ΑΝΑΒΑΘΜΙΣΗ/ΠΑΓΙΟ/0308/30

"Next Generation Hybrid Optical-Wireless Communications Laboratory"

ANNUAL RESEARCH REVIEW 2

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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 second 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 proceeded to develop a ring-based WDM-PON architecture in WP 4 that has significant advantages over the tree-based type of architectures investigated in WP 3 in terms of survivability, network resource allocation, and interconnectivity of the LAN users. We defined the architecture for this ring-based architecture and performed simulations utilizing dynamic bandwidth allocation techniques. Performance results regarding downstream transfer delay experienced in the network, downstream throughput, and required power budget are obtained. The experimental implementation of the ring-based architecture is the next step in this work.

For this work package, we investigated analytically and via simulation EPON and WDM-PON ring-based architectures. For both we performed extensive performance evaluation in terms of scalability, QoS, and survivability. A detailed analysis is included in deliverable D2 of this project.

EPON Ring-Based Architecture:
The novel ring architecture is shown in Fig. 1. A 3-port passive circulator links the long trunk fiber to a distant small ring. This small ring is a unidirectional ring which connects all of the ONUs. The OLT is 10-20km away from the circulator. The small ring is of diameter 1km. There are N ONUs on this ring. The coverage area for this architecture is similar to other architectures. The overall traffic flow in the architecture is as follows: the traffic from OLT (downstream) travels through the long trunk and enter the small ring through the circulator. Then a fraction of downstream signal power is dropped at every ONU while the signal circulates in the ring in a drop and go manner. The downstream broadcast is similar to the tree architecture, but due to architectural differences the implementation is different. The upstream traffic travel in the ring towards the circulator to reach the OLT through the trunk fiber.

The downstream traffic from OLT passes through the trunk and enters circulator port1 (Fig 1a). Then the traffic exits from the circulator port 2 into the ring. The incoming ring of an ONU (point A in Fig.1b) connects to its 2x2 passive splitter input port. The (n: 1-n) 2x2 splitter (n is a small arbitrary percentage assumed here to be 10%) splits the incoming combined (upstream and downstream) signal at each node into a small (10%) “Drop signal component” and a major (90%) “Go signal component”. The small fraction of the circulating combined signal dropped at each node (Drop signal component) is passed through a filter that removes the upstream signal and passes only the downstream broadcast signal, which is then received by the 1490-nm downstream receiver (point B in Fig.1b). If the traffic matches that ONU's address, then it is processed by that ONU; otherwise it is discarded. The upstream transmitter (1310nm) of the ONU is connected to the other input port of the 2x2 splitter. An ONU transmits its upstream traffic in a time slot assigned by OLT. It is coupled with the incoming traffic and comes out of 90% output port of 2x2 splitter (Go signal component); it becomes the ONU's outgoing ring (point C in Fig. 1b). This outgoing ring now becomes the incoming ring for next ONU on the ring. Both signals travel in the ring in drop-and-go manner and 10% of the optical signal is dropped at every ONU until they face filter at the end of the ring where the downstream signal is terminated from going back to OLT (Fig. 1a). Then only upstream traffic passes through the circulator port 3 to port 1 to enter the trunk fiber towards OLT.

