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Subsystems for Future Access Networks

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Abstract: Current evolution and tendencies of Telecom Networks in general and more specifically optical Metro and Access Networks and their convergence are reported. Based on this evolution, a set of research lines are foreseen regarding subsystems and devices as: high speed optical sources, modulators and receivers, for the next generation of Passive Optical Networks. The ICT project EURO-FOS is achieving European level cooperative research among academia and industry, enabling future telecommunication networks.

Keywords: Optical Access Networks, Passive Optical Network PON, Fibre-to-the-Home FTTH, Radio-over-Fibre, Wireless Optical Access Networks, Wavelength Division Multiplexing WDM-PON, GPON, Metro-Access convergence, Wire-wireless convergence.

1. Introduction

The Noble Prize in Physics 2009 recently awarded to Charles K. Kao, half of the prize "for groundbreaking achievements concerning the transmission of light in fibres for optical communication" and Willard S. Boyle and George E. Smith, the other half of the prize "for the invention of an imaging semiconductor circuit – the CCD sensor". Thought both inventions have quickly spread in our day-by-day activities, they are indeed very recent achievements. In the case of the optical fibre, the seeding paper "Dielectric-fibre surface waveguides for optical frequencies" was published at the IEE Proceedings 43 years ago, in July 1966. While during the 1960s available optical fibres have shown losses exceeding 1000 dB/km, fast progress led to reduction of the fibre

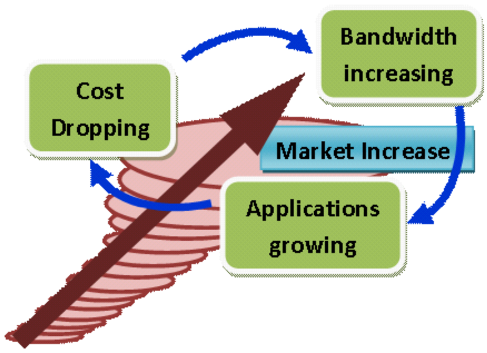

Fig. 1: Upward bandwidth Spiral by self-reinforcing system, driving exceptional market and network growth.

losses to below 20dB/km in 1970 and 0.2 dB/km in 1979. Together with the development of fast detectors, semiconductor lasers and electronics, optical fibre telecommunication networks have been providing a continuous increase in transmission capacity and distance of a factor higher than 10^8 in about 35 years [1] to nowadays 112 Petabit/s·km.

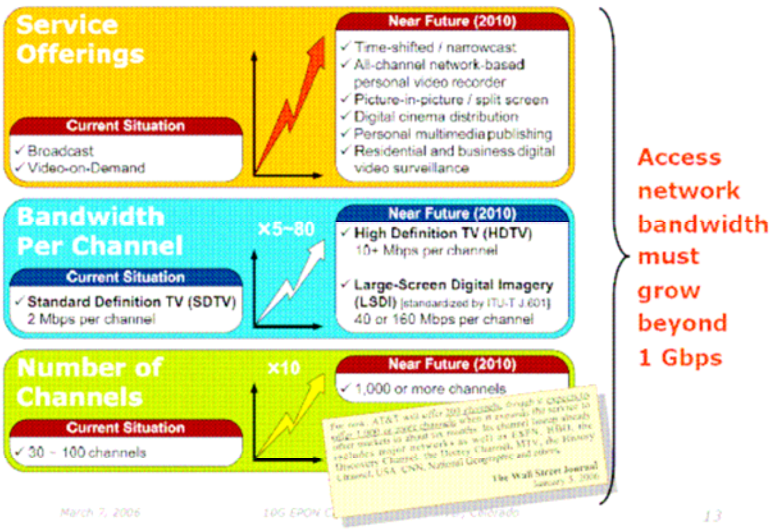

Fig. 2: Service offer and corresponding bandwidth demand increase in near future 2010 (source IEEE).

Having reached this scenario, is there still necessity for even higher transmission capacity? This fast evolution has led to a current situation where: fibre communications have "flattened the World"; people and multi-nationals require more and more connection [2]; "Global Digital Population" is now a day about 1.700 million users [3]; internet user bandwidth is showing to increase at a ratio of 50% per year [4]; and energy and carbon footprint will drive future network architecture and technology decisions [2].

