

## An Integrated Photonics Reservoir Computing Approach to Signal Equalization for Telecommunications

**A. Katumba, B. Schneider, J. Dambre, and P. Bienstman**  
*Photonics Research Group, Gent University - imec, Belgium*

### ABSTRACT

Photonic Reservoir Computing is a brain-inspired computing approach that brings the fast speeds and enormous bandwidth associated with lightwave technology together with the versatility of machine learning to enable the efficient computation of tasks requiring a finite amount of memory such as speech recognition, series prediction, header recognition etc. Broadly, our efforts focus on applying photonic reservoir computing implemented with the Silicon on Insulator (SOI) CMOS-compatible primitives to develop applications in the optical telecommunications space to take advantage of the aforementioned advantages. Specifically, this work presents our results on the implementation of a passive photonic reservoir chip that can be positioned at the receiver of a short or long metro link to invert impairments introduced to the optical transmitted signal due to a variety of imperfections and noise sources.

15:20 Tu.C1.5 Single-frequency radiation from DBR fiber laser: Numerical analysis by the method of single expression <i>(Invited)</i> <i>H. Baghdasaryan, T. Knyazyan, T. Hovhannisyan, M. Marcinik</i>	14:50 Tu.C2.5 Enhanced DC-biased optical OFDM for intensity-modulated optical OFDM Access systems <i>A.W. Azim, Y. Le Guennec, G. Maury</i>	15:10 Tu.C3.5 An emulation environment for SDN enabled flexible IP/optical networks <i>(Invited)</i> <i>A. Kretsis, L. Corazza, K. Christodouloupoulos, P. Kokkinos, E. Varvarigos</i>	15:20 Tu.C4.5 Nonlinear optical properties of tris-(8-hydroxyquinoline)-aluminum <i>(Invited)</i> <i>B. Derkowska-Zielińska</i>	14:50 Tu.C5.5 Topological optical waveguiding in SOI structures <i>(Invited)</i> <i>I. Andonegui, A. Blanco-Redondo, M.J. Collins, G. Harari, Y. Lumer, M.C. Rechtsman, B.J. Eggleton, M. Segev, A.J. Garcia-Adeva</i>	15:10 Tu.C6.5 Self-pulsing and phonon lasing in optomechanical crystals <i>(Invited)</i> <i>D. Navarro-Urrios, N.E. Capuj, J. Gornis-Bresco, M.F. Colombaro, P.D Garcia, M. Sledzinska, F. Alzina, A. Griol, A. Martinez, C.M. Sotomayor-Torres</i>
15:40 Tu.C1.6 Ultra-high power narrow band tuning DBR lasers for telecom applications <i>Yaping Zhang</i>	15:05 Tu.C2.6 All-optical virtual private network based on microwave photonic bandpass filter in OFDM-PON system <i>Chang-Hun Kim, Sang-Min Jung, Sang-Kook Han</i>		Tu.C4.6 Exploration of nonlinear optical response in metal-containing azo-based iminopyridine complexes <i>(Invited, Cancelled)</i> <i>B. Kulyk, A. Ayadi, D. Guichaoua, A. El-Ghayoury, B. Sahrroul</i>		15:30 Tu.C6.6 T-shape slotted photonic crystal based sensor with high sensitivity <i>C. Babayiğit, M. Turdueva, I.H. Giden, E. Bor, H. Kurt</i>

