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Tuesday, April 16

14:30 - 16:15

S1: Opening Session

Chair: Philippe Gravey (Télécom Bretagne, France)

14:30 ***Photonic Network Vision 2020 in Big Data Era (Keynote Speech)***
Ken'ichi Kitayama (Osaka University, Japan)
Data on this globe have been exploding, and the analysis of large datasets, so-called big data create value in various ways and will become a key basis of competition, underpinning new waves of productivity growth, innovation, and a precise market research. Trillions of bytes of information are captured from networked sensors such as mobile phones, smart meters, automobile, and industrial machines, and they are analyzed by the power of cloud computing on a global scale. The capture and post-processing of big data will fuel exponential growth in data volume in 2020. "One-globe photonic cloud," photonic L2 network serves as the platform for cloud computing, connecting mega data centers around the world. One-globe photonic cloud features abundant and elastic bandwidth and the minimum latency, distinct from legacy cloud computing. The photonic L2 network will leverage on software defined networking principles of photonic network virtualization as well as elastic optical circuit and packet switching technologies. One of the key enabling engines will be a photonic network processor, based upon powerful DSP and optical interconnect.

15:15 ***ChoiceNet: Network Innovation Through Choice***
George N. Rouskas (North Carolina State University, USA); Ilia Baldine (RENCI (Renaissance Computing Institute) & UNC Chapel Hill, USA); Ken Calvert (University of Kentucky, USA); Rudra Dutta (North Carolina State University, USA); James Griffioen (University of Kentucky, USA); Anna Nagurney (University of Massachusetts, USA); Tilman Wolf (University of Massachusetts, USA)
Computer networks, in particular the Internet, represent essential infrastructure for business, government, military, and

personal communication. Several recent trends in technology and network use have pushed the capabilities required of the Internet beyond what can be provided by the currently deployed infrastructure. To address these limitations, the network community has developed a variety of technologies to adapt the functionality of network protocols and services. A critical question that remains unanswered is how to integrate these technologies into an ecosystem that involves users, service providers, and developers in such a way that new ideas can be deployed and used in practice. In this work, we discuss how to design a network architecture where choices at different layers of the protocol stack are explicitly exposed to users. Our ChoiceNet system is based on three tightly coupled principles in that it aims to (1) encourage alternatives to allow users to choose among a range of services, (2) let users vote with their wallet to reward superior and innovative services, and (3) provide the mechanisms to stay informed on available alternatives and their performance. This approach ensures that innovative technical solutions can be used and rewarded, which is essential to enourage wide deployment of this architecture. Overall, our work does not aim at reinventing technical solutions to networking problems, but at developing a comprehensive system where these solutions can be deployed and compete to allow the network to adapt to current and future challenges.

15:45 ***The Network Capacity Benefits of Flexgrid***

Paul Wright (BT plc, United Kingdom); Andrew Lord (British Telecom, United Kingdom); Luis Velasco (Universitat Politècnica de Catalunya (UPC), Spain)

Wavelength Division Multiplexing (WDM) networks of the future are likely to use Flexgrid, providing operators with additional flexibility when assigning spectrum compared to traditional WDM networks using the 50GHz ITU grid. Flexgrid breaks the spectrum up into small (typically 12.5GHz) slots, but its key feature is that contiguous slots can be joined together to form arbitrary sized blocks of spectrum. This additional flexibility will allow faster transponders that utilise high spectral efficiency modulation techniques, but no longer fit within a 50GHz slot due to their larger spectral width requirements, to be carried by the optical network. From the use of these new spectrum efficient modulation formats and finer control over spectrum allocations, a key benefit that Flexgrid offers network operators is that their WDM networks can carry more traffic. This paper will look at the capacity improvements that can be realised on a WDM network that is using Flexgrid over those that are using a traditional fixed grid.

16:45 - 18:40

S2: Special session on Data Centres

Chair: Josep Solé-Pareta (UPC, Spain)

16:45 ***Five Resource Allocation Strategies for the Cloud Infrastructure***

Xue Wang (The University of Texas at Dallas, USA); Miguel Razo (University of Texas at Dallas & Computer Science, USA); Marco Tacca (University of Texas at Dallas, USA); Ning So (University of Texas at Dallas, USA); Andrea Fumagalli (UTD, USA)

As both cloud applications and infrastructure technologies become more advanced, there is a general expectation that cloud based applications are going to experience improved end-to-end performance assurance while maintaining a competitive cost of service. In this paper, the authors continue to explore the potential performance and cost advantages, which may originate when applying joint optimization resource allocation strategies to the cloud infrastructure in the presence of dynamic application requests. Five resource allocation strategies are defined and compared to estimate relative performance gains in a number of resource (network bandwidth, data center CPU, memory and storage) distribution scenarios

17:15 ***Optical interconnection networks for data centers***

Christoforos Kachris (Athens Information Technology & Democritus University of Thrace, Greece)

The rise of cloud computing and other emerging web applications has increased significantly the network traffic inside the data centers. In this paper we present the future requirements of data centers such the need for higher bandwidth and the need for more energy-efficient interconnection network inside the data centers. This need comes both from the exponential rise of the network traffic inside the data centers and the limitations of the power consumption in the data center infrastructures. Furthermore, in this paper we discuss the rise of optical interconnection network for data centers that have been proposed in the research literature to address the limitation of the current interconnects. We present the main benefits and drawbacks of each proposed scheme and finally we discuss the research directions in the domain of optical interconnects for data centers.

17:45 ***On The Architectural Considerations of the FISSION (Flexible Interconnection of Scalable Systems Integrated using Optical Networks) Framework for Data-Centers***

Ashwin A Gumaste (Indian Institute of Technology, Bombay, India); Bala Murali Krishna Bheri (Indian Institute of Technology, Bombay, India)

We have proposed the FISSION (Flexible Interconnection of Scalable Systems Integrated using Optical Networks) architecture for data-centers in [1]. The Fission architecture comprises of the creation of sectors that comprise of server systems and switches are backplane wired up using optical buses. These optical buses deploy ultra-dense wavelength division multiplexing (UDWDM). A modified Carrier Ethernet system provides protocol connectivity within the data-center that scales to support beyond a million servers. We delve into the architectural and protocol aspects of the Fission concept, particularly focusing on its scalability, working, wavelength-assignment and protection issues. The working of the Fission concept is further explained through numerical results achieved through rigorous simulation.

Wednesday, April 17

09:30 - 11:00

S3: Energy efficiency of optical networks 1

Chair: Esther Le Rouzic (Orange Labs, France)

09:30 ***Traffic variation-aware networking for energy efficient optical communications***

Annalisa Morea (Alcatel-Lucent, France); Jordi Perelló (Universitat Politècnica de Catalunya (UPC), Spain); Salvatore Spadaro (Universitat Politecnica de Catalunya (UPC), Spain)

"Traffic-aware" networking is a promising solution allowing the improvement of the energy efficiency of optical networks. It is based on adapting the number of fully powered systems to the amount of actual carried traffic. Various traffic-aware schemes have been proposed; some acting at optical link level, others at node level by managing the power state of the the optoelectronic (OE) devices. In this paper we introduce the parameter ρ as a tool to measure the energy savings introduced by a "traffic-aware" scheme. Such energy savings are measured by considering the maximum power required to transport the peak traffic and the average power required by the network to transport the traffic during a defined time-frame (e.g. day, week); the higher the ρ-parameter is, the more energy-efficient the "traffic-aware" solution is. The ρ-parameter is calculated by considering three different strategies, acting separately and/or jointly over links and OE-devices; such strategies are compared with ρ-parameter and also discussed in terms of the complexity of the management implementation and network resiliency.