Today, main bandwidth consuming services and communication activities focus on triple-play and HD video, where high speed services usually precede the commercial technology possibilities. Those factors are then the main driving forces for: working out faster scalable systems for transport and new generation access. Providing an efficient transport and access network infrastructure is essential for starting an upward bandwidth spiral as shown in Fig. 1, where bandwidth increase is promoting applications growing and cost dropping, asking for a next round of bandwidth increase. As shown in Fig. 2, new offered services, requiring higher bandwidth per channel and further increase of the number of channels leads to the conclusion that the access network bandwidth must grow beyond the 1 Gbps.

2. Access Networks convergence and requirements

As the number of Fibre-To-The-Home users is increasing significantly like in Sweden, Norway, and Denmark, and already being the dominant access technology in some countries like Japan and South Korea [5], the standardisation activities of ITU-FSAN and IEEE are increasing. In fact, the next 10G EPON from IEEE standard has been already approved in September 2009 [6] and industrials already start offering the required components for 10G EPONs. Meanwhile, ITU-FSAN targets 2012 for the 10G PON standard finalization and some other standards: WDM-PON, NG-PON and NG-PON2 are already under discussion.

Several requirements are seen for the Access Networks as: a) only mature, safe and lowest cost technology can be implemented; b) high performance devices, while maintaining low cost; c) and being competitive by mass production.

At the same time, hardware and network convergence is desired and foreseen between:

a) Access and Metro networks as in European project “Scalable Advanced Ring-based passive Dense Access Network Architecture” (SARDANA) [7]
b) Wired and Wireless networks as in European project “Fibre Optic Networks for Distributed, Extendible Heterogeneous Radio Architectures and Service Provisioning” (FUTON) [8]

One of the objectives of the European project “Pan-European Photonics Task Force: Integrating Europe’s Expertise on Photonic Subsystems” (EURO-FOS) [9] is to set and develop common research lines between academia and industry. Specifically, at the Centre of Excellence number 4 devoted to “Next-generation Optical Access Subsystems” [9], they are focused on the technological challenges involved in the development of the next generation access networks and required subsystems.

3. Main research lines in access and ongoing results.

Seeing the current situation and tendencies of the telecommunication networks, a set of 4 main research lines are envisioned, including joint and complementary activities and technical challenges related with the evolution of the telecommunication networks described in previous sections.

3.1 – Radio over Fibre technologies and subsystems

One of the indentified tendencies is the merging between wired and wireless networks, together with the merging of Access and Home networks by radio-over-fibre (RoF) technology. This can provide a low-cost solution to wireless access networks, by centralizing microwave signal processing in the central office (CO) and delivering radio frequency (RF) signals. The CO connects the in-building network to the outside access networks, delivering one or more RF signals at different RF carriers to different antenna sites (AS) where the RF signals are radiated [10].

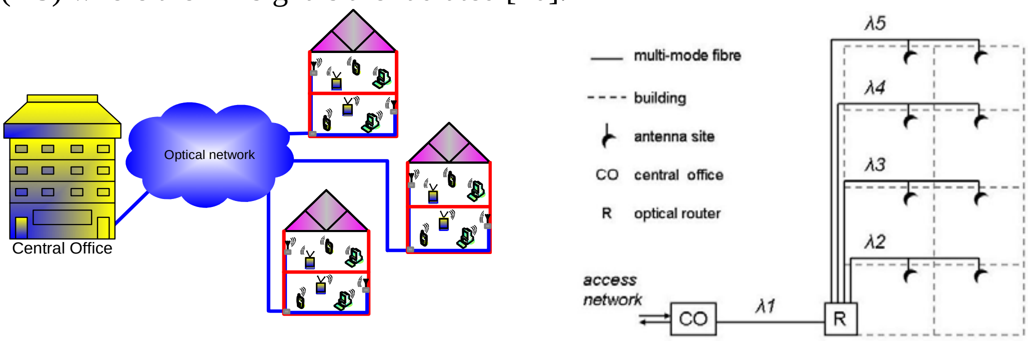

Fig. 3: Routing of Ultra-WideBand (UWB) pulses and multi-standard RoF signals based wavelength conversion

Following with this tendency of wired and wireless integrated networks, this research line also covers the generation of Ultra-WideBand (UWB) pulses transmitted over fibre for short range indoor wireless services.

