We discuss the principle challenges of major optical telecommunication companies.

Microsoft, USA.

Passive Optical Networks have seen a dramatic growth over the past decade. There are now many large deployments, such as those in the US, Japan, and China, and the total number of homes passed with PON technology is approaching 200 million. We have also seen an alphabet soup of PON technologies, including B, E, G, 10GE, XG, and TWDM. But the one constant in all of this is that PON development and deployment is as difficult as it is rewarding. This panel brings together representatives of operator and vendor companies that are the driving force behind this wave of ultra-broadband deployment. This will be a great forum to hear of their experiences, discoveries, happy accidents, and expensive lessons.

Presiders: Frank Effenberger, FutureWei Technologies, Inc. USA; Thomas Pfeiffer, Nokia Bell Labs, Germany

Integrated photonics provides significant opportunities to develop highly compact and extremely functional components and subsystems for a wide range of communication and sensor applications. However, photonic integration brings with it unique manufacturing and packaging challenges, which can limit the commercial exploitation of novel integration concepts and slow the time-to-market. These challenges can be economic or technical in nature, and are often most apparent during the transition from prototype development to manufacturing. This symposium will provide a balanced view of the promises and challenges of integrated photonics, and it will focus on what is being done to get beyond the many roadblocks in order to enable a much larger market adoption. During the symposium, leaders in the field will address applications in traditional and non-traditional markets for integrated photonics, finding the right fabrication model using MPW or custom processing services, choosing Si versus InP platforms, optical and electrical packaging approaches, and other fundamental component challenges.

Speakers (in speaking order)
Roe Hemenway, Macom, USA
Dominic Goodwill, Huawei, Canada
Pascual Munoz, VLC, Spain
John Bowers, Univ. of California Santa Barbara, USA

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M2C.1 • 13:30
FPGA-based Real-Time Receiver for Nyquist-FDM at 112 Gbit/s Sampled with 32 GSa/s, Benedikt Baerle, Ame Josten1, Marco Effenberger1, Edwin Dornbirner1, David HillerKuss1, Juerg Leuthold1, ETH Zurich, Switzerland. We demonstrate an efficient multi-format real-time Nyquist-FDM receiver implemented on a single FPGA. The single-polarization receiver with only 8/7 oversampling receives 56 Gbit/s 4QAM and 112 Gbit/s 16QAM transmitted over 300 km SSMM.

M2C.2 • 13:45
Simple Frequency-domain Hybrid-QAM Superchannel with Path-fitted Pre-filtering and Collaborative-subcarrier Frequency Self-tuning for Flexible ROADM Systems, Takahiro Kodama1, Masashi Binkai1, Yu Sun1, 1Optical Communication Technology Department, Mitsubishi Electric Corporation Information Technology R&D Center, Japan. Flexible spectral efficiency was demonstrated by a frequency-domain hybrid-QAM based 400 Gbit/s superchannel with path-fitted pre-filtering. Subcarrier frequency tuning was also evaluated through offline emulation of laser frequency drift, and mitigated a 2.1 dB Q degradation.

M2C • Symposium: Overcoming the Challenges in Large-Scale Integrated Photonics
Presiders: Po Dong; Nokia, USA; Erik Pennings; 7 Pennies, USA

M2C.3 • 14:00
Non-traditional Markets for Integrated Photonics, Frank Effenberger, FutureWei Technologies, Inc., USA; Thomas Pfeiffer, Nokia Bell Labs, Germany

M2D • Symposium: Advances in Multi-core Fiber Transmission Systems
Presiders: Benn Thomsen; Univ. College London, UK

M2D.1 • 13:30
Transmission of Data at 160 Gbit/s over 40 km of Optical Fiber using a PAM-2 Digital Signal Modulation with a 128-QAM Format, Benedikt Baerle, Ame Josten, Marco Effenberger, Edwin Dornbirner, David HillerKuss, Juerg Leuthold, ETH Zurich, Switzerland

M2D.2 • 13:45
Highly Non-linear Resilient and Adaptive Designs for Advanced Digital Signal Processing, Benedikt Baerle, Ame Josten, Marco Effenberger, Edwin Dornbirner, David HillerKuss, Juerg Leuthold, ETH Zurich, Switzerland

M2E • Symposium: Lessons Learned From Global PON Deployment
Moderators: Frank Effenberger, FutureWei Technologies, Inc. USA; Thomas Pfeiffer, Nokia Bell Labs, Germany

14:00–15:30 M2D • SDM Transmission I
Presider: Cristian Antonelli; Universita degli Studi dell’Aquila, Italy

M2E.1 • 13:30
Open Undersea Cable Systems for Cloud Scale Operation, Tim Stuch, Jamie Gaudette, Microsoft, USA. A true open cable system is designed specifically to operate in a disaggregated, vendor agnostic manner. We outline Microsoft’s approach to open cable systems and discuss the technical challenges.

M2E.2 • 13:45
SDM for Power Efficient Transmission, Yu Sun1, Oleg V. Sinkin1, Alexey v. Tunukhin1, Maxim A. Bolkhtyansky1, Dmitri Foussa1, Alexei Pilipetski1, ‘TE SubCom, USA. We discuss the principles behind the use of space division multiplexing for power efficient transmission in optical fiber communication systems. Experimental demonstration of these principles are realized in a multicore fiber transmission system.
We propose an SDN-enabled orchestration for converged network scenario. In this talk we review ONF SDN architecture and network modeling, Lyndon Ong, Ciena Corporation, USA. This talk reviews ONF SDN standards development for transport networks, focusing on the Transport API (TAPI) NorthBound Interface. This includes basic concepts and modeling, TAPI open source SDK and recent TAPI interop testing, in the context of related industry work such as IETF YANG models.

Integrating Wireless BBUs with Optical OFDM Flexible-grid Transponders in a C-RAN Architecture, Avishek Nag, Yi Zhang, Luiz DaSilva, Linda Doyle, Marco Ruffini, Trinity College Dublin, Ireland. We propose a case study on hardware-level virtualisation of C-RAN BBUs and optical flex-grid OFDM transponders, showing cost savings of integrating fixed and mobile network devices in a realistic converged network scenario.
Room 402AB

M2A • Panel: Lessons Learned From Global PON Deployment—Continued

Room 403A

M2B • Symposium: Overcoming the Challenges in Large-Scale Integrated Photonics I—Continued

Room 403B

M2C • Coherent Transceivers—Continued

Room 404AB

M2D • SDM Transmission I—Continued

Room 406AB

M2E • Advanced and Open Systems—Continued

Room 407

M2F • New Fiber Concepts—Continued

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**Room 402AB**

M2A • Panel: Lessons Learned From Global PON Deployment—Continued

**Room 403A**

M2B • Symposium: Overcoming the Challenges in Large-Scale Integrated Photonics I—Continued

**Room 403B**

M2C • Coherent Transceivers—Continued

**Room 404AB**

M2D • SDM Transmission I—Continued

**Room 406AB**

M2E • Advanced and Open Systems—Continued

**Room 407**

M2F • New Fiber Concepts—Continued

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**M2C.3 • 14:00**

Colorless C-Band WDM System Enabled by Coherent Reception of 56-Gb/s PDM-16QAM Using an High-bandwidth ICR with TiAs, Robert Emmerich1, Robert Elschner1, Carsten Schmidt-Langhorst1, Gijs v. Elzakker1, Jan Hoffmann1, Andreas Umbach1, Colja Schubert1; Fraunhofer Heinrich Hertz Inst., Germany; 1Finisar Germany GmbH, Germany. We demonstrate error-free 80-km transmission of a 400-Gb/s channel in a colorless coherent C-band WDM system using a high-bandwidth micro-ICR. The WDM channels are colorlessly combined at the transmitter and colorlessly split/ detected at the receiver.

**M2C.4 • 14:15**

A Memory Polynomial Based Digital Pre-distorter for High Power Transmitter Components, Ginni Khanna1, Benhard Spinnler2, Stefano Calabro2, Erik De Man1, Uwe Feister1, Tomislav Drenski1, Norbert Hanik1; Technical Univ. of Munich, Germany; 1Comant R&D GmbH, Germany; 2Socionext Europe GmbH, UK. An adaptive digital pre-distortion method based on memory polynomials to compensate for non-linearities in high power optical transmitters is presented. Gains up to 2dB for DP-64QAM are achieved beyond linear pre-distortion.

**M2D.1 • 14:00**

12 Mode, MIMO-free OAM Transmission, Kasper Ingerslev1, Patrick Gregory1, Michael Gilli1, Francesco Da Ros1, Hao Hu1, Fangdi Bao1, Mario A. Usuga Castaneda1, Paul Kristensen1, Andrea Rubano1, Lorenzo Marrucci1, Siddharth Ramachandran1, Karsten K. Rottwitt1, Toshio Morikawa1, Leif K. Oxenlowe1; 1Department of Photonics Engineering, Technical Univ. of Denmark, Denmark; 2Electrical and Computer Engineering Department, Boston Univ., USA; 3OFS-Fitel, Denmark; 4Dipartimento di Fisica, Università di Napoli Federico II, Italy. Simultaneous MIMO-free transmission of a record number (12) of orbital angular momentum modes over 1.2 km is demonstrated. WDM compatibility of the system is shown by using 60 WDM channels with 25 GHz spacing and 10 Gb/s QPSK.

**M2D.2 • 14:15**

5Tb/s Transmission Over 2.2 km of Multimode OM2 Fiber with Direct Detection Thanks to Wavelength and Mode Group Multiplexing, Kaoutar Benyahya1, Christian Simonneau1, Amithossein Ghazaeaeidi1, Nicolas Barrié1, Pu Jian1, Jean-François Morzur1, Guillaume Labroille1, Pierre Sillard1, Jérémie Renaudier1, Gabriel CHARLET1; 1Nokia Bell Labs Paris Saclay, France; 1Prysmian Group, France. We demonstrate 5Tb/s bidirectional transmission (2.5Tb/s in each direction) over 2.2km of OM2 fiber using selective excitation of 4 mode groups and WDM multiplexing with DMT modulation and direct detection.

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**Room 404AB**

**M2E.2 • 14:00**

Lessons Learned from Open Line System Deployments, Valéy Kamalov1, Vinayak Dangui1, Tad Hofmeister1, Bikash Koley1, Chris Mitchell1, Matt Newland1, John O’Shea1, Cody Tomblin1, Vijay Vusirikala1, Xiaoxue Zhao1; Google, Inc., USA. We present on the design and operational aspects of our open line system approach for overcoming cost, capacity and flexibility limitations. Dramatic growth of datacenter traffic was supported by separation of the terminal equipment from the optical layer allowing the introduction of multi-vendor, best-of-breed coherent terminal equipment.

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**Room 406AB**

**M2F.2 • 14:00**

Phosphate Glass Fibers for Optical Amplifiers and Biomedical Applications, Daniel Milanese1, Diego Puggliese1, Nadia G. Boetti1, Edoardo Cecinigrestelli1, Davide Janner1, Vincenzo M. Sglov1, Chiara Vitale-Brovarone1, Joris Lousteau1; 1Department of Applied Science and Technology, Politecnico di Torino, Italy; 2IFN, CNR, Italy; 3Applied Photonics, Istituto Superiore Mario Boella, Italy; 4Optoelectronics Research Centre, Univ. of Southampton, UK; 1Department of Industrial Engineering, Università di Trento, Italy. Phosphate glass optical fibers were designed and fabricated for applications in the fields of remote sensing and biomedicine. Main results are reported together with the recent developments.
M2G • Metro and 5G Transport—Continued

M2G.3 • 14:00 Invited
Benefits of Programmability in 5G Transport Networks, Muhammad Rehan Raza1, Matteo Fiorani1, Ahmad Rostami1, Peter Ohi1, Lena Wosinska1, Paolo Monti1; 1KTH Royal Inst. of Technology, Sweden; 2Ericsson AB, Sweden.
This paper shows how programmability can improve operators’ revenues and it presents a dynamic resource slicing policy that leads to more than one order of magnitude better resource utilization levels than conventional (static) allocation strategies.

M2I • Deployable Optical Access and Edge Networks—Continued

M2I.3 • 14:00 Invited
The Evolution of Outside Plant Architectures Driven by Network Convergence and New PON Technologies, Kevin L. Bourg1; 1Corning Optical Communications, USA.
We show that convergence of access networks together with new PON standards drive lower bandwidth cost, which in turn due to elasticity of demand results in larger number of users. According to Metcalfe’s law that came into existence in 1980’s and explained the wide adoption of Ethernet cards, increase in network value will scale quadratically with the number of users, thus making convergence and new PON standards so valuable to network operators.

M2J • Optical Frequency Combs and Their Applications—Continued

M2J.2 • 14:00
Towards an Integrated-photonics Optical-Frequency Synthesizer With <1 Hz Residual Frequency Noise, Daryl T. Spencer1, Aaron Bluestone2, John E. Bowers1, Travis C. Bribes, Scott Diddams1, Tara Drake1, Robert Ilic2, Tobias Kippenberg1, Tin Komljenovic2, Seung H. Lee1, Qing Li1, Nathan Newbury1, Erik Norberg1, Dong Y. Oh1, Scott Papp1, Pfeiffer Martin Hubert Peter1, Laura Sinclair1, Kartik Srinivasan1, Jordan Stone1, Myoung-Gyun Suh1, Luke Theogarajan1, Kerry Vahala1, Nicholas Volet1, Daron Westley1, Kiyoul Yang2; 1National Inst of Standards & Technology, USA; 2Univ. of California Santa Barbara, USA; 3National Inst. of Standards and Technology, USA; 4Ecole Polytechnique Federale de Lausanne, Switzerland; 5California Inst. of Technology, USA; 6Aurrion Inc., USA.
We introduce an architecture for optical-frequency synthesis using photonic-chip frequency combs and a heterogeneously integrated CW laser. The Kerr dual-comb that we describe offers a microwave-optical link to discipline the laser to an RF clock.

M2J.3 • 14:15
Comb-Assisted Real-time Discrete Fourier Transform Processor, Huan Hu1, Daniel Eisman1, Vahid Ataie1, Eduardo Temprana1, Bill Kuo1, Nikola Alic1, Stojan Radic2; 1UCSD, USA.
We present a high-speed flexible photonic-assisted Discrete Fourier Transform (DFT) processor based on a dual, phase-locked optical parametric combs. A 25-point DFT at 500 Million-DFT-point per second throughput is achieved relying on slow, 20 MS/s Analog to Digital Converter (ADC).
Room 403A
M2A • Panel: Lessons Learned From Global PON Deployment—Continued

Room 403B
M2C • Coherent Transceivers—Continued

Room 404AB
M2D • SDM Transmission I—Continued

Room 406AB
M2E • Advanced and Open Systems—Continued

Room 407
M2F • New Fiber Concepts—Continued

M2A • Panel: Lessons Learned From Global PON Deployment—Continued

Maxim Kuschnerov is a Senior R&D Manager at Huawei Technologies in Munich working on innovation projects. He earned his doctorate in 2011 from the University of the Bundeswehr on digital signal processing for optical DSPs. In 2010, he joined Nokia Siemens Networks in R&D, developing 100Gbps transceivers. In parallel, he was a project lead for developing space division multiplexing network technology based on solid core and hollow core fibers. In 2014, he moved to product line management at Coriant creating the Groove G30 data center interconnect product and managing the ultra-long haul transport system hit 7300.

M2B • Symposium: Overcoming the Challenges in Large-Scale Integrated Photonics I—Continued

M2C • Coherent Transceivers—Continued

M2D • SDM Transmission I—Continued

M2E • Advanced and Open Systems—Continued

M2F • New Fiber Concepts—Continued

M2G • Panel: Challenges in Large-Scale SDM Transmissions—Continued

M2H • Symposium: Improving SDM Transmission Technology II

M2I • Tutorial: Nonlinear Effects and their Impact on Transmission Systems—Continued

M2J • Symposium: New Fiber Developments—Continued

M2K • Coherent Transceivers: From Algorithm Design to Economics, Maxim Kuschnerov1, Huawei Technologies Duesseldorf GmbH, Germany. The divide between generic 100G coherent interfaces and differentiations in solutions is widening. A DSP invest in the age of white box transmission is a careful decision, discussed from a technological and economic point of view.

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M2A • Panel: Lessons Learned From Global PON Deployment—Continued

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M2C • Coherent Transceivers—Continued

M2D • SDM Transmission I—Continued

M2E • Advanced and Open Systems—Continued

M2F • New Fiber Concepts—Continued

M2G • Panel: Challenges in Large-Scale SDM Transmissions—Continued

M2H • Symposium: Improving SDM Transmission Technology II

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M2C • Coherent Transceivers—Continued

M2D • SDM Transmission I—Continued

M2E • Advanced and Open Systems—Continued

M2F • New Fiber Concepts—Continued

M2G • Panel: Challenges in Large-Scale SDM Transmissions—Continued

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M2A • Panel: Lessons Learned From Global PON Deployment—Continued

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M2B • Symposium: Overcoming the Challenges in Large-Scale Integrated Photonics I—Continued

M2C • Coherent Transceivers—Continued

M2D • SDM Transmission I—Continued

M2E • Advanced and Open Systems—Continued

M2F • New Fiber Concepts—Continued

M2G • Panel: Challenges in Large-Scale SDM Transmissions—Continued

M2H • Symposium: Improving SDM Transmission Technology II

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M2A • Panel: Lessons Learned From Global PON Deployment—Continued

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M2B • Symposium: Overcoming the Challenges in Large-Scale Integrated Photonics I—Continued

M2C • Coherent Transceivers—Continued

M2D • SDM Transmission I—Continued

M2E • Advanced and Open Systems—Continued

M2F • New Fiber Concepts—Continued

M2G • Panel: Challenges in Large-Scale SDM Transmissions—Continued

M2H • Symposium: Improving SDM Transmission Technology II

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Dynamic Placement of BaseBand Processing in 5G WDM-based Aggregation Networks, Francesco Musumeci, Giuseppe Belgiovine, Massimo Tornatore, Politecnico di Milano, Italy. We propose and compare different baseband-processing placement strategies in optical aggregation networks. Proper trade-off between baseband-resources consolidation and network blocking can be obtained by dynamically adapting location of processing resources to traffic conditions.

Core VNT Adaptation Based on the Aggregated Metro-Flow Traffic Model Prediction, Fernando Morales, Marc Ruiz, Luis Velasco, Universitat Politècnica de Catalunya, Spain. We propose a model to compute and configure flexi-grid optical networks. Besides presenting new PCEP extensions, performance evaluation compares PCE-based solution with traditional distributed signaling approach.

Cascading of Tenant SDN and Cloud Controllers for 5G Network Slicing using Transport API and Openstack API, Arturo Mayoral, Victor Lopez, CTTC, Spain. We provide a demonstration of the proposed concept.

Managing Service Quality in a Software Defined Network, Jennifer M. Yates, AT&T, USA. We discuss the realistic challenges of network operation and new services for carriers’ metro transport networks. A new metro transport architecture is proposed and evaluated.

Uncompressed 8K Ultra-high Definition Television Transmission over 100G Ethernet in Broadcasting Station, Junichiro Kawamoto, Takuya Kurasaki, Japan Broadcasting Corporation, Japan. We present experiments combining high core-count, homogeneous single-mode multi-core fibers and demonstrate wideband transmission with coded modulation up to 12,300 km.

Experiences and Future Perspective of China Telecom on Optical Access Networks, Chengbin Shen, Shanghai Inst. of China Telecom, China. As the largest FTTH operator in the world, China Telecom faced with technical and engineering issues during FTTH deployment and operation. In the paper, China Telecom’s experience and technical innovation on FTTH networks were given. Moreover, China Telecom’s vision on future FTTH network, including technology upgrades, software-defined access networks and centralized office re-architecture as edge DC, were presented.

High Capacity MCF Transmission with Wideband-Combi, Benjamin J. Puttnam, Ruben S. Luis, Georg Rademacher, Jun Sakaguchi, Werner Klaus, Erik Agrell, John Martiante, Y. Awa!, Naoya Wada, National Inst Info & Comm Tech (NICT), Japan. Signals and Systems, Chalmers Univ. of Technology, Sweden; RAM Photronics, LLC, USA. We describe experiments combining high core-count, homogeneous single-mode multi-core fibers with a wideband comb for high-capacity transmission without high-order MIMO reception and demonstrate wideband transmission with coded modulation up to 12,300 km.

We propose and compare different baseband-processing placement strategies in optical aggregation networks. Proper trade-off between baseband-resources consolidation and network blocking can be obtained by dynamically adapting location of processing resources to traffic conditions.

We provide a demonstration of the proposed concept.

We discuss the realistic challenges of network operation and new services for carriers’ metro transport networks. A new metro transport architecture is proposed and evaluated.

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### M2A • Panel: Lessons Learned From Global PON Deployment—Continued

- Room 402AB

### M2B • Symposium: Overcoming the Challenges in Large-Scale Integrated Photonics I—Continued

- Room 403A

### M2C • Coherent Transceivers—Continued

- Room 403B

### M2D • SDM Transmission I—Continued

- Room 404AB

### M2E • Advanced and Open Systems—Continued

- Room 406AB

### M2F • New Fiber Concepts—Continued

- Room 407

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**M2D.5 • 15:15**

3x10 Gb/s Mode Group-multiplexed Transmission over a 20 km Few-Mode Fiber Using Photonic Lanterns, Huiyuan Liu1, He Wen1,2, Juan Carlos Alvarado Zacarias1, Jose Antonio-Lopez1, Ning Wang1, Pierre Sillard1, Adrian Amezcua-Correa1, Rodrigo Amezcua Correa1, Guifang Li1,2, 1CREOL, The College of Optics & Photonics, Univ. of Central Florida, USA; 2The College of Precision Instruments and Opto-electronic Engineering, Tianjin Univ., China; 3Prysmian Group, France. We experimentally demonstrate 3x10 Gb/s mode group-multiplexed transmission with direction detection in a step-index few-mode fiber over a record reach of 20 km, enabled by low crosstalk photonic lanterns as mode group (de)multiplexers.

**M2E.6 • 15:15**

Shake Before Break: Per-Span Fiber Sensing with In-Line Polarization Monitoring, Jesse E. Simsarian1, Peter Winzer1, 1Nokia Bell Labs, USA.

Fast state-of-polarization transients induced by transmission-fiber disturbances can indicate an imminent fiber break even in the absence of transmission errors. We present a simple in-line polarization monitoring scheme that detects fiber disturbances, enabling proactive protection.

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**15:30–16:00**  **Coffee Break, 400 Foyer**
M2G • Metro and 5G Transport—Continued

M2H • Control Architecture and Network Modeling I—Continued

M2I • Deployable Optical Access and Edge Networks—Continued

M2J • Optical Frequency Combs and Their Applications—Continued

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M2G.7 • 15:15 Top-scored
Cost-Effectiveness Assessment of Transport Networks based on Disaggregated Optical Platforms, Joao Santos1, Nelson Costa, João Pedro1,2; Coriant Portugal, Portugal; Instituto de Telecomunicações, Portugal. This paper compares the routing performance between disaggregated and proprietary optical line systems. Network simulations show that disaggregated solutions attain minimal traffic blocking while reducing OEO interface count with respect to multi-vendor deployments.

M2I.6 • 15:15
Strategies for VNF Placements in Large Provider Networks, Ashwin Gumaste1, Sidharth Sharma2, Tamal Das1, Aniruddha Kushwaha1; Indian Inst. of Technology, Bombay, India. We examine three strategies of VNF placement in a provider network: static service chains; seamless VNF duplication and VNF-dynamic-splitting. A constrained optimization applied to a large provider evaluates these strategies and showcases cost-latency trade-off.

M2J.6 • 15:15
Mitigation of Electrical Bandwidth Limitations using Optical Pre-sampling, Zihan Geng1, Bill Corcoran1,3, Andreas Boes1, Arnan Mitchell2,3, Leimeng Zhuang1, Yiwei Xie1, Arthur Lowery1,3; Dept. of Electrical and Comp. System Eng., Monash Univ., Australia; School of Engineering, RMIT Univ., Australia; Centre for Ultrahigh-bandwidth Devices for Optical Systems (CUDOS), Australia. We propose a novel method to improve a system degraded by a low receiver electrical bandwidth. With optical pre-sampling, 4-dB sensitivity improvement at the 7% hard FEC limit is experimentally demonstrated.

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15:30–16:00 Coffee Break, 400 Foyer
The dynamic compute model provided by the cloud has gained acceptance by business and consumer markets. A new network is required to match the resource scalability, faster automated service deployment model and high resource utilization of the cloud. The promise of Transport SDN to fulfill these requirements has been shown in various demonstrations, proof of concepts and by early adopters. The industry is working to define it in standards bodies for production use in NFV, cloud and IoT.

This panel will discuss what it takes to operationalize Transport SDN. We will discuss business drivers, use cases, progress in standards and prototypes shown to date. We will further discuss what can be put into production now, related technologies such as SD-WAN and what the future holds for new Transport SDN capabilities.

Panelists:
Victor Lopez, Telefonica, Spain
Naoki Miyata, NTT Communications, Japan
Kathy Tse, AT&T, USA

We report on micro-

KF, IBM, USA; Karthik Sethuraman; NEC, USA

M3C.1 • 16:00 Invited
Spectrally-Efficient Single-carrier 400G Transmission Enabled by Probabilistic Shaping, Yanjun Zhu1, An Li2, Wei-Ren Peng2, Clarence Kan1, Zhizhang Li1, Samina Chowdhury1, Yan Cui1, Yusheng Bai1, Futurewei Technologies, Inc, USA. We report experimental results of Probabilistically Shaped 64QAM (PS-64QAM) Single-Carrier 400G transmission over SSMF, in a 50 GHz wavelength grid. Up to 300% reach enhancement over regular 64QAM is achieved, thanks to probabilistic shaping.

M3C.2 • 16:15 Experimental Comparison of PM-16QAM and PM-32QAM with Probabilistically Shaped PM-64QAM, Luca Bertignano1, Dario Piloni1, Antonello Nespoli1, Fabrizio Forgieri2, Gabriella Bosco1, Politecnico di Torino, Italy; 1Istituto Superiore Mario Boella, Italy; 2Cisco Photonics Italy, Italy. We experimentally compare the performance of uniformly distributed and probabilistically shaped constellations with either the same asymptotic mutual information or the same FEC overhead, in order to assess the achievable rate gains.

M3D.1 • 16:00 Invited
Advanced Algorithm for High-baud Rate Signal Generation and Detection, Zhihong Li1, Hong-Chang Chien2, 'ZTE (Ta), USA. We review recent progress on the high-baud rate signal generation and detection, and the corresponding advanced algorithms used in the transmitter- and receiver-side for signal pre- and post- equalization and compensation, respectively.

M3D.1 • 16:00 Invited
Techniques for Highly Linear Radio-over-Fiber Links, Thomas R. Clark1, Jean H. Kalkavage1, Eric J. Adles1, JHU/APL, USA. Hybrid fiber-wireless systems offer the promise of efficient high capacity fiber-optic class data delivery to mobile and fixed wireless devices. Achieving this promise will require systems employing highly linear techniques.

M3E • Radio-over-fiber Systems
Presider: Rod Waterhouse; Pharad, LLC, USA

M3E.1 • 16:00 Invited
Techniques for Highly Linear Radio-over-Fiber Links, Thomas R. Clark1, Jean H. Kalkavage1, Eric J. Adles1, JHU/APL, USA. Hybrid fiber-wireless systems offer the promise of efficient high capacity fiber-optic class data delivery to mobile and fixed wireless devices. Achieving this promise will require systems employing highly linear techniques.

M3F.1 • 16:00 Experimental Investigation of the Effect of EDFA-generated ASE Noise Added to the Pump of a Kerr Frequency Comb, Peicheng Liao1, Changing Bao1, Arne Kordts1, Karpov Maxm1, Pfeiffer Martin Hu1, Lin Zhang1, Yinwen Cao1, Ahmed Almam1, Morteza Ziyadi1, Amrhossein Mohajeri Anaei1, Fatemeh Ali-Shahi1, Ahmad Fallahpour1, Minah Turi1, Tobias Kippenberg1, Alan Willner1; 1Electrical Engineering, Univ. of Southern California, USA; 2Ecole Polytechnique Federale de Lausanne, Switzerland; 3Precision Instrument and Opto-electronics Engineering, Tianjin Univ., China; 4Electrical Engineering, Tel Aviv Univ., Israel. We experimentally investigate the effect of EDFA-induced pump ASE noise on cavity-soliton Kerr combs for 64-QAM transmission. We find that all comb optical carrier-to-noise ratios (OCNRs) are similar with a fixed pump OCNR and comb linewidths almost remain unchanged.

M3F.2 • 16:15 High-Efficiency WDM Sources Based on Microresonator Kerr Frequency Combs, Xiaoxiao Xue1,2,3, Pei-Hsun Wang1, Yi-Xuan1, Minghao Qi1, Andrew Weiner1, 1Tsinghua Univ., China; 2Purdue Univ., USA. We report on micro-combs that achieve ~30% conversion efficiency (~200 mW on-chip comb power) and comb linewidths of 1.5 nm and with an average 7 dBm per comb line.
We demonstrate the first symmetric 100G-PON. First Demonstration of Symmetric 100G-PON in O-band with 10G-Class Optical Devices Enabled by Dispersion-supported Equalization, Lei Xue, Lin Yi, Honglin Ji, Peixuan Li, Weisheng Hu, Shanghai Jiao Tong Univ., China. We demonstrate the first symmetric 100G-PON based on 10Gbps optical devices supporting 20-km reach in O-band. Dispersion-supported equalization enables 25.78-Gb/s NRZ-OOK modulation/detection based on DMLs/APDs with a combined 3-dB bandwidth of 5 GHz.

Dynamic Wavelength Allocation and Rapid Wavelength Tuning for Load Balancing in A-tunable WDM/TDM-PON, Yumiko Seno, Kota Asaka, Jun-ichi Kani, Access Network Service Systems Laboratories, NTT, Japan. Dynamic load balancing (DLB) among OLT-ports can keep good user experience by preventing heavy users from occupying the bandwidth. To realize DLB, we present a dynamic wavelength allocation algorithm and a rapid wavelength tuning sequence.

Polarimetry of Polarization-Modulated Signals Based on Polarization-Selective RF Power Detection, Reinhold Noe1,2, Benjamin Koch1,2, Vitali Mirvoda1, Paderborn Univ., Germany, Novoptel GmbH, Germany. A novel polarimeter identifies the main polarization axes of polarization-modulated, nominally unpolarized signals such as PDM-QPSK, PDM-QAM, PS-QPSK. It measures the electrical AC power detected behind several polarization analyzers and calculates the axes iteratively.

In-service Crosstalk Monitoring for Dense Space Division Multiplexed Multi-core Fiber Transmission Systems, Takayuki Mizuno1, Akira Isoda1, Kohki Shibahara1, Yutaka Miyamoto1, Saurabh Jain2, Carlos Castro3, Klaus Pulverer1, Reinhold Noe1,2. We transmit 25.78-Gb/s NRZ-OOK in-service 32-core MC-EYDFA, 32-core DSDM transmission line incorporating cladding-pumped 32-core MC-EYDFA, and demonstrate −30 dB crosstalk monitoring without affecting transmission performance.

Optical Data Center Management for Future PON, Leif Oxenløwe1,2, DTU Fotonik, Denmark. We present in-service inter-core crosstalk monitoring for MCF transmission systems. We transmit 54-WDM PDM-16QAM signals over 111.6-km 32-core DSM transmission line incorporating cladding-pumped 32-core MC-EYDFA, and demonstrate −30 dB crosstalk monitoring without affecting transmission performance.
We experimentally demonstrated that a 1Tb/s transmitter, using only a low complexity dual-carrier architecture with free running lasers and DP-64QAM, enabled by pilot-aided DSP and low-rate LDPC, is shown to achieve transmission over 400km with 100km amplifier spacing.

A Simplified Dual-Carrier DP-64QAM 1 Tb/s Transceiver, David Millar1, Lida Galdino1, Robert Maher1, Milutin Pajovic1, Toshiaki Koike-Akino1, Dominic Lavery2, Gabriel Saavedra1, Daniel Elson1, Kai Shi1, Mustafa S. Erkilinc2, Eric Sillekens1, Robert Killey1, Benn C. Thomson1, Keisuke Kojima1, Kieran Parsons1, Polina Bayvel1, ‘Mitsubishi Electric Research Labs, USA; 1Univ. College London, UK. A 1Tb/s net bitrate transceiver using a low complexity dual-carrier architecture with free running lasers and DP-64QAM, enabled by pilot-aided DSP and low-rate LDPC, is shown to achieve transmission over 400km with 100km amplifier spacing.

246 GHz Digitally Stitched Coherent Receiver, Kai Shi1, Eric Sillekens1, Benn C. Thompson1, ‘Univ. College London, UK. Phase estimation and 4+2 MIMO equalization techniques are experimentally compared for digital frequency stitching in ultra-wideband coherent reception, using time multiplexing and a single conventional dual polarization coherent receiver, to simultaneously detect a 5×46Gb/s super-channel.

