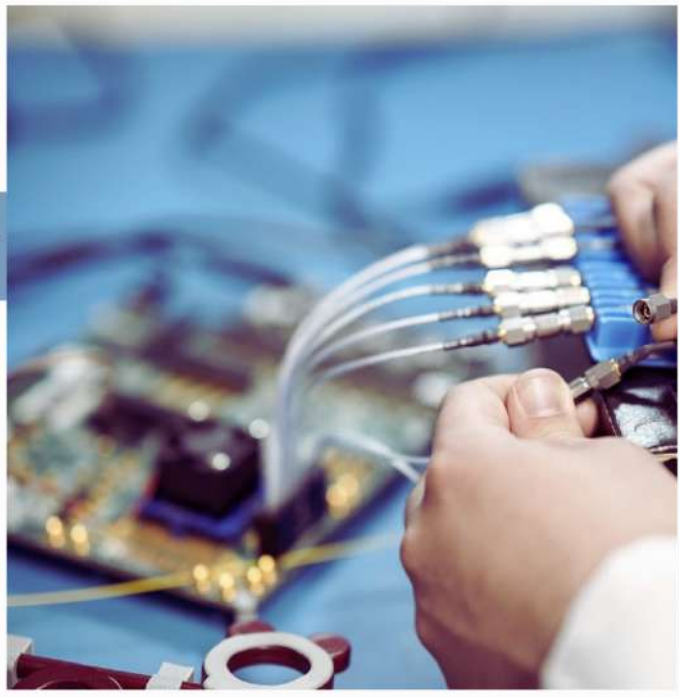
Comparison of Transparent C+L Band Network versus C-band Translucent Upgrade

Abstract:

We investigated the multiband transparent network and compared it with the translucent network with the single band in order to show the capacity, energy, and cost advantages of the multiband transparent network. We will show that the utilization of regenerators to enable higher-order modulation formats has a limited impact in increasing capacity while augmenting cost and power consumption. Exploiting the C+L-band and flexible transceivers is shown to be more effective. Alternatively, using state-of-the-art transceivers (i.e., performing closer to the Shannon limit) could also allow to significantly increase capacity using only the C-band.

Aleksandr Donodin

Aston University
United Kingdom



Bismuth-doped Fibre Amplifier as a Promising Solution for Multi-band Transmission Networks

Abstract:

The bismuth-doped fiber amplifier has proved to be a successful candidate for expanding the existing infrastructure through multi band transmission. However, the numerical modeling of bismuth-doped fiber amplifiers is challenging due to a large number of unknown parameters in the conventional rate equations models. On the other hand, the performance of an amplifier can be predicted using machine-learning frameworks. Thus, we propose a bismuth-doped fiber amplifier model based on a neural network purely trained with experimental data sets in E- and S-bands. Using the proposed approach the spectral dependencies of gain and noise figure for given bi-directional pump currents and input signal powers can be obtained.

Pratim Hazarika

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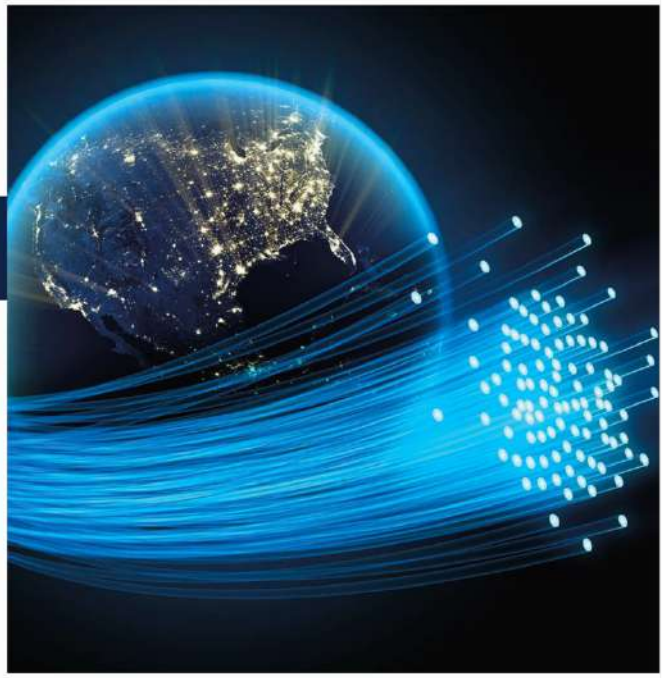


