ΑΝΑΒΑΘΜΙΣΗ/ΠΑΓΙΟ/0308/30

"Next Generation Hybrid Optical-Wireless Communications Laboratory"

ANNUAL RESEARCH REVIEW 1

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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 first year of the project as not all of the equipment required for setting-up the laboratory was acquired, significant work has been done analytically and via simulation for the evaluation of the proposed architectures (so that we will have a benchmark to compare against when all the experiments are conducted). More specifically:

For work package 3 (WP 3) “Development of a tree-based WDM-PON test-bed”, we investigated the problem of designing, and engineering a tree-based WDM-PON architecture. Various tree-based architectures have been investigated analytically in terms of quality-of-service (QoS) performance (required power budget, delay, and scalability) and survivability characteristics, so as to decide on a suitable architecture for the experimental implementation. The experimental implementation of the tree-based architecture is the next step in this work.

Initially, we analyzed theoretically tree-based Ethernet-based PONs specifically utilizing distributed control. An EPON is a point-to-multipoint fiber optical network with no active elements in the signal’s path. It consists of a single, shared optical fiber connecting a service provider’s central office (head end) to a passive star coupler (SC) (optical splitter/combiner), which is located near residential customers. The SC is intentionally positioned a substantial distance away from the central office, but close enough to the Optical Networking Units (ONU’s) in order to save fiber. Each customer receives a dedicated short optical fiber but shares the long distribution trunk fiber. A PON provides full-duplex operation. Traffic from an Optical Line Terminal (OLT) to an ONU is called ‘downstream’ (point-to-multipoint), and traffic from an ONU to the OLT is called ‘upstream’ (multipoint-to-point). Two wavelengths are used: typically 1310 nm for the upstream transmission and 1550 nm for the downstream transmission. The OLT resides in the central office (CO), connecting the optical access network to the metro or backbone network, where the ONU is located at either the curb (Fiber To The Curb; FTTC solution) or the end-user location (Fiber To The Building and Fiber To The Home; FTTB and FTTH). In such systems, upstream data transmission can be scheduled using static bandwidth allocation (SBA), where each ONU is pre-assigned a fixed timeslot to send its backlogged packets at the full capacity of the link. More advanced bandwidth allocation schemes are also used, where the bandwidth is dynamically allocated to different ONUs (e.g., DBA). In the downstream direction, an EPON operates as a broadcast network. The OLT broadcasts standard formatted 802.3 Ethernet frames to all ONUs. Each ONU extracts those packets that contain the ONU’s unique Media Access Control (MAC) address. In the upstream direction, EPON behaves as a timeshared network. This means that collisions may occur if two or more ONUs transmitters start transmitting frames simultaneously, or close enough, such that these frames may overlap at the combiner. Thus, the ONUs need to employ some arbitration mechanism to avoid collisions such that each ONU transmits within a dedicated time slot and the OLT receives a continuous stream of collision-free frames from multiple ONUs.

Analysis was performed in this work for a distributed tree-based EPON architecture where a portion of the optical signal power transmitted by an upstream transmitter toward the OLT is redirected back and broadcasted to all ONUs. This can be achieved by connecting two ports of a 3 x N star coupler (SC) with each other through an optical isolator. Note that in addition to the conventional transceiver maintained at each ONU, this approach requires an extra receiver tuned at upstream wavelength. A baseband direct detection circuit is needed to detect the redirected control channel in order to recover the control update information. This architecture assumes a cycle-based upstream link; a cycle is defined as the time that elapses between two executions of the scheduling algorithm. The cycle size can either have fixed, or variable length (confined within a certain upper bound) to accommodate the dynamic upstream traffic conditions. The cycle is divided into three periods; a static update period (control plane), a fixed waiting period (processing control messages and running the algorithm) and a dynamic transmission period (data plane). Simulation was performed to evaluate the performance of this architecture in terms of mean frame queuing delay, and bandwidth utilization, and we were able to demonstrate the advantages of the distributed over the centralized architectures. Furthermore, different designs were analyzed and evaluated for protection techniques in tree-based EPON architectures. Network reliability in the EPON architectures mainly involves duplicating certain part of the network and utilizing some kind of Automatic protection Switching (APS) to switch the signal to the redundant facilities when a fault has occurred and has been detected.