Real-Time Demonstration of over 20Gbps V- and W-Band Wireless Transmission Capacity in one OFDM-RoF System, Xinying Li1,2, Xin Xiao1, Yuming Xu1, Kaehui Wang1, Li Zhao1, Jianjun Yu1,2; ‘ZTE (TX) Inc., USA; ‘Key Laboratory for Information Science of Electromagnetic Waves (MoE), Fudan Univ., China; ‘Georgia Inst. of Technology, USA; ‘ZTE (TX) Inc., USA; ‘Beijing Univ. of Posts and Telecommunications, China. We experimentally demonstrated the generation and transmission of 60-Gb/s (10-Gbaud) 91-GHz 64QAM-modulated mm-wave signal over 20km SMF-28 and 3-m wireless distance, with BER under 2×10^-3. Receiver-based T-spaced DD-LMS equalization significantly improves the system performance.

Cavity-less 50GHz Frequency Comb Generation by Comb Pitch Multiplication, Bofang Zhang2, Qiye Xie2, Chester Shu1, ‘Chinese Univ. of Hong Kong, USA. A cavity-less optical frequency comb is generated with accurate 50-GHz comb pitch using a 10-GHz RF source via the temporal Talbot effect. The comb is implemented as a Nyquist-shaped 32-Gbaud 16-QAM data transmitter.
M3H.3 • 16:30  Invited  DSP-Based Multi-Band Schemes for High Speed Next Generation Optical Access Networks, Jinlong Wei1; Optical Technology Department, Huawei Technologies Duesseldorf GmbH, European Research Center, Germany. 40-Gb/s/λ long reach multi-band CAP PONs using 10G-class transceivers were demonstrated with transmission over an 80-km (90-km) SMF and a link power budget of 33 dB (29 dB) considering a FEC threshold BER of 3.8×10⁻³.

M3I.2 • 16:30  Feasibility Demonstration of Low Latency DBA Method with High Bandwidth-efficiency for TDM-PON, Saki Hatta1, Nobuyuki Tanaka1, Takeshi Sakamoto1; NTT Corporation, Japan. We propose a DBA method with an adaptive DBA cycle for TDM-PON based MFH and campus LANs. Experiments show that the method achieves minimum latency of 60 μs and high bandwidth efficiency, depending on traffic.

M3I.3 • 16:45  Virtual Dynamic Bandwidth Allocation Enabling True PON Multi-Tenancy, Amr Elrasad1, Nima Afraz1, Marco Ruffini1; CONNECT, Trinity College Dublin, the Univ. of Dublin, Ireland. We propose a virtual-DBA architecture enabling true PON multi-tenancy, giving Virtual Network Operators full control over capacity assignment algorithms. We achieve virtualization enabling efficient capacity sharing without increasing scheduling delay compared to traditional (non-virtualized) PONs.

M3J.3 • 16:30  Real-time Path Monitoring of Optical Nodes, Takayuki Kurosu1, Satoshi Suda1, Kiyohisa Ishii1, Shu Namiki1; Natl Inst of Adv Industrial Sci & Tech, Japan. We demonstrate a novel method for monitoring internal paths of optical nodes exploiting light labeling technique. The optical paths of a 2x2 wavelength cross connect could be monitored in 2ms without affecting transmission performance.

M3J.4 • 16:45  All-optical Reconfigurable Time-lens Based Signal Processing, Jeonghyun Huh1, Jose Azana1; INRS, Canada. All-optical reconfigurable time-to-frequency conversion and temporal magnification of optical waveforms is proposed and experimentally demonstrated using a XPM-based time lens by exploiting chirp rates being directly proportional to the peak power of a parabolic pump pulse.
M3C • Probabilistic Shaping and Advanced Modulation Formats—Continued

M3C.4 • 17:00 🔄 On the Impact of Probabilistic Shaping on SNR and Information Rates in Multi-Stage QAM Systems, Tobias Fehnberger1, Alex Alvarado2, Georg Bächer2, Norbert Hanik1, 1Technical Univ. of Munich (TUM), Germany; 2Univ. College London, UK. Numerical simulations and the EGN model show that probabilistic shaping decreases SNR due to modulation-dependent nonlinear effects. This SNR loss, however, is less important than the rate increase from shaping, resulting in an overall gain.

M3C.5 • 17:15 🔄 100-Gb/s Complex Direct Modulation over 1600-km SSMF Using Probabilistic Transition Estimation, Di Che1, Fang Yuan1, William Sheih1, 1Univ. of Melbourne, Australia. We demonstrate single-channel 100-Gb/s polarization-multiplexed PAM-4 with 2 independent directly modulated lasers using only 12.5-GHz electrical bandwidth. By probabilistic transition estimation, this complex-modulated PAM system achieves a record distance of 1600 km.

M3D • High-Speed Subsystems—Continued

M3D.4 • 17:00 🔄 Invited Extreme Speed Power-DAC: Leveraging InP DHB for Ultimate Capacity Single-carrier Optical Transmissions, Agnieszka Konczykowska1, Jean-Yves Dupuy2, Filippe Jorge1, Muriel Riet1, Virginie Nodjiajdij2, 1III-V Lab, joint laboratory of Nokia Bell Labs, TRT and CEA/LETI, France. With 100-Gbaud operation and 4-Vpp swing, InP DHB Power-DAC enabled experiments with different types of E/O modulators. Single-carrier 100-Gbd PAM-4 DD transceiver for datacenters and 1.08-Tb/s transmitter (90-Gbd PDM-64QAM) were demonstrated.

M3D.5 • 17:30 🔄 Invited On the Use of GMI to Compare Advanced Modulation Formats, Shaoliang Zhang1, NEC Laboratories America Inc, USA. A variety of advanced modulation formats, including set-partitioning M-QAM, tone-hybrid QAM, multi-dimensional formats, geometric- and probabilistic-shaped constellation, are compared by means of GMI metric.

M3E • Radio-over-fiber Systems—Continued

M3E.4 • 17:00 🔄 Optically Generated Single Sideband Radio-over-Fiber Transmission of 60Gbit/s Over 50m at W-Band, Rafael Puerta1, Simon Rollmell1, Juan José Vegas Oslos1, Idelfonso Tafur Monroy1, 1Department of Photonics Engineering, Technical Univ. of Denmark, Denmark; 2ITMO Univ., Russia. 60Gbit/s single sideband multi-band CAP radio-over-fiber transmission at W-band is demonstrated. A spectral efficiency of 3.8bit/s/Hz and bit error rates below 3.8×10−3 are achieved after 50m wireless transmission.

M3F • Frequency Combs and Waveguide Devices—Continued

M3F.5 • 17:00 🔄 Invited Nitride-Based Devices at Telecom Wavelengths, Eva Monroy1, 1INAC-PHELIS, CEA-Grenoble, France. This presentation reviews the progress towards the development of a new technology which relies on intersubband transitions in GaN/AlN nanostuctures to achieve ultra-fast optoelectronic devices operating at telecommunication wavelengths.
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**M3E.7 • 17:45**
Fast Statistical Estimation in Highly Compressed Digital RoF Systems for Efficient 5G Wireless Signal Delivery, Mu Xu¹, Xiang Liu², Narsh Chand², Frank Effenberger², Gee-Kung Chang¹; ¹Georgia Inst. of Technology, USA; ²Huawei R&D USA, Futurewei Technologies, USA.
A fast data compression algorithm is proposed for wireless-signal delivery in a digital RoF system supporting mobile fronthaul. Combined with resampling and advanced modulation formats, data-transmission efficiency is improved by 5 times in experimental demonstrations.

**M3F.7 • 17:45**
Mode-selective Wavelength Conversion of Multicarrier, Multilevel Modulation Signals in a Multimode Silicon Waveguide, Ying Qiu², Xiang Li¹, Ming Luo², Jing Xu¹, Qi Yang¹, Shashua Yu¹; ¹WRI, China; ²Wuhan National Laboratory for Optoelectronics, Huazhong Univ. of Science and Technology, China. We design and fabricate a multimode silicon waveguide to achieve mode-selective wavelength conversions of 100-Gb/s optical signals. Experimental results show that less than 2 dB power penalties are observed after wavelength conversion for both modes.
M3H.7 • 17:45
25Gb/s PAM4 Burst-Mode System for Upstream Transmission in Passive Optical Networks, Marco Dalla Santa¹, Cleitus Antony¹, Mark Power¹, Anil Jain¹, Peter Ossieur¹, Giuseppe Talli¹, Paul D. Townsend¹; ¹Tyndall National Inst., Ireland.
A 25Gb/s PAM4 burst-mode upstream transmission is demonstrated over 25km of fiber using 10G components and a linear burst-mode TIA with a 14.7dB dynamic range and with differential chromatic dispersion equivalent to 25km of fiber.

M3K.5 • 17:45
Emulation of a 16×16 Optical Switch Using Cascaded 4×4 Dilated Hybrid MZI-SOA Optical Switches, Minsheng Ding¹, Adrian Wonfor¹, Qixiang Cheng¹, Richard Penty¹, Ian H. White¹; ¹Department of Engineering, Univ. of Cambridge, UK.
We demonstrate the first cascaded operation of integrated 4x4 hybrid MZI-SOA optical switches. Experimental studies emulate a 16×16 hybrid switch with 15dB IPDR for 1dB penalty and 43% reduced power consumption than equivalent SOA-based switches.
Within the last decade, coherent DSP technology has emerged as the key enabler for optical transmission at rates from 100 Gbps up to 400 Gbps per wavelength. Today, around seven vendors introduce high-performance silicon-based reconfigurable optical add-drop multiplexer for hybrid MDM-WDM systems, with an emphasis on links using short-wavelength VCSELs and PAM-4 modulation.

Up to now, this competition seems to drive innovation in the direction of increased speed and capacity as vendors introduce high-performance soft-decision FEC codes, fiber nonlinearity compensation, and probabilistic constellation shaping. With all these advanced features, performance

continued on page 80
In this paper, we review the progress on high speed silicon photonic modulators. We present demonstrations of silicon-based 90 Gbaud intensity modulator, 100G CWDM transmitters, I-Q modulator and optical frequency comb generator.

Michael R. Watts is a principal investigator in the Research Laboratory of Electronics (RLE) and a member of the Electrical Engineering and Computer

continued on page 81
Tu2A • Panel: Coherent Interoperability Beyond QPSK - Is it Needed and What Will it Take?— Continued

is getting closer and closer to the Shannon limit, making significant performance improvements in the range of >1dB unlikely to occur. At the same time, power consumption is getting more and more important and the timeline of new ASIC genera
tions is following closer and closer the availability of new lower power CMOS process nodes, for which the end of
Moore’s law has been predicted.

This brings up the question whether the industry as a whole would benefit from a successful standardization of coherent DSPs. Today, pretty much all coherent DSPs include a 100G DP-
QPSK mode which is interoperable. However, it uses a hard-decision FEC which cannot compete with more advanced soft-decision FECs. Looking forward, the following questions arise:

- What would it take to standardize higher-order modulation schemes e.g. 16QAM and 64-QAM as well as high-performance FECs?
- Do operators see potential benefits in this?
- Will standardization of coherent DSPs finally be driven by the need for high-capacity short-reach?
- Is the optics market truly unique or will it ultimately be shared among 2-3 players (compare markets like CPU, GPU, LTE, PON, DSL, …)?

On this panel, we want to elude answers to these questions by bringing together speakers from key operators and system vendors.

Panelists:
Marco Bertoloni, Nokia Corporation, Italy
Dirk van den Borne, Juniper Networks, Inc., Germany
Markus Weber, Acacia Communications Inc., Germany
Werner Weiershausen, Deutsche Telekom, Germany

Tu2B • Advanced VCSEL Links—Continued

Tu2C • SDM Switches—Continued

Tu2D • Modulation, Detection and DSP for PAM-4 Systems—Continued

Tu2E • High Bit-rate Transmission Systems—Continued

Tu2F • Microwave Photonics Enabling Devices—Continued

Tu2A • Panel: Coherent Interoperability Beyond QPSK - Is it Needed and What Will it Take?— Continued
Tu2G • Data Center Summit: Open Platforms for Optical Innovation—Continued

Infrastructure Project, Open ROADM Multi-Source Agreement, Central Office Rearchitected as Datacenter and Open Platform for NFV are defining open hardware platforms and reference implementations. To facilitate their control and operation, software projects such as OpenStack, OpenDayLight, Open Network Operating System, Open Platform for NFV, Open Source Manx and OpenConfig, are providing extensible frameworks and software tools.

Numerous proof-of-concept implementations and distributions across various research projects and early stage commercial initiatives, have demonstrated that rapid innovation is possible on basis of open hardware, interfaces, and software. Increasingly, these implementations and distributions will have to support the growing need for open optical hardware platforms.

The Open Platform Summit will discuss recent trends on open platforms and its applications to the optical networking space. It will comprise two technical sessions; the first session will have invited talks to introduce the audience to the topic area. The second session will comprise interactive table-top SDN & NFV demos selected from proposal submitted through the OFC system.

Speakers:
Saurav Das, Open Networking Foundation, USA
Young Lee, Huawei, USA
Anees Shaikh, Network Architect, Google - Open Management Plan for Transport Networks
Yasushi Sugaya, Fujitsu, Japan

Tu2H.2 • 14:30 Efficient Single-drive Push-pull Silicon Mach-Zehnder Modulators with U-shaped PN Junctions for the O-Band, Zheng Yang1, Wesley D. Sach1, Ying Huang1, Jared C. Mikkelsen1, Yisu Yang1, Xianshu Luo1, Patrick Dumas1, Dominic Goodwill1, Hadi Bahrami1, Guo-Qiang Lo1, Eric Bernier1, Joyce K. Poon1, 1Univ. of Toronto, Canada; 2Inst. of Microelectronics, A*STAR, Singapore; 3Huawei Technologies Canada Co. Ltd, Canada. We demonstrate silicon Mach-Zehnder modulators with efficient (Vth/L = 0.46V/cm at a bias of -0.5V) and low-loss phase-shifters for the O-band. A 2-mm long device had a 3-dB bandwidth of 13GHz and supported 24Gb/s modulation.

Tu2I • Integrated Circuits for Signal Processing—Continued

Science Department (EECS) at the Massachusetts Institute of Technology. Professor Watts’ research focuses on photonic microsystems for low-power communications, sensing, and microwave-photonic applications. His current interests include the modeling, fabrication, and testing of large-scale implementations of microphotonic circuits, systems, and networks that are being integrated, directly or through hybrid techniques, with CMOS electronics for high-speed transmitting, switching, and routing applications of digital signals. Additional interests include large-scale microphotonic sensing and imaging arrays, along with optical phased arrays, nanophotonic antennas, nonlinear optics, and manipulations of optical-electromagnetic fields on-chip.

Tu2J.2 • 14:30 MIMO-Free Transmission over Six Vector Modes in a Polarization Maintaining Elliptical Ring Core Fiber, Lixian Wang1, Reza M. Nejad1, Alessandra Corsi1, Jiahuan Lin1, Younes Messaddeq1, Leslie Rusch1, Sophie La-Rochelle1, COPL, Univ. Laval, Canada. We demonstrate an elliptical ring core fiber featuring vector modes with high stability and linear polarization states. We achieve six vector mode channel transmission over 0.9 km of 32 Gbaud QPSK without MIMO/PDM signal processing.

Tu2K • Operation and Architecture for Optical Access—Continued

Multi-dimensional Quasi-passive Reconfigurable (MD-QPAR) Node for Future 5G Optical Networks, Ke Wang1,2, Apurva Gowda1, Yingying Bi1, Leonid G. Kazovsky1, 1School of Engineering, RMIT Univ., Australia; 2Department of Electrical Engineering, Stanford Univ., USA. A multi-dimensional quasi-passive reconfigurable node is proposed and demonstrated for dynamic power and wavelength allocations in future 5G optical network applications. The traffic delay is reduced by >95% and the power penalty is negligible.
Room 402AB

Tu2A • Panel: Coherent Interoperability Beyond QPSK - Is it Needed and What Will it Take?—Continued

Room 403A

Tu2B • Advanced VCSEL Links—Continued

Room 403B

Tu2C • SDM Switches—Continued

Room 404AB

Tu2D • Modulation, Detection and DSP for PAM-4 Systems—Continued

Room 406AB

Tu2E • High Bit-rate Transmission Systems—Continued

Room 407

Tu2F • Microwave Photonics Enabling Devices—Continued

Tu2A.3 • 14:45 Demonstration of SWDM Transmission over OM4 Multimode Fiber with Modal Dispersion Compensation, Xin Chen1, Jason Hurley2, Dong Gui1, Yao Li1, Jeffery Stone1, Ming-Jun Li1, 1Corning Incorporated, USA. We propose simple wavelength-band modal dispersion compensation approach for extended reach SWDM up to 600m and demonstrate experimentally 40Gb/s transmission over 450m OM4 MMF with modal dispersion compensation fiber and 4-channel MUX/DEMUX devices.

Tu2A.4 • 14:45 Beam-Steering All-optical Switch for Multi-core Fibers, Hans Christian H. Mulvad1, Andrew Parker2, Bryan King3, Daryl Smith1, Mate Kovacs2, Saurabh Jain1, John R. Hayes1, Marco Petrovich1, David J. Richardson1, Nick Parsons1, 1Optoelectronics Research Centre, UK; 2Polatis Ltd, UK. We report on the development of the first multi-lane all-optical switch with directly integrated multi-core fibers. A 3-port single-sided beam-steering switch connecting 4-core fibers shows core-to-core losses below 2.2 dB with less than 1-dB variation.

Tu2B.3 • 14:45 Universal Photonic Interconnect for Data Centers, Michael R. Tan1, Paul Rosenberg1, Wayne V. Sorin1, Sagi Mathai1, Georgios Panotopoulos1, Glenn Rankin1, 1Hewlett Packard Enterprise, USA. TuB’s class, co-packaged CWDM optical engine based on 4 wavelength VCSELs around 1um is presented. The capability to scale bandwidth and link distance > 2km using single mode VCSELs and standard SMF28 fiber is demonstrated.

Tu2C.4 • 14:45 Nonlinear Equalizer for 112-Gb/s SSB-PAM4 in 80-km Dispersion Uncompensated Link, Noraki Kaneda1, Jeffrey Lee1, Young-Kai Chen1, 1Nokia Bell Labs, Holmdel, NJ, USA. Mode-division multiplexing adds a new dimension on top of conventional wavelength-dispersion-multiplexed networks. In this tutorial we will review the implications on switching architectures and multiplexing technologies for combined mode and wavelength multiplexed optical networks. continued on page 84

Tu2C.5 • 15:00 Tutorial Switching and Multiplexing Technologies for Mode-division Multiplexed Networks, Roland Ryf1, 1Advanced Photonics, Nokia Bell Labs, Holmdel, NJ, USA. Mode-division multiplexing adds a new dimension on top of conventional wavelength-dispersion-multiplexed networks. In this tutorial we will review the implications on switching architectures and multiplexing technologies for combined mode and wavelength multiplexed optical networks.
We present two SiP modulator architectures for multi-level signal generation and transmission, Ali-reza Sarmadi, Mathieu Chagnon, Eslam Elfiky, David Patel, Maxime Jacques, Venkat Veerasubramanian, David Plant, McGill Univ., Canada. We present two SiP modulator architectures for PAM-4 signal generation. We demonstrate the transmission of 56 Gbaud PAM-4 over 1 km of SMF. An 84 Gbaud PAM-4 generation below KPM FEC threshold is also achieved.

A 44Gbps High Extinction Ratio Silicon Mach-Zehnder Modulator with a 3D-Integrated 28nm FD-SOI CMOS Driver, Zheng You, Stefan Shoptov, Jared C. Mikkelsen, Robert Mallard, Jason C. Maki, Sorin P. Voinigescu, Joyce K. Poon, ‘Univ. of Toronto, Canada; Innovation Park at Queen’s Univ., CMC Microsystems, Canada. We present a silicon electro-optic transmitter consisting of a 28nm UTBB FD-SOI CMOS driver flip-chip integrated onto a Mach-Zehnder modulator. At 44 Gbps, the extinction ratio was 6.4 dB at the modulator quadrature operation point.

Strongly-Coupled Five-mode Ring-core Fiber for MDM Transmission with MIMO DSP, Takayoshi Mori, Taiki Sakamoto, Masaki Wada, Azusa Urushibara, Takashi Yamamoto, Kazuhide Nakajima, ‘VTI Corporation, Japan. The group delay spread reduction induced by a constant bend is experimentally confirmed using a five-mode ring-core fiber. Five spatial modes were successfully transmitted using a low-loss multiplexer composed of a five-core bundle.

Strongly-Coupled Five-mode Ring-core Fiber for MDM Transmission with MIMO DSP, Takayoshi Mori, Taiki Sakamoto, Masaki Wada, Azusa Urushibara, Takashi Yamamoto, Kazuhide Nakajima, ‘VTI Corporation, Japan. The group delay spread reduction induced by a constant bend is experimentally confirmed using a five-mode ring-core fiber. Five spatial modes were successfully transmitted using a low-loss multiplexer composed of a five-core bundle.

In-Service Location of Multiple Fiber Faults in WDM/SCM-PONs with Low-frequency Stepwise Sweep and ILR Regularization, Gustavo C. do Amaral, Joaquim D. Garcia, Bruno F. Santos, Patryk Urban, Jean Pierre van der Weerd, ‘Center for Telecommunications Studies, Pontifical Catholic Univ. of Rio, Brazil, ‘Electrical Engineering, Pontifical Catholic Univ. of Rio de Janeiro, Brazil, ‘Ericsson Research, Ericsson AB, Sweden. We present a monitoring technique that can be directly integrated in the transceiver for WDM/SCM-PON applications. It is based on the detection of the backscattered signal from a baseband tone and interpretation with the LASSO operator for multiple fault detection.

Challenges and Technology Innovations for Interconnections in Smart Cities, Rodney S. Tucker, Ericsson Research, Sweden, Innovative Communications Infrastructure. We offer a perspective on emerging IT infrastructures and communities seeking to enhance public communications infrastructure.

Enabling Next Generation Physical Layer Solutions OIF 13:45–14:45 For more details, see page 46

Advancing Optical Interoperability in Open Networks Session Sponsored by Juniper 14:00–17:00 For more details, see page 44

The Key to Unlocking the Benefits of SDN OIF Interop 15:00–16:00 For more details, see page 47

International Photonic Systems Roadmaps 16:00–17:00 For more details, see page 47

For more details, see page 47
Tu2A • Panel: Coherent Interoperability Beyond QPSK - Is it Needed and What Will it Take?—Continued

Tu2B • Advanced VCSEL Links—Continued

Tu2C • SDM Switches—Continued

Tu2D • Modulation, Detection and DSP for PAM-4 Systems—Continued

Tu2E • High Bit-rate Transmission Systems—Continued

Tu2F • Microwave Photonics Enabling Devices—Continued

Tu2B.5 • 15:30 4×50Gb/s NRZ Shortwave-Wavelength Division Multiplexing VCSEL link over 50m Multimode Fiber, Tam N. Huynh1,2, Fuad Doany1, Daniel Kuchta1, Deepa Gazula1, Edward Shaw1, Jason O’Daniel1, Jim Tatun1, IBM T.J. Watson Research Center, USA; 2R&D, Coriant Advanced Technology, USA; 3Finisar Corp., USA. We demonstrate the first time a 4×50Gb/s NRZ SWDM VCSEL link over 50m OM4 multimode fiber achieving error free operation (BER<1E-12). Transmission of 4×44Gb/s SWDM over 100m OM4 fiber with error free is also presented.

Tu2B.6 • 15:15 Transmission of 56-Gb/s PAM-4 Signal over 20 km of SSMF Using a 1.55-μm Directly-Modulated Laser, Minsk Kim1, Sunghyun Bae1, Hoon Kim1, Yun Chul Chung1; KAIST, USA. We demonstrate the transmission of 56-Gb/s PAM-4 signal over 20 km long SSMF by using a 1.55-μm DML without optical dispersion compensation. Instead, a linear electric equalizer is used for the compensation of dispersion-induced waveform distortions.

Tu2D.6 • 15:30 800 Gbit/s Dual Channel Transmitter with 1.056 Tbit/s Gross Rate, Karsten Schuh1, Fred Buchali1, Wilfried Idles1, Tobias A. Eriksson1, Lars Altenhain2, Ulrich Duemler1, Wolfgang Temp1; 1MICRAM Microelectronics, 2Nokia Bell Labs, SE, USA. We experimentally demonstrate generation of a 4 Gb/s 64 QAM dual polarization dual channel signal from one laser achieving a gross rate of 1,056 Tbit/s. Fiber transmission reach of 730 km over SSMF is also demonstrated.

Tu2E.6 • 15:30 Experimental Beam Displacement Tracking and Correction using Orbital-angular-momentum (OAM) beams in a free-space optical link, Xingwei Pang1, Robert Bock2, Moshe Tur3, Alan Willner2, 1Univ. of Southern California, 2School of Electrical Engineering, Tel Aviv Univ., Israel. We experimentally demonstrate beam displacement tracking and correction using orbital-angular-momentum (OAM) beams based position detection over a 400-Gbit/s OAM-multiplexed link. Power penalties <3 dB are achieved with the displacement up to ±10 mm.
Experiments reveal, for Optical Innovation—
Summit: Open Platforms
Tu2G • Data Center Summit—Open Platforms for Optical Innovation—Continued

Tu2H • Silicon Photonic Modulators—Continued

Tu2H.5 • 15:15
Dual Polarization O-Band Silicon Photonic Intensity Modulator for Stokes Vector Direct Detection Systems, Eslam Elify1, Mohamed Sowallei1, Ali Reza Samani1, Mohammed Osman1, David Patel1, Mathieu Chagnon1, David V. Plant1; McGill Univ., Canada. We present an O-band dual-polarization silicon photonic intensity-modulator for short reach direct-detection applications. We demonstrate 112 Gbit/s DP-64QAM transmission over 10 km at a BER of 6.6x10^-6 using a Stokes vector direct-receiver.

Tu2H.6 • 15:30
Tapless Locking of Silicon Ring Modulators for WDM Applications, Argishi Melikyan1, KW Kim1, Young-Kai Chen1, Po Dong1; Nokia Bell Labs, USA. Novel method for tapless locking of silicon ring modulators for WDM applications is discussed. Wavelength locking with an athermal operation over the temperature variations of 6°C is demonstrated at the data rates of 10 Gbit/s.

Tu2I.3 • 15:30
Full C-band Nyquist-WDM Interleaver Chip, Zhan Geng1, Leimeng Foo1, Arthur Lowery1; Dept. of Electrical and Comp. System Eng., Monash Univ., Monash Univ., Australia; Centre for Ultrahigh-bandwidth Devices for Optical Systems (CUDOS), Australia. We experimentally demonstrate full C-band coverage of a Nyquist-filtering interleaver for super-channel multiplexing. We show N-WDM super-channel multiplexing with zero guard-band, 12.5-GHz spacing, 0.08 roll-off, and a Q fluctuation <0.3 dB across C-band.

Tu2I.4 • 15:30
Experimental Verification of Mode-Dependent Loss Reduction by Mode Coupling Using Long-Period Grating, Azusa Hasegawa-Urushibara1, Takayoshi Mori1, Taiji Sakamoto1, Masaki Wada1, Takashi Yamamoto1, Kazuhide Nakajima1; NTT Corpora., Japan. Experiments reveal, for the first time, the mode-dependent loss (MDL) reduction effect of mode-coupling in long-period-grating. MDL is reduced effectively even if the transmission system has a large differential-mode-attenuation.

Tu2I.5 • 15:30
Reducing Group Delay Spread in a 9-LP mode FMM using Uniform Long-period Gratings, Huijuan Liu1, He Wen1, Rodrigo Amezcua Correa1, Pierre Sillard1, Guifang Li1, CEREL, The College of Optics & Photonics, Univ. of Central Florida, USA; The College of Precision Instruments and Opto-electronic Engineering, Tianjin Univ. China; Physam Group, France. We experimentally demonstrate, for the first time, reducing group delay spread in graded-index few-mode fibers with many LP modes using simple, uniform long-period gratings which have only one grating period.

Tu2J • Fibers and Components for Mode Division Multiplexing—Continued

Tu2J.5 • 15:15
Compacted Low Cost Superimposition of AMCC with Magneto-optic VOA, Gaji Nakagawa1, Kyo Sone1, Setsuo Yoshida1, Shiochio Oda1, Motoyuki Takizawa1, Tomoo Takahara1, Yoshi Hirose1, Takeshi Hoshida1, Fujitsu Laboratories Limited, Japan; Fujitsu Limited, Japan. We have proposed optical superimposition scheme employing a magneto-optic VOA as a simple and low cost implementation of AMCC system and experimentally confirmed lower power penalty in AMCC superimposition.
Tu2B.6 • 15:45 4λ x 100Gbps VCSEL PAM-4 Transmission over 105m of Wide Band Multimode Fiber, Justin Lavrencik¹, Siddharth Varughese¹, Varghese A. Thomas¹, Gary Landry², Yi Sun³, Roman Shubochkin¹, Kasyapa Balemarthy¹, Jim Tatum¹, Stephen E. Ralph¹; ¹Georgia Inst. of Technology, USA; ²Finisar, USA; ³OFS, USA. We demonstrate 100 Gbps PAM-4 transmission over 105m of wideband-MMF for each of four wavelengths from 850nm to 940nm using 25G VCSELs and thereby demonstrate an architecture that enables 400G over a single MMF.

16:00–16:30 Coffee Break, 400 Foyer; Exhibit Hall

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Tu2G • Data Center Summit: Open Platforms for Optical Innovation—Continued

Tu2H • Silicon Photonic Modulators—Continued

Tu2I • Integrated Circuits for Signal Processing—Continued

Tu2J • Fibers and Components for Mode Division Multiplexing—Continued

Tu2H.7 • 15:45 Characterization of Electro-optic Bandwidth of Ultra-high Speed Modulators, Xi Chen1, Sethumadhavan Chandrasekhar1, Gregory Raybon1, Po Dong1, Borui Li1, Andrew Adamiecki1, Peter Winzer1; 1Nokia Bell Labs, USA. We propose and demonstrate a method for measuring the bandwidth of electro-optic modulators up to 100 GHz using an RF synthesizer, a Mach-Zehnder modulator, a photodiode, and an optical spectrum analyzer.

Tu2I.5 • 15:45 K-band RF Multi-beamformer Using Si3N4 TTD for Home-satellite Communications, Netsanet Tessema1, Ziheng Cao1, Johan van Zantvoort1, Ketema Wondi Addis Mekonnen1, Ailee M. Trinidad1, Eduard Tangdiongga1, Bart Smolders1, A. Koonen1; 1Eindhoven Univ. of Technology, Netherlands. An optically controlled multi-RF beamformer for targeting more than one satellite is presented. Two beams in K-band of 6 Gbps each are generated by a 2x1 beamformer attached to a wavelength-dependent ring-based optical chip.

Tu2J.7 • 15:45 Experimental Analysis of the Modal Evolution in Photonic Lanterns, Juan Carlos Alvarado Zacarias1,2, Bin Huang1,2, Nicolas K. Fontaine2, Haoshuo Chen1, Roland Ryf1, Jose Antonio-Lopez1, Rodrigo Amezcua Correa1, Zeinab Sanjabi Eznaveh1; 1Univ. of Central Florida, USA; 2Nokia Bell Labs, USA. We experimentally analyze the modal evolution in a 10 mode-selective photonic lantern along the tapered transition using a swept-wavelength interferometer. Mode conversion to HOM's occurs closer to the beginning of the photonic lantern taper.

16:00–16:30 Coffee Break, 400 Foyer; Exhibit Hall
Tuesday, 21 March

Room 403A

16:30–18:30
Tu3B • Terahertz Systems

Panel: Direct vs. Coherent Detection for Metro-DCI
Moderators: Robert Griffin; Oclaro, UK; Ampalavanapillai Nimalathas; University of Melbourne, Australia

Coherent systems are widely deployed for high capacity long-haul networks, whereas direct detection (DD) implementations with low cost and low power consumption dominate short reach. Both approaches overlap in new fast-growing applications of short reach Metro and data center interconnects (DCI), requiring DWDM transport over distances around 100 km. In 2016 a commercial 100G PAM4 DD solution for 80km DWDM DCI was announced, and single-carrier 400G coherent solutions targeting similar applications have been demonstrated by multiple vendors. Will these solutions coexist, will one become the dominant solution over time, or will new alternatives become available? The panel will discuss the merits of different approaches and what progress we can expect as the technologies develop.

Panelists:
Brandon Collings, Lumentum, USA
Mark Filer, Microsoft Corporation, USA
Radha Nagarajan, Inphi Corporation, USA
Atul Srivastava, NEL-America, USA

Tadao Nagatsuma received B.S., M.S., and Ph.D. degrees in electronic engineering from Kyushu University in 1981, 1983, and 1986, respectively. From 1986 to 2007, he was with Nippon Telegraph and Telephone Corporation. Since 2007, he has been a Professor at Graduate School of Engineering Science, Osaka University. His research interests include millimeter-wave and terahertz photonics and their applications to wireless communications, sensing, and measurement. He is a Fellow of the IEEE, and the Institute of Electronics, Information and Communication Engineers (IEICE), Japan. He currently serves as an Associate Editor of the IEEE Photonics Technology Letters, and a Director of the IEICE.

