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WS 1: Progress and Challenges in MIMO Signal Processing and Channel Modelling for Space Division Multiplexed Transmission Systems

Progress and Challenges in MIMO Signal Processing and Channel Modelling for Space Division Multiplexed Transmission Systems

Benn Thomsen (University College London, United Kingdom)

To date the most impressive single fibre capacity results have utilised Space Division multiplexing either within multiple cores or within a single multimode core or combination thereof. In the 12 years since the Mode Division Multiplexing (MDM) flavour of Space Division Multiplexing (SDM) for coherent systems was first proposed and demonstrated by Hsu et al. we have come a considerable way. From Hsu's First demonstration of 2x2 MIMO at 100Mbit/s per channel over 100m of 62.5um multimode fibre, to the most recently demonstrated 30x30 MIMO at 60Gbit/s per channel over 23 km of specially designed Few Mode Fibre by Fontaine, et al. These impressive results have all used offline MIMO processing to demonstrate the potential capacity of such systems, the challenge now is to develop real-time signal processing technology to show that such systems can outperform conventional single mode fibre approaches and make this a compelling technology to deploy.

WS 2: Exploring the real value of flexible optical networks

Exploring the real value of flexible optical networks

Dimitrios Apostolopoulos (National Technical University of Athens & Institute of Communication and Computer Systems, Greece); Camille Delezoide (Nokia Bell Labs, France)

The world's insatiable demand for bandwidth is stretching physical layer capacity; it is only a matter of years before we are faced with throughputs that are beyond the reach of current static optical networks. Moreover, the changing nature of traffic toward more volatile patterns renders the conventional approach of over-provisioning of resources increasingly inefficient. Operators are finding that room for economically viable growth is shrinking. Flexible optical networks are being touted as a means of avoiding the capacity crunch and increasing costefficiency, through the introduction of adaptability in modulation format and elasticity in spectrum utilization, by dropping the fixed grid and allowing dynamic adjustment of throughput and wavelength allocation.

WS 3: Short range optical transmission for emerging 5G fronthaul, DCI and Metro Networks

Short range optical transmission for emerging 5G fronthaul, DCI and Metro Networks

Gordon Ning Liu (Huawei Technologies Co. Ltd., P.R. China); Volker Jungnickel (Fraunhofer Heinrich Hertz Institute & Technische Universität Berlin, Germany)

With the rapidly increasing data traffic in 5G mobile fronthaul, data center interconnect (DCI), and metro networks, the growing bandwidth demand from high speed short range optical transmission will be much more than that from the long-haul optical transmission. Especially, when using conventional digital transmission such as CPRI in CRAN architecture, 5G performance targets would imply a severe capacity crunch. Besides, there are tremendous amounts of optical equipments in short range optical transmission systems compared with the long-haul transmission systems and thus will induce large cost and huge energy

consumption. Therefore, the power and cost efficiency should be key considerations for short range optical transmission besides the transmission performance. The workshop aims to bring together internationally recognized experts from network operators, equipment/component vendors and academia in order to provide a comprehensive overview of this important field for next-generation short range optical transmission. Some demands, transmission schemes and optical components technologies which can be shared by 5G fronthaul, DCI and metro networks will be discussed in the first session. Then in the second session, the workshop will be focused on several new concepts, e.g. the Next Generation Fronthaul Interface (NGFI) based on Analog or Ethernet technologies and using a new functional split between BBU and RRH.

WS 4: Fiber and waveguide based devices for 2 micron, is there the need?

Fiber and waveguide based devices for 2 micron, is there the need ?

Camille-Sophie Bres (, Switzerland); Periklis Petropoulos (University of Southampton, United Kingdom)
The workshop will put forward a discussion on the recent and rapid development of fiber/waveguide based sources and devices for the short wave infrared (2 micron), and will debate whether there is a real need for this technology, especially in the context of telecommunications. Amongst others, we are seeing the emergence of fiberized components, off the shelf sources, high speed modulators, directly modulated sources as well as demonstrations of 2 micron communications in hollow core fibers. Is there a real potential or is it simply interesting physics? What components/technological developments/improvements would be needed to make the technology an implemented reality?

WS 5: Next Generation Ultra-Broadband Silicon Photonics Based Integrated Circuits

Next Generation Ultra-Broadband Silicon Photonics Based Integrated Circuits

Guang-Hua Duan (III-V Lab, France); Abderrahim Ramdane (CNRS/LPN & Institut National des Télécommunications, France); Johann Peter Reithmaier (University of Kassel, Germany); Jeremy Witzens (Institute for Integrated Photonics, RWTH Aachen, Germany)
Increasing front panel data densities of data center switches as well as increasing reach and data rate of data center state-of-the-art optical interconnects has motivated the emergence of Silicon Photonics based integrated circuits. In parallel, metro and longhaul networks require transceivers with reduced size and power consumption. Silicon photonics is also a candidate for these markets. This Workshop will gather prominent speakers from industry and academia and intends to give an update on the state of the art on Silicon Photonics based integrated circuits, with emphasis on the following two key areas: - Integration of efficient laser source solutions for silicon photonics with advanced material systems such as quantum dots. - Silicon based Photonic Integrated Circuits implementing broadband wavelength division multiplexing.

WS6: Extending reach in long-haul WDM systems: What can be achieved with nonlinear mitigation techniques in fully loaded WDM Transmission?

Extending reach in long-haul WDM systems: What can be achieved with nonlinear mitigation techniques in fully loaded WDM transmission?

Giancarlo Gavioli (Nokia, Italy); David Millar (Mitsubishi Electric Research Laboratories, USA); Robert Killey (University College London, United Kingdom)
Digital coherent technology has enabled compensation of linear fiber impairments and the introduction advanced error-correction coding in optical transmission systems. Fiber nonlinearity has thus become the dominant obstacle towards achieving the ultimate capacity in optical transmission systems.

M.1.A: High Power Fiber Lasers
Chair: Hans G. Limberger (EPFL & Gr-Sci-HL, Switzerland)

High Power Fibre Lasers: Fundamentals, Recent Progress and Challenges

Michael Zervas (University of Southampton & SPI Lasers); Christophe Codemard (SPI Lasers, United Kingdom)

We review the fundamental properties and latest power scaling in fibre lasers, including limitations imposed by fibre nonlinearities, transverse modal instabilities and other parasitic effects. Their impact on the industrial applications space is also considered.

M.1.B: DSP for Receiver Subsystems
Chair: Naoya Wada (NICT, Japan)

Adaptive Transceivers in Nonlinear Flexible Networks
David Ives (University of Cambridge, United Kingdom); Alex Alvarado (University College London, United Kingdom); Seb J Savory (University of Cambridge, United Kingdom)
Transceiver adaptation is essential within an optical network to make effective use of the physical layer resources. We investigate the types of adaptation, the granularity of control and its effect on network data throughput.

Accurate and Robust Channel Spacing Estimation Based on Periodic Training Sequence in Denser Nyquist-WDM System
Ying Zhao (Fujitsu Research and Development Center, P.R. China); Huihui Li (FUJITSU R&D CENTER CO., LTD., P.R. China); Xiaofei Su (Fujitsu R&D Center, P.R. China); Liang Dou (Fujitsu Research & Development Center Co., LTD., P.R. China); Zhenning Tao (Fujitsu R&D Center Ltd., P.R. China); Shoichiro Oda (Fujitsu Laboratories Ltd., Japan); Yasuhiko Aoki (Fujitsu Limited, Japan); Takeshi Hoshida and Jens C. Rasmussen (Fujitsu Laboratories Limited, Japan)
We propose an accurate and robust channel spacing estimation method based on a designed periodic training sequence. Experiment results show that estimation error is less than 50MHz and the method is immune to chromatic dispersion, polarization effects and fiber nonlinearity.

Linewidth-Tolerant Carrier Phase Estimation for N-PSK Based on Pilot-Assisted N/2th-power Method
Tomofumi Oyama (Fujitsu Laboratories Ltd, Japan); Takeshi Hoshida (Fujitsu Limited); Hisao Nakashima (Fujitsu Limited, Japan); Takahito Tanimura (Fujitsu Laboratories Ltd.); Yuichi Akiyama (Fujitsu Limited); Jens C. Rasmussen (Fujitsu Laboratories Ltd.)
We propose a novel pilot-assisted carrier phase estimation method to reduce cycle slips. We numerically confirm that carrier phase recovery based on proposed method outperforms conventional V&V method in BER performance in large linewidth condition without causing any cycle slips.

Time Recovery for Spectrally-Sliced Optical Receivers
Valery Nobl Rozental, André Souza, Sandro M. Rossi, Andrea Chiuchiarelli, Juliano Rodrigues Fernandes de Oliveira and Jacklyn D. Reis (CPqD, Division of Optical Technologies, Brazil)
We propose and experimentally demonstrate a symbol synchronization method for spectrally-sliced optical receivers with MIMO equalizer signal reconstruction in a PM-16QAM 56-GBd 20x400G testbed. A novel timing error detector extracts sampling phase information from equalizer coefficients.

Widely Linear Blind Adaptive Equalization for Transmitter IQ-Imbalance/Skew Compensation in Multicarrier Systems
Edson Porto da Silva (Technical University of Denmark, Denmark); Darko Zibar (DTU Fotonik, depertment of Photonic Engineering, Technical University of Denmark, Denmark)
Simple analytical widely linear complex-valued models for IQ-imbalance and IQ-skew effects in multicarrier transmitters are presented. To compensate for such effects, a 4$\times$4 MIMO widely linear adaptive equalizer is proposed and experimentally validated.

M.1.C: High Speed Subsystems
Chair: Laurent Bramerie (Foton CNRS UMR & ENSSAT / Université de Rennes 1, France)

On Single-Carrier 400G Line Side Optics Using PM-256QAM
Hung-Chang Chien and Jianjun Yu (ZTE (TX) Inc., USA)
For the first time, 400G line side interface based on single-carrier PM-256QAM is proposed and experimentally demonstrated, reaching 1.04-dBQ BTB system margin to the SD pre-FEC limit through fast-converging polarization-tracking blind equalization and LUT nonlinearity compensation.

180-Gb/s (90-GBd QPSK) Single Carrier Transmitter Using a Thin Film Polymer on Silicon I/Q Modulator
Gregory Raybon (Nokia Bell Labs, USA); Junho Cho and Andrew Adamiecki (Nokia Bell labs, USA); Peter Winzer (Lucent Technologies, USA); Luis Carvalho (BrPHOTONICS, Brazil); Julio Cesar Oliveira (BrPhotonics, Brazil); Agnieszka Konczykowska and Jean-Yves Dupuy (III-V Lab, France); Filipe Jorge (Alcatel Thales III-V Lab, joint la: Bell Labs and Thales Research and Technology, France)

We demonstrate high-speed (90-GBd) modulation of a thin film polymer on Silicon (TFPS) I/Q modulator achieving single-polarization quadrature phase shift keyed (QPSK) data rates of 180 Gb/s.

Injection-locked Homodyne Detection System for Higher-order QAM Digital Coherent Transmission

Keisuke Kasai, Masato Yoshida, Toshihiko Hirooka and Masataka Nakazawa (Tohoku University, Japan)

We describe recent advances in a homodyne-detection system with injection locking and its application for higher-order QAM coherent transmission. Injection locking enables precise optical carrier-phase synchronisation with a simple receiver configuration. We demonstrate a 320 Gbit/s, 256QAM-160 km transmission.

100 GSa/s BiCMOS DAC Supporting 400 Gb/s Dual Channel Transmission

Karsten Schuh (Nokia, Bell Labs, Germany); Fred Buchali and Wilfried Idler (Nokia Bell Labs, Germany); Qian Hu (Bell Labs, Nokia, Germany); Wolfgang Templ (Nokia, Bell Labs, Germany); Anna Bielik (MICRAM Microelectronic GmbH, Germany); Lars Altenhain and Henning Langenhagen (Micram Microelectronic, Germany); Jörg Rupeter (MICRAM Microelectronic GmbH, Germany); Ulrich Dümler (Micram Microelectronic, Germany); Tobias Ellermeyer, Rolf Schmid and Michael Möller (MICRAM Microelectronic GmbH, Germany)

We demonstrate generation of a 32Gbaud 16QAM dual polarization dual channel signal from one laser utilizing novel 100GSa/s BiCMOS digital-to-analog converters. Fiber transmission over 2200 km of SSMF is also demonstrated outperforming a 64 GBaud system by 25% in reach.

Single-Detector, Single-ADC, Switched Coherent Optical Receiver for High Symbol Rate Systems Experiments

Gregory Raybon (Nokia Bell Labs, USA); Junho Cho and Andrew Adamiecki (Nokia Bell labs, USA); Peter Winzer (Lucent Technologies, USA); Nicolas K Fontaine (Bell Labs/Alcatel-Lucent, USA); Jean-Yves Dupuy and Agnieszka Konczykowska (III-V Lab, France); Filipe Jorge (Alcatel Thales III-V Lab, joint la: Bell Labs and Thales Research and Technology, France); Peter Pupalaikis (LeCroy Corporation, USA); Roger Delbue, B Bhat and Patrick Connally (Teledyne Lecroy, USA); Roland Ryf (Bell Labs, Nokia, USA); Ellsworth C. Burrows (Bell Labs, Alcatel-Lucent, USA)

We demonstrate a polarization-diversity coherent receiver with 100-GHz electrical bandwidth using only a single photodetector and a single high-speed analog-to-digital converter (ADC). We verify receiver performance using 90-GBd polarization-multiplexed QPSK test signals.

M.1.D: Probabilistic Shaping

Chair: Gabriel Charlet (Bell Labs Nokia, France)

Experimental Comparison of Gains in Achievable Information Rates from Probabilistic Shaping and Digital Backpropagation for DP-256QAM/1024QAM WDM Systems

Edson Porto da Silva, Metodi Yankov, Francesco Da Ros, Soren Forchhammer, Michael Galili and Leif Oxenløwe (Technical University of Denmark, Denmark); Darko Zibar (DTU Fotonik, depertment of Photonic Engineering, Technical University of Denmark, Denmark)

Gains in achievable information rates from probabilistic shaping and digital backpropagation are compared for WDM transmission of 5x10-GBd DP-256QAM/1024QAM up to 1700 km reach. The combination of both techniques its shown to provide gains of up to 0.5 bits/QAM symbol

Field Demonstration of 1 Tbit/s Super-Channel Network Using Probabilistically Shaped Constellations

Wilfried Idler, Fred Buchali, Laurent Schmalen and Eugen Lach (Nokia Bell Labs, Germany); Ralf-Peter Braun (Deutsche Telekom T-Labs, Germany); Georg Böcherer, Patrick Schulte and Fabian Steiner (Technische Universität München, Germany)

We successfully tested the suitability of probabilistically shaped constellations in field environment. We performed 1 Tbit/s 4-carriers super-channel transmission in the German nationwide backbone network with an extended family of probabilistically shaped constellations using 16QAM, 36QAM and 64QAM.

Study of electrical subband multiplexing at 54 GHz modulation bandwidth for 16QAM and probabilistically shaped 64QAM

Fred Buchali and Wilfried Idler (Nokia Bell Labs, Germany); Karsten Schuh (Nokia, Bell Labs, Germany); Laurent Schmalen (Nokia Bell Labs, Germany); Georg Böcherer, Fabian Steiner and Patrick Schulte (Technische Universität München, Germany); Tobias A. Eriksson (Nokia Bell Labs, Germany)

We showed 14% and 9% reach gain for electrical subband multiplexed 16QAM and PS-64QAM signals at 54GHz modulation bandwidth. A detailed analysis exhibits up to 40% gain for best subbands.

Capacity Approaching Transmission using Probabilistic Shaping and DBP for PFE Constrained Submarine Optical Links

Robert Maher, Domanic Lavery, Gabriele Liga, Milen Paskov and Alex Alvarado (University College London, United Kingdom); Tobias Fehenberger (Technical University of Munich (TUM), Germany); Polina Bayvel (UCL, United Kingdom)

Probabilistic constellation shaping and DBP enables the reduction in per-channel launch power by 2.2 dB, in a 150 channel 11000 km submarine link. For a fixed PFE voltage of 12 kV, the total system throughput is increased by 64%.

Mutual information characterization of nonlinear fiber channels

Tobias A. Eriksson (Nokia Bell Labs, Germany); Tobias Fehenberger (Technical University of Munich (TUM), Germany)

Achievable information rates are investigated for different coherent transmission scenarios. By using four-dimensional channel statistics, taken over two polarizations or two consecutive time slots, gains compared to conventional two-dimensional demappers are found, even for links without inline dispersion compensation.

M.1.E: Coherent Pon

Chair: Roberto Gaudino (Politecnico di Torino, Italy)

Demonstration of 100 Gb/s/λ-based Coherent PON System Using New Automatic Gain Controlled EDFA with ASE Compensation Function for Upstream Pre-Amplification

Naoki Suzuki, Hiroshi Miura and Kenichi Uto (Mitsubishi Electric Corporation, Japan)

We demonstrate the first prototype real-time 100 Gb/s/λ-based Coherent-PON. With an improved upstream received sensitivity of -38.1 dBm, a large loss budget of 39.1 dB over 80 km was achieved by a new AGC-EDFA with ACF and a simplified DSP.

Bidirectional symmetric 8 x 10.7 Gb/s WDM-PON over 108 km installed fiber using low complexity polarization-insensitive coherent ONUs

M. Sezer Erkilinc, Domanic Lavery, Kai Shi, Benn C Thomsen, Polina Bayvel and Robert I Killey (University College London, United Kingdom); Seb J Savory (University of Cambridge, United Kingdom)

Polarization-time block-coded OFDM-QPSK downstream channels are robustly detected using a polarization-insensitive coherent receiver, consisting of only a 3-dB coupler and single balanced PD. 8x10.7 Gb/s channels are bidirectionally transmitted over 108km installed fiber achieving a 1:16-way passive split.

Protection Systems for optical access networks

Takashi Nishitani (Mitsubishi Electric Corporation, Japan)

A PON needs a protection scheme to ensure the system's reliability. Fast protection switching is important for outage-free maintenance and rapid recovery from failure. This paper introduces two PON protection systems for fast protection switching in under 50ms.

22-dB Dynamic Range, Real-Time Burst-Mode Reception of Digital Coherent 20-Gb/s QPSK PON Upstream Signals

Ryo Koma (NTT Access Network Service Systems Laboratories, NTT Corporation, Japan); Masamichi Fujiwara (NTT Access Network Service Systems Laboratories, Japan); Jun-ichi Kani (NTT, Japan); Sang-Yuep Kim (NTT Access Network Service Systems Laboratories, Japan); Takahiro Suzuki (NTT & NTT Access Network Service Systems Laboratory, Japan); Hideki Mori and Tomoyuki Wada (NTT Advanced Technology Corp., Japan); Ken-Ichi Suzuki (NTT, Japan); Akihiro Otaka (NTT Corporation, Japan)

We report, for the first time, real-time burst-mode digital coherent reception wherein frame power differences are considered. 20-Gb/s QPSK burst signals with 22-dB dynamic range are successfully received by SOA-based optical power equalizer and burst-mode DSP.

Field-Trial of Low-Cost Coherent UDWDM-PON with Real-Time Processing, λ-Monitoring and EPON Coexistence

Ivan Cano and Josep Prat (UPC, Spain); Jeison Tabares, Juan Camilo Velásquez Micolta and Saeed Ghasemi (Universitat Politècnica de Catalunya, Spain); Victor Polo (UPC, Spain); Guang Yong Chu (Universitat Politècnica de Catalunya, Spain); Marco Presi (Scuola Superiore Sant'Anna University, Italy); Ernesto Ciaramella (Scuola Superiore Sant'Anna, Pisa, Italy); Mario Rannello (Scuola Superiore Sant' Anna University, Italy); Fabio Bottoni (via Moruzzi 1 & Scuola Superiore Sant'Anna, Italy); Massimo Artiglia and Giulio Cossu (Scuola Superiore Sant'Anna University, Italy); Robert Pous, Gregorio Azcárate

and Chantal Vila (Promax, Spain); Helen Debregeas-Sillard (III-V Lab, France); Gemma Vall-llosera (Ericsson Research, Sweden); Albert Rafel (BT, United Kingdom)
An UDWDM-PON with simple real-time ASK and DPSK transceivers is validated in a field-trial with deployed fibre achieving -47 dBm sensitivity at BER=2e-3 with 1.25 Gbit/s effective user bitrate. Real data traffic transmission and EPON coexistence are also demonstrated.

M.1.F: Advanced Optical Networking
Chair: Lena Wosinska (KTH Royal Institute of Technology, Sweden)

Impact of Traffic Profile on the Performance of Spatial Superchannel Switching in SDM Networks
Behnam Shariati (Athens Information Technology, Greece); Dimitrios Klonidis (AIT, Greece); Domenico Siracusa and Federico Pederzolli (CREATE-NET, Italy); Jose Manuel Rivas (Athens Information Technology, Greece); Luis Velasco (Universitat Politècnica de Catalunya (UPC), Spain); I Tomkos (AIT Greece, Greece)
We compare the performance of three SDM switching paradigms under different traffic profiles. We show that their performance is highly traffic dependent. We also show that increasing the spectral switching granularity, significantly improves the performance of spatial group switching.

Comparison of SDM and WDM on Direct and Indirect Optical Data Center Networks
Yifan Liu, Hui Yuan, Adaranijo Peters and Georgios Zervas (University of Bristol, United Kingdom)
We benchmark Data Centre topologies under SDM and WDM transport in terms of network capacity, utilization, blocking probability, cost and power consumption. SDM offers cost and power benefits than WDM while Spine-Leaf demonstrates all-round best performance among all topologies.

Experimental Demonstration of a Flexible Filterless and Bidirectional SDM Optical Metro/Inter-DC Network
George M. Saridis (University of Bristol, United Kingdom); Benjamin J Puttnam (National Institute of Information and Communications Technology, Japan); Ruben S Luís (NICT, USA); Werner Klaus (National Institute of Information and Communications Technology, Japan); Takaya Miyazawa and Yoshinari Awaji (National Institute of Information and Communications Technology (NICT), Japan); Georgios Zervas and Dimitra Simeonidou (University of Bristol, United Kingdom); Naoya Wada (NICT, Japan)
We experimentally evaluate a filterless, all-optical network using architecture-on-demand nodes and MCF-based links for metro and inter-data centre communication. We demonstrate that bidirectional SDM networking with elastic super-channels can eliminate drop-and-waste while supporting hitless dynamic bandwidth allocation.

Cost Benefit Quantification of SDM Network Implementations based on Spatially Integrated Network Elements
Jose Manuel Rivas and Behnam Shariati (Athens Information Technology, Greece); Antonia Mastropaolo (Scuola Superiore Sant'Anna, Italy); Dimitrios Klonidis (AIT, Greece); I Tomkos (AIT Greece, Greece)
We perform a techno-economic analysis of different SDM network implementations considering spatially-integrated transceivers, amplifiers and switches. We quantify the cost reduction of the SDM schemes compared to conventional approaches based on parallel-fiber systems.

Building a Programmable Testbed Infrastructure in the UK to Support Network R&D
David Salmon (Jisc, United Kingdom)
Availability of network testbed infrastructures for the UK academic network research communities is currently at a scale never previously realised. These infrastructures will be described, together with some of the project work being undertaken and the prospects for future developments

M.2.A: Fiber Amplifiers for SDM
Chair: Pierre Sillard (Prysmian, France)

Efficient pumping scheme for amplifier arrays with shared pump laser
Alan Gnauck (Nokia Bell Labs, USA); Peter Winzer (Lucent Technologies, USA); Robert Jopson and Ellsworth Burrows (Nokia Bell Labs, USA)
Tbd

Cladding Pumped Seven-Core EDFA Using an Absorption-Enhanced Erbium Doped Fibre
Yukihiro Tsuchida, Koichi Maeda and Kengo Watanabe (Furukawa Electric co., Ltd., Japan); Koki Takeshima (KDDI R&D Laboratories Inc., Japan); Toru Sasa, Tsunetoshi Saito and Shigehiro Takasaka (Furukawa Electric co., Ltd., Japan); Yu Kawaguchi (KDDI R&D Laboratories Inc., Japan); Takehiro Tsuritani (KDDI R&D Laboratories, Inc., Japan); Ryuichi Sugizaki (Furukawa Electric co., Ltd., Japan)

We fabricate a seven-core erbium doped fibre that has enhanced absorption cores. We demonstrate C-band cladding-pumped amplification with 20 dB gain, 6 dB NF, 15 dBm output power, and -53 dB core-to-core averaged crosstalk.

Novel 6-Mode Fibre Amplifier with Large Erbium-Doped Area for Differential Modal Gain Minimization

Yuta Wakayama (KDDI R&D, Japan); Koji Igarashi (Osaka University, Japan); Daiki Soma and Hidenori Taga (KDDI R&D Laboratories Inc., Japan); Takehiro Tsuritani (KDDI R&D Laboratories, Inc., Japan)

We demonstrate a cladding-pumped six-mode fibre amplifier with a widely erbium-doped distribution over the core for uniform overlap between spatial modes and the gain medium. The differential modal gain of less than 3.3 dB was achieved in the entire C-band.

Core-pumped 10-mode EDFA with Cascaded EDF Configuration

Masaki Wada and Taiji Sakamoto (NTT Corporation, Japan); Shinichi Aozasa (NTT Corporation & NTT Access Network Service Systems Laboratories, Japan); Takayoshi Mori, Takashi Yamamoto and Kazuhide Nakajima (NTT Corporation, Japan)

We experimentally demonstrate a 10-mode fibre amplifier consisting of EDFs with a step-and-ring erbium concentration profile. We achieve a low differential modal gain below 3.5 dB and a low noise figure (4.5-7.0 dB) with a core-pumped configuration in the C-band.

Design and characterization of multicore erbium-doped fibers

Sophie LaRochelle (Université Laval, Canada); Cang Jin and Younes Messaddeq (Université Laval)

We discuss the design and performance of double-cladding multicore erbium-doped fibers for space-division multiplexing. We describe optimization of signal core and pump annular-cladding to improve pumping efficiency and demonstrate designs leading to gain >19 dB and noise figure <6 dB.

M.2.B: DSP for Short Reach

Chair: Dimitrios Apostolopoulos (National Technical University of Athens & Institute of Communication and Computer Systems, Greece)

Reach Enhancement for WDM Direct-Detection Subcarrier Modulation using Low-Complexity Two-Stage Signal-Signal Beat Interference Cancellation

Zhe Li, M. Sezer Erkilinc and Robert Maher (University College London, United Kingdom); Lidia Galdino (Optical Networks Group, University College London, United Kingdom); Kai Shi, Benn C Thomsen, Polina Bayvel and Robert I Killey (University College London, United Kingdom)

We describe a novel low-complexity SSBI cancellation scheme, and experimentally investigate its performance in a 7×25 Gb/s WDM direct-detection single-sideband 16QAM Nyquist-subcarrier modulation system. The scheme achieves a doubling of the transmission reach.

Artificial Neural Networks for Linear and Non-Linear Impairment Mitigation in High-Baudrate IM/DD Systems

Jose Manuel Estaran (Nokia Bell Labs, France); Rafael Rios-Müller (Bell Labs Nokia, France); Miquel A. Mestre (Nokia Bell Labs, France); Filipe Jorge (Alcatel Thales III-V Lab, joint la: Bell Labs and Thales Research and Technology, France); Haik Mardoyan (Nokia Bell Labs, France); Agnieszka Konczykowska and Jean-Yves Dupuy (III-V Lab, France); Sebastien Bigo (Bell Labs, Alcatel-Lucent, France)

We propose using artificial neural networks onto IM/DD optical links to infer simultaneously linear and non-linear channel response. We experimentally exploit this information on an 84-GBd 4-PAM system, proving up to 10x BER improvement over FFE after 1.5-km SSMF

Power Efficient Coherent Transceivers

Jonas C Geyer, Christian Rasmussen, Bhupen Shah, Torben Nielsen and Mehrdad Givehchi (Acacia Communications, Inc., USA)

We review critical areas in the design process of power efficient coherent transceivers, and we highlight the achievable power saving by designing for a particular application as well as power and cost savings when using higher order modulation.

Non-linearity Compensation of High-Speed PAM4 Signals from Directly-Modulated Laser at High Extinction Ratio

Nobuhiko Kikuchi (Center for Technology Innovation, Hitachi Ltd., Japan); Riu Hirai (Center for Technology Innovation, Hitachi Ltd.); Takayoshi Fukui (Oclaro Japan, Japan)

We propose a new non-linear waveform compensation scheme for DML-based PAM signals applicable either at transmitter or receiver-side, and its effectiveness is verified with 56-Gbit/s PAM4 experiments with less than 0.1-dB sensitivity penalties up to 8.9-dB extinction ratio.

Experimental Investigation of Impulse Response Shortening for Low-Complexity MLSE of a 112-Gbit/s PAM-4 Transceiver

Sjoerd van der Heide (Eindhoven University of Technology & ADVA Optical Networking SE, The Netherlands); Nicklas Eiselt (Technical University of Denmark, Denmark); Helmut Griesser (ADVA Optical Networking SE, Germany); Juan Jose Vegas Olmos (Technical University of Denmark, Denmark); Idelfonso Tafur Monroy (Technical University of Denmark, Denmark & ITMO University, Russia); Chigo Okonkwo (Eindhoven University of Technology, The Netherlands)

An optimized channel shortening method for reduced complexity MLSE detection enables the compensation of severe inter-symbol interference. Experimental investigations demonstrate the benefit on the performance for a severely bandwidth limited 112-Gbit/s PAM-4 transmission system with residual chromatic dispersion.

M.2.C: Pulse Amplitude Modalation I

Chair: Michael Galili (Technical University of Denmark, Denmark)

100-Gbaud PAM-4 intensity-modulation direct-detection transceiver for datacenter interconnect

Miquel A. Mestre (Nokia Bell Labs, France); Filipe Jorge (Alcatel Thales III-V Lab, joint la: Bell Labs and Thales Research and Technology, France); Haik Mardoyan (Nokia Bell Labs, France); Jose Manuel Estaran (Nokia Bell Labs); Fabrice Blache (Alcatel-Thales III-V Lab, France); Philippe Angelini and Agnieszka Konczykowska (III-V Lab, France); Muriel Riet (Alcatel Thales III-V Lab, joint la: Bell Labs and Thales Research and Technology, France); Virginie Nodjiadjim (Alcatel-Thales 3-5 Lab, France); Jean-Yves Dupuy (III-V Lab, France); Sebastien Bigo (Nokia Bell Labs)

We demonstrate an IM/DD PAM-4 optical transceiver operating at 84 and 100 Gbaud, and achieve successful demodulation after 1 km and 500 m of standard single mode fiber, respectively. Electrical generation is enabled by an integrated high-speed selector power DAC.

112 Gb/s PAM-4 Using a Directly Modulated Laser with Linear Pre-Compensation and Nonlinear Post-Compensation

Yuliang Gao, John C Cartledge, Scott Yam and Ali Rezania (Queen's University, Canada); Yasuhiro Matsui (Finisar Corp, USA)

For 112 Gb/s PAM-4 short reach transmission using a directly modulated laser, the end-to-end frequency response is used to pre-compensate bandwidth limitations and a Volterra equalizer is used to post-compensate nonlinear signal distortion.

112 Gb/s PAM-4 Optical Signal Transmission over 100-m OM4 Multimode Fiber for High-Capacity Data-Center Interconnects

Fotini Karinou, Nebojsa Stojanovic, Cristian Prodaniuc and Qiang Zhang (Huawei Technologies Duesseldorf GmbH, Germany); Thomas Dippon (Keysight Technologies Deutschland GmbH, Germany)

112 Gb/s PAM-4 transmissions over 100-m OM4 MMF is demonstrated using a multi-mode 850-nm VCSEL. Results show that BER below the FEC limit can be achieved when employing equalization (FFE/MLSE) at the receiver. MLSE complexity vs. performance is also investigated

100 GHz EML for High Speed Optical Interconnect Applications

Oskars Ozolins (Acreo Swedish ICT, Sweden); Miguel Olmedo (Royal Institute of Technology, Sweden); Xiaodan Pang (Acreo Swedish ICT, Sweden); Simone Gaiarin (Technical University of Denmark, Denmark); Aditya Kakkar (Royal Institute of Technology (KTH), Sweden); Aleksejs Udalcovs (KTH Royal Institute of Techology, Sweden); Klaus Engenhardt (Tektronix GmbH, Germany); Tadeusz Asyngier (Tektronix GmbH, Poland); Richard Schatz (Kista Photonic Research Centre (KPRC), Royal Institute of Technology (KTH), Sweden); Jie Li (Acreo Swedish ICT AB, Sweden); Fredrik Nordwall (Tektronix GmbH, Sweden); Urban Westergren (Kista Photonic Research Centre (KPRC), Royal Institute of Technology (KTH), Sweden); Darko Zibar (DTU Fotonik, depertment of Photonic Engineering, Technical University of Denmark, Denmark); Sergei Popov (Royal Institute of Technology, Sweden); Gunnar Jacobsen (Acreo AB, Sweden)

We report on a 116 Gbit/s OOK, 4PAM and 105 Gbit/s 8PAM optical transmitter using InP-based integrated EML for interconnect applications with up to 30 dB static extinction ratio and over 100 GHz 3-dB bandwidth with 2 dB ripple.

M.2.D: Short Distance Direct Detection Systems
Chair: Gordon Ning Liu (Huawei Technologies Co. Ltd., P.R. China)

Experimental Demonstration of 112-Gbit/s PAM-4 over up to 80 km SSMF at 1550 nm for Inter-DCI Applications
Nicklas Eiselt (Technical University of Denmark, Denmark); Sjoerd van der Heide (Eindhoven University of Technology & ADVA Optical Networking SE, The Netherlands); Helmut Griesser (ADVA Optical Networking SE, Germany); Michael Eiselt (ADVA, Germany); Chigo Okonkwo (Eindhoven University of Technology, The Netherlands); Juan Jose Vegas Olmos (Technical University of Denmark, Denmark); Idelfonso Tafur Monroy (Technical University of Denmark, Denmark & ITMO University, Russia)
We experimentally demonstrate 112-Gbit/s PAM-4 over 80 km SSMF at 1550 nm. It is shown, that a channel shortening filter (CSF) matched to the memory of a subsequent MLSE significantly improves the performance while keeping complexity manageable.

Single Wavelength 248-Gb/s transmission over 80-km SMF Based on Twin-SSB-DMT and Direct Detection
Liang Zhang and Tianjian Zuo (Huawei, P.R. China); Qiang Zhang (Huawei Technologies Duesseldorf GmbH, Germany); Jie Zhou (Huawei, P.R. China); Enbo Zhou (Huawei Technologies Ltd., P.R. China); Gordon Ning Liu (Huawei Technologies Co. Ltd., P.R. China)
We propose a single-polarization direct-detection twin-SSB-DMT system. Enabled by MIMO-array DSP, transmissions of 248-Gb/s over 80-km SMF with a BER of 1.8e-2 (<SD-FEC) and 224-Gb/s over 60-km SMF with a BER of 4.2e-3 (<HD-FEC) are successfully demonstrated.

112-Gbit/s Intensity-Modulated Direct-Detect Vestigial-Sideband PAM4 Transmission over an 80-km SSMF Link
Jeffrey Lee (Nokia Bell Labs, USA); Noriaki Kaneda (Bell Labs, USA); Young-Kai Chen (Nokia Bell Labs, USA)
Employing vestigial-sideband 4-level pulse amplitude modulation (VSB-PAM4), single-channel as well as five-channel DWDM 112-Gbit/s per wavelength transmission is experimentally demonstrated over an 80-km standard single-mode fiber. Chromatic dispersion is compensated using digital signal processing at the receiver.