To achieve a seamless integration of wireless and wireline technology, especially in the access segment, wireless links capable of providing gigabit connectivity are needed. These wireless links are crucial in applications like user connectivity to remote areas, wireless extension of FTTH, disaster recovery, inter-building wireless LANs, etc. The current access networks are moving towards 10 Gbps and similarly, the demand for wireless links to the same capacity. Among the current frequency bands, the millimetre wave bands at 60 GHz, 70/80 GHz, and 120 GHz have sufficient bandwidth for providing 10 Gbps connectivity. Radio over fibre technologies provide a great solution for enabling these high capacity wireless links, especially at the millimetre wave frequency band, considering the complexity of the electronic devices, alternatively required for such a high frequency range. Several demonstrations of wireless systems based on radio over fibre technology have been proposed [10-14]. Spectral efficiency is an important parameter in these wireless links for 10 Gbps, and advanced modulation formats based links, as M-QAM, have been proposed [12, 14]. For these future wireless access links, photonic sub-systems capable of generation, transmission and detection are needed. Currently in EURO-FOS, sub-systems based on coherent techniques for both transmission and detection are being investigated. A new demodulation technique which is transparent to the radio frequency, based on optical coherent receiver and digital processing has been proposed. Demonstration of demodulation of 2.5 Gbps QPSK signal at 40 GHz based on the above mention technique has been performed. Based on the same technique, 40 Gbps wireless links are currently under research.

3.2 – Transmission impairments, monitoring and mitigation

Convergence of Metro and Access networks and the increase of bit rate, as the recently standardized 10G EPON, introduce new technical challenges:

- Higher impact of transmission impairments due to higher bit rate, longer distances and higher transmitted power due to wavelength multiplexing in WDM or hybrid TDM/WDM PONs
- Need of monitoring as a higher and higher number of users are being served by the same metro-access network.
- More stringent transmission conditions in access than in long haul networks, bidirectional transmission, as usually a single fibre arrives to the user, leading to specific impairments like Rayleigh Backscattering if centralized optical sources are used.
- New subsystems for monitoring and mitigation of the new impairments are required.

As discussed in section 2, only high performance devices, maintaining low cost and providing competitive mass production are expected to be implemented in future access networks. Reflective Semiconductor Optical Amplifiers (RSOA) are pointed as main candidates as they can provide amplification of the incoming signal and modulation of user's signal using the received seeding signal in a single device in a colourless way. This means that in a large WDM-PON network, a same device can be used for all the users, getting benefit of mass production and avoiding inventory problems.

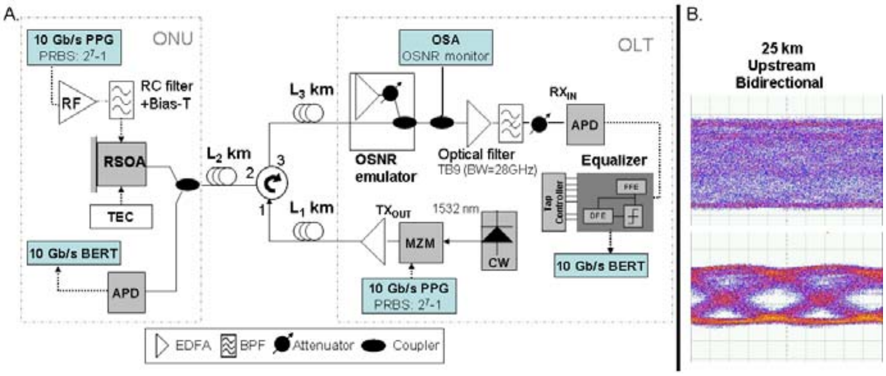

Fig. 4: a) Set-up; b) electrical eye-diagrams for bidirectional upstream transmission after 25 km of SSMF without (top) and with (bottom) optical filter (28 GHz BW) at optimum position for Pin = -10 dBm

This low cost and efficient device still shows some drawbacks as: a) reduced modulation bandwidth to about 1.2 GHz of commercial devices; b) strong signal degradation of transmitted signal, due to chirping of the transmitted signal and chromatic dispersion [15].

As shown in Fig. 4-a) 10 Gbps transmitter subsystem is currently being worked, using low-bandwidth commercial RSOA. Though at this data rate of 10 Gbps the chromatic dispersion is affecting the strongly chirped generated signal (Fig. 4-b) top) avoiding any opened eye, a proper mitigation by optical filtering and electronic equalization as shown in Fig. 4-a), permits a good signal transmission, Fig. 4-b) bottom.

