Photonics in Switching and Computing
19 – 21 September 2018

Workshop 3: Space Division Multiplexing – Systems, Devices, Fibers and Networking

Objectives: To highlight emerging components, fibers and systems including the networking and control plane aspects required for future deployment of Space Division Multiplexing in the field.

- **Chairman:**
- Dr Chigo Okonkwo, Institute for Photonic Integration, Eindhoven University of Technology, The Netherlands.
- Dr. Ruben S. Luis, National Institute of Information and Communications Technology (NICT), Japan.

Workshop Duration: 8 Hours (including 1 hr 40 min break (2x 20 min coffee break + 50 min Lunch Break)

Speakers:

- Werner Klaus - NICT Japan –"*EXAT and the first 10 years of SDM research in Japan*"
- Haoshuo Chen - Nokia Bell Labs, USA – *"Remote spatio-temporal control over multimode fiber"*
- Itsuro Morita - KDDI R&D laboratory, Japan *"Ultra-high capacity transmission using few-mode multi-core fiber"*
- Koji Igarashi - Osaka University, Japan. *"Signal Processing for mode multiplexed transmission in the optical domain and digital domain"*
- Luca Poti - CNIT Pisa, Italy. *"Multi-core fibre applications from the lab to a city test-bed"*
- Takashi Sasaki - Innovation Core, Sumitomo, USA. *"Toward the Practical use of the Multi-core Fiber in Optical Communications"*
- Nick Psaila - Optoscribe UK. *"3D laser written waveguide circuits for SDM and photonic integration"*
- Dan Marom - Hebrew University of Jerusalem, Isreal. *"Rectangular Core Fiber for Mode-Division Multiplexed Optical Communications"*
- Salvatore Spadaro - UPC, Spain. *"Spatial super-channel allocation strategies in dynamic Flex-Grid/MCF optical core networks"*
- Yusuke Hirota - Osaka University, Japan. *"SDM-oriented Networking System with fractional pSSC concept for future optical networks"*
- Konstantinos Manousakis - University of Cyprus, Cyprus *"Routing Spectrum and Core Allocation in SDM Networks with Physical Layer Considerations"*
- Cristina Rottondi - University of Lugano, Switzerland. *"Optimized design of flexi-grid optical networks with SDM Technologies"*

Schedule		
9:00	9:20	Welcome and Workshop Introduction Chigo Okonkwo and Ruben Luis
SYSTEMS		
9:20	10:00	Werner Klaus - NICT Japan - KEYNOTE SPEAKER *"EXAT and the first 10 years of SDM research in Japan"*
10:00	10:20	Haoshuo Chen - Nokia Bell Labs, USA *"Remote spatio-temporal control over multimode fiber"*
10:30	11:00	COFFEE BREAK
11:00	11:20	Itsuro Morita - KDDI R&D laboratory, Japan *"Ultra-high capacity transmission using few-mode multi-core fiber"*
11:20	11:40	Koji Igarashi - Osaka University, Japan. *"Signal Processing for mode multiplexed transmission in the optical domain and digital domain"*
11:40	12:00	Luca Poti - CNIT Pisa, Italy. *"Multi-core fibre applications from the lab to a city test-bed"*
COMPONENTS, DEVICES AND FIBERS		
12:00	12:20	Takashi Sasaki - Innovation Core, Sumitomo, USA. *"Toward the Practical use of the Multi-core Fiber in Optical Communications"*
12:20	12:40	Nick Psaila - Optoscribe UK. *"3D laser written waveguide circuits for SDM and photonic integration"*
12:40	13:00	Dan Marom - Hebrew University of Jerusalem, Isreal. *"Rectangular Core Fiber for Mode-Division Multiplexed Optical Communications"*
13:00	14:00	LUNCH BREAK
NETWORKING AND CONTROL PLANE		
14:00	14:20	Salvatore Spadaro - UPC, Spain. *"Spatial super-channel allocation strategies in dynamic Flex-Grid/MCF optical core networks"*
14:20	14:40	Yusuke Hirota - Osaka University, Japan. *"SDM-oriented Networking System with fractional pSSC concept for future optical networks"*

14:40	15:00	Konstantinos Manousakis - University of Cyprus, Cyprus *"Routing Spectrum and Core Allocation in SDM Networks with Physical Layer Considerations"*
15:00	15:20	Cristina Rottondi - University of Lugano, Switzerland. *"Optimized design of flexi-grid optical networks with SDM Technologies"*
15:30	16:00	COFFEE BREAK
16:00	17:00	ALL SPEAKERS PANEL + INTERACTION WITH AUDIENCE
END OF WORKSHOP		