Improvement in Bandwidth-Limitation Tolerance and Achievement of 1-Sps Chromatic-Dispersion Pre-compensation Using Polarization-Interleaved 4-Level/7-Level Coding PAM
Shuto Yamamoto (NTT, Japan); Akira Masuda and Hiroki Kawahara (NTT); Shingo Kawai (NTT, Japan); Mitsunori Fukutoku (NTT)
We have achieved polarization-interleaved 4-level/7-level coding PAM transmission using 1-Sps pre-compensation for chromatic dispersion with a narrow-electrical-bandwidth limitation based on numerical simulations. We experimentally confirm the scheme feasibility using 112-Gb/s signal and 20-GHz bandwidth limitation in a conventional direct-detection system.

Transmission and Direct Detection of 300-Gbps DFT-S OFDM Signals Based on O-ISB Modulation with Joint Image-Cancellation and Nonlinearity-Mitigation
Yuanquan Wang (Fudan University, P.R. China); Jianjun Yu (ZTE (TX) Inc., USA); Hungchang Chien (ZTE (TX) Inc, USA); Xinying Li and Nan Chi (Fudan University, P.R. China)
By utilizing joint image-cancellation and nonlinearity-mitigation algorithms, we experimentally demonstrate record 300-Gbps and 240-Gbps direct-detection optical independent-sideband DFT-S OFDM signals at BTB and transmission over 160-km SSMF with the BER less than 2×10-2, respectively.

49 Gbit/s Direct-Modulation and Direct-Detection Transmission over 80 km SMF-28 without Optical Amplification or Filtering
Zhixin Liu (University of Southampton, United Kingdom); M. Sezer Erkilinc (University College London, United Kingdom); Brian Kelly (Eblana Photonics, Ireland); John Carroll (Dublin City University, Ireland); Richard Phelan (Eblana Photonics, Ireland); Benn Thomsen and Robert Killey (University College London, United Kingdom); David J Richardson (University of Southampton, United Kingdom); Polina Bayvel (University College London, United Kingdom); Radan Slavík (ORC, University of Southampton, United Kingdom)
We demonstrate direct-modulation of a discrete mode laser using Discrete Multi-Tone modulation for transmission distances up to 100 km in the 1550 nm band. A large operational temperature range (0-65degC) is also demonstrated.

M.2.E: Transmitters I
Chair: Romain Brenot (III-V Lab & Nokia Bell Labs, France)

High-Speed Directly Modulated Heterogeneously Integrated InP/Si DFB Laser
Geert Morthier and Amin Abbasi (Ghent University, Belgium); Jochem Verbist and Shahram Keyvaninia (Ghent University - Imec, Belgium); Xin Yin (Ghent University - IMEC, Belgium); Johan Bauwelinck (Ghent University - iMinds, Belgium); Gunther Roelkens (Ghent University - IMEC, Belgium); Francois Lelarge (Alcatel Thales III-V Lab, France); Guang-Hua Duan (III-V Lab, France)
We discuss how InP membrane laser diodes, heterogeneously integrated on SOI can be designed for high speed operation. This is illustrated with several static and dynamic characteristics of fabricated lasers. We finally report link experiments with the modulated lasers.

10-40 Gbit/s Hybrid III-V/Si wavelength-tunable transmitter for short- and long-reach communications
Guilhem de Valicourt (Alcatel-Lucent, Bell Labs, USA); Chia-Ming Chang (Nokia Bell Labs, USA); Young-Kai Chen (Alcatel-Lucent Bell Labs, USA); Sethumadhavan Chandrasekhar (Nokia Bell Labs, USA); Anaelle Maho (III-V Lab, France); Romain Brenot (III-V Lab & Nokia Bell Labs, France); Po Dong (Bell labs, Alcatel-Lucent, USA)
We demonstrate an ultra-compact hybrid tunable III-V/Si transmitter with more than 28 nm tuning range. We successfully achieved modulation up to 40 Gbit/s and transmission over 20 (100) km at 25 (10) Gbit/s.

50km Error Free Transmission at 10Gb/s with an Integrated Hybrid III-V on Silicon Directly Modulated DFB Laser and Ring Resonator
Antonin Gallet (III-V lab, a joint lab of Nokia, Thales and CEA, France); Alexandre Shen (Alcatel-Thales III-V Lab, France); Dalila Make (Alcatel Thales III-V Lab, France); Guang-Hua Duan (III-V Lab, France); Ségolène Olivier (CEA-Leti, France); Guillaume Levaufre (III-V lab, a joint lab of Nokia, Thales and CEA Leti, France); Stéphane Malhouitre (CEA-Leti, France); Nils Girard (III-V lab, a joint lab of Nokia, Thales and CEA Leti, France); Francois Lelarge (Alcatel Thales III-V Lab, France); Romain Brenot (III-V Lab & Nokia Bell Labs, France); Jean-Guy Provost (Alcatel Thales III-V Lab, France)
A directly-modulated Hybrid III-V/SOI DFB laser and a ring resonator are integrated on a single chip. Thanks to the ring resonator filter which provides extinction ratio enhancement, error free transmission at 10Gb/s over 50 km single mode fibre is demonstrated.

Two-Section RSOA with Enhanced Modulation-Cancelling Effect for Self-Seeded Colorless WDM Transmitter
Peng Zhou (University of Tokyo, Japan); Wenhui Zhan (The University of Tokyo, Japan); Takuo Tanemura (University of Tokyo, Japan); Masaru Mukaikubo (Oclaro Japan, Inc., Japan); Yoshiaki Nakano (University of Tokyo, Japan)
We propose and demonstrate novel RSOA design with segmented electrodes to enhance the modulation cancelling effect without sacrificing the bandwidth for self-seeded colorless WDM transmitter applications. Optimal driving condition is derived numerically and confirmed experimentally at 10 Gb/s.

Novel Approach for Self-Seeded Cavity based on Reflective Electro Absorption Modulator Semiconductor Optical Amplifier
Anaelle Maho (III-V Lab, France); Sophie Barbet (Alcatel-Thales III-V Lab, Italy); Karim Mekhazni (III-V Lab, France); Romain Brenot (III-V Lab & Nokia Bell Labs, France)
We propose a novel approach for self-seeded cavities by replacing the usual RSOA by a REAMSOA. With discrete components, we only achieved transmission on 50km at 2.5Gbit/s, although each device can operate up to 20Gbit/s.

M.2.F: Data Center Networks
Chair: Steinar Bjornstad (NTNU, Norway)

A roadmap for evolving towards optical intra-data-center networks
Lars Dittmann (Technical University of Denmark, Denmark); Anna Manolova Fagertun (Telia Denmark, Denmark); Valerija Kamchevska, Michael Galili, Leif Oxenløwe, Sarah Ruepp and Michael S. Berger (Technical University of Denmark, Denmark)
The paper focuses on presenting an updated view on the state of the art in data centre networks. The EU project COSIGN has provided optical DCN roadmaps, strategies and a techno-economic analysis of the involved industrial partners' value proposition.

Flexible Architecture and Control Strategy for Metro-Scale Networking of Geographically Distributed Data Centers

Matteo Fiorani (KTH Royal Institute of Technology, Sweden); Payman Samadi and Yiwen Shen (Columbia University, USA); Lena Wosinska (KTH Royal Institute of Technology, Sweden); Keren Bergman (Columbia University, USA)

This paper proposes a flexible architecture and control strategy to enable adaptive resource allocation in metro-scale inter data center networks. Experimental implementation and numerical evaluations are presented, proving substantial benefits in terms of transmission time and resource usage.

ARON: Application-Driven Reconfigurable Optical Networking for HPC Data Centers

Guojun Yuan (Institute of Computing Technology & Chinese Academy of Sciences, P.R. China); Roberto Proietti (University of California, Davis, USA); Xiaoli Liu (Institute of Computing Technology, Chinese Academy of Sciences, P.R. China); Alberto Castro Casales (University of California, Davis, USA); Dawei Zang (University of Chinese Academy of Sciences & Institute of Computing Technology, Chinese Academy of Sciences, P.R. China); Ninghui Sun (Institute of Computing Technology, Chinese Academy of Sciences, P.R. China); CheYu Liu (University of California, San Diego, USA); Cao Zheng (ECE University of California Davis, P.R. China); S. J. Ben Yoo (University of California, Davis, USA)

We designed and experimentally demonstrated an application-driven adaptive network that supports fast topology reconfiguration by wavelength routing to match applications' communication characteristics. Even in a small-scale system, 1.25× performance improvement is achieved by performing network reconfiguration.

Scalability Assessment of the OPSquare Architecture for High-capacity and Large-connectivity Data Center Networks

Wang Miao (Eindhoven University of Technology, The Netherlands); Fulong Yan (Eindhoven University of Technology & TU/e, P.R. China); Nicola Calabretta (COBRA Research Institute, The Netherlands)

The OPSquare data center network performance are investigated for different modulation format and high-capacity 4×25Gb/s waveband, 28Gb/s PAM4 and 40Gb/s DMT traffic. Results show >8 dB dynamic range with <3 dB penalty for optical switches at scale of 64×64.

Tu.1.A: Light Sources for Interconnects

Applications of photonic crystal and heterogeneous integration to ultra-low-energy lasers for optical interconnects and datacenter networks

Shinji Matsuo (NTT Corporation, Japan)

This tutorial reviews the latest developments in membrane lasers, including photonic crystal lasers and heterogeneously integrated lasers on Si. These devices are directly modulated with low operating energy. Heterogeneous integration technologies enable us to fabricate large-scale photonic integrated circuits.

Higher Speed VCSEL Links using Equalization

Daniel Kuchta (IBM T.J. Watson Research Center, USA)

With FFE Equalization, VCSEL-based links using NRZ modulation have been demonstrated error-free to 71Gb/s at 850nm, 56Gb/s at 1530nm, and 50Gb/s to 90C. This paper will review this progress and speculate on the realization of 100Gb/s serial links.

Tu.1.B: Multi-Layer SDN

Chair: Raul Muñoz (CTTC, Spain)

Operator use cases that benefit from multi-layer optimization and application awareness

Victor Lopez (Telefonica, Spain); Domenico Siracusa (CREATE-NET, Italy); Dimitrios Klonidis (AIT, Greece); Juan Pedro Fernández-Palacios (Telefónica I+D, Spain)

Multi-layer optimization enables the operators to optimize their packet and transport resources. The application awareness will provide potential savings as well as will offer a better adaptation to the network services to the applications.

Peer SDN Orchestration: End-to-End Connectivity Service Provisioning Through Multiple Administrative Domains

Ricard Vilalta and Arturo Mayoral (CTTC, Spain); Victor Lopez (Telefonica, Spain); Víctor Uceda (Telefónica); Ramon Casellas (Centre Tecnologic de Telecomunicacions de Catalunya (CTTC), Spain); Ricardo Martinez and Raul Muñoz (CTTC, Spain); Alejandro Aguado, Jaume Marhuenda, Reza Nejabati and Dimitra Simeonidou (University of Bristol, United Kingdom); Noboru Yoshikane (KDDI R&D

Laboratories, Japan); Takehiro Tsuritani (KDDI R&D Laboratories, Inc., Japan); Itsuro Morita (KDDI R&D Laboratories, Japan); Thomas Szyrkowiec (ADVA Optical Networking & Technische Universität München, Germany); Achim Autenrieth (ADVA Optical Networking, Germany)

This papers proposes the usage of Control Orchestration Protocol (COP) as an East-West interface in order to interconnect different SDN controllers (peer model) through multiple administrative domains. An experimental validation of network connectivity provisioning is presented in an international testbed.

First demonstration of SDN-controlled Multi-Layer Restoration and its advantage over Optical Restoration

Itay Maor and Ori Gerstel (Sedona Systems, Israel); Victor Lopez (Telefonica, Spain); Thomas Szyrkowiec (ADVA Optical Networking & Technische Universität München, Germany); Achim Autenrieth (ADVA Optical Networking, Germany); Bernd Pruessing and Nuno Borges (Coriant GmbH, Germany); Fisher FU (Huawei Technologies, P.R. China); Guiu Fabregas (Nokia, Spain); Juan P. Fernández-Palacios (Telefónica I+D, Spain)

We demonstrate a full implementation of centrally orchestrated multi-layer restoration over commercial optical and IP gear. The process considers the behavior of the IP layer. Compared to optical restoration, the packet loss is 54% lower

Interoperable Multi-Domain Delay-aware Provisioning using Segment Routing Monitoring and BGP-LS Advertisement

Francesco Paolucci (Scuola Superiore Sant'Anna, Italy); Víctor Uceda (Telefonica); Andrea Sgambelluri (KTH Royal Institute of Technology, Sweden); Filippo Cugini (CNIT, Italy); Oscar González de Dios (Telefonica I+D, Spain); Victor Lopez and Luis M. Contreras (Telefonica, Spain); Paolo Monti (KTH Royal Institute of Technology, Sweden); Paola Iovanna, Fabio Ubaldi and Teresa Pepe (Ericsson, Italy); Piero Castoldi (Scuola Superiore Sant'Anna, Italy)

This paper demonstrates a multi-domain SDN orchestrator using delay information to provision network services using BGP-LS and a novel monitoring system enabled by Segment Routing. Moreover, it is the first implementation and interoperability of the BGP-LS extensions for TE metrics.

Experimental Demonstration of Policy-based Dynamic End-to-End Provisioning over Multi-Layer Network using SDN

Jaume Marhuenda, Alejandro Aguado, Sarvesh Sanjay Bidkar, Emilio Hugues-Salas, Reza Nejabati and Dimitra Simeonidou (University of Bristol, United Kingdom)

Contemporary transport networks require dynamic multi-layer service provisioning to support ever-growing application traffic. We present a software platform architecture based on SDN principles combined with a network policy engine to experimentally demonstrate dynamic multi-layer provisioning over a national dark-fibre network.

Tu.1.C: Advanced Modulation

Chair: David Hillerkuss (ETH Zurich, Switzerland)

Duobinary Pulse-Shaped Complex Modulation of Directly Modulated Lasers

Di Che (The University of Melbourne & National ICT Australia, Australia); Feng Yuan (University of Melbourne, Australia); Hamid Khodakarami (University of Tehran, Iran); William Shieh (University of Melbourne, USA)

We propose duobinary pulse shaping for the complex modulation of directly modulated lasers, which significantly relieves the optical spectrum expansion induced by frequency chirp. The newly designed 3-tap MLSE decoder is verified via both simulation and 10-Gbaud PAM-4 experiment.

Eight Dimensional Optimized Modulation for IM-DD 56 Gbit/s Optical Interconnections Using 850 nm VCSELs

Xiaofeng Lu (Technical University of Denmark, Denmark); Anna Tatarczak (DTU, Denmark); Idelfonso Tafur Monroy (Technical University of Denmark, Denmark & ITMO University, Russia)

A novel 8-dimensional optimized modulation format is designed and compared with PAM-n in a 28-GBd 850 nm VCSEL based IM-DD system, enabling the transmission on 100GBASE-SR4 FEC threshold over various 100 m MMF links.

Stable WDM-Signal-and-LO-frequency Synchronisation and Transmission Employing Multi-Carrier Light Sources and a Multi-Core Fibre for Coherent Photonic Networks

Kunihiko Mori, Fukutaro Hamaoka and Kengo Horikoshi (NTT Corporation, Japan); Mitsunori Fukutoku (NTT Innovation Laboratories, Japan)

We successfully demonstrate a novel technique for synchronising optical frequencies in WDM signals and LO lights. We can simultaneously stabilise the polarisations of multi-carrier LO lights, which are transmitted with SDM-WDM signals via a multi-core fibre for digital coherent detection.

64-Gb/s Optical Transmission Using DFB-EAM Transmitter and SOA-PIN-TIA Receiver with -23.5-dBm Record Sensitivity

Philippe Angelini (III-V Lab, France); Fabrice Blache (Alcatel-Thales III-V Lab, France); Filipe Jorge (Alcatel Thales III-V Lab, joint la: Bell Labs and Thales Research and Technology, France); Christophe Caillaud (Alcatel-Thales III-V Lab, France); Michel Goix, Karim Mekhazni and Bernadette Duval (III-V Lab, France); Franck Mallécot (Alcatel-Thales III-V Lab, France); Philippe Charbonnier and Jean-Yves Dupuy (III-V Lab, France); Mohand Achouche (Alcatel-Thales III-V Lab, France)

This paper reports a transmission system for next generation short-reach high-speed optical communications. It consists of a 63-GHz DFB-EAM transmitter and a SOA-PIN-TIA receiver with -23.5-dBm sensitivity (BER=10-9) at 64 Gb/s in NRZ-OOK operation, yielding penalty<0.5 dB over 2-km transmission.

Tu.1.D: SDM Transmission I

Chair: Yutaka Miyamoto (NTT Network Innovation Laboratories, Japan)

Ultra-high capacity SDM/WDM transmission over multicore and multimode fibers

Takehiro Tsuritani (KDDI R&D Laboratories, Inc., Japan)

Recent progress and future challenges on high-capacity spatial division multiplexing (SDM) transmission technologies using multicore and multimode fibers are reviewed and discussed.

Pb/s, Homogeneous, Single-mode Multi-Core Fiber Systems

Benjamin J Puttnam (National Institute of Information and Communications Technology, Japan); Ruben S. Luís (NICT, USA); Jun Sakaguchi, Werner Klaus and Jose Manuel Delgado Mendinueta (National Institute of Information and Communications Technology, Japan); Yoshinari Awaji (National Institute of Information and Communications Technology (NICT), Japan); Naoya Wada (NICT, Japan); Erik Agrell (Chalmers University of Technology, Sweden)

We discuss multi Pb/s transmission using homogeneous, single-mode, multi-core fibers. We outline the key components of a recent high capacity demonstration, the consequences of fiber properties and the potential for enhanced efficiency from spatial-super-channel transmission.

Demonstration of 0.52 Pb/s Potential Transmission Capacity over 8,830 km using Multicore Fiber

Alexey Turukhin (TE Subcom, USA); Hussam G. Batshon and Matthew Mazurczyk (TE SubCom, USA); Yu Sun (TE Subcom, USA); Carl Davidson (Tyco Telecommunications, USA); Jin-Xing Cai (TE SubCom, USA); Oleg Sinkin (Tyco Telecom, USA); William Patterson (Tyco Electronics Subsea Communications, USA); Gregory Wolter and Maxim Bolshtyansky (TE Subcom, USA); Dmitri Foursa (Tyco Telecommunications, USA); Alexei Pilipetskii (Tyco Electronics Subsea Communications, USA)

We demonstrate feasibility of 0.52Pb/s transmission over 8,830km using a 12-core fiber, C+L band EDFAs, and a new coded modulation format. Compared to optimal 8QAM with the same 4.86b/s/Hz spectral efficiency, our modulation scheme achieves 1.0dB improvement in receiver sensitivity.

Tu.1.E: Coding and Receivers

Chair: Yves Jaouën (Telecom ParisTech, France)

A Low-complexity Implementation of Full-rate Polarization-Time Codes for PDL Mitigation in Single-Carrier Optical Transmissions using the Constant Modulus Algorithm

Elie Awwad and Patrice Tran (Nokia Bell Labs, France); Gabriel Charlet (Bell Labs, Alcatel-Lucent, France)

We demonstrate through simulations and experimental measurements a low-complexity implementation of the 2x2 Silver code to mitigate PDL in a single-carrier PDM system using CMA equalization. The obtained gains are compared to the optimal ones achieved by an ML decoder.

Full-Channel Parallel Measurement of 4x20-Gb/s All-Optical OFDM Signals by Using Loop-Assisted Coherent Matched Detector

Takahide Sakamoto (National Institution of Information and Communications Technology, Japan); Guo-Wei LU (Institute of Innovative Science and Technology, Tokai University & National Institute of Information and Communications Technology (NICT), Japan); Naokatsu Yamamoto (National Institute of Information and Communications Technology, Japan)

We demonstrate measurement of 4x20-Gb/s all-optical OFDM signals by using loop-assisted coherent matched detector. All-optical OFDM signal is projected onto the time-frequency domain first; then, all subchannels are restored through digital matrix processing, without relying on optical FFT.

Quadrature Decomposition of a 20 Gbaud 16-QAM Signal into 2×4-PAM Signals
Abel Lorences-Riesgo (Chalmers University of Technology, Sweden); Tobias A. Eriksson (Nokia Bell Labs, Germany); Mikael Mazur and Peter A. Andrekson (Chalmers University of Technology, Sweden); Magnus Karlsson (Chalmers University of Technology & Photonics Laboratory, Sweden)
We propose a novel phase-sensitive processor capable of operating at low nonlinear phase shifts. With a nonlinear phase shift of 2×15 rad, quadrature decomposition is demonstrated with penalty of 0.5 dB at BER=10e-3.

Receiver Memory Requirement in Mode Delay Compensated Few-Mode Fibre Spans with Intermediate Coupling
Christian Sanchez, Filipe M. Ferreira, Naoise Mac Suibhne, Stylianos Sygletos and Andrew Ellis (Aston University, United Kingdom)
The required receiver time window after propagation through few-mode fibre is studied for a broad range of coupling and mode delay span configurations. Under intermediate coupling, effective mode delay compensation is observed for a compensation period of 25 km.

Joint Modulation and Coding Optimization for Long-Haul Nyquist WDM Transmissions
Rafael Rios-Müller, Jeremie Renaudier and Gabriel Charlet (Bell Labs Nokia, France)
We review modulation format choice and optimization for long-haul optical communications systems taking into account channel coding implementation constraints such as overhead and decoder architecture as well as transmitter impairments.

Tu.1.F: Optical Access for 5G
Chair: Yan Shi (Genexis, The Netherlands)

5G Transport in Future Access Network
Dirk Breuer (Deutsche Telekom T-Labs, Germany); Erik Weis (Deutsche Telekom, Laboratories, Germany); Klaus Grobe (ADVA, Germany); Sandro Krauss (Deutsche Telekom AG, Germany); Francesco Musumeci (Politecnico di Milano, Italy); Jose Alfonso Torrijos Gijon (Telefonica I+D, Spain); Björn Skubic (Ericsson AB, Sweden)
Techno-economic results for 5G back/fronthaul based NG-PON2 with PtP-WDM-PON overlay and WR-WDM-PON for different RAN splits are presented for an urban area. It is shown that the convergence benefit with residential access decreases significantly for high bit rate interfaces.

Optical Network Technologies for Wireless Communication Network
Jun Terada (NTT Corporation, Japan); Tatsuya Shimada and Tatsuya Shimizu (NTT, Japan); Akihiro Otaka (NTT Corporation, Japan)
This paper describes trends of 5G mobile networks and RAN technologies. The Ethernet-based vBBU is expected to support several types of BBU and PON with low-latency scheme is a good candidate for MFH transmission in 5G networks.

Performance Demonstration of Real Time Compressed CPRI Transport
Zakaria Tayq, Antoine Quere, Luiz Anet Neto and Philippe Chanclou (Orange Labs, France); Fabienne Saliou (Orange, France); Kamil Grzybowski (Orange Labs, France); Christelle Aupetit-Berthelemot (XLIM - University of Limoges, France); Sun Yoo and Sung Hong (Solid, Korea)
A real time CPRI compression solution is experimentally investigated. Tests have been performed on a LTE fronthaul link measuring its impact on EVM and latency. The obtained results show a 73% compression compliant with 3GPP specifications.

Optics For 5G: How Can We Combine Low Cost With Demanding Requirements?
Antonio Tartaglia (Ericsson Telecomunicazioni S.p.A., Italy)
5G is the opportunity for optical technologies to become increasingly relevant across all networking domains. We will review how state-of-the-art industrial technologies are evolving to meet its most demanding requirements and discuss the challenge of finding the best cost structures.

CLEO 1: Spatiotemporal Control
Chair: Sergei K. Turitsyn (Aston University & Photonics Research Group, United Kingdom)

Frequency Stability in Optical Networks: Challenges, Implementation and Implications
Stojan Radic (University of California, San Diego, USA)
The role of frequency carrier stability in optical networks is discussed. We show that so-called nonlinear capacity limit for fiber transmission was established erroneously and has no physical basis in any optical network of practical interest.

Pulse Combining and Compression in Multi-core Fibers

Igor Chekhovskoy (Novosibirsk State University & Institute of Computational Technologies, Russia); Alexander Rubenchik (Lawrence Livermore National Laboratory, USA); Olga Shtyrina (Novosibirsk State University & Institute of Computational Technologies, Russia); Sergei K. Turitsyn (Aston University & Photonics Research Group, United Kingdom); Mikhail Fedoruk (Novosibirsk State University & Institute of Computational Technologies, Russia)

We investigate pulse compression and combining efficiency for multi-core fibers of different structures. Coherent combining in one core with efficiency over 80% and pulse compression few hundreds times are demonstrated. We analyse the influence of perturbations of input pulses.

Spatiotemporal Nonlinear Interactions in Multimode Fibers

Katarzyna Krupa (ICB UMR CNRS 6303 Université de Bourgogne Franche-Comté & XLIM UMR CNRS 7252 Université de Limoges, France); Alessandro Tonello (XLIM UMR CNRS 7252 Université de Limoges, France); Abdelkrim Bendahmane (Université de Bourgogne, France); Richard Dupiol (ICB UMR CNRS 6303 Université de Bourgogne Franche-Comté, France); Badr Shalaby and Marc Fabert (XLIM UMR CNRS 7252 Université de Limoges, France); Alain Barthelemy (XLIM Institut de Recherche, France); Guy Millot (CNRS/Université de Bourgogne, France); Stefan Wabnitz (University of Brescia, Italy); Vincent Couderc (Université de Limoges, France)

We observe experimentally a novel spatiotemporal dynamics of multimode fibers allowing for a new type of parametric instability and an original phenomenon of light self-organisation. Our experiments agree well with theoretical predictions and numerical simulations based on the Gross-Pitaevskii equation.

Ultra-Stable Optical Frequency and Accurate Timing Signal Dissemination Using Telecommunication Network

Olivier Lopez (LPL - CNRS - Paris 13 University, France); Nicolas Quintin (LPL - Paris 13 University - CNRS, France); Fabio Stefani (SYRTE - PARIS Observatory - CNRS - UPMC, France); Anthony Bercy (LPL - CNRS - Paris 13 University, France); Nicolas Chiodo (LPL - Paris 13 University - CNRS, France); Fabrice Wiotte (LPL - CNRS - Paris 13 University, France); Emilie Camisard (RENATER, France); Chriistian Chardonnet (LPL - CNRS - Paris 13 University, France); Giorgio Santarelli (LP2N - CNRS - Bordeaux University, France); Paul-Eric Pottie (SYRTE - CNRS - Observatoire de Paris - UPMC, France); Anne Amy-Klein (LPL - Paris 13 University - CNRS, France)

Optical fibre links have been developed to transfer an ultrastable optical frequency between distant laboratories for time and frequency metrology and high-precision measurements. We will review the specificity of this technique, its performance and a few applications.

Tu.2.A: Digital Signal Processing

Chair: Benn C Thomsen (University College London, United Kingdom)

Digital Signal Processing for Multilevel Modulation Formats

Seb J Savory (University of Cambridge, United Kingdom)

In this tutorial we explore digital signal processing (DSP) techniques for multilevel modulation formats. We detail both transmitter DSP (encoding, modulation, equalisation and filtering) and receiver DSP (equalisation, filtering, synchronisation, demodulation and decoding) after which we discuss current research challenges.

Transmitter Impairment Mitigation and Monitoring for High Baud-Rate, High Order Modulation Systems

Chris Fludger and Theo Kupfer (Cisco Optical GmbH, Germany)

Receiver-based compensation algorithms for transmitter impairments such as timing skew, gain and offset imbalance and quadrature error are presented. We demonstrate monitoring and diagnosis functions based on signal processing coefficients.

Sequential MAP Detection for High Baud-Rate Systems with Pattern-Dependent Distortions

Ali Bakhshali, Wai-Yip Geoffrey Chan, Ali Rezania and John C Cartledge (Queen's University, Canada)

A sequential MAP detection strategy with a wide range in its performance-complexity trade-off is proposed to ameliorate pattern-dependent distortions due to transmitter and receiver limitations. A complexity reduction by a factor of 7 is reported based on the experimental results.

Tu.2.B: Network Automation
Chair: Sebastien Bigo (Bell Labs, Alcatel-Lucent, France)

A Learning Living Network for Open ROADM Networks
Shoichiro Oda (Fujitsu Laboratories Ltd., Japan); Masatake Miyabe (Fujitsu Labs. Ltd., Japan); Setsuo Yoshida (Fujitsu Laboratories Ltd.); Toru Katagiri and Yasuhiko Aoki (Fujitsu Limited, Japan); Jens C. Rasmussen (Fujitsu Laboratories Limited, Japan); Martin Birk and Kathy Tse (AT&T Laboratories, USA)
We experimentally demonstrate a "living network" that autonomously keeps record of its path-level performance. The more services are added, the more accurate the performance of a newly to be established service is estimated which enables operation close to performance limits.

Bringing Data Analytics to the Network Nodes
Alba Vela and Anna Via (Universitat Politècnica de Catalunya (UPC), Spain); Marc Ruiz (Universitat Politècnica de Catalunya, Spain); Luis Velasco (Universitat Politècnica de Catalunya (UPC), Spain)
Monitoring every 15 minutes imposes long traffic anomaly detection times and thus, the monitoring frequency needs to be increased to reduce those times, which entails large amount of monitoring data collected. Consequently, we propose bringing data analytics to the nodes.

A Machine Learning Approach for Dynamic Optical Channel Add/Drop Strategies that Minimize EDFA Power Excursions
Yishen Huang (Columbia University, USA); Wiem Samoud (Institut Mines Telecom, Telecom ParisTech, CNRS LTCI, France); Craig Gutterman (Columbia University, USA); Cedric Ware (Institut Mines-Télécom, Télécom ParisTech, CNRS LTCI, France); Mounia Lourdiane (TELECOM SudParis, France); Gil Zussman, Payman Samadi and Keren Bergman (Columbia University, USA)
We demonstrate a machine learning approach to characterize channel dependence of power excursions in multi-span EDFA networks. This technique can determine accurate recommendations for channel add/drop with minimal excursions and is applicable to different network designs.

Adaptive Guard-band Assignment with Adaptive Spectral Profile Equalizer to Improve Spectral Usage of Impairment-Aware Elastic Optical Network
Hitoshi Takeshita, Hidemi Noguchi, Jun-ichi Abe, Shinsuke Fujisawa and Akio Tajima (NEC Corporation, Japan)
We propose an adaptive guard-band assignment method that solves its over-assignment problem and an adaptive spectral profile equalizer to enhance its capability. Simulation and experimental results demonstrate a 12.5% spectral usage improvement and feasibility for application to actual networks.

Elastic all-optical networks: a new paradigm enabled by the physical layer. How to optimize network performances?
Vittorio Curri, Mattia Cantono and Roberto Gaudino (Politecnico di Torino, Italy)
Physical layer equipment is the enabling technology for the elastic use of networks. We propose the statistical network assessment process as benchmarking method. As an example we compare PM-mQAM vs. TDHMF transceivers on a Pan-EU network topology, considering three fibers.

Tu.2.C: Measurement and Control
Chair: Toshihiko Hirooka (Tohoku University, Japan)

OSNR System Margin Estimation by Nonlinear Noise Insensitive OSNR Monitor
Tomohiro Yamauchi and Shoichiro Oda (Fujitsu Laboratories Ltd., Japan); Liang Dou (Fujitsu Research & Development Center Co., LTD., P.R. China); Xiaofei Su (Fujitsu R&D Center, P.R. China); Takeshi Hoshida (Fujitsu Laboratories Limited, Japan); Yasuhiko Aoki (Fujitsu Limited, Japan); Zhenning Tao (Fujitsu R&D Center Ltd., P.R. China); Jens C. Rasmussen (Fujitsu Laboratories Limited, Japan)
We propose an OSNR system margin estimation technique based on nonlinear noise insensitive OSNR monitoring. We experimentally demonstrate its accuracy less than 0.3dB estimation error for five-subcarrier DP-16QAM superchannel in dispersion-uncompensated transmission with various fiber launched power and various reaches.

Deep Learning Based OSNR Monitoring Independent of Modulation Format, Symbol Rate and Chromatic Dispersion
Takahito Tanimura (The University of Tokyo & Fujitsu Laboratories Ltd., Japan); Takeshi Hoshida (Fujitsu Laboratories Limited, Japan); Tomoyuki Kato and Shigeki Watanabe (Fujitsu Laboratories Ltd., Japan); Jens C. Rasmussen (Fujitsu Laboratories Limited, Japan); Makoto Suzuki and Hiroyuki Morikawa (The University of Tokyo, Japan)

A deep neural network (DNN) is employed for optical performance monitoring. We show that DNN-based monitor successfully estimates OSNR of signals modulated in different formats and symbol rates in the presence of chromatic dispersion and polarization rotation without prior knowledge.

Nonlinear Spatially Resolved Interferometer for Distance Resolved Power and Gain Tilt Measurement

Andrew D. Shiner (Ciena Corperation); Andrzej Borowiec and Michael Reimer (Ciena Corporation, Canada); Douglas W Charlton (Ciena Corperation, Canada); Maurice O'Sullivan (Ciena Corporation, Canada)

A new experimental technique for making distance resolved measurements of the wavelength dependent power profile and gain evolution in multi-span telecommunications fiber links is demonstrated. Results for a 10x80km span link agree with directly measured powers to within 0.3 dB.

Polarization Controller for Si photonic integrated circuits with an active closed loop control

Vito Sorianello (CNIT-Laboratory of Photonic Networks, Italy); Gabriele De Angelis, Philippe Velha, Tommasso Cassese and Valerio Preite (Scuola Superiore Sant'Anna, Italy); Alberto Bianchi (Ericsson Telecomunicazioni, Italy); Francesco Testa (Ericsson Lab Italy, Italy); Marco Romagnoli (PGT Photonics, Italy)

A polarization insensitive silicon photonic circuit for the management of any arbitrary polarization state of light coming from a fiber linked to a remote source is demonstrated. WDM channels with a common arbitrary polarization at the input are automatically equalized.

2D Passive Optical Beam-steering Module with 7 Scan Lines within 12.2°×5.6° for Free-space Indoor Communication

Chin Wan Oh (Eindhoven University of Technology, The Netherlands); Robbert van der Linden (Eindhoven University of Technology & Genexis BV., The Netherlands); Gustaaf Sutorius (Keysight Technologies, The Netherlands); Eduward Tangdiongga (Eindhoven University of Technology, The Netherlands); Ton Koonen (COBRA, Eindhoven University of Technology, The Netherlands)

We experimentally demonstrate a two-dimensional (2D) passive optical beam-steering module constructed using reflection and transmission gratings for angular coverage of 12.2°×5.6° with seven scanning lines. We vigorously evaluate the 2D beam-steered system with OOK, 4-PAM and DMT transmission.

Tu.2.D: SDM Transmission II

Chair: Rene Essiambre (Nokia, USA)

Exploiting Selective Excitation of Strongly Coupled Modes to Reduce DMGD in Multi-mode Transmission Systems

John van Weerdenburg (Eindhoven University of Technology, The Netherlands); Jose Antonio-Lopez and Juan Alvarado-Zacarias (CREOL, USA); Denis Molin (Prysmian Group, France); Marianne Bigot-Astruc (Draka Communications, France); Roy van Uden and Huug de Waardt (Eindhoven University of Technology, The Netherlands); Ton Koonen (COBRA, Eindhoven University of Technology, The Netherlands); Rodrigo Anezcua-Correa (CREOL, USA); Pierre Sillard (Prysmian, France); Chigo Okonkwo (Eindhoven University of Technology, The Netherlands)

By exploiting strong coupling in higher-order modes, we experimentally demonstrate reduced differential mode group delay by a factor of 3. Comparing LP02+LP21 with respect to LP01+LP11 3-mode transmission, a 27% reduction in equalizer length is shown after 53.4km MMF transmission.

