



MENTOR Machine LEarning in optical NeTwORks

A European Industrial Doctorate [EC GA 956713]

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Open-to-all Workshop 1 (OTAW I)

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Sant'Anna
School of Advanced Studies – Pisa



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Beneficiaries

Aston Institute Of Photonic Technologies (Lead Beneficiary at Aston University)
Infinera Germany (Non-recruiting Beneficiary)
Infinera Portugal (Non-recruiting Beneficiary)
Sant'Anna School of Advanced Studies
Technical University of Denmark
Polytechnic University of Catalonia

Industrial Partners

Telecom Italia Mobile
Orange Telecom Company

List of Acronyms

AiPT	Aston Institute Of Photonic Technologies
AST	Aston University
CA	Consortium Agreement
DTU	Technical University of Denmark
EC	European Commission
EID	European Industrial Doctorate
ESR	Early Stage Researcher
GA	Grant Agreement
INF-G	INFINERA Germany (Non-recruiting Beneficiary)
INF-P	INFINERA Portugal (Non-recruiting Beneficiary)
MENTOR	Machine LEarning in optical NeTwORks
ORANGE	Orange Telecom Company
SB	Supervisory Board
SSSA	Sant'Anna School of Advanced Studies
TIM	Telecom Italia Mobile
UPC	Polytechnic University of Catalonia

Executive Summary

This document is a deliverable based on the free and Open-To-All-Workshop I (OTAW I) which was organised by MENTOR partner, the Technical University of Denmark (DTU).

It was a hybrid event, taking place online and in-person in Denmark on 7-8 April 2022.

MENTOR's Work Package Leader 2 Professor Darko Zibar of DTU was the overall workshop chair.

OTAW I "ML and AI applied to Mb optical communication" was delivered alongside two similar workshops: "ML methods for Ultra-Wide Band Systems" for ITN ETN WON (EC GA 814276), and "Practical implementation and network applications of Nonlinear Fourier Transform" for ITN EID FONTE (EC GA 766115). For FONTE this was also an Open To All Workshop; for WON, it was a mini symposium.

EID FONTE and ETN WON were co-organisers.

Like MENTOR, both these projects are co-ordinated by the Aston Institute of Photonic Technologies at Aston University.

The name of the combined workshop was "Current and future trends for optical communication systems". It addressed current and future trends and was particularly aimed at Early Career Researchers and PhD students working in the fields of Photonics and Fiber Optical Communications. The workshop brought together researchers from the fields of machine learning and artificial intelligence and Nonlinear Fourier Transform in fiber optical communication.

There were three sessions during this two-day workshop: two half-day sessions on 7th April (EID FONTE and ETN WON) and one half-day session on 8th April (EID MENTOR). These three sessions were chaired (in chronological order) by Vinod Bajaj of TU Delft; Uiara Celine de Moura from the Technical University of Denmark; and Vladislav Neskorniuk of Aston University.

The workshop promoted networking and collaboration between participants from academia and industry.

Participants:

- The event consisted of 17 speakers and was attended by 225 participants, involving 78 organisations.
- There were 11 speakers for WON and FONTE's symposia on 7 April and six speakers for MENTOR's session on 8 April.
- Countries represented include Algeria, Belgium, Brazil, China, Czech Republic, Denmark, Egypt, France, Germany, Greece, Hong Kong, India, Ireland, Israel, Italy, Mexico, Nepal, Netherlands, Pakistan, Portugal, Russia, Spain, Sweden, Turkey, UK and USA.
- Where speakers agreed to make their presentation available, links to them were distributed to participants shortly after the event.

ESR Attendance:

- Five of MENTOR ESRs attended the event online. The sixth (ESR5) had an unavoidable personal commitment coinciding with an overseas piece of in-person outreach. Fellow ESRs were informed and they made summaries of talks so the ESR could catch up easily.

- The two newest ESRs (ESR1 at Aston and ESR6 at UPC) participated online from their home countries Thailand and India respectively, ahead of their official start dates (April 15 for ESR1 (M16) and June 1 2022 (M18) for ESR6).