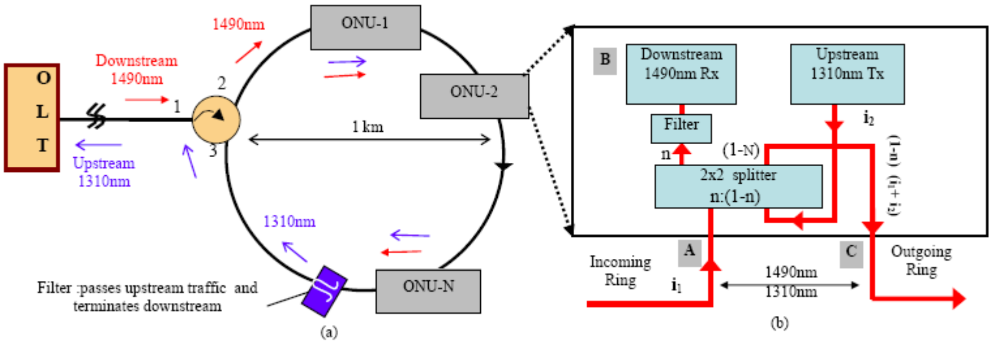

Fig. 1: a) Ring-based EPON architecture, b) ONU architecture

According to the power budget analysis, if N = 16 ONUs, the total loss (worst case) is 30.9 dB. Assuming that the signal power transmitted by the OLT is 5 dBm, a receiver sensitivity of – 25.9 dBm will be required at the last ONU. Thus, a downstream receiver with a –25.9 dBm minimum sensitivity combined with a 16.3 dB dynamic range is required to support 16 ONUs. Note that downstream power budget demands on receiver parameters are still within practical and commercial reach. Note also that the 16 nodes limit is not a shortcoming of an architecture that is specifically devised to support a private ring-based local access infrastructure within a 1 km diameter area. A typical large private organization would have at most 10-15 buildings within such geographically bounded area. To scale beyond 16 ONUs, a much higher transmitted power, highly sensitive receiver and lower components losses are required. Alternative complex solutions to support large number of ONUs by virtually eliminating the downstream power budget problem can be achieved by regeneration of downstream signal at ONUs; but that will require additional downstream transmitter at ONUs, slightly increasing the ONU complexity and cost.

Various simulations were performed for this ring-based EPON architecture utilizing a centralized and a distributed dynamic bandwidth allocation scheme. An event-driven packet-based simulation model was developed using C++. Two simulation programs with identical network parameters were developed, one for the centralized IPACT architecture and the other for the decentralized architecture demonstrating an improvement over the centralized approach in terms of average packet delay and channel utilization.

WDM-PON Ring Architecture

Figure 2 illustrates the proposed ring-based WDM-PON architecture. An OLT is connected to N WDM ONUs (this work assumes N = 16) via a 20-km trunk feeder fiber, a passive 3-port optical circulator, and a small fiber ring. To cover the same local access area as in the tree-based architecture, the small ring at the end of the trunk is assumed to have a 1-4 km diameter. The ONUs are joined by point-to-point links in a closed loop around the access ring. The links are unidirectional: both downstream and upstream signals (combined signal) are transmitted in one direction only. Each ONU is assigned a single dedicated wavelength for both downstream and upstream transmissions. Direct intercommunication among ONUs is achieved via an additional local control/LAN wavelength channel, which is terminated, regenerated, and retransmitted at each ONU. The OLT houses an array of N fixed transmitters (Tx) and another array of N+1 fixed receivers (Rx), a passive 3-port optical circulator, a flow scheduler, and a commercially available low cost thin film-based DWDM multiplexer/ demultiplexer with channel dependent insertion losses between 0.8 and 3.8 dB. Each Tx/Rx pair corresponds to one ONU and utilizes the same wavelength for transmitting and receiving downstream and upstream traffic, respectively. The extra receiver (N+1) located at the OLT is used to detect the local control/LAN channel. Each ONU has a Tx/Rx pair which is matched to the corresponding pair at the OLT and another Tx/Rx pair for transmitting and receiving the local LAN channel. In addition, each ONU houses a commercially available low cost four-port thin film filters-based fixed optical add-drop multiplexer (OADM), where two wavelengths (corresponding dedicated downstream/upstream and LAN wavelengths) are dropped and added at each node.

The DWDM downstream signal is coupled to the ring via port 3 of the optical circulator. After recombining it with the re-circulated LAN signal via a 2x1 WDM combiner (placed on the ring directly after the optical circulator), the combined signal then circulates around the ring (ONU 1 through ONU N) in a drop/add and go-through fashion. For instance, at the first ONU, the dedicated downstream wavelength channel λ_1 along with the re-circulated control/LAN channel are dropped and processed; then, the dedicated upstream signal λ_1 along with the regenerated control/LAN channel are added. Finally, at the last node (ONU 1), wavelengths λ_N and λ_{LAN} are dropped/added. Thus, the DWDM downstream signal is terminated at the last node.

The combined DWDM upstream and LAN signal emerging from the last ONU at the end of the ring is split into two components via a (10:90) 1x2 passive splitter placed on the ring directly after the last ONU. The first component (90 percent) is directed towards the OLT via circulator ports 1 and 2, while the second component (10 percent) passes first through a band rejection filter that terminates the DWDM upstream signal. The LAN signal emerging from the band rejection filter is allowed to re-circulate around the ring after recombining with the downstream signal (originating from the OLT) via the 2x1 WDM combiner. The first component of the combined DWDM upstream and LAN signal is received and processed by the array of N+1 fixed optical receivers (housed at the OLT). Specifically, each of the N upstream optical receivers detects the corresponding upstream signal and recovers the MAN/WAN traffic, while the LAN optical receiver, as will be explained below, processes the control messages and may discard or process the LAN traffic.