10:00 ***Stochastic Service Provisioning in Converged Optical Data Center Networks and Smart Grids***

Markos P. Anastasopoulos (Athens Information Technology, Greece); Anna Tzanakaki (AIT, Greece); Dimitra Simeonidou (University of Bristol, United Kingdom)

The stochastic nature and power fluctuations of renewable energy sources are two major parameters affecting the stability of the power grid. Traditionally, this issue has been addressed through energy storage elements i.e. batteries, having the disadvantages of increased cost and limited operational lifetime. In this paper, it is argued that a cost effective solution to this problem is to orchestrate the operation of Optical Data Center networks and Power Grids. To this end, a novel formulation based on Stochastic Linear Programming that considers jointly the Stochastic Service Provisioning Problem in the Optical Data Center networks and the Continuation Power Flow problem in the Power Grids, is presented. The proposed scheme takes into account both the time variability and uncertainty of cloud services as well the stochastic nature of renewable energy sources. Our modeling results illustrate interesting trade-offs between the stability of the smart grid, the power consumption of the converged optical datacenter networks as well as the utilization of the infrastructure resources.

10:20 ***Evaluation of Centralized Solution Methods for the Dynamic Optical Bypassing Problem***

Frank Feller (University of Stuttgart, Germany)

Due to increasing traffic volumes and access bandwidths, the power consumption of core networks will grow considerably. Adapting network configuration to traffic load is one counter-measure. Dynamic optical bypassing is a promising approach to reconfigure multi-layer networks: it adapts the virtual topology while keeping traffic on fixed paths in the physical topology. So far, research focused on distributed bypassing schemes. In this paper, we evaluate three centralized solution methods for the bypassing problem: one based on linear programming, one based on heuristic optimization, and a greedy heuristic. We find that all methods can achieve similar energy savings while limiting changes to the network configuration.

10:40 ***On the Design of Energy Efficient Optical Networks with Software Defined Networking Control Across Core and Access Networks***

Jiayuan Wang (Technical University of Denmark, Denmark); Ying Yan (Technical University of Denmark, Denmark); Lars Dittmann (Technical University of Denmark, Denmark)

This paper presents a Software Defined Networking (SDN) control plane based on an overlay GMPLS control model. The SDN control platform manages optical core networks (WDM/DWDM networks) and the associated access networks (GPON networks), which makes it possible to gather global information and enable wider areas' energy efficiency networking. The energy related information of the networks and the types of the traffic flows are collected and utilized for the end-to-end QoS provision. Dynamic network simulation results show that by applying different routing algorithms according to the type of traffic in the core networks, the energy efficiency of the network is improved without compromising the quality of service.

11:30 - 13:00

S4: Network design algorithms

Chair: Bernard Cousin (University of Rennes 1 & IRISA Research Laboratory, France)

11:30 ***Operation research tools and methodology for the design and provisioning of survivable optical networks***

Brigitte Jaumard (Concordia University, Canada)

While the design and the provisioning of survivable optical networks have already been studied for a long time, networks across the world are still experiencing a phenomenal growth in data traffic, leading to more complex design and provisioning problems. Network architectures are changing rapidly to meet the new end-user requirements, with many new technological developments and new economical/environmental concerns such as, e.g., network virtualization, anycast routing, elastic networking, energy minimization. While operational research methods have made significant progress over the last 20 years, not much has been done in order to use the full potential of these developments in managing more efficiently communication networks, while, in other areas of applications, they have been used to solve efficiently very large/huge scale optimization problems, e.g., in the transport industry or in financial engineering or in industrial location. This paper gives an overview of some of the developments in solving some optimization problems arising in the design of optical networks or grids. In terms of optimization techniques, we will focus on decomposition techniques, and will discuss their recent success for the protection of optical networks, and of virtual networks built upon optical networks/grids.

12:00 ***Link Selection Algorithms for Link-Based ILPs and Applications to RWA in Mesh Networks***

Zeyu Liu (North Carolina State University, USA); George N. Rouskas (North Carolina State University, USA)

RWA is a fundamental problem in the design and control of optical networks. We propose link selection algorithms that

reduce the size of the link-based ILP formulation for RWA by pruning redundant link decision variables. The resulting formulation scales well to mesh topologies representative of backbone and regional networks. In our experiments, the new formulation decreases the running time by more than two orders of magnitude without any impact on optimality. The link selection techniques are general in that they may be applied to any optimization problem for which the ILP formulation consists of multicommodity flow equations as its core constraints.

12:20 ***A Heuristic Algorithm for Multicast Routing in Sparse-Splitting Optical WDM Networks***

Costas Constantinou (University of Cyprus, Cyprus); Georgios Ellinas (University of Cyprus, Cyprus)

Multicast routing in optical WDM networks is investigated in the current paper in the presence of optical splitters only at a fraction of the network nodes. This work presents a novel multicast routing algorithm for sparse-splitting networks that is specifically designed for this category of networks. The proposed algorithm is compared with the most efficient multicast routing algorithms for sparse-splitting networks that are found in the literature through examples and simulations. Performance results show that the proposed approach achieves an important reduction on the average cost of the calculated multicasting trees, compared to the existing algorithms.

12:40 ***Attack-Survivable Routing and Wavelength Assignment for high-power jamming***

Marija Furdek (University of Zagreb, Croatia); Nina Skorin-Kapov (University of Zagreb, Croatia)

Transparent optical networks (TONs) are vulnerable to high-power jamming attacks aimed at service disruption by exploiting the inherent characteristics of optical fibers, amplifiers and switches. In this type of attack, a high-power jamming signal is injected in the network to degrade the quality of legitimate user signals. Conventional survivability approaches which protect transmission in occurrences of component faults might not provide protection from attacks as the working and the backup path of a connection might both be within the reach of the attacking signal. In this paper, we propose a novel concept of identifying a so-called Attack Group (AG) of each lightpath and develop a dedicated path protection approach which ensures that the primary and the backup path of each connection be attack group disjoint, i.e., not within the reach of a same potential attacker. Furthermore, the proposed attack-survivable routing and wavelength assignment is aimed at reducing the maximum potential damage from these attacks, measured by an objective criterion called Attack Radius (AR), as well as minimizing the number of used wavelengths to be resource-effective. In comparison with generic dedicated path protection without attack awareness, the proposed approach shows an immense enhancement of network survivability in the presence of attacks at a small trade-off of increased wavelength usage.

14:15 - 15:00

S5: Keynote talk 2

Chair: Ken'ichi Kitayama (Osaka University, Japan)

14:15 ***Towards Green and Convergent Broadband Networks***

Stéphane Gosselin (Orange Labs, France)

Information and Communication technologies, although representing 2 to 4% of the worldwide carbon footprint, should allow a reduction by 15% of this global carbon footprint by 2020. But they also result in ever increasing volumes of data traffic and the need for increasingly powerful and energy hungry fixed and mobile broadband networks. Decreasing energy consumption of these networks while steeply increasing their overall capacity is a real challenge that has been addressed for several years. In 2009 for example, the worldwide volume of mobile data traffic exceeded that of voice traffic. As wireless technologies consume more power than wireline technologies for given access rates and traffic volumes, improving the energy efficiency of mobile networks is a key issue. At the same time, making fixed and mobile networks converge is a desirable though very complex target for network operators. Better integration of fixed and mobile networks would result in both an optimal and seamless quality of experience for the end user together with an optimized network infrastructure ensuring increased performance, reduced cost and also reduced energy consumption. As energy efficiency of equipment is of course essential to overcome the energy challenge of broadband networks, this presentation will instead focus on the potential green benefits of converged fixed and mobile network architectures. Various architectural aspects of converged fixed and mobile networks will be addressed and their potential benefits will be commented