Countries represented

Algeria	Israel
Belgium	Italy
Brazil	Mexico
China	Nepal
Czech Republic	Netherlands
Denmark	Pakistan
Egypt	Portugal
France	Russia
Germany	Spain
Greece	Sweden
Hong Kong	Turkey
India	UK
Ireland	USA

**225 participants
78 organisations**

Workshop Info
SCAN ME!

Figure 1 OTAW 1 attendees at DTU, with Jelena Pesic of NOKIA presenting, bottom left.

1. Website and Registration

The six-page website <https://dtu-workshop.astonphotonics.uk/> was launched in late January 2022.

The site consisted of the following information:

- a homepage (with downloadable directions and QR code to conference booklet)
- a schedule page
- a page displaying an A-Z list of the speakers
- a page with travel and venue details
- a registration page for online and in-person attendance
- there was also a contact page for queries.

[Home](#) [Schedule](#) [Speakers \(A-Z\)](#) [Venue](#) [Register](#) [Contact Organisers](#)



FREE and open-to-all 2-day workshop on MACHINE LEARNING, ARTIFICIAL INTELLIGENCE AND NONLINEAR FOURIER TRANSFORM in FIBER OPTICAL COMMUNICATION, held at the Technical University of Denmark 7-8 April 2022 (incl ONLINE participation). Addressing both current and future trends, this workshop is particularly suited for PhD students and Early Career Researchers working in the fields of Photonics and Fiber Optical Communications. Featured sessions will cover 1. Practical Implementation and Network Applications of Nonlinear Fourier Transform; 2. Machine Learning Methods for Ultra-Wide Band Systems; and 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 (Aston Institute of Photonic Technologies).

Figure 2 OTAW1 Homepage <https://dtu-workshop.astonphotonics.uk/>

The site combined workshops from three projects into one big workshop.

There were over 150 online registrations.

Every registered participant received a link to the meetings and further instructions.

REGISTER

Attending the workshop is completely **FREE**, but registration is required.
Limited places are available for *in-person* attendance and will require **confirmation** by the organisers.

Deadlines:

On-site registration: Fri 18 March 2022.

Online registration: Tue 5th April 2022

Your First Name (required)

Your Last Name (required)

Your Email (required)

Your Home University (required)

Your Education: please state 'undergraduate student', 'PhD student', 'post-doc' or 'other' (required)

Attendance mode: please state 'online' or 'on-site' (required)

Optional: Your Message

Send

Figure 3 Registration page for OTAW1

2. Dissemination of the Workshop

A direct link to the workshop webpage was published on the MENTOR website in the training section:

<https://mentor.astonphotonics.uk/open-to-all-workshop-dtu-ml-and-ai-applied-to-mb-optical-communication/>

Furthermore, the Workshop was widely advertised by MENTOR, FONTE and WON using unified branding through personal contacts, LinkedIn and Twitter.

