ΑΝΑΒΑΘΜΙΣΗ/ΠΑΓΙΟ/0308/30

"Next Generation Hybrid Optical-Wireless Communications Laboratory"

ANNUAL RESEARCH REVIEW 3

Coordinator: Prof. S. Iezekiel

Research Activity

The goal of this project is to develop an optical-wireless test-bed using state-of-the-art photonic and millimeter-wave (mm-wave) components and test equipment and conduct experiments on wavelength division multiplexing (WDM) passive optical networks and radio-over-fiber (RoF) systems. Initially, the two systems (WDM-PON and RoF systems) will be set-up independently and then they will be integrated in order to create a converged optical-wireless access system. Various experiments for the independent systems as well as for the converged (integrated) system are scheduled.

In the fourth year of the project we continued with setting-up the laboratory and performing parts of the experiments. More specifically:

- We proceeded to experimentally develop a ring-based WDM-PON working/protection architecture in WP4/WP8 that has significant advantages over the tree-based type of architectures investigated in WP 3 in terms of survivability.

- We compared various types of RoF systems in WP6.

- We integrated the RoF system and the ring-based WDM-PON architecture in WP7 for various applications (WP9).

Ring-Based WDM-PON architecture

The experimental setup of a CWDM PON Ring with 20 Km fiber trunk and two ONUs (JDSU WSS) distanced at 1 Km is shown in Figure 1. In this case, NRZ-OOK PRBS data of up to 2.5 Gb/s with word length 231-1 was applied to both modulator transmitters. All necessary EDFAs were pushed to the OLT and more specifically just before the MUX and right after the DEMUX. OBPFs were also used right after the EDFAs on the transmitter side. 20 Km of trunk fiber is used and two ONUs are employed. Both ONU1 and ONU2 perform all three major functions (add, drop and through) and the two wavelengths that are transmitted to the OLT side have been added at ONU1 and ONU2.

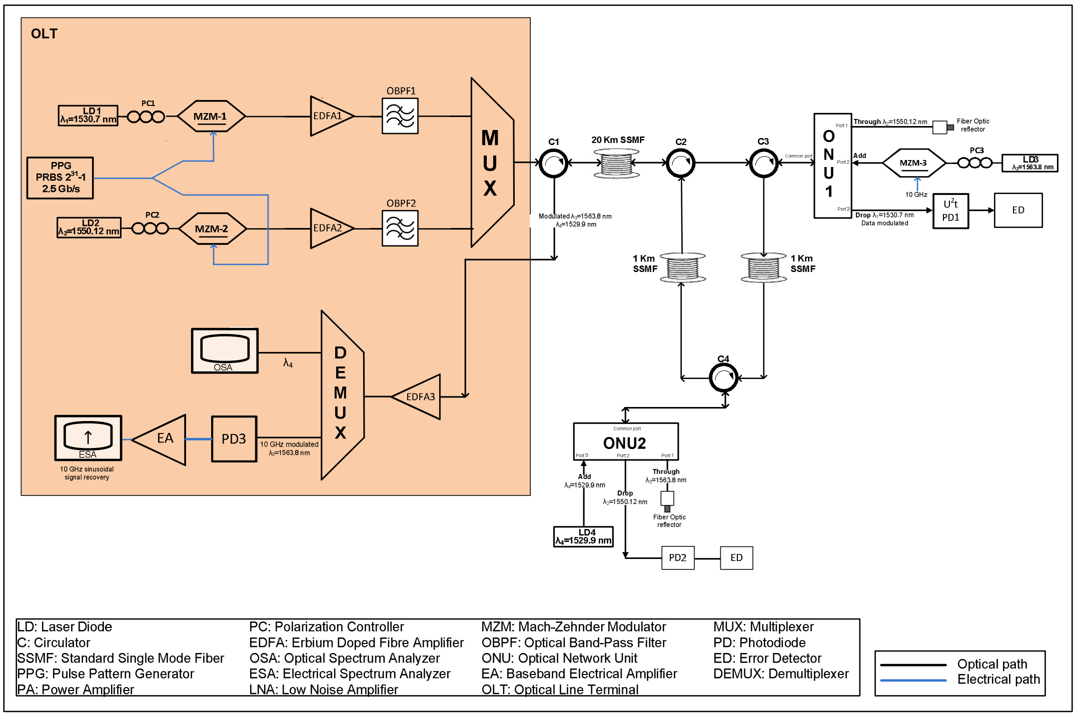

Figure 1. Experimental setup of a CWDM PON Ring with 20 Km fiber trunk and two ONUs (JDSU WSS) separated by 1 Km

In this case, the BoF channel (λ_2) is dropped at port 2 of ONU2 (as shown in Figure 2) and the recovered 10 GHz signal at the OLT can be seen in Figure 3 (note that the signal in this case was weak due to a problem that was encountered with bad coupling of the fiber optic reflector (FC/PC connector) and the fiber of port 1 of ONU 1 (LC connector)).