15:00 - 18:00

W1: OASE Workshop

Thursday, April 18

09:30 - 11:00

S6: Packet and circuit switched optical networks 1

Chair: Bernard Cousin (University of Rennes 1 & IRISA Research Laboratory, France)

09:30 ***Optical Packet and Circuit Integrated Networks***

Hiroaki Harai (National Institute of Information and Communications Technology, Japan)

An optical packet and circuit integrated (OPCI) network provides both high-speed, inexpensive services and deterministic-delay, low-data-loss services according to the users' usage scenarios, from the viewpoint of end users. From the viewpoint of network service providers, this network provides large switching capacity with low energy requirements, high flexibility, and efficient resource utilization with a simple control mechanism. This paper presents the recent progress made in the development of an OPCI network. We have developed OPCI nodes which are capable of layer 3 switching from/to Ethernet frame to/from optical packet in the optical packet edge part and burst-tolerant

optical amplifier and optical buffer with optical fiber delays in 100Gbps optical packet switching part. The OPCI node achieves a packet error rate less than 1e-4 and is used as node in a lab-network has an access to the Internet. A distributed automatic control works in a control plane for the circuit switching part. An address search engine for further power reduction and network management system for shifting from R&D to operation are also described.

10:00 ***Stable Optimal Design of an Optical Packet Ring with Tunable Transmitters and Fixed Receivers***

Bogdan Uscumlic (Telecom Bretagne, France); Annie Gravey (Institut Mines Telecom - Telecom Bretagne, France); Isabella Cerutti (Scuola Superiore Sant'Anna, Italy); Philippe Gravey (Télécom Bretagne, France); Michel Morvan (Telecom Bretagne, France)

Optical packet switching is known to leverage the statistical multiplexing in optical networks, but in turn it may cause stability issues at the input queues containing packets waiting for transmission. Stability issues need to be addressed by a proper scheduling of the packet transmissions and dimensioning of the network. This paper aims to address the problem of dimensioning an optical packet switched ring with stability guarantees. In such a ring, the stability issues occur because a single tunable transmitter can insert the locally generated packets on different wavelengths. The necessary and sufficient stability conditions derived for a class of scheduling policy are identified, linearized and included in the mixed linear programming formulation that models the dimensioning problem. Optimal results show that neglecting the stability conditions may lead to more than 50% of the design to be unstable. To guarantee stability in such design, a 20% increase of the network cost may be required mainly for the additional wavelengths.

10:22 ***A novel approach in modeling multi-service optical packet switched networks with the preemptive drop policy***

Shuna Yang (ITEM, Norwegian University of Science and Technology, Norway); Norvald Stol (Norwegian University of Science and Technology, Norway); Harald Øverby (Norwegian University of Science and Technology, Norway)

This paper investigates packet loss in multi-service Optical Packet Switched (OPS) networks, in which the Preemptive Drop Policy (PDP) is adopted to implement QoS differentiation. A novel approximation model is proposed. In contrast with existing multi-dimensional Markov model, which focuses on analyzing the small system with only two service classes and results in non-closed form expressions of the packet loss ratios (PLRs), our model has four major advantages: 1) it is applicable to analyzing a general multi-service scenario, independent of the number of service classes and wavelengths; 2) the closed form expressions of the PLRs can be derived directly; 3) the computational complexity is reduced dramatically; 4) this model shows excellent extensibility for analyzing larger system which supports more service classes or wavelength channels per fiber. The analytical values are compared with simulation results for a three-service OPS network. Results show that the proposed model provides a high degree of accuracy in the PLRs under different network scenarios.

10:42 ***Electronic architectures of optical slot switching nodes***

Nihel Benzaoui (Alcatel-Lucent Bell Labs France, France); Yvan Pointurier (Alcatel-Lucent Bell Labs, France); Jean-Christophe Antona (Alcatel-Lucent, France)

An optical slot switching node network called POADM (packet optical add-drop multiplexers) has formerly been proposed as a flexible solution for metropolitan ring networks to carry data traffic with a sub-wavelength switching granularity and with a good energy efficiency, which is enabled by optical transparency. In this paper, we propose several architectures for the electronic side of optical slot switching nodes. Those architectures increase the flexibility with which a client, attached to a node, can access the transport medium, through the addition of electronic switches, working either at client frame granularity or at slot granularity (a slot encapsulates several client frames); such electronic switches can be located at either transmitter, receiver, or both sides of a node, thereby decreasing traffic latency, at the expense of increased node cost and/or energy consumption. This paper focuses on the latency aspect only. We assess and compare the latency of these node architectures with simulations; some results are also backed analytically. The utilization of an (electronic) slot switch enables load balancing across the transport channels, while the node architecture with an (electronic) client frame switch additionally permits flow aggregation, resulting in lower queuing delay. The lowest queuing delay is achieved by the architecture embedding client frame switches at both transmitter (Tx) and receiver (Rx) sides, while the absence of electrical switches leads to the worst performance, but presents the advantage of lower cost and consumption with respect to the other architectures. The utilization of client frame switches at Tx or Rx presents intermediate performances.

11:30 - 12:55

S7: Optical network protection

Chair: Massimo Tornatore (Politecnico di Milano & University of California, Davis, Italy)

11:30 ***Panorama of Optical Network Survivability***

Biswanath Mukherjee (University of California, Davis, USA)

This talk will mainly focus on the emerging topic of an optical telecom backbone network's adaptability from disaster disruptions and cascading failures. But, for the sake of completeness, the first few minutes of the talk will be devoted to review the traditional topics on optical network survivability (such as mesh protection and restoration, differentiated protection, availability-aware protection, holding-time-aware protection, reprovisioning, grooming and protection, partial protection, etc.) We will spend a few more minutes on newer topics such as survivability of Virtual Private Networks (VPNs), exploiting the excess capacity in an operational network for improved survivability, etc. Then, the majority of our time will be used to discuss disaster survivability, where we will cover topics such as: (1) Normal Disaster Preparedness (by accounting for risk of disasters in different parts of the infrastructure); (2) Enhanced Disaster Preparedness (under more-accurate intelligence on potential disasters); and (3) Post-Disaster Service Survivability (by employing concepts such as partial protection and degraded services). Note that, while traditional approaches focus on protecting links and nodes (routers, switches, etc.) to provide "network connectivity", the shifting paradigm towards cloud computing/storage require that we protect the data (or content), so we have developed the concept of "content connectivity" and methods to achieve this.

12:15 ***Distributed Design and Provisioning of Survivable Multi-Domain Optical Networks***

Brigitte Jaumard (Concordia University, Canada); Kien Do Trung (Universite de Montreal, Canada)

Providing protection in multi-domain optical networks amounts to ensuring protection for the inter-domain links. Due to

scalability issues, almost all previous studies focused on heuristics. In this study, under the assumption of a distributed network management, we propose a large scale optimization ILP model allowing to obtain exact solutions with various traffic instances, on a network with 10 domains. The model relies on p-cycles in order to protect the inter-domain links, and on FIPP p-cycles for the segment/path protection in each individual domain. Virtual links that connect the inter-domain links in the p-cycles, are protected by FIPP p-cycles, in each domain. Experiments were successfully conducted on a multi-domain network with 10 domains. They include a comparison of bandwidth requirements between the proposed distributed scheme and a centralized scheme.