Further Information

Werner Klaus - NICT Japan
"EXAT and the first 10 years of SDM research in Japan"

Abstract: Numerous research efforts and experimental demonstrations around the world indicate that space division multiplexing (SDM) is perhaps the most promising solution to deal effectively with the looming capacity crunch due to limitations in transmission capacity imposed by single-mode fibers used in today's optical networks. Although the concept of SDM is straightforward, many technological challenges have to be overcome before a cost and energy efficient system can be realized. Within the EXAT initiative, a total of so far 4 national projects funded and supervised by NICT have been stimulating both industry and academia to work together towards the common goal of making SDM practical and ready for the market. In this talk, I will give a general overview of SDM research while highlighting some recent accomplishments on the national scale as well as presenting results of in-house research activities at NICT.

Speaker Biography: Werner Klaus received an MSc degree with highest honors in Communications Engineering from the Vienna University of Technology, Austria, in 1991 and a PhD degree in Electronics Engineering from the University of Tokyo, Japan, in 1995. Since 1995 he has been working at the National Institute of Information and Communications Technology (NICT) in Tokyo on various aspects of optical communications ranging from device to coherent optical system design both in free-space and modern fiber optics including quantum key distribution (QKD) and space division multiplexing (SDM).Werner Klaus was a visiting researcher at the Institute of Microtechnology, Neuchâtel, Switzerland (now part of École Polytechnique Fédérale de Lausanne) working on the simulation and design of holographic and micro-optical elements for security applications from 2002 to 2003, and a visiting researcher at the Institute of Telecommunications, Vienna University of Technology, Austria, working on the simulation and design of optical waveguides and modal filters for space interferometry applications in 2006.

Werner Klaus has published widely both in international and Japanese journals and speaks regularly at international and domestic conferences both in English and Japanese. He is currently serving as a technical committee member for the Optical Fiber Communication Conference (OFC) 2019.and has been serving as program chair for OSA's Advanced Photonics Congress since 2017. He is also a member of the technical committee on Extremely Advanced Optical Transmission Technologies (EXAT) organizing the EXAT International Symposium which is hold in Japan biyearly since 2011 and has become an important platform for information exchange on the latest trends and developments of SDM technology between Japanese and foreign researches.

Haoshuo Chen - Nokia Bell Labs, USA
"Remote spatio-temporal control over multimode fiber"

Abstract: MIMO preprocessing is explored to achieve remote spatio-temporal control over multimode fiber employing single-ended fiber channel monitoring scheme.

Speaker Biography: Haoshuo Chen received B.S. and M.S. degrees in electrical engineering from Shanghai University (SHU) in 2007 and 2009, and Ph.D degree (Cum Laude) in electrical engineering from Eindhoven University of Technology (TU/E), The Netherlands, in 2014. Supported by the European Union FP7 MODE-GAP Project, he investigated free space and photonic integrated spatial multiplexing solutions and demonstrated large capacity few-mode fiber transmission during his PhD. From Since December 2014, he has been working as a member of technical staff at Nokia Bell Labs, Holmdel, NJ, USA. His main research interests include space division multiplexing, photonic integration, digital signal processing, fiber components and wavelength/space.

Itsuro Morita - KDDI R&D laboratory, Japan
"Ultra-high capacity transmission using few-mode multi-core fiber"

Abstract: SDM is a promising technology to increase a system capacity drastically and the highest capacity in a single optical fiber has reached to 10 Pbit/s. In this talk, 10 Pbit/s transmission using 6-mode 19-core fiber will be reviewed.

Speaker Biography: Itsuro Morita received the B.E., M.E., and Dr. Eng. degrees in electronics engineering from the Tokyo Institute of Technology, Tokyo, Japan, in 1990, 1992, and 2005, respectively. He joined Kokusai Denshin Denwa (KDD) Company, Ltd. (currently KDDI Corporation), Tokyo, Japan, in 1992, where he has been with the Research and Development Laboratories since 1994. He has been engaged in research on long-distance and high-speed optical communication systems. In 1998, he was on leave at Stanford University, Stanford, CA. He is currently an Executive Director of KDDI Research, Inc., Saitama, Japan. He is a Senior Member of the Institute of Electronics, Information and Communication Engineers. He was the recipient of the Minister Award from METI in 2006 and the Hisoka Maejima Award from the Tsushinbunka Association in 2011.

