**ΑΝΑΒΑΘΜΙΣΗ/ΠΑΓΙΟ/0308/30**

**"Next Generation Hybrid Optical-Wireless Communications Laboratory"**

# ANNUAL RESEARCH REVIEW 3

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## 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 third year of the project we continued with setting-up the laboratory and performing part of the experiments, as well as continuing with analytical and simulation work for the evaluation of the proposed architectures. More specifically:

We initially completed WP3 by implementing a simple tree-based WDM-PON architecture as the one shown in Figure 1.

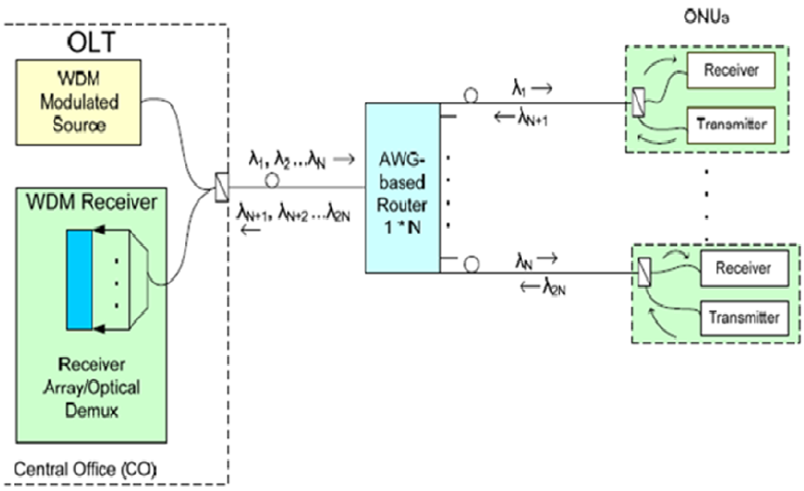


**Figure 1: Tree-based WDM-PON for test-bed implementation employing a separate wavelength channel from the OLT to each ONU, one wavelength for each of the upstream and downstream directions.**

We also proceeded to develop a ring-based WDM-PON protection architecture in WP4/WP8 that has significant advantages over the tree-based type of architectures investigated in WP 3 in terms of survivability. The experimental implementation of the ring-based protection architecture is the next step in this work.

**Protection of the EPON Ring-Based Architecture**

In the proposed hybrid ring there are 2 sections to be protected like the tree architecture. One part is the OLT to circulator and other part is the ring fiber which connects all ONUs (Fig. 2). Few protection mechanisms were proposed for tree architecture without any mention of conventional ring architecture. There are four types of protection and categories of protection are according to the sections of the network it protects. The cost of protection depends on the extent of protection. These four types (A,B,C,D) of protections vary from only the trunk to the entire network. Type A duplicates only the optical fiber between the OLT and the splitter to protect the trunk fiber. Type B duplicates the PON interface of the OLT and the trunk to protect the PON interface failure or a trunk fiber failure. It has great significance because the OLT is the center of intelligence and trunk fiber is shared by all ONUs. Any cut in trunk fiber or failure of OLT PON interface will halt the network. The protection type C duplicates every part of the optical network, from interfaces to the fibers. A failure at any point can be recovered by switching to cold duplicated region (1:1) or using hot standby line (1+1). This kind of protection is comprehensive. Type D protection goes one step further to protect in-house wiring. It is beyond the scope of our discussion.