Room 403B

16:30–18:30
Tu3C • VCSELs

President: Kazuhiro Kurata; PETRA, Japan

Tu3C.1 • 16:30 • Tutorial
High-bandwidth and Low-dimensionval VCSELs for Optical Interconnects, James Lott, Technische Univ., Berlin, Germany. With bandwidths exceeding 30-GHz, error-free bit rates exceeding 50-Gb/s, and energy efficiencies approaching 100-fJ/bit, via innovative grating reflectors, added materials, and unusual device geometries methods to further enhance the performance 980-nm communication VCSELs are explored.

Tu3C.2 • 17:00 • Invited
Nonlinear Frequency-Division Multiplexing in the Focusing Regime, Xianhe Yang, Japan. The talk reviews latest advances in THz communications based on photonics technologies and compares it with other competitive technologies such as THz transceivers enabled by electronic devices as well as free-space light-wave communications.

Tu3C.3 • 17:30 • Invited
Nonlinear Frequency-Division Multiplexing Applications with Dynamic Optical Networks, Ralph Konig, Amneho Deljoo, Stojan Trjavnoski, Ben de Graaf, Paola Grossi, Leon Gommmans, Tom van Engers, Frank Fransen, Robert Meijer, Rodney Wilson, Cees de Laat, University of Amsterdam, Netherlands; Airframe-KLM, Netherlands; TNO, Netherlands; Ciena, Canada. Secure Autonomous Response NETworks (SARNET) is a framework for automated response against attacks on network infrastructures. The framework addresses several cyber-security problems at three crucial levels: strategic, tactical and operational.

Tu3C.4 • 18:00 • Invited
Enabling E-Science Applications with Dynamic Optical Networks Secure Autonomous Response Networks, Zhengyou Wang, Ciena, Canada. Dynamic Optical Networks Secure Autonomous Response Networks (SARNET) is a framework for automated response against attacks on network infrastructures. The framework addresses several cyber-security problems at three crucial levels: strategic, tactical and operational.

Room 404AB

16:30–18:30
Tu3E • Networks Operating in Challenging Environments

President: Patrick Iannone; Nokia Bell Labs, USA

Tu3E.1 • 16:30 • Invited
Enabling E-Science Applications with Dynamic Optical Networks Secure Autonomous Response Networks, Ralph Konig, Amneho Deljoo, Stojan Trjavnoski, Ben de Graaf, Paola Grossi, Leon Gommmans, Tom van Engers, Frank Fransen, Robert Meijer, Rodney Wilson, Cees de Laat, University of Amsterdam, Netherlands; Airframe-KLM, Netherlands; TNO, Netherlands; Ciena, Canada. Secure Autonomous Response NETworks (SARNET) is a framework for automated response against attacks on network infrastructures. The framework addresses several cyber-security problems at three crucial levels: strategic, tactical and operational.

Tu3E.2 • 16:45
Cascaded All-optical Sub-Channel Add/Drop Multiplexing from a 1-Tb/s MB-OFDM or N-WDM Superchannel with Ultra-low Guard-bands, Mengdi Song, Erwan Pincemin, Benedikt Baeuverle, Arne Josten, David Hillerkuss, Jueng Leuthold, Roy Rudnick, Dan M. Mars, Shalva Ben Ezra, Jordi Ferre Ferran, Dimitrios Klonidis, Ioannis Tampakos, Orange Labs, France; ETH Zurich, Switzerland.

Tu3E.3 • 17:00
Cascaded All-optical Sub-Channel Add/Drop Multiplexing from a 1-Tb/s MB-OFDM or N-WDM Superchannel with Ultra-low Guard-bands, Mengdi Song, Erwan Pincemin, Benedikt Baeuverle, Arne Josten, David Hillerkuss, Jueng Leuthold, Roy Rudnick, Dan M. Mars, Shalva Ben Ezra, Jordi Ferre Ferran, Dimitrios Klonidis, Ioannis Tampakos, Orange Labs, France; ETH Zurich, Switzerland.

Tu3E.4 • 17:15
Cascaded All-optical Sub-Channel Add/Drop Multiplexing from a 1-Tb/s MB-OFDM or N-WDM Superchannel with Ultra-low Guard-bands, Mengdi Song, Erwan Pincemin, Benedikt Baeuverle, Arne Josten, David Hillerkuss, Jueng Leuthold, Roy Rudnick, Dan M. Mars, Shalva Ben Ezra, Jordi Ferre Ferran, Dimitrios Klonidis, Ioannis Tampakos, Orange Labs, France; ETH Zurich, Switzerland.

Room 404AB

16:30–18:30
Tu3D • Linear and Nonlinear Multicarrier Systems

President: Alan Pak Tao Lau; Hong Kong Polytechnic Univ.; Hong Kong

Tu3D.1 • 16:30 • Invited
Nonlinear Frequency-Division Multiplexing Applications with Dynamic Optical Networks Secure Autonomous Response Networks, Ralph Konig, Amneho Deljoo, Stojan Trjavnoski, Ben de Graaf, Paola Grossi, Leon Gommmans, Tom van Engers, Frank Fransen, Robert Meijer, Rodney Wilson, Cees de Laat, University of Amsterdam, Netherlands; Airframe-KLM, Netherlands; TNO, Netherlands; Ciena, Canada. Secure Autonomous Response NETworks (SARNET) is a framework for automated response against attacks on network infrastructures. The framework addresses several cyber-security problems at three crucial levels: strategic, tactical and operational.

Tu3D.2 • 16:45
Cascaded All-optical Sub-Channel Add/Drop Multiplexing from a 1-Tb/s MB-OFDM or N-WDM Superchannel with Ultra-low Guard-bands, Mengdi Song, Erwan Pincemin, Benedikt Baeuverle, Arne Josten, David Hillerkuss, Jueng Leuthold, Roy Rudnick, Dan M. Mars, Shalva Ben Ezra, Jordi Ferre Ferran, Dimitrios Klonidis, Ioannis Tampakos, Orange Labs, France; ETH Zurich, Switzerland.
We experimentally demonstrated the state-of-the-art in hollow core optical fibers describing in the process the different structural forms and associated guidance mechanisms possible, their key physical attributes and the steadily increasing range of end applications.

David Richardson joined the Optoelectronics Research Centre (ORC) at Southampton University in 1989. Since 2000 he has been Deputy Director of the ORC with responsibility for optical fibre and laser related research. He has published more than 400 technical journal papers and produced more than 30 patents during his time at Southampton. Professor Richardson is a Fellow of the IEEE, OSA and the IET and was made a Fellow of the Royal Academy of Engineering in 2009. He received a Royal Society Wolfson Research Merit Award in 2013 for his optical communications research.
We experimentally demonstrate the transmission of 50-Gb/s PDM-DMT-SSB signal over 40km SSMF signal using injection-locked single-mode VCSEL. It allows us suppressing an amplitude noise of optical signal and/or double the capacity of an information channel.

Temperature dependent analysis of 50 Gb/s Oxide-confined VCSELs, Curtis Wang, Michael Liu, Milton Feng, Nick Holonyak, ’Univ. of Illinois at Urbana-Champaign, USA.

Temperature dependent analysis of a high speed 850 nm oxide-confined VCSEL with 50 Gb/s error-free capability and a -3 dB modulation bandwidth of 24.7 GHz at 85°C is reported.

Amplitude Noise Suppression and Orthogonal Multiplexing Using Injection-locked Single-mode VCSEL, Vladimir Lyubopytov, Tuomo von Lerber, Matti Lassas, Mohammadreza Malekzandi, Arkadi V. Chipouline, Franko Küppers, ’TU Darmstadt, Germany; ’Dpt. Photonics Engineering, Technical Univ. of Denmark (DTU), Akademiekjæring 343, 2800 Kgs. Lyngby, Denmark, Finland; ’Department of Mathematics and Statistics, Univ. of Helsinki, P.O. Box 68 (Gustaf Hällströmin katu 2B/Fi-00014 Helsinki, Finland, Finland. We experimentally demonstrate BER reduction and orthogonal modulation using an injection locked single-mode VCSEL. It allows us suppressing an amplitude noise of optical signal and/or double the capacity of an information channel.

First Field Trial Demonstration of Hitless Defragmentation with Signals Overlap in Elastic Optical Networks, Francesco Fresi, Gianluca Meloni, Tommaso Foggii, Filippo Cuginii, Luca Potti, ’TeCiP, Scuola Superiore Sant’Anna, Italy; ’CNI, Italy. We experimentally demonstrate for the first time hitless spectrum defragmentation exploiting signals overlap in a field trial. Spectrum resources are shared without signals loss. The defragmentation procedure was successfully verified through 32Gbaud PM-QPSK-TFP signals over 1320km installed fiber.
Tu3G • TDM and TWDM-PON II—Continued

Tu3G.3 • 17:00 40 Gb/s A Optical Amplified PAM-4 PON with Transmission over 30 km SMF using 10-G Optics and Simple DSP, Jinlong Wei1, Elias Giaouridis2; 1Optical Technology Department, Huawei Technologies Dusseldorf GmbH, European Research Center, Germany; 2Centre for Ultrahigh bandwidth Devices for Optical Systems (CUDOS), School of Physics, Univ. of Sydney, Australia. We experimentally demonstrate 40-Gb/s A PAM-4 transmission over a 20-km (30-km) SMF using only 10-G optics and simple post-nonlinear equalizations with a link power budget of 38 dB (30.7 dB) at a threshold BER of 10\(^{-3}\).

Tu3G.4 • 17:15 Demonstration and Application of 37.5 Gb/s Duobinary-PAM3 in PONs, Robbert van der Linden1,2, Nguyen-Cac Tran3, Edward ‘Tangdiogga’ A. Koender1; 1Inst. for Photonic Integration, Eindhoven Univ. of Technology, Netherlands; 2Genexis B.V., Netherlands. Duobinary-PAM3 enables up to 37.5Gb/s with 10G receivers. It has less linearity requirements on transmitters and gains 2dB sensitivity compared to equal-bitrate PAM8. In a 10G flexible modulation scheme, DB-PAM3 enables 190% network utilization increase.

Tu3H • Tailored Propagation Effects—Continued

Tu3H.3 • 17:00 Direct-detection Solutions for 100G and Beyond, Michael H. Eiselt1, Nicklas Eisel1, Annika Dochhan1; 1ADVA Optical Networking SE, Germany. Pulse amplitude modulation (PAM-4) and discrete multi-tone (DMT) transmission are contenders for metro-reach and inter data center transmission. While commercial signal processing components are available, chromatic fiber dispersion effects need to be considered.

Tu3I • Direct-Detection Transmission Systems—Continued

Tu3I.3 • 17:00 Invited Direct-detection Solutions for 100G and Beyond, Michael H. Eiselt1, Nicklas Eiselt1, Annika Dochhan1; 1ADVA Optical Networking SE, Germany. Pulse amplitude modulation (PAM-4) and discrete multi-tone (DMT) transmission are contenders for metro-reach and inter data center transmission. While commercial signal processing components are available, chromatic fiber dispersion effects need to be considered.

Tu3J • Fiber-based Spatial Mode Multiplexers—Continued

Tu3J.2 • 17:00 All-fiber Mode-locked Vortex Laser with a Broadband Mode Coupler, Xianglong Zeng1, Teng Wang1, Fan Shi1, Feng Wang1, Fupei Pang1, Sujuan Huang1, Tingyun Wang1; 1Shanghai Univ., China. We experimentally demonstrated all-fiber passively mode-locked vortex lasers using a broadband mode selective coupler, which can deliver femtosecond optical vortex pulses with topological charges of OAM±1, ±2.

Tu3J.3 • 17:15 Top scored Annular Core Photonic Lantern Spatial Mode Multiplexer, Zerabani Sanjabi Esmaveh1, Juan Carlos Alvarado Zacarias1, Jose Antonio Lopez1, Yang-min Jung1, Kai Shi1, Benn C. Thomsen1, David Richardson1, Sergio G. Leon-Saval1, Rodrigo Amezcua Correa1; 1CREOL, Univ. of Central Florida, USA; 2Optoelectronic Research Center, UK; 3Univ. College London, UK; 4Southampton Univ., UK; 5Univ. of Sydney, Australia. We demonstrate an all-fiber, ring core photonic lantern to generate high quality OAM modes up to the second order at 1550nm. We achieved low-loss coupling of the lantern OAM modes into a ring core fiber.

Tu3J.4 • 17:15 Top scored Metamaterial Waveguides with Low Distributed Backscattering in Production O-Band Si Photonics, Bo Peng1, Chi Xiong1, Marwan Khatir1, Asger Jensen1, William M. Green1, Tymon Barwicz1; 1IBM T.J. Watson Research Center, USA. We report on the first measurement of distributed backscattering in metamaterial (sub-wavelength grating) waveguides. We find distributed backscattering to be < -50 dB/mm in samples fabricated using a CMOS-integrated Si photonic production process.
We fabricate...

The performance of...

Coherent Detection for...

First demonstration of photonically-

dual-polarization QPSK and 16-QAM signals with 33.3-GHz spacing. For upper-layer applications but also recover their data plane services automatically and timely during substrate link failures.

Daniel M. Kuchta is a Research Staff Member in the Communications and Computation Subsystems Department at the IBM Thomas J. Watson Research Center. He received B.S., M.S., and Ph.D. degrees in Electrical Engineering and Computer Science from the University of California at Berkeley in 1986, 1988, and 1992, respectively. He subsequently joined IBM at the Thomas J. Watson Research Center, where he has worked on high-speed VCSEL characterization, multimode fiber links, and parallel fiber optic link research. Dr. Kuchta is an author/coauthor of more than 135 technical papers and inventor/co-inventor of at least 20 patents.

Optical Tunable Filter for Gridless ROADMs, Masaki Niwa, Yojiro Morii, Hiroshi Hasegawa, Ken-ichi Sato, Nago G, USA. We fabricate an optical tunable filter for gridless signal drop in ROADMs. Its effectiveness is confirmed by experiments on 10-Gbaud intensity-modulated signals with 50-GHz spacing and 32-Gbaud dual-polarization QPSK and 16-QAM signals with 33.3-GHz spacing.

Tu3F.4 • 17:30 Optical Tunable Filter for Gridless ROADM, Masaki Niwa, Yojiro Morii, Hiroshi Hasegawa, Ken-ichi Sato; 1Nago G, USA. We fabricate an optical tunable filter for gridless signal drop in ROADMs. Its effectiveness is confirmed by experiments on 10-Gbaud intensity-modulated signals with 50-GHz spacing and 32-Gbaud dual-polarization QPSK and 16-QAM signals with 33.3-GHz spacing.
This paper presents an integrated SOA-PIN/TIA receiver for future generation T(W)DM-PON that demonstrates 112 Gb/s/channel 35GHz-spaced WDM direct-detection SSB Nyquist-SCM transmission at 3.15 b/s/Hz over 240 km SSMF-enabled by novel beating interference compensation method, which offers a 7.6dB required OSNR improvement, and 200% reach enhancement.

Tu3J.5 • 17:30 Top-Scored
Kramers-Kronig PAM Transceiver, Cristian Antonelli1, Antonio Mecozi1, Mark Shtaif2,3, Benn C. Thomsen4, Antonio Mecozzi1, Mark Shtaif2,3, Benn C. Thomsen4, 
1USC, USA; 2IBM TJ Watson Research Center, USA; 3AFL Telecommunications, USA; 4IBM Bromont, Canada; 5Asahi Glass Co, Japan; 6IBM Research - Tokyo, Japan; 7Global Foundries, USA. We have demonstrated photonic packaging compatible with standard, high-throughput, microelectronics assembly lines. We show a 1.3dB fiber-to-chip loss and 1.1dB chip-to-chip loss. We discuss the rationale behind this approach and compare to other packaging directions.

Tu3K.4 • 17:30 Top-Scored
High Throughput Photonic Packaging, Tymon Barwicz1, Ted W. Lifechoula1, Yael T. Tintelnot2,3,4, Benn C. Thomsen5, 1Nokia Bell Labs, Germany; 2Clemson University, USA; 3Nokia Bell Labs, France; 4IBM Bromont, Canada; 5IBM Research Tokyo, Japan. We report on the first successful 17-layer 3-D stacked 3-D waveguide IC photonic module. The module demonstrates high-speed 75 Gb/s PAM-4 signals over 100km silica optical fiber.
Tu3A • Panel: Direct vs. Coherent Detection for Metro-DCI—Continued

Tu3B • Terahertz Systems—Continued

Tu3D • Linear and Nonlinear Multicarrier Systems—Continued

Tu3E • Networks Operating in Challenging Environments—Continued

Tu3F • Reconfigurable Network Elements—Continued

Tu3A.5 • 18:15 Top-Papered

Tu3B.4 • 18:00 Modulation Optimization for D-band Wireless Transmission Link, Xinying Li, Yuming Xu, Jiangnan Xiao, Kaihu Wang, Jiang Yu.

Tu3B.5 • 18:15 Top-Papered
Gaussian Process Regression for WDM System Performance Prediction, Jesper Wess, Jakob Thran, Molly Piels, Rasmus Jones, Darko Zibar, DTU Photonics, Technical Univ. of Denmark, Denmark; Mylyco, Denmark. Gaussian process regression is numerically and experimentally investigated to predict the bit error rate of a 24 x 28 Gbd QPSK WDM system. The proposed method produces accurate predictions from multi-dimensional and sparse measurement data.

Tu3D.6 • 18:00 FPGA-based Layered/Enhanced ACO-OFDM Transmitter, Qibing Wang, Binhuang Song, Bill Corcoran, David Boland, Leimeng Zhuang, Yiwei Xie, Arthur Lowery, Monash Univ., Australia. We present an FPGA-based QPSK-encoded 9.375 Gb/s layered/enhanced ACO-OFDM transmitter giving a high spectral efficiency. The measured Q-factor is greater than 13 dB after 20-km standard single-mode fiber transmission.

Tu3E.6 • 18:00 Invited
What To Do When There’s No Fiber: The DARPA 100Gb/s RF Backbone Program, Ted Woodward, Strategic Technology Office, Defense Advanced Research Projects Agency (DARPA), USA. Intermediate results from a project to deliver 100 Gb/s communication links over ranges of 100 to 200 km in air-to-ground or air-to-air environments are described.

Tu3F.6 • 18:00 Low Phase Noise CO-MB-OFDM Optical Burst Transmitter for Time and Spectral Optical Aggregation, Bing Han, Pauline Gavignet, Erwan Pincemin, Thierry Guilloisau, Michel Cresseaux, Dominique Le Brouster, Benoit Haentjens, Yves Jaouen, ‘Orange Labs, France; Vetrwave, France; ‘Télécom ParisTech, France. We demonstrate experimentally the feasibility of a low phase noise CO-MB-OFDM burst transmitter for time and spectral optical aggregation based on our proposition of a 100 kHz linewidth and 100 ns switching time laser source.
We demonstrate
Room 410

We developed
Room 411

We report mode-selective photonic lanterns from multicore fibres, Stephanos Yerolatsitis¹, Kerrianne Harrington¹, Robert Thomson³, Tim A. Birks¹, Univ. of Bath, UK; ‘Heriot-Watt Univ., UK. We report mode-selective photonic lanterns made from multicore fibres with several dissimilar cores. Six-mode and ten-mode multiplexers are demonstrated. Such designs potentially offer the maximum possible number of multiplexed modes in mode-selective photonic lanterns.

10-Mode Photonic Lanterns Using Low-index Micro-Structured Drilling Preforms, Bin Huang¹, Juan Carlos Alvarado Zacarias¹, Nicolas K. Fontaine¹, Haoshuo Chen¹, Roland Ry¹, Francesco Polletti¹, John R. Hayes¹, Jose Antonio-Lopez³, Rodrigo Amezua Correa¹, Gufang Li¹, Univ. of Central Florida, USA; ‘Nokia Bell Labs, USA; ‘Univ. of Southampton, UK. We demonstrate low mode-dependent loss 10-mode photonic lanterns using low-index micro-structured drilling preforms. The adiabaticity requirement for lantern tapering can be alleviated by the proposed solution leading to improved performances.

Thermally Expanded Core Fiber with a 4-µm Mode Field Diameter Suitable for Low-loss Coupling with Silicon Photonic Devices, Takuya Oda¹, Keisuke Hirakawa¹, Kentaro Ichii¹, Satoshi Yamamoto¹, Kazuhiko Akawa¹, ‘Advanced Technology Laboratory, Fujikura Ltd., Japan. We developed thermally expanded core fibers with a 4-µm mode field diameter. The connection loss with conventional single-mode fibers is below 0.2 dB. The coupling loss with silicon devices can be below 1.5 dB./facet.

Tailoring Nonlinear Frequency Generation in Graded-index Multimode Fibers, Mohammad Amin Eftekhar¹, Zeinab Sanjabi-Ezaveh¹, Jose Antonio-Lopez¹, Miroslav Kolesik², Axel Schulzgen¹, Frank W. Wise⁴, Demetrios N. Christodoulides¹, Rodrigo Amezua Correa¹, ‘CREOL, The College of Optics & Photonics, Univ. of Central Florida, USA; ‘College of Optical Sciences, The Univ. of Arizona, USA; ‘Applied and Engineering Physics, Cornell Univ. We demonstrate that frequency generation in multimode graded-index fibers can be tailored through appropriate fiber design. This is achieved by exploiting a geometric parametric instability which can be utilized for developing novel fiber light sources.

Directly Modulated and ER Enhanced Hybrid III-V/SOI DFB Laser Operating up to 20 Gb/s for Extended Reach Applications in PONs, Valentina Cristofori¹, Francesco Da Ros¹, Mohamed E. Chabi², Yunhong Ding¹, Laurent Bramerie¹, Alexandre Shen¹, Antonin Gallet¹, Guang-Hua Duan¹, Leif K. Oxenlowe¹, Christophe Peucheret², ‘DTU Fotonik, Technical Univ. of Denmark, Denmark; ‘FOTON Laboratory, Univ. of Rennes 1, France; ‘Nokia-Thales-CEA, Ill-V Lab, France. We demonstrate error-free performance of an MRR filtered DML on the SOI platform over 40- and 81-km of SSMF. The device operates up to 17.5 Gb/s over 81 km and 20 Gb/s over 40 km.

Requirements on Resolution and Sampling Jitter of ADC in 10G-Class Optics and MLSD based NG-PON, Zhengxuan Li¹, Qianwu Zhang¹, Yongjia Yin¹, Kerrianne Harrington¹, Robert Thomson³, Tim A. Birks¹, Univ. of Bath, UK; ‘Heriot-Watt Univ., UK. We fabricate and characterize first on-chip prism-like waveguide coupler to high-Q micro-resonator and Optical Frequency Comb Generation, Guangyao Liu¹, Kuaping Shang¹, Siwei Li¹, Tiehui Su¹, Yu Zhang¹, Shaoheng Feng¹, S. J. Ben Yoo², Roberto Proietti³, Vladimir Ilchenko³, Wei Liang³, Anatoliy Savchenkov³, Andrey Matsko³, Lute Maleki³, ‘Electrical Engineering and Computer Science, Univ. of California, Davis, USA; ‘OEwaves Inc., USA. We design, fabricate and characterize first on-chip prism-like waveguide coupler to high-Q (Q>10⁶) micro-resonator with 1.1-dB coupling loss at 1550nm and demonstrate an integrated optical frequency comb generation unit based on this coupler.

16:30–18:30 Tu3L • Data Center Summit: SDN & NFV Demo Zone, 400 Foyer (Extended Coffee Break)

17:30–19:00 Exhibitor Reception, Lucky Strike Live LA, 800 W Olympic Blvd (Exhibitor badge required)
Tu3L1 SDN Control Framework with Dynamic Resource Assignment for Slotted Optical Datacenter Networks, Giada Landi1, Ioannis Patronas1, Konstantinos Konstandiaris1, Muzammil Aaz1, Konstantinos Christodouloupolous2, Angelos Kyriakos2, Marco Capitan2, Amireza F. Hamedani3, Dionysia Reiss3, Emmanuel Varvarigos2, Paraskevas Bakopoulos2, Hercules Avramopoulos2, 1National Technical Univ. of Athens, Greece; 2Computer Engineering and Informatics Department, Univ. of Patras, Greece; 3Networks, Italy; 4Gesellschaft für wissenschaftliche Datenverarbeitung mbH, Germany. An SDN control framework is demonstrated enabling slotted operation for dynamic resource assignment in optically-switched datacenters. The demonstration includes the SDN controller with scheduler plugins and north-southbound interfaces, and the SDN agent communicating to data-plane.

Tu3L2 Fully Automated Peer Service Orchestration of Cloud and Network Resources using ACTN and CSO, Riccardo Vilia1, Young Lee1, Haomin Zheng1, Yi Lu1, Ramon Casillas1, Arturo Mayoral1, Ricardo Martinez2, Raul Muñoz2, Luis Miguel Conteras Murillo2, Victor Lopez2, 1CTCTC, Spain; 2Huawei Technologies USA R&D Center, USA; 3Huawei Technologies Co., China; 4Telefónica Global CTO, Spain. This demo proposes the fully automated establishment of a network service using a peer inter-CSO interface in ACTN. The underlying network resources have been abstracted and virtualized in order to provide a network slice.

Tu3L3 Demonstration of the Benefits of SDN Technology for All Optical Data Centre Virtualisation, Chris R. Jackson1, Reza Nejabati1, Fernando Agra2, Albert Pagès1, Michael Galil1, Salvatore Spadaro1, Dimitra Simeonidou2, 1Univ. of Bristol, UK; 2Universitat Politècnica de Catalunya, Spain; 3Danmarks Tekniske Universitet, Denmark. An integrated software stack made up of extended OpenStack, OpenDaylight and custom OpenFlow agents enabling Virtual Data Centre deployment on an all-optical architecture employing hollow-core fibre, TDM fast switches and a circuit switched backbone.

Tu3L4 E2E Transport API Demonstration in Hierarchical Scenarios, Victor Lopez1, Itziar Nieves1, Nektarios Theoharakis1, Arturo Mayoral1, Lyndon Y. Ong1, Rafal Szwedowski1, Fabio Marques1, Anurag Sharma1, Francesco Bossois1, Oscar Gonzalez de diez1, Ori Gerstel1, Felipe Druesedau1, Ricard Vilia1, Hector Siva1, Achim Autenrieth1, Nuno Borges1, Chris Liu1, Giorgio Cazzaniga1, Juan Pedro Fernandez Palacios1, 1CTTC, Spain; 2GCTO, Telefonica +D, Spain; 3Sedona Systems, Israel; 4NEC, USA; 5Copiant GmbH, Germany; 6Infinea, USA; 7SM Optics, Italy; 8ADVA, Germany; 9Ciena, USA. We validate the Transport API interoperability with a hierarchical architecture layer. The demonstration shows the end-to-end provision of connections based on the topology and connectivity services of the Transport API.

Tu3L5 Demonstration of a SDN-based Spectrum Monitoring of Elastic Optical Networks, Matteo Dallagli0, Gian Quan Pham1, Fabien Boitier1, Camille Delezoide1, Dominique Vercher1, Patricia Layec1, Arnaud Dupas1, Nicola Sambor2, Sébastien Bigo2, Pierre Castoldi2, Noki Bell Labs, France; 2Scuola Superiore Sant’Anna, Italy. We demonstrate optical channel monitoring capabilities executed as SDN applications. To guarantee Quality of Transmission, diagnostic is performed by dynamically selecting the list of optical parameters to be monitored and by adjusting their polling rates.

Tu3L6 IndIRA: Application Intent Network Assistant to Configure SDN-based High Performance Scientific Networks, Aric Mercian1, Mariam Kiran1, Eric Pouyoul2, Brian Tierney1, Inder Monga2, 1ESnet Lawrence Berkeley National Labs, USA. We demonstrate IndIRA (Intelligent Network Deployment Intent Renderer Application), an interactive network assistant that will help us configure a data path between two scientific end-point groups (EPGs) to optimize the transfer of elephant data flows.

Tu3L7 APP Store Installed in ONOS-based Multi-layer and Multi-domain Transport SDN Platform with Novel TE Abstraction, Yongli Zhai1, Boyuan Yan2, Wei Wang1, Haomin Zheng1, Yi Lu1, Young Lee1, Huaying Xu1, Ruijuan Jing2, Yunbin Xu2, Guoying Zhang1, Jie Zhang1, Yuefeng Ji1, 1Beijing Univ of Posts & Telecom, China; 2Huawei Technologies Co., China; 3Huawei Technologies, USA Research Center, USA; 4China Telecom Beijing Research Inst., China; 5China Academy of Information and Communication Technology, China. An APP store is demonstrated over multi-layer and multi-domain transport software defined networks (T-SDN) platform, which is developed based on IETF ACTN standard. A novel traffic engineering (TE) abstraction method is used with different applications demonstrated.

Tu3L8 Open and Disaggregated Multi-layer Networks, Marc De Leenerhe1, Ayaka Kashihi1, Yuta Higuchi1, Naoki Shiota1, Helen Wu2, Toru Furusawa2, Tom Tofigh2, Guru Parulkar3, 1ON Lab, USA; 2NEC, Japan; 3Havard Univ, USA; 4NTT Communications, Japan; 5AT&T, USA; 6Stanford Univ, USA. Disaggregation of both packet and optical networks is driving innovation in transport networks. We demonstrate a proof of concept and detail our plans for a field trial in a major service provider.

Tu3L9 Automation of Optical Provisioning on Multi-vendor Metro Optical Platforms, Marco Razi1, Facebook, USA. This demonstration is going to automate provisioning of multi-vendor optical platforms supporting API based configurations, using transport interfaces such as NETCONF/REST.

Tu3L10 Intent-based In-flight Service Encryption in Multi-layer Transport Networks, Mohit Chamania1, Thomas Szyzkowiec1, Michele Santarini2, Domenico Siracusa2, Achim Autenrieth1, Victor Lopez1, Pontus Skildkorn3, Stephane Juniquet1, 1ADVA Optical Networking, Germany; 2CREATE-NET Research Center, Italy; 3Telefonica +D, Spain; 4ACREO Swedish ICT AB, Sweden. We demonstrate multi-layer encrypted service provisioning via the ACINO orchestrator. ACINO combines a novel intent interface with an ONOS-based SDN orchestrator to facilitate encrypted services at IP, Ethernet and optical network layers.

Tu3L11 Demonstration of NFV Content Delivery using SDN-enabled Virtual Infrastructures, ALI Hammad1, Jaume Marhuenda1, Shuangyi Yan1, Reza Nepbarti1, Dimitra Simeonidou1, 1Univ. of Bristol, UK. We will demonstrate the composition and operation of a virtual infrastructure (VI) for NFV content delivery. The demonstrated VI will be controlled through SDN controller. Furthermore, an infrastructure re-planning mechanism will be also demonstrated.
W1A.1 • 08:00 
Microprocessor Chip with Photonics I/O, Chen Sun1,2, Mark Wade3, Yunsup Lee1, Jason Orcutt1, Luca Alloatti1, Michael Georgas1, Andrew Waterman1, Jeffrey Shanline2, Rimas Avzienis2, Sen Lin1, Benjamin Moss3, Rajesh Kumar1, Fabio Pavanello1, Amir Atabaki1, Henry Cook1, Albert Ou1, Jonathan Leu2, Yu-Hsin Chen3, Krste Asanović1, Rajeev Ram3, Milos A. Popovic1, Vladimir Stojañovic1, EECS, Univ. of California, Berkeley, USA; IEEE, Univ. of Colorado, Boulder, USA; EECS, Massachusetts Inst. of Technology, USA. In this work, we provide an overview of the technology and architecture of a microprocessor chip with optical I/O. Zero-change photonics integration enabled the chip to be fabricated in a commercial electronics CMOS foundry.

W1A.2 • 08:15
One chip, PLC Three-mode Exchanger Based on Symmetric and Asymmetric Directional Couplers with Integrated Mode Rotator, Takeshi Fujisawa1, Eri Taguchi1, Taiji Sakamoto1, Takashi Matsui1, Yoko Yamashita1, Kyoza Tsujikawa1, Kazuhide Nakajima1, Kunimasa Saitoh1, ‘Hokkaido Univ., Japan; ‘NTT, Japan. A three-mode exchanger composed of symmetric and asymmetric directional couplers is proposed for mode-divisemultiplexing system. Theoretical design shows low-loss and highly efficient mode exchanging is possible. Fabricated device exhibits successful mode exchanging for LP01 mode.

W1B.1 • 08:00
Scrambling-type Three-mode Multiplexer Based on Cascaded Y-branch Waveguide with Integrated Mode Rotator on PLC Platform, Takeshi Fujisawa1, Yoko Yamashita1, Taiji Sakamoto1, Takashi Matsui2, Shuntaro Makino1, Kyoza Tsujikawa1, Kazuhide Nakajima1, Kunimasa Saitoh1, ‘Hokkaido Univ., Japan; ‘NTT, Japan. A novel scrambling-type mode multiplexer is proposed for future large-mode-number mode-division-multiplexing. 3-mode multiplexer design based on silica PLC shows low-loss and small wavelength dependence multiplexing is possible and a proof-of-concept device is fabricated.