<b>Coffee break (15:55-18:20)</b>	<b>Coffee break (15:20-15:50)</b>	<b>Coffee break (15:30-18:00)</b>	<b>Coffee break (15:40-18:10)</b>	<b>Coffee break (15:10-15:40)</b>	<b>Coffee break (15:45-16:10)</b>
<b>ICTON VII</b> <i>Chair: Sergey Sergeev (16:20-18:15 Tuesday, July 12)</i>	<b>ACCESS III</b> <i>Chair: Josep Prat (15:50-18:00 Tuesday, July 12)</i>	<b>WAOR IV</b> <i>Chair: Piero Castoldi (16:00-17:50 Tuesday, July 12)</i>	<b>SWP VII</b> <i>Chair: Crina Cojocaru (16:10-17:50 Tuesday, July 12)</i>	<b>PICAW II</b> <i>Chair: Anatole Lupu (15:40-17:20 Tuesday, July 12)</i>	<b>PAM I</b> <i>Chair: Alex Nosich (16:10-17:50 Tuesday, July 12)</i>
16:20 Tu.D1.1 Comparison of linear and nonlinear equalization for ultra-high capacity spectral superchannels <i>(Invited)</i> <i>V. Vgenopoulou, S. Erkilinc, R. Bouziane, A. Tolmachev, M. Nazarathy, R. Killey, I. Tomkos</i>	15:50 Tu.D2.1 Do "master-slave" architectures make sense for optical interconnect? <i>(Invited)</i> <i>S. Straullu, M.S. Khalilq, V. Curri, S. Abrate</i>	16:00 Tu.D3.1 Impact of tunability and blocking fabric on optical slot switching ring performance <i>(Invited)</i> <i>N. Benzaoui, Y. Pointurier</i>	16:10 Tu.D4.1 Hybrid metal nanostructure arrays for colour printing <i>(Invited)</i> <i>K. Wilson, C.A. Marocco, E. Pedreuzza, C. Smith, A.L. Bradley</i>	15:40 Tu.D5.1 An integrated photonics reservoir computing approach to signal equalization for telecommunications <i>(Invited)</i> <i>A. Katumba, B. Schneider, J. Dambre, P. Bienstman</i>	16:10 Tu.D6.1 Site-controlled quantum dots coupled to photonic crystal cavities and waveguides <i>(Invited)</i> <i>B. Rigal, C. Jarlov, A. Lyasota, I. Kulkova, B. Dwir, A. Rudra, E. Kapon</i>
16:40 Tu.D1.2 Network savings enabled by probabilistic shaping and nonlinear compensation <i>(Invited)</i> <i>C.A.S. Diniz, M. Garrich Alabarce, D.A.A. Mello</i>	16:10 Tu.D2.2 Impact of demand uncertainty models on FTTH network design <i>(Invited)</i> <i>M. Żotkiewicz, M. Mycek</i>	16:20 Tu.D3.2 Incorporating an indicator based on modularity to improve routing in optical networks <i>(Invited)</i> <i>C.J.A. Bastos-Filho, D.R.B. Araújo, J.F. Martins-Filho</i>	16:30 Tu.D4.2 Spontaneous oxygen isotope exchange between carbon dioxide and oxygen-containing minerals (Do the minerals "breathe" CO <sub>2</sub> ?) <i>(Invited)</i> <i>S. Čiviš, A. Knížek, P. Kubelík, M. Ferus</i>	16:00 Tu.D5.2 Programmable integrated photonics for space division (de)multiplexing <i>(Invited)</i> <i>A. Melloni</i>	16:30 Tu.D6.2 Enhanced emission near an exceptional point in an asymmetric microcavity <i>(Invited)</i> <i>Kyungwon An</i>