Multistage Raman Amplifier for Ultra-wideband Signal Amplification

Abstract:

We propose a novel multistage discrete Raman amplifier with ~200 nm signal amplification enabling E, S, C and L band WDM transmission. The indigenous amplifier architecture is based on split-combine approach of segregated spectral bands to minimize pump-pump and pump-signal overlapping with optimimal gain and noise figure (NF). Our experimental results show an average net gain of 15 dB and a maximum NF of 8 dB over the targeted spectral bands. WDM transmission experiment conducted over a 70 km fibre span with 10 Gb/s NRZ on-off keying shows a maximum power penalty of 1.6 dB within an assumed BER limit of10-4.

Rafael Kraemer

Technology University of Eindhoven
The Netherlands

Multi-band Wavelength Selective Switching in Metro Network

Abstract:

As fiber-optic systems turn toward multi-band transmission, novel architectures and devices for wavelength management become of interest. In this context, we report several approaches toward multi-band WSS, first on a photonic integrated WSSs based on AWGs and thermo-optic switch gates and then another approach based on band-specific filters and SOAs. Operation across the O, S, C and L-bands is reported with limited power and OSNR penalty in all tested cases.

Yu Wang

Technology University of Eindhoven
The Netherlands

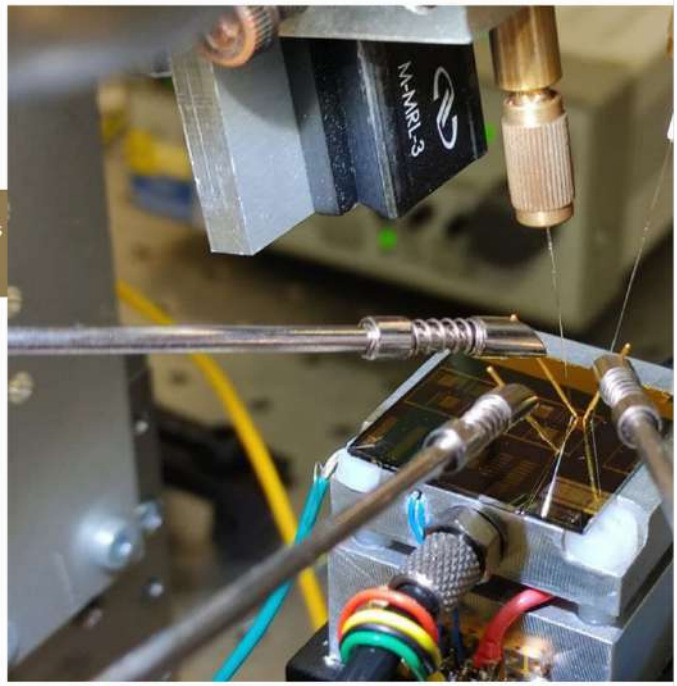
Ultra-wide band (O to L) integrated polymer TIR thermo-optic switch matrix

Abstract:

We present an ultra-wide band photonic integrated 4×4 polymer cross-bar switch matrix based on total internal reflection (TIR) effect. The photonic integrated polymer TIR switch matrix owns low insertion loss, low power consumption, wavelength and polarization independent operation for all switching paths. Experimental results show ultra-wide band (O- to L- band) operation with fiber to fiber insertion losses ranging from -3.7 dB to -6.5 dB, polarization dependent losses less than 0.6 dB, switching on-off ratio above 36 dB in average, and power consumption of 25 mW per path. Error free operation with power penalty less than 0.2 dB at 1E-9 BER was measured for ultra-wideband NRZ OOK WDM switched signals at 10, 25, 40 and 50 Gbit/s, and 510 Gbps dual polarization (DP)-64-QAM switched data with negligible penalty.

Emadreza Soltanian

Ghent University, IMEC
Belgium



Micro-transfer-printing Integration of III-V-on-Si to Realize SOAs and Tuneable Lasers

Abstract:

The wideband transceiver requires a wideband tuneable laser source. The wavelength coverage of a semiconductor laser is determined by the bandwidth of the gain medium and the losses in the laser cavity. In order to cover a broader wavelength range, multiple III-V gain elements need to be co-integrated to form wide and ultra-widely tuneable laser sources, especially for coherent communication.
As these types of lasers will be used to transmit and receive advanced modulation formats, the instantaneous linewidth of the laser needs to be small. One of the main obstacles to achieving the ultra-wide bandwidth lasers is the difficulty of scaling the integration of different III-V dies on a single waveguide circuit based on conventional integration technologies like die-to-wafer bonding.
The progress towards achieving mentioned targets based on the uTP technology will be presented at the WON-special event on ECOC21.