Nonlinear Distortion in Mode Delay Compensated Few-Mode Fibre Spans with Intermediate Coupling

Filipe M. Ferreira, Christian Sanchez, Naoise Mac Suibhne, Stylianos Sygletos and Andrew Ellis (Aston University, United Kingdom)

Nonlinear distortion in delay-compensated spans for intermediate coupling is studied for the first time. Coupling strengths under -30dB/100m allow distortion reduction using shorter compensation lengths and higher delays. For higher coupling strengths no significant penalty results from shorter compensation lengths.

10-Mode Mode-Multiplexed Transmission with Inline Amplification

Roland Ryf (Bell Labs, Nokia, USA); Haoshuo Chen (Nokia Bell Labs, USA); Nicolas K Fontaine (Bell Labs/Alcatel-Lucent, USA); Amado Velázquez-Benítez (Nokia Bell Labs, USA); Jose Antonio-Lopez, Juan Alvarado-Zacarias and Zeinab Sanjabi Eznaveh (CREOL, USA); Cang Jin (Université Laval & COPL, Canada); Bin Huang (Nokia Bell Labs, USA); Sun Hyok Chang (ETRI, Korea); Burcu Ercan (UC Davis, USA); Cedric Gonnet (Prysmian Group, France); Marianne Bigot-Astruc and Denis Molin (Draka Communications, France); Frank Achten (Prysmian Group, The Netherlands); Pierre Sillard (Prysmian, France); Rodrigo Anezcua-Correa (CREOL, USA)

We demonstrate combined wavelength- and mode-multiplexed transmission over a fiber with 10 spatial modes using all multimode components including an erbium-doped amplifier, an acousto-optics switch and a splitter arranged as a recirculating loop.

Study of Inter-Modal Four Wave Mixing in Two Few-Mode Fibres with Different Phase Matching Properties

Francesca Parmigiani (ORC, University of Southampton, United Kingdom); Yongmin Jung (Optoelectronics Research Centre, University of Southampton, Southampton, United Kingdom); Søren M. M. Friis (Technical University of Denmark, Denmark); Qiongyue Kang (Optoelectronics Research Centre, University of Southampton, Southampton); Ioannis Begleris (Optoelectronics Research Centre, University of Southampton, Southampton, United Kingdom); Peter Horak and Periklis Petropoulos (University of Southampton, United Kingdom); Karsten Rottwitt (Technical University of Denmark, Denmark); David J. Richardson (University of Southampton, United Kingdom)

We experimentally study inter-modal four-wave mixing (FWM) in few-mode fibres with different phase matching properties. The possibility of transmitting two spatial modes without inter-modal FWM cross-talk in the C-band is presented.

Tu.2.E: MM-Wave Devices

Chair: Pascual Muñoz (VLC Photonics, Spain)

40 dB-Rejection Sharp-Edge Integrated SOI Phase-Shifted Bragg Grating Filter for Microwave Photonics

Giovanni Serafino (Scuola Superiore Sant'Anna, Italy); Claudio Porzi (Consorzio Nazionale Interuniversitario per le Telecomunicazioni, Italy); Philippe Velha and Nicola Andriolli (Scuola Superiore Sant'Anna, Italy); Paolo Ghelfi (CNIT, Italy); Antonella Bogoni (Scuola Superiore Sant'Anna)

An integrated, high-order phase-shifted Bragg-grating realizing steep-sloped optical passband filter with measured 41.5 dB out-of-band rejection and a transition bandwidth roll-off of 288 GHz/nm is demonstrated in passive Silicon-on-Insulator technology and verified in two different microwave photonics applications.

Wavelength-tunable True Time Delay for Multi-beam Radio Beamformer in Multi-Gbps Satellite Communication

Netsanet Tessema (University of Eindhoven & COBRA Research Institute, The Netherlands); Zizheng Cao (Eindhoven University of Technology, The Netherlands); J. H. C. (Johan) van Zantvoort (University of Eindhoven, The Netherlands); Eduward Tangdiongga and A. B. (Bart) Smolders (Eindhoven University of Technology, The Netherlands); Ton Koonen (COBRA, Eindhoven University of Technology, The Netherlands)

We present a Si3N4 photonic integrated chip providing wavelength-dependent true time delay for forming multiple radio beams: a number of multi-Gbps connections from home-to-multiple satellites can be supported simultaneously.

Fully-Packaged 71-76 GHz Coherent Photonic Mixer featuring WR-12 Output for CRoF Backhauling

Besher Khani and Vitaly Rymanov (University of Duisburg-Essen, Germany); Jörg Honecker (u2t Photonics AG, Germany); Andreas Gerhard Steffan (Finisar Berlin, Germany); Andreas Stöhr (University of Duisburg-Essen, Germany)

Here, we report on a novel fully-integrated 70 GHz band (71-76 GHz) rectangular-waveguide-type coherent photonic mixer (WR12-CPX) module for coherent radio-over-fiber (CRoF) backhaul links, featuring a high-speed balanced photodetector and a rectangular waveguide output (WR-12) for direct fiber-to-the-antenna connectivity.

Optoelectronic comb generation and cross-injection locking of photonic integrated circuit for millimetre-wave generation

Andrzej Jankowski (III-V Lab Thales Research & Technology and CEA-LETI, France); Gael Kervella (III-V Lab, France); Mourad Chtioui (Thales Air Systems, France); Marco Lamponi (Huawei Technologies, France); Frédéric Van Dijk (Alcatel Thales III-V Lab, France)

We demonstrate how a monolithically integrated heterodyne source was used for a 33.6 GHz signal generation using an optical solution by a combination of cross-optical injection locking inside the chip and electrical injection locking at the RF signal 7th sub-harmonic.

Narrow Linewidth Operation (<10 kHz) in Self-injection-locked Tunable DFB Laser Array (SIL-TLA) Integrated with Optical Feedback Planar Lightwave Circuit (PLC)

Hiroyuki Ishii, Naoki Fujiwara and Kei Watanabe (NTT Corporation, Japan); Shigeru Kanazawa (NTT Photonics Laboratories, NTT Corporation, Japan); Mikitaka Itoh and Hirokazu Takenouchi (NTT Photonics Laboratories, Japan); Yutaka Miyamoto (NTT Network Innovation Laboratories, Japan)

A novel self-injection-locked tunable DFB laser array (SIL-TLA) integrated with an optical feedback planar lightwave circuit (PLC) is proposed. The fabricated device operates with a stable single mode and a narrow linewidth of <10 kHz over the full C-band.

Mitigation of Mode Partition Noise in Quantum-Dash Fabry-Perot Mode-Locked Lasers using Manchester Encoding

Mohamed Essghair Chaibi (University of Rennes 1, France); Laurent Bramerie and Sebastien Lobo (ENSSAT / Université de Rennes 1, France); Christophe Peucheret (University of Rennes 1, France)
The use of Manchester encoding with balanced detection is proposed in order to overcome the mode partition noise (MPN) limit of quantum-dash mode-locked lasers used as multi wavelength sources. Successful MPN mitigation is demonstrated for a 10-mode laser at 10Gbit/s

Tu.2.F: Novel Fibre Technologies

Chair: Camille-Sophie Bres (Switzerland)

Optical Fibre Technologies for Future Communication Networks

Periklis Petropoulos (University of Southampton, United Kingdom)
New transmission technologies need to be developed to satisfy the ever increasing demand for communication traffic. This paper reviews some recent research on optical fibre technology that aims at addressing this challenge.

Experimental demonstration of Compact and Robust All-Fiber Orbital Angular Momentum Generator

Xinglin Zeng, Yan Li, Jian Wu and Yongjie Tian (Beijing University of Posts and Telecommunications, P.R. China); Q Mo (Fiberhome Telecommunication Technologies Co. Ltd, P.R. China); Wei Li (Beijing University of Posts and Telecommunications, P.R. China)
An all-fiber scalar orbital angular momentum generator is demonstrated by cascading mode selective coupler and few mode-polarization maintaining fiber. With the compactness and robustness, this generator may play a key role in space division multiplexing systems.

Microbending effects in hollow-core photonic bandgap fibers

Eric Numkam Fokoua, Yong Chen, David J Richardson and Francesco Poletti (University of Southampton, United Kingdom)
We developed a model for the study of how microbends affect the operation of hollow-core photonic bandgap fibers. Increased loss due to intermodal coupling is predicted. Preliminary experimental observations are in good agreement with the model's predictions.

Dispersion-Flattened Composite Highly Nonlinear Fibre Optimised for Broadband Pulsed Four-Wave Mixing

Mads Lillieholm (Technical University of Denmark); Michael Galili and Leif Oxenløwe (Technical University of Denmark, Denmark)
We present a segmented composite HNLF optimised for mitigation of dispersion-fluctuation impairments for broadband pulsed four-wave mixing. The HNLF-segmentation allows for pulsed FWM-processing of a 13-nm wide input WDM-signal with -4.6-dB conversion efficiency.

Mode-Selective Fiber Laser Using a Photonic Lantern

Ning Wang (University of Central Florida, USA); Jose Antonio-Lopez, Juan Alvarado-Zacarias and Zeinab Sanjabi Eznaveh (CREOL, USA); He Wen (Tsinghua University, P.R. China); Pierre Sillard (Prysmian, France); Sergio Leon-Saval (University of Sydney & Sydney Astrophotonic Instrumentation Laboratory (SAIL), Australia); Axel Schulzgen (University of Central Florida, USA); Rodrigo Anezcua-Correa (CREOL, USA); Guifang Li (University of Central Florida, USA)
We experimentally demonstrate a transverse mode-selective fiber laser using a photonic lantern. The output modes of laser are switchable among the 6 LP modes supported by the gain fiber. Their slope efficiency, optical spectra, and mode profiles are measured.

CLEO 2: Optical Information Processing

Chair: Stefan Wabnitz (University of Brescia, Italy)

Photonic Reservoir Computing for Ultra-Fast Information Processing Using Semiconductor Lasers

Ingo Fischer, Julian Bueno, Daniel Brunner, Miguel Soriano and Claudio Mirasso (IFISC (UIB-CSIC), Spain)
Neuro-inspired computational concepts like reservoir computing can now be implemented in telecommunication-compatible hardware, with high hardware and energy efficiency and exhibiting excellent computing performance. This provides interesting perspectives for applications in telecommunication.

Enhanced nonlinear spectral compression in fibre by sinusoidal phase modulation

Christophe Finot (University of Burgundy, France); Sonia Boscolo (Aston University, United Kingdom)

We propose a simple approach to enhance the spectral compression arising from nonlinear pulse propagation in a Kerr medium. We numerically show that an additional sinusoidal temporal phase modulation enables efficient reduction of the intensity level of spectral side lobes.

Linear and Nonlinear Frequency-Division Multiplexing

Mansoor Isvand Yousefi (Telecom ParisTech, France); Xianhe Yangzhang (Technical University of Munich, Germany)

Achievable rates of WDM and nonlinear frequency-division multiplexing (NFDM) are computed as a function of transmit power. The NFDM rate increases monotonically with power, in contrast to the WDM rate which characteristically vanishes at high powers. The improvement results from nonlinear signal multiplexing.

Periodic Nonlinear Fourier Transform Based Transmissions with High Order QAM Formats

Morteza Kamalian, Kopae (Aston University & Aston Institute of Photonic Technologies, United Kingdom); Jaroslaw Prilepsky (Aston University & Aston Institute of Photonic Tehcnologies, United Kingdom); Son Thai Le (Nokia-Bell-Labs, Germany); Sergei K. Turitsyn (Aston University & Photonics Research Group, United Kingdom)

We propose, for the first time, a technique of constructing signals with high order QAM formats (128-512 QAM) for periodic nonlinear Fourier transform based systems. The proposed method effectively eliminates the inverse transformation stage reducing significantly the system's complexity.

Programmable single-photon to single-atom quantum interface

Juergen Eschner, Christoph Kurz, Pascal Eich, Michael Schug and Philipp Müller (Saarland University, Germany)

Integration of quantum photonic systems into future telecommunication technologies, for example for quantum cryptography, requires interfacing single photons as quantum information carriers with single atoms as quantum memories. We demonstrate a programmable interface for bi-directional quantum state conversion between single photons and single trapped atomic ions.

Sources for Integrated Quantum Information Processing

Christine Silberhorn, Benjamin Brecht, Christof Eigner, Harald Hermann, Stephan Krapick, Kai-Hong Luo, Regina Kruse, Raimund Ricken and Linda Sansoni (University of Paderborn & Faculty of Sciences, Germany); Viktor Quiring (Universitaet Paderborn, Germany)

Integrated optics provides a promising platform for the implementation of highly complex and compact circuits for quantum information applications. Integrated waveguide sources feature high brightness and interferometric stability. Here we present our work on advanced multi-channel devices.

Tu.3.A: Modulators

Chair: Andreas Umbach (Finisar, Germany)

Multi-level Optical Signal Generation Using a Segmented-Electrode InP IQ-MZM with Integrated CMOS Binary Drivers

Michael Vanhoecke (Ghent University, Belgium); Nikolaos Argyris (National Technical University of Athens, Greece); Alessandro Aimone (Fraunhofer HHI, Germany); Stefanos Dris (National Technical University of Athens, Greece); Dimitrios Apostolopoulos (National Technical University of Athens & Institute of Communication and Computer Systems, Greece); Koen Verheyen and Renato Vaernewyck (Ghent University, Belgium); Guy Torfs (Ghent University & Imec, Belgium); Xin Yin (Ghent University - IMEC, Belgium); Erwin Bosman (Ghent University & IMEC, Belgium); Gerrit Fiol, Marko Gruner and Robert Klötzer (Fraunhofer Institut für Nachrichtentechnik, Heinrich-Hertz-Institut, Germany); Johan Bauwelinck (Ghent University - iMinds, Belgium); Hercules Avramopoulos (National Technical University of Athens, Greece)

We present a segmented-electrode InP IQ-MZM, capable of multi-level optical signal generation (5-bit per I/Q arm) by employing direct digital drive from integrated, low-power (1W) CMOS binary drivers. Programmable, multi-level operation is demonstrated experimentally on one MZM of the device.

Ultra-High Bandwidth InP IQ Modulator with 1.5 V Vπ

Yoshihiro Ogiso (NTT Device Innovation Center, NTT Corporation, Japan); Takashi Yamada, Josuke Ozaki and Yuta Ueda (NTT, Japan); Norihide Kashio (NTT Device Innovation Center, NTT Corporation, Japan); Nobuhiro Kikuchi (NTT, Japan); Eiichi Yamada (NTT Corporation, Japan); Hiroyasu Mawatari and Hiromasa Tanobe (NTT, Japan); Shigeru Kanazawa (NTT Photonics Laboratories, NTT Corporation,

Japan); Hiroshi Yamazaki (NTT Corporation, Japan); Yoshitaka Ohiso (NTT Photonics Laboratories, NTT Corporation, Japan); Takuro Fujii (NTT Corporation, Japan); Mitsuteru Ishikawa and Masaki Kohtoku (NTT, Japan)

We propose a new high-bandwidth (> 67 GHz) and low-Vπ (< 1.5 V) InP-based IQ modulator for more flexible modulation formats, and demonstrate the first up to 120-Gbaud IQ modulations without optical pre-equalization.

High-Speed Silicon-Organic Hybrid (SOH) Modulators

Stefan Wolf, Wladislaw Hartmann, Matthias Lauermann, Heiner Zwickel, Yasar Kutuvantavida and Clemens Kieninger (Karlsruhe Institute of Technology, Germany); Wolfgang Freude and Christian Koos (Karlsruhe Institute of Technology (KIT), Germany)

We report on recent progress in high-speed SOH modulators. We demonstrate generation of 100 Gbit/s on-off-keying (OOK) and 252 Gbit/s 16QAM signals, as well as amplifier-less, DAC-less 16QAM signaling at peak-to-peak voltages 0.4 Vpp. Thermal stability at 80°C was shown.

Record-high Modulation-efficiency Depletion-type Si-based Optical Modulator with In-situ B Doped Strained SiGe Layer on Si Waveguide for 1.3 um Wavelength

Junichi Fujikata and Masataka Noguchi (Photonics Electronics Technology Research Association, Japan); Jaehoon Han (The University of Tokyo, Japan); Shigeki Takahashi (Photonics Electronics Technology Research Association, Japan); Mitsuru Takenaka (The University of Tokyo, Japan); Takahiro Nakamura (Photonics Electronics Technology Research Association)

We develop depletion-type Si optical modulator with strained SiGe on lateral Si pn junction. Owing to in-situ B doping for SiGe, we achieve high modulation efficiency of 0.6-0.67 Vcm at 1.3 um wavelength with clear eye opeing at 28 Gbps.

Characterization and Digital Pre-compensation of Electro-optic Crosstalk in Silicon Photonics I/Q Modulators

Xi Chen (Nokia Bell Labs, USA); Po Dong (Bell labs, Alcatel-Lucent, USA); Sethumadhavan Chandrasekhar, Kwangwoong Kim, Borui Li and Haoshuo Chen (Nokia Bell Labs, USA); Andrew Adamiecki (Nokia Bell labs, USA); Alan Gnauck (Nokia Bell Labs, USA); Peter Winzer (Lucent Technologies, USA)

Electro-optic crosstalk in Silicon Photonics I/Q modulators is characterized and up to -19 dB crosstalk is found. Digital pre-compensation is performed which shows up to 3.7 dB Q2 factor improvement or 64-QAM signals

Tu.3.B: DSP for Nonlinearity Mitigation

Chair: John C Cartledge (Queen's University, Canada)

Prospects for Real-Time Compensation of Fiber Nonlinearities

Michael Reimer, Maurice O'Sullivan and Qunbi Zhuge (Ciena Corporation, Canada); Shahab Oveis Gharan (Ciena Corporation); Andrzej Borowiec, Loren Berg and Priyanth Mehta (Ciena Corporation, Canada)

We estimate limits on capacity and reach improvements achievable through nonlinear compensation for realizable coherent transceivers over a range of network applications. Methods for low-complexity electronic nonlinear compensation on regional long-haul and ultra-long-haul submarine applications are considered.

Equalization-Enhanced Phase Noise in Nonlinear Inverse Synthesis Transmissions

Son Thai Le (Nokia-Bell-Labs, Germany); Ian Phillips (Aston University, United Kingdom); Jaroslaw Prilepsky (Aston University & Aston Institute of Photonic Tehcnologies, United Kingdom); Morteza Kamalian, Kopae (Aston University & Aston Institute of Photonic Technologies, United Kingdom); Andrew Ellis and Paul Harper (Aston University, United Kingdom); Sergei K. Turitsyn (Aston University & Photonics Research Group, United Kingdom)

We experimentally investigate, for the first time, the performance penalty due to equalization-enhanced phase noise in nonlinear inverse synthesis transmissions with QPSK and 16QAM OFDM modulation formats

Blind Adaptive XPM Model Based Digital Backpropagation for Subcarrier-Multiplexing Systems

Fangyuan Zhang (McGill University, Canada); Qunbi Zhuge (Ciena Corporation, Canada); Meng Qiu (McGill University, Montreal, Canada); Mathieu Chagnon and David Plant (McGill University, Canada)

We propose a low complexity blind adaptive digital backpropagation (DBP) scheme for subcarrier multiplexing (SCM) systems and experimentally demonstrate its fast convergence to the optimal performance without any prior knowledge of the link parameters.

Demonstration of Coherent Transmission Reach Tripling by Frequency-Referenced Nonlinearity Pre-compensation in EDFA-only SMF Link

Eduardo Temprana (University of California, San Diego, USA); Evgeny Myslivets and Vahid Ataie (University of California San Diego, USA); Bill Ping Piu Kuo (University of California, San Diego, USA); Nikola Alic (University of California San Diego, USA); Vijay Vusirikala and Vinayak Dangui (Google Inc, USA); Stojan Radic (University of California, San Diego, USA)

A 200% reach extension in a coherent WDM link is demonstrated for the first time by relying on mutually referenced frequency carriers. The reach tripling was achieved by transmitter-side nonlinear impairment cancellation.

Polarization Effects in Nonlinearity Compensated Links

Ivan Fernandez de Jauregui Ruiz, Amirhossein Ghazisaeidi, Elie Awwad and Patrice Tran (Nokia Bell Labs, France); Gabriel Charlet (Nokia Bell Labs)

We experimentally assess the impact of PDL and PMD on the performance of nonlinear compensation algorithms in dispersion unmanaged links. We show that perturbative nonlinear compensation is more robust to PDL, but more sensitive to PMD compared to filtered digital-backpropagation.

Tu.3.C: Multicarrier Modulation

Chair: Mario Martinelli (Politecnico di Milano, Italy)

400 Gbit/s Real-Time All-Analogue FBMC/OFDM based on a Mode Locked Laser

Fernando Gutiérrez and Eamonn Martin (Dublin City University, Ireland); Philip A Perry (University College Dublin, Ireland); Andrew Ellis (Aston University, United Kingdom); Aravind Anthur (IIT Madras, India); Vivek Panapakkam (CNRS Laboratory for Photonics and Nanostructures, France); Quentin Gaimard (CNRS, France); Kamel Merghem (CNRS Laboratory for Photonics and Nanostructures, France); Francois Lelarge (Alcatel Thales III-V Lab, France); Abderrahim Ramdane (CNRS/LPN & Institut National des Télécommunications, France); Liam Barry (Dublin City University, Ireland)

A real-time 20x21.6 Gbit/s WDM electro-optical transceiver is presented. Optical carriers were spaced by 37 GHz and each one transmitted four orthogonally overlapping broadband subchannels. Only analogue electronics were employed for the OFDM (de)modulation and subcarrier synchronization.

Discrete Multi-tone Transmitter at Net Data Rate of 200 Gbps Using a Digital-Preprocessed Analog-Multiplexed DAC

Hiroshi Yamazaki and Munehiko Nagatani (NTT Corporation, Japan); Shigeru Kanazawa (NTT Corporation); Hideyuki Nosaka (NTT Corporation, Japan); Toshikazu Hashimoto (NTT Corporation); Fukutaro Hamaoka (NTT Corporation, Japan); Yutaka Miyamoto (NTT Network Innovation Laboratories, Japan)

We demonstrated 214-Gbps/λ single-polarization discrete multi-tone optical transmission using a digital-preprocessed analog-multiplexed DAC based on two CMOS sub-DACs. Diversity synthesis utilizing image signal was introduced to enhance the performance. A bit error rate below 3.8x10-3 was obtained.

Real-Time Hardware Demonstration of 180 Gbps DFT-S OFDM Receiver Based on Digital Sub-banding

Alex Tolmachev, Maxim Meltsin, Rolf Hilgendorf and Mordechay Orbah (Technion - Israel Institute of Technology, Israel); Yitzhak Birk (Technion, Israel); Shalva Ben Ezra (Finisar, Israel); Moshe Nazarathy (Technion, Israel Institute of Technology, Israel)

In just 3 FPGAs we realize fastest (180 Gbps) real-time filter-bank based DFT-S CO-OFDM 16-QAM 25 GHz Rx, at record 1.06 samples/symbol (7.3 b/Hz), demonstrating dual polarization SMF transmission. Extrapolated ASIC would save <50% power.

56 Gb/s DMT Transmission with VCSELs in 1.5 um Wavelength Range over up to 12 km for DWDM Intra-Data Center Connects

Annika Dochhan (ADVA Optical Networking SE, Germany); Nicklas Eiselt (Technical University of Denmark, Denmark); Robert Hohenleitner (Vertilas GmbH, Germany); Helmut Griesser (ADVA Optical Networking SE, Germany); Michael Eiselt (ADVA, Germany); Markus Ortsiefer (VERTILAS GmbH, c/o GATE Garching, Germany); Christian Neumeyr (VERTILAS, GmbH, Germany); Juan Jose Vegas Olmos (Technical University of Denmark, Denmark); Idelfonso Tafur Monroy (Technical University of Denmark, Denmark & ITMO University, Russia); Jörg-Peter Elbers (ADVA AG Optical Networking, Germany)

We demonstrate up to 12 km, 56 Gb/s DMT transmission using high-speed VCSELs in the 1.5 um wavelength range for future 400Gb/s intra-data center connects, enabled by vestigial sideband filtering of the transmit signal.

Tu.3.D: Elastic Optical Networks III
Chair: Piero Castoldi (Scuola Superiore Sant'Anna, Italy)

Adaptive and Efficient Multilayer Elastic Optical Network Planning
Takafumi Tanaka and Tetsuro Inui (NTT, Japan); Akihiro Kadohata (NTT); Akira Hirano (NTT, Japan); Wataru Imajuku (Kindai University)
We overview our current works on the heuristic IP-over-elastic optical network (EON) planning algorithms including modulation-aware virtual topology planning in the planning phase and multiperiod multilayer network planning which adapts to dynamic traffic conditions in the operational phase.

Broker-based Cooperative Game in Multi-Domain SD-EONs: Nash Bargaining for Agreement on Market-Share Partition
Lu Sun (University of Science and Technology of China, P.R. China); Xiaoliang Chen (University of California, Davis & University of Science and Technology of China, USA); Shilin Zhu and Zuqing Zhu (University of Science and Technology of China, P.R. China); Alberto Castro Casales and S. J. Ben Yoo (University of California, Davis, USA)
We model the cross-domain lightpath provisioning in multi-broker based multi-domain SD-EONs as a cooperative game, propose to obtain Pareto-efficient market-share partition for the brokers with Nash bargaining, and design the system framework to realize the proposal.

Time and Spectrum Aggregation in Metropolitan Network for Heterogeneous Traffic Profile
Ion Popescu (KDDI R&D Laboratories, Inc., Japan); Ahmed Triki (Insititut mines Télécom, Télécom Bretagne, France); Xiaoyuan Cao (KDDI R&D Laboratories, Inc., Japan); Annie Gravey (Institut Mines Telecom - Telecom Bretagne & UMR CNRS 6074 IRISA, France); Takehiro Tsuritani (KDDI R&D Laboratories, Inc., Japan); Philippe Gravey (Télécom Bretagne, France); Noboru Yoshikane (KDDI R&D Laboratories, Japan); Michel Morvan (Telecom Bretagne, France)
We propose a new optical transport solution, TSAN, based on variable bit rate packet transmission and passive switching. The expected CAPEX and OPEX savings in TSAN are assessed using scenarios based on current and next generation network architectures.

Comparing Networking Benefits of Digital Back-Propagation vs. Lightpath Regeneration
Mattia Cantono, Roberto Gaudino, Pierluigi Poggiolini and Vittorio Curri (Politecnico di Torino, Italy)
We compare the networking benefits of Ideal-Single-Channel Digital-Back-Propagation (ISC- DBP) vs. Lightpath Regeneration as Quality-of-Transmission enhancing techniques. By analyzing three different topologies, we show that ISC-DBP has the potential to substantially reduce the number of required regenerators in all-optical networks.

Latency-aware Multi-layer Network Optimization in IP-over-WDM Core Networks
Ćiril Rožić (Athens Information Technology, Greece); I Tomkos (AIT Greece, Greece); Dimitrios Klonidis (AIT, Greece)
We study the handling of latency-sensitive traffic in a IP/optical core network. We show the superiority of our proposed latency-aware multi-layer network optimization approach, and evaluate the impact of propagation and electronic processing delays.

Tu.3.E: Nonlinear and Quantum Techniques
Chair: Magnus Karlsson (Chalmers University of Technology & Photonics Laboratory, Sweden)

Design of 2-Soliton Spectral Phase Modulated Pulses Over Lumped Amplified Link
Vahid Aref and Henning Buelow (Nokia Bell Labs, Germany)
Over a lumped amplified link, we explain numerically how to design solitonic pulses keeping the same breathing period. We demonstrate experimentally the transmission of 2-Solitonic pulses with QPSK spectral amplitude modulation over 1600 km with a low error rate.

Transmission of Waveforms Determined by 7 Eigenvalues with PSK-Modulated Spectral Amplitudes
Henning Buelow, Vahid Aref and Wilfried Idler (Nokia Bell Labs, Germany)
2-ns waveforms with 7 eigenvalues and their QPSK-modulated spectral amplitudes were optimized by taking constraints of link, transmitter, and receiver into account. In experiment these signals were transmitted with a BER of 3.2E-3 over 1440-km of NZ-DSF fiber spans.

34.6 Tbit/s WDM Transmission Using Soliton Kerr Frequency Combs as Optical Source and Local Oscillator
Pablo Marin, Juned N Kemal and Philipp Trocha (Karlsruhe Institute of Technology); Stefan Wolf (Karlsruhe Institute of Technology, Germany); Arne Kordts, Karpov Maxim, Martin Pfeiffer and Victor Brasch (Ecole Polytechnique Federale de Lausanne, Switzerland); Wolfgang Freude (Karlsruhe Institute of

Technology (KIT), Germany); Tobias Kippenberg (Ecole Polytechnique Federale de Lausanne, Switzerland); Christian Koos (Karlsruhe Institute of Technology (KIT), Germany)
We demonstrate massively parallel WDM transmission using Soliton Kerr frequency combs both as multi-wavelength source at the transmitter and as multi-wavelength local oscillator at the receiver. The viability of the concept is proven by transmitting 34.6Tbit/s over 75km

Heterodyne Coherent Scheme for Long Distance Quantum Key Distribution Using a Real Local Oscillator
Sebastian Kleis and Christian Schaeffer (Helmut Schmidt University, Germany)
We present a novel heterodyne coherent scheme for secure key distribution. In contrast to most other QKD schemes it is very practical because it works with a real free running LO at the receiver side.

Tu.3.F: Advanced Modulation for Access
Chair: Dirk Breuer (Deutsche Telekom T-Labs, Germany)

Transmission of 100-Gb/s DSB-DMT over 80-km SMF Using 10-G class TTA and Direct-Detection
Jie Zhou, Liang Zhang and Tianjian Zuo (Huawei, P.R. China); Qiang Zhang (Huawei Technologies Duesseldorf GmbH, Germany); Sen Zhang (Huawei, P.R. China); Enbo Zhou (Huawei Technologies Ltd., P.R. China); Gordon Ning Liu (Huawei Technologies Co. Ltd., P.R. China)
We experimentally demonstrate 100-Gb/s DSB-DMT transmission over 80-km SMF using 10-GHz TTA and Direct-Detection technique. Maximum capacities up to 125 Gb/s, 106 Gb/s and 103 Gb/s are achieved with BER at 4.5×10-3 for BTB, 40-km and 80-km SMF transmissions, respectively.

25Gb/s PAM4 Adaptive Receiver Equalisation Requirements for Burst-Mode Transmission Systems
Marco Dalla Santa (Tyndall National Institute, University College Cork, Ireland); Cleitus Antony (Tyndall National Institute, Ireland); Giuseppe Talli (Tyndall National Institute & Tyndall National Institute, Ireland); Paul Townsend (Tyndall National Institute, Ireland)
Requirements for burst-mode equalisation in a 25Gb/s PAM4 system for passive optical network upstream traffic are analysed for different linear equaliser solutions, with transmission over 40km of fibre. The impact of chromatic dispersion, transmitter bandwidth restriction and non-linearities is considered.

Demonstration and Analysis on PAM-4/8, DB-PAM-2/4 and DMT Formatted TDM-PON with 25Gbps, 40Gbps, 50Gbps Capacity per Lane using Economical 10Gbps Transceivers
Chenhui Ye and Xiaofeng Hu (Alcatel-Lucent Shanghai Bell, P.R. China); Kaibin Zhang (Alcatel-Lucent Bell Labs, P.R. China)
We demonstrate 25Gbps/40Gbps/50Gbps TDM-PONs using PAM-2/4/8, duo-binary PAM-2/4, and DMT formats on economical 10Gbps transceivers. Based on the performance/cost analysis and comparison, we also introduce a general guidance on format choice for 25Gbps+ PONs.

Demonstration of Upstream Flexible 2-/4-PAM Formats for Practical PON Deployments
Robbert van der Linden (Eindhoven University of Technology & Genexis BV., The Netherlands); Xin Yin (Ghent University - IMEC, Belgium); Nguyen-Cac Tran (Genexis B.V., Eindhoven, the Netherlands); Johan Bauwelinck (Ghent University - iMinds, Belgium); Eduward Tangdiongga (Eindhoven University of Technology, The Netherlands); Ton Koonen (COBRA, Eindhoven University of Technology, The Netherlands)
Adaptive 2-/4-PAM modulation in PONs leverages the distribution of optical path losses to increase capacity. Upstream 2-/4-PAM burst transmission is demonstrated with a selectable fixed 4-tap FIR-filter, improving the performance of each gain mode of the burst-mode receiver.

Recent Progress on 25G EPON and beyond
Vincent Houtsma (Nokia, Bell Labs, USA); Dora van Veen (Bell Labs, Nokia, USA); Ed Harstead (Alcatel-Lucent, Belgium)
An overview of recent developments in next generation high speed PON and the progress being made in IEEE P802.3ca working group on 25G EPON and beyond is given.

CLEO 3: Optoelectronics
Chair: Stojan Radic (University of California, San Diego, USA)

Subwavelength Index Engineered Structures: Fundamental Building Blocks for the Next Generation Photonic Integrated Circuits
Pavel Cheben (NRC Institute for Microstructural Sciences, Canada); Danxia Xu (NRC Institute for Microstructural Sciences, Germany)

Subwavelength engineered all-dielectric metamaterial structures are likely to become key building blocks for the next generation of integrated photonic circuits. This unique technology allows synthesis of an effective photonic medium with an unprecedented control of material properties. We present an overview of emerging implementations, including high-efficiency broadband fibre-chip surface grating couplers and edge couplers, ultra-broadband splitters, sensors and mid-infrared waveguide components, to name a few.

New Ultrafast Laser Sources and Nonlinear Devices Based on TM:II-VI Semiconductors

Sergey Vasilyev, Igor Moskalev, Mike Mirov, Viktor Smolski and Sergey Mirov (IPG Photonics Mid-IR Lasers, USA); Valentin Gapontsev (IPG Photonics Corporation, USA)

Transition-metal-doped II-VI semiconductors possess a unique blend of physical, spectroscopic, optical, and technological parameters. These materials enable high power lasers in important middle-infrared range; they are also well suited for generation and efficient nonlinear frequency conversion of ultra-short optical pulses.

Fundamental and Applied Aspects of Submonolayer Quantum Dots as Active Medium in Opto-electronics

Bastian Herzog, Mirco Kolarczik, Yücel Kaptan, Benjamin Lingnau, Kathy Lüdge, Jan-Hindrik Schulze and Ricardo Rosales (Technische Universität Berlin, Germany); Dieter Bimberg (Technical University of Berlin, Germany); Andre Strittmatter (Technische Universität Berlin, Germany); Udo Pohl, Ulrike Woggon and Nina Owschimikow (Technische Universitaet Berlin, Germany)

Submonolayers promise to combine the high gain of quantum wells with the stability of quantum dots. We investigate the carrier dynamics by phase sensitive heterodyne pump-probe experiments and find a fast <2ps relaxation and high gain, accompanied by large nonlinearities.

Realization of Arbitrary Complex Apodization Profiles in Integrated Waveguide Bragg Gratings on SOI

Hamed Pishvaibazargani (Institut National de la Recherche Scientifique (INRS), Canada); Jose Azana (INRS, Canada)

We implement waveguide Bragg gratings (BGs) with misaligned sidewall corrugations in order to realize user-defined complex apodization profiles. In particular a very challenging grating design, namely photonic Hilbert transformer, has been successfully demonstrated on SOI.

Nonlinear Integrated Photonics in Lithium Niobate by Direct Femtosecond Laser Writing

Sebastian Kroesen, Lukas Wesemann, Kemal Tekce and Jörg Imbrock (Institute of Applied Physics, University of Münster); Cornelia Denz (Institute of Applied Physics, University of Münster, Germany)

We report on the monolithic fabrication of integrated optical elements in lithium niobate by direct femtosecond laser writing. Advanced designs and processing schemes enable a novel synthesis of complex refractive index structures and tailored nonlinearity.