12:35 ***Disaster-Resilient Virtual-Network Mapping and Adaptation in Optical Networks***

Carlos Colman Meixner (University of California, Davis, USA); Ferhat Dikbiyik (U. C. Davis, USA); Massimo Tornatore (Politecnico di Milano & University of California, Davis, Italy); Chen-Nee Chuah (University of California, Davis, USA); Biswanath Mukherjee (University of California, Davis, USA)

Today's Internet applications include grid- and cloud-computing services which can be implemented by mapping virtual networks (VNs) over physical infrastructure such as an optical network. VN mapping is a resource-allocation problem where fractions of the resources (e.g., bandwidth and processing) in the physical infrastructure (e.g., optical network and servers/data-centers) are provisioned for specific applications. Researchers have been studying the survivable VN mapping (SVNM) problem against single-physical-link/node failure (typically by deterministic failure models), because this type of failure may disconnect one or more VNs, and/or reduce their capacities. However, disasters can cause multiple link/node failures which may disconnect many VNs and dramatically increase post-disaster vulnerabilities for a single-physical-link failure. Hence, we investigate the disaster-resilient and post-disaster-survivable VN mapping problem using a probabilistic model to reduce the expected VN disconnections and capacity loss, while providing an adaptation to minimize VN disconnections by a post-disaster failure. We model the problem as an integer linear program (ILP). Numerical examples show that our approach reduces VN disconnections and the expected capacity loss after a disaster and post-disasters failure.

14:00 - 15:30

P: Poster session

14:00 ***A Proposal of Burst Cloning for Video Quality Improvement in Optical Burst Switching Networks***

Felix Espina (Universidad Publica de Navarra, Spain); Daniel Morato (Universidad Publica de Navarra, Spain); Mikel Izal (Public University of Navarra (UPNA), Spain); Eduardo Magaña (Universidad Publica de Navarra, Spain)

This paper presents two novel cloning schemes for video delivery in Optical Burst Switching Networks. These schemes take into account the special characteristics of compressed video traffic and dramatically improve received video quality. Analytical and simulation results show up to 40% quality improvement without a substantial increase in the overall network traffic. The results show the strong dependency of these novel cloning schemes on the video traffic structure due to the coding mechanisms. Rules based on the GoP structure are presented to decide the frames to clone.

14:05 ***Stateless security filtering of optical data signals: an approach based on code words***

Maha Sliti (Communication Networks and Security Research Lab., Tunisia); Noureddine A. Boudriga (University of Carthage, Tunisia)

In this paper, we propose an optical stateless filtering architecture which allows the traffic filtering at the optical layer. Indeed, each traffic stream will be identified by a unique identifier composed of a set of code words. In the core node, a set of optical filtering rules will be applied to this traffic stream based on its corresponding identifier in order to accept or reject the traffic stream. The stateless filtering process is based on the logical comparison between the received traffic identifier and the optical filtering signal which are composed of a set of code words. The proposed architecture is composed by two main components. The first component is an encoder implemented in the edge node, which generates traffic stream identifiers. And, the second component is the optical stateless filtering module which is implemented in the core node.

14:10 ***Multicast Provision in Transparent Optical Networks with Mixed Line Rates***

Fen Zhou (University of Avignon, France)

The Elastic Optical Network is attractive for its flexibility in providing diverse line rates. We study the multicast provisioning problem in transparent optical networks with Mixed Line Rates. For each multicast session, light-trees with different line rates are used to route the traffic demands. We aim at minimizing the joint cost of transponders and wavelength channels in the light-trees for routing multicast sessions. However, different line rates are subject to different maximum transmission reaches. Besides, the line rate selection, routing and wavelength assignment problems should be resolved simultaneously, what makes light-tree optimization complicate. In light of this, we formulate the multicast provisioning problem as a Mixed Integer Linear Programming (MILP). Simulation results validate our model and show that both the transponder cost and the wavelength channel cost can be saved by flexibly using the combination of mixed line rates for provisioning multicast communications.

14:15 ***Area and Laser Power Scalability Analysis in Photonic Networks-on-Chip***

Sergi Abadal (Universitat Politècnica de Catalunya & Nanonetworking Center in Catalonia, Spain); Albert Cabellos-Aparicio (Universitat Politècnica de Catalunya, Spain); Jose A Lazaro (Universitat Politècnica de Catalunya (UPC), Spain); Mario Nemirovsky (ICREA Research at CNS - BSC & Barcelona Supercomputing Center, Spain); Eduard Alarcon (Technical University of Catalunya, Spain); Josep Solé-Pareta (UPC, Spain)

In the last decade, the field of microprocessor architecture has seen the rise of multicore processors, which consist of the interconnection of a set of independent processing units or cores in the same chip. As the number of cores per multiprocessor increases, the bandwidth and energy requirements for their interconnection networks grow exponentially and it is expected that conventional on-chip wires will not be able to meet such demands. Alternatively, nanophotonics has been regarded as a strong candidate for chip communication since it could provide high bandwidth with low area and energy footprints. However, issues such as the unavailability of efficient on-chip light sources or the difficulty of implementing all-optical buffering or header processing hinder the development of scalable photonic on-chip networks.

In this paper, the area and laser power of several photonic on-chip network proposals is analytically modeled and its scalability is evaluated. Also, a graphene-based hybrid wireless/optical-wired approach is presented, aiming at enabling end-to-end photonic on-chip networks to scale beyond thousands of cores.

14:21 ***Enhancement of an Optical Burst Switch with Shared Electronic Buffers***

Pierre Delesques (Mitsubishi Electric R&D Centre Europe, France); Thomas Bonald (Telecom ParisTech, France); Gwillerm Froc (Mitsubishi Electric R&D Centre Europe, France); Philippe Ciblat (Telecom ParisTech, France); Cedric Ware (Institut Mines-Télécom, Télécom ParisTech, CNRS LTCI, France)

Future data networks face an energy consumption challenge: traffic grows exponentially, but the energy cost per bit in electronic routers and switches does not decrease so fast. All-optical switching techniques have not delivered a solution to this problem: despite their requiring fewer energetically-costly optical-to-electronic conversions, they suffer from poor contention handling even at low network loads, thus needing heavy overprovisioning, which negates the energy savings achieved in the first place. This contention issue largely stems from the lack of sufficiently-mature optical buffers. Thus a proposition of hybrid switch architecture supplementing optical switching with an electronic buffer. We analyze such a hybrid switch in terms of loss probability and sustainable load. Simulations and an Engset-type analytical model both find significant performance improvements for relatively few electronic ports to/from the buffer. The highest gains are shown when few channels are available per destination. Moreover, we note that traffic re-emitted from the buffer is a major cause of unnecessary buffering and secondary collisions. An adjustment to the re-emission policy is found to mitigate such collisions and offer slight gains on the sustainable load.

14:26 ***Protecting Real-Time Traffic Service in a 3-LIHON Hybrid Node***

Alvaro Fernandez (Norwegian University of Science and Technology & University of Valladolid, Norway); Michele Savi (Norwegian University of Science and Technology, Norway); Norvald Stol (Norwegian University of Science and Technology, Norway)

Recently a new hybrid optical network, integrating circuit and packet transport services has been proposed. This network, called 3-Level Integrated Hybrid Optical Network (3- LIHON), provides different transport services for guaranteed, real-time, and best-effort traffic. This article proposes a protection mechanism for the real-time traffic in the 3-LIHON network. Indeed real-time traffic carries a small but important portion of the traffic, i.e. control traffic. The proposed scheme exploits the redundancy provided by 3-LIHON nodes, thus not requiring additional hardware, representing a cost-efficient solution. The availability achieved by this protection scheme is assessed by means of structural models, and a sensitivity analysis is performed. Simulation results measuring the real-time and best-effort traffic delays, obtained with the protection method, are presented and evaluated. The effectiveness of the mechanism is demonstrated, since the delay experienced by real-time traffic is below required limits. Also the delay for best-effort traffic is not really affected by the application of the protection mechanism.