Thyago Monteiro

Technical University of Denmark
Denmark

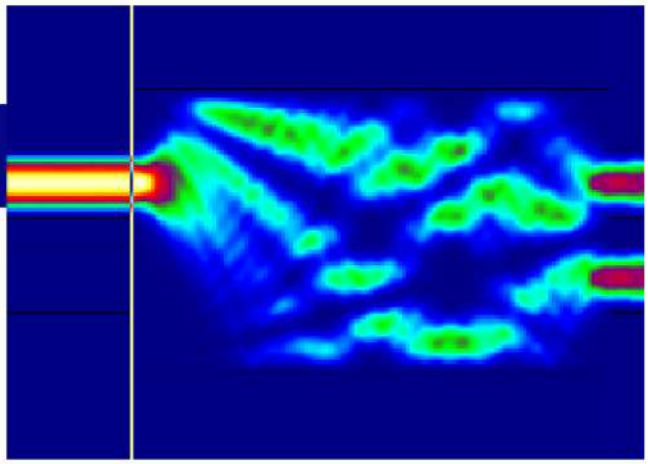
Optical Frequency Combs Optimization using Evolutionary Algorithms

Abstract:

We propose and validate, numerically and experimentally, an online metaheuristic framework for flatness optimization of optical frequency combs (OFCs) based on gain-switching (GS) lasers. OFCs are an alternative to multichannel optical communications and the OFC flatness is a main element in the OFC performance. We demonstrate the harmonic composition in the laser driving signal combined with particle swarm optimization (PSO) and differential evolution (DE) algorithms to improve the OFC flatness. The stand-alone laser diode is utilized for generating the comb, without additional components for flatness compensation. Numerical results provide a 9-lines OFC spectrum with 2.9-dB flatness. The online experimental DE-based optimization provides a 2-dB flatness 7-lines OFC.

Yaonian Cui

Fraunhofer HHI
Germany



Broadband InP based Mach-Zehnder Modulator

Abstract:

Indium Phosphide (InP) is a competitive candidate for modulators owing to its high integration with lasers, compact footprint, low loss, etc. In this talk, we simulate three different InP based broadband (O to L band) 2x2 Multimode Interference (MMI) couplers used in Mach-Zehnder Modulator (MZM). They include geometry reconfigured MMI, tunable MMI and Sub-Wavelength Grating (SWG) structure based MMI. The results show that the insertion loss can be < 0.8 dB in SWG MMI over entire wavelength range while it does not help to splitting ratio. On the other hand, the splitting ratio can be < 0.2 dB in tunable MMI from O to L band, which has no improvement on insertion loss.

Matheus Sena

Fraunhofer HHI
Germany

Enabling Cognitive Transceivers for Multiband Operation

Abstract:

Wideband (WB) optical systems have shown to be a promising solution to cope with the ever-growing increase in network traffic by efficiently utilizing the spectral resources of deployed optical fiber infrastructure. One alternative to enable the short-term operation of WB systems is to optimize standard C-band technologies for out-of-band use via the utilization of sophisticated digital signal processing (DSP) tools. These tools can learn the current conditions, and then plan, decide, and act to correct distortions that arise from components (e.g., transceivers) in WB operation. In this regard, this work shows a DSP scheme based on Bayesian optimization that autonomously adapts the design of Volterra and memory polynomial digital pre-distortion filters in S+C+L-band transmission.