W.1.A: Advanced Silicon Photonics

Chair: Richard Pitwon (Xyratex, United Kingdom)

Advanced Silicon Photonics for Post-Moore Era

Koji Yamada (National Institute of Advanced Industrial Science and Technology, Japan)

Telecom/Datacom traffic is growing explosively as device technology development guided by Moore's law nears it end. Although silicon photonics technology offers immediate solutions, much further evolution is needed in order to cope with the continual growth expected in the future.

High-Speed Photonics for Side-by-Side Integration with Billion Transistor Circuits in Unmodified CMOS Processes

Luca Alloatti (ETH Zurich, Switzerland)

Monolithic integration of photonics and electronics is key to chip-to-chip optical interconnects. However, high-yield CMOS nodes impose strict constraints on materials and design rules. We review high-responsivity photodiodes and low-voltage modulators for 12.5Gbaud links in an unmodified 45nm CMOS node.

W.1.B: Fiber Sensing and Measurement

Chair: Patrice Mégret (University of Mons (UMONS) & Faculté Polytechnique, Belgium)

High Dynamic Range Linear Optical sampling with Coherence Recovery for Measuring Fibre Impulse Response

Fumihiko Ito and Naoto Kono (Shimane University, Japan); Daisuke Iida (NTT Corporation, Japan); Tetsuya Manabe (NTT Corp., Japan)

Impulse responses of 2-mode fibres are measured by a method based on linear optical sampling with newly developed amplitude averaging technique with phase noise compensation. The intermodal coupling is observed with 10-ps time resolution and 80 dB dynamic range.

Measurement of Temperature-Induced Polarization Drift and Correlation in a 7-Core Fiber

Mikael Mazur (Chalmers University of Technology, Sweden); Thierry Taunay (OFS Laboratories, USA); Tommy Geisler and Lars Grüner-Nielsen (OFS Fitel Denmark, Denmark); Magnus Karlsson (Chalmers University of Technology & Photonics Laboratory, Sweden); Peter A Andrekson (Chalmers University of Technology, Sweden)

We study the correlation in polarization drift between different cores of a 7-core fiber subjected to temperature fluctuations. We present a method to quantify these changes and show that the drift in different cores is correlated to 98%.

Multicore optical fiber grating arrays for sensing applications

Paul Westbrook, Tristan Kremp, Kenneth Feder and Thierry Taunay (OFS Labs); Eric Monberg and Hongchao Wu (OFS Labs, USA); Debra Simoff (OFS, USA); Roy Ortiz (OFS Labs, USA)

We review recent advances in optical fiber sensor array technology aimed at next generation applications such as shape sensing and enhanced scatter enabled distributed sensing.

W.1.C: Signal Shaping

Chair: Andrew Ellis (Aston University, United Kingdom)

Probabilistically Shaped QAM for Independent Reach, Spectral Efficiency and Bit-rate Adaptation

Fred Buchali, Wilfried Idler and Laurent Schmalen (Nokia Bell Labs, Germany); Georg Böcherer, Patrick Schulte and Fabian Steiner (Technische Universität München, Germany)

In this paper we review probabilistically shaped constellations and experimentally investigate probabilistically shaped QAM systems operated at both high bit-rate and high reach requiring high baudrate transmission. We demonstrate up to 29% reach increase by probabilistic shaping.

Low-Complexity Shaping for Enhanced Nonlinearity Tolerance

Junho Cho (Nokia Bell labs, USA); Sethumadhavan Chandrasekhar (Nokia Bell Labs, USA); Ronen Dar (Bell Labs, Nokia, USA); Peter Winzer (Lucent Technologies, USA)

We present a novel low-complexity signal shaping method which offers significant linear and nonlinear gains. The shaping gain exceeds the coding gain, and the data rate can be easily adapted by shaping.

Implicit Constellation Shaping in Regenerative Optical Networks

Laurent Schmalen and Fred Buchali (Nokia Bell Labs, Germany)

In this paper, we consider optical coherent networks with regenerative nodes. We show that by properly optimizing the regenerators, we can improve the network's spectral efficiency with minor receiver modifications. This method automatically includes a fall-back to lower-order modulation formats.

Four-Dimensional Trellis Coded Modulation for Flexible Optical Transponders

Saleem Alreesh (Technische Universität Berlin, Germany); Carsten Schmidt-Langhorst, Robert Emmerich, Pablo Wilke Berenguer, Colja Schubert and Johannes K. Fischer (Fraunhofer Heinrich Hertz Institute)

We experimentally demonstrate 4-D TCM based on PDM-16QAM, PDM-32QAM and PDM-64QAM formats. A multi-rate optical transponder is enabled by only a single encoder/decoder structure. The scheme is resilient to cycle-slip events due to its 90° phase rotation invariant property.

Temporal Probabilistic Constellation Shaping for WDM Optical Communication Systems

Metodi Yankov and Soren Forchhammer (Technical University of Denmark, Denmark)

Finite state machine sources transmitting QPSK are studied as input to WDM optical fiber systems with ideal distributed Raman amplification. The probabilities of successive constellation symbols are shaped for nonlinear transmission and gains of around 500km (5-10%) are demonstrated.

W.1.D: Nonlinear Distortions

Chair: Yann Frignac (Insitut Mines-Télécom, France)

Experimental Study of Nonlinear Phase Noise and its Impact on WDM Systems with DP-256QAM

Metodi Yankov, Francesco Da Ros and Edson Porto da Silva (Technical University of Denmark, Denmark); Tobias Fehenberger (Technical University of Munich (TUM), Germany); Luca Barletta (Politecnico di Milano, Italy); Darko Zibar (DTU Fotonik, depertment of Photonic Engineering, Technical University of Denmark, Denmark); Leif Oxenløwe, Michael Galili and Soren Forchhammer (Technical University of Denmark, Denmark)

A probabilistic method for mitigating the phase noise component of the non-linear interference in WDM systems with Raman amplification is experimentally demonstrated. The achieved gains increase with distance and are comparable to the gains of single-channel digital back-propagation.

Impact of WDM Channel Correlations on Nonlinear Transmission

Ronen Dar (Bell Labs, Nokia, USA); Sethumadhavan Chandrasekhar (Nokia Bell Labs, USA); Alan Gnauck (Bell Labs, Nokia, USA); Borui Li (Nokia Bell Labs, USA); Junho Cho (Nokia Bell labs, USA); Ellsworth Burrows (Bell Labs, Nokia, USA); Peter Winzer (Lucent Technologies, USA)

We study the impact of channel correlations on the accumulation of nonlinear interference noise in WDM transmission experiments. Theoretical predictions, split-step simulations and experimental measurements indicate negligible impact for QPSK transmission, but notably strong artifacts for high-order QAM formats.

Independence of the Impact of Inter-Channel Non-Linear Effects on Modulation Format and System Implications

Antonino Nespola and Luca Bertignono (Istituto Superiore Mario Boella, Italy); Gabriella Bosco, Andrea Carena and Pierluigi Poggiolini (Politecnico di Torino, Italy); Fabrizio Forghieri (Cisco Photonics Italy srl, Italy)

We show by simulation that the impact of inter-channel non-linear effects is independent of modulation format in long-haul systems, once long-correlated non-linear phase-noise has been removed. We back-up the finding experimentally and investigate the system implications.

Experimental Analysis of Correlations in the Nonlinear Phase Noise in Optical Fiber Systems

Tobias Fehenberger (Technical University of Munich (TUM), Germany); Mikael Mazur (Chalmers University of Technology, Sweden); Tobias A. Eriksson (Nokia Bell Labs, Germany); Magnus Karlsson (Chalmers University of Technology & Photonics Laboratory, Sweden); Norbert Hanik (Munich University of Technology, Germany)

A dual-link self-homodyne receiver is used to measure the phase correlations introduced by the interplay of dispersion and fiber nonlinearities. The dependence of the memory on the WDM setup, signal power and transmission distance is experimentally demonstrated.

Analytical and Semi-Analytical Models for Nonlinear Transmission

Ronen Dar (Bell Labs, Nokia, USA)

We review recent advances in modeling nonlinear interference noise (NLIN) in WDM systems. We explore the time-domain and frequency-domain representations of NLIN and discuss techniques for evaluating its statistical properties and impact on system performance.

W.1.E: Photonics-Based Wireless Access

Chair: Guillermo Carpintero (Universidad Carlos III de Madrid, Spain)

Demonstration of a Real-Time FPGA-Based CPRI-Compatible Efficient Mobile Fronthaul Transceiver Supporting 53 Gb/s CPRI-Equivalent Data Rate Using 2.5-GHz-Class Optics

Huaiyu Zeng and Xiang Liu (Futurewei Technologies, USA); Sharief Megeed (Futurewei Technologies, Huawei R&D USA, USA); Naresh Chand (Futurewei Technologies, USA); Frank Effenberger (Huawei Technologies, USA)

We experimentally demonstrate a real-time CPRI-compatible mobile fronthaul transceiver using 5-GSa/s DAC/ADC, Xilinx Virtex 7 FPGA, and 2.5-GHz-class DML and APD. A CPRI-equivalent aggregated throughput of 53 Gb/s is achieved with an one-way processing latency as low as 1.8 ms.

Full-Duplex Mobile Backhaul Transportation based on Fiber-Wireless Integrated FSO and MMW Hybrid Links with Adaptive Signal Processing to Combat Diverse Weather Conditions

Junwen Zhang, Gk Chang, Jing Wang and Mu Xu (Georgia Institute of Technology, USA); Jianjun Yu (Fudan Univerisity, P.R. China); Lin Cheng (Georgia Institute of Technology, USA)

We propose and experimentally demonstrate a novel full-duplex mobile backhaul network based on fiber-wireless integrated MMW and FSO hybrid links using adaptive diversity combining technique. Performance improvements and enhanced reliability are validated under diverse weather conditions at 11.25-/8.4-Gb/s for down-/up-links.

PIC-enabled Dynamic Bidirectional Indoor Network Employing Optical Wireless and Millimeter-wave Radio Techniques

Ketamaw Mekonnen, Chin Wan Oh, Zizheng Cao and Amir Masood Khalid (Eindhoven University of Technology, The Netherlands); Nicola Calabretta (COBRA Research Institute, The Netherlands); Eduward Tangdiongga (Eindhoven University of Technology, The Netherlands); Ton Koonen (COBRA, Eindhoven University of Technology, The Netherlands)

We propose a hybrid radio-optical wireless system using a photonic integrated chip to realize highly reconfigurable indoor networks which provide ultimate capacities per user. Bidirectional transmission rates of >35Gb/s are demonstrated using discrete-multitone modulation.

Photonics-Aided over 100-Gbaud All-Band (D-, W- and V-Band) Wireless Delivery

Xinying Li (Fudan University, P.R. China); Jianjun Yu (ZTE (TX) Inc., USA); Jiangnan Xiao, Yuming Xu and Long Chen (Fudan University, P.R. China)

We experimentally demonstrate photonics-aided D-band (110GHz-170GHz) wireless mm-wave signal delivery with a record baud rate of 46Gbaud and photonics-aided all-band (D-, W- and V-band) wireless mm-wave signal delivery with a record baud rate of over 100Gbaud (400Gbps).

80 Gbit/s 16-QAM Multicarrier THz Wireless Communication Link in the 400 GHz Band

Shi Jia (Tianjin University, Denmark); Xianbin Yu (Zhejiang University, P.R. China); Hao Hu (Technical University of Denmark, Denmark); Jinlong Yu (Tianjin University, P.R. China); Toshio Morioka (Technical University of Denmark, Denmark); Peter Uhd Jepsen (Denmark Technical University, Denmark); Leif Oxenløwe (Technical University of Denmark, Denmark)

We experimentally demonstrate a high-speed multicarrier THz wireless communication system operating in the 400 GHz band. The use of spectrally efficient 16-QAM modulation and broadband THz transceivers enable link data rates up to 80 Gbit/s.

W.1.F: SDN and NFV

Chair: Achim Autenrieth (ADVA Optical Networking, Germany)

Multi-tenant 5G Network Slicing Architecture with Dynamic Deployment of Virtualized Tenant Management and Orchestration (MANO) Instances

Arturo Mayoral, Raul Muñoz and Ricard Vilalta (CTTC, Spain); Ramon Casellas (Centre Tecnologic de Telecomunicacions de Catalunya (CTTC), Spain); Ricardo Martinez (CTTC, Spain)

We present and experimentally assess a multi-tenant network slicing architecture that dynamically provides 5G slices (virtual network and cloud resources, and virtualized network functions) and SDN/NFV control instances for a full control of allocated resources as if they were real.

First Experimental Demonstration of Secure NFV Orchestration over an SDN-Controlled Optical Network with Time-Shared Quantum Key Distribution Resources

Alejandro Aguado, Emilio Hugues-Salas, Paul Anthony Haigh, Jaume Marhuenda, Alasdair Price, Phil Sibson, Jake Kennard, Christopher Erven, John Rarity and Mark Thompson (University of Bristol, United Kingdom); Andrew Lord (British Telecom, United Kingdom); Reza Nejabati and Dimitra Simeonidou (University of Bristol, United Kingdom)

We demonstrate, for the first time, a secure optical network architecture that combines NFV orchestration and SDN control with quantum key distribution (QKD) technology. A novel time-shared QKD network design is presented as a cost-effective solution for practical networks.

On-Demand Allocation of Control Plane Functions via SDN/NFV for Monitoring-enabled Flexi-grid Optical Networks with Programmable BVTs

Ramon Casellas (Centre Tecnologic de Telecomunicacions de Catalunya (CTTC), Spain); Josep M. Fabrega (Centre Tecnologic de Telecomunicacions de Catalunya, Spain); Raul Muñoz (CTTC, Spain); Laia Nadal Reixats (Centre Tecnològic de Telecomunicacions de Catalunya (CTTC), Spain); Ricard Vilalta (CTTC, Spain); Michela Svaluto Moreolo (Centre Tecnològic de Telecomunicacions de Catalunya (CTTC), Spain); Ricardo Martinez (CTTC, Spain)

A modular SDN architecture for flexi-grid networks, relying on the NFV framework, allows on-demand allocation and composition of virtualized control plane functions into instances, in a cost effective way. We demonstrate its use in the adaptive control of BVTs

Experimental Assessment of VDC Provisioning in SDN/OpenStack-based DC infrastructures with optical DCN

Albert Pagès (Universitat Politècnica de Catalunya (UPC), Spain); Fernando Agraz (Universitat Politècnica de Catalunya, Spain); Rafael Montero (Universitat Politècnica de Catalunya (UPC), Spain); Giada Landi and Roberto Monno (Nextworks, Italy); José I Aznar (I2cat, Spain); Albert Viñés (Fundació i2CAT, Internet i Innovació Digital a Catalunya, Spain); Chris Jackson and Dimitra Simeonidou (University of Bristol, United Kingdom); Salvatore Spadaro (Universitat Politecnica de Catalunya (UPC), Spain)

VDC provisioning requires the coordinated configuration of several types of resources. We present a DC architecture for the orchestration and provisioning of VDC instances on top of DCs with optical DCN and experimentally validate the proposed architecture.

Experimental Evaluation of YAMATO, a SDN Control Plane for Joint and Fractional-Joint Switched SDM Optical Networks

Federico Pederzolli and Matteo Gerola (CREATE-NET, Italy); Andrea Zanardi (Create-Net, Italy); Xavier Forns and J. Ferran (W-Onesys, Barcelona, Spain); Domenico Siracusa (CREATE-NET, Italy)

Managing (Fractional) Joint Switching will enable the deployment of cost-effective SDM networks. This paper describes a network model and the first control plane implementation handling these paradigms. We show, using an emulated testbed, that the system is responsive and scalable.

Virtualized Routing and Frequency Allocation Functions in Elastic Optical Networks

Quan Pham Van (Telecom Sudparis & Nokia Bell Labs, France); Dominique G. Verchere (Nokia Bell Labs & France, France); Selma Khebbache (Télécom SudParis, Institut Mines-Télécom, France); Djamal Zeghlache (Institut Mines-Telecom, Telecom SudParis & UMR 5157 CNRS - Samovar, France); Patricia Layec (NOKIA Bell Labs France, France); Arnaud Dupas (Nokia Bell-Labs, France); Sebastien Bigo (Bell Labs, Alcatel-Lucent, France)

Optical channels are configured according to changing data traffic demands through virtualized routing and frequency allocation (VRFA) functions executed as SDN applications. Two algorithms are evaluated considering the trade-off between allocated DWDM frequency grid ranges and execution time.

CLEO 4: Nonlinear Cavities

Chair: Bertrand Kibler (CNRS / Université Bourgogne Franche-Comté, France)

Using Kerr combs for coherent optical communications

Yanne Chembo (FEMTO-ST Institute, France)

Kerr optical frequency combs can be used as multi-wavelength sources for coherent optical fiber telecommunication networks. We here discuss some results perspectives and challenges in this emerging field.

Chipscale Frequency combs: From soliton physics to coherent telecommunication

Michael Geiselmann, Victor Brasch, Martin Pfeiffer and Karpov Maxim (Ecole Polytechnique Federale de Lausanne, Switzerland); Junqiu Liu and Hairun Guo (EPFL, Switzerland); Grigoriy Lihachev (Lomonosov Moscow State University, Russia); Michael Gorodetsky (M. V. Lomonosov Moscow State University, Russia); Tobias Kippenberg (Ecole Polytechnique Federale de Lausanne, Switzerland)

We generate soliton Kerr frequency combs in a silicon nitride microresonator. These combs are fully coherent and are used as channel generator for coherent telecommunication. With the right dispersion engineering we can broaden the spectrum to 75THz span around 1550nm.

Seeding of Modulation Instability in a Nonlinear Fiber Ring Cavity

Abdelkrim Bendahmane (Université de Bourgogne, France); Julien Fatome (CNRS/Université de Bourgogne, France); Christophe Finot (University of Burgundy, France); Guy Millot (CNRS/Université de Bourgogne, France); Bertrand Kibler (CNRS / Université Bourgogne Franche-Comté, France)

We experimentally and numerically investigate the impact of coherent and incoherent seeding of the modulation instability process in a nonlinear fiber ring cavity. Our results highlight the sensitivity of the nonlinear dynamics in term of sideband bandwidth and temporal coherence.

Comb Peculiarities of the Dispersion-managed Soliton in the Hybrid Mode-locked Erbium-doped All-fiber Ring Laser

Dmitriy Dvoretskiy, Stanislav Sazonkin, Maxim Negin, Dmitry Shelestov, Alexey Pniov and Valery Karasik (Bauman Moscow State Technical University, Russia); Alexander Krylov (Fiber Optics Research Center of the RAS, Russia); Elena Obraztsova (A M Prokhorov General Physics Institute of the RAS, Russia)

We studied optical comb peculiarities of the ultra-short dispersion-managed soliton generation in the erbium-doped all-fiber ring laser hybrid mode-locked with Carbon: Boron Nitride Single-Walled Nanotubes in the co-action with a nonlinear polarization evolution.

Kerr Frequency Combs in a Bichromatically Pumped Nonlinear Fiber Ring Cavity

Abdelkrim Bendahmane (Université de Bourgogne, France); Davide Ceoldo (Università di Brescia, Brescia, Italy); Julien Fatome and Guy Millot (CNRS/Université de Bourgogne, France); Tobias Hansson and Daniele Modotto (Università di Brescia, Brescia, Italy); Stefan Wabnitz (University of Brescia, Italy); Bertrand Kibler (CNRS / Université Bourgogne Franche-Comté, France)

We report numerical and experimental studies of four-wave mixing processes emerging from dual-frequency pumping of a passive fibre ring cavity. We observe the emission of a periodic train of nearly-background-free soliton pulses associated with Kerr frequency combs.

W.2.A: Trends on Passive Optical Network
Chair: Philippe Chanclou (Orange Labs, France)

Industrial Trends and Roadmap of Access
Frank Effenberger (Huawei Technologies, USA)
Optical access has grown in speed, from 50 Mb/s pi-PON to 10 Gb/s XG-PON. Further capacity increases are envisioned to employ multiple wavelengths and advanced line coding. This paper reviews the current trends in access, and predicts a likely roadmap.

Cost Effective 25 Gbps Optical Access Technology
Dora van Veen (Bell Labs, Nokia, USA); Vincent Houtsma (Nokia, Bell Labs, USA)
Overview and discussion of cost effective 25 Gb/s TDM-PON based on 10G optical components using electrical duobinary signalling and electronic equalization methods is presented.

W.2.B: Multicore Fibers
Chair: Kunimasa Saitoh (Hokkaido University, Japan)

125 μm 5-core fibre with heterogeneous design suitable for migration from single-core system to multi-core system
Tomohiro Gonda, Katsunori Imamura and Ryuichi Sugizaki (Furukawa Electric co., Ltd., Japan); Yu Kawaguchi (KDDI R&D Laboratories Inc., Japan); Takehiro Tsuritani (KDDI R&D Laboratories, Inc., Japan)
125 μm 5-core fibre with heterogeneous core design suitable for the migration from single-core system to multi-core system was designed and fabricated. This fibre has high space division multiplexing factor comparable to 19-core fibres.

Crosstalk-Managed Heterogeneous Single-Mode 32-Core Fibre
Yusuke Sasaki, Ryohei Fukumoto, Katsuhiro Takenaga and Kazuhiko Aikawa (Fujikura Ltd., Japan); Kunimasa Saitoh (Hokkaido University, Japan); Toshio Morioka (Technical University of Denmark, Denmark); Yutaka Miyamoto (NTT Network Innovation Laboratories, Japan)
A heterogeneous single-mode 32-core fibre with a cladding diameter of 243 μm is designed and fabricated. The highest core count in single-mode multi-core fibres and low worst-case crosstalk of less than −24 dB/1000 km in C-band are achieved simultaneously.

Coupled Few-mode Multi-core Fibre for Ultra-high Spatial Density Space Division Multiplexing
Taiji Sakamoto, Takayoshi Mori, Masaki Wada, Takashi Yamamoto, Fumihiko Yamamoto and Kazuhide Nakajima (NTT Corporation, Japan)
We review our recent work on coupled few-mode multi-core fibre and describe a super-mode-based MCF design for suppressing MIMO processing complexity. We also report 125 um-cladding strongly coupled 3-mode 7-core fibre for reducing inter-core non-uniformity induced differential mode delay.

Compact 32-Core Multicore Fibre Isolator for High-Density Spatial Division Multiplexed Transmission
Yongmin Jung (Optoelectronics Research Centre, University of Southampton, Southampton, United Kingdom); Shaif-ul Alam (University of Southampton, United Kingdom); Yusuke Sasaki (Fujikura Ltd., Japan); David J Richardson (University of Southampton, United Kingdom)
We present a fully integrated 32-core multicore fibre isolator with low insertion loss (average loss <0.8dB, core-to-core variation <2dB) and low inter-core crosstalk (<-40dB).

Effects of Core Count/Layout and Twisting Condition on Spatial Mode Dispersion in Coupled Multi-Core Fibers
Tetsuya Hayashi (Sumitomo Electric Industries, Ltd.); Haoshuo Chen and Nicolas K Fontaine (Bell Labs, Nokia); Takuji Nagashima (Sumitomo Electric Industries, Ltd.); Roland Ryf and Rene Essiambre (Bell Labs, Nokia); Toshiki Taru (Sumitomo Electric Industries, Ltd.)
We investigated the dependence of the spatial-mode dispersion (SMD) of coupled-core fibers on core count/layout and twisting conditions. The results indicate the importance of the core count/layout design optimization taking account of the twisting conditions.

W.2.C: Error Correction
Chair: Helmut Griesser (ADVA Optical Networking SE, Germany)

Experimental Demonstration of Nonbinary LDPC Convolutional Codes for DP-64QAM/256QAM
Toshiaki Koike-Akino (Mitsubishi Electric Research Laboratories (MERL)); Kenya Sugihara (Mitsubishi Electric Corporation, Japan); David Millar (Mitsubishi Electric Research Laboratories, USA); Milutin Pajovic (Mitsubishi Electric Research Laboratories (MERL), USA); Wataru Matsumoto (Mitsubishi

Electric Corporation, Japan); Alex Alvarado, Robert Maher, Domanic Lavery and Milen Paskov (University College London, United Kingdom); Keisuke Kojima and Kieran Parsons (Mitsubishi Electric Research Laboratories, USA); Benn C Thomsen (University College London, United Kingdom); Seb J Savory (University of Cambridge); Polina Bayvel (UCL, United Kingdom)

We show the great potential of nonbinary LDPC convolutional codes (NB-LDPC-CC) with low-latency windowed decoding. It is experimentally demonstrated that NB-LDPC-CC can offer a performance improvement of up to 5 dB compared with binary coding.

Optimal Layered Scheduling for Hardware-Efficient Windowed Decoding of LDPC Convolutional Codes

Toshiaki Koike-Akino (Mitsubishi Electric Research Laboratories (MERL), USA); Stark Draper (University of Toronto, Canada); Ye Wang (Mitsubishi Electric Research Laboratories, USA); Kenya Sugihara and Wataru Matsumoto (Mitsubishi Electric Corporation, Japan); David Millar and Kieran Parsons (Mitsubishi Electric Research Laboratories, USA); Valeria Arlunno (Mitsubishi Electric Research Laboratories (MERL)); Keisuke Kojima (Mitsubishi Electric Research Laboratories, USA)

We propose an optimal design method for layered scheduling in low-power windowed decoding of LDPC convolutional codes. Our optimal scheduling achieves up to a 70% complexity reduction and a 1 dB gain over conventional scheduling for limited decoding iterations.

Scalable SD-FEC for Efficient Next-generation Optical Networks

Kenya Sugihara, Keisuke Dohi, Kazuo Kubo, Takashi Sugihara, Wataru Matsumoto and Kenji Ishii (Mitsubishi Electric Corporation, Japan)

An SD-FEC has an even potential of a further optimization of a spectral efficiency and a power consumption in optical networks. A scalable SD-FEC is the key idea that improves efficiency of next-generation optical networks.

Improvement on FEC performance by Turbo Equalization for Super-Nyquist WDM systems

Shuai Yuan and Koji Igarashi (Osaka University, Japan); Takehiro Tsuritani (KDDI R&D Laboratories, Inc., Japan); Itsuro Morita (KDDI R&D Laboratories, Japan)

In Super-Nyquist WDM systems, maximum likelihood decoder for duobinary shaping degrades the post-FEC BER performance. We experimentally confirm that degradation of post-FEC BER characteristics can be remarkably suppressed by introducing turbo equalization.

Improved Soft-Decision Forward Error Correction via Post-Processing of Mismatched Log-Likelihood Ratios

Alex Alvarado (University College London, United Kingdom); Leszek Szczecinski (INRS-EMT, Canada); Tobias Fehenberger (Technical University of Munich (TUM), Germany); Polina Bayvel (UCL, United Kingdom); Milen Paskov (University College London, United Kingdom)

Correction of soft information based on achievable information rates for SD-FEC is discussed. Linear scaling of LLRs is shown to offer gains of up to 0.75 dB for a rate 0.8 LDPC code in a channel dominated by phase noise.

W.2.D: Advanced Modulation Formats I

Chair: Giancarlo Gavioli (Nokia, Italy)

5 and 7 bit/symbol 4D Modulation Formats Based on 2A8PSK

Keisuke Kojima (Mitsubishi Electric Research Laboratories, USA); Tsuyoshi Yoshida (Mitsubishi Electric Corporation, Japan); Toshiaki Koike-Akino (Mitsubishi Electric Research Laboratories (MERL), USA); David Millar and Kieran Parsons (Mitsubishi Electric Research Laboratories, USA); Valeria Arlunno (Mitsubishi Electric Research Laboratories (MERL), USA)

We propose 5 and 7 bit/symbol 4D modulation formats based on 2A8PSK, which outperform previously known modulation formats for each spectral efficiency. Combined with the recently reported 6 bit/symbol 2A8PSK, the 2A8PSK family covers 5-7 bits without significant hardware modifications.

Digital Subcarrier Multiplexing 4-D Set-Partitioning QAM Signals

Xiang Meng (Huazhong University of Science and Technology, P.R. China); Qunbi Zhuge (Ciena Corporation, Canada); Meng Qiu (McGill University, Montreal, Canada); Thang Hoang (McGill University, Canada); Mohammad Sowailem (McGill University, Egypt); Xingyu Zhou (UESTC, P.R. China); Fangyuan Zhang (McGill University, Canada); Ming Tang (Huahzong University of Science and Technology, P.R. China); Changjian Ke, Deming Liu and Songnian Fu (Huazhong University of Science and Technology, P.R. China); David Plant (McGill University, Canada)

We experimentally investigate 4-D set-partitioning formats in digital subcarrier multiplexing systems. The proposed 4-D set-partitioning of signals across two subcarriers outperforms the conventional approach implemented across two polarizations in terms of both nonlinearity and optical filtering tolerance.

96-GBaud Coded 8-Dimensional 16QAM Transmission over 5,252 km Using Iterative Soft-Output Decoding
Masanori Nakamura, Fukutaro Hamaoka, Asuka Matsushita, Kengo Horikoshi, Hiroshi Yamazaki and Munehiko Nagatani (NTT Corporation, Japan); Akihide Sano (NTT Network Innovation Laboratories, Japan); Akira Hirano (NTT, Japan); Yutaka Miyamoto (NTT Network Innovation Laboratories, Japan)
We propose novel coded 8-dimensional 16QAM demonstrating 576-Gbps transmission over 5,252km. At the same spectral efficiency, 8D-16QAM using iterative soft output decoding can expand the transmission reach by 1,212km compared to conventional PDM-8QAM.

Folded Orthogonal Frequency Division Multiplexing for Super-Channel Sub-Banding
Bill Corcoran and Chen Zhu (Monash University, Australia); Arthur Lowery (Monash Univ, Australia); Binhuang Song (Monash University, Australia)
Orthogonal, periodic-sinc-shaped sub-carrier spectra allow multi-carrier bands with the precise, rectangular frequency definition of Nyquist-WDM. Experimental demonstration of these 'folded' OFDM bands shows a 0.5-1.7-dB implementation penalty, allowing 520-Gb/s super-channel transmission over 4160 km

Improved Flexibility in Rate and Reach by Time-Frequency Packed QPSK
Qian Hu (Bell Labs, Nokia, Germany); Fred Buchali, Laurent Schmalen, Wilfried Idler, Roman Dischler and Henning Buelow (Nokia Bell Labs, Germany)
We experimentally demonstrate a transmission system with adaptable rate and reach based on time-frequency-packing technique. Packed by a digital filter, the DP-QPSK signal is transmitted at various baud rates in a sub-Nyquist channel with fixed bandwidth.

W.2.E: Transmitters II
Chair: Leo Spiekman (Aeon Corp., USA)

Quantum-dot lasers monolithically grown on silicon substrates
Huiyun Liu (University College London & Torrington Place, London WC1E 6BT, United Kingdom)
Monolithically integrating III-V lasers on Si is the most promising solution to overcome the issue of lack of efficient light sources on Si. We demonstrated the first practical silicon-based telecommunications-wavelength quantum-dot laser with high output power and long lifetime.

Polymer-based Integrated Tuneable laser with On-Chip Wavelength Locker
David De Felipe, Magnus Happach and Moritz Kleinert (Fraunhofer Institute for Telecommunications, Heinrich Hertz Institute, Germany); Crispin Zawadzki and Walter Brinker (Fraunhofer Institute for Telecommunications, Heinrich-Hertz-Institut, Germany); Wolfgang Rehbein (Fraunhofer-Institut für Nachrichtentechnik, Heinrich-Hertz-Institut, Germany); Martin Moehrle (Fraunhofer Heinrich-Hertz-Institute, Germany); Norbert Keil (HHI, Fraunhofer Institute, Germany); Werner Hofmann (Technische Universität Berlin, Germany); Martin Schell (Fraunhofer Institute for Telecommunications, Heinrich-Hertz-Institut, Germany)
A polymer-based integrated tuneable laser with on-chip wavelength locker is presented. The device incorporates a free-space-based 100-GHz etalon, and monitor planar photodiodes coupled by means of 45° mirrors. Wavelength stabilization with a resolution of ±4 GHz has been demonstrated.

Wavelength Stabilized Silicon/III-V Hybrid Laser
Argishti Melikyan (Nokia & Bell Labs, USA); Guilhem de Valicourt (Alcatel-Lucent, Bell Labs, USA); Po Dong (Bell labs, Alcatel-Lucent, USA); Nicolas K Fontaine (Bell Labs/Alcatel-Lucent, USA); Kwangwoong Kim and Chia-Ming Chang (Nokia Bell Labs, USA); Young-Kai Chen (Bell Labs, Alcatel-Lucent, USA)
We demonstrate wavelength stabilized hybrid silicon/III-V laser. The on-chip silicon diode temperature sensor integrated with the laser cavity allows sub-10pm wavelength stabilization in temperature fluctuation of 2 C around pre-set temperature.

Transmission Characteristics of 32-Gbaud PDM IQ Monolithic Silicon Modulator Operating with 2-VPPD Drive Voltage
Norihiro Ishikura, Kazuhiro Goi and Haike Zhu (Fujikura Ltd., Japan); Mikhail Illarionov (Fujkura Ltd., Japan); Hiroki Ishihara, Akira Oka, Takuya Oda, Koichiro Masuko, Teijiro Ori and Kensuke Ogawa (Fujikura Ltd., Japan); Yuki Yoshida (National Institute of Information and Communications Technology, Japan); Ken'ichi Kitayama (The Graduate School for the Creation of New Photonics Industries, Japan); Tsung-Yang Liow, Xiaoguang Tu, Patrick Lo and Dim-Lee Kwong (Institute of Microelectronics, Singapore)

Monolithic silicon PDM IQ modulator having vertical PN-junction rib-waveguide phase shifters in a ceramic-based metal package operating with RF drive voltage as low as 2 VPPD is characterized in 32-Gbaud optical-fibre transmission. Signal-to-noise ratio penalty is obtained as 5.5 dB.

High-Speed Monolithically Integrated Silicon Photonic Transmitters in 0.25 μm BiCMOS Platform

Despoina Petousi (IHP GmbH & IHP GmbH, Germany); Iria Garcia Lopez (IHP GmbH, Germany); Stefan Lischke (IHP Frankfurt/Oder, Germany); Dieter Knoll (IHP GmbH, Germany); Pedro Rito, Marcel Kroh and Georg Winzer (IHP, Germany); Christian Mai (IHP Frankfurt/Oder, Germany); Karsten Voigt (Technical University of Berlin, Germany); Ahmet Cagri Ulusoy and Dietmar Kissinger (IHP, Germany); Lars Zimmermann (IHP & Technical University of Berlin, Germany); Klaus Petermann (Technical University of Berlin, Germany)

Monolithically integrated Si depletion-type transmitters in 0.25 μm photonic BiCMOS platform with different driving approaches are discussed. A power efficient implementation featuring integrated 4-bit DAC functionality is presented, from which PAM-4 eye diagrams up to 40 Gb/s are demonstrated.

W.2.F: Switching and Routing

Chair: Oded Raz (Eindhoven University of Technology, The Netherlands)

High radix all-optical switches for software-defined datacentre networks

Nick Parsons (Polatis, United Kingdom); Rich Jensen (Polatis, USA); Adam Hughes (Polatis, United Kingdom)

We review use cases for optical circuit switching (OCS) in datacentre networks, together with results for a 384x384 port dark fibre OCS with median loss of 1.5dB. Challenges of scaling SDN-enabled OCS fabrics to greater than 50,000 endpoints are discussed.

Large-Scale Optical Circuit Switch for Intra-Datacenter Networking Using Silicon-Photonic Multicast Switch and Tunable Filter

Koh Ueda, Yojiro Mori and Hiroshi Hasegawa (Nagoya University, Japan); Ken-Ichi Sato (School of Engineering - Nagoya University, Japan); Keijiro Suzuki, Hiroyuki Matsuura, Ken Tanizawa, Satoshi Suda, Kazuhiro Ikeda, Shu Namiki and Hitoshi Kawashima (National Institute of Advanced Industrial Science and Technology, Japan); Shigeru Nakamura, Shigeyuki Yanagimachi and Akio Tajima (NEC Corporation, Japan)

We propose a novel optical circuit switch architecture for intra-datacenter networking. The key components, optical multicast switches and tunable filters are fabricated using silicon photonics. Proof-of-concept transmission experiments are performed using newly developed silicon-photonic devices.