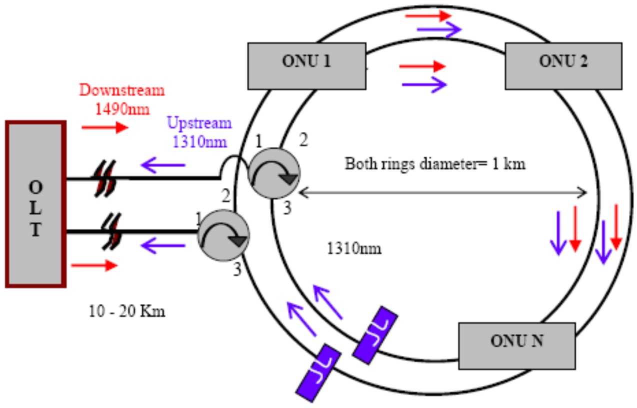


**Fig. 2. Protection architecture of hybrid EPON ring**

Since our architecture is a hybrid ring, all its fiber must be protected to ensure network protection. So, our primary concern is to protect the entire network fiber and the PON interface of the OLT. Even though it is possible to duplicate the ONU PON interfaces similar to type C protection, the expense becomes an issue. We employ the 1+1 protection in the fiber network. The advantage of 1+1 over 1:1 is that the traffic is always running on both fibers concurrently. Thus, no head-end switching is required in the case of a fiber cut, and there is no delay or packet loss associated with this type of failure protection. Furthermore, it is widely deployed and simple to implement. Along with additional transmitters and receivers in OLT, it will require twice the fiber required for the single ring operational architecture. Thus, this novel hybrid ring requires redundancy of the following: trunk fiber, ring, OLT PON interface and circulator (Fig. 2). For 1+1 protection, the ONUs are connected to two incoming and outgoing fibers, which requires internal modification of the ONUs. The rest of the architecture is almost similar to single ring operation as described above. The two incoming ring fibers are connected to the ONU 2x2 coupler/splitter and the 10% of that combined signal is dropped to the ONU downstream receiver and 90% of that signal is coupled with the ONU upstream transmitter output through a 2x2 passive splitter/coupler. Then, the combined signal splits and exits through the two outgoing rings towards the next ONU. Signals travel through all ONUs in a drop-and-go manner up to the end of the rings, where the filters terminate downstream traffic from going back to OLT. Only the upstream traffic passes through the circulators to two independent trunk fibers towards the OLT receivers. In single ring operation, the OLT has one transmitter and one receiver. The OLT is also modified for the protection scheme. Since the OLT is a single point of failure, there is redundant transmitter and receiver in it; traffic is independently transmitted from them into the two trunk fibers. Traffic of the two separate trunk fibers travels towards the circulators attached to the end of trunk to enter the two independent rings connecting all the ONUs (Fig. 2).

## Protection of WDM-PON Ring-Based Architecture

Figure 3 illustrates the self healing ring-based WDM-PON architecture. The solid lines (normal working fiber) represent the normal state architecture while the dotted lines (protection fiber) represent the redundant protection components. The protected architecture is identical to that of the normal working architecture except for the following additional components (dotted lines): i) a redundant short distribution fiber ring and a trunk fiber; ii) two 2x1 optical switches located at the OLT; iii) Automatic Protection Switching (APS) module located at each ONU.

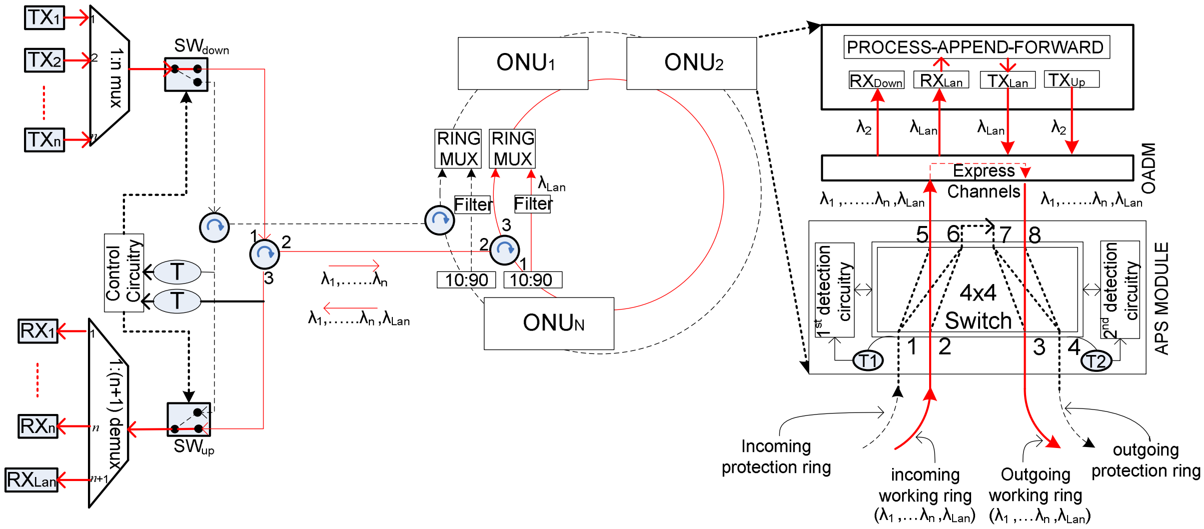


**Figure 3: Distributed self healing CWDM-PON architecture.**
**Solid Lines (normal state architecture), Dotted lines (protected state architecture)**

## Protected State Operation

The APS module attached to each ONU is the basic building block of the proposed self-healing mechanism that monitors the state of its adjacent distribution fiber paths and the ONU to which it is attached and performs both fault detection and automatic switching process. The APS module connects to both incoming and outgoing working and protection fibers. Each APS module houses a commercially available low loss 4x4 bidirectional Optical Switch (OS) that is capable of switching from any input port to any output port. It also includes two detection circuits, where each circuit comprises a band splitter (to separate the combined downstream/upstream/ LAN signal into its constituents LAN and downstream/upstream signals), a control circuit to configure the OS, and a p-i-n detector (except the first detection circuit of $ONU_1$, which has two p-i-n detectors).

The first/second detection circuit of each ONU (except $ONU_1$) is used to detect the LAN signal via taping a small portion (about 1%) of the incoming/outgoing combined signal and then passing it through the band splitter. However, the first detection circuit of $ONU_1$ is used to detect both the LAN and downstream signals via taping a small portion (about 1%) of the incoming combined signal and then passing it through the band splitter. Under normal operation, the combined signal traverses the incoming and outgoing working fibers via ports 2-5 and 8-3, respectively.