14:31 ***Sharing Wavelength Converters in Optical Switching Fabrics: When, How, and Which Kind of?***

Michele Savi (Norwegian University of Science and Technology, Norway); Harald Øverby (Norwegian University of Science and Technology, Norway); Norvald Stol (Norwegian University of Science and Technology, Norway); Carla Raffaelli (University of Bologna, Italy)

In this paper a parametric cost model is applied to compare switching fabrics sharing a reduced number of fixed/tunable wavelength converters with a fully equipped architecture. This cost model allows to understand in which switch configuration a sharing scheme leads to effective cost reduction, according to the cost parameters. Sample results show how sharing wavelength converters is not always the best choice, in particular when the cost ratio between a wavelength converter and an optical gate is low. Actually sharing converters requires a relevant number of additional optical gates. The sharing leads to reduced cost when the number of fibers/wavelengths is not very high, while the fully equipped architecture is often preferable for large switch sizes. Furthermore, fixed wavelength converters lead to further cost saving in many cases.

14:37 ***A Converged Optical Wireless Architecture for Mobile Backhaul Networks***

Kostas Ramantas (University of Patras, Greece); Kyriakos Vlachos (University of Patras, Greece); Georgios Ellinas (University of Cyprus, Cyprus); Antonis Hadjiantonis (University of Nicosia & Cyprus Academic Research Institute, Cyprus)

In this work we propose a new unified PON-RAN architecture for LTE mobile backhaul networks, employing ring-based WDM PONs. The proposed architecture supports dynamic setup of virtual circuits for inter-base station communication, over a dedicated λLAN channel. The reservation mechanism is arbitrated by the OLT, which also monitors the traffic imbalances of downstream channels. The proposed architecture also supports load balancing, by dynamically reallocating and sharing the capacity of the downstream wavelengths.

14:42 ***A Thresholder for All-Optical Digitising Radio-over-Fibre Transceivers***

Ricardo Marques Ribeiro (Universidade Federal Fluminense & Laboratorio de Comunicacoes Opticas, Brazil); Frédéric Lucarz (Telecom Bretagne & Institut Mines Telecom, France); Bruno Fracasso (Télécom Bretagne, France)

This paper describes an optical Thresholder (T) intended to be part of a transmitter module for future all-optical Digitised Radio-over-Fibre (o-DRoF) transceivers. The proposed device is based on an Attenuation-Imbalanced Semiconductor Laser Amplifier Loop Mirror (AI-T-SLALOM) in self-switching regime, using the nonlinearities of a semiconductor optical amplifier. Simulations of the proposed AI-T-SLALOM have shown promising results in comparison with the use of standard optical fibre and highly nonlinear fibre alone. The newly proposed device is rather compact, optically integrable and requires much less input optical power than conventional devices (by several orders of magnitude). It provides enhanced/amplified optical RZ bits at 1550 nm wavelength window, 1.25 GHz repetition rate and 80 ps time-width.

14:47 ***WiFi Transmission in Radio-over-Fiber Systems: Performance of the IEEE 802.11n Aggregation Mechanism***

Sebastien Deronne (University of Mons, Belgium); Sébastien Bette (Faculté Polytechnique de Mons (F.P.Ms), Belgium); Véronique Moeyaert (Université de Mons (UMONS), Belgium)

Radio-over-fiber (RoF) systems use an optical network to transparently distribute radio signals from the access point to distributed remote antennas, combining the flexibility and the mobility offered by wireless networks with the capacity and the transparency of fiber-fed networks. In order to offer higher throughput, the recent IEEE 802.11n standard introduced new mechanisms at the physical and MAC layers. In this paper, we investigate the performance when the IEEE 802.11n protocol is used in a RoF architecture. We show that the aggregation mechanism provided by IEEE

802.11n limits the effect of the extra propagation delay introduced by optical fibers in RoF systems. In addition, we report that the adaptation of the slottime parameter significantly improves the frame aggregation efficiency in RoF networks.

14:53 ***A Design Algorithm for Ring Topology Centralized-Radio-Access-Network***

Naoki Agata (KDDI R&D Laboratories Inc., Japan); Akira Agata (KDDI R&D Laboratories Inc., Japan); Kosuke Nishimura (KDDI R&D Laboratories Inc. & Optical Access Network Laboratory, Japan)

To meet the rapidly increasing demand for mobile data traffic, centralized-radio-access-network (C-RAN) has been attracting attention because C-RAN architecture is expected to enable operators to decrease the implementation cost of mobile access networks. There are two possible network topologies for realizing C-RAN architecture; one is tree topology and the other is ring topology. The tree topology is widely used for optical access networks, which is known as a "passive optical network (PON)," because of its low implementation cost. However, considering network resilience against link failures, a ring network is attractive in spite of its higher implementation cost compared to that of a tree network. In this paper, we propose a novel design algorithm of the access network having the ring topology for applying to the C-RAN architecture. It can automatically design a ring network having low construction cost, by shortening the total cable construction length, under realistic restrictions.

14:58 ***Protection Algorithms for Groupcast Sessions in Transparent Optical Networks with Mesh Topologies***

Tania Panayiotou (University of Cyprus, Cyprus); Georgios Ellinas (University of Cyprus, Cyprus); Neo Antoniades (College of Staten Island, USA)

Next-generation networks are expected to support traffic that will be heterogeneous in nature with bandwidth-intensive unicast, multicast, and groupcast applications. This paper presents two novel heuristic algorithms, namely Cycle-for-two (CFT) and Tree-for-two (TFT), for protecting groupcast sessions in mesh optical networks. The proposed schemes outperform other protection techniques that are mainly extensions of known multicast protection algorithms with the CFT heuristic algorithm performing the best amongst all of them.

15:03 ***Impact of Aggregation Level on the Performance of Dynamic Lightpath Adaptation under Time-Varying Traffic***

Adrian Asensio (Universitat Politècnica de Catalunya (UPC), Spain); Mirosław Klinkowski (National Institute of Telecommunications, Poland); Marc Ruiz (Universitat Politècnica de Catalunya, Spain); Victor López (Telefonica I+D, Spain); Alberto Castro (Universitat Politècnica de Catalunya, Spain); Luis Velasco (Universitat Politècnica de Catalunya (UPC), Spain); Jaume Comellas (UPC, Spain)

In this article we focus on lightpath adaptation under time-varying traffic in a dynamic elastic optical network (EON) implementing flexgrid optical technology. In the considered scenario, a number of IP/MPLS metro area networks performing traffic aggregation are connected through a core EON. We explore the elastic spectrum allocation (SA) capability of EON and, in this context, we study the effectiveness of three alternative SA policies, namely Fixed, Semi-Elastic and Elastic. For each elastic SA policy, we develop a dedicated algorithm which is responsible for adaptation of spectrum allocated to lightpath connections in response to traffic changes. The evaluation is performed for a set of network scenarios, each one characterized by a different level of traffic aggregation, and hence different traffic variability. As simulation results show, the effectiveness of SA policies highly depends on both the aggregation level and maximum lightpath capacity. In particular, in our experiments up to 21% more traffic is served with the proposed elastic SA than with the fixed SA in a network with low aggregation and high lightpath capacity.

15:08 ***Fiber-supported 60 GHz mobile backhaul links for access/metropolitan deployment***

Alexander Lebedev (TU Denmark, Denmark); Xiaodan Pang (Technical University of Denmark, Denmark); Juan Jose Vegas Olmos (Technical University of Denmark, Denmark); Marta Beltrán (Universidad Politécnica de Valencia, Spain); Roberto Llorente (Universidad Politecnica de Valencia, Spain); Soren Forchhammer (Technical University of Denmark, Denmark); Idelfonso Tafur Monroy (Technical University of Denmark, Denmark)

We present a 60 GHz wireless link fully supported with the optical fiber infrastructure. The architecture that we implement is suitable to provide the efficient wireless/fiber mobile backhaul in access/metropolitan area. We present bit error rate (BER) performance below the 7% overhead forward error correction (FEC) limit for transmission of 1.25 Gbps data signals. Ultimately, transmission through fiber-wireless-fiber link is achieved including 4m of wireless distance and 20 km of standard single mode fiber (SSMF) interfacing the antennas on each side.