System Performance Assessment of a Monolithically Integrated WDM Cross-Connect Switch for Optical Data Centre Networks

Nicola Calabretta (COBRA Research Institute, The Netherlands); Wang Miao, Kristif Prifti and Kevin Williams (Eindhoven University of Technology, The Netherlands)

We assess the system performance of a photonic integrated 4x4x4lamba WDM cross-connect switch with nanoseconds wavelength, space, time switching operation. Experimental results show error-free dynamic switching of 10 Gb/s, 20 Gb/s, and 40 Gb/s data packets with <2dB penalty.

Coherent Optical Subcarrier Processing and Add/Drop Multiplexing

Carsten Schmidt-Langhorst (Fraunhofer Heinrich Hertz Institute, Germany); Thomas Richter and Robert Elschner (Fraunhofer Heinrich Hertz Institute); Tomoyuki Kato (Fujitsu Laboratories Ltd., Japan); Takahito Tanimura (Fujitsu Laboratories Ltd.); Shigeki Watanabe (Fujitsu Laboratories Ltd., Japan); Takeshi Hoshida (Fujitsu Laboratories Ltd.); Colja Schubert (Fraunhofer Heinrich Hertz Institute)

Frequency conversion in optical fiber allows for coherent optical processing of densely multiplexed subcarriers in spatially separated nodes. Proof-of-concept experiments show the applicability to up to 32QAM subcarriers, broadband operation (400 GHz) and selective processing of PDM subcarrier tributaries.

CLEO 5: Lasers and instabilities

Chair: Yanne Chembo (FEMTO-ST Institute, France)

Real-Time Single-Shot Diagnostics of Mode-Locked Lasers

Georg Herink (University of Goettingen & UCLA, Germany); Felix Kurtz (University of Goettingen, Germany); Bahram Jalali (University of California, Los Angeles, USA); Claus Ropers (University of Goettingen, Germany); Daniel Solli (UCLA, USA)

The combination of photonic time-stretch techniques and real-time electronics enables rapid single-shot spectral acquisition over millions of consecutive laser pulses. We present the first real-time spectral view onto the evolution of femtosecond-pulses from noise, onto stable and meta-stable multi-pulse operation.

Real Time Measurements of Noise-induced Rogue Waves Generated by Modulation Instability in Optical Fibre

Mikko Närhi (Tampere University of Technology, Finland); Benjamin Wetzel (INRS-EMT, Canada); Cyril Billet (Université de Franche-Comté, France); Thibaut Sylvestre (Femto-ST Institute & CNRS, France); Shanti Toenger and Jean-Marc Merolla (FEMTO-ST Institute, France); Roberto Morandotti (INRS-EMT, Canada); Frederic Dias (University College Dublin, Ireland); Goëry Genty (Tampere University of Technology, Finland); John Dudley (Université de Franche-Comté, France)

Using a parametric temporal magnifier system, we report for the first time on the direct temporal measurement of rogue waves and breather-like structures arising from spontaneous modulation instability.

FBG Reflectivity Impact on RIN in Ultralong Laser Amplifiers

Giuseppe Rizzelli Martella (CSIC - Instituto de Optica, Spain); Md Asif Iqbal (Aston University, United Kingdom); Francesca Gallazzi and Paweł Rosa (CSIC - Instituto de Optica, Spain); Mingming Tan (Aston University & AIPT, United Kingdom); Pedro Corredera (CSIC - Instituto de Optica, Spain); Juan Diego Ania-Castanon (CSIC - Instituto de Optica); Paul Harper (Aston University, United Kingdom)

We analyse, both numerically and experimentally, the Relative Intensity Noise transfer in ultra-long Raman laser amplifiers isolating the combined effect of front-FBG reflectivity and pump power split and quantitatively showing their impact on a 100 km, 2nd-order, bidirectionally pumped configuration.

Extremely Pulsating Solitons in a Mode-locked Fiber Laser

Junsong Peng (AstonUniversity, United Kingdom); Nikita Tarasov, Srikanth Sugavanam and Dmitry Churkin (Aston University, United Kingdom)

Extremely pulsating solitons were observed experimentally in a mode-locked fiber laser. The solitons changed their intensity by an order of magnitude and exhibited time shift with a period of 1100 cavity roundtrips; meanwhile their optical spectrum breathed and compressed periodically.

High-order linearly-polarized random Raman fiber laser for telecom applications

Ekaterina Zlobina and Sergey Kablukov (Institute for Automation and Electrometry SB RAS, Russia); Sergey Babin (Institute for Automation and Electrometry SB RAS & Novosibirsk State University, Russia)

We demonstrate an efficient linearly polarized random lasing in a 1.8-km PM fiber up to the 5th order Stokes component at ~1360 nm. Potential applications and problems of further expansion to longer wavelengths are discussed.

W.3.A: Elastic Optical Networks I

Chair: Ioannis Tomkos (Athens Information Technology, Greece)

Roles and Benefits of Elastic Optical Networks in Beyond 100-Gb/s Era

Masahiko Jinno (Kagawa University, Japan)

This tutorial reviews elastic optical networking technology and presents its roles and benefits in a new era where major line rates in metro/core optical networks are 100 Gb/s and beyond.

How deploying elastic and fixed 100 Gb/s transponders can further optimize cost per Gb/s during ageing of WDM networks

Thierry Zami (Nokia, France); Jelena Pesic (Alcatel-Lucent Bell labs, France); Petros Ramantanis (Nokia Bell Labs, France)

This study illustrates how jointly deploying relatively low cost 100 Gb/s optical transponders and elastic optical transponders fitting the ageing of margins can further improve return on investment for the operators of WDM networks

Low-cost CD-ROADMs Based Elastic Optical Networks Employing Wavelength Defragmentation

Yutaka Takita (Fujitsu Limited, Japan); Kazuyuki Tajima and Tomohiro Hashiguchi (Fujitsu Limited); Toru Katagiri (Fujitsu Limited, Japan)

We evaluate low-cost CD-ROADMs (L-CD-ROADMs) based elastic optical networks where wavelength defragmentation is applied. Through simulations, we confirm that such networks can save close to 50% of ROADM cost in the add/drop part with negligible impact on wavelength utilization efficiency.

W.3.B: Fibres for Mode Division Multiplexing
Chair: Francesco Poletti (University of Southampton, United Kingdom)

Linear and Nonlinear Properties of OAM in Fibers
Siddharth Ramachandran (Boston University, USA)
Stable propagation of OAM in fibers has opened up a new design space with applications ranging from telecommunications to biomedical imaging. This talk will review progress in the field, elucidating the unique linear and nonlinear properties of OAM fiber modes.

Low-Loss 25.3km Few-Mode Ring-Core Fibre for Mode-Division Multiplexed Transmission
Yongmin Jung (Optoelectronics Research Centre, University of Southampton, Southampton, United Kingdom); Qiongyue Kang (ORC, UNiversity of Southampton, United Kingdom); Hongyan Zhou (State Key Laboratory of Optical Fiber and Cable Manufacture Technology, P.R. China); Rui Zhang, Su Chen, Honghai Wang and Yucheng Yang (Yangtze Optical Fibre and Cable Joint Stock Limited Company, P.R. China); Xianqing Jin (USTC, P.R. China); Frank Payne (University of Oxford, United Kingdom); Shaif-ul Alam and David J Richardson (University of Southampton, United Kingdom)
We report the design, fabrication and characterisation of a few-mode ring-core fibre supporting 4 mode groups. The low loss (~0.3dB/km) and length (25.3km) are both records for a ring-core fibre.

Group Delay Spread in Graded-Index 10-Spatial-Mode Fibers
Carmen Castineiras (Prysmian Group & University Lille 1, France); Denis Molin and Marianne Bigot (Prysmian Group, France); Laurent Bigot (University of Lille - CNRS, France); Yves Quiquempois (Université de lille, France); Pierre Sillard (Prysmian, France)
We theoretically investigate the group delay spread (GDS) of 10-spatial-mode fibers. The strongly-coupled regime leading to the increase of GDS with the square root of distance is only achieved for high perturbations and below a certain effective index difference value.

Fibers with High Numbers of Modes and Low DMGDs
Pierre Sillard (Prysmian Group); Marianne Bigot and Denis Molin (Prysmian Group, France); Koen de Jongh and Frank Achten (Prysmian Group, The Netherlands)
Fibers with high numbers of spatial modes (≥15) and low DMGDs (<90ps/km) are designed and fabricated. In such fibers, the highest-order modes are not used to reduce the impacts of cladding and DMGD sensitivity to process variability.

Demonstration of a Thin-Ring Air Core Fiber Supporting 22 Stable Angular Momentum Modes
Patrick Gregg (Boston University, USA); Poul Kristensen (OFS Fitel, Denmark); Steven Golowich (MIT-Lincoln Laboratory, USA); Siddharth Ramachandran (Boston University, USA)
A thin-ring air-core fiber design suppressing higher radial-order modes enables supporting a record number (22) of stable spin-orbit coupled angular momentum modes over 10m. Output projection measurements of all non-degenerate modes reveal >18dB purity relative to nearest neighbours.

W.3.C: Nonlinear Optical Signal Processing
Chair: Leif Oxenløwe (Technical University of Denmark, Denmark)

THz-Range Optical Frequency Shifter for Dual Polarization WDM Signals Using Frequency Conversion in Fibre
Tomoyuki Kato and Shigeki Watanabe (Fujitsu Laboratories Ltd., Japan); Takahito Tanimura (The University of Tokyo & Fujitsu Laboratories Ltd., Japan); Thomas Richter (Fraunhofer Heinrich-Hertz-Institut, Germany); Robert Elschner (Fraunhofer Heinrich-Herz-Institut, Germany); Carsten Schmidt-Langhorst (Fraunhofer Heinrich Hertz Institute, Germany); Colja Schubert (Fraunhofer Heinrich-Hertz-Institut, Germany); Takeshi Hoshida (Fujitsu Laboratories Limited, Japan)
We propose an optical frequency shifter for dual-polarization signals using frequency conversion in fibre. We achieve THz-range frequency shift with the original signal suppression without an optical filter and demonstrate combining of two dual-polarization 400-Gb/s superchannels with acceptable in-band crosstalk.

QPSK Phase-Regeneration in a Silicon Waveguide Using Phase-Sensitive Processing
Isaac Sackey and Erik Liebig (Technische Universitaet Berlin, Germany); Thomas Richter (Fraunhofer Heinrich-Hertz-Institut, Germany); Andrzej Gajda (IHP GmbH, Germany); Lars Zimmermann (IHP & Technical University of Berlin, Germany); Klaus Petermann (Technical University of Berlin, Germany); Colja Schubert (Fraunhofer Heinrich-Hertz-Institut, Germany)

We present an in-line 4-level phase-regenerator which utilizes phase-sensitive amplification in a silicon waveguide with reverse-biased p-i-n junction. Phase noise reduction is investigated for a QPSK signal in a 1,040-km dispersion-managed link.

Characterization of a Wavelength Converter for 256-QAM Signals Based on an AlGaAs-On-Insulator Nano-waveguide

Francesco Da Ros, Metodi Yankov, Edson Porto da Silva, Minhao Pu, Luisa Ottaviano and Hao Hu (Technical University of Denmark, Denmark); Elizaveta Semenova (Department of Photonics Engineering, Technical University of Denmark, Denmark); Soren Forchhammer (Technical University of Denmark, Denmark); Darko Zibar (DTU Fotonik, depertment of Photonic Engineering, Technical University of Denmark, Denmark); Michael Galili, Kresten Yvind and Leif Oxenløwe (Technical University of Denmark, Denmark)

High efficiency and broadband wavelength conversion in a 9-mm AlGaAs-On-Insulator waveguide is shown to provide high-quality (OSNR > 30 dB) idler generation over a 28-nm bandwidth enabling error-free conversion of 10-GBd 256-QAM with OSNR penalty below 2.5 dB.

Experimental Demonstration of Phase-Sensitive Regeneration of a 20-40 Gb/s QPSK Channel without Phase-Locked Loop using Brillouin Amplification

Ahmed Almainman, Yinwen Cao, Morteza Ziyadi, Amirhossein Mohajerin-Ariaei, Peicheng Liao and Changjing Bao (University of Southern California, USA); Fatemeh Alishahi (University of Southern Calliforni, USA); Ahmad Fallahpour (USC, USA); Bishara Shamee (University of Southern California, USA); Joe Touch (USC/ISI, USA); Youichi Akasaka and Tadashi Ikeuchi (Fujitsu Laboratories of America, Inc., USA); Steven Wilkinson (Raytheon, USA); Moshe Tur (Tel-Aviv University, Israel); Alan Willner (University of Southern California, USA)

We experimentally demonstrate all-optical phase-sensitive regeneration of a 20-40Gb/s QPSK signal without a phase-locked loop by amplifying the fourth harmonic using Brillouin amplification. We observe up to 65% reduction in phase noise and 3.4 dB gain at BER of 10-4.

W.3.D: Advanced Modulation Formats II

Chair: Hiroshi Onaka (Fujitsu Limited, Japan)

82.29-Tb/s (182×560-Gb/s) Transmission of 42GHz-Spaced WDM PDM-128-QAM OFDM Signals over 100-km SMF

Fan Li and Jianjun Yu (ZTE (TX) Inc., USA); Yuanquan Wang, Junwen Zhang and Xinying Li (Fudan University, P.R. China); Hung-Chang Chien (ZTE (TX) Inc., USA)

Transmission of 42GHz-spaced 182×560-Gb/s PDM-128QAM-OFDM over 2×50-km SMF with DFT-S PAPR suppression and DD-LMS post-equalization is successfully demonstrated for the first time to enable large-capacity systems on 400G wavelengths.

Super-Nyquist 9-WDM 126-GBaud PDM-QPSK Transmission over 7878km using Digital-Preprocessed Analog-Multiplexed DAC for Long-Haul Applications

Asuka Matsushita, Fukutaro Hamaoka, Masanori Nakamura, Kengo Horikoshi, Hiroshi Yamazaki and Munehiko Nagatani (NTT Corporation, Japan); Akihide Sano (NTT Network Innovation Laboratories, Japan); Akira Hirano (NTT, Japan); Yutaka Miyamoto (NTT Network Innovation Laboratories, Japan)

We successfully demonstrate 400Gbps/carrier data transmission (504Gbps line-rate assuming 25.5% FEC) over 7878km using 126-GBaud PDM-QPSK signal generated by a digital pre-processed analog multiplexed DAC. Spectral efficiency of 3.21bit/s/Hz is achieved with super-Nyquist 125-GHz WDM spacing and optical pre-filtering.

Comparison of Single Carrier 200G 4QAM, 8QAM and 16QAM in a WDM Field Trial Demonstration over 612 km SSMF

Ginni Khanna (Technical University of Munich, Germany); Talha Rahman (Eindhoven University of Technology, Eindhoven, The Netherlands); Erik Man (Coriant R&D GmbH, Germany); Emilio Riccardi (Telecom Italia Lab, Italy); Annachiara Pagano and Anna Chiado`Piat (Telecom Italia, Italy); Bernhard Spinnler, Stefano Calabro, Danish Rafique and Uwe Feiste (Coriant R&D GmbH, Germany); Huug de Waardt (Eindhoven University of Technology, The Netherlands); Bernd Krombholz (Coriant R&D GmbH, Germany); Tomislav Drenksi (Socionext Europe GmbH, United Kingdom); Marc Bohn and Antonio Napoli (Coriant R&D GmbH, Germany); Norbert Hanik (Munich University of Technology, Germany)

We present results of a field trial carried on Telecom Italia EDFA-only legacy link with 0.3 dB/km average fiber attenuation. Single carrier 200G WDM DP-4QAM, DP-8QAM and DP-16QAM were successfully transmitted with system margin of 4.1dB, 4.3dB and 2.6dB respectively.

Experimental Study of Subcarrier Multiplexing Benefit in 74 nm Bandwidth Transmission up to 20,450 km

Jin-Xing Cai and Matthew Mazurczyk (TE SubCom, USA); Oleg Sinkin (Tyco Telecom, USA); Maxim Bolshtyansky (TE Subcom, USA); Dmitri Foursa (Tyco Telecommunications, USA); Alexei Pilipetskii (Tyco Electronics Subsea Communications, USA)

We experimentally demonstrate 0.8dB subcarrier-multiplexing benefit for QPSK signals transmitted in 74nm bandwidth over 20,450km, and only 0.2dB benefit is achieved for 16QAM signals. We observe subcarrier index performance dependence due to the transmitter RF noise spectrum.

Solutions for 400 Gbit/s Inter Data Center WDM Transmission

Annika Dochhan (ADVA Optical Networking SE, Germany); Nicklas Eiselt (Technical University of Denmark, Denmark); Helmut Griesser (ADVA Optical Networking SE, Germany); Michael Eiselt (ADVA, Germany); Juan Jose Vegas Olmos (Technical University of Denmark, Denmark); Idelfonso Tafur Monroy (Technical University of Denmark, Denmark & ITMO University, Russia); Jörg-Peter Elbers (ADVA AG Optical Networking, Germany)

We review some currently discussed solutions for 400 Gbit/s inter-data center WDM transmission for up to 100 km. We focus on direct detected solutions, namely PAM4 and DMT, and present two WDM systems based on these formats.

W.3.E: TWDM PON

Chair: Derek Nesset (BT plc, United Kingdom)

Field-Trial of a Real-Time 100 Gb/s TWDM-PON Based on 10G-Class Optical Devices

Lilin Yi, Honglin Ji and Zhengxuan Li (Shanghai Jiao Tong University, P.R. China); Xiang Li (Wuhan Research Institute of Posts and Telecommunications, P.R. China); Cai Li (Wuhan Research Institute of Post & Telecommunication, P.R. China); Qi Yang (FiberHome, P.R. China); Lei Xue and Xiaodong Wang (Shanghai Jiao Tong University, P.R. China); Suyi Wang, Ying Yang and Junbo Xu (Fiberhome, P.R. China); Shaohua Yu (Huazhong University of Science&Technology, P.R. China); Weisheng Hu (Shanghai Jiao Tong University, P.R. China)

We show the first field trial of 100G-PON with downstream/upstream data rates of 25/10Gb/s/λ based on 10G-class optical devices supporting 40-km reach and 33-dB loss budget. The system stability is verified by 67-hour real-time BER measurement.

Experimental Demonstration of Low Cost Wavelength Drift Mitigation for TWDM Systems

Gael Simon and Fabienne Saliou (Orange, France); Philippe Chanclou and Luiz Anet Neto (Orange Labs, France); Didier Erasme (Telecom ParisTech, France)

We experimentally proved that a harmful wavelength drift of tunable DMLs under burst mode is induced by adiabatic and thermal chirp. We demonstrate the possibility to compensate one phenomenon by the other. The wavelength drift can be reduced by 50%.

Burst-Mode Optical Amplifier Technologies for TWDM-PON

Masamichi Fujiwara (NTT Access Network Service Systems Laboratories, Japan)

We introduce our burst-mode optical amplifier technologies for TWDM-PONs that support E2 class power budget, allow service providers to flexibly locate optically-amplified repeaters in long-reach systems, and also accommodate many more users through higher splitting ratios.

Dynamically Reconfigurable TDM-DWDM PON Ring Architecture for Efficient Rural Deployment

Daniel Carey, Nicola Brandonisio, Stefano Porto, Alan Naughton and Peter Ossieur (Tyndall National Institute, Ireland); Nick Parsons (Polatis Ltd., United Kingdom); Giuseppe Talli (Tyndall National Institute & Tyndall National Institute, Ireland); Paul Townsend (Tyndall National Institute, Ireland)

A novel chained amplifier node access architecture for rural areas has been demonstrated for the first time using FEC in burst mode operation at 10Gb/s implemented on FPGAs supporting 40 channels and 1024 users with a reach of 120km.

User/Service Group Separation in Optical Domain Using Overlayed Modulation Technique for 40 Gbit/s Single Wavelength TDM PON

Robert Borkowski (Nokia, Germany); Rene Bonk (Alcatel-Lucent, Germany); Wolfgang Poehlmann (Nokia, Germany); Thomas Pfeiffer (Alcatel-Lucent, Germany)

We experimentally demonstrate optical layer separation between user/service groups in burst-mode upstream of 40 Gbit/s TDM PON using overlayed modulation technique. Loss budget exceeding 29 dB and C-band transmission up to 40 km with 12 km differential reach is achieved.

W.3.F: Silicon Photonics and Integration
Chair: Antonio Fincato (STMicroelectronics, Italy)

2:00 *Optimization of Integrated Silicon Doped Heaters for Optical Microring Resonators*
Paolo Pintus, Costanza Manganelli, Fabrizio Gambini and Fabrizio Di Pasquale (Scuola Superiore Sant'Anna, Italy); Maryse Fournier (CEA-LETI, France); Olivier Lemonnier (CEA LETI, France); Christophe Kopp (CEA, LETI, MINATEC DOPT Grenoble, France); Claudio Oton (Scuola Superiore Sant'Anna, Italy)
We present the design, the fabrication and the characterization of thermally tunable integrated silicon-doped heaters for optical switches. Their performance, with focus on Reconfigurable Optical Add/Drop Multiplexer, has been investigated in term of power consumption and time response.

2:15 *Ge Waveguide Photodetector on Wafer-Bonded Ge-on-Insulator Substrate Monolithically Integrated with Amorphous Si Waveguide*
Jian Kang and Mitsuru Takenaka (The University of Tokyo, Japan); Shinichi Takagi (University of Tokyo, Japan)
We demonstrate the proof-of-concept of Ge/a-Si hybrid photonic integrated circuits on Ge-on-insulator (GeOI) substrate fabricated by wafer bonding. We successfully demonstrate waveguide Ge PIN photodetector with low-dark-current operation on GeOI wafer monolithically integrated with a-Si passive waveguide.

2:30 *Novel Nonreciprocal Devices with Integrated Electromagnet for Silicon Photonics*
Paolo Pintus (Scuola Superiore Sant'Anna, Italy); Duanni Huang (University of California Santa Barbara, USA); Chong Zhang (University of California, Santa Barbara, USA); Yuya Shoji (Tokyo Institute of Technology, Japan); Tetsuya Mizumoto (Tokio Institute of Technology, Japan); John Bowers (University of California, USA)
We present a novel approach to construct integrated isolators and circulators based on magneto-optical materials. An integrated electromagnet is designed and fabricated, eliminating the need for a permanent magnet. The fabricated devices exhibit high performance and can be easily integrated/packaged.

2:45 *Hybrid 2D/3D Photonic Integration for Non-Planar Circuit Topologies*
Aleksandar Nesic, Matthias Blaicher and Tobias Hoose (Karlsruhe Institute of Technology (KIT), Germany); Matthias Lauermann (Now with Infinera Corporation); Yasar Kutuvantavida (Karlsruhe Institute of Technology, Germany); Wolfgang Freude and Christian Koos (Karlsruhe Institute of Technology (KIT), Germany)
We present a concept for realizing crossing-free photonic integrated circuits (PIC) using 3D freeform waveguides. We prove the viability of the approach using a silicon photonic 4x4 switch-and-select device. The method is applicable to a wide range of PIC technologies.

3:00 *Monolithic Electronic-Photonic Co-Integration in Photonic BiCMOS*
Lars Zimmermann (IHP & Technical University of Berlin, Germany)
Monolithic co-integration of silicon photonics with high-performance BiCMOS is a new technology for implementing efficient sub-systems in high-speed optical communications. Present status of the technology will be reviewed, pros and cons in comparison to other integration technologies will be discussed.

W.4.P1.SC1: Fibres, Fibre devices and Fibre

Experimental Observation of Mid-infrared Supercontinuum Generation in an As2Se3- AsSe2 Fiber
Tonglei Cheng, Kenshiro Nagasaka, Hoang Tuan Tong and Xiaojie Xue (Toyota Technological Institute, Japan); Morio Matsumoto and Hiroshige Tezuka (Furukawa Denshi Co., Ltd., Japan); Takenobu Suzuki and Yasutake Ohishi (Toyota Technological Institute, Japan)
We experimentally investigate supercontinuum generation spanning 2.0 to 15.1 μm in a 3 mm-long As2Se3-AsSe2 fiber with the mid-infrared femtosecond pulse pump source.

Low-loss and Low-nonlinearity Few-mode Fibre for LP21 Mode Transmission with Low DSP Complexity
Takayoshi Mori, Taiji Sakamoto, Masaki Wada, Azusa Urushibara, Takashi Yamamoto and Kazuhide Nakajima (NTT Corporation, Japan)
A few-mode fibre with a low-loss (0.180 dB/km) and large-Aeff (366 um2) at 1550 nm in the LP21 mode is presented. We demonstrate a low-DSP-complexity transmission over 100 km few-mode fibre and reveal high nonlinear tolerance using the LP21 mode.

Theoretical study of mode coupling via the gain medium in FM-EDFA including mode beating effects

Jean-Baptiste Trinel, Guillaume Le Cocq and Olivier Vanvincq (Université de Lille, France); Yves Quiquempois (Université de lille, France); Esben Andresen (Université de Lille, France); Laurent Bigot (University of Lille - CNRS, France)

A field-propagating model for active optical fibers is applied to the particular case of Few-Mode EDFA. Mode coupling through the amplifying medium is analyzed and results show significant differences compared to usual intensity models.

Bi/Er Co-doped Fibers as an Active Medium for Optical Amplifiers for the C-, L- and U- Telecommunication Bands

Sergei Firstov (Fiber Optics Research Center, RAS); Vladimir F. Khopin (Institute of Chemistry of High Purity Substances of RAS, Russia); Konstantin Riumkin and Sergey Alyshev (Fiber Optics Research Center, RAS, Russia); Mikhail Melkumov (Fiber Optics Research Center of the Russian Academy of Sciences, Russia); Aleksey N. Guryanov (Institute of Chemistry of High Purity Substances of RAS, Russia); Evgeny M. Dianov (Fiber Optics Research Center of the Russian Academy of Sciences, Russia)

We report the first results on the fabrication of Bi/Er co-doped fibers with the gain bandwidth over 200 nm ranging from 1530 to 1770 nm. The main fiber characteristics affecting the amplification are discussed.

Angular Momentum Dependence of the Twist-Induced Effect in Few-Mode Fibres

Paolo Martelli, Annalaura Fasiello, Oriana Soccali, Pierpaolo Boffi and Mario Martinelli (Politecnico di Milano, Italy)

The twist-induced effect on fibre modes has been recognized as a phase shift depending on the total angular momentum. The amount of this phase shift has been measured through an interference experiment in a few-mode fibre, confirming the theoretical predictions.

Improved Method for Measuring Inter-Core Crosstalk in Multi-Core Fibres Using a Near-Infrared Camera

Shota Saitoh, Yoshimichi Amma, Yusuke Sasaki, Katsuhiro Takenaga and Kazuhiko Aikawa (Fujikura Ltd., Japan)

We present an improved method that enables measurement of crosstalk as low as approximately −50 dB using a near-infrared camera. Measured results of a 32-core fibre are in good agreement with those by the conventional method using a power meter.

Highly Nonlinear Few-Mode Fiber for Optical Parametric Amplification

Elham Nazemosadat and Abel Lorences-Riesgo (Chalmers University of Technology, Sweden); Magnus Karlsson (Chalmers University of Technology & Photonics Laboratory, Sweden); Peter A Andrekson (Chalmers University of Technology, Sweden)

A highly nonlinear dispersion-shifted few-mode fiber is designed. The dispersion properties and high nonlinearity of this fiber allow simultaneous single-pump parametric amplification of four spatial modes (LP01, LP11, LP02, LP21), with high gain and low cross-talk, over the C-band.

W.4.P1.SC2: Waveguide and Optoelectronic Devices

Low Operating-Energy Directly Modulated Membrane Distributed-Reflector Lasers on Si

Takuro Fujii, Koji Takeda, Erina Kanno, Koichi Hasebe, Hidetaka Nishi, Ryo Nakao and Tsuyoshi Yamamoto (NTT Corporation, Japan); Takaaki Kakitsuka (NTT Corporation); Shinji Matsuo (NTT Corporation, Japan)

We achieve a low operating energy and high modulation speed in a directly modulated membrane laser on Si. A relatively thick (350 nm) membrane structure enables us to reduce the series resistance, which reduces the operating energy to 97 fJ/bit.

8-channel InP OFDM Transmitter PIC with Integrated Optical Fourier Transform

Braulio Gomez Saavedra (Fraunhofer-Institut für Nachrichtentechnik, Heinrich-Hertz-Institut, Germany); Ronald Kaiser (Fraunhofer Institut für Nachrichtentechnik, Heinrich-Hertz-Institut, Germany); Johannes Beyer and Marko Rausch (Fraunhofer-Institut für Nachrichtentechnik, Heinrich-Hertz-Institut, Germany); Marko Gruner (Fraunhofer Institut für Nachrichtentechnik, Heinrich-Hertz-Institut, Germany); Walter Fürst (Fraunhofer-Institut für Nachrichtentechnik, Heinrich-Hertz-Institut, Germany); Martin Schell (Fraunhofer Institute for Telecommunications, Heinrich-Hertz-Institut, Germany)

An InP-based 8-channel 1550 nm OFDM transmitter PICs is demonstrated for the first time. The PIC integrates a 1x8 splitter/combiner, eight TWE Mach-Zehnder IQ modulators, an 8-port AWG, 50-Ohms termination resistors, and CPW/CPS transmission line connections/transitions

Integrated 8-Channel Mode and Wavelength Demultiplexer for MDM and WDM Transmission over Few-Mode Fibers

Daniele Melati, Andrea Alippi, Andrea Annoni, Nicola Peserico and Andrea Melloni (Politecnico di Milano, Italy)

We demonstrate a photonic integrated circuit for simultaneous demultiplexing of two fiber modes and four wavelength channels. Combined with integrated MDM multiplexer the circuit is successfully exploited for the transmission of 10Gbit/s channels with cross-talk lower than -15 dB.

PDM-QPSK WDM Signal Amplification Using PPLN-Based Polarization-Independent In-Line Phase-Sensitive Amplifier

Masashi Abe, Takushi Kazama, Takeshi Umeki and Koji Enbutsu (NTT Device Technology Laboratories, Japan); Yutaka Miyamoto (NTT Network Innovation Laboratories, Japan); Hirokazu Takenouchi (NTT Photonics Laboratories, Japan)

We demonstrate the in-line phase-sensitive amplification of PDM-QPSK WDM signals. The amplifier consists of PPLN waveguides and has a net gain of 12 dB. These signals are transmitted over 80 km by recovering the pilot tone.

Broadband Frequency Comb Generation in Aluminum Nitride Microring Resonators

Xianwen Liu, Changzheng Sun, Bing Xiong, Jian Wang, Lai Wang, Yanjun Han, Zhibiao Hao, Hongtao Li and Yi Luo (Tsinghua University, P.R. China); Jianchang Yan, Tongbo Wei, Yun Zhang and Junxi Wang (Institute of Semiconductors, Chinese Academy of Sciences, P.R. China)

Nearly octave frequency comb spanning from 1075 to 2075 nm is generated in epitaxial aluminum nitride microring resonator with intrinsic quality factor as high as ~1.6 million. Blue-shifted dispersive-wave emission is observed, which helps extend the frequency comb coverage.

Broadband 8 × 8 Si-Wire PILOSS Switch with Double Mach-Zehnder Switch Elements

Keijiro Suzuki, Ken Tanizawa, Satoshi Suda, Hiroyuki Matsuura, Kazuhiro Ikeda, Shu Namiki and Hitoshi Kawashima (National Institute of Advanced Industrial Science and Technology, Japan)

We report a broadband 8×8 Si-wire optical switch based on a double Mach-Zehnder element switch. An operating bandwidth of 20 nm for -20 dB crosstalk is obtained, which is 2.7-times broader than that with single Mach-Zehnder element switches.

Route-and-Select Type Wavelength Cross Connect for Core-Shuffling of 7-Core MCFs with Spatial and Planar Optical Circuit

Keita Yamaguchi (NTT Corporation & NTT Device Technology Labs, Japan); Mitsumasa Nakajima, Yuichiro Ikuma, Kazunori Seno and Osamu Moriwaki (NTT Corporation, Japan); Kenya Suzuki (NTT Device Technology Laboratories, NTT Corporation, Japan); Mikitaka Itoh (NTT Photonics Laboratories, Japan); Mitsunori Fukutoku (NTT Innovation Laboratories, Japan); Yutaka Miyamoto (NTT Network Innovation Laboratories, Japan); Toshikazu Hashimoto (, Japan)

We demonstrated a route-and-select type 7×7 core-shuffle wavelength cross connect switch based on a spatial and planar optical circuit. The spatial beam transformer enables us to integrate 14-in-1 WSSs in the same optical system as the conventional 1×N WSS.

Flexible, Multi-channel, Ultra-dense Optical Interface for Silicon Photonics

Victor I. Kopp (Chiral Photonics Inc, USA); Jongchul Park, Mitch Wlodawski, Jonathan Singer and Dan Neugroschl (Chiral Photonics Inc., USA); Peter De Heyn, Brad Snyder and Joris Van Campenhout (IMEC, Belgium); Philippe Absil (Imec, Belgium)

We demonstrate an all-glass, 61-channel, flexible, two-dimensional optical fiber array with 37 inner channels matched to an array of vertical grating couplers of a multi-channel (16 Tx and 16 Rx) transceiver prototype occupying a chip area of only 0.16 mm2

On-chip Optical Sampling using an Integrated SOA-based Nonlinear Optical Loop Mirror

Leimeng Zhuang, Chen Zhu, Bill Corcoran, Zihan Geng, Binhuang Song and Arthur Lowery (Monash University, Australia)

We report the first demonstration of on-chip optical sampling using an integrated SOA-based nonlinear optical loop mirror. The device implements a compact design featuring a size of 2 x 1.2 mm2 and a sampling window of about 30 ps.

Experimental Demonstration of On-Chip Orbital Angular Momentum Carrying Twisted Light Generation Using Dielectric Metasurfaces on Silicon Platform

Hongya Wang (Huazhong University of Science and Technology & Wuhan National Laboratory for Optoelectronics, P.R. China); Jun Liu, Jing Du and Jian Wang (Huazhong University of Science and Technology, P.R. China)

We demonstrate a method of generating twisted lights OAM whose topological number ranges from l = 1 to 4 at the wavelength of 980 nanometer using dielectric metasurfaces array on silicon-on-insulator platform.

Integrated Switchable Mode Exchange for Reconfigurable Mode-Multiplexing Optical Networks

Chunlei Sun, Yu Yu, Guanyu Chen and Xinliang Zhang (Huazhong University of Science and Technology, P.R. China)

We propose and demonstrate an on-chip switchable mode exchange utilizing a mode dependent Mach-Zehnder interferometer assisting by a phase shifter. By controlling the phase difference, the data carried on different modes can be exchanged with power penalty less than 1dB.

Integrated-optic Demultiplexer for Variable Capacity Optical OFDM Signals Composed of Slab Star Coupler-type Optical DFT Circuit and Variable Optical Attenuators

Koichi Takiguchi (Ritsumeikan University, Japan)

I report a novel waveguide-type OFDM filter that can adaptively demultiplex 10 to 50 Gbaud symbol rate sub-carrier channels. It was fabricated with silica waveguide technology and the adoption of variable attenuators reduced loss variation when changing the filter characteristics.

W.4.P1.SC3: Digital and Optical Signal Processing

Experimental Demonstration of All-Optical FEC Coding Scheme with Convolutional Code using Single Signal Source

Yohei Aikawa and Hiroyuki Uenohara (Tokyo Institute of Technology, Japan)

We experimentally demonstrate all-optical FEC coding scheme consisting of all-optical HNLF-based wavelength converters and XOR gates with (7,5)_8 convolutional code. The proposed scheme offers 3.5 dB net coding gain at BER=10^{-9} with DPSK-modulated RZ-format signals at 10 Gbps.

