Recent Progress in Optical Access and Home Networks: Results from the ALPHA Project

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Abstract: ALPHA has made substantial contributions to passive and Ethernet optical access networks, home networks based on silica and plastic optical fibers as well as to optical transmission (including OFDM/DMT) and radio-over-fiber technologies.

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1. Introduction

The expected traffic evolution and emerging applications will push the next-generation networks to higher bandwidths, higher flexibility in service delivery, and higher quality of service (QoS) demands. The European project “Architectures for Flexible Photonic Home and Access networks” – ALPHA, which ran from January 1, 2008 to March 31, 2011, made substantial contributions in developing the future optical access (including the metro part) and in-building/home networks as well as relevant optical transmission (including real-time optical orthogonal frequency division multiplexing - OFDM) and radio-over-fiber technologies. The project also developed roadmaps for these network domains and areas as well as for cross-domain issues for up to 10+ year perspective [1].

2. Project scope

The project covered the access and in-building (with focus on home) network domains as well as included the metro domain at the final stage of the project. The project scope and key activity areas of the project are illustrated on the integrated network model shown in Fig.1.

3. Access and metro networks

The project implemented and demonstrated a WDM 10G TDM PON system with 8 upstream and 8 downstream wavelengths running at 10 Gb/s for the distances up to 75 km showing multiformat transport, multi-bit-rate operation, and multi-modulation formats coexistence [1]. The PON incorporated a radio-over-fiber (RoF) system
which was made to run over PON [2]. This was, to the best of our knowledge, the first successful experimental implementation of the RoF over PON. At the final project demonstrator, the access network was interconnected to the packet-OADM metro concept with total 40 wavelengths operating at 10 Gb/s each in a double-ring configuration [3].

For next-generation Ethernet optical access networks, the ALPHA adapted a mesh-like architecture supported by the Generalized Multi-Protocol Label Switching (GMPLS) as the control plane [4]. The project also elaborated the concept of GMPLS-controlled Ethernet used in core networks (i.e. GMPLS controlled IEEE 802.1Qay used in PBB-TE) to include more flavors of IEEE Ethernet switching used in home, access and aggregation such as the IEEE 802.1Q, ad, ah (VLAN, QinQ, and MACinMAC). Through this work, the GMPLS-controlled Ethernet has advanced from a single-layer Ethernet solution to a multi-layer one allowing for better traffic engineering and covering most flavors of Ethernet used in the distribution, access and home networks.

The project has also developed a reference model for fair techno-economic comparison of various optical access architectures, including passive and Ethernet optical networks [5]. The CAPEX analysis of various architectures showed the importance of keeping the ONU costs low for urban and rural scenarios and the importance of sharing (using e.g. WDM) for the rural ones. The project also conducted extensive studies, both technical and economical, on the dynamic bandwidth allocation including that in the optical layer. The project showed that a more advanced (flexible or reconfigurable) remote node does not affect the cost per subscriber significantly (compared to the total CAPEX), as long as the sharing ratio is large enough (e.g. 512 or 1024 customers connected to the same remote node). In the access roadmap, the project foresees, in 10+ year perspective, a convergence scenario between access and metro with one unique data protocol and unified control and management plane completed with a full fixed-mobile convergence.

4. Home and in-building networks

The studies for in-building and home networks covered both passive (PON-like) and active (Ethernet and multi-format switch) architectures [6]. The passive architecture was represented by a Broadcast & Select (based on a passive N x N optical splitter) solution. The multi-format switch was experimentally demonstrated with simultaneous Ethernet, digital TV broadcasting and ultra wideband (UWB) radio transmissions. The metro, access and home networks were interconnected and demonstrated with a multiple services running across all domains in the final project demonstration [1].

The project made extensive studies in home networks based on plastic optical fibers (POF) including techno-economics studies which supported competitiveness of POF solutions against the copper (Cat5 cable) ones [7, 8]. ALPHA developed a prototype of cost-optimized Gigabit Ethernet transceiver for 1-mm core POF ready for commercial production which was integrated into a residential gateway of an ALPHA partner within the project [1].

The project implemented, tested and demonstrated the Universal Plug-and-Play (UPnP) QoS control & management framework for providing QoS in home networks [9]. The UPnP QoS functionality has been ported on the Ethernet switch and router of the ALPHA partners. The project also developed a model for interworking of UPnP QoS with the ALPHA-developed RoF MAC protocol and with the InterMAC QoS concept for home networks developed within the ICT Omega project [1]. The project also made contributions to indoor MIMO RoF solutions and reconfiguration issues in in-building networks.

The project incorporated the studies for including the femtonode (which is a simplified basestation) into the home/in-building network for providing mobile service coverage. In the in-building/home roadmap, the project foresees, in 10+ year perspective, an integrated backbone architecture based on optical fiber with support of wavelength-division multiplexing and radio-over-fiber.

4. Cross-domain issues

The project addressed the issues of integrating the domains of interest (metro, access and in-building/home) through the data and control planes. In particular, the developed GMPLS access framework was interfaced with the UPnP-QoS in home networks, which enabled the end-to-end QoS reservation by a device in the home network to a service in the metro or access network via the home and access network domains. The framework for mapping of UPnP-QoS parameters into GMPLS was detailed and the functionality of the system was verified experimentally. Also, an analysis and discussion for including the GPON into the GMPLS framework was provided. A proposal on how a GMPLS-controlled GPON can be implemented was detailed. Finally, an integrated control plane for converged
wired & wireless networks (EPON-WiMAX) was evaluated to maximize QoS and throughput for high priority flows. The issues related to transferring the results from EPON to GPON were also identified [1].

5. Transmission technologies

The project carried out extensive theoretical and experimental investigations as well as techno-economic analysis [10] of advanced optical transmission techniques for access and in-building networks. In particular, the project experimentally demonstrated real-time optical OFDM modems [11] at 20 Gb/s, and explored technical solutions enabling real-time OOFDM transceivers up to 100 Gb/s as well as made steps towards commercializing the OOFDM technology. Apart from the extensive optical OFDM studies, the other notable transmission achievements include the study and evaluation of different modulation formats for large-core POF, demonstration of multi-Gb/s transmission over 50 meters of large-core graded-index POF, demonstration of a bidirectional Gigabit Ethernet transmission over a single step-index POF up to 75 meters, simultaneous transmission of radio and baseband signals over POF and RoF-over-MMF achievements. Furthermore, the generation and distribution of UWB radio signals through different techniques and the use of broadband sources for the converged transport of wired and wireless signals in subcarrier-multiplexed transmission systems were demonstrated among many other achievements. The project also elaborated the prospects and roadmaps for optical OFDM, RoF and POF for up to 10+ year perspective [1].

6. Conclusions

In its 39 months of duration, the ALPHA project made a number of breakthroughs in access and in-building networks as well as in optical transmission technologies. The public technical reports are available at the project web-site [1].

7. Acknowledgements

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4. References