W1B.2 • 08:15
One chip, PLC Three-mode Exchanger Based on Symmetric and Asymmetric Directional Couplers with Integrated Mode Rotator, Takeshi Fujisawa1, Eri Taguchi1, Taiji Sakamoto1, Takashi Matsui1, Yoko Yamashita1, Kyoza Tsujikawa1, Kazuhide Nakajima1, Kunimasa Saitoh1, ‘Hokkaido Univ., Japan; ‘NTT, Japan. A three-mode exchanger composed of symmetric and asymmetric directional couplers is proposed for mode-divisemultiplexing system. Theoretical design shows low-loss and highly efficient mode exchanging is possible. Fabricated device exhibits successful mode exchanging for LP01 mode.

W1C.1 • 08:00
Experimental Demonstration of a Period (P1) Nonlinear Dynamic Modulated Optical OFDM Signal Employing to a Millimeter Wave (MMW) Mobile Fronthaul Uplink, Jhh-Heng Yan1, Yu-Han Hung2, Kun-Lin Sheih2, Yi-Ting Liao2, Sheng-Kwang Hwang2, Kai-Ming Feng3, ‘Inst. of Communications Engineering, National Tsing Hua Univ., Taiwan; ‘Department of Photonics, National Cheng Kung Univ., Taiwan; ‘Inst. of Photonics Technologies, National Tsing Hua Univ., Taiwan; ‘Advanced Optoelectronic Technology Center, National Cheng Kung Univ., Taiwan. For the first time, a period-one (P1) nonlinear dynamic modulated MMW OFDM signal is employed to mobile fronthaul uplink. A proof-of-concept experimental demonstrations show successfully retrieved signals after 1.5m wireless and 25km SMF transmissions.

W1C.2 • 08:15
Millimeter-wave Radio Bundling for Reliable Transmission in Multi-section Fiber-Wireless mobile Fronthaul, Lin Cheng1, Peng Lu1, Ling Wang1, Mu Xu1, Shuyi Shen1, Gee-Kung Chang1, ‘Optoelectronic Technology Center, National Tsing Hua Univ., Taiwan; ‘Photonics Technologies, National Tsing Hua Univ., Taiwan; ‘Optoelectronic Technology Center, National Cheng Kung Univ., Taiwan. We propose a reconfigurable millimeter-wave radio bundling method to improve system efficiency and transmission reliability in multi-section fiber-wireless mobile fronthaul. A multi-point multi-section experiment demonstrates improved signal quality and reliability.

W1D.1 • 08:00
A Direct Comparison between Heterogeneously Integrated Widely-tunable Ring-based Laser Designs, Linjun Liang1, Zhanhui Jia1, Jin-Lin Chao1,2,3, Tin Komjellenovic1, Jin-Wei Shi1,2, Shusheng Jian2, John E. Bowers1,2, ‘Univ. of California Santa Barbara, USA; ‘Instit. of Lightwave Technology, Beijing Jiaotong Univ., China; ‘Department of Electrical Engineering, National Central Univ., Taiwan. Four ring-based tunable lasers are demonstrated in the heterogeneous silicon platform. Except for double-sided CRR structure, the other three show comparable narrow-linewidth (~200kHz) and output power (~10mW) across entire wide-tuning ranges (~40nm) with SMSR (>40dB).

W1D.2 • 08:15
Top Scored Full C-band, Mode-hop-free Wave-length-Tunable Laser Diode with a Linewidth of 8 kHz and a RIN of ~130 dB/Hz, Kensuke Kasa1, Masataka Nakazawa2, Yasunori Tomomatsu3, Takeshi Endo1, ‘Research Inst. of Electrical Communication, Tohoku Univ., Japan; ‘Kashin Kagaku Co., Ltd., Japan. We demonstrate a wavelength-tunable external-cavity laser diode with a linewidth of less than 8 kHz and a RIN below ~130 dB/Hz. The oscillation wavelength can be tuned over the entire wide-tuning ranges (~40nm) with SMSR (>40dB).

W1E.1 • 08:00
A RIN below -130 dB/Hz. The oscillation wavelength can be tuned over the entire wide-tuning ranges (~40nm) with SMSR (>40dB).

W1E.2 • 08:15
Dual-Emission Band All-Fiber Laser Fabricated by Chelate Precursor Doping Technique, Aoxiang Lin1, Xuan Tang1, Huan Zhan1, Qi Li1, Yuying Wang1, Kun Peng1, Li Ni1, Xiaolong Wang2, Cong Gao, Zhananion Jia, Yuwei Li, Ani You1, Jianjun Wang2, Feng Jing2, Honghuin Lin1, ‘China Academy of Engineering Physics, China. By chelate precursor doping technique, a 30μm-core Yb-doped alumino-phosphosilicate fiber was fabricated and presented 6.03kW laser output at 1080nm. The slope efficiency is 68.37% and the M2 factor is ~2.38 when stably running at 5.16kW.
An innovative search & development center, China; Aoki ning Tao

Power Estimation, Pilot Based Cross Phase Modulation
W1G.2 • 08:15
Pilot Based Cross Phase Modulation Power Estimation, Ying Zhao, Shenning Tao, Shoichiro Oda, Yasuhiro Aoki, Takeshi Hoshide; Fujitsu research & development center, China; Fujitsu Laboratories Ltd., Japan; Fujitsu Limited, Japan. An inter-channel cross phase modulation power estimation method is proposed based on angular squeezing of polarization diversified pilot tones. Simulation and experiment verify the estimator successfully indicates the power of the cross phase modulation impairment.

Experimental Investigation of Nonlinear Signal Distortions in Ultra-wideband Transmission Systems, Gabriel Saavedra, Mingming Tan, Daniel J. Elson, Lidia Galdino, Daniel Semrau, Md Asif Ibqar, Ian Phillips, Paul Harper, Naoise MacSuibhne, Andrew Ellis, Domenic Lavery, Bem C. Thomsen, Robert Kelley, Polina Bayvel; Univ. College London, UK; Aston Univ., UK. The impact of nonlinear interference (NLI) is experimentally investigated in the ultra-wideband regime. For signal bandwidths up to 7.3 THz it is confirmed that NLI continues to accumulate as predicted by the Gaussian Noise model.

Mixed Channel Traffic Grooming in Shared Backup Path Protected IP over Elastic Optical Network, Fengxian Tang, Longlei Li, Bowen Chen, Sanjay K. Base, Gangxiang Shen, Soochow Univ., China; HIT Guwahati, India. For mixed channel traffic grooming in shared backup path protected IP over elastic optical network, we develop an auxiliary graph based heuristic algorithm allowing working and protection traffic flows to share common optical channels. Results show that the scheme is efficient in greatly improving capacity and transponder utilization.

Signal Overlap for Efficient 1+1 Protection in Elastic Optical Networks (EONs), Filippo Cugini, Nicola Sambo, Tommaso Foggi, Marc Ruiz, Luis Velasco, Piero Castoldi, CNIT, Italy; Scuola Superiore Sant’Anna, Italy; Optical Communications Group (GCO), Universitat Politcnica de Catalunya (UPC), Spain. An innovative transmission technique enabling signal overlap is introduced for spectrally-efficient 1+1 protection. Simulation results show that the proposed technique successfully reduces the overall amount of occupied spectrum resources.
W1A • Photonic/Electronic Integration and Packaging—Continued

W1A.2 • 08:30
Low Crosstalk Simultaneous 12 ch x 25 Gb/s Operation of High-density Silicon Photonics Multichannel Receiver, Tsuyoshi Aoki1,2, Tomoyuki Akiyama1,2, Akio Sugama1, Akinori Hayakawa1,2, Hidenobu Muranaka3, Takasi Simoyama1, Shinuke Tanaka1, Motoyuki Nishizawa1, Nobuaki Hatori1, Yohei Sobu1, Yafei Chen1,2,3, Hidenobu Muranaka3, Yohei Sobu1, Yafei Chen1,2,3, Hidenobu Muranaka3, Yohei Sobu1, Yafei Chen1,2,3, Hidenobu Muranaka3, Yohei Sobu1, Yafei Chen1,2,3.

W1A.3 • 08:45
Demonstration of a Packaged Photonic Integrated Network on Chip controlled by an FPGA-based scheduler, Yule Xiong1, Nicola Andriolli2, Stefano Faralli2, Fabrizio Gambini2, Paolo Pintus2, Marco Chiesa3, Ruben Ortuño4, Odille Laborin-Ladouceur5, Isabella Cerutti6,7, McGill Univ., Canada; 8Scuola Superiore Sant’Anna, Italy; 9Univ. of California, Santa Barbara, USA; 10Universidad Politécnica de Valencia, Spain. The dynamic performance of a packaged photonic network-on-chip (NoC) based on multi-microrings is experimentally demonstrated. Controlled by a scheduler implemented in an FPGA, the packaged photonic NoC exhibits a BER penalty of approximately 0.5 dB.

W1B • SDM Multiplexers and 3D Waveguides—Continued

W1B.3 • 08:30
Invited
Capacity Limits for Spatially Multiplexed Free-space Communication, Joseph M. Kahn1, Guifang Li2, Xiaoying Li1, Ningbo Zhao1, Stanford Univ., USA; 2CREOL, Univ. of Central Florida, USA; 3Tsinghua Univ., China. We show that OAM multiplexing does not realize the capacity limits of free-space channels, and is outperformed by multiplexing in parallel Gaussian beams or any complete modal basis.

W1C • Novel Fronthauling Techniques—Continued

W1C.3 • 08:30
Real-time Measurements of an Optical Recomfigurable Access Unit for 5G Wireless Access Networks, Sebastian Rodríguez1, Alvaro Morales1, Simon Rommel1, Juan José Vegas Olmos1, Idefonso Tafur Monroy2,3, Technical Univ. of Denmark, Denmark; 2ITMO Univ., Russia. A reconfigurable radio access unit able to switch wavelength, RF carrier frequency and optical path is experimentally demonstrated. The system is able to do the switching processes correctly, while achieving BER values below FEC limit.

W1C.4 • 08:45
Simultaneous Transmission of Multi-RATs and Mobile Fronthaul in the MIMW Bands over an IFoF System, Pham Tien Dat1, Atsushi Kanno5, Naokatsu Yamamoto4, Hirohito Yamada4, Tsuyoshi Aoki1,2,3,2Peta, Japan; 4Fujitsu Laboratories Ltd., Japan. We designed high PI and SI free operations of 12 ch x 25 Gb/s with a small crosstalk penalty of 1.2 dB.

W1D • Control Architecture and Network Modeling II—Continued

W1D.3 • 08:30
Invited
Silicon Photonic Waveband Tunable Lasers for High-capacity Optical Communication System, Tomohiro Kita1, Hiroiyuki Yamazaki2, Naokatsu Yamamoto3, Hirohito Yamada4, Tsuyoshi Aoki1,2,3,2Peta, Japan; 4Fujitsu Laboratories Ltd., Japan. We demonstrate ultra-broadband gain medium exploiting cascaded Raman amplification. Pumping the 5-km long linear cavity fiber laser at 1349 nm we show the tunability of the laser operation from 1400 to 1622 nm.

W1E • Tunable Lasers and Transmitters—Continued

W1E.3 • 08:30
Invited
Power Fiber Laser Operating at 1.349 nm we show the tunability of the laser operation from 1400 to 1622 nm.
This paper presents blind estimation of nonlinear operator product in back-propagation algorithm for Coherent Optical Transmission Systems, Lin Jiang1, Lianhuan Yan1, Anlin Yi1, Yan Pan1, Jun Ge1, Liangliang Dai1, Wei Pan1, Bin Luo1, ‘Southwest Jiaotong Univ., China. Blind estimation of nonlinear operator product in back-propagation algorithm is proposed. Significantly enhanced flexibility of nonlinear compensation is experimentally demonstrated in a 5x64-Gb/s WDM PDM-QPSK system over 1920-km SMF link with ~1.5-dB performance improvement.

W1G.3 • 08:30 Invited
Toward Blind Nonlinearity Estimation in Back-propagation Algorithm for Coherent Optical Transmission Systems, Lin Jiang1, Lianhuan Yan1, Anlin Yi1, Yan Pan1, Jun Ge1, Liangliang Dai1, Wei Pan1, Bin Luo1, ‘Southwest Jiaotong Univ., China. Blind estimation of nonlinear operator product in back-propagation algorithm is proposed. Significantly enhanced flexibility of nonlinear compensation is experimentally demonstrated in a 5x64-Gb/s WDM PDM-QPSK system over 1920-km SMF link with ~1.5-dB performance improvement.

W1G.4 • 08:45
Time-Domain Digital Back Propagation: Algorithm and Finite-Precision Implementation Aspects, Christoffer Fougstedt1, Mikael Mazur1, Lars Svensson1, Henrik Eliasson1, Magnus Karlsson1, Per Larsson-Edelfors1, ‘Chalmers Univ. of Technology, Sweden. We propose a nonlinear mitigation algorithm designed from an ASIC perspective, and analyze implementation aspects. Given 9 signal and 11 coefficient bits, reach is increased by 105% compared to linear compensation in single-channel 16-QAM transmission.

W1H.2 • 08:30
Control Plane Architectures for Flexi-Grid Networks, Oscar Gonzalez de Dios1, ‘Telefonica, Spain. Elastic optical networks are based on a flexible allocation of the spectrum and configurable transponders. The control architecture is key to unlock their potential. This paper presents the architectural choices, including GMPLS, SDN and TAPI.

W1I • Elastic Optical Networks—Continued
W1I.1 • 08:30 Nonbinary Staircase Codes for Spectrally and Energy Efficient Fiber-optic Systems, Alimea Sheikh1, Alexandre Graell i Amat1, Magnus Karlsson1, ‘Chalmers Tekniska Hogskola, Sweden. We consider the design of nonbinary staircase codes with higher order modulation for spectrally and energy efficient fiber-optic systems. We optimize the code parameters based on density evolution.

W1J.1 • 08:30
Distributed Rate-adaptive Staircase Codes for Connectionless Optical Metro Network, Laurent Schmalen1, Lei M. Zhang1, Ulrich Gebhardt1, ‘Bell Labs, Nokia, USA; ‘ECE, Univ. of Toronto, Canada. We demonstrate a multipoint-to-point network architecture for optical metro networks with distributed staircase codes. We present a simple rate-adaptation scheme and demonstrate throughput maximization on the network.

W1J.2 • 08:45
A High Loss Budget 400-Gbps WDM-OFDM Long Reach PON over 60 km Transmission by 10G-class EAM and PIN without In-line or Pre-amplifier, C. Y. Chung1, Chia-Chien Wei1, Jun-Jie Liu1, Hsin-Yu Wu1, Hong-Minh Nguyen1, Chun-Wei Wang1, Shao-Yu Lu1, Young-Kai Chen1, Jye-hang Chen1, ‘Department of Photonics, National Chiao Tung Univ., Taiwan; ‘Department of Photonics, National Sun Yat-sen Univ., Taiwan; ‘Communication Science Research Department, Bell Laboratories, Alcatel-Lucent at Murray Hill, USA. A 400-Gbps WDM-OFDM LR-PON over 60-km SMF is demonstrated with a 10G-class EAM and PIN. 25-dB loss budget is realized without in-line or pre-amplifier to economically support 128 ONUs with 3.1-Gbps/ONU capacity.
We demonstrate the potential of on-chip mode division multiplexing (MDM) for high-speed optical interconnects. The optical engine for high-density optical interconnects exhibits a good signal quality in an air-cooling environment with an ambient temperature of 40°C.

We investigate the performance of F-OFDM in 5G fronthauling networks for seamless carrier-aggregation and asynchronous transmission. We propose a novel control and hierarchical management plan for supporting F-OFDM systems in 5G networks. Our proposed control and management plan is able to configure actions and finite state machine in the transponder controller.

We propose a new approach to supporting Flip-Chip-Integrated III-V/Si hybrid external-cavity laser using a photonic crystal reflector. We demonstrate an efficient surface-normal-coupled tunable external-cavity hybrid laser using a novel photonic crystal reflector. The ultra-compact reflector enables a single wavelength reflection and a short laser cavity to improve lasing stability.

We demonstrate a Flip-Chip-Integrated III-V/Si hybrid external-cavity laser using a photonic crystal reflector. We propose a new approach to supporting Flip-Chip-Integrated III-V/Si hybrid external-cavity laser using a photonic crystal reflector. We demonstrate an efficient surface-normal-coupled tunable external-cavity hybrid laser using a novel photonic crystal reflector. The ultra-compact reflector enables a single wavelength reflection and a short laser cavity to improve lasing stability.
For the first time, super-Gaussian orders in 32, Andrew Lord, implemented digital nonlinear compensation was demonstrated.

Different approaches are emerging to address these problems. A perturbation-based digital nonlinear compensation and effective means of using it in an optical network were reviewed, and a real-time transmission by a 100 Gbit/s transceiver with the compensation and effective means were studied, Japan;

Hoshida, Ohshima, Communication Systems, Technologies in Coherent Optical Digital Nonlinear Compensation—Continued

Invited, Japan;

Fujitsu R&D Center, China.

Mitigation and Monitoring—Continued

W1H.3 • 09:00 Invited
Digital Nonlinear Compensation Technologies in Coherent Optical Communication Systems, Hisao Nakashima1, Tomofumi Oyama2, Chihiro Ohshima1, Yuichi Akisaka1, Takeshi Hoshida1, Zhenning Tao3, Fujitsu Limited, Japan; 2Fujitsu Laboratories Ltd., Japan; 3Fujitsu R&D Center, China. A perturbation-based digital nonlinear compensation and effective means of using it in an optical network were reviewed, and a real-time transmission by a 100 Gbit/s transceiver with the implemented digital nonlinear compensator was demonstrated.

Impact of WSS passband shape needs to be optimized to the 3.6th and 3.2th super-Gaussian orders in BT-UK and PAN-Europe networks, respectively, for realizing the 30% capacity increase promised by the flexible-spectrum standard.

We evaluate the potential benefits of finer granularity rate adaptive transponders to better progressively fit ageing of the margin in WDM networks. The underlying technology and cost savings are presented for two network core topologies.

We introduce lattice precoding (LP) as an improved version of Tomlinson-Harashima precoding (THP) for direct intensity modulation & direct detection (IM/DD) communications over plastic optical fiber (POF). We show that LP offers a significant gain greater than 5 dB over conventional methods for short-range IM/DD SI-POF systems.
Continued

The interaction between embedded waveguides and surface optical structures produced by semiconductor microfabrication will be discussed.

W1C.7 • 09:30  RAN Revolution with NGFI (xHaul) for 5G, Chih-Lin I; 1 China Mobile, China. From “Rethinking Ring and From "Rethinking Ring and Room 404AB 1 Regional Business Machines Corp, Japan. We present a 60-micrometer pitch polymer waveguide array attached active optical flexible module which is useful for compact and high-channel count optical interconnect. We fabricated this module and realized 20-Gbps optical signal transmission.

W1C.7 • 09:30  RAN Revolution with NGFI (xHaul) for 5G, Chih-Lin I; 1 China Mobile, China. From “Rethinking Ring and Young” in 2011 to proposing NGFI (xHaul) in 2014, the RAN revolution path to meet ambitious 5G demands has been charted out. Traditional TDM-based fronthaul solutions, e.g., CPRI, fell short both in required BW and architecture flexibility. Next generation fronthaul interface (NGFI, aka xHaul) proposed by China Mobile targeting a packet-based, traffic-dependent, and antenna scale-independent interface will be central to the 5G RAN revolution. The concept has been widely accepted in the industry and both IEEE and 3GPP, among others, are taking this approach towards 5G. This presentation will bring forth the latest progress within China Mobile and in the global industry. Specifically, a two-level NGFI architecture will be highlighted, and the function split options with associated requirements in, e.g. latency, bandwidth and synchronization will be presented. In addition, the opportunity of SDAI integration and challenge of SDN application will be discussed.

W1D.4 • 09:30  Field Trial of Data Analysis-based Autonomic Bandwidth Adjustment in Software Defined Multi-Vendor OTN Networks, Yajie Li; Yongli Zhao; Xiaosong Yu; 1 Beijing Univ. of Posts and Telecommunications, China. To achieve cost-effective bandwidth provisioning, this paper proposes an autonomic bandwidth adjustment scheme based on data analysis of traffic load. The scheme is verified in field trial networks with commercial OTN equipment from three vendors.

W1D.5 • 09:45  Demonstration of Fast Cooperative Operations in Disaggregated Optical Node Systems, Kiyo Ishii; 1, Satoshi Suda; 1 , Shigeyuki Yanagimachi; 2, Hitoshi Takeshita; 2, Dai Suzuki; 3 , Takaumi Tera- hara; 3, Shu Namiki; 3, 1 AIST, Japan; 2ToT Device Labs., NEC Corporation, Japan; 3 Network Products Business Unit, Fujitsu Ltd., Japan. A node controller is addressed to ease operations such as alarm monitoring and path provisioning for the centralized controller. It is actually implemented on off-the-shelf servers to successfully perform fast protections in disaggregated optical nodes.

W1E.6 • 09:30  A Mode-hop-free III-V/Si Hybrid External-cavity Laser, Jin Hyoung Lee; 1, Ivan Shubin; 2, Jack Bovington; 2, Ying Luo; 1, Daniel Y. Lee; 1, Stevan S. Djordjevic; 3, Shiyun Lin; 2, Jin Yao; 2, Hiren D. Thacker; 1, John E. Cunningham; 2, Kannan Raj; 2, Ashok V. Krishnamoorthy; 1, Xuezheng Zheng; 1, Oracle, USA. We propose a novel approach of passive stabilization for on-chip hybrid laser over temperature variation by thermo-optic compensation. By engineering the effective thermal-optic coefficient of the cavity, we demonstrated mode-hop-free operation of an on-chip hybrid laser over 35°C temperature change without any active controls.

W1E.7 • 09:45  Small Form Factor Hybrid III-V/Si Wavelength-tunable Push-pull Micro-ring based Transmitter, Chia-Ming Chang; 1, Guilhem de Valicourt; 1, Jeffrey Lee; 1, KW Kim; 2, Michael Eggleston; 1, Po Dong; 2, Anselle Maho; 2, Romain Brenot; 2, Young-Kai Chen; 2, Nokia Bell Labs, USA; 2-III-V labs, France. We demonstrate a compact low-chip and energy-efficient integrated hybrid III-V/Si transmitter based on a Vernier tunable laser that covers the entire C-band, and a low drive voltage push-pull ring modulator that provides large extension ratio and low chirp.
We review, respectively.

12% and 222% by using LDPC-coded

Compared to QPSK and 8-QAM, the

9-QAM are experimentally studied

USA.

Ivan B. Djordjevic

ing, based on fixed-margins.

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nonlinear impairment estimation that

proposed. Compared with the CI-BCH

code, the error floor is lowered from

BER of 1e-9 to 1e-16 at small latency

and storage cost.

10:00-17:00 Exhibition and Show Floor, Exhibit Hall G-K (coffee service 10:00–10:30)

10:00-17:00 OFC Career Zone Live, South Lobby
We demonstrate a novel Broadband Gain-spectrum Measurement Technique for Raman and Parametric Amplifiers, Vladimir Gordienko1, Marc F. Stephens1, Atalla El-Taher1, Niall D. Doran1, Asthon Univ., UK. We report a quick and accurate gain-spectrum measurement technique for broadband (>10Hz) Raman and parametric amplifiers. Using a depolarized broadband source we predict WDM signal gain experimentally for both single and diverse polarization schemes.

W2A.9
Compact 4×5 Gb/s Silicon-on-Insulator OFDM Transmitter, Yu-Xie Xie1, Leiming Zhuang1, Ronald Broeve2, Qibing Wang1, Binhuang Song1, Zihan Gong2, Arthur Lowery1, Monash University, Australia; ‘Bright Photonics B.V., Netherlands. We characterize an integrated silicon 4×5 Gb/s OFDM transmitter PIC (2.1×4.8 mm2) with four modulators and an optical Fourier transform. This PIC features a channel spacing of 5 GHz and an 80-GHz free spectral range.

W2A.10
C-C Bond Enriched SiC Add-drop Micro-ring Based All-Optical Logic Gate. Shih-Chang Syu1, Wei-Ting Lai1, Wei-Ting Lin2, Siwei Li1, Wei-Ting Lai1, Wei-Ting Lai1, Wei-Ting Lai1. National Taiwan Univ., Taiwan; ‘National Inst. of Information and Communications Technology, Japan. We develop a periodically poled LiNbO3 (PPLN) waveguide device and experimentally demonstrate a phase-sensitive amplification based on a cascaded SHG and CPA process. We successfully obtain the high phase-sensitive parametric gain of 21.9 dB.

W2A.11
Three-stage Quasi-phase-matched Fiber Optical Parametric Amplifier with Flat 30-dB Gain with 8.7-dB TE/TM bandwidth. Shigehiro Takasaka1, Ryuchi Sugizaki1, Furukawa Electric Co., Ltd., Japan. We demonstrate a FM-POPA using three dispersion stable PM-HNLFs alternately concatenated with PM pump phase shifters for quasi-phase-matching. We achieve gain as high as 30 dB with 31 nm bandwidth.

W2A.12
High-efficiency Light Injection and Extraction Using Fiber Bending, Taku Uematsu1, Takanoi Kiyokura1, Hidenobu Hirota1, Tomohiro Kawano1, Tetsuya Manabe1, 3NTT Corporation, Japan. We achieve a temporary optical coupler that injects/extracts light into/from a fiber with high efficiency by using fiber bending. We demonstrate experimentally that extraction efficiency is improved by using a double-clad fiber.

W2A.13
Simple Geometric Approach for Optimization of Phase-sensitive Fiber Optic Parametric Amplifiers, Alexey Redyuk1, Anastasia Bednyakova1, Sergey Medvedev2, Mikhail Fedoruk2, Sergey K. Turunen3, Novosibirsk State Univ., Russia; ‘Inst. of Computational Technologies SB RAS, Russia; ‘Aston Inst. of Photonic Technologies, UK. We demonstrate application of a simple design method - geometric approach for optimisation of the performance of phase-sensitive fiber optical parametric amplifier.
A black phosphorus-coated tilted fiber Bragg grating for ultra-sensitve ion sensing, Chen Liu, Zhengbo Sun1, Liang Zhang1, Jiancheng Liu2, Peng Yu, Xinmin Cheng, 1Bangor Univ, UK, 2Shenzhen Insts of Advanced Technology, Chinese Academy of Sciences, China. We propose and experimentally demonstrated tilted fiber Bragg grating based on black phosphorous coated 81nm tilted fiber grating for Pb2+ ion detection, demonstrating significant performance improvement. The high sensitivity (8.6 x 10^8 dB/ppb) lower detection limit (0.4ppb) and wider concentration range (0.1ppb - 1.5 x 10^6 ppb).

Wideband Fully-Distributed Vibration Sensing by using UWFPS-Based Coherent OTDR, Fan Ai1, Qizhen Sun1, Wei Zhang1, Tao Liu1, Zhijun Yan1, Deming Liu2, 1Huzhou Univ of Science and Technology, China; 2National Engineering Laboratory for Next Generation Internet Access System, China. A scheme combining coherent OTDR with UWFPS to realize wideband and high sensitive distributed vibration sensing is proposed. Frequency response from 2Hz to 5kHz, and 4m spatial resolution are experimentally demonstrated over 1.3km fiber.

Design of Elliptical-core Few-mode Fibers for Optical Parametric Amplification, Cheng Guo1, Zhenxu Zhang1, Ningbo Zhao1, Lin Zhang1, Xiaoying Li1, Guifang Li1, 1The College of Precision Instruments and Opto-electronic Engineering, Tianjin Univ, China; 2The College of Optics & Photonics, Univ. of Central Florida, USA. We present a dispersion-compensated elliptical-core few-mode fiber for broadband parametric amplification in the C-band. The asymmetry structure is beneficial to eliminate crosstalk in transmission system and degradation to parametric gain.

Demonstration of Orbital Angular Momentum (OAM) Fiber Amplifier in Data-Carrying OAM-Division Multiplexing and Wavelength-Division Multiplexing (WDM) System, Jun Liu1, Hongya Wang1, Shi Chen1, Shuang Zheng1, Long Zhu1, Andong Wang1, Nan Zhu1, Shuhui Li1, Li Shen1, Cheng Du1, Qi Mo1, Ju Wang1, 1Huazhong Univ of Science and Technology, China; 2Fiberoptik Telecommunication Technologies Co. Ltd, China. We demonstrate an orbital angular momentum (OAM) fiber amplifier and evaluate its performance in an OAM and wavelength multiplexing system. The small signal gain is up to 19 dB from 1530 nm to 1565 nm. The OSNR penalties at a BER of 2e-3 are less than 1.8 dB for all channels.

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Wednesday, 22 March

W2A.32
Experimenting with Multi-controller Collaboration for Large-scale Intra-data Center Networks, Yingju Jia1, Nan Hua2, Yufang Yu1, Yanhe Li1, Xiaoping Zheng1, 1Tsinghua National Laboratory for Information Science and Technology (TNList), China; 2Department of Electronic Engineering, Tsinghua Univ., China.

W2A.35
SINR-based Equalization for Full-duplex LTE-A and Gbps 4-PAM Transmission over 50m Thick-core GI-PoF Wireless Link, Federico Forni1, Yan Shi2, Hennie v. Boom1, Eduard Tangdiongga1, A. Koonen1, 1Eindhoven Univ. of Technology, Netherlands; 2Genexis, Netherlands.

W2A.38
Improving Performance of Mobile Fronthaul by high-order Delta-sigma Modulation based on PAM-4 IM-DD Channels, De-Yu Chen1, Ming-Te Cheng1, Jiaqi Zhao1, 1National Taipei Univ. of Science and Technology, Taiwan; 2Department of Photonics, National Chiao Tung Univ., Taiwan; 3Information and Communications Research Labs, Industrial Technology Research Inst., Taiwan; 4Department of Photonics, Feng Chia Univ., Taiwan.

W2A.39
6.36 Gbit/s RGB LED-based WDM MIMO Visible Light Communication System Employing OFDM Modulation, K-Cheng Lui, Chi-Han Lai, Chien-Hung Yeh1, Jye-Hong Chen1, 1Department of Photonics, National Chiao Tung Univ., Taiwan; 2Information and Communications Research Labs, Industrial Technology Research Inst., Taiwan; 3Department of Photonics, Feng Chia Univ., Taiwan.

W2A.40
A Novel Memoryless Power Series Based Adaptive Nonlinear Pre-distortion Scheme in High Speed Optical Communication, Yingjun Zhai1, Zhihong Wang1, Can Wang2, Jiao Zhao1, Mengjie Zhang1, Muding Zeng1, Nan Chi1, 1Fudan Univ., China; 2Huazhong Univ. of Sci.&Techn, China.

W2A.41
Non-orthogonal Multiple Access Based on SCMA and OFDM/OQAM Techniques in Bidirectional RoF System, Zixin Wang1, Yufang Yu2, Can Wang1, 1National Taipei Univ. of Science and Technology, Taiwan; 2Fudan Univ., China.

W2A.42
4.05-Gb/s RGB LED-based VLC System Utilizing PS-Manchester Coded Nyquist PAM-8 Modulation and Hybrid Time-frequency Domain Equalization, Mengjie Zhang1, Meng Shi1, Fumin Wang1, Jiaqi Zhao1, Yingjun Zhai1, Na Chen1, 1Fudan Univ., China; 2A novel PS-Manchester coded Nyquist PAM-8 modulation scheme is proposed and tested for links over a distance of 64 PM-4 LTE A signal and a 1.8Gbps 4-PAM signal over 50m of 1mm core diameter GI-PoF and 3.5mm wireless for in-home networks.

W2A.43
Reconfigurable Radio-over-multi-core Optical Fronthaul for Seamless 2G, UMTS and LTE-A MIMO Wireless Provision, Maria Morant1, Roberto Lopez2, 1Department of Photonics Technologies, Univ. Politecnica de Valencia, Spain; 2Flexible and reconfigurable radio-over-multi-core fiber fronthaul capable of providing simultaneous 2G, 3G and 4G cellular wireless services in the same frequency band with the advantage of antenna equipment reusability is proposed and evaluated experimentally.

W2A.44
Faster-than-Nyquist Signal Generation of Single Carrier 483-Gb/s (120.75-Gbaud) PDM-QPSK with 92-Gb/s DAC, Yanhao Lu1, Yi Xu2, Ming Liu1, Yunda Huang1, Xie Wang1, Liangchuan Liu1, 1Huawei Technologies Co. Ltd., China; 2Department of Electronic and Information Engineering, Tsinghua Univ., China.

W2A.45
Modified Constant Modulus Algorithm Based on Minimization of Mutual Information for Mode-division Multiplexed Transmission, Xiang Li1, Ming Luo1, Hong Gu1, Cai Li1, Ying Gai1, Qi Yang1, 1Wuhan Research Inst. of Posts and Telecommunications, China. We propose a modified CMA based on minimization of mutual information for mode-division multiplexing. In comparison with conventional CMA, the modified algorithm can improve the convergence speed by more than 50% after few-mode fiber transmission.

W2A.46
Kalman-MLESE Equalization of Non-linear Noise, Ori Golan1, 1Mier Feder, 2Mark Stalzer, 1Tel Aviv Univ., Israel. We investigate the potential of adaptive equalization techniques to mitigate intra-channel nonlinear interference noise (NLIN). We develop an equalizer tailored for NLIN reduction, based on Kalman filtering and maximum likelihood sequence estimation (MLSE).