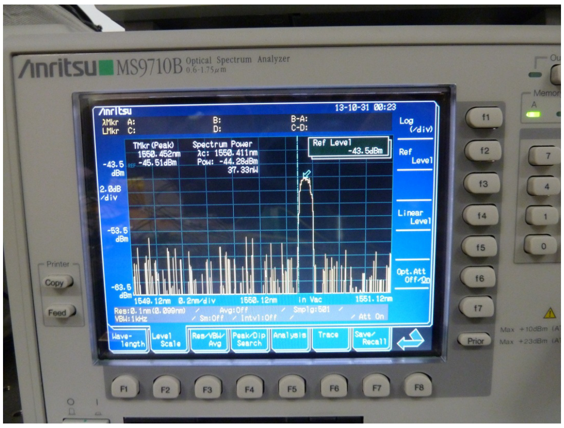

Figure 2: The modulated lightwave λ_2 dropped at port 2 of ONU2.

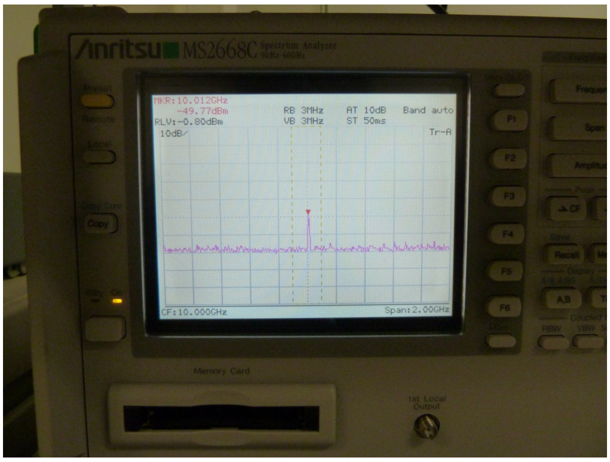

Figure 3. The 10 GHz modulated lightwave λ_3 added at ONU1 and reflected at ONU2 is recovered at the OLT receiver.

From all the ring-based experimental set-ups and results (discussed in D2), it is clear that the functionality of the WDM-PON ring architecture was successfully implemented.

Comparison of various types of RoF

The small size of picocells in mm-wave radio-over-fiber systems means that a large number of remote antenna units must be produced, implying that their architecture must be simple. In this manner the complexity moves to the central office, in which the functions of data modulation and multiplexing are housed. There are trade-offs between complexity of the picocells and the central office, leading to different schools of thought as to which is the best overall approach. These can be broadly defined as (i) optical generation and transport of mm-wave signals at 60 GHz and (ii) optical transport of data signals with remote up-conversion to 60 GHz at the picocell. The former approach is known as RF-over-fibre. It results in simple picocells. It does, however, require use of optical techniques in order to generate the mm-wave carrier. The second approach is known as baseband over fibre and it removes the need for high-speed components, but in its place it requires local oscillators to be generated locally at each picocell unit. A third approach, known as IF-over-fibre is also possible, and this technique is illustrated in Fig. 4 along with the other two main signal transport approaches.