Koji Igarashi - Osaka University, Japan.
"Signal Processing for mode multiplexed transmission in the optical domain and digital domain"

Abstract: We review signal processing in the optical domain and the digital domain required for strongly-coupled and weakly-coupled mode multiplexed transmission systems.

Speaker Biography: Koji Igarashi received the B.E. degree in electrical and computer engineer- ing from Yokohama National University, Yokohama, Japan, in 1997, and the M.E. and Ph.D. degrees in electronic engineering from the University of Tokyo, Tokyo, Japan, in 1999 and 2002, respectively. From 2002 to 2004, he joined Furukawa Electric Corporation, Ltd. After 2004, he was with the University of Tokyo. From 2007 to 2011, he was an Assistant Professor. Before that, he was with the Department of Frontier Informatics, followed by a position with the Department of Electrical Engineering and Information Systems. He then moved to KDDI R&D Laboratories, Inc., Saitama, Japan, from 2012 to 2013. He is currently an Associate Professor with the Department of Electrical, Elec- tronic and Information Engineering, Osaka University, Suita, Japan, as well as a Visiting Researcher with KDDI R&D Laboratories, Inc. (currently KDDI Research, Inc.). His current research interests include high-capacity long-haul optical fiber transmission systems, signal processing for coherent optical com- munication systems, and optical fiber devices for space-division-multiplexed optical transmission systems.

Luca Poti - CNIT Pisa, Italy.
“Multi-core fibre applications from the lab to a city test-bed”

Abstract: We will show some results using multicore fibres for different applications including optical communications, networking, and integrated devices. A new city test-bed will be even described together with innovative research opportunities.

Speaker Biograhy: Luca Potì is currently Head of Research with the Inter-university National Consortium for Telecommunications (CNIT) at the Photonic Networks Nat'l Lab and external collaborator for Scuola Superiore Sant'Anna, at the Excellence Center for Communication and Information Engineering (CEIIC) both located in Pisa, Italy. In 1997 he was visiting researcher at the Centre d'Optique, Photonique et Laser (COPL), Quebéc, Canada working on recirculating loop experiment for ultra-long haul transmission. In 1998 he received a Marconi Communication grant on the topic: "WDM communication systems on optical fibre" at the Marconi Laboratory of Parma University working on Nonlinear effects due to fibers and EDFAs in WDM systems. From 1999 to 2000 he worked as a responsible for the optical communications laboratory at the University of Parma, Italy. Since 2001 he is senior researcher with CNIT at the Photonics Networks National Laboratory in Pisa. In 2002 he was visiting researcher at the National Institute of Information and Communications Technology (NICT), Tokyo, Japan, working on ultra-fast phase comparison for 160 GHz signals. In 2005 he started, together with two researchers, PhoTrix S.r.l. an Italian company producing pulsed fibre lasers and ultra-fast subsystems. He has published more than 100 international journal papers, conference papers, and patents. He was Scientific Coordinator for the EU Project 'Large Optical Bandwidth by amplifier Systems based on Tellurite fibres doped with Rare earths' (LOBSTER). He was involved in several projects supported by the Italian Ministry of University and Research (MIUR) and Ministry of Foreign Affairs (MAE). He is currently managing the FIRB project 'Photonic Enabling Devices for Regeneration and Optical Switching' (PEDROS) supported by the MIUR. His research interests were mainly focused on ultra-fast communication systems, in fact, in 2001 his group demonstrated first Italian transmission system working at 160 Gbit/s. For such purpose strong expertise has been developed in ultra-short optical pulse generation for telecommunication. Recently he is interested in all-optical processing subsystems for ultra-fast communications and Optical Packet Switching networks.

Takashi Sasaki - Innovation Core, Sumitomo, USA.
“Toward the Practical use of the Multi-core Fiber in Optical Communications”

Abstract: *In this talk, we will address the practical aspects and considerations for the use of Multi-core fiber in optical communication systems.*

Speaker Biograhy: Dr Takashi Sasaki is currently the Vice President for Marketing at Innovation Core SEI, California USA. Takashi Sasaki received the B.S. and M.E. degree in 1992 and 1994 in electric engineering from Tohoku University, Miyagi, Japan. In the same year, he joined Sumitomo Electric Industries, Ltd., and since then has been engaged in research and development of optical fibers and optical fiber components. Mr. Sasaki is a member of the Optical Society of America (OSA), and Institute of Electronics, Information and Communication Engineers (IEICE) of Japan.