15:14 ***Digital Radio over Fiber for LTE-Advanced: Opportunities and Challenges***

Ahmed Saadani (Orange Labs, France); Mamdouh El Tabach (Orange Labs, France); Anna Pizzinat (Orange Labs Networks and Carriers, France); Michel Nahas (Lebanese International University (LIU), Lebanon); Pascal Pagnoux (Orange Labs, France); Serban Purge (France Telecom Research & Develpment, France); Yu Bao (Orange Labs, France)

This paper investigates the opportunities of using the Digital-RoF for LTE-Advanced and beyond systems. It shows that the D-RoF is an enabler of several LTE-Advanced features that need high information exchanges and coordination between base stations. It can also reduce the network deployment costs and increase the energy saving. However, this implies several challenges such as the existence of standards able to define connections between different base station components with the fiber. Besides, the use of carrier aggregation and the enhanced MIMO increases the bitrate supported by the D-RoF which could be critical for the fiber availability.

15:19 ***An optical interconnection network with wavelength time slot routing***

Ireneusz Szcześniak (Częstochowa University of Technology, Poland); Roman Wyrzykowski (Technical University of Czestochowa, Poland)

We propose an optical interconnection network with the wavelength time slot routing, a novel routing scheme that allows for a simple design of optical interconnection networks. The simulative performance evaluation shows that the proposed scheme demonstrates optimal performance at the maximal uniform exponential network load, and performs well in comparison to store-and-forward routing.

15:24 ***Bandwidth Allocation Schemes for a Lossless Optical Burst Switching***

Ahmed Triki (Orange Labs, Networks and Carriers, France); Paulette Gavignet (Orange Labs, Networks and Carriers, France); Bernard Arzur (Orange Labs, Networks and Carriers, France); Esther Le Rouzic (Orange Labs, France); Annie Gravey (Institut Mines Telecom - Telecom Bretagne, France)

Resource allocation mechanism remains a challenging issue in the conception of the actual and future networks. In this paper, we study several resource allocation schemes for the control plane of a lossless Optical Burst Switching (OBS) solution. We carry out a comparison of the proposed schemes using simulation approach. The performances of the proposed schemes are compared in terms of waiting time, service time, jitter and throughput. Simulation parameters are chosen according to implementation constraints.

16:00 - 18:00

S8: Energy efficiency of optical networks 2

Chair: Annalisa Morea (Alcatel-Lucent, France)

16:00 ***TREND towards more energy-efficient optical networks***

Esther Le Rouzic (Orange Labs, France); Edoardo Bonetto (Politecnico di Torino, Italy); Luca Chiaraviglio (University of Rome Sapienza, Italy); Frederic Giroire (CNRS, France); Filip Idzikowski (Technical University of Berlin, Germany); Felipe Jiménez (Telefónica I+D, Spain); Christoph Lange (Deutsche Telekom AG, Germany); Julio Montalvo (Telefónica I+D, Spain); Francesco Musumeci (Politecnico di Milano, Italy); Issam Tahiri (INRIA, I3S, CNRS, Université de Nice Sophia, France); Alessandro Valenti (Fondazione Ugo Bordoni, Italy); Ward Van Heddeghem (Ghent University - iMinds, Belgium); Yabin Ye (Huawei Technologies Duesseldorf GmbH, Germany); Andrea Bianco (Politecnico di Torino, Italy); Achille Pattavina (Politecnico di Milano, Italy)

With one third of the world population online in 2013 and an international Internet bandwidth multiplied by more than eight since 2006, the ICT sector is a non-negligible contributor of worldwide GHG emission and power consumption. Indeed, power consumption of telecommunication networks has become a major concern for all the actors of the domain, and efforts are made to reduce their impact on the overall figure of ICTs, and to support its foreseen growth in a sustainable way. In this context, the contributors of the European Network of Excellence TREND have developed innovative solutions to improve the energy efficiency of networks. This paper gives an overview of the solutions related to optical networks.

16:30 ***Efficient and Agile Optical Networks***

Daniel Kilper (Columbia University, USA); Michael Wang (Columbia University, USA); Atiyah Ahsan (Columbia University, USA); Keren Bergman (Columbia University, USA)

We describe how dynamic physical layer functionality or agility in optical networks can be used to improve the energy efficiency of communication networks. Using the network global expectation model approach, we derive expressions for the total mean electrical power used by an agile optical network and use these to identify the key opportunities for energy efficiency as well as challenges that must be addressed to realize efficiency benefits. Recent progress related to both the network agility speed and the network performance is discussed in the context of energy efficiency.

17:00 ***Provisioning in Elastic Optical Networks with Non-Disruptive Defragmentation***

Rui Wang (University of California, Davis, USA); Biswanath Mukherjee (University of California, Davis, USA)

How serious is spectrum fragmentation in an elastic optical network? It is addressed by the significant provisioning gain achievable by eliminating a particular kind of fragmentation, namely, one that could be removed by Hitless Optical Path Shift (HOPS), a non-disruptive defragmentation method. An intelligent provisioning framework, along with a series of HOPS-based defragmentation methods, presents a "win-win" solution, in which higher service-acceptance rate is achieved at a lower reconfiguration cost.

17:20 ***Green WDM-PONs: Exploiting Traffic Diversity to Guarantee Packet Delay Limitation***

Pawel Wiatr (Royal Institute of Technology (KTH), Sweden); Jiajia Chen (The Royal Institute of Technology (KTH), Sweden); Paolo Monti (Royal Institute of Technology (KTH), Sweden); Lena Wosinska (Royal Institute of Technology KTH, Sweden)

In this paper we propose a scheme tailored for WDM-PONs, which employs dozing mode in transceivers not only at the user side but also at the central office. The objective is to reduce the energy consumption while minimizing the impact on the total packet delay. The proposed scheme is able to take into account the diverse delay requirement of multiple traffic classes by adapting the wakeup time of the transmitter. Simulation results confirm that the proposed scheme can significantly improve the power efficiency in WDM-PONs while maintaining the maximum packet delay at an acceptable level, in particular in cases where multiple traffic classes are considered.

17:40 ***Energy Saving via Dynamic Wavelength Sharing in WDM-PON***

Rui Wang (University of California, Davis, USA); Han Hyub Lee (ETRI, Korea); Sang Soo Lee (ETRI, Korea); Biswanath Mukherjee (University of California, Davis, USA)

Significant energy saving is achievable by adapting the number of operating wavelengths to the varying traffic in a reconfigurable WDM-PON deploying passive splitter at the remote node. When dynamic wavelength sharing by ONUs is intelligently planned, the traffic disruption incurred by reconfiguration can be kept at a minimum. Moreover, ONUs need only limited wavelength tunability, in contrast to full wavelength tunability, to save significant energy via wavelength sharing.