W2A.47
Correlation-Based Polarization Demultiplexing for Clock Recovery in Coherent Optical Receivers, Valery N. Rosenthal1, Ruanzhi Guo1, 1Collaborative Innovation Center of Geospatial Technology, China. This paper proposes a symbol flipping decoding algorithm based on prediction for non-binary LDPC codes, considering not only soft reliability, but also hard reliability. It provides 2.6 dB improvement compared with the weighted Algorithm B.
W2A.50 Performance Evaluation of Clock Recovery Performance of Clock Mode Division Multiplexed Systems, Julio C. Dinza, Molly Piels, Darko Zibar, DTU Fotonik, Denmark. The impact of mode mixing and group delay spread on clock tone quality of a 6-mode 32 Gbd NRZ-PAM5 MDM system is investigated. Even for low group delay spread, strong coupling causes clock tone disappearance.

W2A.51 Experimental Estimation of Optical Nonlinear Memory Channel Conditional Distribution Using Deep Neural Networks, Rafael Rios-Muller, José Manuel Estaran, Jeremy Rendauf, Nokia Bell Labs, France. We demonstrate that neural networks can approximate the conditional distribution of non-linear channels with memory. This distribution then feeds the BCJR algorithm to detect transmission using pre-compensation. We experimentally demonstrate 112-Gb/s 4-level/7-level coding PAM C-band transmission using pre-compensation.
The optical interconnect industry is embracing higher speeds and higher order modulation formats to meet the continuing growth in bandwidth demand. Does the industry have a technology roadmap consistent with these market needs? Are there bottlenecks in the electronics: drivers, TiAs, ADCs, DSPs or the optics: lasers, modulators, detectors? This panel discussion will address these questions with industry experts sharing their view of optimal solutions with constraints such as cost and power consumption, and insight into future innovations that may be needed. Come be a part of the discussion and gain an understanding of what the industry is doing and where it is headed.

Panelists:
Beck Mason, Oclaro, USA
Torben Nielsen, Acadia, USA
Vasudevan Parthasarathy, Broadcom, Canada
Kim Roberts, Ciena, Canada

David V. Plant received the Ph.D. degree from Brown University in 1989. He was a Research Engineer at UCLA 1989 to 1993, and has been a Professor at McGill University, Montreal, QC, Canada, since 1993, where he holds a James McGill Professorship. He has received five teaching awards and other awards including the IEEE Photonics Society Distinguished Lectureship, the IEEE Microwave Theory and Techniques Society Microwave Prize, the IEEE Photonics Society Distinguished Service Award, and a Killam Research Fellowship. He is a Fellow of the Royal Society of Canada, IEEE OSA, CAE, and EIC.
In this presentation, we will experimentally review the evolution of Google’s intra-datacenter interconnects and network over the past decade, then outline future technology directions which, along with a more holistic design approach, will be needed to keep pace with the requirements and growth of the datacenter.

We report the fabrication of a multicore fiber attenuator in which the attenuation of each core is independently set using fs-laser inscription. We present a novel approach for proportioning low-loss optical-interconnection services. A video analytics use case is demonstrated.

An application-aware multi-layer service provisioning algorithm based on auxiliary graphs, Marco Savoi, Fedenco Pederzoli, Domenico Siracusa; ‘CREATE-NET, Italy. A novel application-aware multi-layer resource allocation algorithm is proposed. We demonstrate that it prevents the violation of application requirements (bandwidth, latency, availability, encryption), while keeping blocking probability lower than an existing algorithm.

An exemplar 4-core device with ~1 dB loss-variation between adjacent cores is demonstrated. We demonstrate that it prevents the violation of application requirements (bandwidth, latency, availability, encryption), while keeping blocking probability lower than an existing algorithm.
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<td><strong>W3A</strong> • Panel: Are Electronic and Optical Components Ready to Support Higher Symbol Rates and Denser Constellations?—Continued</td>
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<td><strong>W3B</strong> • Direct-Detection Transceivers—Continued</td>
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<td><strong>W3C</strong> • Symposium: What is Driving 5G, and How Can Optics Help I—Continued</td>
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<td><strong>W3E</strong> • III-V / Silicon Integrated Devices—Continued</td>
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<td><strong>W3F</strong> • Low Cost Systems for Wireless and Non-telecom Applications—Continued</td>
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**W3D.2 • 13:30**
Self-Adaptive, Multi-rate Optical Network for Geographically Distributed Metro Data Centers, Payman Samadi1, Matteo Fiorani2, Yiwen Shen1, Lena Wosinska1, Keren Bergman1; 1Columbia Univ., USA; 2KTH, Sweden. We propose a self-adaptive, multi-rate converged architecture and control-plane for metro-scale inter-data-center networks, enabling live autonomous bandwidth steering. Experimental and numerical evaluations demonstrate up to 5x and 25% improvements in transmission times and spectrum usage.

**W3D.3 • 13:45**
Evaluating the Impact of Data Center Locations and Distance-adaptive Transmission on the Wavelength Resources for Serving Cloud Traffic, Kyle Guan1, Tao Zhang, Cisco Systems, Inc, USA. In this work, we evaluate the impact of distance-adaptive transmission and the locations of data centers (DCs) on the required bandwidth resources for serving DC-to-user and DC-to-DC cloud traffic.

**W3F.2 • 13:30**
3 Gb/s OOK VLC Link Using Bandwidth-Enhanced CMOS Avalanche Photodiode, Bassem Fahs1, Mona M. Hella1; 1ECSE - LESA, Rensselaer Polytechnic Inst., USA. This paper presents a 3-Gb/s OOK VLC link over 1.5-m distance with BER <10−6. The setup uses a custom CMOS Avalanche photodiode with a 3×3 subsections design for bandwidth enhancement and a 680-nm laser diode.

**W3F.3 • 13:45**
Microwave Photonic Link Based on Coherent Detection Using Low-cost Free-Running Laser Sources Incorporating Optical Independent Sideband and Optical Orthogonal Modulation for 4×4 MIMO, Xiang Chen1, Jianping Yao2; 1Univ. of Ottawa, Canada. A microwave photonic link based on coherent detection using low-cost free-running laser sources incorporating optical independent sideband and optical orthogonal modulation with improved spectral efficiency for 4×4 MIMO is proposed and experimentally demonstrated.
Impact of Damping on 50 Gbps 4-PAM Modulation of 25G Class VCSELs, Tamás Lengyel¹, Emanuel P. Haglund¹, Johan Gustavsson¹, Krzysztof Szczerba¹, Anders G. Larson¹, Magnus Karlsson¹, Peter A. Andrekson¹, Chalmers Univ. of Technology, Sweden; Finisar Corp., USA. We investigate the effects of photon lifetime and damping of the modulation response on the quality of 50 Gbps 4-PAM signal generation with directly modulated 25G class VCSELs and identify the appropriate values for the k-factor.

Multicore and Multimode Fiber Devices—Continued

Application of Multicore Optical Fibers in Astronomy, Nemanja Jovanovic¹,², Olivier Guyon², Hajime Kawahara³, Takuji Kotani³, Subaru Telescope, USA; Physics and Astronomy, Macquarie Univ., Australia; Department of Earth and Planetary Science, The Univ. of Tokyo, Japan; National Astronomical Observatory of Japan, Japan. Multicore fibers are desirable for astronomy as they offer superior fill factors and can transport light in many channels with the overhead of only a single fiber. We provide an overview of several astronomical applications.

Eye Skew Modeling, Measurements and Mitigation Methods for VCSEL PAM-4 Channels at Data Rates over 66 Gb/s, Jose M. Castro¹, Rick Pimpinella¹, Bulent Kose¹, Paul Huang¹, Asher Novick¹, Brett Lane¹; Panduit Corp., USA. Investigation of eye skew and techniques for reducing its impact on system performance at data rates from 64 Gb/s to 70 Gb/s using PAM-4 directly modulated VCSELs over 100 m MMF is presented.

Effectiveness of Symbol-rate Optimization with PM-16QAM Subcarriers in WDM Transmission, Fernando Guomare³, Andrea Carena³, Gabriella Bosco³, Antonella Nespoli³, Luca Bertignon³, Pierluigi Poggio³; Politecnico di Torino, Italy; Istituto Superiore Mario Boella, Italy. We demonstrate up to 9% reach gain provided by symbol-rate optimization over PM-16QAM subcarriers in WDM transmission. Applying an ideal CPE, we also discuss on the potentially achievable SRO gains enabled by enhanced phase noise compensation.

Electronically Subcarrier Multiplexed PM-32QAM with Optimized FEC Overheads, Tobias A. Eriksson¹, Fred Buchali¹, Wilfried Idler¹, Laurent Schmaler¹, Gabriel CHARLET¹; Nokia Bell Labs, Germany; 'Nokia Bell Labs, France. We experimentally investigate PM-32QAM with up to 16 subcarriers per wavelength and demonstrate that at a net bitrate of 350 Gbit/s, the distance can be increased by 300 km in WDM transmission using variable rate FEC.
W3B • Direct-Detection Transceivers—Continued

W3B.2 • 14:00 Top-Sorted 504 and 462 Gb/s Direct Detect Transceiver for Single Carrier Short-reach Data Center Applications, Mathieu Chagnon1, David Plant1; ‘McGill Univ., Canada. We demonstrate a single carrier direct detect transceiver operating at 84 Gsymbols/s providing 5.5 and 6 bits per symbol delivering 462 and 504 Gb/s employing a novel modulation format and DSP for 400+ GbE PMD.

W3B.3 • 14:15 Experimental Demonstration of Novel Simple Blind Polarization-demultiplexing Algorithm for Stokes Vector Direct Detection Receivers, Shota Ishimura1, Kosuke Nishimura1; ‘KDDI Research, Inc., Japan. We propose a novel blind polarization-demultiplexing algorithm for SV-DD receivers which significantly reduces computational complexity. We numerically confirmed that the algorithm is robust against SOP fluctuations and experimentally demonstrated its effectiveness by 20-km transmission.

W3B.4 • 14:00 Invited Disaggregated Compute, Memory and Network Systems: A New Era for Optical Data Centre Architectures, Georgios S. Zervas1, Fangsheng Jiang1, Qianqiao Chen1,2, Vaibhawa Mishra1, Hui Yuan1, Kostas Katrinis2, Dimitris Syrivelis1, Andrea Reale2, Dionysios Pnevmatikatos1, Michael Enrico2, Nick Parsons1; ‘Univ. College London, UK; ‘Univ. of Bristol, UK; ‘IBM Research, Ireland; ‘UPTH, Greece; ‘FORTH, Greece; ‘Huber-Suhner Polatis, UK. The disaggregated dRedBox Data Centre architecture is proposed that enables dynamic allocation of pooled compute and memory resources. An orchestration platform is described and algorithms are simulated that demonstrate the efficient utilization of IT infrastructure.

W3E • III-V / Silicon Integrated Devices—Continued

W3E.4 • 14:00 Monolithic Integration of InGaAsP MZI Modulator and InGaAs Driver MOSFET using III-V CMOS Photonics, Jin-Kwon Park1,2, Shinichi Takagi1,2, Mitsuru Takenaka1,2; ‘Univ. of Tokyo, Japan; ‘JST-CREST, Japan. We monolithically integrated carrier-injection InGaAsP optical modulator and InGaAs driver MOSFET on III-V-on-insulator wafer. InGaAsP modulator was successfully driven directly by InGaAs driver MOSFET, exhibiting a proof-of-concept of electronic-photonic integration capability of III-V CMOS photonics platform.

W3F • Low Cost Systems for Wireless and Non-telecom Applications—Continued

W3F.4 • 14:00 Invited Mm-Wave Based Bio-Sensing and Data Communications Using Low-cost CMOS Circuits, Hua Wang1; ‘Georgia Tech, USA. Abstract not available.

W3E.5 • 14:15 Three Modes Multiplexed Photonic Integrated Circuit for Large Capacity Optical Interconnection, Guanyu Chen1, Yu Yu1, De Zhou1, Wenhao Wu1, Xi Xiao1, Songnian Fu2, Xiniang Zhang3; ‘Wuhan National Lab for Optoelectronics, China; ‘State Key Laboratory of Optical Communication Technologies and Networks, Wuhan Research Inst. of Posts Telecommunications, China. We demonstrated a three modes multiplexed photonic integrated circuit suitable for chip-scale large capacity optical interconnection. The 30 Gb/s link including modulation, multiplexer/demultiplexer and detection is experimentally demonstrated with superior performance.
In an SDN-based network, Fiber...
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<td><strong>W3A</strong> • Panel: Are Electronic and Optical Components Ready to Support Higher Symbol Rates and Denser Constellations? — Continued</td>
<td><strong>W3B</strong> • Direct-Detection Transceivers—Continued</td>
<td><strong>W3C</strong> • Symposium: What is Driving 5G, and How Can Optics Help I— Continued</td>
<td><strong>W3D</strong> • Inter/Intra Data Center Networks— Continued</td>
<td><strong>W3E</strong> • III-V / Silicon Integrated Devices— Continued</td>
<td><strong>W3F</strong> • Low Cost Systems for Wireless and Non-telecom Applications— Continued</td>
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**W3B.4 • 14:30** ▶ Top-pivoted 280-Gb/s 320-km Transmission of Polarization-division Multiplexed QAM-PAM with Stokes Vector Receiver, Thang M. Hoang¹, Mohammed Sowailam¹, Mohammed Osman¹, Carl Paquet¹, Stephane Paquet¹, Ian Woods¹, Qunbi Zhuge², David Plant¹; ¹McGill Univ., Canada; ²Ciena, Canada. We propose a novel three-dimensional modulation scheme on Stokes space for metro and regional optical transmissions. Based on this scheme, 320-km transmission of 280-Gb/s 16QAM-PAM2 signals using a Stokes vector receiver is experimentally demonstrated.

**W3B.5 • 14:45** ▶ H-V Plane Projection Based Polarization Recovery and Probabilistic Shaping for Stokes Vector Direct Detection, An Li¹, Wei-Ren Peng¹, Clarence Kan¹, Yanjun Zhu¹, Zhong Li¹, Samina Chowdhury¹, Yan Cui¹, Yusheng Bai¹; ¹Futurewei Technologies, Inc., USA. We propose a novel polarization recovery method and probabilistically shaped 64QAM-OFDM for Stokes-vector direct detection enabling high Baud rate and cost-effective short reach application. A single-A 176-Gb/s signal was successfully received after 20km SMF transmission.

**W3E.6 • 14:30** ▶ Invited 850 nm Hybrid Vertical Cavity Laser Integration for On-chip Silicon Photonics Light Sources, Gunther Roelkens², Emanuel P. Haglund², Sulakshana Kumasi², Erik Haglund², Johan Gustavsson², Roel Baets², Anders G. Larson²; ²Ghent Univ. - imec, Belgium; ¹Chalmers Univ. of Technology, Sweden. The realization of 850 nm hybrid III-V/dielectric VCSELs is reported in order to realize low power consumption integrated light sources for SiN waveguide circuits, which find applications both in short-reach optical communication and optical sensors.

**13:30–15:00** IEEE Women in Photonics/WICE Luncheon, 515A (separate registration required)

**15:00–15:30** Coffee Break, 400 Foyer; Exhibit Hall

**17:00–19:30** Photonic Society of Chinese-Americans Workshop and Social Networking Event, Room 518
W3G • Data Center Interconnect Technologies—Continued

W3G.5 • 14:30 High Bit-Rate Distance Product of 128 Gbps•km 4-PAM Transmission over 2-km OM4 fiber Using an 850-nm VCSEL and a Volterra Nonlinear Equalizer, Jun-Jie Liu1, Kae-Lun Chi2, Chia-Chien Wei1, Tien-Chien Lin1, C.Y. Chuang1, Xin-Nan Chen1, Jin-Wei Shi1, Jyhong Chen1; 1Department of Photonics, National Chiao Tung Univ., Taiwan; 2Department of Electrical Engineering, National Central Univ., Taiwan. We successfully demonstrate a 64-Gbps 4-PAM transmission over 2-km OM4 fiber incorporating a Volterra equalizer with BER of 6.5×10^{-5}. Record high bit-rate distance product of 128 Gbps•km is confirmed for optical-interconnect applications.

W3G.6 • 14:45 Experimentally Benchmarked Fiber Propagation Model for 50Gbps PAM-4 MMF Links Employing Multimode VCSELs, Alirio Melgar1, Varghese A. Thomas1, Justin Lavrencik1, Siddharth Varughese1, Stephen E. Ralph1; 1Georgia Inst. of Technology, USA. MMF propagation of multimode VCSEL signals with preferential coupling of VCSEL modes into fiber modes and colored noise is modeled and benchmarked using 50Gbps PAM-4 and 25Gbps PAM-2 experimental results at 850nm and 940nm.

W3H • Multicore and Multimode Fiber Devices—Continued

W3H.6 • 14:30 Simultaneous Measurement of Temperature and Strain Based on a Polarization-Maintaining Few-Mode Fiber, Liyao Yu1, Jian Zhao1, Qi Ma1, Lin Zhang1, Guifang Li3,1; 1Key Laboratory of Opto-electronic Information Technology Science of Ministry of Education, School of Precision Instruments and Opto-electronics Engineering, Tianjin Univ., China; 2Fiberhome & Fujikura Optics Co., Ltd, China; 3CREOL, The College of Optics & Photonics, Univ. of Central Florida, USA. An optical sensor based on a polarization-maintaining few-mode fiber (PM-FMF) for simultaneous sensing of temperature and strain is demonstrated, for the first time. The sensor has a temperature sensitivity of about 175 pm/°C and a strain sensitivity of about 5 pm/με with an accuracy of 0.1°C and 10 με.

W3I • Control of Multi-layer Networks—Continued

W3I.6 • 14:30 Invited Packet-Optical Integration and Trend Towards White Boxes, Hans-Juergen Schmidtke1, Ilya Lyubomirsky1, Brian Taylor1; 1Facebook Inc., USA. Many implementations have been developed to integrate Packet (mostly IP) networks with underlying transport networks. The paper describes the benefits of packet-optical integration and an opportunity how to use the white box approach to realize the integration. Voyager as an example is described.

W3K • Perspectives in Quantum Communication—Continued

W3K.6 • 14:30 Invited High Bit-Rate Distance Product of 128 Gbps•km 4-PAM Transmission over 2-km OM4 fiber Using an 850-nm VCSEL and a Volterra Nonlinear Equalizer, Jun-Jie Liu1, Kae-Lun Chi2, Chia-Chien Wei1, Tien-Chien Lin1, C.Y. Chuang1, Xin-Nan Chen1, Jin-Wei Shi1, Jyhong Chen1; 1Department of Photonics, National Chiao Tung Univ., Taiwan; 2Department of Electrical Engineering, National Central Univ., Taiwan. We successfully demonstrate a 64-Gbps 4-PAM transmission over 2-km OM4 fiber incorporating a Volterra equalizer with BER of 6.5×10^{-5}. Record high bit-rate distance product of 128 Gbps•km is confirmed for optical-interconnect applications.

W3L • 14:30 Exponentially Benchmarked Fiber Propagation Model for 50Gbps PAM-4 MMF Links Employing Multimode VCSELs, Alirio Melgar1, Varghese A. Thomas1, Justin Lavrencik1, Siddharth Varughese1, Stephen E. Ralph1; 1Georgia Inst. of Technology, USA. MMF propagation of multimode VCSEL signals with preferential coupling of VCSEL modes into fiber modes and colored noise is modeled and benchmarked using 50Gbps PAM-4 and 25Gbps PAM-2 experimental results at 850nm and 940nm.

13:30–15:00 IEEE Women in Photonics/WICE Luncheon, 515A (separate registration required)

15:00–15:30 Coffee Break, 400 Foyer; Exhibit Hall

17:00–19:30 Photonic Society of Chinese-Americans Workshop and Social Networking Event, Room 518
Room 403A

15:30-17:30
W4A • Coded Modulation
Presider: Sebastian Randel; Karlsruher Institut für Technologie, Germany

The talk reviews a higher-order modulation method that approaches Shannon capacity extremely closely. The design, called Probabilistic Amplitude Shaping (PAS), is layered, rate adaptive, systematic, and can substantially improve communication over fiber and wireless links.

W4A.1 • 15:30 Invited Advances in Coded Modulation for Optical Communications, Gerhard Kramer; Electrical and Computer Engineering, Technical Univ. of Munich, Germany. The talk reviews a higher-order modulation method that approaches Shannon capacity extremely closely. The design, called Probabilistic Amplitude Shaping (PAS), is layered, rate adaptive, systematic, and can substantially improve communication over fiber and wireless links.

W4A.2 • 15:45 56Gb/s Chirp-managed Symbol Transmission with Low-cost, 10-G Class LD for 400G Intra-data Center Interconnection, Jianjun Yu, Junwen Zhang1, Hung_Chang Chen1, Xinying Li1, Yuming Xu1, Bingkun Zhou2,2,1, LIU Hang3,2,4, Xiangjun Xin4, 1Fudan Univ., China; 2ZTE (TX) Inc, USA; 3Georgia Inst. of Technology, USA; 4Beijing Univ. of Posts and Telecommunications, China. We have demonstrated up to 56-Gb/s cost-efficient transmission for data center interconnection over 10-km SMF-28 with negative power penalty. This 56-Gb/s transmitter comprises a low-cost 10-G-class directly-modulated distributed-feedback laser without requiring any expensive DAC, ADC and power-consuming DSP.

Room 403B

15:30-17:30
W4C • Microwave Photonic Subsystems
Presider: Paul Matthews; Northrop Grumman Corp, USA

We propose a novel SDN-based parallel lightpath re-completion mechanism enabled by high-precision time synchronization for crosstalk reduction in multi-core fiber networks. Experimental and simulation results show that the proposed mechanism can significantly reduce re-optimization time.

W4C.1 • 15:45 Fast Parallel Lightpath Re-optimization for Crosstalk Reduction in Multi-core Fiber Networks, Rujuje Luo1, Nan Hua2, YAO Li2, XIAoping Zheng1, Bingkun Zhou2,1, TSINGHUA National Lab for Information Science and Technology, China; 2College of Optical Sciences, Univ. of Arizona, USA. We propose a novel SDN-based parallel lightpath re-optimization mechanism enabled by high-precision time synchronization for crosstalk reduction in multi-core fiber networks. Experimental and simulation results show that the proposed mechanism can significantly reduce re-optimization time.

Room 404AB

15:30-17:30
W4D • PAM-4 Inter-data Center Transmission
Presider: Marc Bohn; Corant, Germany

Large-scale Silicon Photonic Switches Using Electro-optic MZIs, Linjie Zhou1, Lianjun Lu1, Shuaii Zhao1, Zhanzhi Guo1, Dong Li1, Jianping Chen1,1, Shanghai Jiao Tong Univ., China. We review recent progress on silicon photonic switches based on electro-optic MZI and dual-ring assisted MZI switch elements. Phase error corrections are performed using thermal tuning to set the initial switching state.

W4D.1 • 15:30 TDECQ (Transmitter Dispersion Eye Closure Quaternary) Replaces Historic Eye-mask and TDP Test for 40 Gb/s PAM4 Optical Transmitters, Jonathan King1,2, David Leyba1, Greg LeCheminant1,3, Keyysight Technologies, USA; 2Finisar Corporation, USA. For PAM4 transmission in 40 Gb/s Datacom networks, use of equalization and FEC, and a need to reduce cost, force a replacement of historic eye-mask and TDP tests. We describe that replacement: TDECQ.

W4D.2 • 15:45 Large-scale Silicon Photonic Switches Using Electro-optic MZIs, Linjie Zhou1, Lianjun Lu1, Shuaii Zhao1, Zhanzhi Guo1, Dong Li1, Jianping Chen1,1, Shanghai Jiao Tong Univ., China. We review recent progress on silicon photonic switches based on electro-optic MZI and dual-ring assisted MZI switch elements. Phase error corrections are performed using thermal tuning to set the initial switching state.

Room 404B

15:30-17:30
W4E • Photonic and Planar Switches
Presider: Benjamin Lee; IBM Thomas Watson Research Center, USA

The vision of 5G is commonly presented as part of the network vision for 2020 and beyond, which in turn embodies a number of services for the future information society in which everything that can connect to this society will do so. The typical services identified span areas such as enhanced mobile broadband services, media distribution, Smart Cities, and the internet of things (IoT), with massive as well as ultra-reliable and low latency critical machine-type communications to support both end-user and operational purposes. Besides new services and applications, 5G will also need to support a wide range of business ecosystems and cooperation models supporting digitalization of industry and trends of business horizontalization. 5G goes far beyond the definition of new radio interfaces. 5G is about a new end-to-end network vision, in which softwareization and virtualization allow a common network infrastructure to be flexibly used for a variety of diverse applications.

The symposium will consist of two sessions. The first session will focus on “What is driving 5G?” with speakers from the 5G community as well as vertical industries that can be benefited adapting the 5G vision. This session will give an overview of the services, applications and ecosystems that are driving 5G and provide some insight on how these can create a new and substantial business opportunity for optical networking and its most advanced technologies. The second session will focus on the role of optics and will include speakers from the optical networking/communications community. This session will give an overview of how optics can play a key role for realizing 5G networks and will continued on page 120

Room 406AB

15:30-17:30
W4F • WDM and SDM Networking
Presider: Masahiko Jinno; KAGAWA Univ., Japan

What is driving 5G?” with speakers from the 5G community as well as vertical industries that can be benefited adapting the 5G vision. This session will give an overview of the services, applications and ecosystems that are driving 5G and provide some insight on how these can create a new and substantial business opportunity for optical networking and its most advanced technologies. The second session will focus on the role of optics and will include speakers from the optical networking/communications community. This session will give an overview of how optics can play a key role for realizing 5G networks and will
Larry A. Coldren is the Fred Kavli Professor of Optoelectronics and Sensors at the University of California, Santa Barbara, CA. He received his Ph.D. in EE from Stanford Univ. and spent 13 years in research at Bell Labs before joining UCSB in 1984, where he holds appointments in the ECE and Materials Departments. He acted as Dean of Engineering at UCSB from 2009-2011. In 1991 he co-founded Optical Concepts, acquired as Gore Photonics, to develop novel Vertical-Cavity Surface-Emitting Laser (VCSEL) modules; and later in 1998, Agility Communications, acquired by JDS-Uniphase (now Lumentum), to develop widely-tunable integrated optical transmitters. He has authored continued on page 121
We report a novel post-probabilistically-shaped PAM as a simple channel coding being applicable to optical communication systems with SD-FEC. It directly controls the distribution and achieves 0.52 dB required SNR reduction with 4% incremental overhead.

We developed a 100 GHz optical-to-radio converter module and its Application in Radio and Power Over Fiber Transmission through Multi-core Fiber, Toshimasa Umezawa, Pham T. Dat, Eiichi Hasl, Kenichi Kashima, Atsushi Kanno, Kouichi Akahane, Atsushi Matsumoto, Naokatsu Yamamoto, Tetsuya Kawanishi. A National Inst of Information & Comm Tech, Japan; Hitachi Kokusai Electric Ltd., Japan; Waseda Univ., Japan. We developed a 100 GHz optical-to-radio converter module integrated with a 100 GHz amplifier, which was applied in radio (12-Gbps, OFDM, 16-QAM, IF = 92-GHz) and power over fiber transmission through a multi-core fiber.

We presented a toolkit that leverages optical layer re-routing to efficiently mitigate soft-failures, rendering Elastic Optical Networks with low-cost re-routing. The tool identifies affected demands, triggers affected demands re-routing, and the crosstalk values are below -15dB. The 8 channels are tested with 4-Tb/s metro-DCI system using Quantum-dot laser and silicon ring-modulator, Sidarth Patel, Animesh Adhikari, Aramideh Aminpour, Nicklas Sandgren; ADVA Optical Network PTY LTD, Germany; Adva Optical Networking SE, Germany; Astit Politècnica de Catalunya, Spain; Scuola Superiore Sant'Anna, Italy; CNIT, Italy. Early optical layer BER degradation detection is proposed to trigger affected demands re-routing, targeting at reducing SLA violation. Results show that the proposed detection and re-routing algorithms noticeably reduce bandwidth and number of demands affected.

We report a novel photonic transmitter sub-assembly comprising multi-wavelength quantum-dot laser and silicon ring modulators. Pre-FEC BERs below 1E-4 are achieved after 80-km, allowing error-free operation with HD-FEC.

We demonstrated and performance analysis of 4-Tb/s WDM Metro-DCI System with 100G PAM4 QSF1P28 Modules, Mark M. Flierl, Steven Seearcy, Zayr Fu, Radhakrishnan Nagarajan, Sorin Tibleacu, Microsoft Corp., USA; ADVA Optical Network, USA; Inphi Corp, USA. We demonstrated a 4-Tb/s metro-DCI system with commercial QSF1P28 modules (40×100G dual-wavelength 56-Gb/s PAM4). We detail system performance over 80km and quantity tolerance to chromatic dispersion and nonlinearity over a wide range of fiber types.
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<td><strong>W4G • Indium Phosphide Photonic Integration—Continued</strong></td>
<td><strong>W4H • Evolution of Optical Networks—Continued</strong></td>
<td><strong>W4I • High-speed Interconnects—Continued</strong></td>
<td><strong>W4J • SDN/NFV and Service Function Chaining—Continued</strong></td>
<td><strong>W4K • Panel: Quantum Communication Programs Around the World—Continued</strong></td>
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**W4H.3 • 16:00**
Migrating Elastic Optical Networks from Standard Single-Mode Fibers to Ultra-low Loss Fibers: Strategies and Benefits, Yanxin Guan, Haomin Jiang, Mingyi Gao, Sanjay K. Bose, Gangxiang Shen, Soochow Univ., China; IIT Guwahati, India. We consider replacing standard single-mode fibers with ultra-low loss fibers in an elastic optical network. Replacement strategies are compared based on bandwidth blocking performance. Simulations show that the OSNR-blocking-based strategy is efficient and saturation exists between the fiber attenuation factor and blocking performance improvement.

**W4I.2 • 16:00**
Single Wavelength 100G Real-Time Transmission for High-Speed Data Center Communications, Andrea Chiuchiarelli, Rohan Gandhi, Sandro Rossi, Luis H. Carvalho, Francesco Caggiano, Julio C. Oliveira, Jacklyn Reis, CPqD, Brazil; Applied Micro, USA; Buck Photonics, Brazil. The first demonstration of real-time 53.125-Gb/s PAM-4 optical transmission over 2-km SSMF enabled by 16-nm DSP-ASIC and small-size, high-bandwidth optoelectronics is reported. Pre-FEC BER < KP4 threshold is demonstrated for future high-speed data center connectivity.

**W4J.2 • 16:00**
Invited Efficient and Verifiable Service Function Chaining in NFV: Current Solutions and Emerging Challenges, Ying Zhang, Sujata Banerjee; Hewlett Packard Labs, USA. The ability to deploy Service Function Chains (SFC) efficiently and correctly is important in Network Functions Virtualization (NFV) infrastructures. This talk discusses the challenges and emerging solutions for scalable instantiation and verification of SFCs.

**W4H.4 • 16:15**
Evolution of Core Traffic for Growing CDNs: Is the Growth Rate of Core Network Traffic Overestimated?, Pablo Pavan-Marino, Francesco-Javier Moreno-Muro, Nina Skorin-Kapov; Politechnical Univ. of Cartagena, Spain; Univ. Center of Defense, Spain. The dramatic growth of user traffic will precipitate CDN expansion, both in capacity and new datacenter locations, the latter bringing content closer to the user. We investigate how this may partially alleviate core traffic growth.

**W4I.3 • 16:15**
Intra-Datacenter Links Exploiting PCI Express Generation 4 Interconnections, Alberto Gatto, Paola Palan, Marco Brunero, Francesco Corapi, Viscardo Costa, Claudio Meani, Pierpaolo Boffi; Politecnico di Milano, Italy; ItalTEL S.p.A., Italy. We demonstrate few-km reaches for PCIe-based optical fiber interconnections according to latency limitations, characterizing 16-GB/s per lane Generation4 up to 10 km and confirming the Generation3 compliance of 2-km links employing suitable PCIe cards.
Nonlinearity-tolerant Time Domain Hybrid Modulation for 4-8 bits/symbol based on 2APSK, Keisuke Kojima1, Tsuyoshi Yoshida1, Kieran Parsons1, Toshiaki Koike-Akino1, David Millar1, Keisuke Kojima1. Mitsubishi Electric Research Labs, USA; ‘Mitsubishi Electric Corp., Japan. We propose time domain hybrid modulation to cover 4-8 bits/symbol range, based on 5, 6, and 7 bits/symbol 4D-2APSK. Simulation results indicate that they have up to 1.6 dB higher span loss budget than the hybrid modulation based on conventional modulation formats in nonlinear channels.

Sudeep Bhoja has served as Infph’s Chief Technology Officer, Networking Interconnect since March 2012. At Infph, he leads the DSP system architecture team responsible for the development of Pulse Amplitude Modulation (PAM4) DSP transceiver chips. Prior to Infph, he was Technical Director in the Infrastructure and Networking Group at Broadcom and played an instrumental role in developing 10-Gigabit Ethernet optical and copper transceivers. Prior to Broadcom, he was Chief Architect at Big Bear Networks, a maker of 10Gb/s and 40Gb/s optical transceivers and developed the industry leading 10G Electronic Dispersion Compensation (EDC) products. He also held R&D positions at Lucent Technologies and Texas Instruments. He is the named inventor of over 30 pending and approved patents. He received an M.S.E.E. from Purdue University, West Lafayette, IN, USA.