Nick Psaila - Optoscribe UK.
“3D laser written waveguide circuits for SDM and photonic integration”

Abstract: In this talk, we will discuss the application of unique 3D glass-based photonic integrated circuit platform which is ideally suited for creating custom transceiver fiber coupling and attaching solutions designed to specifically address the challenges of individual optical transceiver architectures and configurations. These minimises network costs whilst maximising cable performance are critical for the deployment of compact and robust optical interconnects and Space division multiplexed transmission systems.

Speaker Biography: Nick Psaila is a recognised expert in the manufacture and use of photonic technologies in optical communications. In 2010 he was awarded an Enterprise Fellowship from the Royal Society of Edinburgh, providing support, business training, and facilitating commercialisation of university-based technology. Dr Psaila has a BSc (Hons) in Physics from Imperial College London; a MSc in Photonics and Optoelectronic Devices from the University of St Andrews and a PhD in Photonics from Heriot-Watt University, Edinburgh, Scotland. He is a member of IEEE, IoP, SPIE and OSA.

Dan Marom - Hebrew University of Jerusalem, Isreal.
"Rectangular Core Fiber for Mode-Division Multiplexed Optical Communications"

Abstract: Fibers supporting mode-division multiplexing may come in many geometric forms. We investigate rectangular core fiber as a solution that can offer low mode mixing and facilitates interfacing to planar devices

Speaker Biography: Dan Marom is a Full Professor in the Applied Physics Department at Hebrew University, Israel, heading the Photonic Devices Group and currently serving as the Department Chair. He received the B.Sc. Degree in Mechanical Engineering and the M.Sc. Degree in Electrical Engineering, both from Tel-Aviv University, Israel, in 1989 and 1995, respectively, and was awarded a Ph.D. in Electrical Engineering from the University of California, San Diego (UCSD), in 2000.

His 20+ year research career in optical communications started during his Master's degree, where he investigated free-space, polarization rotation-based bypass-exchange (2×2) space switches, which led to the founding of a start-up company. In his doctoral dissertation he demonstrated real-time optical signal processing using parametric nonlinearities applied to spectrally dispersed light, for possible modulation and detection schemes in serial ultrafast communications (tera-baud rate and beyond). From 2000 until 2005, he was a Member of the Technical Staff at the Advanced Photonics Research Department of Bell Laboratories, Lucent Technologies, where he invented and headed the research and development effort of MEMS based wavelength-selective switching solutions for optical networks. Since 2005, he has been with the Applied Physics Department, Hebrew University of Jerusalem, Israel, where he leads a research group pursuing his research interests in creating photonic devices and sub-systems for switching and manipulating optical signals, in guided-wave and free-space optics solutions using light modulating devices, nonlinear optics, and compound materials.

Prof. Marom is a Fellow of the Optical Society of America and a Senior Member of the IEEE Photonics Society. He was awarded the IEEE Photonics Society Distinguished Lecturer Award for 2014 and 2015, and is currently serving on the Society's Board of Governors. From 1996 through 2000, he was a Fannie and John Hertz Foundation Graduate Fellow at UCSD, and was a Peter Brojde Scholar in 2006-2007.

Prof. Marom will give a Tutorial on optical switching of spatial and spectral communication channels in Optical Fiber Communications (OFC) 2018, as well as an Invited Talk at Photonic Networks and Devices (NETWORK) 2018. He also serves as Program co-Chair for Photonics in Switching and Computing (PSC) 2018, and Steering Committee Chair for the International Conference on Optical MEMS and Nanophotonics (OMN). Next OMN meeting to take place in Lausanne, Switzerland, August 2018

Salvatore Spadaro - UPC, Spain.
"Spatial super-channel allocation strategies in dynamic Flex-Grid/MCF optical core networks"

Abstract: In this talk, different cost-effective super-channel allocation strategies for flex-grid/multicore fibers core networks in dynamic scenarios are discussed, highlighting the potential benefits brought by MCFs compared to equivalent multi-fibers scenarios.