Friday, April 19

09:30 - 10:40

S9: Fixed mobile network convergence

Chair: Annie Gravey (Institut Mines Telecom - Telecom Bretagne, France)

09:30 ***Modeling of LTE back-hauling through OFDMA-PONs (Invited)***

Wansu Lim (University of Hertfordshire, United Kingdom); Pandelis Kourtessis (University of Hertfordshire, United Kingdom); Konstantinos Kanonakis (Athens Information Technology, Greece); Milos Milosavljevic (University of Hertfordshire, United Kingdom); Ioannis Tomkos (AIT, Greece); John Micheal Senior (University of Hertfordshire, United Kingdom)

This paper evaluates a novel mapping and scheduling scheme which allows efficient control over the quality-of-service (QoS) experienced by long term evolution (LTE) users when backhauled over an orthogonal frequency division multiple access-passive optical network (OFDMA-PON). With respect to mapping, the LTE QoS class identifiers (QCIs) are assigned to the OFDMA-PON priorities based on class-of-service (CoS) differentiation. Scheduling involves the allocation of subcarriers to each optical network unit/enhanced node B (ONU/eNB) ensuring that the bandwidth allocation accounts for the QoS requirements of the respective LTE wireless bearers. Since the transmission pipes allocated to each ONU/eNB are to be shared by all CoS queues, fairness across traffic priorities throughout the network is achieved by introducing a weighted dynamic subcarrier assignment (WDSA) algorithm. Simulations are based on a 10Gbps OFDMA-PON with 1024 subcarriers, 20km reach and 32 eNB/ONUs. Performance evaluation figures confirm that the end-end wireless packet delay and queue lengths of the high priority queues benefit significantly from the application of the WDSA algorithm without failing the rest of the network performance.

10:00 ***Placement of Base-Band Units (BBUs) over Fixed/Mobile Converged Multi-Stage WDM-PONs***

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

The convergence between fixed access networks and mobile backhauling networks is the basis of the evolution towards future Next-Generation Access Networks. Multi-Stage WDM-PONs are the ideal converged infrastructures for carrying both fixed access and mobile backhauling, because they inherit some features of WDM core/metro networks, e.g., large capacity and high transparency. Moreover, they provide support for the "BBU Hotelling" backhauling solution, which consists in separating base stations' Base-Band Units (BBU) from their Remote Radio Heads (RRH), and grouping them into consolidated "Hotels", with reduced costs and energy consumption. In this work, we propose and model by an ILP formulation the novel "BBU Placement" network optimization problem, on a converged Multi-Stage WDM-PON. The aim is to decide in which nodes to place BBUs, together with the routing and wavelength assignment of traffic demands, such that the number of Hotels is minimized. We capture the importance of the maximum latency of Digitized Radio-over-Fiber (D-RoF) flows exchanged between each BBU and its RRH, which becomes a constraint on the maximum propagation delay of corresponding routes. Simulation results are obtained by generating some random multi-stage tree instances and solving them via CPLEX. The analysis of the number of Hotels versus network sizes and maximum D-RoF delay validates the proposed model and highlights the strong impact of such parameters on the achievable BBU consolidation.

10:20 ***Performance Evaluation for DFB and VCSEL-based 60 GHz Radio-over-Fiber System***

Xiaodan Pang (Technical University of Denmark, Denmark); Alexander Lebedev (TU Denmark, Denmark); Juan Jose Vegas Olmos (Technical University of Denmark, Denmark); Marta Beltrán (Universidad Politécnica de Valencia, Spain); Roberto Llorente (Universidad Politecnica de Valencia, Spain); Idelfonso Tafur Monroy (Technical University of Denmark, Denmark)

In this paper, we report on a detailed analysis and performance comparison work between 60 GHz radio-over-fiber systems based on a DFB laser and a C-band VCSEL. Coherent photonic up-conversion method is applied for the 60 GHz millimeter-wave signal generation. The generated signals are evaluated by means of phase noise and bit error rate for different transmission scenarios. The results show a positive potential to adopt both DFB lasers and VCSELs for the next generation 60 GHz hybrid fiber-wireless access networks.

11:40 - 13:00

S10: Packet and circuit switched optical networks 2

Chair: Hiroaki Harai (National Institute of Information and Communications Technology, Japan)

11:40 ***Packet reordering in the Lightpath Bundling & Anycast Switching (LB+AS) paradigm***

Jose-Luis Izquierdo-Zaragoza (Universidad Politécnica de Cartagena, Spain); Pablo Pavon-Marino (Technical University of Cartagena, Spain)

In optical networks, Lightpath Bundling & Anycast Switching paradigm (LB+AS) consists of (i) bundling together the lightpaths which follow a common route (LB), and (ii) perform a fine-grained per-packet granularity balance of the traffic among the lightpaths in the bundle (AS). Recent works suggest that, with seamless changes in the electronic equipment, and no changes in the optical infrastructure, LB+AS can bring promising advantages to existing optical networks. In particular, AS operation spreads the traffic among the lightpaths in the bundle, to enhance the statistical multiplexing gain. However, this type of operation could bring up packet reordering problems if different packets of the same flow traverse different lightpaths. Packet reordering issues especially affect protocols such as TCP, reducing the goodput and increasing the flow completion time. This paper addresses this problem and investigates viable implementations of anycast switching techniques that: (i) allow a practical implementation in commercial high-speed switches, and (ii) eliminate the packet reordering problem in practice. Among several solutions presented and tested, the e-JSQ scheme has emerged as a solution fulfilling both requirements.

12:10 ***Fully transparent design of a hybrid optical packet/circuit metropolitan area network***

Lida Sadeghioon (Telecom Bretagne, France); Bogdan Uscumlic (Telecom Bretagne, France); Annie Gravey (Institut Mines Telecom - Telecom Bretagne, France); Philippe Gravey (Télécom Bretagne, France)

We present a new method to design a regional network based on optical hybrid packet and circuit switching. Our approach aims at providing packet-level grooming only where it is profitable. The method relies on splitting the original traffic matrix in two parts, which will be transported either through optical packets or through circuits, according to a maximum wavelength capacity threshold. The network dimensioning can be then performed for circuit and packet traffic matrices separately. As the circuit WDM network design problem is well documented, we put the emphasis on the optical packet network dimensioning. This later is performed in the context of Packet OADM (POADM) technology, involving fast tuneable emitters and receivers dedicated to specific wavelengths. First, all candidate sets of rings are identified. Then, the resources needed for each ring of a given set are evaluated by taking into account both. receiver and wavelength costs. The "wavelength cost" depends on the considered ring, as it is proportional to its circumference. A linear programing formulation, previously established for unidirectional rings, is adapted to bi-directional ones with shortest distance routing and 1+1 protection. The proposed method is applied to a 7 nodes network by considering different scenarios in terms of content-delivery node positions, wavelength capacity threshold or network geographical extension. Even if most of the traffic is carried by circuits, POADM technology is widely used as a grooming technique across the network. The benefits of using POADM technology are achieved without necessitating O/E/O conversions at packet ring interconnections and alleviating inter-ring synchronization issues, resulting in a fully transparent network

12:26 ***Experimental Demonstration of a PCE for Wavelength-Routed Optical Burst-Switched (WR-OBS) Networks***

Oscar González de Dios (Telefonica I+D, Spain); Ignacio de Miguel (University of Valladolid, Spain); Juan P. Fernández-Palacios (Telefónica I+D, Spain); Juan Carlos Aguado (University of Valladolid, Spain); Noemí Merayo (University of Valladolid, Spain); Ramón J. Durán (University of Valladolid, Spain); Patricia Fernández (University of Valladolid, Spain); Rubén M. Lorenzo (University of Valladolid, Spain); Evaristo J. Abril (University of Valladolid, Spain)

Despite what the name may suggest, Wavelength-Routed Optical Burst-Switched networks (WR-OBS) are in fact highly dynamic optical circuit-switched networks, where requests for lightpath establishment are triggered by the arrival of data at the edge routers. While a WR-OBS, like any other wavelength-routed network, can benefit from the Path Computation Element (PCE) technology for route calculations, its high dynamism requires the introduction of a number of upgrades and extensions on the PCE and on its associated protocol (PCEP). Thus, we have designed, implemented and experimentally validated a novel PCE architecture for fast circuit-switched networks, like WR-OBS. Therefore, we discuss the key challenges when implementing a PCE for such a highly dynamic network, as well as the PCEP extensions required. Since PCEP runs on top of the TCP protocol, we also analyze the impact of the combination of two TCP features -delayed acknowledgment and the Nagle algorithm- on the performance of the PCEP protocol. Furthermore, we describe the implementation of an emulated experimental setup to validate and evaluate the performance of the new PCE architecture, and demonstrate its feasibility.