Hybrid Modulation for 4-8 bits/symbol based on conventional modulation formats in nonlinear channels.
W4G • Indium Phosphide Photonic Integration—Continued

W4G.2 • 16:30 Multi-channel Interference (MCI) Widely Tunable Laser Integrated with Semiconductor Optical Amplifiers, Quanan Chen1,2, Xiang Ma1,2, Wei Sun1,2, Ye Lu1,2, Gonghai Liu1,2, Gongyuan Zhao1,2, Qiayin Lu1,2, Weihua Gup1,2, Hua Zhong Univ. of Science and Technology, China; 1Wuhan National Laboratory for Optoelectronics, China. We demonstrate the MCI laser integrated with SOA through a two-port multi-mode interference reflector. A tuning range of more than 45 nm with 5MSRs up to 47 dB is achieved.

W4I • High-speed Interconnects—Continued

W4I.4 • 16:45 100 Gbit/s Serial Transmission Using a Silicon-Organic Hybrid (SOH) Modulator and a Duobinary Driver IC, Heiner Zwickel1, Timothy De Keulenaer1, Stefan Wolf1, Clemens Kieninger1, Yuasir Kutuvaantivada1, Matthias Lauermann2, Michel Verplaetse3, Ramses Piero2, Renato Vaemewyck2, Amo Vyncke1, Xin Yin1, Guy Torfs1, Wolfgang Freude1, Edaf Mentovich2, Johan Bauwelinck1, Christian Koos2, Ghent Univ., Belgium; 2Infinera Corp., USA; 3Mellanox Technologies Ltd., Israel; 1Karlsruhe Inst. of Technology, Germany. 100 Gbit/s three-level (50 Gbit/s OOK) signals are generated using a silicon-organic hybrid modulator and a BiCMOS duobinary driver IC at a BER of 8.5×10−10. We demonstrate dispersion-compensated transmission over 5 km.

W4J • SDN/NFV and Service Function Chaining—Continued

W4J.3 • 16:30 Service Chaining in Multi-Layer Networks using Segment Routing and Extended BGP Flowspec, Francesco Paolucci1, Alessio Giorgetti2, Filippo Cugini3, Piero Castoldi1, Scuola Superiore Sant’Anna, Italy; 2CNI; 3Italy. Effective service chaining enforcement along TE paths is proposed using Segment Routing and extended BGP Flowspec for micro-flows mapping. The proposed solution is experimentally evaluated with a deep packet inspection service supporting dynamic flow enforcement.
We present 1, Uzma Waheed 2, Shin 1, 2, 3, David Plant 3, Room 406AB Room 404AB, Fatih Yaman 1, 2, 3, 4, 3, David Plant 3, Room 407

Wednesday, 22 March

A modified pairwise optimization algorithm has been proposed to optimize N-dimensional constellation. The resulting optimized 2- and 4-dimensional 8QAM formats outperform star-8QAM by >0.4 dB at the SNR above the FEC limit in both simulation and experiments.

We propose to use adaptive bit and power loading in digital subcarrier-multiplexing (SCM) systems based on time-domain hybrid QAM to increase optical filtering tolerance. 17.5% capacity improvement is achieved in experimental demonstrations.

We consider two different network topologies and eleven different hybrid amplification solutions. We consider different network topologies and eleven different hybrid amplification solutions.
W4G • Indium Phosphide Photonic Integration—Continued

W4H • Evolution of Optical Networks—Continued

W4I • High-speed Interconnects—Continued

W4J • SDN/NFV and Service Function Chaining—Continued

W4K • Panel: Quantum Communication Programs Around the World—Continued

W4G.4 • 17:00 Invited

DAC-free Generation of M-QAM Signals with InP Segmented Mach-Zehnder Modulators, Martin Schell\textsuperscript{1}, Gerrit Fiol\textsuperscript{1}, Alessandro Aimone\textsuperscript{1}; \textsuperscript{1}Fraunhofer Institut, Germany. The concept of DAC-less generation of multi-level optical signals is discussed together with its latest InP-based results. A flexible transmitter sub-assembly enabling 32 Gb/s M-QAM operation up to 256-QAM is shown.

W4H.6 • 17:00 Invited

Multinational Submarine Networks, Lara D. Garrett\textsuperscript{1}; \textsuperscript{1}TE SubCom, TE Connectivity, USA. We discuss system design issues introduced by different ownership models in undersea OADM cables, including the selection of OADM node architectures and the level of OADM reconfigurability.

W4I.6 • 17:00

Broadband Plasmonic Modulator Enabling Single Carrier Operation Beyond 100 Gbit/s, Claudia Hoesbacher\textsuperscript{1}, Arne Josten\textsuperscript{1}, Benedikt Baueuerle\textsuperscript{1}, Yury Fedoryshyn\textsuperscript{1}, Horst Hettich\textsuperscript{1}, Yannick Salamin\textsuperscript{1}, Wolfgang Heni\textsuperscript{1}, Christian Haffner\textsuperscript{1}, Rolf Schmidt\textsuperscript{2}, Delwin Elder\textsuperscript{3}, David Hillekuss\textsuperscript{4}, Michael Moeller\textsuperscript{2}, Larry Dalton\textsuperscript{3}, Juerg Leuthold\textsuperscript{1}; \textsuperscript{1}ETH Zurich, Switzerland; \textsuperscript{2}Micram Microelectronic GmbH, Germany; \textsuperscript{3}Univ. of Washington, USA. We demonstrate a plasmonic Mach-Zehnder modulator with a flat frequency response exceeding 170 GHz. Modulation of the device is shown at 100 Gb/s NRZ and 60 Gb/s PAM-4.

W4I.7 • 17:15

High Speed 160 Gb/s DMT VCSEL Transmission Using Pre-equalization, Christoph Kottke\textsuperscript{1}, Christoph Caspar\textsuperscript{2}, Volker Jungnickel\textsuperscript{2}, Ronald Freund\textsuperscript{2}, Mikel Agustin\textsuperscript{3}, Nikolay Ledentsov\textsuperscript{3}; \textsuperscript{1}Technische Universität Berlin, Germany; \textsuperscript{2}Fraunhofer Heinrich Hertz Inst., Germany; \textsuperscript{3}VI Systems, Germany. High speed single channel DMT operation of a directly modulated 850 nm VCSEL with 26 GHz bandwidth is presented. Successful transmission of 161, 152, 143 Gb/s over 10, 20, 30 m of OM4 MMF is demonstrated at the SD-FEC BER limit.

W4J.5 • 17:00

On Efficient Incentive-Driven VNF Service Chain Provisioning with Mixed-strategy Gaming in Broker-based EO-IDCNs, Xiaoliang Chen\textsuperscript{1}, Lu Sun\textsuperscript{2}, Zuqing Zhu\textsuperscript{2}, Hongbo Lu\textsuperscript{1}; \textsuperscript{1}Univ. of California, Davis, USA; \textsuperscript{2}Univ. Scien. Techn. China, China. We propose to realize incentive-driven virtual network function service chain provisioning in broker-based elastic optical inter-datacenter networks with mixed-strategy gaming and design a heuristic to find the near-equilibrium solutions. Simulation results verify both the effectiveness and stability of the proposed approach.

W4J.6 • 17:15

Exploiting Time-synchronized Operations in Software-defined Elastic Optical Networks, Abubakar Siddique Muqaddas\textsuperscript{1}, Miquel Garrich A.\textsuperscript{1}, Paolo Giaccone\textsuperscript{1}, Andrea Bianco\textsuperscript{1}; \textsuperscript{1}Politecnico di Torino, Italy. We propose and discuss NETCONF / OpenFlow implementations of timesynchronized operations, recently standardized in SDN, to minimize disruption time during lightpath reassignment in Elastic Optical Networks. 75% disruption time reduction is reported in our test scenario.
Room 402AB
08:00–10:00
Th1A • Detectors/Receivers
Presider: Andreas Steffan; Finisar Corporation, Germany

Room 403A
08:00–10:00
Th1B • Silicon Photonics
Presider: Ken Morito; Fujitsu Laboratories Ltd., Japan

Room 403B
08:30–10:00
Th1C • SDM Transmission II
Presider: Takayuki Mizuno; NTT Network Innovation Laboratories, Japan

Room 404AB
08:00–09:45
Th1D • Advances in Coherent Subsystems
Presider: Han Henry Sun; Infinera Corporation, Canada

Room 406AB
08:00–09:45
Th1E • Visible Light Communications
Presider: Christina Lim; University of Melbourne, Australia

Room 407
08:00–09:45
Th1F • Applications of Parametric Nonlinear Processors
Presider: Robert Elschner; Fraunhofer Heinrich Hertz Inst., Germany

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**Th1A.1 • 08:00**
Low Power Consumption and High-Speed Ge Receivers, Laurent Vivien1, L. Virot1, D Benedikovic1, B Szelag2, C Alonso-Ramos1, JM Hartmann1, Paul Crozat1, E Cassan1, Delphine Marris-Morini1, Charles Baudot2, Frederic Boeuf3, J.M Fedieli1, C Kopp4, 1Universite de Paris-Sud XI, France; 2Univ. Grenoble Alpes and CEA, France; 3STMicroelectronics, France. A new Si/Ge/Si heterojunction based waveguide photodetector has been demonstrated in order to reduce the fabrication cost, increase the responsibility, and improve process robustness. State of the art characteristics in terms of dark current, responsivity and bandwidth have been obtained.

**Th1B.1 • 08:00**
Driver-integrated 56-Gb/s Segment-ed Electrode Silicon Mach Zehnder Modulator using Optical Domain Equalization, Benjamin G. Lee1, Nicolas Dupuis2, Renato Rinaldo-Donado1, Tam Huy1, Christian W. Baks3, Douglas M. Gill1, William M. Green1, IBM TJ Watson Research Center, USA. We report an IC-driven silicon photonic segmented electrode Mach Zehnder modulator exploiting optical domain feed-forward equalization resulting in 56-Gb/s NRZ operation with BER $10^{-12}$. The result could enable FEC-free links for latency sensitive datacenter applications.

**Th1C.1 • 08:00**
Design Considerations for a Digital Subcarrier Coherent Optical Modem, David Krause1, Ahmed Awadalla1, Abdullah Karar1, Han Henry Sun1, Kuang-Tsan Wu1; 1Infinera Canada Inc, Canada. Subcarrier modulation is shown to provide a number of system benefits including complexity savings in dispersion compensation, Kerr nonlinearity mitigation and flexibility in spectral efficiency. Design considerations are discussed.

**Th1D.1 • 08:00 Invited**
Continuously Tunable Optical Frequency Comb Lifetime and Performance, Robert Elschner1, Carsten Schmidt-Langhorst2, Joel Glor1, Takahito Tanimura3, Thomas Richter3, Robert Elschner1, Carsten Schmidt- Langhorst2, Joel Glor1, Takahito Tanimura3, Thomas Richter3, Robert Elschner1, Carsten Schmidt- Langhorst2, Joel Glor1, Takahito Tanimura3, Thomas Richter3.

**Th1E.2 • 08:15**
Experimental Demonstration of Continuous Tunable Optical Frequency Shift of 1.6-Tb/s Superchannel up to THz-Range by Polarization Switched Frequency Conversion, Tomoyuki Kato1, Shigeki Watanabe2, Takahito Tanimura3, Thomas Richter3, Robert Elschner1, Carsten Schmidt- Langhorst2, Joel Glor1, Takahito Tanimura3, Thomas Richter3.

**Th1F.2 • 08:15**
Continuously Tunable Optical Frequency Shift of 1.6-Tb/s Superchannel up to THz-Range by Polarization Switched Frequency Conversion, Tomoyuki Kato1, Shigeki Watanabe2, Takahito Tanimura3, Thomas Richter3, Robert Elschner1, Carsten Schmidt- Langhorst2, Joel Glor1, Takahito Tanimura3, Thomas Richter3.
We demonstrate this tutorial.

We investigate and a record high filter roll-off of 2.5 dB/nm for the first time.

We find that the passband of the filter device with a flat-top passband of \( \Delta \mu > 10 \) nm is demonstrated using multi-mode SOI waveguide with a side-wall grating. The passband is bounded by highly extinguished sidebands of \( \Delta \mu > 10 \) nm.

Steven Scott Gorshe received his B.S.E.E. from the University of Idaho (1979) and M.S.E.E. (1982) and Ph.D. (2002) from Oregon State University. His work includes a variety of hardware design, system architecture, and applied research for GTE, NEC America, PMC-Sierra, and Microsemi where he is a Distinguished Engineer. He is ITU-T Q11/15 Associate Rapporteur. His standards activity there and in other bodies includes >400 contributions, and multiple technical editorships. He is an IEEE Fellow, has 38 patents granted/pending, is co-author of two books, three chapters and many papers. His IEEE ComSoc activities include editor-in-chief and Board-of- Governors MAL.
Room 402AB

Th1A • Detectors/Receivers—Continued

Th1A.2 • 08:30
64 Gbaud High-bandwidth Micro Intradyn Coherent Receiver using High-efficiency and High-speed InP-based Photodetector Integrated with 90° Hybrid, Masaru Takechi1, Yoshihiro Tateiwa1, Munetaka Kurokawa1, Yasushi Fujimura2, Hideki Yagi3, Yoshihiro Yonezawa1; Sumitomo Electric Device Innovations, Inc., Japan; 1Transmission Devices Laboratories, Sumitomo Electric Industries, Ltd., Japan. 64 Gbaud high-bandwidth micro intradyne coherent receiver using InP-based 90° hybrid integrated with photodiodes is demonstrated. A 3 dB bandwidth of 40 GHz with differential transimpedance of 400 ohm and high average responsivity more than 70 mA/W within the C-band are achieved.

Th1A.3 • 08:45
Schottky Diodes in 40nm Bulk CMOS for 1310nm High-speed Optical Receivers, Wouter Diels1, Michel Steyaert1, Filip Tavernier1; Katholieke Universiteit Leuven, Belgium. Schottky diodes in CMOS as 1310 photodiodes are proposed. N-well and p-well Schottky diodes are fabricated and characterized in 40nm bulk CMOS. To the authors’ knowledge, this is the first 1310nm CMOS photodetector reported.

Room 403A

Th1B • Silicon Photonics—Continued

Th1B.3 • 08:30
Invited Complexity Scaling in Silicon Photonics, Amit Khanna1, Yaoja Chen1, Ari Novack1, Yang Liu2, Ran Ding3, Tom Baehr-Jones3, Michael Hochberg1; 1Elenion Technologies, USA. Silicon photonics provides an excellent platform for scaling photonic systems on-chip complexity and bandwidth. We continue to see chip complexity doubling every 12-18 months.

Room 403B

Th1C • SDM Transmission II—Continued

Th1C.1 • 08:30
Transmission of 256Gb/s-16QAM Signal through Hybrid Clladding and Core Pumping Scheme MC-EDFA Controlled for Reduced Power Consumption, Emmanuel Le Taillandier de Gabory1, Keichi Matsumoto2, Sadao Fujita3, Shigenori Nakamura1, Shigeyuki Yanagimachi1, Jun’ichi Abe1; 1NEC Corporation, Japan. We transmit 256Gb/s signal through 40km, passing 8 times a hybrid pumping scheme MC-EDFA controlled depending on monitored temperature. Received Q value variations are within ±0.15dB while power consumption is reduced by up to 38.0%.

Th1C.2 • 08:45
200 Gbit/s 16QAM WDM Transmission over a Fully Integrated Cladding Pumped 7-Core MCF System, Carlos Castro1, Saurabh Jain1, Yongmin Jung2, Erik De Man3, Stefano Catabani4, Klaus Pulverer5, Marc Bohn5, John Hayes1, Shai-ul Alam1, David J. Richardson1, Katsuhiro Takenaga1, Takayuki Muzuno1, Yutaka Miyamoto1, Toshio Morikawa1, Werner Rosenkrantz1; 1Univ. of Kiel, Germany; 2NICT, Japan; 3Technical Univ. of Denmark, Denmark. A complete, realistic integrated system is investigated, consisting of directly spliced 7-core MCF, cladding-pumped 7-core amplifiers, isolators, and couplers. The system is demonstrated in a 16QAM C-band WDM scenario over 720 km.

Room 404AB

Th1D • Advances in Coherent Subsystems—Continued

Th1D.2 • 08:30
Transmission Performance of Layer-2/3 Modular Switch with mQAM Coherent ASIC and CFP2-ACOs over Flex-grid OLS with 104 Channels Spaced 37.5 GHz, Mark M. Filer1, Hacene Chauouch1, 1Microsoft Corp., USA; 2Arista Networks, USA. 1500 8QAM and 200G 16QAM signals, residing on a layer-2/3 modular switch card with integrated coherent optics, are sent over a fully-loaded, flexible-grid open line system with 104 co-propagating 37.5 GHz channels.

Room 406AB

Th1E • Visible Light Communications—Continued

Th1E.3 • 08:30
Invited Enabling Technologies for High Speed Visible Light Communication, Nan Ch1, Yingqiu Zhou1, Jian Yang Shi1, Yuguang Wang1, Xinxing Huang1; 1Fudan Univ., China. We summarized the latest progress on enabling technologies for high speed VLC system beyond Gigabit/s including advanced modulation formats, software and hardware pre-equalization, advanced coding and nonlinear compensation.

Room 407

Th1F • Applications of Parametric Nonlinear Processors—Continued

Th1F.3 • 08:30
Design and Demonstration of 30-nm Tunable Guard-band-less All-optical Wavelength Converter for WDM Signals, Takeshi Inoue1, Shigehiro Takasaka2, Kazuya Ota1, Shu Namiki3; 1Nat’l Inst of Adv Industrial Sci & Tech, Japan; 2Funakawa Electric Co., Ltd., Japan; 3Trimatiz Ltd., Japan. We design an all-optical wavelength converter enabling guard-band-less tunable operation over 30-nm bandwidth for WDM signals. Arbitrary conversion operations in 1530-1560nm range for 8-channel 32-Gbaud DP-QPSK signals with the bandwidth of 1THz are successfully demonstrated.
We demonstrated delta-MCFs fabricated with a preform rotation mechanism. Such MCFs were experimentally used in mesh networks with 0.6 dB Q-factor accuracy. We demonstrate quality of transmission was achieved supporting 16384QAM on all 20 DOCSIS channels. The architecture is experimentally assessed through a use case.

**Time-dependent Crosstalk from Multiple Cores in a Homogeneous Multi-core Fiber**

- **Invited**: Shinichi Aozasa, Taiji Sakamoto, Sakii Nozoe, Yuto Sagae, Masaki Wada, Takayoshi Morii, Kyozo Tsuchikawa, Takashi Yamamoto, Kazuhide Nakajima
- **NTT Access Network Service Systems Laboratories, NTT Corporation, Japan.**

**Bending Radius Dependence of Spatial Mode Dispersion in Randomly Coupled Multi-Core Fiber**

- **Access Network Service Systems Laboratories, NTT Corporation, Japan.**

- **Randomly coupled multi-core fiber (MCF) with a uniform twist realized lower spatial mode dispersion (SMD) and bending-radius dependence. The SMD-macrobending relationship was examined numerically and experimentally using MCFs fabricated with a preform rotation mechanism.**

**Accurate Prediction of Quality of Transmission with Dynamically Configurable Optical Impairment Model**

- **Invited**: Zhenhua Feng, Liang Xu, Qiong Wu, Ming Tang, Songnian Fu, Weijun Tong, Deming Liu, Jorge Lopez de Vergara, Luis Velasco, Universitat Politecnica de Catalunya, Spain; Department of Electronics and Communication Technologies, Universidad Autonoma de Madrid (UAM), Spain. An architecture supporting the OAA loop is proposed. It consists on extending nodes and the domain controller with analytics capabilities for local and network-wide operation automation. The architecture is experimentally assessed through a use case.

**Experimental Assessment of Node and Control Architectures to Support the Observe-Analyze-Act Loop**

- **Invited**: Naoya Wada, Takeshi Hoshiba, Tadashi Ikeuchi, Fujitsu Laboratories of America Inc, USA; Fujitsu Laboratories Ltd., Japan; Fujitsu Limited, Japan. We propose a dynamically configurable optical impairment model for a physical layer abstraction enabling physical parameters learning in multi-vendor networks. We experimentally demonstrate quality of transmission prediction in mesh networks with 0.6 dB Q-factor accuracy.

**Large-Capacity Optical Access Network Utilizing Multicore Fiber and Self-Homodyne Coherent Detection**

- **Invited**: Zhenhua Feng, Liang Xu, Qiong Wu, Ming Tang, Songnian Fu, Weijun Tong, Deming Liu, Jorge Lopez de Vergara, Luis Velasco, Universitat Politecnica de Catalunya, Spain; Department of Electronics and Communication Technologies, Universidad Autonoma de Madrid (UAM), Spain. We proposed a cost-efficient large-capacity WDM-SDM optical access network employing MCF and self-homodyne detection. 4×6×200-Gb/s PDM-16QAM-OFDM downstream transmission was realized over 37-km 7-core fiber with simplified DSP enabling use of low-cost 10MHz linewidth DFB lasers.
High-gain Phase Modulated Analog Photonic Link Using High-power Balanced Photodiodes, Zhanyu Yang, Andreas Beling, 1Tosho Morioka, 1and Toshio Morioka. We report the demonstration of an ultra-compact 5-channel integrated III-V/InP photodiode for the generation of a 69Gb/s discrete multitone signal with a cutoff wavelength at 1310 nm. We successfully achieved modulation up to 40 Gbit/s/channel providing a total aggregated capacity of 200 Gbit/s and transmission over 10 km at 21.4 Gbit/s/channel for 100Gbit/s.

Integrated 5-channel WDM hybrid III-V/Si transmitter enabling 100Gb/s and beyond, Guilhem de Valicourt, Chia-Ming Chang, Sathish Sundaramohan Chandrasekhar, Young-Kai Chen, Anaelle Mato, Romain Benaix, Po Dong, 1Wiley Lab, France; 1Nokia Bell Labs, USA. We report the demonstration of an ultra-compact 5-channel hybrid integrated III-V/InP transmitter. We successfully achieved modulation up to 40 Gbit/s/channel providing a total aggregated capacity of 200 Gbit/s and transmission over 10 km at 21.4 Gbit/s/channel for 100Gbit/s.

High-gain phase modulated analog photonic link with interferometric detection is experimentally demonstrated. A link gain of 15 dB at 100 mA is achieved.

High-gain Phase Modulated Analog Photonic Link Using High-power Balanced Photodiodes, Zhanyu Yang, 1Andreas Beling, 1Qianhuan Yu, 1Peng Yao, 1Xiaojun Xie, 1Christopher Schuetz, 1Joe C. Campbell, 1Univ. of Virginia, USA; 1phase sensitive innovation, USA. A phase modulated analog photonic link with interferometric detection is experimentally demonstrated. A link gain of 15 dB at 100 mA photocurrent and 10 GHz modulation frequency is achieved.

Th1B • Silicon Photonics—Continued

Th1C • SDM Transmission II—Continued

Th1D • Advances in Coherent Subsystems—Continued

Th1E • Visible Light Communications—Continued

Th1F • Applications of Parametric Nonlinear Processors—Continued

Recent progress in large-capacity transmission technologies based on multicore fibers is reviewed with future perspectives towards well beyond 1PB/s. We discuss the key metrics of analog coherent interfaces for today’s 200G 16QAM and future 400-600G 64QAM pluggable systems. A cloud service provider perspective on next generation DCI requirements is also discussed.

We propose recent progress in large-capacity transmission technologies based on multicore fibers is reviewed with future perspectives towards well beyond 1PB/s. We discuss the key metrics of analog coherent interfaces for today’s 200G 16QAM and future 400-600G 64QAM pluggable systems. A cloud service provider perspective on next generation DCI requirements is also discussed.

We experimentally demonstrate a software-defined 2x2 MIMO VLC system employing link adaptation to boost throughput of VLC-based two-way relay networks. Experimental results show that the network capacity can be improved by 100% with ~2.5 dB SNR penalty.

Th1E.5 • 09:15
Software Defined Adaptive MIMO Visible Light Communications after an Obstruction, Peng Deng, Mohsen Kavehrad, 1The Pennsylvania State Univ., USA. We experimentally demonstrate a software-defined 2x2 MIMO VLC system employing link adaptation of spatial multiplexing and diversity. The average error-free spectral efficiency of 12 b/s/Hz is achieved over 2 meters indoor transmission after an obstruction.

We successfully achieved modulation up to 40 Gbit/s/channel providing a total aggregated capacity of 200 Gbit/s and transmission over 10 km at 21.4 Gbit/s/channel for 100Gbit/s.

Integrated 5-channel WDM hybrid III-V/Si transmitter enabling 100Gb/s and beyond, Guilhem de Valicourt, Chia-Ming Chang, Sathish Sundaramohan Chandrasekhar, Young-Kai Chen, Anaelle Mato, Romain Benaix, Po Dong, 1Wiley Lab, France; 1Nokia Bell Labs, USA. We report the demonstration of an ultra-compact 5-channel hybrid integrated III-V/InP transmitter. We successfully achieved modulation up to 40 Gbit/s/channel providing a total aggregated capacity of 200 Gbit/s and transmission over 10 km at 21.4 Gbit/s/channel for 100Gbit/s.

High-gain Phase Modulated Analog Photonic Link Using High-power Balanced Photodiodes, Zhanyu Yang, 1Andreas Beling, 1Qianhuan Yu, 1Peng Yao, 1Xiaojun Xie, 1Christopher Schuetz, 1Joe C. Campbell, 1Univ. of Virginia, USA; 1phase sensitive innovation, USA. A phase modulated analog photonic link with interferometric detection is experimentally demonstrated. A link gain of 15 dB at 100 mA photocurrent and 10 GHz modulation frequency is achieved.

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The TNLC functions as an achromatic optical resonator that reflects strongly at the resonance wavelength. The GMR grating acts as an optical resonator that reflects light into aguided-mode resonant (GMR) filter that incorporates a 90° polarization rotator that alters the optical properties of the light passing through it. The TNLC is a twisted nematic liquid crystal cladding material that is used to create strongly anti-parallel twisted nematic liquid crystal (TNLC) microstructures. The GMR grating is a highly efficient device for splitting the light into two orthogonal polarization states, with each state being reflected by the TNLC cladding material. The TNLC microstructure is designed to achieve a high reflectivity for the light passing through it, which results in a strong interference pattern. The TNLC microstructure is fabricated using a novel fabrication technique without any drilling process. Core-to-core crosstalk is reduced to -63 dB/km at 1550 nm by intentionally remaining the air-holes during the fabrication.
Th1A • Detectors/Receivers—Continued

10:00–16:00 Exhibition and Show Floor, Exhibit Hall G-K (coffee service from 10:00–10:30)

10:00–16:00 OFC Career Zone Live, South Lobby

10:00–16:00 Wellcome Exhibition, South Lobby

Thursday, 23 March

Th1A.6 • 09:30 Top- scored
Simple Direct-detection-based Stokes Vector Receiver Circuit on InP, Samir Ghosh1, Takuo Tanemura1, Yuto Kawabata1, Kazuhiro Katoh1, Kazuhiro Nakano1, Yoshiaki Nakano1, Kazuo Kikuchi1, *The Univ. of Tokyo, Japan. Compact and robust photonic-integrated circuit for low-cost direct-detection-based Stokes vector (SV) receiver is presented. A proof-of-concept device is fabricated on InP to demonstrate successful decoding of multilevel SV-modulated signal at 1 Gb/s.

Th1A.7 • 09:45 Top- scored
Spectral-temporal Imaging Techniques for Real Time Characterization of High Speed VCSEL Mode Interaction, Jose M. Castro1, Rick Pimpinella1, Asher Novick2, Bulent Kose1, Paul Huang1, Brett Lane1, *Panduit Corp., USA. We demonstrate real-time spectral-temporal imaging methods for real-time characterization of VCSEL noise and mode interaction. OCIS codes: 060.2340 Fiber optics, 060.2360 Fiber optics.

Th1B • Silicon Photonics—Continued

Th1B.6 • 09:30 Optical Circuit Switching/Multicast of Burst Mode PAM-4 using a Programmable Silicon Photonic Chip, Calm Browning1, Alexander Gazman1, Vidak Vujicic1, Aarond P. Arthur1, Ziyi Zhu1, Keren Bergman1, Liam Barry1, Dublin City Univ., Ireland; *Colu mbia Univ., USA. Aiming to increase intra-datacenter throughput and reconfigurability, the use of a programmable silicon photonic chip to achieve optical circuit switching and multicasting of 12 Gb/s burst mode PAM-4 is experimentally demonstrated for the first time.

Th1B.7 • 09:45 Top- scored
Ultra-Dense 16x56Gb/s NRZ GeSi EAM-PD Arrays Coupled to Multicore Fiber for Short-Reach 896Gb/s Optical Links, Peter De Heyn1, Colm Browning2, I. Kopp1, Paul Huang1, Brett Lane1, Dublin City Univ., Ireland; *Columbia Univ., USA. We discuss a multi-vendor line-side interoperability field trial using Juniper and Cisco 100G coherenDWM routers interfaces. The field trial demonstrates 100G DP-QPSK transmission over a 1030-km link from Boca Raton to Jacksonville using the HG-FEC line-side interoperability mode for 100G coherent DWDM transceivers.

Th1C • SDM Transmission II—Continued

Th1C.5 • 09:30 Multi-Vendor 100G DP-QPSK Line-side Interoperability Field Trial over 1030 km, Nestor Garrara1, Omar Salame1, Thomas Mueller2, Oscar P. Carcellen1, Gianluca Calabretta1, Nacho Carretero1, Gabriele M. Galimberti1, Steven Keck2, Victor Lopez2, Dirk Van Den Borne2, *Telkious, USA; Juniper Networks, USA; *Cisco Systems Inc., Italy; *Telefónica Global CTO, Spain. We discuss a multi-vendor line-side interoperability field trial using Juniper and Cisco 100G coherent DWDM routers interfaces. The field trial demonstrates 100G DP-QPSK transmission over a 1030-km link from Boca Raton to Jacksonville using the HG-FEC line-side interoperability mode for 100G coherent DWDM transceivers.

Th1D • Advances in Coherent Subsystems—Continued

Th1D.5 • 09:30 Bi-directional 35-Gbit/s 2 Beam Steered Optical Wireless Downlink and 5-Gbit/s Localized 60-GHz Communication Uplink for Hybrid Indoor Wireless Systems, Amir Masoood Khalid1, Peter Baltus1, Rainier van Donmele1, Ketemaw Addis Mekonnen1, Zhieng Cao1, *Univ. of Electro-Communications, Japan. We present a novel optical quantization technique based on intensity-to-frequency conversion using frequency chirp in a quantum-dot semiconductor optical amplifier. A four-level signal at 10-GSamples/s is successfully achieved for photonic analog-to-digital conversions.

Th1E • Visible Light Communications—Continued

Th1E.6 • 09:30 Optical Quantization Based on Intensity to Frequency Conversion Using Frequency Chirp in a QD-SOA, Norikiko Ninomiya1, Hi- ruki Hoshino1, Motoharu Matsumura1, *Univ. of Electro-Communications, Japan. We present a novel optical quantization technique based on intensity-to-frequency conversion using frequency chirp in a quantum-dot semiconductor optical amplifier. A four-level signal at 10-GSamples/s is successfully achieved for photonic analog-to-digital conversions.
Ultra-broadband Fabrication-tolerant Polarization Splitter and Rotator, Kang Tan1,2, Ying Huang1, Guo-Qiang Lu1, Changyuan Yu1,3, Chengkuo Lee1. 1Inst. of Microelectronics, A*STAR, Singapore; 2Department of Electrical & Computer Engineering, National Univ. of Singapore, Singapore; 3National Univ. of Singapore (Suzhou) Research Inst., China. A polarization splitter and rotator that supports simultaneous O-, C-, and L-band operation is first experimentally demonstrated, with record 1-dB bandwidth over 360 nm, high fabrication tolerance, and high TE-TM conversion efficiency of -0.33 dB.

Field Trial of a Novel SDN Enabled Network Restoration Utilizing In-depth Optical Performance Monitoring Assisted Re-planning, Fanchao Meng1, Yanni Ou1, Shuangyu Yan1, Reza Nejabati2, Dimitra Simeonidou1. 1Univ. of Bristol, UK. We experimentally demonstrate a monitoring scheme utilizing both intermediate node and receiver monitoring for network re-planning. Either modulation format switching or light-path re-routing is adopted for restoration. The recovered signal performs better compared with static planning.

Adaptive Stokes Space Based Polarization Demultiplexing for Flexible UDWDM Metro-Access Networks, Somayeh Ziaie1,2, Nelson J. Muga1,2, Ricardo Ferreira3,4, Fernando Guimari1, Ali Shahpari2, António L. Teixeira2,4, Armando Pinto1,2,3,4. 1Univ. of Aveiro, Portugal; 2Dipartimento di Elettronica e Tele comunicazioni, Politecnico di Torino, Italy; 3Instituto de Telecomunicações, Portugal. We experimentally demonstrate a flexible coherent UDWDM system with support to optical-wireless links and adaptive DP-QPSK/DP-16QAM modulation, enabled by Stokes-based polarization-demultiplexing. The system is shown to be resilient to dynamic power ranges of >12 dB.