Various tree-based WDM-PON architectures were investigated next as the focus of this testbed is on WDM-PONs. Various architectures have been proposed in the last few years and were examined in this work. The main ones are: (a) Composite PON (CPON), (b) Local Access Router Network (LARNET), (c) Remote Interrogation of TErminal NETwork (RITENET), (d) Multistage AWG-Based WDM-PON architecture, (e) DWDM Super-PON (SPON) Architecture, and (f) SUCCESS-DWA PON architecture. CPON uses a single-wavelength, burst-mode receiver at the OLT to receive the upstream signal. Even though it avoids the drawbacks of upstream WDM, it is economically prohibitive, as it is limited to the use of a single frequency laser, such as a distributed-feedback (DFB) laser diode (LD) at the ONU. LARNET on the other hand, employs a broad-spectrum source at the ONU, in order to avoid the limitations of CPON, using an inexpensive light-emitting diode (LED) whose spectrum is sliced by the AWG-based router into different optical bands in the upstream direction. However, spectrum slicing with AWG may lead to high power loss. Therefore, the distance from the OLT to the ONU is considerably reduced. A detailed description of the architectures including their advantages and disadvantages is provided in the report for deliverable 1 of this project. For our test-bed implementation we are planning to use a simple (default) WDM-PON tree-based architecture. As it is explained later, ring-based architectures have significant advantages over the tree-based approaches so we are only planning to use the tree-based approach as a benchmark in our experiments.

During the first year work also took place for work-package 5 (WP5) 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, a number of experiments were performed on (a) technology for optical single sideband (SSB) carrier suppression based on optical notch filters was tested that will be used in a RoF system for the improvement of the dynamic range through the elimination of shot noise, (b) a 100GHz Photonic Wireless System employing Passive RoF Transmitters was tested and performance results were obtained. Additional experiments are scheduled in the second year for the completion of this work package.

1. Optical and microwave characterization in OSSB Radio-Over-Fiber system of SOI and Si_3N_4 ring resonator filters

The first part of the work involved the testing of technology for optical single sideband (SSB) carrier suppression based on optical notch filters that will be used in a RoF system for the improvement of the dynamic range through the elimination of shot noise. The first set of optical ring resonators were fabricated on both SOI and Si_3N_4 platforms.

The first step was to optically characterize these devices. We measured the transmission spectra of multiple devices and selected the "best" devices on Si3N4 and SOI. These devices were then taken for microwave characterization in a radio-over fiber system setup. We employed a technique based on OSSB modulation which uses a dual-drive electro-optic Mach-Zehnder modulator (MZM) and a Vector Network Analyzer (VNA) to act a "sweeping" RF input to the modulator. The system we have setup is depicted in Fig. 1.