Speaker Biography: Dr Spadaro received the M.Sc. (2000) and the Ph.D. (2005) Degrees in Telecommunications Engineering from Universitat Politècnica de Catalunya (UPC). He also received the Dr. Ing. Degree in Electrical Engineering from Politecnico di Torino (2000). He is currently an Associate Professor in the Optical Communications group of the Signal Theory and Communications Dept. of UPC. Having participated in various European and National research projects as scientific coordinator and contributor, his research interests are in the fields of all-optical networks with emphasis in Traffic Engineering and Resilience, Optical Transmission technologies, multi-granular optical switching, Optical network devices virtualization, Control and management of optical networks, intra/inter data centres architecture design, Software Defined Networking/Network Function Virtualization, Planning and operation of multi-core/SDM optical networks, Data Centres Federation, IoT, Cloud/Fog computing.
Dr Spadaro is currently serving on the editorial board of the Springer Photonic Network Communications journal. He regularly participates in several TPCs, including IEEE Globecom and ICC. Since November 2016, Dr Spadaro is IEEE Senior Member.

Yusuke Hirota - Osaka University, Japan. "*SDM-oriented Networking System with fractional pSSC concept for future optical networks*"

Abstract: Spatial division multiplexing is one of the essential technologies for accommodating large amount of future traffic demand.

Speaker Biography: Yusuke Hirota received the B.E., M.E. and Ph.D. degrees from Osaka University, Osaka, Japan, in 2004, 2006 and 2008, respectively.
He joined the Department of Information Net- working, Graduate School of Information Science and Technology, Osaka University, in 2008, as an Assistant Professor. Since 2017, he is with the Na- tional Institute of Information and Communications Technology (NICT), Tokyo, Japan. His research in- terest includes all-optical networking, optical fiber communication systems, multimedia streaming sys- tems, and autonomous networks. Dr. Hirota is a member of IEEE, OSA and IEICE

Konstantinos Manousakis - University of Cyprus, Cyprus
"*Routing Spectrum and Core Allocation in SDM Networks with Physical Layer Considerations*"

Abstract: From optical network resource assignment problem, Crosstalk-aware routing, core and spectrum assignment are recently studied for SDM-based elastic optical networks. These studies focus on optical circuit switching based SDM-EONs without super-channel technology. On the other hand, time-slotted optical packet switching with spatial super-channel switching is one of promising solutions to realize high throughput, low latency and low cost. We have developed a switching node system for the time-division packet spatial super-channel (pSSC) transmissions. In this study, basic concept of pSSC is firstly introduced. In addition, a fractional pSSC switching system design with spatial resource slicing is also introduced to overcome the overhead of pSSC with small data transmission. Through performance evaluations, we confirmed that the proposed fractional pSSC switching networks achieves better performance compared with no slicing system.

Speaker Biography: Dr Konstantinos Manousakis is a Research Fellow at KIOS Research and Innovation Center of Excellence. He holds a Diploma (2004) in Computer Engineering and Informatics from the University of Patras, Greece, an MSc (2007) and a PhD (2011) from the same department. In his doctoral research he worked on the design of impairment-aware routing and wavelength assignment (IA-RWA) algorithms for optical wavelength division multiplexing networks.
In parallel to doctoral research, he was able to contribute to Greek and EU projects, in the field of optical networks. He also worked in the Networking Technologies Sector (NTS) of the Research Academic Computer Technology Institute as a Computer Engineer. NTS focuses on the planning and the implementation of networking infrastructures, telematic services and optical networks.
His current research interests include optimization algorithms for high speed networks, physical layer security in optical networks, routing and wavelength assignment algorithms, network planning and operation tools, protection and restoration techniques for optical networks, energy optimization algorithms in optical networks and techno-economic aspects of telecom networks.

Cristina Rottondi - University of Lugano, Switzerland. *"Optimized design of flexi-grid optical networks with SDM Technologies"*

Abstract: SDM techniques introduce new modelling challenges for effective design and planning of optical networks. This talk overviews some recent approaches to solve Routing and Spectrum Assignment in optical networks with multicore/multimode fibers, in presence of multiple baud rates and modulation formats and considering inter-modal/inter-core crosstalk. Both exact and heuristic approaches will be presented and their trade-off between optimality and scalability will be discussed.

Speaker Biography: Cristina Rottondi received the master's (cum laude) and Ph.D. (cum laude) degrees in telecommunications engineering from the Politec- nico di Milano in 2010 and 2014, respectively. She is currently a Researcher with the Dalle Molle Institute for Artificial Intelligence, Lugano, Switzerland. Her research interests include cryp- tography, communication security, design and planning of optical networks, and networked music performance.