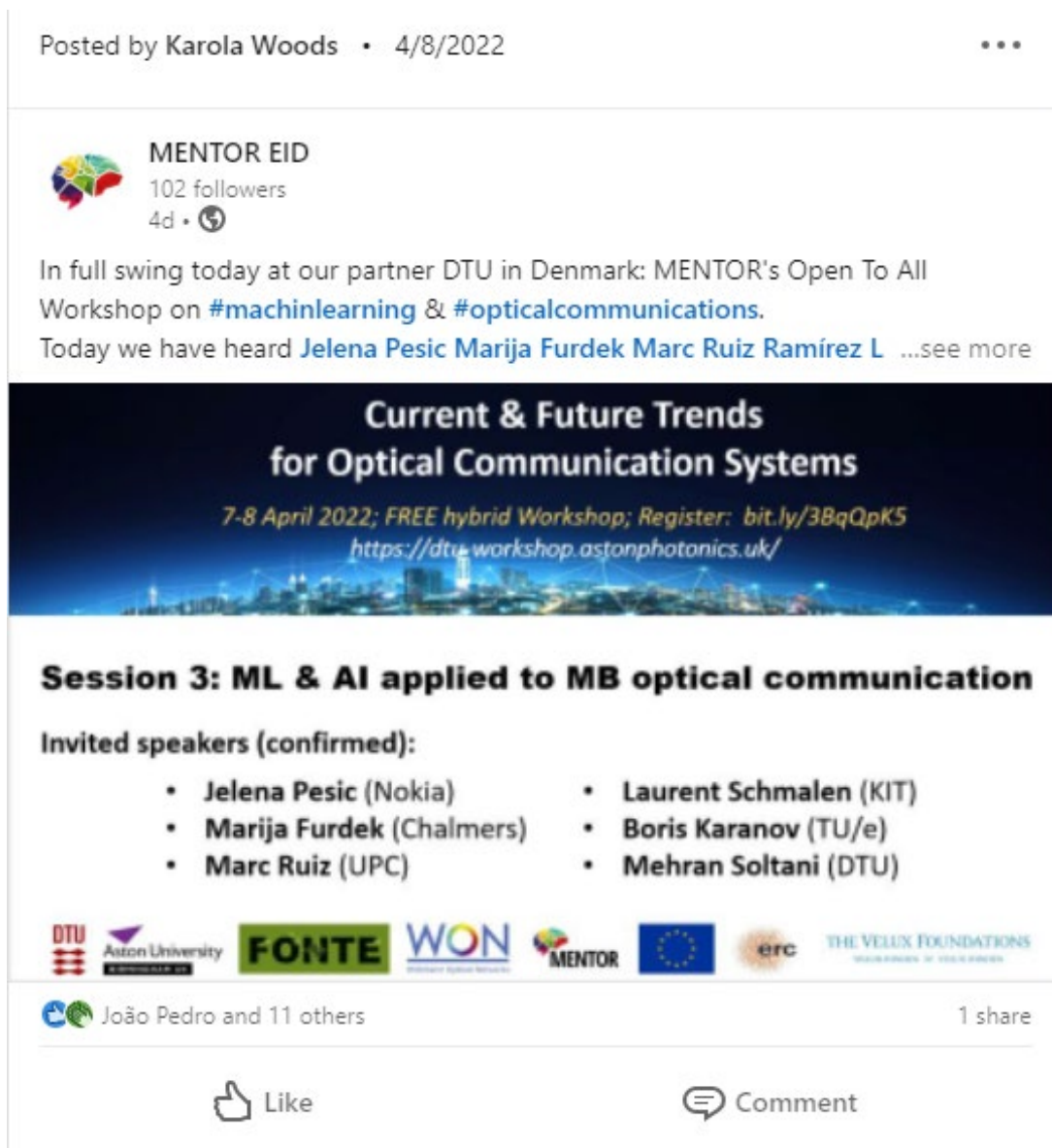


Figure 4 OTAW1 on MENTOR's LinkedIn profile

MENTOR (@MENTOR-EID, 168 followers) advertised the project on Twitter from early February onwards, as did ITN projects EID Fonte (@EIDFonte, 340 followers) and ETN Won (@ETNWon, 453 followers).



Figure 5 OTAW1 on EID FONTE's Twitter stream

From early February 2022, MENTOR, FONTE and WON tweeted approximately thirty times about the workshop, resulting in an impressive 90 retweets.

As MENTOR, FONTE and WON are all coordinated by Aston Institute of Photonic Technologies at Aston University, the event was also tweeted approximately five times on the AIPT stream too; ([@AstonPhotonics](#), 1,104 followers).

Retweets occurred regularly throughout the publicity period (early February until the workshop in April), with retweets peaking slightly at the campaign’s start.

In late March on Twitter, the MENTOR Management also promoted the workshop in a more granular way, with Tweets on individual MENTOR speakers:

**Current & Future Trends
for Optical Communication Systems**

7-8 April
2022

FREE workshop
online and at
DTU, Denmark

<https://dtu-workshop.astonphotonics.uk/>
Register: bit.ly/3BqQpK5

Jelena PESIC
Systems Integration Specialist; NOKIA

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

Figure 6 Individual speaker talks were published on Twitter from late March 2022, M15

Retweets also frequently occurred with these ‘spotlight’ tweets that highlighted a particular speaker. Naturally, there was more engagement if the person ‘featured in the spotlight’ was on Twitter too.

A QR code leading to a full Conference Booklet was also publicised via email, on the workshop website and on social media.