Sidelobe Suppression using Cancellation Sub-Carriers for OFDM Superchannels

Yiwei Xie, Chen Zhu, Binhuang Song and Arthur Lowery (Monash University, Australia)

We mitigate the inter-channel-interference (ICI) in orthogonal frequency division multiplexing (OFDM) superchannel by adding cancellation sub-carriers (CCs). We experimentally show that CC-OFDM outperforms conventional OFDM by 0.4-dB in a dual-polarization 400-Gbps 3360-km OFDM superchannel.

Real-Time Flexible Heterogeneous UDWDM System for Coherent PON

Ricardo Ferreira (Instituto de Telecomunicações, Portugal); Ali Shahpari (University of Aveiro, Portugal); Sofia Amado (University of Aveiro & Instituto de Telecomunicações, Aveiro, Portugal); Jacklyn D. Reis (CPqD, Brazil); Armando Pinto (Instituto de Telecomunicações - Universidade de Aveiro, Portugal); Antonio Teixeira (DETI, University of Aveiro & Insitituto de Telecomunicações, Portugal)

We demonstrate the first reconfigurable real-time receiver DSP in a flexible heterogeneous UDWDM system for coherent PON applying different modulation formats. The evaluation reports the ODN power budget for multiple UDWDM configurations using QPSK, 8PSK and 8QAM signals.

Cluster Analysis of Received Constellations for Optical Performance Monitoring

John van Weerdenburg, Roy van Uden, Eric Sillekens and Huug de Waardt (Eindhoven University of Technology, The Netherlands); Ton Koonen (COBRA, Eindhoven University of Technology, The Netherlands); Chigo Okonkwo (Eindhoven University of Technology, The Netherlands)

Performance monitoring based on centroid clustering to investigate constellation generation offsets. The tool allows flexibility in constellation generation tolerances by forwarding centroids to the demapper. The relation of fibre nonlinearities and singular value decomposition of intra-cluster noise is experimentally demonstrated.

Embedded In-Band DQPSK Signaling within n-QAM Data Transmission

Roman Dischler, Fred Buchali and Laurent Schmalen (Nokia Bell Labs, Germany)

We propose embedded sequences of DQPSK-symbols in a n-QAM data stream for independent signaling on transponder level. Experimentally we demonstrate a simplified processing chain with low additional processing effort obtaining a BER margin of factor 10 vs. data-BER.

Characterization and Pre-Distortion of Linear and Non-Linear Transmitter Impairments for PM-64QAM Applications

Thomas Duthel, Peter Hermann, Johann Schießl, Chris Fludger, Andreas Bisplinghoff and Theodor Kupfer (Cisco Optical GmbH, Germany)

A characterization approach for optical IQ transmitter's skew, frequency response and non-linear properties is presented. Its effectiveness is proven by performance measurements of digitally pre-distorted PM-64QAM at 384Gbit/s. Special attention is given to the optical loss induced by modulation.

A Novel Fixed Throughput Nonlinear Cross-Polarization Compensation: Flexible k-Best GML

Patricia Layec (NOKIA Bell Labs France, France); Nicola Rossi (Nokia Bell Labs, France); Sebastien Bigo (Bell Labs, Alcatel-Lucent, France)

We propose a novel blind nonlinear cross-polarization compensation method based on Generalized Maximum Likelihood. It offers a fixed throughput implementation easing the hardware logic integration thanks to a breadth-first search. Simulations show a 1dB gain in nonlinear tolerance.

A Trellis-Based Phase Correction for Mitigating Nonlinear Effects

Mahdi Zamani (Huawei Technologies Canada Research Centre, Canada); Hossein Najafi and Jeebak Mitra (Huawei Technologies Canada, Canada); Chuandong Li and Zhuhong Zhang (Huawei Technologies (Canada), Canada)

A hardware-efficient trellis-based algorithm is proposed for fiber nonlinearity mitigation in coherent systems, especially for high order modulations. Experimental results, in 200 Gb/s DP-16QAM co-propagated with 10-G channels, demonstrate significant performance improvement over other existing methods of comparable complexity.

Ultra-Wideband Nonlinearity Compensation Performance in the Presence of PMD

Gabriele Liga (University College London, United Kingdom); Cristian B. Czegledi (Chalmers University of Technology, Sweden); Tianhua Xu (Optical Networks Group, University College London, United Kingdom); Erik Agrell (Chalmers University of Technology, Sweden); Robert I Killey and Polina Bayvel (University College London, United Kingdom)

We numerically investigate the performance of multi-channel digital backpropagation for 1 THz optical fibre transmission in the presence of polarisation-mode dispersion. We show that the average SNR performance rapidly saturates as a function of the compensation bandwidth.

Novel IM/DD Single-Sideband OFDM Generation Featuring Tolerance to Dispersion-Related Fading and Distortion

Yi-Hsiang Wang and Chia-Chien Wei (National Sun Yat-Sen University, Taiwan); Hidenori Taga (KDDI R&D Laboratories Inc., Japan); Takehiro Tsuritani (KDDI R&D Laboratories, Inc., Japan)

Based on a cascaded DML/EAM, we proposed a novel IM/DD scheme to generate SSB-OFDM signals, featuring tolerance to dispersion-related fading and distortion. Without compensation for dispersion and nonlinear distortion, 5-GHz SSB-OFDM signal can achieve 12.8 Gbps after 250 km.

Precoded Faster-than-Nyquist Coherent Optical Transmission

Mrinmoy Jana, Ahmed Medra and Lutz Lampe (University of British Columbia, Canada); Jeebak Mitra (Huawei Technologies Canada, Canada)

In this paper we propose a novel symbol-by-symbol memoryless soft demapping method for coded coherent optical systems that employ Faster-than-Nyquist (FTN) transmission for improved spectral efficiency and Tomlinson-Harashima precoding for low-complexity equalization of FTN.

Electro-Optic Frequency Offset Estimator for Optical OFDM

Jokhakar Jignesh, Bill Corcoran and Chen Zhu (Monash University, Australia); Arthur Lowery (Monash Univ, Australia)

We present a new design for an electro-optic carrier frequency offset (CFO) estimator for optical OFDM systems, and experimentally demonstrate CFO estimation using off-the-shelf components, capable of tracking up to ±500 MHz offsets from a 28-Gbaud OFDM signal.

W.4.P1.SC4: Subsystems for Optical Networking and Datacoms

Adaptive RF Signal Stability Distribution Over Remote Optical Fiber Transfer Based on Photonic Phase Shifter

Shanguo Huang, Wensheng ZHai, Xinlu Gao, Mutong Xie, Mingyang Zhao and Wenjing Xu (Beijing University of Posts and Telecommunications, P.R. China); Wanyi Gu (Key Laboratory of Optical Communication and Lightwave Technologies, Ministry of Education, Beijing U, P.R. China)

We demonstrate adaptive RF signal distribution stability over 50 km optical fiber using phase pre-compensation technology. The experimental results implement 360° phase shift over 20 GHz to 30 GHz with Allan deviation approximate 8.35×10-17 at average time of 1000 s.

Techno-Economic Analysis of Carrier Sources in Slice-able Bandwidth Variable Transponders

Muhammad Imran (Scuola Superiore Sant'Anna, Italy); Antonio D'Errico (Ericsson, Italy); Andrew Lord (British Telecom, United Kingdom); Luca Potì (Consorzio Nazionale Interuniversitario per le Telecomunicazioni, Italy)

Different carrier source implementation strategies in sliceable bandwidth variable transponders have been compared in terms of cost and power consumption. A reduction factor up to 4 has been obtained through novel centralized carrier source schemes.

Experimental Validation of Scalability Improvement for Passive Optical Interconnect by Implementing Digital Equalization

Rui Lin (KTH Royal Institute of Technology & Huazhong University of Science and Technology, P.R. China); Xiaodan Pang and Oskars Ozolins (Acreo Swedish ICT, Sweden); Zhenhua Feng (Huazhong University of Science and Technology, P.R. China); Anders Djupsjöbacka (Acreo, Sweden); Urban Westergren and Richard Schatz (Kista Photonic Research Centre (KPRC), Royal Institute of Technology (KTH), Sweden); Gunnar Jacobsen (Acreo AB, Sweden); Ming Tang (Huahzong University of Science and Technology, P.R. China); Songnian Fu and Deming Liu (Huazhong University of Science and Technology, P.R. China); Sergei Popov (Royal Institute of Technology, Sweden); Jiajia Chen (KTH Royal Institute of Technology, Sweden)

We experimentally investigate scalability of a coupler-based passive optical interconnect (POI) employing cost-efficient modulation formats, pulse amplitude modulation and discrete multi-tone. Results reveal that digital equalization significantly boosts the POI scalability, particularly for the cases requiring higher transmission performance.

Drive-amplitude-independent Auto Bias Control Circuit for QAM Signals and Its Demonstration with an InP-based IQ Modulator

Hiroto Kawakami and Shoichiro Kuwahara (NTT Corporation, Japan); Akira Hirano (NTT, Japan)

A novel auto bias control technique for various types of IQ modulators is proposed. The technique can generate any order quadrature amplitude modulation signals with no dependence on drive amplitude. The measured penalty was found to be almost negligible.

Direct Measurement on Frequency Response of Common Mode Rejection Ratio in Coherent Receiver

Keizo Inagaki (National Institute of Information and Communications Technology, Japan); Tetsuya Kawanishi (Waseda University & National Institute of Information and Communications Technology, Japan); Atsushi Kanno and Naokatsu Yamamoto (National Institute of Information and Communications Technology, Japan)

We propose a direct measurement method of CMRR frequency response in coherent receivers. Measured CMRR frequency response is drastically improved over 2 to 40 GHz frequency range by tuning the amplitude and skew balance in a coherent receiver under test.

SDN-enabled Backpropagation Correction for OSNR Estimation and Optimization in Under-Monitored EDFA-based Optical Links

Juliano Assine, Anderson Bravalheri and Heitor Carvalho (CPqD, Brazil); Miquel Garrich (Politecnico di Torino, Brazil); Yue Fei (University of Texas at Dallas, USA); Xue Wang (The University of Texas at Dallas, USA); Andrea Fumagalli (UTD, USA); Jacklyn D. Reis (CPqD, Brazil); Juliano Rodrigues Fernandes de Oliveira (CPqD Foundation & University of Sao Paulo, Brazil)

SDN is a key technology to address the challenges in quasi-static and over-provisioned undermonitored EDFA-based optical links. We propose and experimentally demonstrate a SDN-enabled backpropagation correction technique to efficiently estimate and increase OSNR while minimizing remote network operations.

MxM WSS Based ROADM Architecture with Topology-Insensitive Routing Performance

Masaki Niwa, Yojiro Mori and Hiroshi Hasegawa (Nagoya University, Japan); Ken-Ichi Sato (School of Engineering - Nagoya University, Japan)

We propose MxM WSS based ROADM architecture that employs main/junction subsystem OXCs and OXC-assisted transponder-bank add/drop. Extensive computer simulations verify that the proposed architecture offers high routing performance regardless of the physical network topology cost-effectively.

SEFDM Based Spectrum Compressed VLC System Using RLS Time-domain Channel Estimation and ID-FSD Hybrid Decoder

Yiguang Wang and Yingjun Zhou (Fudan University, P.R. China); Tao Gui (The Hong Kong Polytechnic University); Kangping Zhong and Xian Zhou (The Hong Kong Polytechnic University, P.R. China); Liang Wang, Alan Pak Tao Lau and Chao Lu (The Hong Kong Polytechnic University, Hong Kong); Nan Chi (Fudan University, P.R. China)

For the first time we experimentally demonstrate an 800Mb/s SEFDM based VLC system over 3m free-space transmission for 20% bandwidth saving. RLS time-domain equalizer is proposed for channel estimation, and an ID-FSD hybrid decoder is utilized for ICI elimination.

Real Time 10Gb-Ethernet Transmission over 2D Indoor Passive Beam Steered Optical Wireless System based on High Port Arrayed Waveguide Gratings

Amir Masood Khalid, Maria Torres Vega, Ketamaw Mekonnen, Zizheng Cao and Antonio Liotta (Eindhoven University of Technology, The Netherlands); Ton Koonen (COBRA, Eindhoven University of Technology, The Netherlands)

We demonstrate the real-time 10Gb-Ethernet data delivery to multiple users simultaneously over an indoor optical wireless system based on 2D passive optical beam-steering using high-port count arrayed waveguide gratings. The transmitted optical power is kept below eye safety limit

Multi-Wavelength Multiplexer with Independent Mode Control Based on Multi-Plane Light Conversion

Guillaume Labroille, Nicolas Barré, Pu Jian and Jean-François Morizur (CAILabs SAS, France)

We report dual wavelength spatial multiplexers based on the technique of Multi-Plane Light Conversion, which have the capability of independently multiplexing signals at different wavelengths with high mode selectivity, enabling applications to FM-EDFA and PON over multi-mode fibers.

Capacity Improvement Using Bandwidth-Variable Transceiver in Meshed Optical Networks with Cascaded ROADMs

Xingyu Zhou (University of Electronic Science and Technology of China); Qunbi Zhuge (Ciena Corporation, Canada); Meng Qiu (McGill University, Montreal, Canada); Xiang Meng (Huazhong University of Science and Technology, P.R. China); Fangyuan Zhang (McGill University, Canada); Baojian Wu (University of Electronic Science and Technology of China, P.R. China); David Plant (McGill University, Canada)

We experimentally demonstrate the capacity improvement achieved by bandwidth-variable transceivers (BVT) in fiber links with cascaded ROADMs. Compared with a fixed symbol rate transceiver with standard QAMs, the BVT increases capacity by up to 17%.

Up to 108 Gb/s PAM 850 nm Multi and Single Mode VCSEL Transmission over 100 m of Multi Mode Fiber

Grzegorz Stepniak (Warsaw University of Technology, Poland); Lukasz Chorchos (Warsaw University of Technology & Institute of Telecommunications, Poland); Mikel Agustin (VI Systems GmbH, Germany); Joerg Kropp (VI System, Germany); Nikolai Ledentsov (VI Systems GmbH, Germany); Vitaly Shchukin (VI System, Germany); Nikolai Ledentsov, Jr (VI Systems GmbH, Germany); Jarosław P. Turkiewicz (Warsaw University of Technology & Institute of Telecommunications, Poland)

Studies on ultra-high speed 850 nm VCSEL transmission are presented. Various system configurations regarding fibre length, VCSEL type and uncoded and coded PAM modulation schemes are investigated. Successful record 108 Gb/s PAM-4 transmission over 100 m MMF is shown.

PAM-n Solutions for Low-Cost Implementations of 100 Gbps/Lambda Transmissions

Cristian Prodaniuc, Nebojsa Stojanovic, Fotini Karinou and Qiang Zhang (Huawei Technologies Duesseldorf GmbH, Germany); Thomas Dippon (Keysight Technologies Deutschland GmbH, Germany); Roberto Llorente (Universidad Politecnica de Valencia, Spain)

We experimentally demonstrate 112 Gbps PAM-4 and 126 Gbps PAM-8 BTB transmissions using bandlimited setups with less than 12 GHz 3-dB bandwidth. 4D-PAM-5 TCM is also implemented, showing power sensitivity gains over PAM-4 at rates of up to 88 Gbps.

Low Latency Optical Label Switched Add-Drop Node for Multi-Tb/s Data Center Interconnect Metro Networks

Wang Miao, John van Weerdenburg, Roy van Uden and Huug de Waardt (Eindhoven University of Technology, The Netherlands); Ton Koonen (COBRA, Eindhoven University of Technology, The Netherlands); Chigo Okonkwo (Eindhoven University of Technology, The Netherlands); Nicola Calabretta (COBRA Research Institute, The Netherlands)

We demonstrate an optical label-switched add-drop node with Terabit/s channels and sub-microsecond switching for data center interconnect metro networks. Experiments show excellent scalability with limited performance degradation up to 15 nodes and 2.688 Tb/s capacity.

W.4.P1.SC5: Point-to-Point Transmission Systems

Cascadability Investigation of High Granular Optical Channel Defragmentation Node for Flexible Optical Networks

Satoshi Shimizu (National Institute of Information and Communications Technology, Japan); Gabriella Cincotti (University Roma Tre, Italy); Naoya Wada (NICT, Japan)

Two different node configurations are testes: no-guard-interval (No-GI) and inter-band guard-interval (IB-GI) configuration. The bit-error-rate of No-GI exceeds 10^-3 after 8-hop, whereas 16-hop was achieved in IB-GI configuration with BER~10^-3, owing to the elimination of tight filtering.

Inter-Island Demonstration of an FSO High Speed Laser Ethernet Transceiver for Telerobotic Space-Surface Control

Amita Shrestha, Julio César Ramírez Molina, Dirk Giggenbach and Jorge Pacheco-Labrador (German Aerospace Center, Germany); Christopher Schmidt (German Aerospace Center (DLR), Germany)

This paper presents the experimental results of 100Mbps Laser Ethernet Transceivers for high-speed communications in a 142 Km free-space optical inter-island link. Round-trip times below 1.6 ms and error free transmission at full throughput during several time intervals were demonstrated.

Quantum-limited Measurements of Signals from Geostationary Earth Orbit

Dominique Elser, Kevin Günthner, Imran Khan, Birgit Stiller, Ömer Bayraktar and Christian Müller (Max Planck Institute for the Science of Light, Germany); Karen Saucke, Daniel Troendle, Frank F Heine, Stefan Seel, Peter Greulich and Herwig Zech (Tesat Spacecom, Germany); Bjorn Guetlich, Ines Richter and Rolf Meyer (DLR, Germany); Christoph Marquardt (Max Planck Institute for the Science of Light, Germany); Gerd Leuchs (University Erlangen-Nuremberg, Germany)

Quantum key distribution (QKD) has been implemented in metropolitan area networks around the world. Optical satellite communication is seen as suitable to provide the missing long-haul interconnections. We validate this approach by quantum measurements of optical signals from space.

Single-channel 5.12 Tbit/s (1.28 Tbaud) DQPSK Transmission over 300 km Using Non-coherent Nyquist Pulses

Daiki Suzuki, Koudai Harako, Toshihiko Hirooka and Masataka Nakazawa (Tohoku University, Japan)

We demonstrate a single-channel 5.12-Tbit/s, 300-km transmission using non-coherent Nyquist pulses with polarization-multiplexed DQPSK at 1.28 Tbaud. Despite this ultrahigh baud rate, we achieved a record distance at 5.12 Tbit/s thanks to the high PMD tolerance of the Nyquist pulse.

56 Gb/s 20-km Transmission of PAM-4 Signal Employing an EML in C-band without in-line Chromatic Dispersion Compensation

Fotini Karinou, Nebojsa Stojanovic and Cristian Prodaniuc (Huawei Technologies Duesseldorf GmbH, Germany)

We experimentally demonstrate 56 Gb/s PAM-4 transmission using a 1.55-μm EML over a 20-km SMF maximum reported distance without employing DCFs in the link, for low-cost metro and short-reach WDM applications. Performance is optimized and compared for various DSP schemes

552 Gbit/s, 46 Gbaud, 64 QAM Coherent Transmission over 160 km with Simple LD-based Injection-locked Homodyne Detection

Keisuke Kasai, Masato Yoshida and Masataka Nakazawa (Tohoku University, Japan)

We describe a single-carrier, polarisation-multiplexed 46 Gbaud 64 QAM coherent transmission. Using an LD-based injection-locked local oscillator for homodyne detection, we transmitted 552-Gbit/s data over 160 km with a bit-error rate of 6×10^-4. The potential spectral efficiency reached 9.2 bit/s/Hz.

178 Gb/s Short-Range Optical Transmission Based on OFDM, Electrical Up-Conversion and Signal Combining

Christoph Kottke (Fraunhofer Heinrich Hertz Institute, Germany); Christian Schmidt (Technische Universität Berlin & Fraunhofer Heinrich Hertz Institut, Germany); Kai Habel (Fraunhofer HHI, Germany); Volker Jungnickel (Fraunhofer Heinrich Hertz Institute & Technische Universität Berlin, Germany)

We demonstrate our improved wideband OFDM transmission system, using electrical up-conversion and signal combining. Transmission rates of 178 Gb/s over 2 km of SSMF were achieved with an IM/DD system on a single wavelength and single polarization.

High Resolution Characterization of the Spectral Broadening Due to Inter-Channel Fiber Nonlinearities

Aazar Kashi, John C Cartledge, Ali Rezania and Ali Bakhshali (Queen's University, Canada); Maurice O'Sullivan, Charles Laperle, Andrzej Borowiec and Kim Roberts (Ciena Corporation, Canada)

The spectral broadening due to inter-channel fiber nonlinearities is quantified in terms of the spectral edge power for 256 Gb/s dual-polarization 16-QAM signals in a 9-channel system with 37.5 GHz channel spacing.

Evaluation of High-Speed EML-based IM/DD links with PAM Modulations and Low-Complexity Equalization

Xiaodan Pang and Oskars Ozolins (Acreo Swedish ICT, Sweden); Simone Gaiarin (Technical University of Denmark, Denmark); Miguel Olmedo (Royal Institute of Technology, Sweden); Richard Schatz and Urban Westergren (Kista Photonic Research Centre (KPRC), Royal Institute of Technology (KTH), Sweden); Darko Zibar (DTU Fotonik, depertment of Photonic Engineering, Technical University of

Denmark, Denmark); Sergei Popov (Royal Institute of Technology, Sweden); Gunnar Jacobsen (Acreo AB, Sweden)

We experimentally evaluated up to 96 Gb/s/λ PAM IM/DD transmissions with an EML and digital equalizations. Symbol-spaced FFE/DFEs with fewer than 10 taps are shown being sufficient for a high and stable performance over a 4 km SMF link.

Experimental Demonstration of Physical-Layer Security in a Fiber-Optic Link by Information Scrambling

Junho Cho (Nokia Bell labs, USA); Kyle C Guan (Bell Labs, Nokia, USA); Sethumadhavan Chandrasekhar (Nokia Bell Labs, USA); Peter Winzer (Lucent Technologies, USA)

We experimentally demonstrate a physical-layer secure optical fiber communication link that prohibits an eavesdropper from detecting any useful information. Our classical approach is based on a simple linear feedback shift register, thus scaling to multi-Terabits/s of secure bit rates.

Achievable Information Rates Estimation for 100-nm Raman-Amplified Optical Transmission System

Nikita A. Shevchenko (University College London, United Kingdom); Tianhua Xu (Optical Networks Group, University College London, United Kingdom); Daniel Semrau, Gabriel Saavedra, Gabriele Liga, Milen Paskov, Lídia Galdino, Alex Alvarado, Robert I Killey and Polina Bayvel (University College London, United Kingdom)

The achievable information rates of optical communication system using ultra-wide bandwidth 100-nm distributed Raman amplification have been investigated for each individual sub-channels, based on the first-order perturbative analysis of nonlinear distortions.

Seed Lightwave Distribution over 1600 km for 64QAM-based Coherent WDM Optical Networks with Low DSP-complexity

Jun Sakaguchi (National Institute of Information and Communications Technology, Japan); Yoshinari Awaji (National Institute of Information and Communications Technology (NICT), Japan); Naoya Wada (NICT, Japan)

Seed lightwave distribution eliminates degradation of coherent signals by phase noise and frequency offset. Seed lightwave was distributed over 1600 km, which amounts to factor five or ten improvement from previous results, while maintaining sufficient quality for DP-64QAM transmission.

Effect of Statistical Variations in the Response of Cascaded ROADMs on 100 Gb/s DP QPSK System Performance

John C Cartledge and Clay Doggart (Queen's University, Canada); Maurice O'Sullivan, Charles Laperle, Andrzej Borowiec and Kim Roberts (Ciena Corporation, Canada)

Using a real-time transceiver, the performance implications of passband impairments and bandwidth narrowing resulting from the cascading of ROADMs are assessed using a programmable optical filter and variable bandwidth optical filter to emulate the overall response.

Real-time 70 Gbit/s, 128 QAM Quantum Noise Stream Cipher Transmission over 100 km with Secret Keys Delivered by Continuous Variable Quantum Key Distribution System

Masataka Nakazawa, Masato Yoshida, Toshihiko Hirooka and Keisuke Kasai (Tohoku University, Japan); Takuya Hirano (Gakushuin University, Japan)

We demonstrate a real-time quantum noise stream cipher transmission with a continuous variable quantum key distribution system to greatly increase encryption security. 70 Gbit/s, 128 QAM encrypted data have been successfully transmitted over 100 km.

Experimental Investigation of the Impact of Distributed Link PDL on a Coherent Transmission System

Hou-Man Chin (Orange Polska & University College London, Poland); Douglas W Charlton (Ciena Corperation, Canada); Andrzej Borowiec, Charles Laperle, Michael Reimer and Maurice O'Sullivan (Ciena Corporation, Canada); Seb J Savory (University of Cambridge, United Kingdom)

We experimentally investigate the impact of distributed PDL in a 35 Gbaud PM-QPSK optical coherent transmission system implemented by commercially available transceivers over 800 km dispersion uncompensated SMF. 60,000 random instances of distributed link PDL were realized for performance measurements.

W.4.P1.SC6: Core, Metro and Data Center Networks

Filterless Networks Based on Optical White Boxes and SDM

Ajmal Muhammad (Royal Institute of Technology (KTH), Stockholm & Linköping University, Sweden); Marija Furdek (KTH Royal Institute of Technology, Sweden); Georgios Zervas (University of Bristol, United Kingdom); Lena Wosinska (KTH Royal Institute of Technology, Sweden)

We propose an agile and programmable multicore fiber (MCF)-based filterless network that exploits the flexibility offered by spatial domain multiplexing and programmable optical switches to eliminate the waste of spectrum due to unfiltered transmission.

Experimental Assessment of Seamless Interconnection of OPS and EPS Networks with IP Addressing and Routing Control

Sugang Xu and Kenji Fujikawa (National Institute of Information and Communications Technology, Japan); Hideaki Furukawa (NICT, Japan); Hiroaki Harai (National Institute of Information and Communications Technology, Japan); Yoshinari Awaji (National Institute of Information and Communications Technology (NICT), Japan); Naoya Wada (NICT, Japan)

We demonstrate the OPS network which is empowered with the fully distributed and automated control capabilities of IP addressing and routing. Seamless interconnection of OPS and EPS networks is achieved with the IP-layer protocols HANA/HQLIP as the unified C-Plane mechanism.

Optical Networking Utilizing Virtual Direct Links

Yusaku Ito, Yojiro Mori and Hiroshi Hasegawa (Nagoya University, Japan); Ken-Ichi Sato (School of Engineering - Nagoya University, Japan)

We propose efficient optical networking technology employing virtual direct links that offer coarse/fine hybrid granular routing. We compare the effectiveness of the proposal to different networking technologies that employ coarse granular routing.

Passive Optical Metro Network based on NG-PON2 with Sharing Burst-mode Receiver between Continuous-mode and Burst-mode Transmitters to Support Cloud Edges

Kyota Hattori and Masahiro Nakagawa (NTT Corporation, Japan); Toshiya Matsuda (NTT, Japan); Masaru Katayama (NTT Network Service Systems Labs, Japan); Katsutoshi Koda (NTT, Japan)

We propose a future metro network architecture based on NG-PON2 to achieve high-reliability and cost-effectiveness for the VM migration of cloud edges. Experimental results showed the feasibility of reducing the number of receivers and unavailability could be reduced by half.

Spectrum sharing for elastic transmission parameter adaptation

Nicola Sambo (Scuola Superiore Sant'Anna, Italy); Kostas Christodoulopoulos (University of Patras, Greece); Piero Castoldi (Scuola Superiore Sant'Anna, Italy); Emmanouel Varvarigos (University of Patras & Computer Technology Institute, Greece)

We propose spectrum sharing between different service classes: part of spectrum used by low-priority traffic can be reconfigured and used by high-priority traffic, enabling adaptation to more robust transmission. Even 70% of high-priority traffic is recovered from soft-failures without rerouting.

Methods of Designing Green Optical Networks with Parallel Integration of Optical Components

Onur Turkcu, Abishek Gopalan, Biao Lu, Abhijit Chitambar, Pravin Mahajan and Parthiban Kandappan (Infinera, USA)

We study the effects of network designs using Discrete and Integrated models into network energy consumption. We evaluate both models on three different network architectures with optical and/or digital switching capabilities. We demonstrate the power efficiency of the Hybrid architecture.

Techno-Economic Evaluation of Optical Transport Network in Metropolitan Deployments

Tamara Jiménez (University of Valladolid, Spain); Victor Lopez (Telefonica, Spain); Felipe Jiménez (Telefónica I+D, Spain); Oscar González de Dios (Telefonica I+D, Spain); Juan P. Fernández-Palacios (Telefónica I+D, Spain)

Optical Transport Network (OTN) technology provides multiple benefits to the network operator in backbone networks. This paper presents a techno-economic comparison of optical solutions for metropolitan scenarios to assess when OTN must be deployed.

W.4.P1.SC7: Access, Local Area and Home Networks

10-Gbaud OOK / PAM4 Digital Mobile Fronthaul based on One-Bit / Two-bit Delta-Sigma Modulation Supporting Carrier Aggregation of 32 LTE-A Signals with up to 256 and 1024QAM

Jing Wang (Georgia Institute of Technology, USA); Zhenhua Yu (Texas Instruments, USA); Kai Ying, Junwen Zhang, Feng Lu, Mu Xu, Lin Cheng and Xiaoli Ma (Georgia Institute of Technology, USA); Gee-Kung Chang (Georgia Tech, USA)

10-Gbaud OOK/PAM4 digital mobile fronthaul was experimentally demonstrated by using one-bit/two-bit delta-sigma modulation supporting 32 LTE-A carrier aggregation for 3GPP release 13 with up to 256 and 1024QAM. Compared with CPRI, the mobile fronthaul capacity is increased by 4 times.

Analysis of Performance Degradations Induced by Multipath Interferences in RoF-based Mobile Fronthaul Network Implemented by Using Directly Modulated Lasers

Byung Gon Kim (KAIST (Korea Advanced Institute of Science and Technology), Korea); Hoon Kim (KAIST, Korea); Kazuki Tanaka (KDDI R&D Laboratories Inc., Japan); Takashi Kobayashi (KDDI R&D Laboratories, Japan); Kosuke Nishimura (KDDI R&D Laboratories Inc. & Optical Access Network Laboratory, Japan); Masatoshi Suzuki (KDDI R&D Laboratories, Japan); Yun C. Chung (KAIST, Korea)

We investigate the effects of multipath interferences on the performance of a radio-over-fiber-based mobile fronthaul network using directly modulated lasers. Our theoretical model obtained without using the quasi-static approximation agrees well with the measured data

Experimental Demonstration of 25/30/40-Gb/s Flexible-PON Downstream Transmission by Using Pre-Compensated DMT with Adaptive Modulation/Bandwidth and 10G EML/APD

Minghui Tao (Advanced Access Network Research Center, Huawei Technologies, Wuhan, P.R. China); Huaiyu Zeng (Futurewei Technologies, USA); Lei Zhou (Huawei Technologies & Advanced Access Network Research D, P.R. China); Shuchang Yao (Huawei Technologies, P.R. China); Shengping Li (Huawei Technologies Co., Ltd., P.R. China); Xiang Liu (Futurewei Technologies, USA)

We demonstrate the downstream transmission of a flexible-PON at 25/30/40-Gb/s data rates by using low-cost 10G EML/APD and pre-compensated variable-bandwidth DMT with 8/16-QAM subcarrier formats, respectively achieving -24/-22/-15.5dBm receiver sensitivities at BER=10-3 after 20-km SSMF transmission in the C-band.

Demonstration of NG-PON2 Coexisting with Other Systems on Same ODN by Using WDM filter with Low Power Penalty of under 1.0 dB

Yuki Sakaue (NTT Corporation, Japan); Katsuhisa Taguchi (NTT, Japan); Kazutaka Hara (NTT Access Network Service Systems Laboratories, Japan); Toshiaki Shitaba and Tomohiro Taniguchi (NTT Corporation, Japan); Susumu Nishihara and Kota Asaka (NTT Access Network Service Systems Laboratories, Japan); Ken-Ichi Suzuki (NTT, Japan); Akihiro Otaka (NTT Corporation, Japan)

We demonstrate the coexistence of TWDM-PON, GE/10G-EPONs, and video service system on the same ODN by using a WDM-filter based coexistence element. Thanks to a sufficient isolation at the filter, a power penalty of <1.0dB in all PONs is achieved.

190-Gb/s CPRI-Equivalent Rate Fiber-Wireless Mobile Fronthaul for Simultaneous Transmission of LTE-A and F-OFDM Signals

Tien Dat Pham, Atsushi Kanno and Naokatsu Yamamoto (National Institute of Information and Communications Technology, Japan); Tetsuya Kawanishi (Waseda University & National Institute of Information and Communications Technology, Japan)

We propose an efficient, flexible fiber-wireless mobile fronthaul for simultaneous transmission of different RATs. We successfully transmit 2×20-MHz LTE-A and 4×800-MHz F-OFDM signals with a CPRI-equivalent data rate of 190 Gb/s over a converged 20-km fiber and 1-m 90 GHz.

Experimental Optimization of DSP-Aggregated Front-hauling Transmission for up to 4x96 LTE radio waveforms

Stefano Straullu and Silvio Abrate (Istituto Superiore Mario Boella, Italy); Roberto Gaudino and Mengesha Befekadu (Politecnico di Torino, Italy)

In this paper we demonstrate the transmission of up to 384 LTE channels with the DSP-based channel aggregation, for fronthauling applications, over a conventional PON infrastructure. An analysis on the impact of the optical link on the EVM is shown.

10 Gbit/s Phase Time Diversity Directly Modulated DFB with Single-PD Intradyne Receiver for Coherent WDM-PON

Ivan Cano (UPC, Spain); Juan Camilo Velásquez Micolta (Universitat Politècnica de Catalunya, Spain); Victor Polo and Josep Prat (UPC, Spain)

A 10 Gbit/s directly modulated DFB laser with phase diversity in time is experimentally tested with polarization independent intradyne detection. Rx sensitivity of -34 dBm at BER=10e-3 is achieved in a 40 GHz channel spaced WDM-PON.

Transmission Experiment of LTE Signals by IF-over-Fiber Using Commercial Base Station and Deployed Optical Fibers

Byung Gon Kim (KAIST (Korea Advanced Institute of Science and Technology), Korea); Kazuki Tanaka (KDDI R&D Laboratories Inc., Japan); Takashi Kobayashi (KDDI R&D Laboratories, Japan); Abdelmoula Bekkali (KDDI R&D Laboratories Inc., Japan); Kosuke Nishimura (KDDI R&D Laboratories Inc. & Optical Access Network Laboratory, Japan); Hoon Kim (KAIST, Korea); Masatoshi Suzuki (KDDI R&D Laboratories, Japan); Yun Chur Chung (KAIST, Korea)

We experimentally verify the practicality of the IF-over-Fiber (IFoF) transmission scheme by using commercial base stations and deployed optical fibers. No significant degradation is observed under this realistic condition similar to commercial LTE systems.

A Techno-Economic Outlook to Optical-Interface Requirements for Midhauling of 5G Small Cells

Francesco Musumeci (Politecnico di Milano, Italy); Massimo Tornatore (Politecnico di Milano & University of California, Davis, Italy); Achille Pattavina (Politecnico di Milano, Italy)

We estimate the amount of optical interfaces to support fronthaul of Small Cells under aggressive 5G traffic forecasts, considering different functional splits (midhaul) and cell configurations. Cost of interfaces can be minimized by properly selecting functional split and radio configuration.