12:46 ***QoS-Aware Optical Burst Switching in OpenFlow Based Software-Defined Optical Networks***

Ankitkumar N. Patel (NEC Laboratories America, Inc., USA); Philip N. Ji (NEC Laboratories America, Inc., USA); Ting Wang (NEC Laboratories America, USA)

OBS over WSON is one of the promising paradigms for future optical networks, which offers statistical multiplexing over high speed optical networks while eliminating electronic bottlenecks. In such legacy IP/WDM networks, control planes at IP and WDM layers are independently operated and managed, which may not optimize network performance. Recently, OpenFlow-based Software Defined Network (SDN) architecture is introduced, which enables unified control protocols for multilayer networks to improve network agility and automation while reducing capital and operational expenditures. In this paper, we introduce a Software Defined Optical Network (SDON) architecture and develop a QoS-aware unified control protocol for optical burst switching in OpenFlow-based software-defined optical networks. A novel adaptive-burst assembling algorithm, a latency-aware burst routing and scheduling algorithm, and an effective OpenFlow-based signaling protocol are investigated. The performance of the proposed protocol is evaluated with a well-known GMPLS-based distributed protocol. The proposed QoS-aware unified control protocol significantly improves burst blocking, network throughput, and packet latency while offering better quality of service (QoS) to different classes of traffic with heterogeneous delay requirements compared to the GMPLS-based distributed protocol.

13:06 ***CapEx/OpEx Evaluation of Circuit vs Packet Switched Optical Networks***

Andrea Bianco (Politecnico di Torino, Italy); Edoardo Bonetto (Politecnico di Torino, Italy); Francesco Musumeci (Politecnico di Milano, Italy); Achille Pattavina (Politecnico di Milano, Italy); Massimo Tornatore (Politecnico di Milano & University of California, Davis, Italy)

Future telecommunication networks will be designed to guarantee energy-efficiency and sustainability. Optical networks, given their capability to switch and transport large traffic amounts for a relatively-limited energy consumption, are expected to play an increasingly important role in the evolution towards energy efficiency. While traditional optical network design strategies are aimed at minimizing Capital Expenditures (CapEx), i.e., the cost associated to network equipment, several research studies have recently proposed novel strategies targeting the reduction of Operational Expenditures (OpEx) mainly identified as the network energy consumption. In this paper, we compare two possible switching paradigms in optical networks, i.e., circuit switching (at the optical layer) and packet switching (at the electronic/IP layer). For each of them, we first provide novel network design strategies that minimize CapEx or OpEx and then we quantitatively identify and discuss under which conditions (network size, load, etc.) one paradigm is the more convenient than the other from a cost and/or power consumption point of view.

14:00 - 15:20

S11: Optical access networks

Chair: Lena Wosinska (Royal Institute of Technology KTH, Sweden)

14:00 ***EPON Protocol over Coax (EPoC): Round-trip Time Aware Dynamic Bandwidth Allocation***

Partha Bhaumik (University of California, Davis, USA); Saigopal Thota (University of California, Davis, USA); Jim Chen (Huawei Technologies, USA); Biswanath Mukherjee

(University of California, Davis, USA); Hesham ElBakoury (Huawei Technologies, USA); Kira Zhangli (Huawei Technologies, P.R. China); Liming Fang (Huawei Technologies, USA)

We propose a dynamic bandwidth allocation (DBA) scheme for EPON (Ethernet Passive Optical Network) Protocol over Coax, or EPoC in short. EPoC is the transparent extension of EPON over a cable operator's Hybrid Fiber-Coax (HFC) network, and is set to become a rapidly-evolving standard within the next few years, with strong backing from the industry, and with the creation of the IEEE 802.3bn Task Force. For managing and controlling EPoC, a service operator prefers to have a unified scheduling and quality-of-service (QoS) environment that includes both the optical and coax portions of the network. This is achieved by extending the EPON Medium Access Control (MAC) to run over the coax physical layer, to have a centralized end-to-end network control from the cable head-end to the end-users' premises. In this paper, we describe a centralized DBA scheme for EPoC, where all allocation decisions are made at the operator's head-end. The DBA is aware of the hybrid nature of the network, and considers round-trip times between optical and coax network units for intelligent and efficient allocations. We also formulate the allocation problem as a generalized optimization problem, which can be extended according to specific deployment scenarios. We present some initial simulation results to demonstrate the performance of the DBA.

14:20 ***Tolerant-Scheduling With Channel Switch Latency Consideration for Hybrid WDM/TDM PON***

Zhao Zhou (Shanghai Jiao Tong University, P.R. China); Shilin Xiao (Shanghai Jiao Tong University, P.R. China); Meihua Bi (Shanghai Jiao Tong University, P.R. China); Min Zhu (Nanyang Technology University, P.R. China); Pingqing Li (Shanghai Jiao Tong University, P.R. China); Tao Qi (Shanghai Jiao Tong University, P.R. China); Weisheng Hu (Shanghai Jiao Tong University, P.R. China)

Owing to the large capacity and flexible wavelength allocation, the hybrid Wavelength division multiplexing/time division multiplexing (WDM/TDM) passive optical networks (PON) is becoming a promising candidate for the next generation access network. However, the switch latency (SL) of tunable components deployed in hybrid WDM/TDM PON will constrain the network performance. In this paper, we propose a dynamic bandwidth allocation (DBA) algorithm in hybrid WDM/TDM PON with the consideration of SL. The simulation results show that the proposed scheme can significantly reduce or even eliminate the performance degeneration caused by SL.

14:40 ***Technology-independent Topology Design Heuristics for Point-to-Multipoint Optical Access Networks***

Attila Mitcsenkov (Budapest University of Technology and Economics, Hungary); Péter Bakos (Budapest University of Technology and Economics, Hungary); Géza Paksy (Budapest University of Technology and Economics, Hungary); Tibor Cinkler (Budapest University of Technology and Economics, Hungary)

Next Generation Access (NGA) networks offer enormous bandwidth and low latency, mainly due to the exploitation of optical transmission. Deploying optical fiber in the access network, however, requires a huge investment, therefore topology design and optimization plays an important role. In the recent years, algorithmic access network design became viable, mainly due to the existence of digital maps and GIS databases. In the previous work, we have proposed technology-dependent, scalable heuristics for Passive Optical Network (PON) and Active Ethernet (AETH) network design. In this paper, we present a novel technology-independent solution based on the Simulated Annealing (SA) metaheuristics for any point-to-multipoint optical access network technology. The newly proposed heuristics deliver competitive results, within 5-10% of the theoretical optimum, even for scenarios with up to thousands of demand points. The key for scalability is the concept Voronoi-diagrams applied for demand point clustering and evaluation within the Simulated Annealing scheme.

15:00 ***Towards 40Gbps downstream FDM PON***

Aurelien Lebreton (Orange Labs, France); Benoit Charbonnier (Orange Labs, France)

We demonstrate experimentally a downstream capacity of 20Gbps for our proposed FDM PON system. Using simulations, we derive the necessary improvement to reach a total capacity of 40Gbps. This would require an increase in the usable RF bandwidth to 12GHz as well as an improvement at high frequencies of the system's RF response.