3.3 – User Terminal sub-systems

High performance and low cost user terminals are key subsystems for the Metro-Access convergence and commented in the previous section. Special effort is being done in high speed Burst-Mode transmitters (BM-Tx) for ONUs for next-generation PONs and also in Burst-Mode receivers (BM-Rx). The Fig. 5 shows the four BM Physical Medium Dependent (PMD) prototypes of the 10 Gbps uplink, being the heart of the BM front-ends that terminate the fibre plant. Recent results demonstrate the shortest ever published upstream burst overhead of only 55 ns without any time-critical control signals [16]. Fig. 5 also shows BM-Rx to be discussed in next section of OLT sub-systems.

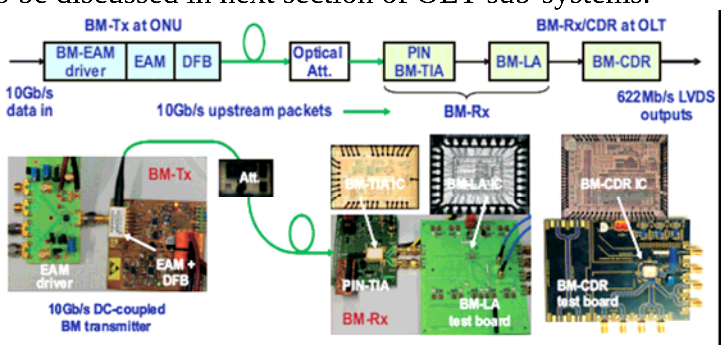

Fig. 5: 10 Gb/s BM-PMD subsystems (BM-Tx, BM-TIA, BM-LA, BM-CDR) developed for long reach PONs within the FP6 IST PIEMAN project and further integrated within the EURO-FOS project

Also more robust modulation formats are required for centralized source WDM-PONs architectures, where optical carriers are generated at the CO, and ONUs are using the downstream signals for both, receiving information, and also remodulation of the upstream data. The use of orthogonal modulation formats as FSK and ASK is a good choice, as the crosstalk between downstream and upstream data is minimized. The challenge for this kind of WDM-PONs is to provide low cost RX and TX able to implement this advantageous modulation format scheme in a single integrated device.

In collaboration with Alcatel-Lucent-Thales III-V Labs, FSK demodulation and ASK remodulation, showing a good performance, has been demonstrated at an integrated Reflective Electro-Absorption Modulator (REAM) plus SOA single chip as shown in Fig. 6 a) [17].

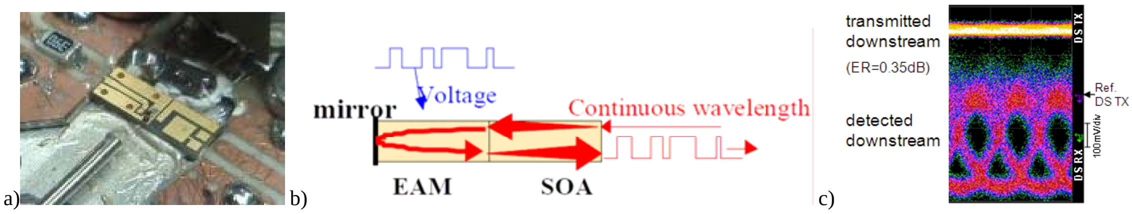

Fig. 6: a) integrated REAM+SOA chip; b) basic scheme of the device; d) constant level FSK downstream transmitted signal and demodulated eye diagram.

This research line of user terminals subsystems is complemented with the last research topic about Optical Line Terminal (OLT) devices and Remote Node.

3.4 – Optical Line Terminal and Remote Node sub-systems

Optical Line Terminal includes as key technologies Burst-mode receivers and optical transmitters, including key optical signal generation devices.

Regarding BM-Rx, currently this activity is focusing on the design of a generic (overhead fully programmable) and robust 10 Gbps APD-based BM-Rx for future 10 Gbps symmetric G-PONs, contributing to the state-of-the-art of the 10G BM-Rx and 10G XG-PON2 standardization discussions.

On the other hand, two main approaches are nowadays focusing the research on optical signal generation devices: a) very low cost fixed wavelength laser sources; and b) tuneable laser for advanced applications like dynamic WDM-PON networks and Optical Burst Switching networks. EURO-FOS is collaborating in this topic with laser manufacturers, cooperating in the analysis and characterization of tuning process of tuneable lasers, obtaining the optical spectrum at every instant and its evolution along the tuning transient in order to optimize driving electronics for the aforementioned applications.