Gabriele Di Rosa

VPIphotonics, Germany

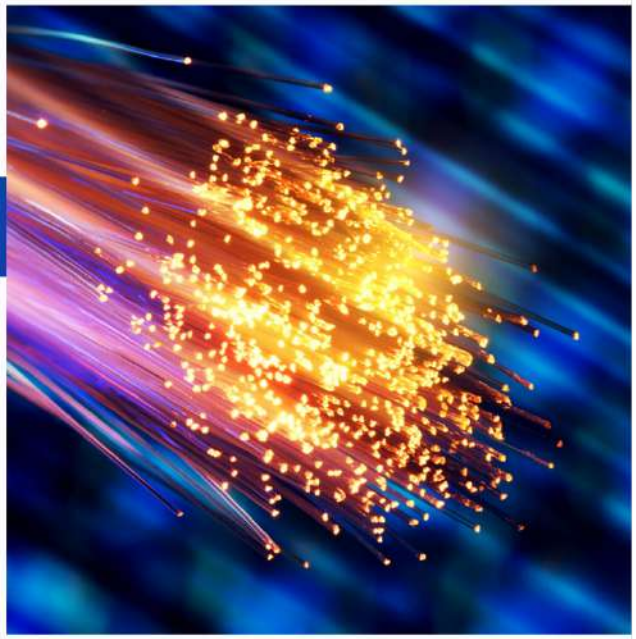
Wavelength-Dependency of Standard C-Band Transceivers Performance in Multiband Systems

Abstract:

Next-generation optical communication systems aim to vastly increase capacity by exploiting a larger optical transmission window extending beyond the conventional C-band. At the same time, the market trend is to maximize capacity per wavelength to reduce operational costs. This approach poses severe requirements on the transceivers, which may not be satisfied in a wideband scenario by current commercial components designed for operation in C-band. To investigate this aspect, we characterize wavelength-dependent I/Q imbalance of standard C-band IQ-modulator and coherent receiver operating in an S-C-L-band system. We find a negligible impact of the characterized transceiver imperfections on the achievable entropy rate for probabilistically shaped PDM-256/64-QAM for up to 150 nm transmission bandwidth.

André Souza

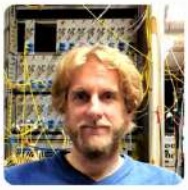
Infinera
Portugal



Going beyond C+L-band Transmission: Accurate and Scalable Quality of Transmission Estimation and its applications

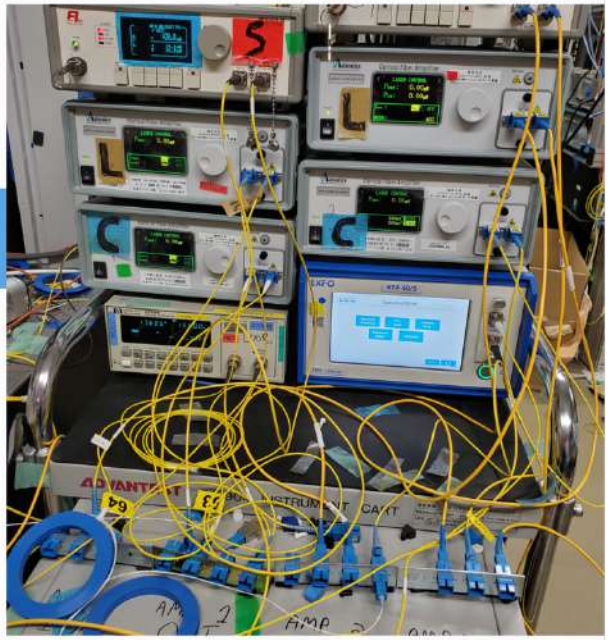
Abstract:

Fast and accurate quality of transmission (QoT) estimation algorithms are fundamental for the efficient and cost-effective network planning and operation. This work analyses different QoT estimation methods suitable for wideband transmission systems and their application for system optimization and capacity prediction.



Benjamin Puttnam

National Institute of Information and Communications Technology
Japan



Extending Transmission Window and Data-rates in SMF and low Spatial-channel count SDM Fibers

Abstract:

The ever-increasing demand for enhanced data transmission capacity has led to the exploration of new transmission windows, beyond the C and L band typical in medium to long range optical fiber communications. Indeed, recent demonstrations have shown that although the fiber loss in the S-band is typically higher than the C-band, adoption of new amplifiers can enable a broad new transmission band that may be exploited both to extend the life of deployed fibers and to increase throughput in new space-division multiplexing fibers. In particular lower-wavelength bands are of interest to low-core count multi-core fibers where the strong wavelength dependence of inter-core crosstalk can place a limit on core-density for C/L-band transmission. Here, we describe a series of experiments, exploring S-, C and L-band transmission in single-mode, multi-core and few-mode fibers covering bandwidths >150 nm and distances over 8000 km.