17:00 Tu.D1.3 Perturbative discrete-time multivariate fiber channel model with finite memory <i>(Invited)</i> <i>M. Sorokina, S. Sygletos, S. Turitsyn</i>	16:30 Tu.D2.3 Wavelength agnostic WDM-PON systems <i>(Invited)</i> <i>C. Wagner, M. Eiselt, S. Zou, M. Lawin, B. Teipen, K. Grobe, J.J. Vegas Olmos, I. Tafur Monroy</i>	16:40 Tu.D3.3 Influence of the spatial super channel guard-band width on the performance of dynamic flex-grid/SDM optical core networks <i>(Invited)</i> <i>R. Rumipamba-Zambrano, J. Perelló, A. Pagès, J.M. Gené, S. Spadaro</i>	16:50 Tu.D4.3 Silver nanoparticles in titanium dioxide host plasmonic absorbers <i>(Invited)</i> <i>P. Nyga, S. Chmiel, M. Szczurek, M. Liszewska, M. Stefaniak, J. Firak, M. Michalska-Domanska, J. Mierczyk, M. Norek</i>	16:20 Tu.D5.3 Infrared emitting erbium-doped quinolines for silicon organic hybrid technology <i>(Invited)</i> <i>S. Penna, S. Di Bartolo, V. Attanasio, L. Mattiello</i>	16:50 Tu.D6.3 Rigorous model for the design of ultra-high Q-factor resonant cavities <i>(Invited)</i> <i>C. Ciminelli, F. Innone, G. Brunetti, D. Conteduca, F. Dell'Olio, T. Tatoli, M.N. Arsenise</i>
17:20 Tu.D1.4 Compensation of nonlinear distortion through frequency shift free mid-span spectral inversion using counter-propagating dual pumped FWM in fiber <i>(Invited)</i> <i>A. Anchal, P. Kumar, P. Landais</i>	16:50 Tu.D2.4 BER performance improvement in FFH-OCDMA networks with BPSK modulation format <i>(Invited)</i> <i>A.L. Sanches, T.R. Raddo, J.V. dos Reis Jr., L.H. Bonani, B.V. Borges</i>	17:00 Tu.D3.4 Recent advances in optical and hybrid packet switching <i>(Invited)</i> <i>C. Ware, W. Samoud, P. Gravey, M. Lourdiane</i>	17:10 Tu.D4.4 Lattice effects in second-harmonic generation from metasurfaces <i>(Invited)</i> <i>R. Czaplicki, A. Kiviniemi, J. Laukkanen, J. Lehtolahti, M. Kuitinen, M. Kauranen</i>	16:40 Tu.D5.4 Electrical switching in hybrid VO <sub>2</sub> /Si photonic structures <i>(Invited)</i> <i>L.D. Sánchez, A. Rosa, T. Angelova, J. Hurtado, A. Griol, P. Sanchis, M. Menghini, P. Homm, B. van Blizen, A. Brown, J-P. Locquet, L. Zimmermann</i>	17:10 Tu.D6.4 Optimising fibre-tip microcavities with Gaussian-shaped mirrors for quantum networks <i>(Invited)</i> <i>N. Podoliak, H. Takahashi, M. Keller, P. Horak</i>
17:40 Tu.D1.5 Evaluation of the impact of spatial and spectral granularities on the performance of spatial superchannel switching schemes <i>(Invited)</i> <i>B. Shariati, D. Klionidis, J.M. Rivas-Moscoco, I. Tomkos</i>	17:10 Tu.D2.5 Design of flexible udWDM metro-access network devices assisted by high resolution complex spectroscopy <i>(Invited)</i> <i>J.A. Altabas, D. Izquierdo, A. Pascual, S. Sarmiento, J.A. Lazaro, I. Garces, A. Villafranca</i>	17:20 Tu.D3.5 Performances of all optical logical gates for packet forwarding <i>R. Farhat, A. Farhat, M. Menif</i>	17:30 Tu.D4.5 Subwavelength optics with hyperbolic metamaterials: Waveguides, scattering, and optical topological transitions <i>(Invited)</i> <i>S. Ishii, V.E. Babicheva, M.Y. Shalaginov, A. Boitasseva, A.V. Kildishev, E. Narimanov</i>	17:00 Tu.D5.5 Integrated optics on single-crystal lithium niobate thin film: Some recent progress <i>(Invited)</i> <i>Lutong Cai, Huangpu Han, Shuang Li, Hul Hu</i>	17:30 Tu.D6.5 Ultra-long photon lifetime in a slow-light microcavity <i>(Invited)</i> <i>V. Huet, P. Guillemé, M. Mortier, Y. Dumeige, P. Féron</i>