A Bayesian-based Approach for Virtual Network Reconfiguration in Elastic Optical Path Networks, Takayoshi Mori1, Shin’ichi Arakawa2, Masayuki Murata2, Thierry Klein1. 1Univ. of Melbourne, Australia; 2Bell Labs, USA. We summarize the various techniques developed by the GreenTouch consortium over the past 5 years to minimize core network power consumption. Adopting GreenTouch techniques can potentially improve the energy efficiency by 316x in a 2020 reference network compared to the state of the art in 2010.
A new optical devices.

We characterize an optical waveguide material, with 0.19 dB/cm loss at 1550 nm, wide spectral window of transparency, environmental stability, and solder-reflow compatibility. Flexible ribbons are sufficiently robust for standard high-throughput microelectronic assembly.

A Polymer Waveguide Based Spot-size Converter For Low-loss Coupling Between Si Photonics Chips And Single-mode Fibers, Kazuki Yashara, Fuj Ut, Takeaki Ishigure; Graduate School of Science and Technology, Keio Univ., Japan; Japan research center, Huawei technologies Japan K.K., Japan; Faculty of Science and Technology, Keio Univ., Japan. By applying the Mosquito method, we fabricated polymer waveguides for low-loss coupling between Si waveguides and standard single mode fibers. The fabricated 55C exhibits remarkably low insertion loss as 2.7 dB.

Stochastic Simulation and Sensitivity Analysis of Photonic Circuit through Morris and Sobol Method, Abhi Waqas, Daniele Melati, Andrea Melloni; Politecnico Di Milano, Italy. Two different sensitivity analysis methods are applied to the coupled ring resonator filter to assess how the fabrication processes variation of some geometrical parameters can influence the performance of the photonic devices.

A Polymer Waveguide Material Optimized for Vertical Coupling Between Si Photonic Integrated Circuits and Vertical Cavity Surface Emitting Lasers, Shotaor Takanobu; Tymon, Barwicz, Nobuhiko Imajo; Kenta Kobayashi; Takashi Sayama; Seiki Ohashi; Paul Fortier; Yoshi Taira; Ashish Glass Co. Ltd., Japan; IBM TJ Watson Research Center, USA; IBM Bromont, Canada. We report on a polymer optical waveguide material with 0.29 dB/cm loss at 1550 nm, wide spectral window of transparency, environmental stability, and solder-reflow compatibility. Flexible ribbons are sufficiently robust for standard high-throughput microelectronics assembly.

Low-loss and Polarization-insensitive Photonic Integrated Circuit Based On Micron-scale SOI Platform for High Density TDM PONs, Qiang Zhang; Huawei, China. We present a photonic integrated circuit of four-channel bidirectional optical sub-assembly on micrometer scale silicon. Experimental results with loss less than 1.4 dB, PDL<0.5 dB, and near 300 nm bandwidth, allow for realization of Class C+ QSPF TDM-PON OLT module.

M EMS Tunable Hybrid Plasmonic Si Waveguide, Xu Sun, Lars Thylén, Lech Wosinski, KTH, Sweden. A MEMS tunable hybrid plasmonic Si (HF) waveguide is investigated, showing very large changes of both effective refractive index and propagation loss when applying bias voltage. Preliminary experimental results show that: with 15 µm MEMS structure in Si waveguide platform, the extinction ratio can be over 20 dB between “on” and “off” states.

A Modal Waveguide Material Optimized for On-Board Optical Interconnects and Si Photonic Interfaces, Zhongren Wang; Tymon Barwicz, Nobuhiko Imajo; Kenta Kobayashi; Takashi Sayama; Seiki Ohashi; Paul Fortier; Yoshi Taira; Ashish Glass Co. Ltd., Japan; IBM TJ Watson Research Center, USA; IBM Bromont, Canada. We report on a polymer optical waveguide material with 0.29 dB/cm loss at 1550 nm, wide spectral window of transparency, environmental stability, and solder-reflow compatibility. Flexible ribbons are sufficiently robust for standard high-throughput microelectronics assembly.

Th2A.5 Mode-field diameter of a single mode waveguide. The polygonal model is used to design waveguides with high efficiency of light confinement. Experimental results show that the proposed mode-field diameters are less than 1.3 dB.

Th2A.6 Design and Characterization of an Optical Chip for Data Compression based on Haar Wavelet Transform, Catin Yin, Ana Tavares, Guilherme Cabral, Tiago Morgado, Ali Shahpari, Maria Lima, Antonio L Teixeira, Department of Electronics, Telecommunications and Informatics (DETI), Univ. of Aveiro, Portugal; Instituto de Telecomunicacoes, Univ. of Aveiro, Portugal. A new optical chip for data compression based on Haar Transform (HT) was designed and tested. Assymmetric couplers and multimode interconnectors (1x2 and 2x2) are implemented in the chip to perform all-optical HT operations.

Th2A.7 Broadband, modal, and cross-modal characteristics of multimode fiber systems. The modal characteristics of multimode fibers are investigated, showing high coupling efficiency. Experimental results show average 4.4 dB insertion loss and 23 dB mode selectivity.

Th2A.8 Large Mode-field diameter optical FiberCoupler Based on SiO2-capsuled Vertically Curved Si Waveguide, Yuki Atsumi, Tomoya Yoshida, Emiko Omoda, Youichi Sakakibara, AIST, Japan. We design surface optical couplers based on vertically-curved Si waveguide for 5-µm MFD SMFs. The device shows high-efficient coupling of < 1 dB loss in wavelength range of 330 nm with high device-size and fiber-alignment robustness.

Th2A.9 Design and Characterization of an Optical Chip for Data Compression based on Haar Wavelet Transform, Catin Yin, Ana Tavares, Guilherme Cabral, Tiago Morgado, Ali Shahpari, Maria Lima, Antonio L Teixeira, Department of Electronics, Telecommunications and Informatics (DETI), Univ. of Aveiro, Portugal; Instituto de Telecomunicacoes, Univ. of Aveiro, Portugal. A new optical chip for data compression based on Haar Transform (HT) was designed and tested. Assymmetric couplers and multimode interconnectors (1x2 and 2x2) are implemented in the chip to perform all-optical HT operations.

Th2A.10 Rectangular Versus Circular Fiber Core Designs: New Opportunities for Mode Division Multiplexing, Lior Rechtman, Dan M. Marom; Hebrew Univ. of Jerusalem, Israel. The properties of rectangular core fiber are investigated for mode division multiplexing. Polarization degenerates mode groups, favorable mode profiles for device coupling, modal area uniformity, and good splice performance suggests its a good candidate.

Th2A.11 Comparison of Multimode Fiber Modal Bandwidth Metrics, Petr Sterling1; Corning SNG Ltd., Russia. We describe a multimode fiber bandwidth metric significantly more strongly correlated to link inter-symbol interference (ISI) penalties than conventional metrics. The improvement is demonstrated in plots of ISI vs. bandwidth for various link lengths.

Th2A.12 Mode-dependent Gain Characterization of Erbium-doped Multimode Fiber Using C Imaging, Haoshuo Chen, Bin Huang, Nicolas K. Fontaine, Roland Ryl, Jose Antonio Lopez, Li Guangfu, Rodrigo Amezquita Correa, Pierre Sillard, Cedric Gonnert, Juan Carlos Alvarez Zanorias, Zainab Sanjabi Eznaveh, Axel Schulz-zenger, Nickie Bell Labs, USA; Univ. of Central Florida, USA; Prysmian Group, France. We characterize an erbium-doped step-index multimode fiber using C imaging based on a swept-wavelength interferometer. Modal contents, delays and mode-dependent gains are fully characterized using space-to-time mapping.

Th2A.13 Performance Analysis of Flexible Regeneration and Modulation Conversion in Elastic Optical Networks, Mirosław Klinkowski, Krzysztof Walkowik; Wrocław Univ. of Science and Technology, Poland; National Inst. of Telecommunications, Poland. We study potential performance gains resulting from deliberate use of signal regeneration along with modulation conversion in transient elastic optical networks (EONs) realizing super-channel transmission.

Th2A.14 Energy Saving in SBPPP-Based IP over WDM Networks with Protection Router Card in Sleep Mode, Sin Zhu, Haomin Jiang, Yongcheng Li, Sanjay K. Bose; Gangxiang Shen; Soochow Univ., China; ILT Guwahati, India. We develop an energy-saving scheme for the shared backup path protected (SBPPP) IP over WDM network through sleeping protection router cards. Results show that the scheme is efficient in saving energy cost and is significantly compared to other conventional schemes.

Th2A.15 A Capacity Analysis for Space Division Multiplexing Optical Networks with MIM0 Equalization, Yao Li, Nan Hua; 1TU Braunschweig, Germany. The known technique of HTI-aware routing can be used for connection admission, or spectrum defragmentation. We show that HTI used for defragmentation is the most beneficial in reducing blocking in space-division multiplexed elastic optical networks.

Th2A.16 Benefits of Higher Modulation in Flexible Grid Networks using Optical WDM and Digital OTN Switching, Onur Turkcu1, Abishek Gopalan; Biao Liu, Steve Sanders, Parthiban Kandappan; Infineon, USA. We study the effects of higher modulation formats on the design of optical network architectures using Flexible Grid and Singlewavelength Variable Transponders. We show architectures with digital switching getting more benefit from higher modulation.

Th2A.17 Holding-Time Information (HTI): When to Use it?, Sandeep Kumar Singh, Ademla Jukan; TU Braunschweig, Germany. The known technique of HTI-aware routing can be used for connection admission, or spectrum defragmentation. We show that HTI used for defragmentation is the most beneficial in reducing blocking in space-division multiplexed elastic optical networks.
This paper proposes a distributed sub-light-tree construction scheme for multi-tecture is proposed with a heuristic scalable SDM/WDM ROADM architecture.

Yongli Zhao, Xin Li, Tatsuya Terada, Naoki Suzuki, Takahiro Kubo, Tatsuya Shimizu, and Koji Terada.

A novel rank-based low-latency scheduling for maximum frontthaul accommodation in bridged networks is proposed. The proposed scheme increases the number of accommodated frontthaul streams by 40%.

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Th2A.27

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Th2A.19

An impairment-aware resource allocation scheme for dynamic elastic optical networks (EDON). Moo Kyeong Jang, Min Jeong Lee, Joo Yeong Kim, Doo Ho Kim, and Joo Seong Park.

Demonstration of data-rate and power-budget adaptive 100 Gb/s/A-based coherent PON downlink transmission, Takahiro Kodama, Ryosuke Matsumoto, Naoki Suzuki, and Encor Distributed Optical Networks, Corporation. A data-rate and power-budget controlled 100 Gb/s/A-based coherent PON downlink using 16-dimensional optical resource mapping and VOQ-balanced modulation has been demonstrated. We show 0.9 dB power-budget improvement for 25 Gb/s/SONI 80-km transmission.

Novel rank-based low-latency scheduling for maximum frontthaul accommodation in bridged networks, Yu Nakayama, Daisuke Hisano, Takahiro Kubo, Tatsuya Shimizu, Hirota Nakamura, Jun Terada, Akihiko Otaka, and Access Network Service Systems Laboratories, NTT, Japan. This paper proposes a novel rank-based queue scheduling method for achieving low latency in a frontthaul bridged network. We confirmed with computer simulations the proposed scheme increased the number of accommodated frontthaul streams by 40%.

Equalization strategies for 25G PONs, Andrew Stark, Thomas De Bakker, and Adtran, USA. We explored performance limits of equalization strategies on bandwidth-constrained NRZ transmissions. Without de-emphasis FFE/DFE equalizers achieve excellent link performance at normalized bandwidths 0.45 to 0.65. Signal de-emphasis with FFE/DFE enables link operation at bandwidth 0.25.

Investigation of the performance of GFDM and OFDMA for spectrally efficient TDM-DWDM PONs, Nicola Brandonisoni, Stefano Porto, Daniel Careglio, and Polatis, Denmark; Nokia Bell Labs, USA. We experimentally demonstrate a flexible downstream channel are analyzed experimentally by measuring true burst-mode pre- and post-error correction BER, frame loss rate and error probabilities obtained with sources typical of 100 Gb/s.

Forward error correction analysis for 10Gb/s Burst-mode transmission in TDM-DWDM PONs, Nicolas Qian, Yongli Zhao, Xin Li, and Huawei Technologies Co., Ltd., China. The performance limits of 10Gbps forward error correction for a PON upstream channel are evaluated experimentally by the burst-mode pre- and post-error correction. We show frame error rate and error correction performance of the proposed scheme.

Channel bonding design for 100 Gb/s PON based on FEC codeword alignment, Liang Zhang, Yuanqiu Luo, Bo Gao, Xiang Liu, Frank Ellenberger, Nirwan Ansari, andFixed Access Network, Futurewei (Huawei) Technologies, USA; Fixed Access Network, Huawei Technologies Wuhan Research Center, China. We propose a channel bonding system structure and algorithms for 100 Gb/s PON. The algorithms schedule FEC codeword transmission among 25 Gb/s wavelength channels, and they are demonstrated with high efficiency and low latency.

Real-time demonstration of 28 Gbit/s Electrical Dubinary TDM-PON extension using Remote Nodes, Rene Borwein, Robert Borkowski, Wolfgang Pohlmann, Joris Van Kerrebroeck, Chris Chase, Robert Lucas, Timothy De Keulearnaar, Johan Bawelinken, Doutte Van Veeren, Vincent Houtsma, Xin Yin, Thomas Pfeiffer, and Nokia, Bell Labs, Germany. An experimental real-time reach and split extension of a 28 Gbit/s electrical dubinary TDM-PON is demonstrated. 50 dB budget is achieved using either remote nodes based on SOA or based on a distributed OLT concept.

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Th2A.33
Co-design of a Low-latency Centralized Controller for Silicon Photonic Multistage MZI-based Switches, Yule Xiong, Felipe Gohring de Magalhães2, Gabriela Nicolleusco, Fabiano Hessel, Odile Libaron-Ladouceur1, McGill Univ., Canada; FPGCPC/PUCRS, Brazil; Ecole Polytechnique de Montreal, Canada. An FPGA-based centralized controller architecture for silicon photonic switches is experimentally demonstrated achieving scheduling decision in one clock cycle. The FPGA simultaneously operates as the controller, and the traffic payload generator with error detection.

Few-Mode 850-nm VCSEL Chip with Direct 16-QAM Transmission using OAM Modes over 1 km Ring-Core Fiber without MIMO Processing, Feng Feng, Xianqin J., Dominic O’Brien, Frank Payne, Timothy Wilkinson, Univ. of Cambridge, UK; Univ. of Science and Technology of China, China; Univ. of Oxford, UK. We demonstrate mode-group multiplexed transmission over 1km ring-core fiber to transmit 2×10Gbit/s using OOK modulation and direct detection. SLM based spatial (de)multiplexers perform all-optical multiplexing and demultiplexing in an OAM mode basis.

Dual Laser Switching for Dynamic Wavelength Operation in Amplified Optical Transmission, Shengyan Zhu, Weiyan Mo, Daniel C. Kilper, Aravind P. Anthur, Liam Barry, Univ. of Arizona, USA; Dublin City Univ., Ireland. Fast switching of a dual laser PM-QPSK transceiver is used to experimentally demonstrate optical switching using polarization-multiplexed PAM-4 system by varying signal baud-rate with data-rate up to 120 Gbps. Experiment shows that 10-Gbaud degrades >4 dB OSNR sensitivity compared with 10-Gbaud.

Bi-Inspired Optical Microwave Phase Lock Loop Based on Silicon Linear Effects in Semiconductor Optical Amplifier, Ruizhe Lin1, Luis A. Pereira2, The Phiet T. Do1, Jia Ge1, Li Xu1, Mable P. Fok3, Univ. of Sydney, Australia. Optical microwave phase lock loop using semiconductor optical amplifiers is experimentally demonstrated. By measuring chirp characteristics and implemented with photonics, the proposed scheme is compact, has a simple architecture, and has a wide operating frequency range.

2.4 GHz wide 3.7–4.0 GHz Bandwidth Optical Phase Lock Loop using a QD-SLED, Pushkar Mehta, P. Vinayak Reddy, J. Vinoth, Jayesh A. Vora, Indian Institute of Technology, Mumbai, India; Indian Institute of Technology, Roorkee, India. Demonstrate an ultra-broadband optical phase lock loop with 3.7–4.0 GHz wide bandwidth and 2.4 GHz center frequency.

Optical Signal-to-Noise-Ratio in Coherent Systems using Polarization Multiplexed Transmission, Wolfgang Moench1, Eberhard Loebeln1, Viavi, Germany. A new method for measuring Optical Signal-to-Noise-Ratio (OSNR) in systems using polarization multiplexed transmission was investigated. The OSNR can be calculated from the correlation between spectral components in the optical spectrum of a transmission signal.

Eberhard Loebeln1, Viavi, Germany. A new method for measuring Optical Signal-to-Noise-Ratio (OSNR) in systems using polarization multiplexed transmission was investigated. The OSNR can be calculated from the correlation between spectral components in the optical spectrum of a transmission signal.

Exhibit Hall K

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Th2A.34 VCSELs to Multicore Fiber Reconfigurable Optical Switch Based on Diffractive MEMS Mirrors, Mahmoud Gadalla1, Véronique François1, Bora Ung1, 1École de technologie supérieure (ÉTS), Canada; VCSELs light was coupled to any selected core(s) in a multicore fiber with average max crosstalk -10.4 dB using diffractive MEMS. This is a step toward agile multicore fiber interconnects and ROADMs.

Hardware Programmable Network Function Service Chain on Optical Rack-Scale Data Centers, Qianqiao Chen1, Véronique François1, Yonglin Yu3, Hung2, Lei Deng, Zu-Kai Weng1, Fengguang Luo1, Luis1,3, Jian Jang Huang, Nick Par1, Ming2,1,1, Nick Par1, Ming2,1,1, Nick Par1, Ming2,1,1, Nick Par1, Ming2,1,1, Nick Par1, Ming2,1,1, Nick Par1, Ming2,1,1, Nick Par1, Ming2. Demonstrate an end-to-end testbed delivers hitless on-chip service chain switch-over, 9.8G throughput and sub-microsecond latency.

Network Synthesis of a Topology Reconfigurable Disaggregated Rack Scale Datacentre for Multi-Tenancy, Adelina Peters1, Georgios S. Zervas1, 1Univ. of Bristol, UK. A datacenter network that supports programmable optical and multi-layer service chaining by adopting miniaturized reconfigurable optical backplanes and FPAGs is demonstrated. The end-to-end testbed delivers hitless on-chip service chain switch-over, 9.8G throughput and sub-microsecond latency.

Network Synthesis a Topology Reconfigurable Disaggregated Rack Scale Datacentre for Multi-Tenancy, Adelina Peters1, Georgios S. Zervas1, 1Univ. of Bristol, UK. A performance analysis of a hybrid reconfigurable disaggregated datacentre is presented. It offers substantial benefits in terms of network blocking, power consumption and cost when compared to pure circuit switched and statistical hybrid architectures.

A Silicon Metamaterial Chip-to-Chip Coupler for Photonic Flip-Chip Applications, Tymon Barwicz1, Swetha Kamalpurkar1, Yves Martin1, Robert L. Bruce1, Sebastian Engellmann1, IBM T.J. Watson Research Center, USA. We demonstrate a metamaterial coupler with a highly elongated coupler mode optimized for direct optical chip-to-chip connections. We show a highly broadband converter response with <0.35dB penalty over the 120nm spectrum measured.

A Silicon Metamaterial Chip-to-Chip Interconnect System for High-speed illumination of 40-Gb/s WDM Channels, Bora Ung1, 1Univ. of Bristol, UK. A new approach to the design and implementation of silicon chip interconnects is described. The approach builds fast reconfigurable wavelength converters with <30 ns switching time.

Reconfigurable Broadband Optical Noise Generation Based on Phase Modulation to Intensity Modulation Conversion and a Nonlinear Transform, Xingsong Jiang1, Mengfan Cheng1, Fengguang Luo1, Lei Deng1, Changan K1, Sangmin Fu1, Ming Tang1, Deming Lu1, Minming Zhang1, Ping Shui1, 1HuaZhang Univ. of Sci. & Tech., China; 1Nanyang Technological Univ., Singapore. We experimentally demonstrate a reproducible broadband optical noise generation scheme. A flat spectrum and a symmetrical distribution can be obtained. The complexity of the analogue noise can be determined by the input binary sequence.

Capacity Limits of Space-Division Multiplexed Submarine Links Subject to Nonlinearities and Power Feed Constraints, Omar Domingues1, Darli Mello1, Reginaldo Silva1, Sergio O. Arik2, Joseph M. Kahn1, 1School of Electrical and Computer Engineering, Univ. of Campinas, Brazil; 2Department of Electrical Engineering, Stanford Univ., USA. 2Padtec S/A, Brazil. We calculate capacity limits for a 10-Gbaud and 40-Gbaud dispersion compensation methods using a 2x3 64-QAM and a 1x16 64-QAM space division multiplexed submarine link. We demonstrate that limitations due to nonlinearities become negligible compared to power-feed limitations as the propagation distance and the total number of spatial channels increase.

1.6Tb/s (4x400G) Unrepeated Transmission over 205-km SSMF using 65-GbD PAM-16QAM with Joint LUT Pre-distortion and Post DBP Nonlinearity Compensation, Junwen Zhang1, Jianjun Yu1, Hung Chang Chen1, 2TE Tt Inc, USA. With joint LUT-based pre-distortion and DBP-based post-compensation to mitigate the opto-electronic components and fiber nonlinearity impairments, we demonstrated the unrepeated transmission of 1.6Tb/s based on 4-lane 400G single-carrier PDM-16QAM over 205-km SSMF without distributed amplifier.
A spatial pulse

We, Alex Alvara, Ko, Fatih Ya, Shun Ka Lo, Denis Molin, Andrew Ellis, Peter, Richard, Christian Sanchez, Yoshihisa Inada, Andrew Ellis, Marc F. Stephens, Laurent Schmalen, Rodrigo Amezcua Cor.

with high order QAM formats, e.g. modulated perturbed plane waves systems with hard decision FEC and Turitsyn E. Prilepsky.

Perturbative plane waves were also demonstrated for multi-carrier Gb/s transmission over 150 km with Frequency-locked laser. Single-channel 3.84 Tbit/s data were successfully transmitted over 150 km with a spectral efficiency of 10.6 bit/s/Hz.

We experimentally demonstrated and validated for a 12 spatial channel transmission over 53 km multi-mode fiber. Improved data rates up to 300 Gb/s were demonstrated with respect to conventional QPSK.

Low-Complexity Chromatic Dispersion Equalizer for 400G Transmission Systems, Celestino Sanches Martins, Sofia Amado, Sandra Rossi, Andrea Chiuchiarelli, Jacklyn D. Reis, Andrea Carenat, Fernando Guimarães, Armando Pinto, University of Camerino, Italy.

We experimentally demonstrated and compared various 4 bits/symbol phases and amplitude modulation formats on a single discrete eigenvalue. 4Gb/s with a total bit rate of 16 Gb/s transmission over 750 km is achieved.


We show that 32 Gbaud single-carrier vs. multi-carrier Gb/s transmission can deliver a Comparable reach for the same capacity at 64 Gb/s DP-QPSK. However, 64 Gbaud multi-carrier DP-QPSK signal can provide 12% longer reach than single-carrier 32 Gb/s DP-QPSK.

Nonlinear Mitigation using Probabilistically Shaped Real-Valued Modulation Formats, Tobias A. Eriksson, Fred Buchali, Laurent Schmalen, Nokia Bell Labs, Germany. We experimentally demonstrate probabilistically-shaped modulation formats with increased spectral efficiency and nonlinear mitigation capabilities compared to phase-conjugated twin-waves at 54 Gb/s, with 21% increased reach.

Nonlinear Mitigation using Probabilistically Shaped Real-Valued Modulation Formats, Tobias A. Eriksson, Fred Buchali, Laurent Schmalen, Nokia Bell Labs, Germany. We experimentally demonstrate probabilistically-shaped modulation formats with increased spectral efficiency and nonlinear mitigation capabilities compared to phase-conjugated twin-waves at 54 Gb/s, with 21% increased reach.
Owing to the breakthrough of SiFotonics Technologies Co., Ltd., this tutorial will provide an overview of the current status of 5G mobile communication including the main 5G use cases with corresponding requirements and service characteristics. Key technologies pursued to address these use cases—Standardization activities and corresponding time line to reach the target of first 5G specifications targeting to be available in 2018.}

Th3A.1 • 13:00
Architecture and Technologies for the Current and Future Radio Access Network
Presider: Volker Jungnickel; Fraunhofer HHI, Germany
Eric Dahlman is currently Senior Expert in Radio Access Technologies within Ericsson Research. He was deeply involved in the development and standardization of 3G radio access technologies (WCDMA and HSPA), first in Japan and later within the global 3GPP standardization body. Later on he was involved in the standardization/development of the 3GPP Long Term Evolution (LTE) and its continued evolution. His currently focuses on research and development of future 5G wireless access technologies.

Erik Dahlman is the co-author of the books 3G Evolution – HSPA and LTE for Mobile Broadband, 4G – LTE and LTE-Advanced for mobile broad-
We experimentally realize
We fabricate

We propose a novel shared-

We discuss trade-offs

is increased through the symbol rate

when the bit rate of an optical channel

mission reach and transceiver power

of important parameters such as trans-

Modulation Order,

through Higher Baud Rate and

the numbers of bits per symbol.

and select the

View Presentations link.

Power and Reach Trade-offs In-
creasing the Optical Channel Rate
through Higher Baud Rate and
Modulation Order, Christian Rasmus-

sen1; ‘Acacia Communications, Inc.,
USA. This paper discusses trade-offs
of important parameters such as trans-
mission reach and transceiver power
when the bit rate of an optical channel
is increased through the symbol rate
and the numbers of bits per symbol.
band and, most recently, 4G – LTE-Advanced Pro and The Road to 5G. He is a frequent invited speaker at different international conferences and holds more than 100 patents within the area of mobile communication. In 2009, Eik Dahlman received the Mayor Technical Award, an award handed out by the Swedish Government, for his contributions to the technical and commercial success of the 3G HSPA radio-access technology. In 2010, he was part of the Ericsson team receiving the LTE World Summit. In 2014 he was nominated for the European Inventor Award, the most prestigious inventor award in Europe, for contributions to the development of 4G LTE.

Continued

Multi-wavelength 100Gb/s Silicon Photonics Based Transceiver with Silicon mux/demux and MEMS-coupled InP Lasers, Lucas B. Soldano, Jay Kubicki, Dinh Ton; *Kamai Corporations, Italy; A QSPF packaged 100Gb/s CWDM4 transceiver is demonstrated by a hybrid assembly of a commercial silicon photonics chip containing modulators and electronics, a silica based mux/demux PLC, and a MEMS carrier with four InP lasers.

A 10m/10Gbps Underwater Laser Transmission System, Chun-Ming Ho, Chang-Kai Lu, Hai-Han Lu, Sheng-Jhe Huang, Ming-Te Cheng, Zhi-Yi Yang, Xin-Yao Lin; *National Taipei Univ. of Technology, Taiwan; **Jinwen Univ. of Science and Technology, Taiwan. A 10Gbps/5GHz 16-QAM-OFDM underwater wireless laser transmission system based on light injection and optoelectronic feedback techniques is proposed and demonstrated. Good bit error rate performance and constellation map are achieved over a 10-m underwater link.

High-Spectral Efficiency DWDM transmission of 100-Gbit/lambda IM/DD Single Sideband-baseband Nyquist-PAM8 Signals, Rui Hirai; Nobuhiko Kikuchi; Takayoshi Fukui; *Hitachi Ltd, Japan; Oclaro Japan, Japan; 107.52-Gbit/s 558-Nyquist-PAM8 signaling is realized for the first time, achieving high-spectral efficiency of 4.30 bit/s/Hz (net SE 3.58), with intensity-modulation and polarization-independence conventional direct-detection and the longest 80-km SSMF transmission of PAM8 signals.

Novel a-Si en Garnet Nonreciprocal Phase Shift Optical isolator with TE Mode Operation, Eiichi Ishida; Kengo Miura, Yuya Shoji; Hideki Yoko; Tetsuya Mymoto; Nobuhiko Nishiyama; Shigehisa Arai; *Department of Electrical and Electronic Engineering, Tokyo Inst. of Technology, Japan; **Laboratory for Future Interdisciplinary Research of Science and Technology, Tokyo Inst. of Technology, Japan; *Department of Electronic Engineering, Shibaura Inst. of Technology, Japan. A waveguide optical isolator operating in TE mode was demonstrated with an isolation of 17.9 dB. Amorphous silicon core along lateral walls of magneto-optical garnet was fabricated to induce nonreciprocal phase shift in TE mode.

Th3B • Practical Solutions to Transceiver Integration—Continued

Free Space to Few-mode Fiber Coupling Efficiency Improvement with Adaptive Optics under Atmospheric Turbulence, Donghao Zheng; Yan Li; Biebei Li; Wei Li; Eruh Chen; Jian Wu; *Beijing Univ. of Posts & Telecom, China; **Beijing Insitute of Tracking & Telecom Technology, China. Coupling efficiency between free-space-optical beam and few-mode-fibers with adaptive optics is investigated. The experimental results show that coupling efficiency of single-mode-fiber and few-mode-fiber is improved by over 10% with adaptive optics under moderate turbulence.

Inverse-designed Ultra-compact Star-crossings Based on PhC-like Subwavelength Structures, Luli Liz Li, Minming Zhang; Dongyu Li; Fei-ya Zhou; Weije Chang; Jiang Tang; Deming Lu; *Huazhong Univ. of Sci. & Tech., China. Inverse-designed star-crossings with 8 and 10 ports are proposed, with ultra-short coupling lengths of 5.28µm and 5.4µm respectively. Their measured ILs are less than 1.6dB and 2.4dB respectively over 60nm bandwidth centered 1550nm wavelength.

The development of 4G LTE.

Award, the most prestigious inventor nominated for the European Inventor LTE World Summit. In 2014 he was part of the Ericsson team receiving the Major Technical Award, an award handed out at the Swedish Government, for his contributions to the technical and commercial success of the 3G HSPA radio-access technology. In 2010, he was part of the Ericsson team receiving the LTE World Summit. In 2014 he was nominated for the European Inventor Award, the most prestigious inventor award in Europe, for contributions to the development of 4G LTE.

Continued

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A 10m/10Gbps Underwater Laser Transmission System, Chun-Ming Ho, Chang-Kai Lu, Hai-Han Lu, Sheng-Jhe Huang, Ming-Te Cheng, Zhi-Yi Yang, Xin-Yao Lin; *National Taipei Univ. of Technology, Taiwan; **Jinwen Univ. of Science and Technology, Taiwan. A 10Gbps/5GHz 16-QAM-OFDM underwater wireless laser transmission system based on light injection and optoelectronic feedback techniques is proposed and demonstrated. Good bit error rate performance and constellation map are achieved over a 10-m underwater link.

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Th3G.2 • 13:30
Optimizing Power Consumption of a Coherent DSP for Metro and Data Center Interconnects, Theodor Kupter1, Andreas Bisplinghof1, Thomas Duth1, Chris R. Fludger1, Stefan Langenbach1; 1Cisco Optical GmbH, Germany. We discuss several options for reducing power consumption of DSP used for coherent interfaces. These options are put in perspective with the needs of metro and data center interconnects for an overall optimized solution.

Th3G.3 • 13:30
3-Dimensional Soft Shape Sensor based on Dual-layer Orthogonal Fiber Bragg Grating Mesh, Li Xu1, Jia Ge1, Jay H. Patel1, Mable P. Fok2; 1Univ of Georgia, USA. We present a soft silicone shape sensor for 3D surface shape measurement. The sensor is based on dual-layer fiber Bragg grating arrays with orthogonal mesh structure, which enable 3D bi-directional shape sensing.

Th3G.4 • 13:45
Power-efficient Electro-optical Single-tone Optical-frequency Shifter Using X-cut Y-Propagating Lithium Tantalate Waveguide Emulating a Rotating Half-wave-plate, Chuan Qiu1, Hengbo Lu1, Andrea Pollick2, Sn Srim1, S. J. Ben Yoo1; 1Univ. of California Davis, USA, 2Srico Inc., USA. We demonstrate a single-tone electro-optical frequency shifter based on an X-cut, Y-propagating Zn-diffused lithium tantalate waveguide emulating a rotating half-wave plate achieving 10 dB reduction in power consumption compared to Z-propagating LiNbO3 counterparts.