Flexible 2/4-PAM-Modulation 25-Gb/s PON for Next Generation Access Network

Jianhe Gao and Huafeng Lin (Huawei Technologies, P.R. China); Xiang Liu (Futurewei Technologies, USA); Xuming Wu (Huawei Technologies, P.R. China); Lei Zhou (Huawei Technologies & Advanced Access Network Research D, P.R. China); Shuchang Yao (Huawei Technologies, P.R. China)

A novel low-cost 2/4-PAM dual-mode 25-Gb/s PON is proposed based on commercial 10-Gb/s TOSA/ROSA. By introducing the rate-detector, dual-modes with different DSP algorithms could adaptively work. This scheme could meet the requirements of different ODNs.

Improving the CoMP Performance through Wavelength Reconfiguration in Cloud Radio and Optical Access Networks

Jiawei Zhang (Beijing University of Posts & Telecommnication, P.R. China); Ji Yuefeng, Songhao Jia, Hui Li, Xiaosong Yu, Yongli Zhao and Jie Zhang (Beijing University of Posts and Telecommunications, P.R. China)

A minimum-cut graph based wavelength reconfiguration scheme (MCG-WR) is proposed to improve coordinated multipoint (CoMP) performance in a TWDM-PON based cloud radio access network. Simulation results show that MCG-WR can effectively reduce the inter-BBU CoMP traffic through dynamic wavelength reconfiguration

Th.1.A: Nonlinear Mitigation

Chair: Rob Smets (SURFnet, The Netherlands)

Mitigation of Nonlinear Propagation Impairments by Digital Signal Processing

Takeshi Hoshida (Fujitsu Laboratories Limited, Japan)

Various digital signal processing algorithms have been studied in order to offset the nonlinear Shannon limit dominated by the optical Kerr effect. This tutorial attempts to overview the operation principles, implementation challenges and achievement, and future outlook on those techniques.

Experimental Demonstration of Modulation-Dependent Nonlinear Interference in Optical Fibre Communication

Lídia Galdino, Gabriele Liga and Gabriel Saavedra (University College London, United Kingdom); David Ives (University of Cambridge, United Kingdom); Robert Maher and Alex Alvarado (University College London, United Kingdom); Seb J Savory (University of Cambridge, United Kingdom); Robert I Killey and Polina Bayvel (University College London, United Kingdom)

For the first time the modulation format dependence of nonlinear interference in long-haul optical fibre transmission is experimentally demonstrated for polarisation-division multiplexed 4, 16, 64 and 256-QAM.

Dispersion Map Optimization for Nonlinearity Mitigation in Two-Span Phase-Sensitive Amplifier Links

Egon Astra (Tallinn University of Technology, Estonia); Samuel L. I. Olsson and Henrik Eliasson (Chalmers University of Technology, Sweden); Taavi Laadung (Tallinn University of Technology, Estonia); Peter A Andrekson (Chalmers University of Technology, Sweden)

The first investigation of dispersion map optimization in two-span PSA-amplified links is presented. We show numerically and experimentally, that the nonlinearity mitigation improves by 1.4dB if different dispersion maps are applied in each span, compared to single-span optimized maps.

Th.1.B: Multiplexing and Switching Devices

Chair: Takuo Tanemura (University of Tokyo, Japan)

Wavelength Selective Switch for Commercial Multimode Fiber Supporting 576 Spatial Channel

Haoshuo Chen (Nokia Bell Labs, USA); Nicolas K Fontaine (Bell Labs/Alcatel-Lucent, USA); Roland Ryf (Bell Labs, Nokia, USA); Bin Huang and Amado Velázquez-Benítez (Nokia Bell Labs, USA); Cang Jin (Université Laval & COPL, Canada); Burcu Ercan (UC Davis, USA); David Neilson (Bell Labs, USA)

We demonstrate a 1 x 16 wavelength selective switch with commercial multimode fibers (OM3) supporting 36 spatial modes. It provides a switch throughput of 576 spatial channels with a mode-dependent loss below 5.5 dB.

Waveguide-Frontend with Integrated Polarization Diversity Optics for Wavelength Selective Switch Array

Hiroshi Kudo, Yuichiro Ikuma, Kota Shikama, Yohei Sakamaki and Mitsumasa Nakajima (NTT Corporation, Japan); Keita Yamaguchi (NTT Corporation & NTT Device Technology Labs, Japan); Kazunori Seno (NTT Corporation, Japan); Kenya Suzuki (NTT Device Technology Laboratories, NTT Corporation, Japan); Mikitaka Itoh (NTT Photonics Laboratories, Japan); Toshikazu Hashimoto (NTT Corporation, Japan)

We propose a waveguide-frontend with integrated polarization diversity optics for a wavelength selective switch (WSS) with a spatial and planar optical circuit. We demonstrate a 2-in-1 1×20 WSS and confirmed operation with a polarization dependent loss of <0.43 dB.

Compact Silicon Photonic Interleaver Using an Interfering Loop Containing a Fabry-Perot Cavity Formed by Sagnac Loop Mirrors

Xinhong Jiang, Yuxing Yang, Boyu Liu, Yong Zhang and Ciyuan Qiu (Shanghai Jiao Tong University, P.R. China); Yikai Su (Shanghai jiao tong university, P.R. China)

A compact (106.4 × 55.1 μm2) silicon photonic interleaver is proposed and experimentally demonstrated. The 3-dB and 20-dB bandwidths of the passband are ~1.09 nm and ~1.585 nm, respectively. The central wavelength can be changed by tuning only one waveguide.

Ultra-compact and Highly Efficient Polarization Splitter and Rotator Based on a Silicon Bent Directional Coupler

Yong Zhang, Yu He, Xinhong Jiang, Boyu Liu and Ciyuan Qiu (Shanghai Jiao Tong University, P.R. China); Yikai Su (Shanghai jiao tong university, P.R. China)

An ultra-compact (coupling length ~ 8.77 micrometer) silicon polarization splitter and rotator is demonstrated based on a bent directional-coupler. The peak TM-TE coupling efficiency reaches 96.6%. The crosstalk values are < -10 dB over a wavelength range of 40 nm.

Ultrafast laser inscription of 3D waveguides for SDM applications

Robert R. Thomson (Heriot Watt University, United Kingdom)

I will present the work that has been conducted on the application of ultrafast laser inscription to the fabrication of three-dimensional components, such as 3D fan-outs and photonic lanterns, for future applications in space division multiplexing (SDM).

Th.1.C: Pulse Amplitude Modulation II

Chair: Xin Yin (Ghent University - IMEC, Belgium)

Experimental Demonstration of 56 Gbit/s PAM-4 over 15 km and 84 Gbit/s PAM-4 over 1 km SSMF at 1525 nm using a 25G VCSEL

Nicklas Eiselt (Technical University of Denmark, Denmark); Helmut Griesser (ADVA Optical Networking SE, Germany); Jinlong Wei (ADVA Optical Networking SE); Annika Dochhan (ADVA Optical Networking SE, Germany); Robert Hohenleitner (Vertilas GmbH, Germany); Markus Ortsiefer (VERTILAS GmbH, c/o GATE Garching, Germany); Michael Eiselt (ADVA, Germany); Christian Neumeyr (VERTILAS, GmbH, Germany); Juan Jose Vegas Olmos (Technical University of Denmark, Denmark); Idelfonso Tafur Monroy (Technical University of Denmark, Denmark & ITMO University, Russia)

Record 28-GBd PAM-4 transmission over 15 km SSMF and 42-GBd PAM-4 over 1 km SSMF using a low-power 25G VCSEL are demonstrated at 1525 nm without optical dispersion compensation and only simple transceiver DSPs.

Single Lane 150-Gb/s, 100-Gb/s and 70-Gb/s 4-PAM Transmission over 100-m, 300-m and 500-m MMF Using 25-G Class 850nm VCSEL

Tianjian Zuo, Liang Zhang and Jie Zhou (Huawei, P.R. China); Qiang Zhang (Huawei Technologies Duesseldorf GmbH, Germany); Enbo Zhou (Huawei Technologies Ltd., P.R. China); Gordon Ning Liu (Huawei Technologies Co. Ltd., P.R. China)

We experimentally demonstrated a record transmission with bit-rates of 150-Gb/s, 100-Gb/s and 70-Gb/s over 100-m, 300-m and 500-m MMFs. More than 2-dB performance gain has been observed employing a 13-level duobinary 4-PAM format for bandwidth limited system.

High-Speed VCSELs for Datacom

Anders Larsson and Johan Gustavsson (Chalmers University of Technology, Sweden); Petter Westbergh (Finisar, USA); Erik Haglund, Emanuel Haglund and Ewa Simpanen (Chalmers University of Technology, Sweden)

VCSEL-MMF is the dominating technology for short-reach optical interconnects in datacenters and high performance computing systems at current serial rates of up to 25-28 Gb/s. This is likely to continue at 50-56 Gb/s. The technology shows potential for 100 Gb/s.

56 Gb/s PAM-4 Driver IC for Long-Wavelength VCSEL Transmitters

Wouter Soenen (Ghent University & iMinds-imec, Belgium); Renato Vaernewyck (Ghent University, Belgium); Xin Yin (Ghent University - IMEC, Belgium); Silvia Spiga (Walter Schottky Institut, Technische Universität München, Germany); Markus-Christian Amann (Technische Universität München, Germany); Geert Van Steenberge (Ghent University - IMEC, Belgium); Elad Mentovich (Mellanox Technologies, Israel); Paraskevas Bakopoulos (National Technical University of Athens, Greece); Johan Bauwelinck (Ghent University - iMinds, Belgium)

We present the first 56 Gb/s PAM-4 driver IC, developed in 130 nm SiGe BiCMOS, for long-wavelength VCSEL transmitters. Efficiency of the integrated 4-tap FFE driving a state-of-the-art 1.5 um VCSEL is verified, showing back-to-back BER below 1E-6.

100 Gbps PAM-4 Transmission over 100m OM4 and Wideband Fiber using 850nm VCSELs

Justin Lavrencik, Siddharth J Varughese and Varghese A. Thomas (Georgia Institute of Technology, USA); Gary Landry (Finisar Corp, USA); Yi Sun, Roman Shubochkin and Kasyapa Balemarthy, Balemarthy (OFS, USA); Jim Tatum (Finisar Corp, USA); Stephen Ralph (Georgia Institute of Technology, USA)

We experimentally demonstrate 100 Gbps PAM-4 transmission over 105m of OM4 and wideband MMF fibers. The 107Gbps line rates allow 100Gbps user rates with FEC. The link included unpackaged 850nm VCSELs designed for 25G operation and offline equalization and decoding.

Th.1.D: Auxiliary Managementand Control Channel Technologies for Mobile Fronthaul

Chair: Kota Asaka (NTT Access Network Service Systems Laboratories, Japan)

Experimental Investigation of an Optically-superimposed AMCC in 100 Gb/s Coherent WDM-PON for 5G Mobile Fronthaul

Satoshi Yoshima (Mitsubishi Electric Corporation, Japan); Takaaki Katsumata (Mitsubishi Electric Corporation); Hiroshi Miura, Yuita Noguchi, Akiko Nagasawa, Naoki Suzuki and Masaki Noda (Mitsubishi Electric Corporation, Japan)

We experimentally demonstrated a 100 Gb/s coherent WDM-PON for 5G mobile fronthaul controlled by an AMCC superimposed on the DP-QPSK signal. The required receiver sensitivity of -26dBm was achieved when the modulation index was set to between 5% and 40%.

Experimental Investigation of AMCC Superimposition Impact on CPRI Signal Transmission in DWDM-PON Network

Goji Nakagawa (Fujitsu Limited, Japan); Kyosuke Sone (Fujitsu Limited); Shoichiro Oda (Fujitsu Laboratories Ltd., Japan); Setsuo Yoshida (Fujitsu Laboratories Ltd.); Yasuhiko Aoki and Motoyuki Takizawa (Fujitsu Limited, Japan); Jens C. Rasmussen (Fujitsu Laboratories Limited, Japan)

We have investigated and clarified the impact of AMCC superimposition on CPRI signal transmission, and confirmed that the impact of message channel was negligibly small for CPRI option 8 client signal. We demonstrated AMCC signal detection with DWDM-PON network.

Low-frequency Pilot Tone Management for WDM-PON toward Future Mobile Fronthaul employing 64B/66B Line Coding

Kazuaki Honda (NTT Corporation, Japan); Takayuki Kobayashi (NTT, Japan); Susumu Nishihara (NTT Access Network Service Systems Laboratories, Japan); Tatsuya Shimada (NTT, Japan); Jun Terada and Akihiro Otaka (NTT Corporation, Japan)

Low frequency embedded pilot tone can provide protocol-free management channels for WDM-PON-based mobile fronthaul systems. Experiments show modulation index control enables 128 kb/s pilot tones to be inserted into 64B/66B-line-coded CPRI option 8 signals, which have a low frequency component.

Experimental Real Time AMCC Implementation for Fronthaul in PtP WDM-PON

Zakaria Tayq, Luiz Anet Neto and Philippe Chanclou (Orange Labs, France); Christelle Aupetit-Berthelemot (XLIM - University of Limoges, France)

A real-time pilot tone implementation allowing fronthaul monitoring and wavelength tunability in WDM-PON systems is experimentally demonstrated. The obtained results show transmission of a 128 kb/s control signal with minor impact on CPRI.

Experimental Demonstration of Accommodation of TDD-based Mobile Fronthaul and Secondary Services in a TDM-PON

Daisuke Hisano and Takayuki Kobayashi (NTT, Japan); Hiroshi Ou (NTT Corporation, Japan); Tatsuya Shimada (NTT, Japan); Jun Terada and Akihiro Otaka (NTT Corporation, Japan)

We experimentally demonstrate a novel bandwidth allocation scheme using a TDD frame monitor. We confirm that the average throughput of the secondary system is increased over ninefold and a mobile fronthaul is transmitted with a less than 50 μs latency.

Dynamic Resource Sharing for C-RANs with Joint Orchestration of Radio and Transport

Muhammad Rehan Raza and Matteo Fiorani (KTH Royal Institute of Technology, Sweden); Ahmad Rostami (Ericsson Research, Sweden); Björn Skubic and Peter Öhlen (Ericsson AB, Sweden); Lena Wosinska and Paolo Monti (KTH Royal Institute of Technology, Sweden)

We present a resource allocation strategy for centralized radio access network architectures able to adapt to the wireless network capacity requirements. Both simulation and emulation results show that it is possible to reuse up to 33.3% of the transport resources.

Th.1.E: Elastic Optical Networks II

Chair: Dimitra Simeonidou (University of Bristol, United Kingdom)

Can Metro Networks Be the Next Playground for (True) Elastic Networks

Patricia Layec (NOKIA Bell Labs France, France); Arnaud Dupas (Nokia Bell-Labs, France); Dominique G. Verchere (Nokia Bell Labs & France, France); Sebastien Bigo (Bell Labs, Alcatel-Lucent, France)

We review elastic optical networks experiments and associated use cases. Metro networks are particularly well-suited to the introduction of some level of dynamics in the optical networks, leveraging elastic building blocks such as transponders and optical nodes

Demonstration of Bandwidth Maximization between Flexi/Fixed Grid Optical Networks with Real-Time BVTs

Shuangyi Yan and Emilio Hugues-Salas (University of Bristol, United Kingdom); Ali Hammad (Bristol University, United Kingdom); Yan Yan, George M. Saridis, Sarvesh Sanjay Bidkar, Reza Nejabati and Dimitra Simeonidou (University of Bristol, United Kingdom); Arnaud Dupas (Nokia Bell-Labs, France); Patricia Layec (NOKIA Bell Labs France, France)

Real-Time SDN-based BVT enables baud-rate tunability to combat the filtering effect of the legacy filters for interoperability between fixed-grid/flexigrid. Based on the passed filters and link-distance, SDN controller configures BVTs to maximize the link capacity.

Spectral-Efficiency Maximization with Subcarrier-Multiplexed Hybrid-QAM Signals Adaptive to Distance and Hop Count

Yuma Isono, Masaki Niwa, Yojiro Mori and Hiroshi Hasegawa (Nagoya University, Japan); Ken-Ichi Sato (School of Engineering - Nagoya University, Japan)

We propose a novel spectral efficiency maximization method adaptive to distance and hop count for subcarrier-multiplexed hybrid-QAM signals. Simulation results show that the proposed scheme substantially improves spectral efficiency in all the networks topologies tested.

Energy Efficiency of General-Purpose Systems Employing Virtualization Concepts in Operator Networks

Christoph Lange and Dirk Kosiankowski (Deutsche Telekom AG, Germany); Michael Schlosser (Berlin Institute for Software Defined Networks, Germany); Andreas Gladisch (Deutsche Telekom AG & Innovation Labs, Germany)

The energy efficiency of purpose-built and virtualization-aided general-purpose telecom equipment is compared based on power measurements, traffic observations and network modelling. The results show improved energy efficiency of software realizations based on general-purpose systems originating from finer-granular capacity provisioning.

Software Defined Contention in Wavelength Cross-Connects

Thierry Zami (Nokia, France); Colin Kelly (Nokia, Canada)

We assess the paradoxical benefit of lightly degrading by software restriction the blocking ratio of an initially contentionless add/drop stage in a wavelength routing cross-connect, to maximize its capacity and keep as much as possible efficient transponders and internal amplification

Th.2.P2.SC1: Fibres, Fibre Devices and Fibre Amplifiers

Demonstration of an Ultra-Flat Raman-Enhanced Fibre Optical Parametric Amplifier (FOPA) with >110nm Gain-Bandwidth

Vladimir Gordienko and Marc Stephens (Aston University, United Kingdom); Shigehiro Takasaka (Furukawa Electric co., Ltd., Japan); Atalla El-Taher, Ian Phillips and Wladek Forysiak (Aston University, United Kingdom); Ryuichi Sugizaki (Furukawa Electric co., Ltd., Japan); Nick Doran (Aston University, United Kingdom)

We demonstrate a Raman-enhanced FOPA achieving record unfiltered gain variation of only ±0.5dB over 111nm bandwidth and 9.6dB gain. We amplify a 60Gb/s QPSK signal error-free across the L-band with maximum Q2 penalty of 0.9±0.3dB.

Millimeter-Resolution Long Range Optical Frequency Domain Reflectometry for Health Monitoring of Access Network

Bin Wang, Xinyu Fan, Guangyao Yang, Qingwen Liu and Zuyuan He (Shanghai Jiao Tong University, P.R. China)

We greatly improve the performance of optical frequency domain reflectometry by using high-order sideband modulation and injection-locking technique. A spatial resolution of 4.2 mm over 10 km measurement range is obtained, and polarization beat length of 10.5 cm is measured.

High-speed Dynamic Strain Measurement Based on Frequency-swept Pulsed BOTDA

Chihiro Kito, Hiroshi Takahashi and Kunihiro Toge (NTT Corporation, Japan); Tetsuya Manabe (NTT Corp., Japan)

We propose a high-speed, dynamic strain measurement based on real-time Brillouin time-domain analysis of correlated gain measured with an oscilloscope. We achieved the highest recorded speed of 97 kilo-points/s over 1 km fibre, which is close to the repetition limit.

Experimental Evaluation of RF crosstalk in Multicore Fibers for Radio over fiber Applications

Jose Manuel Galve Higon, Jose Capmany and Ivana Gasulla (Universidad Politecnica de Valencia, Spain); Tiago Alves (Instituto de Telecomunicações, Portugal); Adolfo Cartaxo (IST-TUL, Portugal); Salvador Sales (Universidad Politecnica de Valencia, Spain)

We present a simple theoretical formalism and experimental characterization of RF-crosstalk due to inter-core coupling in homogeneous Multicore Fibers. Measurements confirm the behaviour predicted by the model. The results are relevant for the design of radio over fiber systems.

Dependence of Kerr Comb Linewidth and Coherent System Performance on the Pump Linewidth

Peicheng Liao and Changjing Bao (University of Southern California, USA); Arne Kordts, Karpov Maxim and Martin Pfeiffer (Ecole Polytechnique Federale de Lausanne, Switzerland); Lin Zhang (Tianjin University, P.R. China); Amirhossein Mohajerin-Ariaei, Yinwen Cao, Ahmed Almainman and Morteza Ziyadi (University of Southern California, USA); Youichi Akasaka (Fujitsu Laboratories of America, Inc., USA); Tomer Yeminy (Ben Gurion University, Israel); Moshe Tur (Tel-Aviv University, Israel); Tobias Kippenberg (Ecole Polytechnique Federale de Lausanne, Switzerland); Alan Willner (University of Southern California, USA)

We experimentally investigate the dependence of Kerr comb linewidth, generation and coherent system performance on the pump linewidth. The linewidth of generated combs could be determined by the pump demonstrating the pump-limited system performance of Kerr combs.

Optimizing the Curvature of Elliptical Cladding Elements to Reduce Leakage Loss in Antiresonant Hollow Core Fibres

Lieke van Putten, Eric Numkam Fokoua, Seyedmohammad Abokhamis mousavi, Walter Belardi and Francesco Poletti (University of Southampton, United Kingdom)

We study systematically the effect of the curvature of glass membranes on the confinement loss of an antiresonant negative curvature hollow core fibre. Optimum curvatures are found that can reduce the fibre loss by orders of magnitude.

A Crosstalk Analysis of Heterogeneous 30-Core Fibre

Takeshi Fujisawa (Hokkaido University, Japan); Yoshimichi Amma, Shoichiro Matsuo and Kazuhiko Aikawa (Fujikura Ltd., Japan); Kunimasa Saitoh and Masanori Koshiba (Hokkaido University, Japan)

Intercore crosstalk of heterogeneously arranged 30-core fibre having four kinds of cores is investigated. Measured crosstalk for all the combinations of cores are in good agreement with calculated values by coupled-mode theory with single correlation length, assuming longitudinal random twist.

Th.2.P2.SC2: Waveguide and Optoelectronic Devices

Monolithically Integrated 40 Gbit/s Tunable Transmitter in an Experimental Generic Foundry Process for Large-Scale Integration

Weiming Yao (Eindhoven University of Technology & COBRA Research Institute, The Netherlands); Meint K Smit (Technical University Eindhoven, The Netherlands); Michael J. Wale (Oclaro, United Kingdom)

We present a tunable transmitter photonic integrated circuit fabricated on an experimental generic III-V foundry platform, consisting of a DBR-laser with 10 nm continuous tuning range, monolithically integrated with a traveling-wave Mach-Zehnder modulator capable of 40 Gbit/s operation.

Simultaneous Two-Wavelength Hybrid III/V-Si Laser Based on Single-Section Quantum Dot Gain

Michael Eggleston (Nokia Bell Labs, USA); Guilhem de Valicourt (Nokia Bell Labs); Jeffrey Lee and Kwangwoong Kim (Nokia Bell Labs, USA); Ting-Chen Hu (Nokia Bell Labs); Vitalii Sichkovskyi and Johann Peter Reithmaier (University of Kassel, Germany); Young-Kai Chen (Nokia Bell Labs, USA)

We demonstrate a novel selectable multi-wavelength hybrid III-V/Si laser using in-homogeneously broadened quantum dot gain material. Simultaneous stable lasing on two wavelengths is achieved while maintaining low RIN one order of magnitude better than previously demonstrated with mode-locked lasers.

Ultra-broadband Integrated Four-Channel Mode-Division-Multiplexing Based on Tapered Mode-Evolution Couplers

Jing Wang (Huawei Technologies Co., Ltd., P.R. China); Yi Xuan (Purdue University, USA); Minghao Qi (Purdue University, P.R. China); Lei Liu (Huawei Technologies Co., Ltd., P.R. China); Gordon Ning Liu (Huawei Technologies Co. Ltd., P.R. China)

We reported an ultra-broadband integrated four-channel mode-division multiplexing (MDM) scheme based on tapered mode-evolution couplers. This MDM link exhibits a very large −1 dB bandwidth of >180 nm, which is considerably larger than most of the previously reported MDM links.

Experimental Study of Phase and Intensity Noise in a Monolithically Integrated DFB Laser IQ Modulator PIC at QPSK operation

Sophie Lange (Fraunhofer Heinrich-Hertz-Institute, Germany); Ronald Kaiser and Marko Gruner (Fraunhofer Institut für Nachrichtentechnik, Heinrich-Hertz-Institut, Germany); Martin Schell (Fraunhofer Institute for Telecommunications, Heinrich-Hertz-Institut, Germany)

Phase noise in monolithic optical laser-modulator PICs influences QPSK performance depending on laser bias current and internal optical feedback. The phase noise was most significant at lower symbol rates and minimized at high symbol rates at selected bias points.

Emission Beam Engineering of 1.3-μm High-power DFB Laser Using Monolithically-integrated Mirror and Lens for Silicon Photonics

Koichiro Adachi, Takanori Suzuki, Kouji Nakahara, Akira Nakanishi, Kazuhiko Naoe and Shigehisa Tanaka (Oclaro Japan, Inc., Japan)

A beam-angle control of 1.3-μm high-power DFB laser without mode-profile degradation was demonstrated using monolithically-integrated mirror and lens. By tuning the mirror angle and lens position, wide-range angled beam (up to 20º) without degradation in mode profile was successfully achieved.

Optical Amplitude Modulator Linearized by Integration of Optical Interferometric Waveguides

Yuya Yamaguchi (National Institute of Information and Communications Technology & Waseda University, Japan); Atsushi Kanno (National Institute of Information and Communications Technology, Japan); Tetsuya Kawanishi (Waseda University & National Institute of Information and Communications Technology, Japan); Masayuki Izutsu and Hirochika Nakajima (Waseda University, Japan)

We propose an optical amplitude modulator with tailored transfer function by integration of Mach-Zehnder-interferometer-based waveguides. The fabricated modulator designed to enhance the linearity showed a unique transfer function in good agreement with the theoretical one.

120 Gbit/s PAM-4 Signaling Using a Silicon-Organic Hybrid (SOH) Mach-Zehnder Modulator

Heiner Zwickel, Stefan Wolf, Yasar Kutuvantavida, Clemens Kieninger and Matthias Lauermann (Karlsruhe Institute of Technology, Germany); Wolfgang Freude and Christian Koos (Karlsruhe Institute of Technology (KIT), Germany)

Four-level pulse amplitude modulation (PAM-4) signals are generated using a silicon-organic hybrid (SOH) push-pull Mach-Zehnder modulator. We demonstrate data rates (symbol rates) of 120 Gbit/s (60 GBd) with a 500 μm long device fabricated through a commercial silicon photonic foundry.

Differential Microring Binary Phase-shift Keying Modulators

Chia-Ming Chang (Nokia Bell Labs); Guilhem de Valicourt (Alcatel-Lucent, Bell Labs, USA); Sethumadhavan Chandrasekhar (Nokia Bell Labs, USA); Po Dong (Bell labs, Alcatel-Lucent, USA)
We experimentally demonstrate a nested microring modulator in a Mach-Zehnder interferometer for BPSK at 10 Gbps. Differential drive of such a modulator facilitates BSPK modulation and offers several advantages such as cancellation of imperfection from single ring modulator.

Femtosecond Laser Written Integrated Spatial Multiplexers for Few-Mode Multicore Fibre
Nicolas Riesen (University of Adelaide, Australia); Simon Gross (Macquarie University, Australia); John Love (The Australian National University, Australia); Yusuke Sasaki (Fujikura Ltd., Japan); Michael Withford (Macquarie University, Australia)
We demonstrate compact femtosecond laser written 3D spatial multiplexers for few-mode multicore fibre operating across the C+L bands. The integrated tapered mode couplers feature direct mode-selectivity, excellent mode extinction ratios (up to 25 dB) and low insertion loss (~2 dB).

Ultra-efficient interleaved depletion modulators by using advanced fabrication technology
Anna Lena Giesecke, Andreas Prinzen, Heiko Füser, Caroline Porschatis, Holger Lerch, Jens Bolten, Stephan Suckow, Bartos Chmielak and Thorsten Wahlbrink (AMO GmbH, Germany)
We fabricated highly efficient silicon photonic depletion modulators utilizing interdigitated pn-junctions with critical dimensions <200 nm. With this concept, record low values <2VdB of ($V_\pi L\alpha$)_2V as key figure of merit for the efficiency of such modulators have been achieved.

50-GHz+ Thin-Film Polymer on Silicon Modulator for PAM4 100G-per-wavelength Long-Reach Data Center Interconnects
Andrea Chiuchiarelli (CPqD, Brazil); Sandro M. Rossi (CPqD Telecom & IT Solutions, Brazil); Valery Nobl Rozental (CPqD, Division of Optical Technologies, Brazil); Glauco Simões (CPqD, Brazil); Luis Carvalho (BrPHOTONICS, Brazil); Julio Cesar Oliveira (BrPhotonics, Brazil); Juliano Rodrigues Fernandes de Oliveira (CPqD Foundation & University of Sao Paulo, Brazil); Jacklyn D. Reis (CPqD, Brazil)
This paper demonstrates 50-GHz+ Mach-Zehnder modulator based on thin-film Polymer on Silicon platform for Data Center Interconnects. System level demonstration is successfully carried out for 40x112 Gb/s, 56-GBd PAM4 optical channels in 100-GHz WDM grid over record 140-km link distance.

Physical Layer Compact Models for Ring Resonators based Dense WDM Optical Interconnects
Sébastien Rumley, Meisam Bahadori, Dessislava Nikolova and Keren Bergman (Columbia University, USA)
Two compact models relating the coupling and attenuation coefficient of ring resonators to their physical dimensions are introduced. We leverage these models to delimit the capabilities of ring resonators for dense WDM optical interconnects.

Back-Reflection Free Grating Couplers on Silicon-on-Insulator
Jeong Hwan Song and Xavier Rottenberg (IMEC, Belgium)
We propose a design of novel grating couplers having low back-reflections on silicon-on-insulator (SOI) where grating trenches are asymmetrically etched. 3D-FDTD simulations show that the average back-reflection of 1dB bandwidth in the proposed grating coupler is -41dB.

Th.2.P2.SC3: Digital and Optical Signal Processing

Nonlinear Blind Equalization for 16-QAM Coherent Optical OFDM using Support Vector Machines
Elias Giacoumidis (University of Sydney, CUDOS, IPOS, Australia); Mhatli Sofien (ENIT, Tunisia); Son Thai Le (Nokia-Bell-Labs, Germany); Ivan A Aldaya (University of Campinas, Brazil); Mary McCarthy and Andrew Ellis (Aston University, United Kingdom); Benjamin Eggleton (University of Sydney, Australia)
A novel blind nonlinear equalizer (BNLE) based on support vector machines is experimentally demonstrated for ~41-Gb/s 16-QAM CO-OFDM at 2000 km. For 2 dBm launched optical power, BNLE reduces the fiber nonlinearity penalty by ~1 dB compared to Volterra-based NLE.

Machine Learning for Optical Performance Monitoring from Directly Detected PDM-QAM Signals
Jesper Wass, Jakob Thrane, Molly Piels, Júlio C. M. Diniz and Rasmus Jones (Technical University of Denmark, Denmark); Darko Zibar (DTU Fotonik, depertment of Photonic Engineering, Technical University of Denmark, Denmark)
Supervised machine learning methods are applied and demonstrated experimentally for inband OSNR estimation and modulation format classification in optical communication systems. The proposed methods accurately evaluate coherent signals up to 64QAM using only intensity information.

Experimental Investigation of Compression with Fixed-length Code Quantization for Convergent Access-Mobile Networks

Luiz Anet Neto, Philippe Chanclou, Zakaria Tayq and Bidossessi Charlyse Zabada (Orange Labs, France); Fabienne Saliou and Gael Simon (Orange, France)

We experimentally assess compression with scalar and vector quantization for fixed-mobile convergent networks. We show that four-dimensional vector quantization allows 73% compression compliant with 3GPP EVM recommendations for transmissions over 25 km SSMF with 1:16 split ratio.

Timing Jitter Impact on QAM Modulation of Frequency Combs Obtained by Cross Phase Modulation of Mode-locked Lasers

Mark Pelusi (University of Sydney, Australia); Karen Solis-Trapala (EFFECT Photonics, The Netherlands); Takashi Inoue (National Institute of Advanced Industrial Science and Technology, Japan); Hung Nguyen Tan (Danang Uni. of Science & Technology, Vietnam); Shu Namiki (National Institute of Advanced Industrial Science and Technology, Japan)

Lower noise frequency combs obtained from mode-locked semiconductor and mode-locked fiber lasers by cross-phase modulation of output pulses in nonlinear fiber are compared. The importance of low timing jitter for enabling comb-line modulation with 96-Gb/s-DP-16QAM and 64QAM signals is shown.

Polarization-Mode Dispersion Aware Digital Backpropagation

Cristian B. Czegledi (Chalmers University of Technology, Sweden); Gabriele Liga and Domanic Lavery (University College London, United Kingdom); Magnus Karlsson (Chalmers University of Technology & Photonics Laboratory, Sweden); Erik Agrell (Chalmers University of Technology, Sweden); Seb J Savory (University of Cambridge, United Kingdom); Polina Bayvel (University College London, United Kingdom)

We study a modified DBP algorithm that accounts for PMD. Based on the accumulated PMD at the receiver, the algorithm distributively compensates for PMD in the reverse propagation and outperforms the conventional approach by up to 2.1 dB.

On the Design of Capacity-Approaching Unit-Memory Spatially Coupled LDPC Codes for Optical Communications

Laurent Schmalen, Detlef Suikat, Vahid Aref and Detlef Rösener (Nokia Bell Labs, Germany)

We consider unit-memory spatially coupled LDPC codes for optical communications. We analyze the region of wave-like convergence using an FPGA-based windowed decoding emulator. We show that the post-FEC errors occur in long bursts and highlight some design guidelines.

Hardware-efficient Precise and Flexible Soft-demapping for Multi-Dimensional Complementary APSK Signals

Tsuyoshi Yoshida and Keisuke Matsuda (Mitsubishi Electric Corporation, Japan); Keisuke Kojima (Mitsubishi Electric Research Laboratories, USA); Hiroshi Miura and Keisuke Dohi (Mitsubishi Electric Corporation, Japan); Milutin Pajovic and Toshiaki Koike-Akino (Mitsubishi Electric Research Laboratories (MERL), USA); David Millar and Kieran Parsons (Mitsubishi Electric Research Laboratories, USA); Takashi Sugihara (Mitsubishi Electric Corporation, Japan)

We propose the combination of log-likelihood ratio (LLR) table and min-sum algorithm-based LLR updates for simple, precise, and flexible soft-demapping of multi-dimensional complementary APSK signals. Transmission experiment verifies the demapping loss is limited to 0.15 dB in Q-factor.

Sub-Symbol-Rate Sampling of Super-Nyquist Signals

Cheng Xu, Guanjun Gao and Jie Zhang (Beijing University of Posts and Telecommunications, P.R. China); Sai Chen (Beijing University of Posts and Telecommunications & Bell Labs, Alcatel-Lucent, USA); Ming Luo (FiberHome, P.R. China); Rong Hu (State Key Lab. of Optical Comm. Technologies and Networks, P.R. China)

We demonstrate 12-Gbaud WDM PDM-QPSK transmission with 10GHz channel spacing and only 9.6-GSa/s ADC sampling rate. By using 4PB shaping with MLSE, the sampling rate can be reduced to 0.8-times symbol-rate without OSNR penalty, compared with that of 2-times symbol-rate.

Efficient SDM-MIMO Stokes-Space Equalization

Francisco Javier Vaquero Caballero (Technical University of Denmark, Germany); Abdullah Zanaty (University of Kiel, Germany); Fabio Pittalá, Gernot Goeger and Yabin Ye (Huawei Technologies Duesseldorf GmbH, Germany); Idelfonso Tafur Monroy (Technical University of Denmark, Denmark & ITMO University, Russia); Werner Rosenkranz (University of Kiel, Germany)

We propose a novel frequency-domain 6x6 MIMO Stokes-space equalizer and compare its performance to a 6x6 MIMO LMS architecture. This method is suited to overcome DSP complexity and laser linewidth issues in SDM transmission systems.