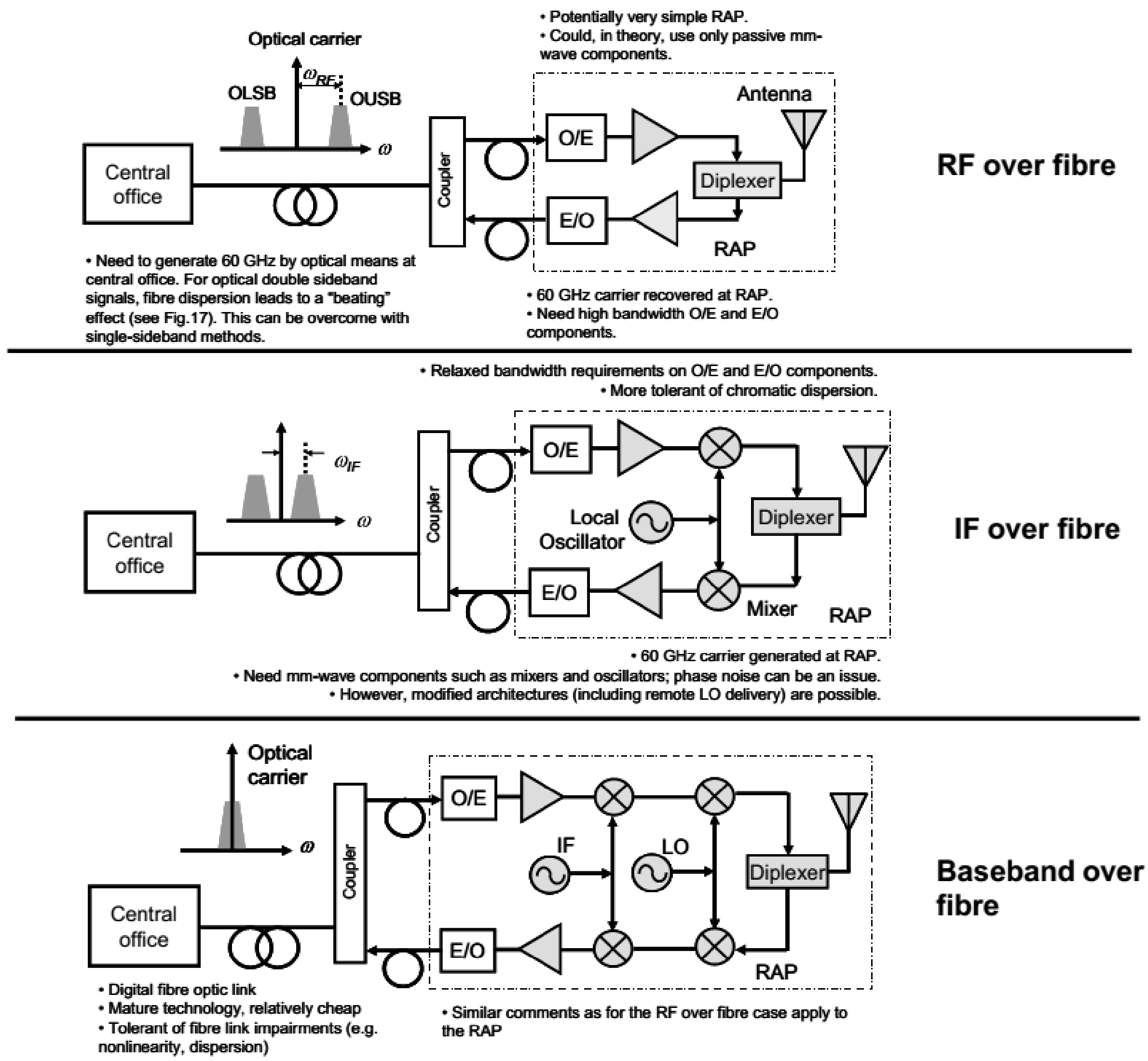

Fig. 4. Three main RoF transmission schemes

The aim of this part of the work is the comparison and evaluation of the three main radio-over-fibre (RoF) transmission schemes. In this part of the study, we set up link models for the three RoF transmission schemes. A large number of approaches have been used to implement radio-over-fibre systems, but in general three main schemes can be identified for the transmission of data over RoF. These are:

(1) Baseband. This uses digital fibre-optic link technology, and upconversion (first to IF and then RF) is performed in the base station.
(2) IF-over-fibre. In this case, the data is upconverted to IF before transmission, with final conversion to RF occuring at the base station.
(3) RF-over-fibre. Here, both the data and the mm-wave RF carrier are transmitted optically, before being recovered at the base station.

Our objective is to evaluate and compare all three approaches for their OFDM performance. Although comparisons have been made for simpler modulation schemes, electrical OFDM signals represent a more realistic assessment of realistic communication system conditions. Our studies are focused on the effects of the noise and intermodulation distortion in the RoF links in order to establish the limitations on system performance. With all three approaches, there is a trade-off between base station complexity (complexity decreases in going from approach (1) to (3)) and the need for high bandwidth optical sources and photoreceivers (approach (3) requiring higher bandwidth fibre components than either (2) or (1)).

Simulation results show how the transmission of the OFDM signal through each of the three radio over fibre (RoF) schemes can be affected by intermodulation distortion (IMD) resulting from the nonlinear nature of the optical link. We conducted simulations for externally modulated fibre radio links in order to examine the impact of the modulator on the overall performance of the OFDM RoF system. In these simulations, we use five OFDM-QAM radio channels (2 GHz carrier frequency, 100 MHz channel spacing). Second- and third-order IMD are generated by increasing the fibre length. The Error-Vector-Magnitude (EVM) of the central radio channel is displayed against the ratio "3rd order spur"/carrier. The carrier, "3rd order spur" (3rd IMD) and "spurious free dynamic range" (SFDR) are displayed against the fibre length as well.

Thus, for this part of the work we have evaluated and compared the three approaches (i.e. baseband, IF-over-fibre and RF-over-fibre) in terms of their OFDM signal propagation performance through the various parts of the links. For each transport scheme we investigated many transmitter and receiver driver circuit configurations, selecting the best for each transport technique. We have also examined the impact of individual microwave and optical components on the overall performance and we found that the nonlinear characteristics of the MZM are the major source of performance degradation of the RoF links (Baseband-over-fibre, IF-over-fibre and RF-over-fibre). The comparison of the three transport schemes shows that RF-over-fibre transport scheme gives improved performance. This enables an informed choice of RoF architecture to be taken for realistic communication signals.