In general, we classify failure scenarios into three different classes, a trunk failure, a general distribution link failure and a general node (ONU) failure. A general distribution link is defined here as a fiber segment that connects two adjacent ONUs. All links connecting adjacent ONUs are general distribution links except the following two special links, which require different detection and recovery mechanisms: 1) the distribution fiber segment that connects the first ONU ($ONU_1$) and the circulator; this link will be referred here as the first link; 2) the distribution fiber segment that connects the last ONU ($ONU_N$) and the circulator; this link will be referred here as the last link. All nodes distributed around the ring are general nodes except the last ONU, which requires only different recovery mechanisms.

Recovery time is defined here as the time from when a failure occurs to when service is fully restored and a new cycle resumes. The total recovery time is the sum of several delay components including timeout, fault detection time, REPORT/GATE transmission time, time it takes for the REPORT/GATE message to travel from the source node/OLT to the OLT/source node, REPORT GATE message processing time, and OS time. Our initial simulation results indicate that in general, the switching time is much longer than all other delay components combined and, therefore, the total recovery time is mainly dominated by the switching time (about 10-13 ms).

During the third year work also continued on work-packages 5 and 6 that deal with the development of a radio-over-fiber (RoF) systems and on WP7 which is the integration of WDM-PON and RoF systems. For WPs 5 and 6 we continued with the experiments on the 60 GHZ Radio-over-fiber testbed that was also described in the second Annual Review (Figure 4).

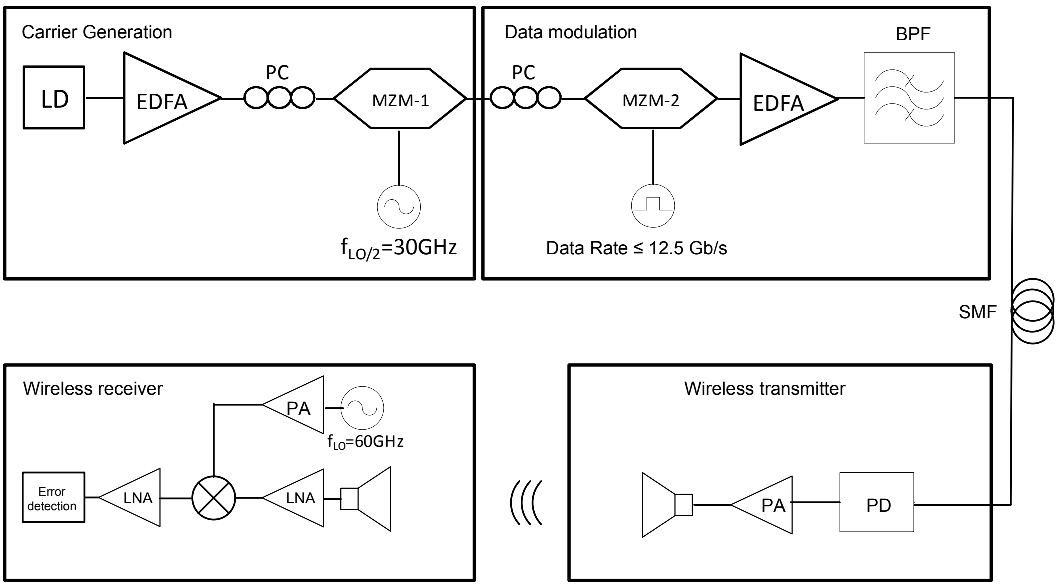


**Figure 4: 60GHz wireless RoF link (DSB-SC) for broadband wireless transmission ≤ 12.5 Gb/s**

We performed experiments using a Double Side-Band Suppressed Carrier signal (DSB-SC) and we also investigated conventional DSB modulation with insertion of an optical band-stop notch filter at the output of MZM-1 to perform carrier rejection.

Additional work on WP7 was also performed that WP7 integrated the simple tree-based WDM-PON architecture with the RoF system. This work will be expanded to include the integration of the ring-based architecture with the RoF system as well.

**Dissemination Activity**

During the third year of the project the following dissemination activities took place:

**Conference Papers:**

[1] S. Iezekiel, G. Ellinas, and A. Perentos, Integration of radio-over-fiber with WDM passive optical networks, PIERS 2012 (Progress in Electromagnetics Research), Moscow, August 2012.

**Public talks:**

[1] S. Iezekiel, Design of microwave fibre-optic links, Workshop on Advances in Optical-Wireless Communications, XXX URSI General Assembly, Istanbul, Turkey, 13th August 2011.

[2] S. Iezekiel, Microwave fibre-optics links: Design and measurement issues, IEEE SB Talk, Tel Aviv University, Israel, 5th July 2011.

[3] S. Iezekiel, Microwave fibre-optics links: Design and measurement issues, IEEE SB Talk, Technion Haifa, Israel, 4th July 2011.