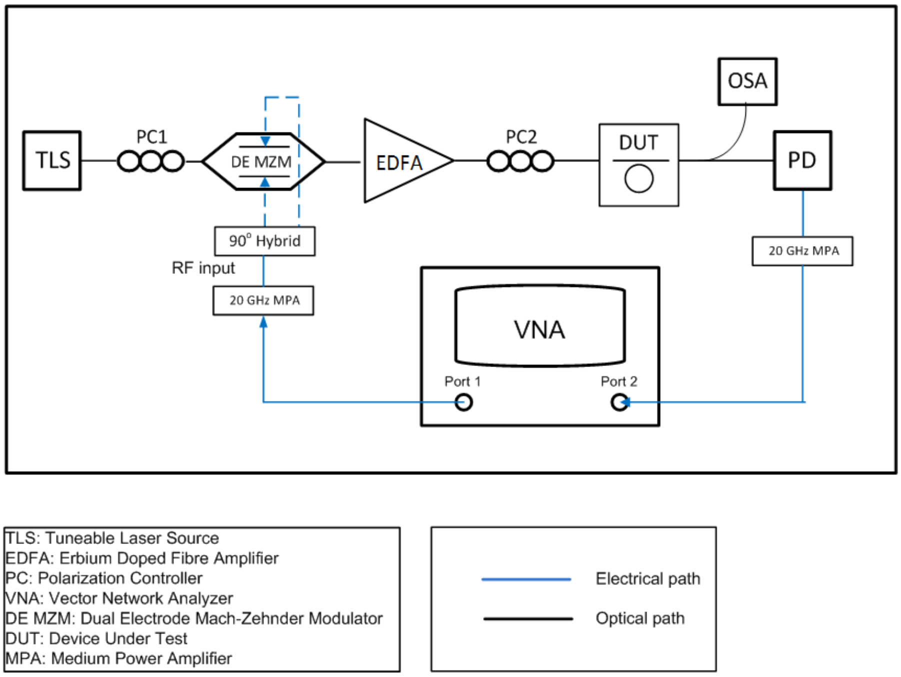

Fig.1: OSSB VNA test-bed for microwave characterization of ring resonator filters

2. Development of a 100 GHz Band Photonic Wireless System employing Passive RoF Transmitters

A compact architecture was developed for a high data rate photonic wireless system operating in the W-band (75-110 GHz). Figure 2 shows a block diagram of the system setup. It basically consists of a photonic carrier generator, an optical data modulator, as well as a passive wireless transmitter and a wireless receiver. The photonic carrier generator is composed of a 1550 nm laser diode (LD) followed by a booster semiconductor optical amplifier (BOA), a single-drive Mach-Zehnder modulator (MZM) and an Erbium-doped fiber amplifier (EDFA). The MZM in the photonic carrier generator is biased at minimum transmission point for generating double-sideband signals with a suppressed carrier (DSB-SC). The frequency of the local oscillator (LO) driving the MZM can be tuned between 35- 60 GHz. Thus, the generated wireless carrier can be tuned over the entire W-band (75-110 GHz). The data modulator consists of a second single-drive Mach-Zehnder modulator (MZM2) followed by another EDFA and an optical band pass filter (OBPF). Polarization controllers (PC) were used in front of each MZM and in front of the BOA. Also, optical isolators were used in front and behind the BOA to prevent the BOA from starting to lase because of reflections. The MZM2 in the data modulator unit is biased to the quadrature point and it is driven by the non-return-to zero on-off keyed (NRZ-OOK) data signal. The data signal is generated using a pseudo random bit sequence (PRBS) generator with a word length of 231-1 Bits. The passive wireless transmitter consists of a photodiode (PD) and a 21 dBi horn antenna. In this work, only short-range wireless communications were experimentally studied, i.e. no amplifier was used in the transmitter to keep it as simple as possible. The PD used in the RoF transmitter is a high-power waveguide PD with a cut-off frequency of 97 GHz. The wireless receiver consists of a 21 dBi horn antenna, a W-band low nose amplifier (LNA), a zero-biased envelope detector (ED), and a baseband amplifier. An error detector is used to acquire the bit error ratios (BER) of the received signals. All RF-components, like the horn antennas, the LNA, the envelope detector as well as the waveguides used for connecting these RF components are of course specified for W-Band operation.