Integration of WDM-PON Ring Architecture and RoF System (Working/Protection)

During the fourth year work also continued on work-packages WP7-WP9 that deal with the experimental development of an integrated WDM-PON and radio-over-fiber (RoF) system together with various applications for this integrated system.

The fully integrated 60 GHz RoF – CWDM-PON ring with PRBS data modulation is shown in Fig 5. The ring design is exactly the same as previously discussed. With regards to the 60 GHz RoF system, it is now fully functional with local oscillator (30 GHz and 60 GHz) synchronization fully in place, hence enabling us to perform BER measurements. A maximum bit rate of 2.5 Gb/s was achieved for a wireless error free transmission of a NRZ PRBS of word length 2^{31}-1 using OOK modulation (Fig. 7). The measured eye diagram can be seen in Fig. 8 with the eyes clearly open.

Recent results have indicated a possible maximum bit rate of 3 Gb/s for this system for NRZ-OOK PRBS data with word length 231-1. This rate is deemed sufficient for the transmission of high definition video, given the available bandwidth of 7 GHz (57 GHz - 64 GHz) of the 60 GHz band.

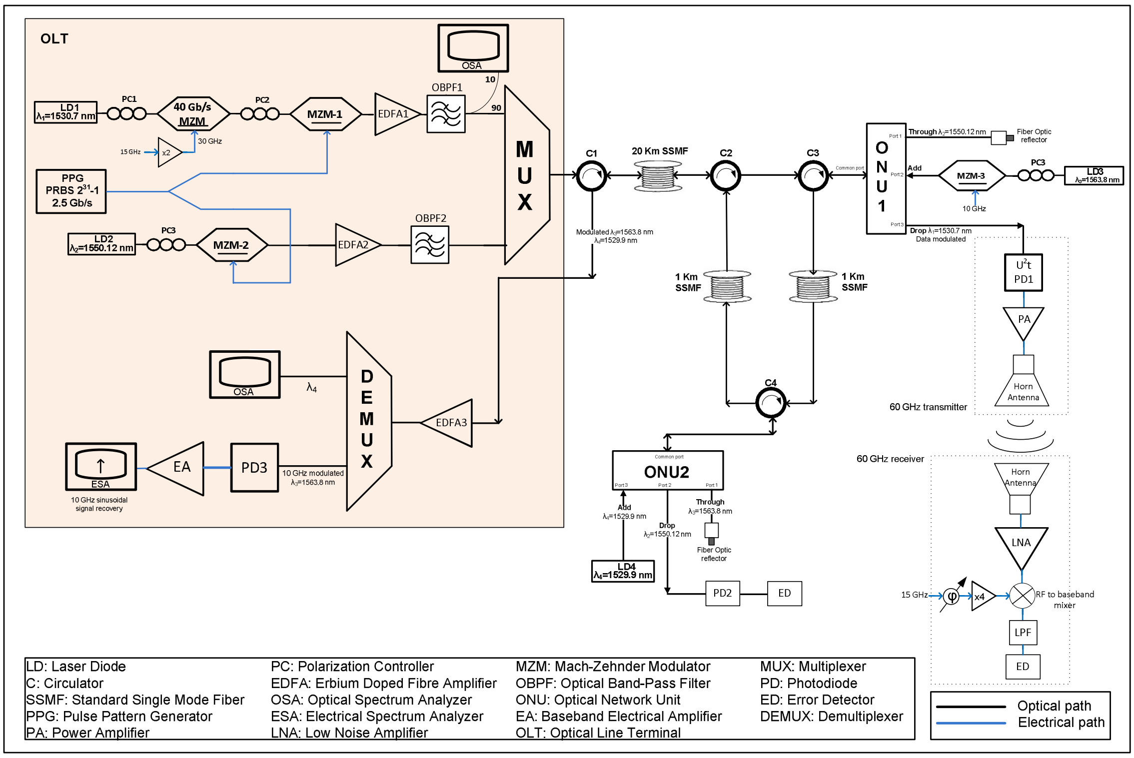

Fig. 5. Integrated ring-based WDM-PON architecture with RoF system.

