Introduction to the JOCN special issue on future PON architectures enabled by advanced technology

Introduction to the JOCN Special Issue on Future PON Architectures Enabled By Advanced Technology

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This JOCN Special Issue, which spans the September and October 2020 issues, investigates the future of passive optical networks (PONs) in light of new enabling technologies that are currently under consideration. The papers present a broad overview of topics of current interest, across both the physical and network layers. They investigate how new technologies (e.g., higher-speed direct detection transceivers, coherent systems, advanced digital signal processing, and new optoelectronic components) and new network-layer approaches may drive the medium to long-term evolution of PONs.

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Optical access networks are continuously evolving to keep pace with the ever-increasing demands of telecom operators and end-users, playing a fundamental role in delivering reliable, high-speed digital connections to homes. The ability to deliver capacity when and where needed, especially in response to unexpected stresses on the network, and support for a range of edge services are important goals for future access networks. This JOCN special issue focuses on the technological trends in the evolution of passive optical networks (PONs), the architecture that is today accepted worldwide as the most suitable for massively deployed fiber-to-the-home (FTTH).

The twelve papers that have been selected for this special issue present an overview of the technological evolution of PONs from several different perspectives. The special issue reports in particular on the following trends:

- A group of four papers report on the different solutions that are currently under investigation in standardization bodies for the evolution of PON towards 50 Gb/s per wavelength using direct-detection receivers. The papers analyze in depth the physical-layer issues and different technological evolutions (with regard to components and/or digital signal processing (DSP)) that can reliably support an upgrade to 50 Gb/s.
- Two papers report on a longer term evolution towards even higher bit rates (e.g., 100 Gb/s per wavelength), investigating the use of different flavors of coherent technologies in PONs.
- One (invited) paper presents a different direction for PON evolution, by proposing a significant change to the optical distribution network (ODN) to obtain extended reach (up to 50 km) and a higher number of end users (up to 1024). This would be accomplished by taking advantage of the degrees of freedom afforded by WDM and through the use of optical amplification.
- Three papers (one invited) focus on utilizing PONs for converged fixed-mobile access and fronthauling, with a focus on reducing latency.
- Finally, two papers (one invited) investigate future modularization and softwarization of PONs.

In the following, we briefly summarize each of the papers, grouping them according to the aforementioned topics.

Evolution towards 50 Gb/s per wavelength PON

In the paper "From 25 Gb/s to 50 Gb/s TDM PON: transceiver architectures, their performance, standardization aspects, and cost modeling" (by E. Harstead et al.), the authors review the current IEEE and ITU-T standardization activities for 25G and 50G PON. The paper provides an in-depth description of the different technical options for the implementation of the physical layer in terms of the power budget associated with different solutions, discussing topics such as avalanche photodiode (APD) vs. semiconductor optical amplifier (SOA) based receivers and different adaptive equalizer implementations. It also includes a techno-economic study that estimates the cost of the different options, using the current XGS-PON transceiver cost as a benchmark.

Similarly, in "Progress of ITU-T higher speed passive optical network (50G-PON) standardization" (by D. Zhang et al.), the authors discuss

the standardization evolution towards 50 Gb/s, with specific emphasis on the wavelength plan, the selection of the best forward error correction (FEC) solutions, and the latency requirements.

An analysis of the feasibility of pure TDM-PON at 50G is presented in the paper "DSP enabled next generation 50G TDM-PON" (by B. Li et al.). Use is made of available 25G optoelectronics, in conjunction with advanced DSP, to overcome the limited APD bandwidth, the chromatic dispersion in the O+ band and the link budget. The latter is handled by using NRZ signaling instead of PAM4, while the bandwidth limitation is combated by combining linear feedforward equalization, noise-whitening filters, maximum likelihood sequence estimation (MLSE), and soft-decision FEC. A real-time prototype is effectively built at 50G downstream and burst-mode 25G upstream with field-programmable gate arrays (FPGAs).

The paper "Flexible transmitters based on directly modulated VCSELs for next-generation 50G passive optical networks" (by P. Parolari et al.) exploits the recent enhancements to long-wavelength VCSELs (vertical-cavity surface-emitting lasers) with fast direct modulation to reach 50G capacity, by means of combining adaptive discrete multi-tone modulation and optical single-side-band modulation, whilst considering the distance statistics of deployed PONs for efficient distribution and extension of the bandwidth capacity. The experimental set-up and the simulation tool provide insight on the transmitter hardware efficiency, as an alternative technique for next generation PONs with advanced DSP.