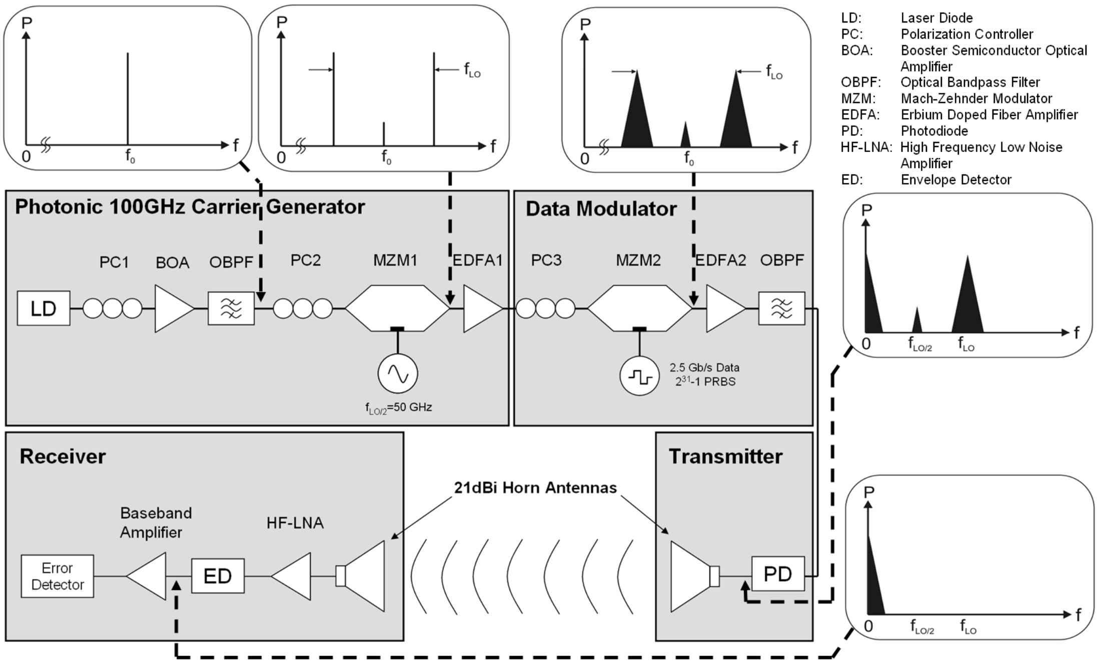

Figure 2. Block diagram of a 100 GHz photonic wireless system

By using a cascaded optical RF and data modulation approach with advanced photonic components as well as radio-over-fiber (RoF) transmission and simple NRZ-OOK modulation format, the system allows flexible adjustment of the wireless RF carrier frequency within the 75-110 GHz (W-band). In first experiments, error-free wireless transmission of 1 Gb/s and 1.25 Gb/s for a wireless span of 2 m has been achieved. The maximum system's data rate of 2.5 Gb/s is limited by the wireless receiver bandwidth. Wireless experiments were carried out in a lab environment up to 2.5 m span using a passive, i.e., amplifier-less W-band RoF wireless transmitter with an EIRP of 21 dBm. In our experiments we achieved a carrier suppression of approximately 26 dB in the photonic carrier generator. The transmitted power level was further varied using a variable optical attenuator directly in front of the PD. We have opted for amplifier-less experiments in order to be in line with the recent trend towards green photonics and green ICT.

Dissemination Activity

Dissemination of the research work has also progressed initially with the set-up of a web site that publicizes the project details and results (http://www.eng.ucy.ac.cy/gellinas/RofLab.html) Furthermore, the Photonics Laboratory web-page (http://www.ece.ucy.ac.cy/Photonics/Project/.htm) was also set up that also contains information on the research project and the laboratory in general.

Furthermore, the following related publications were completed and the following public talks took place during the first year of the project:

Conference Papers:

[1] S. Iezekiel, Design and Characterization of Microwave Fiber-Optic Links, MMS2009, Mediterranean Microwave Symposium, Tangiers, Morocco, November 2009 (Invited).

Books:

[1] S. Iezekiel (Editor), Microwave Photonics, Wiley, 2009.

Public Talks:

[1] S. Iezekiel, Design and Characterization of Microwave Fiber-Optic Links, MMS2009, Mediterranean Microwave Symposium, Tangiers, Morocco, November 2009

[2] S. Iezekiel, Traveling Wave Effects in Microwave Photonics, IEEE LEOS 2009 Annual Meeting, Belek-Antalya, Turkey, October 2009

[3] S. Iezekiel, Microwave fibre-optics links: Design and measurement issues, IEEE SB Talk, Katholieke Universiteit Leuven, Belgium, 26th May 2009.