Short-Reach Distance Extension through CAPS Coding and DSP-free Direct Detection Receiver

Francesco Fresi and Gianluca Meloni (CNIT, Italy); Marco Secondini (Scuola Superiore Sant'Anna, Italy); Fabio Cavaliere (Ericsson Telecomunicazioni, Italy); Luca Potì (Consorzio Nazionale Interuniversitario per le Telecomunicazioni, Italy); Enrico Forestieri (Scuola Superiore Sant'Anna, Italy)

Order-3 CAPS coding for short-reach direct-detection systems is experimentally demonstrated. Chromatic dispersion tolerance is compared to that of OOK and PAM-4 modulations, with respect to which transmission distance can be increased by a factor of 4 and 1.5, respectively.

Comparison of Multi-Channel Nonlinear Equalization using Inverse Volterra Series versus Digital Backpropagation in 400 Gb/s Coherent Superchannel

Vassiliki Vgenopoulou (Athens Information Technology); M. Sezer Erkilinc and Robert I Killey (University College London, United Kingdom); Yves Jaouën (Telecom ParisTech, France); Ioannis Roudas (Corning Inc., USA); Ioannis Tomkos (Athens Information Technology, Greece)

We investigate the performance of a Volterra-based nonlinear equalizer and the digital backpropagation (DBP) method in multi-channel nonlinear equalization after 20×80 km transmission distance. The Volterra equalizer, which operates with single-step-per-span, performs similarly compared to DBP with 40 steps-per-span

Experimental Investigation of GF(3 2) Nonbinary LDPC-coded Non-uniform 9-QAM Modulation Format

Zhen Qu, Changyu Lin, Tao Liu and Ivan B. Djordjevic (University of Arizona, USA)

A specially designed GF (3^2) nonbinary LDPC-coded non-uniform 9-quadrature amplitude modulation (QAM) is proposed. The experimental and numerical results show that the proposed scheme outperforms nonbinary GF (2^3) LDPC-coded uniform 8-QAM by ~0.8-dB.

Selective wavelength conversion of multi-channel 16-QAM signal in a graphene-silicon microring resonator

Yun Long, Xiao Hu, Mengxi Ji, Li Shen and Andong Wang (Huazhong University of Science and Technology, P.R. China); Yi Wang (Wuhan National Laboratory for Optoelectronics & Huazhong University of Science and Technology, P.R. China); Jian Wang (Huazhong University of Science and Technology, P.R. China)

By exploiting graphene-enhanced FWM in a graphene-silicon microring, we propose and experimentally demonstrate selective wavelength conversion of multi-channel 16-QAM signal. Efficient wavelength conversion and low crosstalk are observed when the channel spacing is 100 GHz and 50 GHz, respectively.

Th.2.P2.SC4: Subsystems for Optical Networking and Datacoms

Optical DAC for Generation of PAM4 Using Parallel Electro-Absorption Modulators

Wan-Jou Huang and Chia-Chien Wei (National Sun Yat-Sen University, Taiwan); Jyehong Chen (National Chiao Tung University, Taiwan)

Employing a proposed optical 2-bit DAC based on parallel EAMs, we experimentally demonstrated 50- and 64-Gbps optical 4-PAM signals. Compared to using an electrical DAC, the optical DAC has better performance and higher tolerance to the operation conditions of modulators.

Hexagonal Reconfigurable Lattice Mesh for Programmable Photonic Processors

Daniel Pérez (Universidad Politécnica de Valencia, Spain); Ivana Gasulla and Jose Capmany (Universidad Politecnica de Valencia, Spain); Richard Soref (University of Massachusetts Boston, USA)

We propose a hexagonal tuneable-coupler-based mesh design, for the implementation of reconfigurable optical cores in programmable processors. This hexagonal mesh outperforms the previously proposed square mesh topology in on-chip integration metrics and performance. We provide application examples and robustness simulations.

Single-Ended In-Service Hybrid Monitoring of Fibre-Extended Copper Lines

Gustavo Amaral, Andrea Baldivieso and Joaquim Dias Garcia (Pontifical Catholic University of Rio de Janeiro, Brazil); Patryk Urban (Ericsson AB, Sweden); Jean Pierre von der Weid (Pontifical Catholic University of Rio de Janeiro, Brazil)

We report on the simultaneous monitoring of both fibre and copper links in a fibre-extended copper mobile fronthaul network. The monitoring signal, which is allocated to an optical subcarrier channel, is used to determine both the fibre's and copper's characteristics.

A Self-Optimizing 4-Channel 30 Gbaud/s PAM-4 Packaged Silicon Photonics Subsystem with Binary Driving Signals

Nathan Abrams, David M Calhoun, Christine Chen and Keren Bergman (Columbia University, USA)

We demonstrate four channel PAM-4 modulation in a silicon-photonic platform driven by push-pull binary electrical signals. The subsystem self-optimizes through a gradient descent algorithm across the full range of starting voltages.

Overall Frequency Response Measurement of DSP-based Optical Transmitter Using Built-in Monitor Photodiode

Yangyang Fan (Fujitsu Research & Development Center Co., LTD., P.R. China); Zhenning Tao (Fujitsu R&D Center Ltd., P.R. China); Liang Dou (Fujitsu Research & Development Center Co., LTD., P.R. China); Ying Zhao (Fujitsu Research and Development Center, P.R. China); Hao Chen (Fujitsu Research and Development Center Company Limited, P.R. China); Saito Taku and Komaki Kousuke (Fujitsu Limited, Japan); Takeshi Hoshida and Jens C. Rasmussen (Fujitsu Laboratories Limited, Japan)

To pre-equalize the bandwidth limitation at the transmitter side, the overall response of the transmitter is required. An accurate response measurement assisted by the photodiode built in Mach-Zehnder modulator is proposed and experimentally demonstrated.

Demonstration of a 71.8 Gbps 4-PAM 850 nm VCSEL-based Link with a Pre-emphasizing Passive Filter

Tamás Lengyel and Krzysztof Szczerba (Chalmers University of Technology, Sweden); Magnus Karlsson (Chalmers University of Technology & Photonics Laboratory, Sweden); Anders Larsson and Peter A Andrekson (Chalmers University of Technology, Sweden)

We present 71.8 Gbps 4-PAM back-to-back transmission in an 850 nm VCSEL-based link using a passive pre-emphasis filter and FEC with no post-equalization. Bit error rates below 10-8 are demonstrated with 72 Gbps uncoded data.

Service-triggered failure identification/localization through monitoring of multiple parameters

Marc Ruiz (Universitat Politècnica de Catalunya, Spain); Francesco Fresi (CNIT, Italy); Alba Vela (Universitat Politècnica de Catalunya (UPC), Spain); Gianluca Meloni (CNIT, Italy); Nicola Sambo (Scuola Superiore Sant'Anna, Italy); Filippo Cugini (CNIT, Italy); Luca Potì (Consorzio Nazionale Interuniversitario per le Telecomunicazioni, Italy); Luis Velasco (Universitat Politècnica de Catalunya (UPC), Spain); Piero Castoldi (Scuola Superiore Sant'Anna, Italy)

Failures in the optical layer might impact the quality of supported services. We experimentally characterize several failure causes and propose an effective machine learning-based algorithm to localize and identify the most probable cause of failure impacting a given service.

Cascadability Performance of a High-speed Electro-absorption Optical Switch for DP-16QAM and DP-QPSK Optical Signals

Hideaki Furukawa (NICT, Japan); Jose Manuel Delgado Mendinueta (National Institute of Information and Communications Technology, Japan); Toru Segawa (NTT Corporation & NTT Device Technology Laboratories, Japan); Ryo Takahashi (NTT Device Technology Laboratories, Japan); Satoshi Shinada (National Institute of Information and Communications Technology, Japan); Naoya Wada (NICT, Japan)

We experimentally investigate the cascadability of electro-absorption optical switches for optical packet switched networks. Dual-polarization QPSK and 16QAM optical signals can cascade more than 50 and 10 EA optical switches, respectively, which is 1.6 times greater compared to SOA switches.

Direct Modulation of a Hybrid III-V/Si DFB Laser with MRR Filtering for 22.5-Gb/s Error-Free Dispersion-Uncompensated Transmission over 2.5-km SSMF

Valentina Cristofori, Francesco Da Ros and Yunhong Ding (Technical University of Denmark, Denmark); Alexandre Shen (Alcatel-Thales III-V Lab, France); Antonin Gallet (III-V lab, a joint lab of Nokia, Thales and CEA, France); Dalila Make (Alcatel Thales III-V Lab, France); Guang-Hua Duan (III-V Lab, France); Leif Oxenløwe (Technical University of Denmark, Denmark); Christophe Peucheret (University of Rennes 1, France)

Error-free and penalty-free transmission over 2.5 km SSMF of a 22.5 Gb/s data signal from a directly modulated hybrid III-V/Si DFB laser is achieved by enhancing the dispersion tolerance using a silicon micro-ring resonator.

Characterization of a Packaged Network on Chip based on Multi-Microrings

Stefano Faralli, Isabella Cerutti, Fabrizio Gambini and Paolo Pintus (Scuola Superiore Sant'Anna, Italy); Giovan Battista Preve (CNIT, Italy); Marco Chiesa (Scuola Superiore Sant'Anna, Italy); Rubén Ortuño (Universidad Politécnica de Valencia & Nanophotonics Technology Center, Spain); Nicola Andriolli (Scuola Superiore Sant'Anna, Italy)

A multi microring network on chip with 6 ports has been fabricated in SOI, packaged and characterized. The BER penalty for two simultaneous 10Gb/s transmissions of up to 5 hops is below 1 dB at BER of 10-9

Single-Lane 112Gbps Transmission over 300m OM4 Multimode Fiber Based on A Single-Transverse-Mode 850nm VCSEL

Bo Wu (Huawei Technologies Co. Ltd, P.R. China); Xian Zhou (The Hong Kong Polytechnic University, P.R. China); Yanan Ma (Huawei Technologies Co., Ltd, P.R. China); Jun Luo (Huawei Technologies co ltd, P.R. China); Shaofeng Qiu (Huawei Technologies Co., Ltd, P.R. China); Kangping Zhong (The Hong Kong Polytechnic University, Hong Kong); Feng Zhiyong (Huawei Technologies Co., P.R. China); Chao Lu (The Hong Kong Polytechnic University, Hong Kong); Vitaly Shchukin and Joerg Kropp (VI System, Germany); Nikolay Ledentosov (VI Systems GmbH, Germany)

Single-lane 120Gbps-BtB, 118Gbps-100m, 117Gbps-200m and 112Gbps-300m discrete multi-tone transmission based on a single-transverse-mode 850nm band VCSEL is investigated respectively over standard OM4 multimode fiber. This proves our previous conclusion of single-lane capacity beyond 100G by more optical coupling power

Precise Sub-carrier Frequency Monitor and Control Method for Superchannel Transmission in Cascaded ROADM Network

Guoxiu Huang (Fujitsu Laboratories LTD., Japan); Shoichiro Oda (Fujitsu Laboratories Ltd., Japan); Ying Zhao (Fujitsu Research and Development Center, P.R. China); Huihui Li (FUJITSU R&D CENTER CO., LTD., P.R. China); Tomohiro Yamauchi (Fujitsu Laboratories Ltd., Japan); Setsuo Yoshida and Yasuhiko Aoki (Fujitsu Limited, Japan); Zhenning Tao (Fujitsu R&D Center Ltd., P.R. China); Jens C. Rasmussen (Fujitsu Laboratories Limited, Japan)

We proposed precise sub-carrier frequency monitor and control method to eliminate laser frequency uncertainness in super-channel transmission. Based on digital signal processing without additional hardware, the relative frequency accuracy reached 10 times higher than ITLA specification.

End-to-end Optical 25Gb/s Link Demonstrator with Embedded Waveguides, 90°Out-of-Plane Connector and On-board Optical Transceivers

Marika Immonen (TTM Technologies, Finland); Ruiyong Zhang (FCI Deutschland GmbH, Germany); Marie Press, Hong Tang and Wanlu Lei (Ericsson AB, Sweden); Jinhua Wu and Hui Juan Yan (TTM Technologies, P.R. China); Long Xiu Zhu (TTM Technologies, Finland); Murat Serbay (FCI Deutschland GmbH, Germany)

We present optical/electrical demonstrator with 96-optical channels totalling 2.4Tb/s aggregate capacity tested with 300Gb/s on-board transceivers, embedded waveguides, and connectors with 90° reflectors in a standard PCB. Results show BER 1E-12at 25Gb/s, <0.1dB/cm transmission loss and 2.5dB connector loss.

Monolithic Photonic-Electronic Linear Direct Detection Receiver for 56Gbps OOK

Marcel Kroh (IHP, Germany); Ahmed Awny (IHP Microelectronics, Germany); Georg Winzer (IHP, Germany); Rajasekhar Nagulapalli (Inphi, United Kingdom); Stefan Lischke (IHP Frankfurt/Oder, Germany); Dieter Knoll and Anna Peczek (IHP GmbH, Germany); Daniel Micusik (Rohde & Schwarz, Germany); Ahmet Cagri Ulusoy and Dietmar Kissinger (IHP, Germany); Lars Zimmermann (IHP & Technical University of Berlin, Germany); Klaus Petermann (Technical University of Berlin, Germany)

A monolithic photonic-electronic direct detection single pol linear receiver chip is presented. Electro-optical bandwidth and BER measurements reveal state-of-the-art performance of the integrated receiver.

Experimental Demonstration of Full-Duplex Data Transmission Link using Twisted Lights Multiplexing over 1.1-km Orbital Angular Momentum (OAM) Fiber

Shi Chen and Jun Liu (Huazhong University of Science and Technology, P.R. China); Yifan Zhao (Huazhong University of Science and Technology & Wuhan National Laboratory for Optoelectronics, P.R. China); Long Zhu, Andong Wang, Jing Du, Shuhui Li and Jian Wang (Huazhong University of Science and Technology, P.R. China)

We propose and demonstrate a full-duplex data transmission link using twisted light multiplexing over 1.1-km OAM fiber. The measured full-duplex OSNR penalties at BER of 2×10-3 for uplink and downlink are about 2.3 dB.

Th.2.P2.SC5: Point-to-Point Transmission Systems

Experimental Studies on Characteristics of Polarization Parameters over Atmospheric Turbulence

Jiankun Zhang, Ruijie Li and Anhong Dang (Peking University, P.R. China)

We report an investigation on turbulence-induced changes for overall polarization parameters of light beams, with different wavelength and under different Rytov indexes. Experimental results show strong correlations between state of polarization and turbulent strength, which is consistent with theoretical predictions.

Investigation of Potential MPI Effects on Supervisory Channel Transmission Below Cable Cut-off in G.654 Fibres

John D Downie, Jason Hurley and Hector DePedro (Corning Incorporated, USA); Steven Garner (Corning Incorporated); Jeremy Blaker, Aramais Zakharian, Sergey Ten and Greg Mills (Corning Incorporated, USA)

We examine supervisory channel transmission at wavelengths below cable cut-off in G.654 fibres via modelling and cabled fibre tests. We find negligible MPI and no penalty for 2.5 Gb/s transmission in a worst-case configuration up to 40 nm below cut-off.

Experimental Investigation of Quasi-Periodic Power Spectrum in Raman-Assisted Phase Sensitive Amplifier for 10/20/50-Gbaud QPSK and 10-Gbaud 16QAM Signals

Yinwen Cao (University of Southern California, USA); Fatemeh Alishahi (University of Southern Calliforni, USA); Youichi Akasaka (Fujitsu Laboratories of America, Inc., USA); Morteza Ziyadi, Ahmed Almainman, Amirhossein Mohajerin-Ariaei, Changjing Bao and Peicheng Liao (University of Southern California, USA); Ahmad Fallahpour (USC, USA); Bishara Shamee (University of Southern California, USA); Tadashi Ikeuchi (Fujitsu Laboratories of America, Inc., USA); Shigehiro Takasaka and Ryuichi Sugizaki (Furukawa Electric co., Ltd., Japan); Joe Touch (USC/ISI, USA); Moshe Tur (Tel-Aviv University, Israel); Alan Willner (University of Southern California, USA)

Raman-assisted PSA without phase-stabilization-loop is experimentally evaluated by placing signals at different locations in a quasi-periodic PSA power spectrum. With phase adjustment, an 18dB peak-dip gain-extinction-ratio difference is observed. Improved performance is demonstrated using 10/20/50-Gbaud QPSK and 10-Gbaud 16QAM signals.

5-band (O, E, S, C, and L) WDM Transmission with Wavelength Adaptive Modulation Format Allocation

Seiji Okamoto, Kengo Horikoshi, Fukutaro Hamaoka, Kyo Minoguchi and Akira Hirano (NTT Corporation, Japan)

We propose wavelength adaptive modulation format allocation method for extremely wide WDM system. We successfully demonstrated 5-band WDM transmission for the first time, and showed potential capacity achieves 106.77 Tbit/s within 23.5 THz or 173.83 nm using proposed method.

A Digital Coherent Optical Code Division Multiplexing Network with 16-Tb/s (2560×6.25-Gb/s) Capacity

Xie Wang (Huawei Technologies Co., Ltd., P.R. China); Yuanda Huang (Huawei Technologies Co., Ltd., Shenzhen, P.R. China); Yanzhao Lu, Yi Yu and Liangchuan Li (Huawei Technologies Co., Ltd., P.R. China)

We experimentally demonstrate a digital coherent optical code division multiplexing network with total capacity of 16-Tb/s (80×32×6.25-Gb/s) in C-band featuring 6.25-Gb/s per node for 2560 supported nodes over 300-km standard-single-mode-fiber.

150-Gb/s DMT over 80-km SMF transmission based on Spectrally Efficient SSBI cancellation using guard-band Twin-SSB Technique

Liang Zhang and Tianjian Zuo (Huawei, P.R. China); Qiang Zhang (Huawei Technologies Duesseldorf GmbH, Germany); Jie Zhou (Huawei, P.R. China); Enbo Zhou (Huawei Technologies Ltd., P.R. China); Gordon Ning Liu (Huawei Technologies Co. Ltd., P.R. China)

We propose a spectrally efficient SSBI cancellation scheme based on guard-band twin-SSB technique. 112-Gb/s DMT transmission over 80-km SMF is experimentally demonstrated with an ROSNR of 30.7 dB and the highest achieved capacity is up to 150 Gb/s.

Advanced Receiver Design enables PDM-16QAM DWDM Transmission over 2660 km of SSMF with Only EDFA

Xiaozhou Wang (Universität der Bundeswehr München & Coriant GmbH, Germany); Stefano Calabro and Bernhard Spinnler (Coriant R&D GmbH, Germany); Ginni Khanna (Technical University of Munich, Germany); Berthold Lankl (University of Federal Armed Forces Munich, Germany)

We demonstrate experimental DWDM PDM-16QAM transmission at 200 Gb/s over 2660 km of SSMF, using EDFA-only amplification and advanced DSP techniques, including powerful digital pre-distortion, iterative carrier recovery and decoding using 50% OH soft-decision FEC.

Experimental Nonlinear Frequency Division Multiplexed Transmission using Eigenvalues with Symmetric Real Part

Alexander Geisler and Christian Schaeffer (Helmut Schmidt University, Germany)

We demonstrate the nonlinear transmission of a PSK modulated discrete spectrum consisting of up to 3 eigenvalues, 2 of them having non-zero symmetric real parts. A low error rate using NFT detection at 4Gbps is shown.

Correlation Between Modulated and Probe Signals for Superchannel Inter-Subcarrier Nonlinear Phase Perturbations

Ali Rezania, John C Cartledge, Aazar Kashi, Ali Bakhshali and Ahmed Abd El-Rahman (Queen's University, Canada)

For a 1 Tb/s dual-polarization 16-QAM Nyquist-superchannel, the degree of correlation for the inter-subcarrier nonlinearity induced phase perturbation is assessed between a modulated center subcarrier and a CW probe center subcarrier.

Power Consumption of a Minimal-DSP Coherent Link with a Polarization Multiplexed Pilot-Tone

Lars Lundberg, Christoffer Fougstedt, Per Larsson-Edefors and Peter A Andrekson (Chalmers University of Technology, Sweden); Magnus Karlsson (Chalmers University of Technology & Photonics Laboratory, Sweden)

We experimentally study the trade-off between performance and DSP power consumption. While minimal DSP allows transmission of 16QAM at 5GBaud, the symbol rate can be increased if an extra equalizer is added, leading to energy savings in optical components.

Cross Polarization Modulation (XPolM) Compensation for Submarine Upgrade Links using DP-8QAM

Milutin Pajovic (Mitsubishi Electric Research Laboratories (MERL), USA); David Millar and Kieran Parsons (Mitsubishi Electric Research Laboratories, USA); Keisuke Matsuda and Hiroshi Miura (Mitsubishi Electric Corporation, Japan); Keisuke Kojima (Mitsubishi Electric Research Laboratories, USA); Toshiaki Koike-Akino (Mitsubishi Electric Research Laboratories (MERL), USA); Tsuyoshi Yoshida (Mitsubishi Electric Corporation, Japan)

We propose a method of XPolM compensation suitable for submarine upgrade systems, and experimentally validate performance for a 70 × 192 Gb/s DP-8QAM system. The method improves the Q-factor by 0.16dB and outperforms the conventional NPCC by 0.12dB.

Stochastic Nonlinear Interference in Dispersion Managed Coherent Optical Links

Nicola Rossi (Nokia Bell Labs, France); Amirhossein Ghazisaeidi (Université Laval, Canada); Petros Ramantanis (Nokia Bell Labs, France)

We numerically investigate the stochastic nature of nonlinear interference in dispersion managed links. We show deviation of signal statistics from Gaussian assumption and significant performance variability due to interaction between nonlinearity and polarization mode dispersion.

Improving 100-Gb/s Transmission Performance in a 1250-km Legacy Dispersion-Managed Link with Co-Propagating 10-Gb/s OOK Channels via Modified Phase-Conjugated Twin Waves

Xuefeng Tang, Zhuhong Zhang and Zhiping Jiang (Huawei Technologies (Canada), Canada); Xiang Liu (Futurewei Technologies, USA); Chuandong Li (Huawei Technologies (Canada), Canada)

We experimentally demonstrate the improved nonlinear transmission performance of a 100-Gb/s channel using modified phase-conjugated twin waves in a 1250-km legacy dispersion-managed SSMF link and 50-GHz-spaced co-propagating 10-Gb/s OOK channels, achieving 0.7dB improved performance over a common 100-Gb/s DP-QPSK channel.

Optimum Capacity Utilization in Space-Division Multiplexed Transmission Systems with Multimode Fibers

Georg Rademacher and Friederike Schmidt (Technische Universitaet Berlin, Germany); Klaus Petermann (Technical University of Berlin, Germany)

For maximum capacity utilization, all spatial channels in space-division multiplexed transmission systems are desired to perform equally. We show that an optimized per-mode power is capable of increasing the overall system OSNR.

Mitigation of Fading Caused by Atmospheric Turbulence with FMF Coupling and Maximum Ratio Combining Used in 320-m Free-Space Optical Transmission of 10 Gb/s BPSK

Manabu Arikawa, Takashi Ishikawa, Kohei Hosokawa, Seigo Takahashi, Yoshimasa Ono and Toshiharu Ito (NEC Corporation, Japan)

We experimentally demonstrated the sum of the six modes of FMF improved coupling efficiency by 6.5 dB for the optical beam impaired by 320-m open-air free-space transmission, and fading was suppressed by digital maximum ratio combining for 10 Gb/s BPSK.

Achievable Information Rate of Nonlinear Inverse Synthesis Based 16QAM OFDM Transmission

Son Thai Le (Nokia-Bell-Labs, Germany); Ian Phillips (Aston University, United Kingdom); Jaroslaw Prilepsky (Aston University & Aston Institute of Photonic Tehcnologies, United Kingdom); Morteza Kamalian, Kopae (Aston University & Aston Institute of Photonic Technologies, United Kingdom); Andrew Ellis and Paul Harper (Aston University, United Kingdom); Sergei K. Turitsyn (Aston University & Photonics Research Group, United Kingdom)

We experimentally investigate, for the first time, the achievable information rate of the nonlinear inverse synthesis system with 16QAM OFDM format employing hard and soft FEC, showing that 3 bits/symbol can be achieved over a distance of 1632 km

Th.2.P2.SC6: Core, Metro and Data Center Networks

Demonstration of a Hybrid SDN/GMPLS Control Plane for Optical Virtual Private Networks with Restoration Capabilities

Domenico Siracusa, Federico Pederzolli and Matteo Gerola (CREATE-NET, Italy); Andrea Zanardi (Create-Net, Italy); Domenico La Fauci and Gabriele Maria Galimberti (Cisco Photonics, Italy)

Creating Optical Virtual Private Networks (OVPNs) over existing deployments is becoming an operator concern. This paper describes the first hybrid SDN/GMPLS implementation addressing this problem and demonstrates, through an emulated testbed, that the system is responsive and provides OVPN-specific restoration.

Crosstalk-aware Virtual Optical Network Embedding (VONE) in Spatial Division Multiplexing Enabled Elastic Optical Networks with Multi-core Fibers

Ruijie Zhu and Yongli Zhao (Beijing University of Posts and Telecommunications, P.R. China); Hui Yang (Beijing University of Posts and Telecommunications (BUPT), P.R. China); Yuanlong Tan, Xiaosong Yu, Guanjun Gao and Jie Zhang (Beijing University of Posts and Telecommunications, P.R. China); Nannan Wang and Jason P. Jue (University of Texas at Dallas, USA)

A crosstalk-aware VONE (CA-VONE) algorithm is proposed for spatial division multiplexing enabled elastic optical networks with multi-core fibers. Simulation results show that CA-VONE can achieve better performance than the previous algorithms in terms of blocking probability and resource utilization.

Experimental Demonstration of a Programmable S-BVT with PDM Capability for Flexible Optical Metro Networks

Laia Nadal Reixats and Michela Svaluto Moreolo (Centre Tecnològic de Telecomunicacions de Catalunya (CTTC), Spain); Josep M. Fabrega (Centre Tecnologic de Telecomunicacions de Catalunya, Spain); Francisco Javier Vílchez (Centre Tecnològic de Telecomunicacions de Catalunya, Spain)

We experimentally demonstrate a programmable sliceable-BVT with PDM capability and adaptive FEC selection based on DD-OFDM, achieving 40G-100G transmission rates. PDM slice-ability is also assessed within the ADRENALINE network nodes enabling up to 50\% spectral saving.

Transport API: A Solution for SDN in Carriers Networks

Victor Lopez (Telefonica, Spain); Ricard Vilalta (CTTC, Spain); Víctor Uceda (Universidad Autónoma de Madrid, Spain); Arturo Mayoral (CTTC, Spain); Ramon Casellas (Centre Tecnologic de Telecomunicacions de Catalunya (CTTC), Spain); Ricardo Martinez and Raul Muñoz (CTTC, Spain); Juan P. Fernández-Palacios (Telefónica I+D, Spain)

The ONF Transport API is an interface to enable control of Transport networks, including services such as topology, or connectivity setup. We present the first demonstration of a connectivity service over a DWDM network using the ONF Transport API.

Nonlinear-impairments- and crosstalk-aware resource allocation schemes for multicore-fiber-based flexgrid networks

Madushanka Nishan Dharmaweera and Li Yan (Chalmers University of Technology, Sweden); Magnus Karlsson (Chalmers University of Technology & Photonics Laboratory, Sweden); Erik Agrell (Chalmers University of Technology, Sweden)

In this study, we propose a novel spectrum and core allocation scheme that incorporates both intra-core physical layer impairments and inter-core crosstalk. We demonstrate that accounting for the latter increases spectral efficiency by at least 50% when crosstalk is significant.

On Deploying Encryption Solutions to Provide Secure Transport-as-a-Service (TaaS) in Core and Metro Networks

Kyle C Guan and Joseph Kakande (Bell Labs, Nokia, USA); Junho Cho (Nokia Bell labs, USA)

We study different architectural options of deploying OTN encryption solutions for the core or metro transport networks, by evaluating the equipment cost, bandwidth utilization, and complexity of key management under different traffic patterns.

Results of Empirical Searches for k-Connected Minimum-Mean-Hop Network Topologies

Joseph Kakande and Steve Korotky (Bell Labs, Nokia, USA)

We identify members of the sets of non-degenerate k-connected Minimum-Mean-Hop topologies for a given number of nodes and links using empirical searches and substantiate the accuracy of an approxi-mation for the minimum average hops for 2-connected graphs.

Th.2.P2.SC7: Access, Local Area and Home Networks

Unified Evolution-Ready 25 Gbps NG-PON Architecture

Vincent Houtsma (Nokia, Bell Labs, USA); Dora van Veen (Bell Labs, Nokia, USA); Ed Harstead (Alcatel-Lucent, Belgium)

First experimental proof of a unique evolution-ready 25G TDM-PON architecture featuring dual-rate 10 and 25 Gbps upstream. The architecture supports a novel black-box approach taking into account future optical and electronic component cost evolutions.

Multi-Core Based 94-GHz Radio and Power over Fiber Transmission Using 100-GHz Analog Photoreceiver

Toshimasa Umezawa (National Institute of Information and Communication Technology (NICT), Japan); Atsushi Kanno, Tien Dat Pham and Kouichi Akahane (National Institute of Information and Communications Technology, Japan); Yoshinari Awaji (National Institute of Information and Communications Technology (NICT), Japan); Naokatsu Yamamoto and Tetsuya Kawanishi (National Institute of Information and Communications Technology, Japan)

We propose a multi-core-based radio and power over fiber transmission using a 100 GHz photoreceiver, and demonstrate 1 m photonic wireless transmission at 10 Gbps (OFDM, 16QAM, 3 GHz) through a photonic power supply via cores in a multi-core fiber.

Ultrahigh-Fidelity Mobile Fronthaul Using Analog Angle Modulation

Di Che (The University of Melbourne & National ICT Australia, Australia); Feng Yuan (University of Melbourne, Australia); William Shieh (University of Melbourne, USA)

We propose angle modulation to remarkably enhance the SNR of channel-aggregation-based analog fronthaul link. Experiments show >27-dB SNR improvement using CPRI-equivalent bandwidth and >5 dB advantage of nonlinearity tolerance, compared with amplitude modulation.

TWDM-PON ONUs Optical Frequency Drift versus Tuning

Gael Simon and Fabienne Saliou (Orange, France); Philippe Chanclou (Orange Labs, France); Bertrand Le Guyader (Orange, France); Laurent Guillo (France Telecom R&D, France); Luiz Anet Neto (Orange Labs, France); Didier Erasme (Telecom ParisTech, France)

A vendor's TWDM-PON system and a commercial laser permit to demonstrate that reaching optical budget requirements for all NG-PON2 capable channels signifies failing upstream spectral excursion requirements, and reciprocally.

Multi-Dimensional Resources Integration for Service Provisioning in 5G Cloud Radio over Fiber Network

Hui Yang (Beijing University of Posts and Telecommunications (BUPT), P.R. China); Wei Bai (BUPT, P.R. China); Yuanlong Tan (Beijing University of Posts and Telecommunications, P.R. China); Ao Yu (BUPT, P.R. China); Jie Zhang (Beijing university of posts and telecommunications, P.R. China); Young Lee (Huawei Technologies Co., Ltd, USA); Yuefeng Ji (Beijing University of Posts and Telecommunications, P.R. China)

We propose a multi-dimensional resources integration (MDRI) architecture for services provisioning with resources integrated provisioning (RIP) scheme in software defined cloud radio over fiber network of 5G. The feasibility and efficiency are verified on OpenFlow-based enhanced SDN testbed.

Feasibility Study on In-Band Unidirectional ONU Control of the 10G-class WDM Overlaid Digital Baseband UHD Video Distribution System

Toshiaki Shitaba, Tomohiro Taniguchi and Hidekazu Shimizu (NTT Corporation, Japan); Toshihito Fujiwara (NTT & NTT Access Network Service Systems Laboratories, Japan); Hisao Yoshinaga and Tomoki Sugawa (NTT Corporation, Japan)

This paper describes a downlink digital baseband video distribution system using WDM-overlay technology. An experiment confirms the feasibility of in-band carousel ONU control, a key technology of the system.

Direct Detection OFDM PON using Ge-on-Si Photodetector Employing Volterra Filtering for Nonlinear Compensation

Yung Hsu (Institute of Electro-Optical Engineering, National Chiao Tung University, Taiwan); Jun-jie Liu (National Chiao Tung University, Taiwan); Xinru Wu (The Chinese University of Hong Kong, Hong Kong); Hsin-Yu Wu (National Chiao Tung University, Taiwan); Chien-Hung Yeh (Industrial Technology Research Institute, Taiwan); Hon Tsang (The Chinese University of Hong Kong, Hong Kong); Jyehong Chen and Chi-Wai Chow (National Chiao Tung University, Taiwan)

We propose and demonstrate a Ge-on-Si photodetector-based direct-detection orthogonal-frequency-division-multiplexing passive-optical-network (OFDM-PON) employing Volterra-filtering for nonlinear

compensation. Capacity is enhanced by 49.55% to data-rate of 53.8Gbit/s after 20-km standard-single-mode-fiber (SSMF).

LTE-A Multiband and Ethernet over Large-core Diameter GI POF for Wired and Wireless In-home Networks

Federico Forni (Eindhoven University of Technology & Genexis B. V., The Netherlands); Yan Shi (Genexis, The Netherlands); Henrie van den Boom (TU Eindhoven, The Netherlands); Eduward Tangdiongga (Eindhoven University of Technology, The Netherlands); Ton Koonen (COBRA, Eindhoven University of Technology, The Netherlands)

We demonstrate the successful co-transmission of 7 standard-compliant 64-QAM LTE-A bands and 2Gb/s 4-PAM over 35m of 1mm core diameter GI-POF and 3.5m LOS and NLOS wireless links. This demonstrates the suitability of POF for the next-generation home-appliance wireless-wired services.

Optical Beating Interference Reduction by Using Optical Pulse Division Multiplexing in IM/DD based OFDMA-PON Uplink

Sun-Young Jung, Chang-Hun Kim, Sang-Min Jung and Sang-Kook Han (Yonsei University, Korea)

Optical beating interference (OBI) hinders signal detection in IM/DD based multiple access with single nominal wavelength. Optical pulse division multiplexing based OBI reduction is proposed and experimentally demonstrated in OFDMA-PON uplink by considering spectrum broadening and near-orthogonality.

Real-Time Demonstration of an Optically Powered Radio Head for Low-Power Small Cells with 94 dB End-to-End Budget

Bernhard Schrenk (AIT Austrian Institute of Technology, Austria); Thomas Zemen (AIT Austrian Institute of Technology GmbH, Austria)

End-to-end analogue down- and uplink radio transmission with real-time signal processing is experimentally demonstrated using a technologically lean and energy-conscious remote radio head. Powering through the fronthaul at an optical feed of 290 mW enables a centralised power supply.

Multilevel Pulse Width Modulation Fibre Optic Transmission for Next Generation Mobile Fronthaul

Paola Parolari and Alberto Gatto (Politecnico di Milano, Italy); Lorenzo Combi (DEIB Politecnico di Milano, Italy); Pierpaolo Boffi, Mario Martinelli and Umberto Spagnolini (Politecnico di Milano, Italy)

Multilevel pulse width modulation for optical C-RAN fronthaul is proved and compared with standard pulse width modulation for aggregated LTE channels. Transmission over 7.5-km SSMF in a WDM PON fronthaul network is experimentally demonstrated for 16 LTE-64QAM aggregated channels.

Energy-Efficient Cycle Length Compressing Scheme for TDM based Passive Optical Network

Yunxin Lv, Ning Jiang and Chenpeng Xue (University of Electronic Science & Technology of China, P.R. China); Kun Qiu (University of Electronic Science and Technology of China, P.R. China)

An energy-efficient scheme based on cycle length compressing is proposed and analysed. By periodically compressing polling cycle length, longer sleeping time as well as substantial energy saving are obtained at ONU.