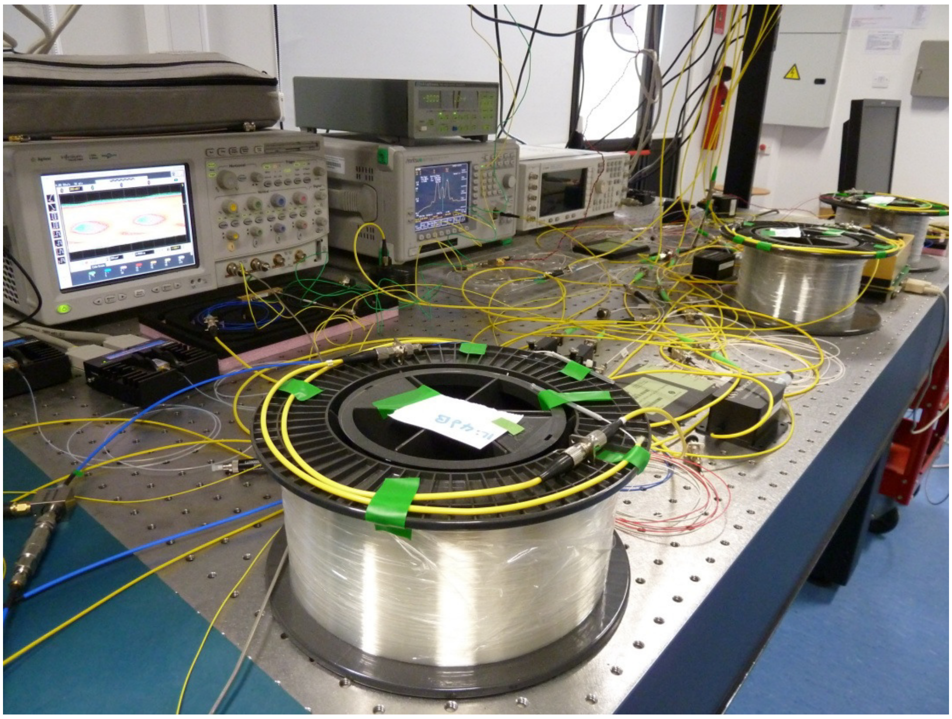

Fig. 6: A view of the entire system setup with the 20 km and 1 km (x2) Standard Single Mode Fiber spools.

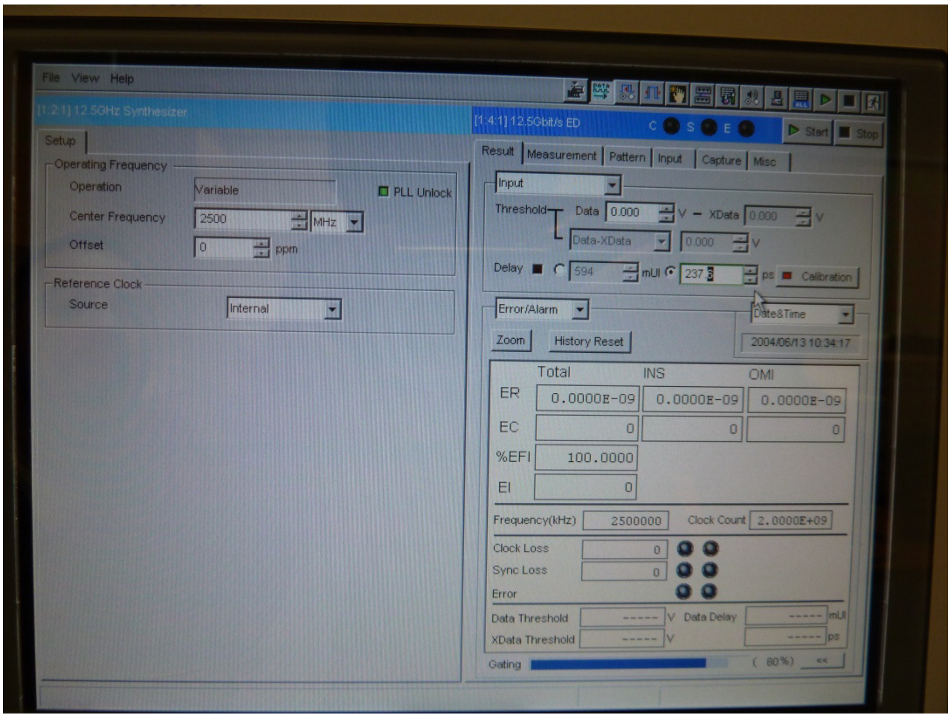

Fig. 7: The Anritsu Error Detector (or Bit Error Rate Tester) showing the maximum bit rate achieved of 2.5 Gb/s for NRZ-OOK modulation and PRBS data of word length 2^{31}-1.