- 10:40 **Th.B1.2** Evaluation of the hybrid FTTx/VDSL2-vectoring approach in an access network (*Invited*)  
*V. Attanasio, A. Valenti, F. Persia, A. Rufini, S. Penna, D. Del Buono, G. Verticale, G. Maier*
- 11:00 **Th.B2.2** Dispersion and off-set filtering in RSOA based networks (*Invited*)  
*E. Udvary, Á. Schranz, B. Matolcsy*
- 10:30 **Th.B3.2** Optimal sustainable management of backbone networks (*Invited*)  
*L. Amorosi, L. Chiaraviglio, P. Dell'Olmo, M. Listanti*
- 10:40 **Th.B4.2** The ACTION project: Application Coordinating with Transport, IP and Optical Networks (*Invited*)  
*N. Yamanaka, S. Okamoto, Y. Imakiire, M. Arase, E. Oki, M. Veeraghavan*
- 10:50 **Th.B5.2** The Hi-Ring architecture for datacentre networks (*Invited*)  
*M. Gallii, V. Kamchevska, Yunhong Ding, L.K. Oxenløwe*
- 10:50 **Th.B6.2** Novel nanomaterial-based saturable absorbers for ultrashort-pulsed mid-infrared waveguide chip lasers (*Invited*)  
*A. Fuerbach, X. Jiang, S. Gross, H. Zhang, Z. Guo, F. Rotermund, D. Yeom, M.J. Withford*
- 11:00 **Th.B1.3** Open FTTH networks and digital home-care services: Experiences from the Connected for Health project (*Invited*)  
*M. Forzati*
- 11:20 **Th.B2.3** Frequency invariance in a new allocation scheme for optical communications (*Invited*)  
*J. Ladvánszky*
- 10:50 **Th.B3.3** Server-centric PON data center architecture (*Invited*)  
*A. Hammadi, T.E.H. El-Gorashi, M.O.I. Musa, J.M.H. Elmirghani*
- 11:00 **Th.B4.3** Dynamic operation of an IP/MPLS-over-WDM network using an open-source active stateful BGP-LS-enabled multilayer PCE (*Invited*)  
*J.-L. Izquierdo-Zaragoza, J.-J. Pedreno-Manresa, P. Pavon-Marino, Ó. González de Dios, V. López*
- 11:10 **Th.B5.3** Ring versus bus topology: A network performance comparison of photonic integrated NoC (*Invited*)  
*I. Cerutti, A.M. Behredin, N. Andrioli, O. Liboiron Ladouceur, P. Castoldi*
- 11:10 **Th.B6.3** Materials approaches to mitigating parasitic effects in optical networks: Towards the perfect optical fiber (*Invited*)  
*J. Ballato, P. Dragic*
- 11:20 **Th.B1.4** Technical and market feasibility of high-speed software-reconfigurable OOFDM/DFMA-based optical transceivers for next generation access network PONs (*Invited*)  
*R.M. Dorward, M.J. Anderson, R.P. Giddings*
- 11:40 **Th.B2.4** Experimental comparison of simultaneous transmission of LTE A multi band and Gigabit/s 4 PAM signals up to 50 m of large core graded-index POF  
*F. Fomi, Y. Shi, H.P.A. van den Boom, E. Tangdionga, A.M.J. Koonen*
- 11:10 **Th.B3.4** Energy efficient resource provisioning with VM migration heuristic for disaggregated server design (*Invited*)  
*H.M.M. Ali, A.M. Al-Salim, A.Q. Lawey, T. El-Gorashi, J.M.H. Elmirghani*
- 11:20 **Th.B4.4** Network and datacenter resource orchestration strategies for mobile virtual networks over telco clouds (*Invited*)  
*B. Martini, M. Gharbaoui, I. Cerutti, P. Castoldi*
- 11:30 **Th.B5.4** Machine learning based adaptive flow classification for optically interconnected data centers (*Invited*)  
*N. Viljoen, H. Rastegarfar, Mingwei Yang, J. Wissinger, M. Gilck*
- 11:30 **Th.B6.4** The use of ion beam techniques for the fabrication of integrated optical elements (*Invited*)  
*I. Bányász, S. Berneschi, M. Fried, V. Havranek, N.Q. Khanh, G.U.L. Nagy, A. Németh, G. Nunzi-Conti, S. Pelli, I. Rajta, C. Righini, E. Szilágyi, M. Veres, Z. Zolnai*
- 11:40 **Th.B1.5** Low-cost 100 Gbps transport solution based on DCO-CFP and G.657.A2 fibre for long-haul WDM transmission (*Invited*)  
*E. Pincemin, Mengdi Song, Y. Loussouarn, T. Guilloussou, N. Evanno, F. Lissillour, L.-A. de Montmorillon, P. Sillard*
- 11:30 **Th.B3.5** Energy-efficient software-defined AWGR-based PON data center network  
*A. Hammadi, T.E.H. El-Gorashi, J.M.H. Elmirghani*
- 11:50 **Th.B5.5** Greening big data networks: Volume impact  
*A.M. Al-Salim, H.M.M. Ali, A.Q. Lawey, T. El-Gorashi, J.M.H. Elmirghani*
- 11:50 **Th.B6.5** Concentration dependence of the infrared photoluminescence of Pr<sup>3+</sup> in fluorindate glasses (*Invited*)  
*S.J.L. Ribeiro, G. Galleani, L. Fortes, D. Manzani, R.A.S. Ferreira, L.D. Carlos*
- 12:00 **Th.B1.6** Impact of node/fiber/WSS degrees in creating cost effective OXCs (*Invited*)  
*Ken-ichi Sato*
- 11:45 **Th.B3.6** A framework for energy efficient NFV in 5G networks  
*A. Al-Quzweeni, A. Lawey, T. El-Gorashi, J.M.H. Elmirghani*
- 12:00 **Th.B3.7** Network coding for energy efficiency in bypass IP/VDM networks  
*M.O.I. Musa, T.E.H. El-Gorashi, J.M.H. Elmirghani*

**PLENARY (Thursday, July 14, 12:30-12:50) Auditorium**12:30 **Th.C.1** Challenges and future trends in fiber lasers (*Invited*)

**Stefano Taccheo, K. Schuster, M. Ferrari, A. Seddon, M. Marciniak, C. Taudt, J. Troles, G. Valentini, D. Dorosz, F. Prudenzeno, M. Jaeger, C. Dandrea, M. Ivanda, A. Chiasera, S. Sujecki, V. Nazabal, D. Comelli, H. Baghdasaryan, T. Baselt, P. Hartmann, A. Lucianetti, P. Peterka, A. Klotzbach, J.L. Adam, and H. Gebavi**

(Thursday, July 14, 12:50) Closing Ceremony and Announcement of ICTON 2017 Auditorium

13:10 **Lunch**