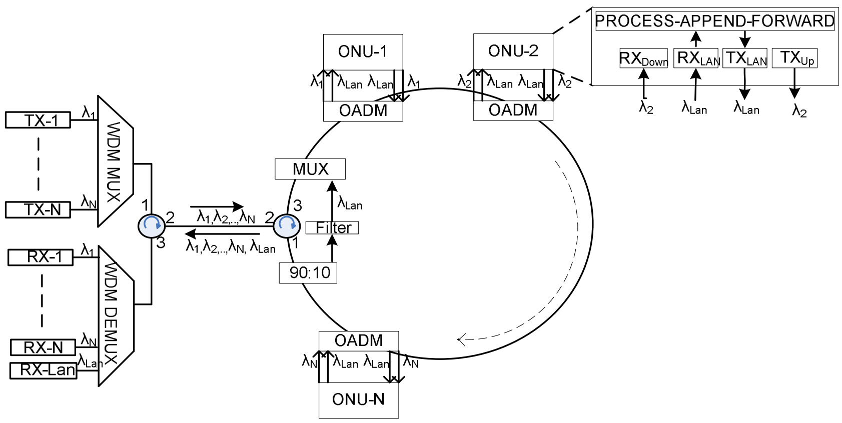

Figure 2. Ring based WDM-PON architecture

The proposed architecture supports a distributed control plane that enables intercommunication among the access nodes (ONUs) as well as signaling and scheduling algorithms and procedures that operate in a distributed manner. Supported by the distributed control plane, several resource allocation schemes that efficiently support dynamic allocation and sharing of overall fixed-mobile network resources (including downstream, upstream, and LAN wavelength channels as well as time slots) among the ONUs were developed. Simulation results were obtained on buffer sizes, downstream throughput and transfer delay.

Worst case power loss for N = 16 ONUs is about 29.1 dB. Assuming that the OLT transmitted power into the fiber is 3 dBm per channel and allowing a 2 dB power margin, a downstream receiver with −28 dBm sensitivity is required at the last ONU to support 16 ONUs.

During the second year work also continued on work-package 5 that deals with the development of a radio-over-fiber (RoF) test-bed. A number of experiments were performed in support of the work described in WP5. Specifically, experiments were performed on a 60 GHz Radio over Fiber link system is being set up for broadband wireless transmission up to 12.5 Gbps data rate. We have also performed additional experiments and simulation studies on technology that supports the development of the RoF systems. Additional experiments are scheduled for the completion of this work package (development of system using IF-over-fiber and RF-over fiber techniques and testing of the RoF picocells).

1. Development of a 60 GHz Radio over Fiber link system for broadband wireless transmission with up to 12.5 Gbps data rate.

Figure 3 shows the proposed 60 GHz Radio over Fiber link system demonstrator offering data rates up to 12.5 Gb/s. This system is based on two MZMs in cascade. The first MZM modulates a 1550 nm optical signal emerging from a laser diode and is biased to suppress the carrier producing a Double Side-Band Suppressed Carrier signal (DSB-SC). This modulation scheme has the advantage of generating the 60 GHZ carrier by applying an RF tone to the modulator of half the required RF frequency, i.e. 30 GHz. We will also investigate conventional DSB modulation with insertion of an optical band-stop notch filter at the output of MZM-1 to perform carrier rejection. This will allow a comparison to be made between the optical filtering approach and the bias-approach for carrier suppression. The generated 60 GHz signal is then applied to a second MZM, biased at quadrature and modulated by NRZ-OOK data at rates up to 12.5 Gb/s. The BPF, which will basically be the device under test, will remove the noise from the EDFA. After propagating through the fiber, the 60 GHz signal will be detected by a 70 GHz photodiode, amplified and transmitted by a standard horn antenna. An equivalent receiver antenna will detect the 60 GHz wireless signal which will undergo further amplification by an LNA and then down-conversion to baseband using a balanced mixer and an LNA for measuring the Bit-Error-Rate (BER). We are in the process of assembling this test-bed. The test-bed can also accommodate a sideband suppression filter after MZM-1 in order to create an Optical Single Sideband (OSSB) spectrum that will be more tolerant of fiber dispersion.