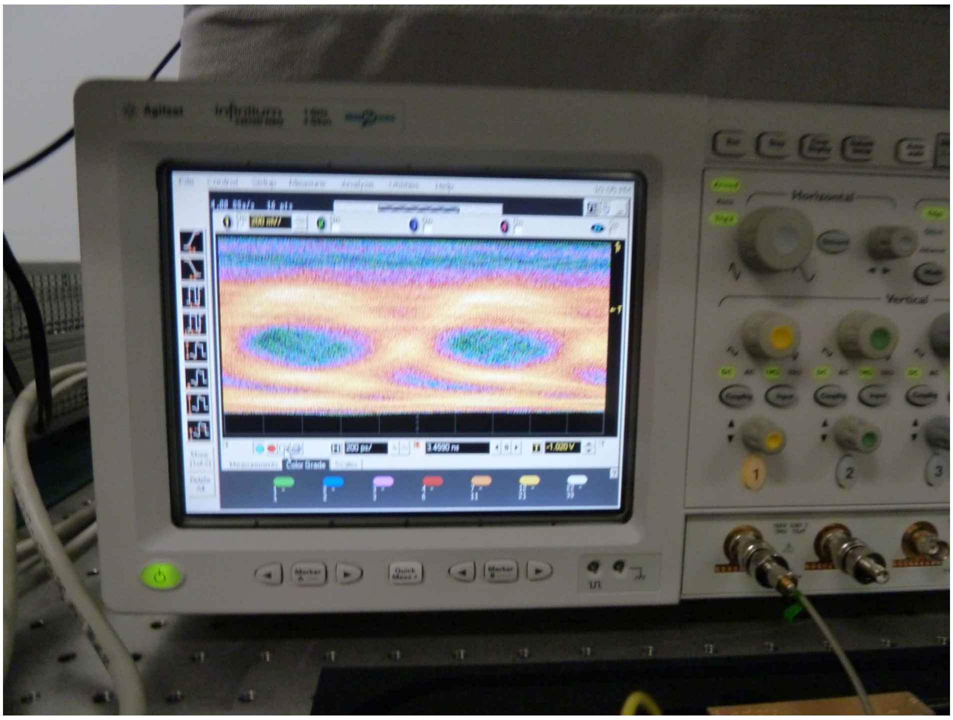

Fig. 8: 1 GHz oscilloscope displaying the eye diagram for 1 Gb/s PRBS wireless data transmission

Finally, Figures 9 -11 illustrates the protected integrated architecture and some performance results for the case of failure recovery. In Figure 9 the redundant fiber is shown with dashed lines and protection switches are also shown that are used to switch the signal to the protection fibers when a failure event is detected. Figs 9-10 demonstrate the transmission of 3 byte data (on wavelength 2 that is dropped at an ONU) on the regular and protection paths respectively for proof-of-concept of protection scheme. In this case a failure at the trunk fiber was initiated.

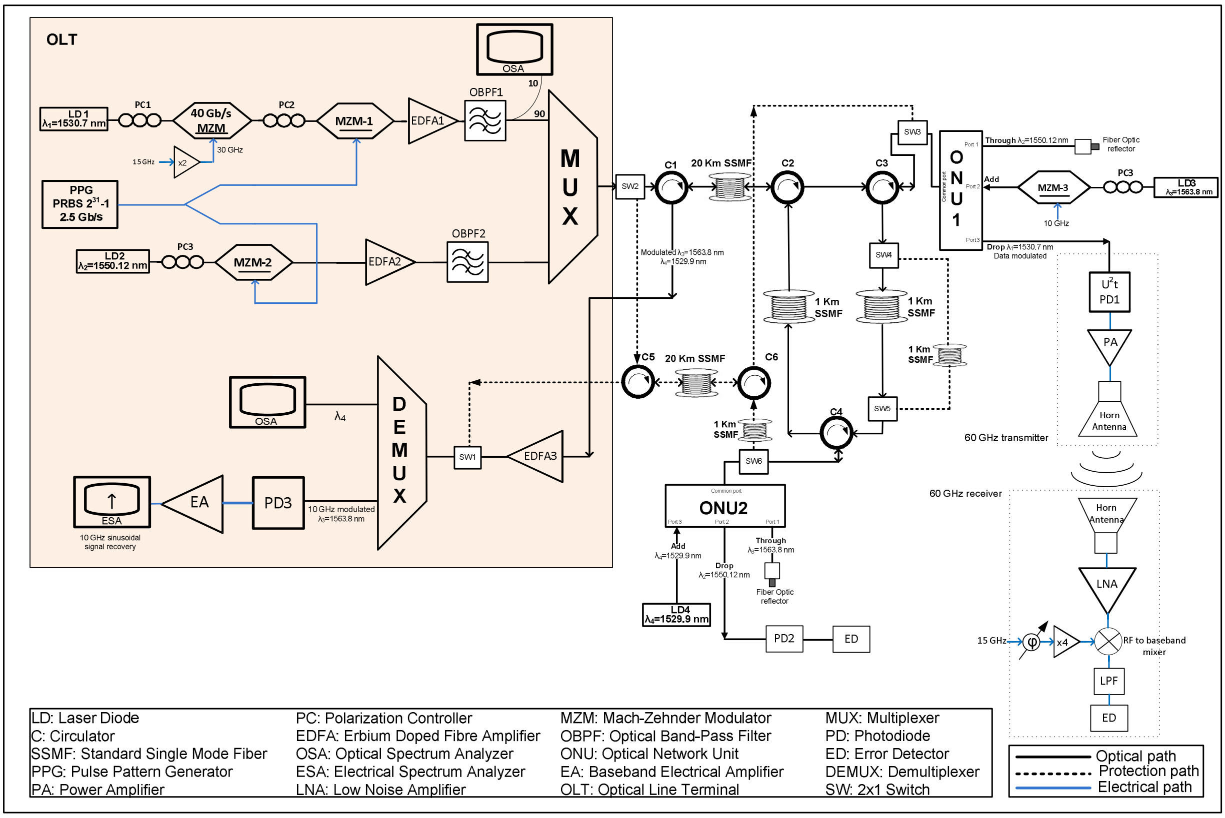

Fig. 9. Integrated ring-based WDM-PON architecture with RoF system that offers survivability capabilities.