Room 408A
Th3H • Sensors for Telecom and Biomedical Applications—Continued

Room 408B
Th3H.2 • 13:30
Invited
Optics—Continued

Room 409AB
Th3I • Novel Photonic Devices—Continued

Room 410
Th3J • Nonlinear Mitigation Techniques—Continued

Room 411
Th3K • Network Survivability—Continued

Colloidal Quantum Dots Based Integrated Fiber-optic Detector, Ao Yang1, Xin Tian1, Kecheng Yang1, Junyu Li1, Xiaochao Tan1, Huan Liu1, Hasheng Song1, Jiang Tang1, Fei Yi2; 1Huazhong Univ. of Science and Technology, China. We report an integrated fiber-optic power meter by dip coating PbS colloidal quantum dots onto a pretreated specialty fiber. We measured the readout current at 1550nm as a function of the optical power, the bias voltage and the distance between the contact electrodes.

Fiber Bragg Grating Mesh, Li Xu1, Jia Ge1, Jay H. Patel1, Mable P. Fok2; 1Univ of Georgia, USA. We present a soft silicone shape sensor for 3D surface shape measurement. The sensor is based on dual-layer fiber Bragg grating arrays with orthogonal mesh structure, which enable 3D bi-directional shape sensing.

The challenges of enhancing protection performance by improving the spectral efficiency of elastic optical networks are studied. Novel optical filter configuration, signal equalization, and spectral bandwidth assignment techniques are shown to reduce the guard band.
Real Time Demonstration of the Transport of Ethernet Fronthaul Based on vRAN in Optical Access Networks, Zakaria Tayi, Luiz Anet Neto, Bertrand le guyader, Arnau de Lannoy, Maha Chouaref, Christelle Aupetit-Berthelemot, Mahesh Nelamangala Anjanappa, Si Nguyen, Kuntal Chowdhury, Philippe Chancelou, Orange, France; Xlim, France; AlloStar, USA. A real time transmission of the new functional split fronthaul interface over PTP and PMP optical access networks is experimentally demonstrated. The data traffic investigation is well as the impact of latency and packet loss.

Mobile-PON: A High-efficiency Low-latency Mobile Fronthaul Based on Functional Split and TDM-PON with a Unified Scheduler, Siyu Zhou, Xiang Liu, Frank Effenberger, Jonathan Chaos, New York Unv., USA; Futurewei Technologies, Huawei R&D, USA. We propose and numerically demonstrate a novel mobile fronthaul architecture based on functional-split and TDM-PON with a unified mobile-PON scheduler, eliminating the need for PON scheduling and increasing the bandwidth efficiency by ~10× over CPRI.

Emerging Integrated Devices for Coherent Transmission - Digitally Assisted Analog Optics, Takashi Saida, NTT Device Innovation Center, NTT Corporation, Japan. Digital signal processing has been widening our choice of material systems for optical integration platforms. We review recent work on digital coherent optics, and show our results for high-speed InP modulators and ultra-compact Si-based coherent-optical-subassemblies.

Trends and Progress in Optical Wireless Communications, Steve Hirolovich, Electrical & Computer Engineering, McMaster University, Canada. Free-space optical communications has been of interest for many years, however, there remain theoretical and algorithmic challenges in its implementation. In this paper, I describe recent trends and results from our research in advancing the modeling and information theory for free-space optical channels in space and in scattering environments.

Poly-binary is low complexity and good for the 5G fronthaul and DCI scenarios while DMT is suitable for metro transmission due to better bandwidth utilization and higher dispersion tolerance.

Mobile-Fronthaul Based on Functional-Split Fronthaul Interface over CPRI. The bandwidth efficiency by ~10× for PON scheduling and increasing PON scheduler, eliminating the need for TDM-PON with a unified mobile-Fronthaul Based on functional-split architecture based on functional-split and TDM-PON with a unified mobile-PON scheduler, eliminating the need for PON scheduling and increasing the bandwidth efficiency by ~10× over CPRI.

Passive Waveguide Device Technologies - Building Block of Functionality and Integration, Yasuo Kokubun, Yokohama National University, Japan. Passive waveguide devices and related fabrication technologies are reviewed from the view point of functionality which is related to material and operating principle, and the possible scheme of integration.

42.3-Tbit/s Self-Homodyne 64-QAM Superchannel Transmission with 4% Spectral Overhead, Mikael Mazur, Abel Lorences-Riesgo, Magnus Karlsson, Peter A. Andrekson, Chalmers Univ. of Technology, Sweden. We use a 10nm frequency comb to transmit a 10Tb/s 50x2GBaud PM-64QAM superchannel over 80km SMF. Using two unmodulated carriers we regenerate a phase locked receiver comb, enabling self-homodyne detection with record-low spectral overhead.

42.3-Tbit/s, 18-Gbaud 64QAM WDM Coherent Transmission of 160 km over Full C-band using an Injection-Locking Technique with a Spectral Efficiency of 9 bit/s/Hz, Takashi Kan, Keisuke Kaza, Masato Yoshida, Masatake Nakazawa, Research Inst. of Electrical Communication, Tohoku Univ., Japan. We demonstrate a 235-channel WDM 18-Gbaud 64QAM coherent transmission of 160 km over the full C-band with a new homodyne detection technique using injection locking. 42.3-Tbit/s data were successfully transmitted with a 9-bit/s/Hz spectral efficiency.

Yasuo Kokubun received his Dr. Eng. degree from Tokyo Institute of Technology, Japan, in 1980. After he worked as a research associate from 1980 to 1983, he joined the Yokohama National University as an associate professor in 1983, and is now a professor. From 1984 to 1985 he was with AT&T Bell Laboratories, NJ. He served as the Dean of the Faculty of Engineering from 2006 to 2009 and as the Vice-President from 2009 to 2015. Professor Kokubun is a Fellow of IEEE, the Japan Society of Applied Physics, the Institute of Electrical, Information and Communication Engineers, and a member of OSA.
A multimode SiGe VCSEL link achieving 8.7 pJ/bit of energy efficiency with a 0.13-μm SiGe VCSEL achieving 84 mW only.

Ultra-low Power SiGe Driver-IC for high-speed Electroabsorption Modulated DBF Lasers, Jung Han Choi, Marko Gruner, Heinz-Gunter Bach, Michael Theurer, Ute Troppe, Martin Mährle, Martin Schell, Fraunhofer-Hannich-Hertz Inst., Germany. A small footprint electroabsorption modulated DBF laser TOSA with an ultra-low power SiGe driver with a power efficiency of 3.99 pJ/bit is demonstrated. Good optical eye openings up to 56 Gb/s NRZ and 64 Gb/s PAM-4 were obtained. The novel SiGe EML driver consumes 84 mW only.

A Low-power SiGe VCSEL Driver consumes 84 mW only.

Optical OFDM Transmission using Low-Noise Kerr Frequency Comb Generated in On-Chip Microresonator, Heng Zhou, Zengjie Zhang, Jing Zhang, Xingwen Yi, Shu-Wei Huang, Hao Liu, Minbing Yu, D. L. Kwong, Kun Qiu, Chee Wei Wong, UESTC, China; UCLA, USA; IME, Singapore. We demonstrate high-bitrate coherent optical OFDM transmission utilizing low-noise Kerr frequency comb as multi-channel laser source. 4QAM-OFDM data with total bitrate of 136.0 Gb/s are successfully transmitted over a 100 km fiber link.

Demonstration of Tunable Mitigation of Interchannel Interference of Spectrally Overlapped 16-QAM/QPSK Data Channels using Wave Mixing of Delayed Copies, Amirhossein Mohajerian Ariaei, Mortezza Ziyadi, Yinwen Cao, Ahmed Almaiman, Bishara Shamee, Joseph Touch, Moshe Tur, Carsten Langrock, Martin Fejer, Alan Willner, Univ. of Southern California (USC), USA; Information Sciences Inst., USA; Tel Aviv Univ., Israel; Stanford Univ., USA. A tunable all-optical inter-channel interference mitigation method is proposed for an overlapped channel system that avoids the need for multi-channel detection. We experimentally demonstrate the system performance improvement for 16QAM and QPSK overlapped channels for both 20/25 Gbaud data and under different channel spacing conditions.
We experimentally demonstrate an efficient, and has low-latency/high-efficiency, and has low-latency/high-performance. Bi-directional new-radio/LTE-A mobile-fronthaul with 32×32 channel architecture, in which 48 20-MHz LTE channels are aggregated via CDM in single IM-DD channel with an average EVM of ~3.6% after 5-km transmission and low-complexity mobile fronthaul architecture, in which 48 20-MHz LTE signals are aggregated via CDM in single IM-DD channel with an average EVM of ~3.6% after 5-km transmission over SSMF.
Use of Embedded Optics to Decrease Power Consumption in IO Dense Systems, Rob Stone1; 1Broadcom Corporation, USA. Use of embedded optical modules in highly IO dense systems such as network switches or routers has the potential to deliver solutions with overall lower power consumption. We consider this from a historical perspective and consider implications of these new architectures, with SerDes power savings of 50% possible by moving to embedded modules.

Quantum Dot Lasers Grown on (001) Si Substrate for Integration with Amorphous Si Waveguides, Yating Wan1, Qiang Li1, Alan Y. Liu1, Yu Geng1, Justin Norman1, Weng Chou1, Arthur C. Gossard1, John E. Bowers2, Evelyn Hu1, Ke M. Lau1; 1HKUST, Hong Kong; 2UCSB, USA; 3Sandia National Laboratories, USA. Heteroepitaxially grown InAs quantum dot lasers were demonstrated on (001) Si under continuous-wave optical pumping with low thresholds (down to 35 µW). The feasibility of integrating active and passive devices through electrical injection was analyzed.

Correlated-failure-aware VON mapping, Jian Kong1, Nannan Wang1, Jason P. Jue1, Inwoong Kim2, Xi Wang2, Qiong Zhang2, Hakki C. Cankaya3, Weisheng Xie1, Tadashi Ikeuchi2; 1The Univ. of Texas, Dallas, USA; 2Fujitsu Laboratories of America, USA; 3Fujitsu Network Communications, USA. We analyze the availability of virtual optical networks (VONs) mapped over a physical optical network with correlated failures, and we propose a correlated-failure-aware VON mapping algorithm to support high availability while reducing the penalty cost and total link cost.

Single-λ 312 Gb/s Discrete Multi-tone Interconnect of Mode-division Multiplexed Network with a Multicore Fiber, Xinru Wu1, Chaoran Huang1, Ke Xu1, Wen Zhou1, Chester Shu1, Hon Ki Tsang1; 1The Chinese Univ. of Hong Kong, USA; 2Harbin Inst. of Technology, Shenzhen Graduate School, China. We demonstrate a single wavelength discrete multi-tone interconnect with on-chip mode-division multiplexing and off-chip multicore fiber. A gross data rate of 312 Gb/s is achieved under HD-FEC limit of $3.8 \times 10^{-3}$.
We report the amplification and reduced ASE noise level demonstration. Comparing to a 4dB-noise-QPSK system, more than 25dB net gain is experimentally evaluated. In a 20-Gbaud black-box Raman-assisted PSA amplifier is characterized using a polarization-insensitive single-pump FOAPA, whilst achieving fiber-to-fiber net signal gains of 10-20dB over >2THz gain bandwidth.

Experimental Demonstration of Raman-Assisted Phase Sensitive Amplifier with Reduced ASE Noise Level and More than 25dB Net Gain, Yinwen Cao1, Ahmed Almamain1, Yusichi Akasaka1, Fatemeh Alishahi1, Morteza Zyadi1, Amirhossein Mohajerin Ariaei1, Charringjing Bao1, Peicheng Liao1, Ahmad Falahpour1, Bishara Shamei1, Tadashi Ikeyuchi1, Shigehiro Takasaka1, ryuichi Sugizaki3, Joseph Touci1, Moshe Tur1, Alan Willner1; Univ. of Southern California, USA; Fujitsu Laboratories of America, USA; Furukawa Electric Co. LTD, Japan; Tel Aviv Univ., Israel; Information Sciences Inst., USA. The performance of a black-box Raman-assisted PSA amplifier is experimentally evaluated. In a 20-Gbaud QPSK system, more than 25dB net gain is demonstrated. Comparing to a 4dB-noise-figure EDFA, ~1.5dB ASE noise level reduction is observed.

Improved Linewidth Tolerant Carrier Phase Recovery Based on Polar MAP Metric Estimate, Marti Sales Llopis1, Md Suhiddin Faruki1, Seb J. Savory2; Univ. of Cambridge, UK. A new metric that analytically approximates the maximum a posteriori (MAP) solution is presented. Used with a decision-directed carrier phase estimation algorithm, the linewidth tolerance exceeds the limits achieved when using the conventional Euclidean distance.

Incorporated, USA. This paper demonstrates a record single-carrier 400 Gb/s unrepeatered WDM transmission over 403 km with 64.7-dB span loss. Using optimized amplification map with 1st-order Raman amplifiers, ROPAs, and 112/150-um2 Aeff fibers, error-free transmission is demonstrated for 16 x 66 Gbd-16QAM.
Th4F • Network Design
Presider: Qiong Zhang; Fujitsu Laboratories of America Inc, USA
15:30–17:30

Techniques for Agile Network Re-Optimization Following Traffic Fluctuations, Tomohiro Hashiguchi¹, Kazuyuki Tajima¹, Yutaka Takita¹, Toru Katagiri¹; Fujitsu Limited, Japan. We study the cost effectiveness of network re-optimization for both short-term traffic variations and long-term traffic growth. The presented re-optimization operation is effective in reducing equipment cost while curbing the increase of operational cost.

Th4G • Laser Transmitters
Presider: Thomas Schrans; Rockley Photonics, USA
15:30–17:30

Laser Transmitters: Status and Trends, Martin Möhrle¹, Ute Troppenz¹, Heinz-Gunter Bach¹, Ariane Sigmund¹, Georges Przyrembel¹, Martin Schell¹; Fraunhofer Heinrich Hertz Inst., Germany. We present the latest developments in laser technology and their impact on optical communication systems.

Th4H • Characterization of SDM Fibers
Presider: Axel Schulzgen; Univ. of Central Florida, USA
15:30–17:15

Characterization of SDM Fibers for Data Center Applications, Andrew Forbes¹; Univ. of Witwatersrand, South Africa. We outline recent progress in the creation and detection of vector modes, and use the tools to study their propagation in free space and fiber.

Th4I • Coherent Optical Signal Processing
Presider: Michael Vasilyev; Univ. of Texas at Arlington, USA
15:30–17:15

Coherent Optical Signal Processing: Challenges and Opportunities, Michael A. Theurer¹, Martin Möhrle¹, Ute Troppenz¹, Heinz-Gunter Bach¹, Ariane Sigmund¹, Georges Przyrembel¹, Martin Schell¹; Fraunhofer Heinrich Hertz Inst., Germany. We present recent advances in coherent optical signal processing, including new techniques and applications.

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Th4G.1 • 15:30
Top Scored
4 x 56 Gb/s High Output Power Electroabsorption Modulated Laser Array, Michael A. Theurer¹, Martin Möhrle¹, Ute Troppenz¹, Heinz-Gunter Bach¹, Anane Sigmund¹, Georges Przyrembel¹, Martin Schell¹; Fraunhofer Heinrich Hertz Inst., Germany. We demonstrate a high output power EML-array operating at 4 x 56 Gb/s NRZ. On chip RF transmission lines enable flexibility for packaging and driver integration. A common active layer structure allows for cost effective fabrication.

Th4I.1 • 15:30
Bit-rate-transparent Optical RZ-to-NRZ Format Conversion Based on Linear Spectral Phase Filtering, Reza Maram¹, Francesco Da Ros², Pengyu Guan², Kasper M. Røge², Michael Galili², Leif K. Oxenlowe², Jose Azana³; ¹INRS-Energie Matériaux et Télécom, Canada; ²Department of Photonics Engineering, Technical Univ. of Denmark, Denmark. We propose a novel and strikingly simple design for all-optical bit-rate-transparent RZ-to-NRZ conversion based on optical phase filtering. The proposed concept is experimentally validated through format conversion of a 640 Gbit/s coherent RZ signal to NRZ signal.

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Th4G.2 • 15:45
56 Gb/s Electro-Absorption Modulation of a Heterogeneously Integrated InP-on-Si DFB Laser Diode, Amin Abbasi¹, Bart Moeneclaey¹, Jochem Verbra¹, Xin Yin¹, Johan Bauwelinck¹, Gunther Roelkens¹, Geert Morthier¹; INTEC, Ghent Univ.- imec, IDLab, Belgium; ²INTEC, Ghent Univ.-Imec, Belgium. Electro-absorption modulation of a heterogeneously integrated InP/Si DFB laser is demonstrated by reverse biasing the InP tapers, used to couple the light between the InP and the Si waveguides. Modulation at 56 Gb/s is demonstrated.

Th4I.2 • 15:45
Enhanced Self-coherent Optical OFDM using Stimulated Brillouin Scattering, Elias Giacoumidis¹, Eric Magi¹, Amal Choudary¹, David Marpaung¹, Bill Corcoran¹, Mark D. Pelusi¹, Benjamin Eggleton¹; ¹CUDOS, Univ. of Sydney, Australia; ²Monash Univ., Australia. We experimentally demonstrate the first self-coherent optical OFDM (SCO-OFDM) based on received optical carrier amplification by stimulated Brillouin scattering. Compared to the conventional CO-OFDM, SCO-OFDM has similar performance with 9.6-Gb/s (16-QAM) enhanced data rate.
The performance of a...information capacity growth.

...such as size and weight reduction together with bottleneck problems associated with satellites, is part of a solution that aims to overcome...Telecommunication Satellite Purposes, Optical Amplifier Based on a 7-core Fiber for Radio Access Network II—Continued

Continued

...Continued

Th4E • Novel Applications of Microwave Photonics—Continued

Th4E.3 • 16:15 Real-time Gigabit RS-coded OFDM Signal Transmission over WDM-based X-Band 2x2 MIMO RoF System, Ming Chen1, Xin Xiao, Jianjun Yu, Xingjun Li, Fan Li, Human Normal Univ., China; 2ZTE(TX) Inc., USA. We experimentally demonstrate a real-time 2.3-Gbs/s WDM-based 2x2 MIMO RS-coded OFDM-RoF system at X-band for future high-speed fiber-wireless access. The real-time measured BER after 2.24-km SMF-28 and 10-m wire...
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<th>Room 408A</th>
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<td><strong>Th4F • Network Design—Continued</strong></td>
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<td><strong>Th4F.2 • 16:00</strong></td>
<td>Demonstration of Reconfigurable WDM Multicast Supporting Content Replication and Protection Switching for Content Delivery Optical Network, Ze Li¹, Min Zhang¹, Danshi Wang¹, Dequan Xie², Yue Cui³, Qi Yang¹, Beijing Univ of Posts &amp; Telecom, China; iWuhan Research Inst. of Posts and Telecommunications, China. We propose a reconfigurable WDM multicast scheme supporting content replication and protection switching for CDN through SOA and our LCOS-based TB-WSS. One-to-six/seven/eight 25 Gb/s QPSK WDM multicsalso with protection switching function have been successfully demonstrated.</td>
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<td><strong>Th4F.3 • 16:15</strong></td>
<td>Dynamic Control of Coarse/Fine Hybrid Granular Routing Optical Networks, Yuaku Ito¹, Yojirō Mori¹, Hiroshi Hasegawa¹, Ken-ichi Sato¹, Nagaoya Univ., Japan. Dynamic control of coarse/fine granular routing optical networks is proposed. The routing scheme exploits virtual direct links, which enhances fiber frequency utilization and eliminates the need to control intermediate nodes. Its effectiveness is numerically verified.</td>
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<td><strong>Th4F.4 • 16:30</strong></td>
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<td><strong>Th4G • Laser Transmitters—Continued</strong></td>
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<td><strong>Th4G.3 • 16:00</strong></td>
<td>Ultra-broadband EA-DFB Laser Module for 200-Gbit/s PAM4 Transmitter, Hiroshi Yamazaki¹, Shigeru Kanazawa¹, Yasuhiro Nakanishi², Yuta Uedai³, Wataru Kobayashi², Yoshifumi Muramoto³, Hiroyuki Ishii³, Hiroaki Sanjoh³, NTT Device Technology Laboratories, Japan; NTT Device Innovation Center, Japan. A lumped-electrode EA-DFB laser module with a modulation bandwidth of ~59 GHz was designed and fabricated based on a flip-chip interconnection technique. It enables 107-Gbaud PAM4 transmission.</td>
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<td><strong>Th4G.4 • 16:30</strong></td>
<td>28-Gbit/s 80-km Transmission using SOA-assisted Extended-reach EADFB Laser (AXEL), Koichi Hasebe¹, Wataru Kobayashi¹, Naoki Fujiwara¹, Takahiko Shindo¹, Toshihide Yoshimatsu¹, Shigeru Kanazawa¹, Tetsuhiro Ohno¹, Hiroyuki Ishii¹, Yoshitaka Ohso¹, Hiroyuki Ishii¹, Yoshiaki Sone¹, Hideaki Matsuzaki¹, NTT Device Technology Labs, Japan; NTT Device Innovation Center, Japan; NTT Network Innovation Labs, Japan. We fabricated 1.3-mm AXELs to extend the transmission distance with 28-Gbit/s NRZ signal. SOA-assisted gain is effective in increasing the average output power. We successfully demonstrated 80-km transmission with an APD-ROSA.</td>
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<td><strong>Th4H • Characterization of SDM Fibers—Continued</strong></td>
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<td><strong>Th4H.2 • 16:00</strong></td>
<td>Nondestructive Characterization of Differential Mode Delay in Few-mode Fiber Link Using Rayleigh Backscattering Spectral Shifts, Shingo Ohno¹, Daisuke Iida², Toge Kunihito¹, Tetsuya Manabe¹, NTT Access Service Systems Laboratories, Japan. We propose a nondestructive method for characterizing accumulated differential mode delay along a few-mode fiber link using Rayleigh backscattering spectral shifts caused by slight environmental disturbances, and achieve 20-ps accuracy and 40-nm resolution.</td>
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<td><strong>Th4H.3 • 16:15</strong></td>
<td>Distributed Measurement of Single-way Inter-modal Crosstalk in Spliced FMFs Based on BOTDA, Hiroshi Takahashi¹, Chihito Kito¹, Kunihiro Toge¹, Tetsuya Manabe¹, Fumihiko Ito¹, NTT, Japan; Shimane Univ., Japan. This paper focuses on the distributed measurement of inter-modal crosstalk for spliced FMFs, and reveals that single-way inter-modal crosstalk in spliced FMFs, unlike round-trip crosstalk with reflectometric methods, can be characterized using a BOTDA-based method.</td>
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<td><strong>Th4H.4 • 16:30</strong></td>
<td>Nearfield Complex Imaging, Yifei Wang¹, Jian Fang¹, An Li¹, Qi Yang¹, William Sheih¹, The Univ. of Melbourne, Australia; ‘Victoria research laboratory, NICTA Ltd., Australia; ’Wuhan Research Inst. of Post and Telecommunications, China. Complex imaging via coherent detection is proposed for acquiring two-dimensional near-field optical image recovering amplitude and phase simultaneously. We experimentally demonstrate the technique using few-mode-fiber (FMF) modes with high extinction ratio, and characterize the FMF differential-group-delay.</td>
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<td><strong>Th4I • Coherent Optical Signal Processing—Continued</strong></td>
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<td><strong>Th4I.3 • 16:00</strong></td>
<td>Optical Injection Locking for Carrier Phase Recovery and Regeneration, Radan Slavik¹, Zhenxu Liu¹, David J. Richardson¹, Univ. of Southampton, UK. We review various scenarios for using optical injection locking for phase synchronization of signals to a local oscillator. We concentrate on the principle of operation and key properties needed.</td>
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<td><strong>Th4I.4 • 16:30</strong></td>
<td>Polarization-independent Optical Injection Locking, Jignesh Jokhakar¹, Monash Univ., Australia. We review various scenarios for using optical injection locking for phase synchronization of signals to a local oscillator. We concentrate on the principle of operation and key properties needed.</td>
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Millimeter-wave RoF technology is also discussed for application to high bitrate wireless communication in fiber-wireless bridge configuration and railway communication systems. Non-telecommunication application such as a millimeter-wave radar system is also shown in the paper.

**Room 407**

**Th4E.6 • 17:00 Invited**

High Bitrate Mm-Wave Links Using RoF Technologies and Its Non-telecom Application, Atsushi Kanno¹, National Inst. of Information and Communications Technology, Japan. Millimeter-wave RoF technology is discussed for application to high bitrate wireless communication in fiber-wireless bridge configuration and railway communication systems. Non-telecommunication application such as a millimeter-wave radar system is also shown in the paper.

**Room 408A and 408B**

**Th4D.5 • 16:45 Top scored**

50Gb/s 64APSK Coded Modulation Transmission over Long Haul Submarine Distance with Nonlinearity Compensation and Subcarrier Multiplexing, Matt Mazurczyk¹, Jin-Xing Cai¹, Huassam G. Bashor¹, Yu Sun¹, Oleg V. Sinkin¹, Maxim A. Bolshtyansky¹, Dmitrii Fourta¹, Alexei Pilipetski¹; ¹TE SubCom, USA. We achieve transoceanic distance transmission with 350-390 Gb/s 64APSK coded modulation channels and explore the benefit of nonlinearity compensation with subcarrier multiplexing. Estimated total capacity with variable spectral efficiency is 66.8 Tbps.

**Room 404AB**

**Th4D • Submarine Transmission Systems—Continued**

**Th4D.6 • 17:00 Performance Comparison of Advanced Modulation Formats for Transoceanic Coherent Systems**, Ivan Fernandez de Jauregui Ruiz¹, Amirhossein Ghazisaeidi¹, Rafael Rios-Muller¹, Patrice Tran¹; ¹Nokia Bell Labs, France. We experimentally compare the performance of probabilistically-shaped 64QAM (P56QAM), 64APSK, 64QAM and 32QAM in terms of SNR and GMI in B2B and after 6600km transmission. We show that P56QAM outperforms all formats by 0.4 bits/symbol.

**Room 402AB**

**Th4C • DSP for Coherent Systems—Continued**

**Th4C.7 • 17:00**

Optical Transport Network Architecture Enabling Ultra-Low Latency for Communications among Base Stations, Jun Li¹, Xiang Liu¹, Erik Agrell¹, Masaki Wada¹, Georgia Inst. of Technology, USA; ¹KTH-Royal Inst. of Technology, Sweden. We propose a novel transport network architecture for mobile backhauling along with its tailored communication protocol to offer ultra-low latency. Results show that less than 0.5 milliseconds packet delay can be achieved for inter-base-station communications.

**Room 403A**

**Th4B • Optical Technologies for Radio Access Network II—Continued**

**Th4B.5 • 17:00**

Broadband Near Infrared (NIR) Luminescence Spectra of Bi/Er Co-doped Silicate Fiber (BEDF) under 830 nm and dual Pumping, Zhao Qiancheng¹, Yue Li¹, Yuhua Luo¹, Georgia Inst. of Technology, USA; ¹Univ. of New South Wales, Australia. The luminescence characteristics for BEDF are investigated under 830 nm, 980 nm and dual pumping. Dual pumping scheme proves to flatten and broaden the emission spectrum in the range 950-1600 nm with multiple active centers.

**Room 403B**

**Th4C • DSP for Coherent Systems—Continued**

**Th4C.7 • 17:15 Phase-Noise Compensation for Spatial-Division Multiplexed Transmission**, Arni F. Alfredsson¹, Erik Agran¹, Feng Feng¹, Magnus Karlsson¹; ¹Chalmers Univ. of Technology, Sweden. The problem of correlated phase noise in spatial-division multiplexed transmission is studied. To compensate for the phase noise, an algorithm for joint-core phase-noise estimation and symbol detection is proposed, which outperforms conventional methods.

**Room 407**

**Th4E • Novel Applications of Microwave Photonics—Continued**

**Th4E.5 • 16:45**

Orthogonal Chirp Division Multiplexing in Millimeter-wave Fiber-wireless Integrated Systems for Enhanced Mobile Broadband and Ultra-reliable Communications, Feng Lu¹, Lin Cheng¹, Mu Xu¹, Jing Wang¹, Shuyi Shen¹, Gee-Kung Chang¹; ¹Georgia Inst. of Technology, USA. We firstly propose to apply orthogonal-chirp-division-multiplexing in MMW fiber-wireless-integrated systems. It supports enhanced-mobile-broadband and ultra-reliable low-latency communications, and is more robust to system degradations and interferences, as experimentally demonstrated with up to 5-dB EVM improvement.

**Room 408A and 408B**

**Th4D • Submarine Transmission Systems—Continued**

**Th4D.5 • 16:45 Top scored**

Coupled 2-LP 6-core EDFA with 125 μm Cladding Diameter, Masaki Wada¹, Naresh Chand¹, Frank Effenberger¹, Ivan Fernandez de Jauregui Ruiz¹, Georgia Inst. of Technology, USA; ¹TE SubCom, USA. We demonstrate a cladding-pumped 2-LP mode coupled 6-core EDFA with a 125-μm cladding diameter. A differential mode-core gain of less than 4-dB and a 6.5-dB average noise figure are successfully achieved in the C-band.

**Room 404AB**

**Th4D • Submarine Transmission Systems—Continued**

**Th4D.6 • 17:00 Performance Comparison of Advanced Modulation Formats for Transoceanic Coherent Systems**, Ivan Fernandez de Jauregui Ruiz¹, Amirhossein Ghazisaeidi¹, Rafael Rios-Muller¹, Patrice Tran¹; ¹Nokia Bell Labs, France. We experimentally compare the performance of probabilistically-shaped 64QAM (P56QAM), 64APSK, 64QAM and 32QAM in terms of SNR and GMI in B2B and after 6600km transmission. We show that P56QAM outperforms all formats by 0.4 bits/symbol.
Th4F.6 • 17:00
Network Utilization Improvement using Format-agnostic Multi-channel Wavelength Converters, Kyoo Ishi1, Takashi Inoue1, Inwoong Kim1, Xi Wang2, Hung Nguyen Tan2,3, Qiong Zhang1, Tadashi Ikeuchi1, Shu Namiki1;1 AIST, Japan;2 Fujitsu Laboratories of America, Inc., USA;3 The University of Danang-Univ. of Science and Technology, Viet Nam. We demonstrate the effectiveness of multi-channel, format-agnostic, all-optical wavelength converters (AO-WCs) in improving network utilization. Simulations show doubled network utilization with significantly fewer AO-WCs and experiments confirm successful multi-channel conversion over full operating wavelength range.

Th4G.6 • 17:00
Low-cost E1-class 10-Gb/s Directly Modulation Laser in TO-can Package with Optical Filtering for XG-PON Application, Enyu Zhou1, Ning Cheng1, Sulin Yang1, Liqiang Yu1, Xiang Liu1, Cong Chen1, Lingjie Wang1;1 Huawei Technology Co. Ltd, China. A low-cost E1-class 1577nm 10Gb/s directly modulated DFB laser in TO-can package is demonstrated with 7.3dBm output power and 8.9dB extinction ratio using optical filtering. 37.6dB power budget is achieved after 20km single-mode fiber transmission.

Th4H.5 • 16:45
Flexible Scheme for Measuring Chromatic Dispersion Based on Interference of Frequency Tones, Kyle Bottrell1, Mohamed A. Ettabili2, James C. Gates1, Cosimo Lacava3, Francesca Parmigiani1, David J. Richardson1, Periklis Petropoulos1;1 Univ. of Southampton, UK. We propose and demonstrate a flexible new scheme for measuring chromatic dispersion profiles of optical devices. This is achieved by measuring the phase difference between two mutually coherent tones that are mixed together through a modulator.

Th4H.6 • 17:00
Investigation of Inter-core Crosstalk and Raman Nonlinearity in Wideband MCF Transmission, Ruben S. Luis1, Benjamin J. Puttnam1,2,3, Mingshan Li1,2,3, Edward Liang1,2,3, Prashant P. Baveja4,5,6,7,8,9;1 The University of Southampton, UK;2 University of California, San Diego, USA;3 Pacific Northwest National Laboratory, USA;4 Ericsson, Sweden;5 Huawei Technologies, Sweden;6 Ericsson, Singapore;7 Electronic & Computer Engineering, National University of Singapore, Singapore;8 Ericsson, Singapore;9 Ericsson, Sweden. A 56 Gb/s PAM-4 directly modulated laser for 200G/400G data-center optical links is shown by de-aggregation of multiple channels into two 4-PAM channels using a single stage high-performance SASE Amplifier, resulting in a 20km single-mode fiber transmission with Q-factor of 6dBm per stage.

Th4I.6 • 17:00
Experimental Demonstration of Tunable Optical De-aggregation of Each of Multiple Wavelength 16-QAM Channels into Two 4-PAM Channels, Ahmad Fallahpour1,2, Mortega Ziyadi1,2, Amirhossein Mohajerin Anaei2.1 AIST, Japan;2 Fujitsu Laboratories of America, Inc., USA;3 Tel Aviv Univ., Israel;4 Stanford Univ., USA;5 Infinera Corporation, USA;6 Tel Aviv Univ., Israel;7 Stanford Univ., USA. We experimentally demonstrate tunable all-optical simultaneous de-aggregation of multiple wavelength 16-QAM channels into two 4-PAM channels using a single stage nonlinear element. Tunability of the proposed approach over modulation format and bitrate is shown by de-aggregation of multiple channels for 10/15-Gbaud QPSK signals into two BPSK signals.

17:30–18:00 Beverage Break, 400 Foyer
18:00–20:00 Postdeadline Papers, 403A, 403B, 408A and 408B