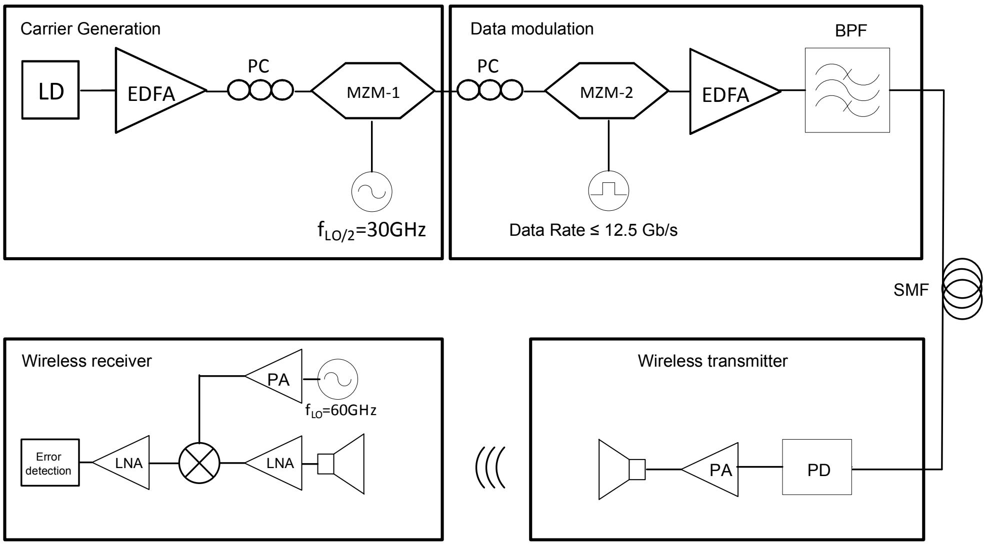

Figure 3: 60GHz wireless RoF link (DSB-SC) for broadband wireless transmission ≤ 12.5 Gb/s

2. Simulation of a 60 GHz optical carrier NRZ-OOK 1 Gb/s PRBS data modulation system

Various simulation results were obtained utilizing the VPI software simulation tool for a 60 GHz optical carrier NRZ-OOK 1-10 Gb/s PRBS data modulation system. The set-up of the system used in the simulations is shown in Figure 4.

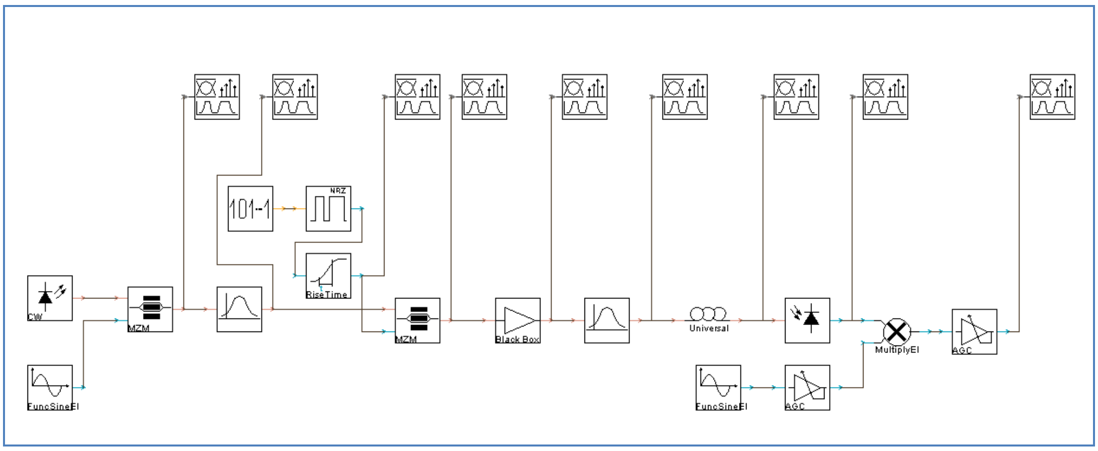

Figure 4: Set-up of the system used in the NRZ-OOK 1 Gb/s PRBS data system simulations.