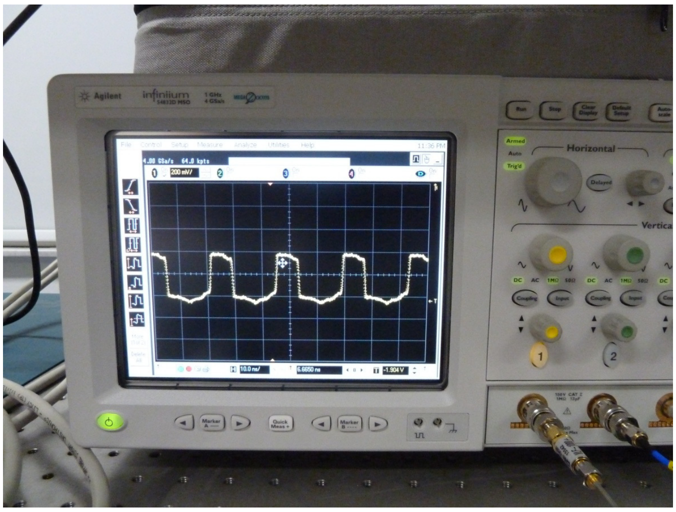

Fig 10: Transmission of 3 byte data (on wavelength 2 that is dropped at an ONU) for proof-of-concept of protection scheme: Regular path

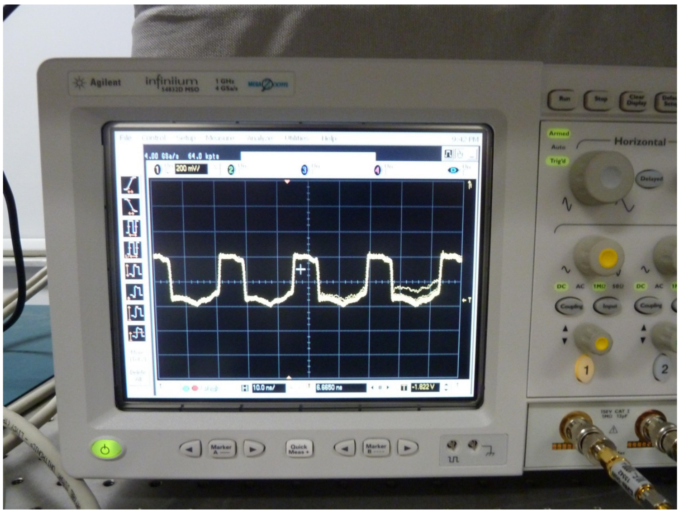

Fig 11: Transmission of 3 byte data (on wavelength 2 that is dropped at an ONU) for proof-of-concept of protection scheme: Redundant/protection path

Finally, it is important to note that project partners Primetel Plc have visited the laboratory during these evaluations in order to assess the test-bed suitability for future trial experiments, and have determined that it is suitable for initial experiments in large data file transfer and HDTV transmission.

Dissemination Activity

A workshop was also organized in Cyprus in the area of optical-wireless access networks to highlight the progress of the project and present work by other interested parties in this area of research. The workshop took place in Nicosia on July 3rd 2013 and was attended by students, academics, and people from the industry. The talks were followed by an open discussion on applied research results and activities on converged wireless/wired technologies.

Furthermore, during the fourth year of the project the following dissemination activities took place:

Conference Papers:

[1] S. Iezekiel, Application of Microwave Photonics to Future Broadband Wireless Systems: Implications or Measurement [Invited], Workshop on Measurement Developments for Future Wireless Technologies (WS2), IEEE IWS 2013 Beijing, April 2013.

[3] S. Iezekiel, Developments in photonic and mm-wave component technology for fiber radio [Invited paper], Broadband Access Communication Technologies VII, SPIE OPTO, San Francisco, February 2013.

Journal Papers:

[1] H. Erkan, G. Ellinas, R. Dorsinville, A. Hadjiantonis, and M. Ali, "“Reliability Considerations of the Emerging PON-Based 4G Mobile Backhaul RAN Architecture”, submitted to Springer Photonic Network Communications.

[2] S. Iezekiel, "Microwave-photonic links based on transistor-lasers: Small-signal gain analysis, IEEE Photonics Technology Letters, Vol. 26, No.2, Jan. 2014

Books and Book Chapters:

[1] M. Tornatore, G. Ellinas, and G-K. Chang, (Editors), Fiber-Wireless Convergence in Next-Generation Communication Networks: Systems, Architectures, and Management, Springer, 1st Edition, in progress (to be completed Nov. 2014).