Extended-reach PON

An alternative approach to optical access networks is described in the invited paper "Super-PON: an evolution for access networks" (by C. DeSanti et al.). Here the authors present the Super-PON idea and the appeal of such an architecture for a non-incumbent network operator. The main benefit of the long system reach (up to 50 km) is realized through a reduction in the number of required central office buildings. The authors provide an update on the standardization of Super-PON within the IEEE P802.3cs Task Force and describe some of the key physical layer issues that are being addressed.

Coherent technologies for PON

The authors of the paper "Comparative study of cost-effective coherent and direct detection schemes for 100 Gb/s/λ PON" (by Y. Zhu et al.) present an in-depth comparison of different flavors of coherent detection technologies to enable an evolution of PON towards 100 Gb/s per wavelength, by investigating a mix of different physical layer solutions tailored for upstream and downstream PON.

The activation process of optical network units (ONUs) in a tunable ultra-dense WDM-PON (UDWDM-PON) system is the focus of the paper "Flexible coherent UDWDM-PON with dynamic user allocation based on limited-tunability lasers" (by J. Segarra et al.). The authors report the design of a low-cost coherent UDWDM-PON employing coherent transceivers in the ONUs with two paired low-cost distributed feedback (DFB) lasers, one as local oscillator and another as transmitter. Thermal tuning and medium access control are used to adjust the wavelengths of the ONU DFB lasers across the PON system. The paper introduces the concept and describes experimental results for the activation process and the channel reassignment.

Support for converged fixed-mobile access networks and fronthauling

The subject of the invited paper "Advanced optical access technologies for next-generation (5G) mobile networks" (by J. Zou et al.) is the future requirements and technological solutions of optical access transport systems for 5G mobile data. The paper covers the challenges of 5G fronthaul transport. The concept of wavelength-agnostic passive WDM technology is presented and the associated key component, a low-cost tunable WDM transceiver designed on a hybrid InP-polymer platform, is described. Additionally, the current trends and standardization of the protocol layer to allow more deterministic latencies are reviewed.

The central proposal in the paper "Virtualized EAST-WEST PON architecture supporting low-latency communication for mobile functional split based on multiaccess edge computing" (by S. Das et al.) is a modified PON architecture to support migration of traffic between ONUs and local edge processing nodes in a cloud radio access network to enable ultra-low latency end-to-end communication with high reliability for 5G fronthaul networks. The paper presents an introduction of the concept and includes protocol-level simulations for performance evaluation of the proposed architecture.

The paper "Analog fiber-wireless downlink transmission of IFoF/mmWave over in-field deployed legacy PON infrastructure for 5G fronthauling" (by K. Kanta et al.) proposes the transmission of analog radio signals at intermediate frequency (IF), modulating an optical carrier in the C band, over a standard PON fiber architecture. After transmission over 1 km of fiber, the 400 MHz signal, modulated with 16-QAM-OFDM, is upconverted at 60GHz to support wireless rates of 1.4 Gb/s. The system performance is demonstrated over a field experiment, where the IF-over-fiber (IFoF) optical signal is multiplexed with a standard XGS-PON transmission system, without generating significant impairment.

PON Modularization and Softwarization

Network operators are considering new approaches, beyond just the physical layer, to architect future access systems. In the invited paper "Future optical access network enabled by modularization and softwarization of access and transmission functions" (by J. Kani et al.) the authors describe their long-term vision (10 years ahead) for access systems. Firstly, the paper promotes the idea of modularization of the optical line terminal (OLT) functions in the central office of future optical access networks. It describes how functions can be split between dedicated hardware, general purpose hardware and software functions. Next, it discusses full softwarization of access equipment functions that might normally be undertaken by dedicated hardware. The authors foresee a more flexible optical access system architecture in the long-term that can be more adaptable to the required services and connectivity.

A new automation concept for PON devices is proposed in the paper "Automated provisioning method for a modular PON-OLT device toward Plug & Provision" (by K. Nishimoto et al.). This can be applied to a disaggregated modular pluggable OLT. The proposed architecture features auto set-up of an in-band management network linking the modular OLT and associated software and the abstraction of the components into a logical OpenFlow switch. The paper introduces the concept of automation and provisioning and its incorporation into the modular OLT prototype, and presents an experimental demonstration.