Figure 7 OTAW1 Workshop QR Code

The tweet yielding the most engagement on MENTOR’s Twitter stream was speaker Marija Furdek retweeting and engaging with MENTOR’s tweet a week before the workshop, and before registration closed, as the tweet itself indicates. It caused a flurry of activity and 7 retweets.

It was also the Tweet that gained the highest number of impressions, 1,215 (impressions are the number of times users see a Tweet on Twitter). The average number of impressions per workshop tweet for MENTOR was 200, however another peak was during the workshop itself when impressions reached 400).



Figure 8 The top tweet in March in the run up to the workshop

3. Schedule

The workshop schedule can be seen here: <https://dtu-workshop.astonphotonics.uk/schedule/>

For the purposes of this report, the schedule is also here below. However, please also see the Annex in Section 6, page 17, for the schedule within a full conference booklet.

Thursday 7 April 2022 – EID FONTE Speakers

Morning: Practical implementation & 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

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

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 reduction techniques in the nonlinear Fourier domain

Thursday 7 April 2022 – ETN WON Speakers

Afternoon: 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: Spatial multiplexing for high-capacity fiber-optic communication

14:40 – 15:15

Michael Galili

Technical University of Denmark

Title: Compensation of Nonlinear Signal Distortion using Optical Phase Conjugation

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 Vasychenkova

University College London

Title: Analytical models for quality of information estimation in the ultrawideband transmission

Friday 8 April 2022 – EID MENTOR Speakers

Morning: ML & 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

11:00 – 11:35

Laurent Schmalen

Karlsruhe Institute of Technology

Title: Autoencoders in Optical Communications – From Modulation Format Optimization

11:35 – 12:10

Boris Karanov

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 and further networking opportunities with workshop participants and DTU members of staff.

4. Speakers and Abstracts

The workshop's 17 speakers and their abstracts are listed here:

<https://dtu-workshop.astonphotonics.uk/speakers/>

Please also see the full conference booklet in the Annex, section 6, further below. It includes the schedule, speaker biographies and speakers' abstracts.

5. Conclusion

The Workshop "Current and future trends for optical communication systems" gave the opportunity for participants to network and increase their knowledge. The hybrid format allowed brilliant speakers from different countries both from academic and industrial sector to exchange ideas online and in person, and this was often with real joy and enthusiasm following the bar on travel caused by the pandemic.

The discussion after talks gave an opportunity to researchers and our ESRs to find new ideas for their work and create new connections.

6. Annex

The OTAW1 conference booklet and schedule follows from page 17.

The booklet was downloadable through the QR code on page 11.

EC Funding



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement number 956713

Open to all Workshop Abstracts and Speakers

CURRENT & FUTURE TRENDS FOR OPTICAL COMMUNICATION SYSTEMS

7-8 April 2022

Technical University of Denmark (DTU) and online

<https://dtu-workshop.astonphotonics.uk>

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

Time (CET)	Chair: Vinod Bajaj, TU Delft
09:00 – 09:05	Darko Zibar ; Technical University of Denmark <i>Welcome and Opening Remarks</i>
09:05 – 09:40	Sander Wahls ; Delft University of Technology <i>Title: Pulse shaping in the nonlinear Fourier domain</i>
09:40 – 10:15	Marco Secondini ; Scuola Superiore Sant’Anna <i>Title: To NFT, or not to NFT, different ways of dealing with fiber nonlinearity</i>
10:15 – 10:50	Alan Pak Tao Lau ; The Hong Kong Polytechnic University <i>Title: Multi-symbol DSP techniques for discrete eigenvalue transmissions based on NFT</i>
10:50 – 11:05	Break
11:05 – 11:40	Stas Derevyanko ; Ben Gurion University of the Negev <i>Title: Channel models and spectral efficiency limits for optical fiber transmission systems employing the Nonlinear Fourier Transform</i>
11:40 – 12:15	Morteza Kamalian-Kopae ; Aston University <i>Title: Noise in the nonlinear Fourier domain</i>
12:15 – 13:30	Lunch