Nevertheless, next generation and extended PONs are not complete without including also the required technologies and subsystems for supporting: required extended reach, increased number of users, and augmented number of wavelengths. This research topic is also a priority for industry as reflected by the new Mid-span reach extension recommendation [18]. Collaboration with Orange/France Telecom is providing relevant data, comparing alternative technologies for mid-span extenders as: double-SOA, Fig. 7-b), Remotely Pumped Optical Amplifiers (ROPA), Fig. 7-c), and Optical-Electrical-Optical 3R converters [19].

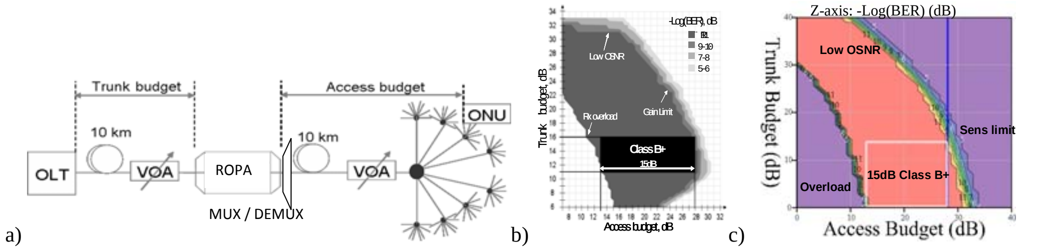

Fig. 7: Subsystem for Mid-span reach extension G.984.6: a) DWM-PON extended architecture; b) BER values with a Double-SOA for both Upstream and Downstream Signal; c) BER values with a ROPA with 15 m of HE980 EDF and 20 dBm of pump power (Max BER: 10^{-11} min : 10^{-5})

Finally, as stated by highly relevant industrial advisors, energy and carbon footprint will drive future network architecture and technology decisions [2]. This opens a relevant common research line between industry and academia, on reducing as much as possible PON power consumption and maintaining the PON passive, without the requirement of electrical supply to the different new elements introduced at the extended PON and the Metro-Access networks like mid-span extenders and Remote Nodes. Due to that, this research line also includes the topic of harvesting of optical energy from the network, with the objective of controlling optical devices and minimizing human intervention in remote systems used in optical communications, Fig. 8.

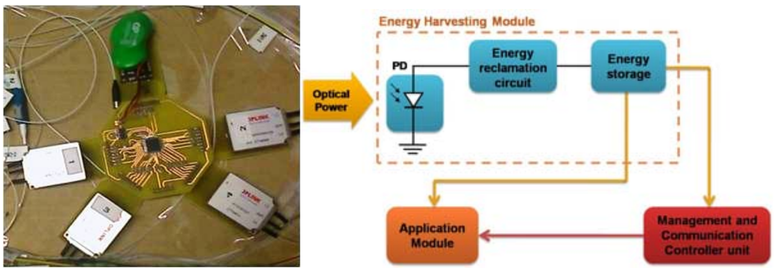

Fig. 8: Green energy conversion for remote powering passive optical networks

A possible application of this technology can be to remotely drive optical active components, such as optical switches or tuneable power splitters, located in the nodes of an optical network (or any other intermediate point, where no energy but the one from light is available), with the goal of increasing the intelligence and functionality degree of the network, e.g. reconfigurability or protection. This is especially interesting as residual lights, e.g., amplified spontaneous noise (ASE) in amplified WDM-PONs can be used for feeding the harvesting modules [20].

4. Conclusions

Taking into account the past evolution of optical fibre communication networks, the current status of bandwidth, number of final users connexions worldwide and current demands due to new applications and opening markets, it is needed an intensive research for providing subsystems and access networks architectures able to provide bandwidths growing beyond 1 Gpbs. Providing technical solutions for significantly increasing the offered bandwidth is key for maintaining a self-reinforcing: system performance, market drivers and networks growth. A set of 4 main research topics have been identified at the Centre of Excellence number 4 devoted to “Next-generation Optical Access Subsystems” by joint research collaboration between academia and industry encouraged by Pan-European Photonics Task Force: Integrating Europe's Expertise on Photonic Subsystems" (EURO-FOS), Each one showing current results and future research lines, pushing the state-of-the-art of current solutions for providing the required subsystems for future access networks.

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