Sample simulation results in terms of the eye diagrams after down conversion demonstrate that the signal can be recovered for 1 and 10 Gbps data rates and various distances (e.g., 2km, 5km, 10km) of SMF for varying bit-error-rates (BERs).

3. Simulation of a 60 GHz RoF system employing OSSB+C and DSB-SC modulation schemes

A second simulation study undertaken involved the simulation of a 60 GHz RoF system employing OSSB+C and DSB-SC modulation schemes, again utilizing the VPI commercial simulation tool. For the OSSB study we used (a) Generation of OSSB + C using a dual electrode MZM and application of a 90 degree phase shift using a Hilbert transform function, and (b) Generation of OSSB + C by applying a Parallel Coupled Ring Resonator (PCRR) shifted notch filter on a DSB + C modulated signal. Figure 5 shows as an example the model used for the generation of OSSB + C using a dual electrode MZM and application of a 90 degree phase shift using a Hilbert transform function.

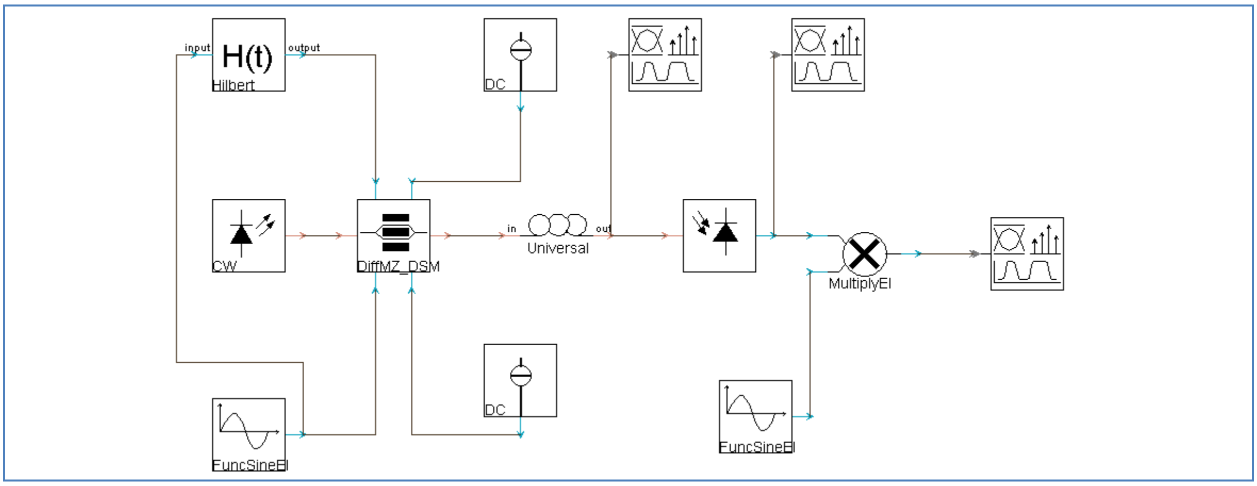

Figure 5: Model used for the generation of OSSB + C using a dual electrode MZM and application of a 90 degree phase shift using a Hilbert transform function

Simulation results show the optical spectrum of the signal after transmission through 40km of fiber and demonstrate the recovery of the 60GHz signal for the various architectures.

Dissemination Activity

In addition to the activities in Year 1, further activities in Year 2 include the following papers and presentations:

Conference Papers:

[1] S. Babiel, A. Perentos, S. Fedderwitz, B. Kunz, S. Iezekiel, and A. Stöhr, "100 GHz Band Photonic Wireless System employing Passive RoF Transmitters", Proc. International Symposium on Green Radio over Fibre and All Optical Technologies for wireless Access Networks (Growan 2011), Brest, France, June 2011.

Public Talks:

[1] S. Iezekiel, Microwave Photonics Seminar Series, Université Paris-Est - Esycom - ESIEE Paris, France, 14th – 23rd March 2011.

[2] S. Iezekiel, Microwave fibre-optics links: Design and measurement issues, IEEE SB Talk, University of Manchester, UK, 28th June 2010.

[3] S. Iezekiel, Microwave fibre-optics links: Design and measurement issues, Université ParisEst - Esycom - ESIEE Paris, France, 15th April 2010.

[4] S. Iezekiel, Microwave fibre-optics links: Design and measurement issues, IEEE SB Talk, University of Twente, The Netherlands, 13th April 2010.