Session 2: ML methods for Ultra-Wide Band systems

Time (CET)	Chair: Uiara Celine de Moura, Technical University of Denmark
13:30 – 14:05	Antonio Napoli ; Infinera Germany <i>Title: Coherent-based point-to-multipoint optical networks: potentialities, challenges and benefits.</i>
14:05 – 14:40	Cristian Antonelli ; University of L’Aquila <i>Title: Modeling of Multiple-Mode Propagation in Fibers for Space-Division Multiplexing</i>
14:40 – 15:15	Michael Galili ; Technical University of Denmark <i>Title: Compensation of Nonlinear Signal Distortion using Optical Phase Conjugation</i>
15:15 – 15:30	Break
15:30 – 16:05	Andrea Carena ; Politecnico di Torino <i>Title: ML models for the abstraction of photonic components in UWB systems</i>
16:05 – 16:40	Thomas Bradley ; Eindhoven University of Technology <i>Title: High Capacity Data Transmission with Space Division Multiplexing</i>
16:40 – 17:15	Anastasiia Vasylychenkova ; University College London <i>Title: Analytical models for quality of information estimation in the ultrawideband transmission</i>
	Dinner, drinks and networking
18:00 – 21:00	Dinner and Beer tasting at Noerrebro Bryghus (transport will be arranged)

Session 3: ML and AI applied to MB optical communication

Time (CET)	Chair: Vladislav Neskorniuk; Aston University
09:00-09:35	<p>Jelena Pesic; Nokia France Title: <i>Will Machine Learning mitigate the extra cost of increase in capacity?</i></p>
09:35 – 10:10	<p>Marija Furdek; Chalmers University of Technology Title: <i>Monitoring optical network security with machine learning</i></p>
10:10 – 10:45	<p>Marc Ruiz; <u>Universitat Politècnica de Catalunya</u> Title: <i>Opportunities and challenges of AI-based autonomous operation in MB scenarios</i></p>
10:45 – 11:00	Break
11:00 – 11:35	<p>Laurent Schmalen; Karlsruhe Institute of Technology Title: <u>Autoencoders in Optical Communications</u> – From Modulation Format Optimization to Blind Equalization</p>
11:35 – 12:10	<p>Boris Karanov; Eindhoven University of Technology Title: <i>End-to-end deep learning for communication over dispersive nonlinear channels</i></p>
12:10 – 12:45	<p>Mehran Soltani; Technical University of Denmark Title: <i>Spatial and spectral power evolution design using machine learning-enabled Raman amplification</i></p>
12:45 – 14:00	Lunch
14:00-17:00	<p>Guided tour of the DTU Laboratories Facilities Building 343, download map here, and further networking opportunities with workshop participants and DTU members of staff.</p> <p>In parallel: FONTE Project Networking and Management Meeting (closed event)</p>
18:00-21:00	Informal networking opportunity

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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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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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 -coefficients $b(\lambda)$ 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 -coefficients 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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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.



<https://www.ee.bgu.ac.il/~stasd/>

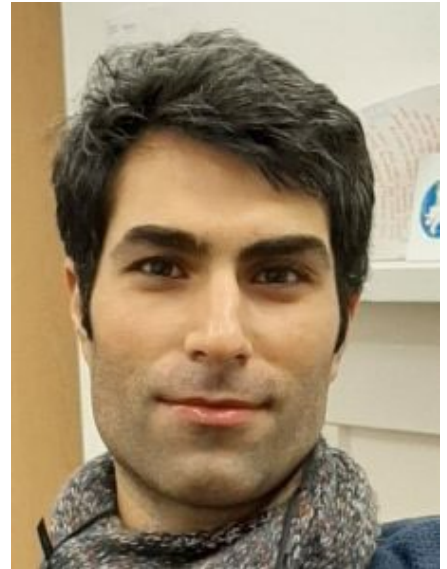
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Noise reduction techniques in the nonlinear Fourier domain

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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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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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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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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ML models for the abstraction of photonic components in UWB systems

Andrea Carena

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

Anastasiia Vasylychenkova

University College London

Anastasiia Vasylychenkova 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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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 joined Telecom Bretagne 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 networks 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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The Nokia logo, consisting of the word "NOKIA" in a bold, white, sans-serif font, centered on a solid blue rectangular background.

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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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 Politècnica 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 addition, 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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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 recipient 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

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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.