[2] M. Tornatore, G. Ellinas, and G-K. Chang, "Fi-Wi Convergence: The Overall Picture", chapter in book titled Fiber-Wireless Convergence in Next-Generation Communication Networks: Systems, Architectures, and Management, M. Tornatore, G. Ellinas, and G-K. Chang (Eds), Springer Verlag, (to be published Nov. 2014).

[3] G. Ellinas, et al., "WDM-PON for Fixed Mobile Convergence", chapter in book titled Fiber-Wireless Convergence in Next-Generation Communication Networks: Systems, Architectures, and Management, M. Tornatore, G. Ellinas, and G-K. Chang (Eds), Springer Verlag, (to be published Nov. 2014).

[4] M. Tornatore, G. Ellinas, and G-K. Chang, "Fi-Wi Convergence: Future Directions", chapter in book titled Fiber-Wireless Convergence in Next-Generation Communication Networks: Systems, Architectures, and Management, M. Tornatore, G. Ellinas, and G-K. Chang (Eds), Springer Verlag, (to be published Nov. 2014).

Posters:

Three (3) posters were also presented in the KIOS 2nd and 3rd Annual Workshops and at the COST Action IC0806 IntelliCIS Second Training School. The poster information is as follows:

[1] C. Christodoulou and G. Ellinas, "Converged Optical-Wireless Access Network Architectures", KIOS 2nd Annual Workshop, University of Cyprus, Nicosia, Cyprus, 9th April 2012.

[2]. C. Christodoulou and G. Ellinas, "Dynamic Bandwidth Allocation in Integrated FiWi Access Networks", KIOS 3rd Annual Workshop, University of Cyprus, Nicosia, Cyprus, 25th June 2013.

[3] C. Christodoulou and G. Ellinas, "Converged Optical-Wireless Access Networks", COST Action IC0806 IntelliCIS Second Training School, Aachen, Germany, 4-8 March 2013.

Public talks:

[1] G. Ellinas, "Converged Fixed-Mobile Networking Transport Infrastructure for Next-Generation Broadband Access", Converged Optical-Wireless Seminar, University of Cyprus, Nicosia, Cyprus, 3rd July 2013.

[2] S. Iezekiel, "Mm-wave Radio-over-Fibre", Converged Optical-Wireless Seminar, University of Cyprus, Nicosia, Cyprus, 3rd July 2013.

[3] A. Perentos, “Silicon Photonics Filtering for Radio-over-Fibre Links”, Converged Optical-Wireless Seminar, University of Cyprus, Nicosia, Cyprus, 3rd July 2013.

[4] C. Christodoulou, “Next Generation PON based LTE Architectures”, KIOS Seminar, University of Cyprus, Nicosia, Cyprus, 25th July 2013.

[5] C. Christodoulou, “Optical Access Networks Design and Analysis”, KIOS Seminar, University of Cyprus, Nicosia, Cyprus, 22nd January, 2013.

[6] C. Christodoulou, “WDM-RING Based Access Networks for Backhauling Wireless Traffic”, KIOS Seminar, University of Cyprus, Nicosia, Cyprus, February 18, 2014.

[7] S. Iezekiel, Silicon Photonics Filtering for Radio-over-Fibre Links, University of Birmingham, UK, 27 September 2013.

[8] S. Iezekiel, Silicon Photonics Filtering for Radio-over-Fibre Links, University of Kent, UK, 26 September 2013.

[9] S. Iezekiel, Silicon Microwave Photonics for Radio-over-Fibre, Tsinghua University, Beijing, 19th April 2013.

[10] S. Iezekiel, Silicon Microwave Photonics for Radio-over-Fibre – Design and Measurement Issues, IEEE Spanish AP-MTT Chapter Talk, CTTC Barcelona, 22nd March 2013.

[11] S. Iezekiel, Silicon Photonics Filtering for Radio-over-Fibre Links, IEEE Swedish ED Chapter Talk, KTH Stockholm, 22nd November 2012.

[12] S. Iezekiel, Silicon Photonics Filtering for Radio-over-Fibre Links, IEEE UKRI MTT/ED/AP/Photonics Talk, City University, London, 5th November 2012.

[13] S. Iezekiel, Microwaves and Photonics: A Comparison, 5th IEEE Greek Student Conference, Xanthi, Greece, 6th April 2012.

Finally, Prof. Iezekiel is co-guest editing a forthcoming Special Issue on Microwave Photonics to be published in late 2014 in the IEEE/OSA Journal of Lightwave Technology.

In terms of exploitation, discussions have been ongoing with PrimeTel Plc. for possible exploitation of the work that resulted from this project. PrimeTel will evaluate the architectures/techniques/algorithms developed for possible incorporation in their network infrastructure.