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Bidirectional WDM-OOFDM access network based on a sliceable optical transceiver with colorless ONUs

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ABSTRACT

A WDM-OOFDM access network using a centralized optical transceiver based on a single optical broadband sliced source at the Central Office is presented as a low cost solution. Such network offers downlink and uplink signal transmission by using double sideband modulation and optical carrier re-use, as well as dynamic bandwidth allocation, multiple band selection and tunable OFDM band selection in reconfigurable networks at moderate bitrates.

1. Introduction

Orthogonal frequency division multiplexing (OFDM) is currently employed as a digital multi-carrier modulation preferred technique over optical carriers in passive optical networks (PON) due to robustness to chromatic dispersion and other impairments as well as its high spectral efficiency and flexible bandwidth allocation [1].

High definition video, multimedia applications or on-line gaming presently drive an exponential growth on high speed broadband and flexible networks deploying data rates of the order of 100 Gbps and beyond. Elastic Optical Networks (EON) have been proposed to improve the wavelength routed optical networks efficiency by offering efficient spectrum management, flexible, scalable and adaptive features [2] as has been also recently implemented in OFDM-PON networks [3].

OFDM access PONs consist of assigning sub-bands of the total signal bandwidth to optical network units (ONUs) in order to implement low-cost ONUs. Optical multiband OFDM systems have been recently proposed for a wide set of applications including dynamic bandwidth allocation in OFDMA schemes showing high granularity and flexible access to a large number of users over tenths of kilometers [4] in addition to the compatibility with both conventional time division multiplexing (TDM) and wavelength division multiplexing (WDM) passive optical networks (PONs) [5].

WDM PON networks allow to support a larger number of ONUs by simply adding wavelengths. However, WDM lasers at each ONU require temperature controllers which drastically increases the overall network cost. A solution to reduce the number of wavelengths is based on colorless WDM PON systems which allow any optical carrier from the Optical Line Terminals (OLT) transporting downstream signals to be reused for carrying upstream signals [6] and also lead to cost efficient PON architectures [7].

Previous works report architectures deploying intensity modulated and directly detected (IM-DD) optical OFDM for downlink (DL) and uplink (UL) for cost effective reasons. Examples of them employ distributed feedback (DFB) lasers [8] and vertical cavity surface emitting lasers (VCSELs) [9] which allowed to demonstrate real-time 11.25 Gb/s OOFDM transmission over 25 km SSMF-based PON systems. End-to-end real time colorless transmissions of IMDD OOFDM signals were also reported by using reflective semiconductor optical amplifiers (RSOA) intensity modulators [10], and furtherly improved REAM-IM-based system allowed to demonstrate bidirectional, real-time, colorless 10 Gb/s over 25 km SSMFs [11]. Other approaches employ RSOAs [12,13] or gain saturated SOAs [14] in the ONU. Moreover, multi-carrier sources based on external cavities [15], semiconductor mode-locked [16] or distributed feedback [17] lasers have demonstrated 10 Gb/s over 50 km and beyond by using DD-OFDM systems.

However, other approaches in the literature propose to employ DDO-OFDM for DL but deploy a coherent receiver at OLT for the UL signal transmission in order to take advantage of superior performance for UL to enable symmetric data transmission rates. Remotely seeded approaches with separate fibers [17] or employing one sideband for each DL/UL signal transmission [18] are examples to demonstrate symmetrical single-feeder, lightwave centralized OFDMA-PON architectures but a larger number of components is required as the expense

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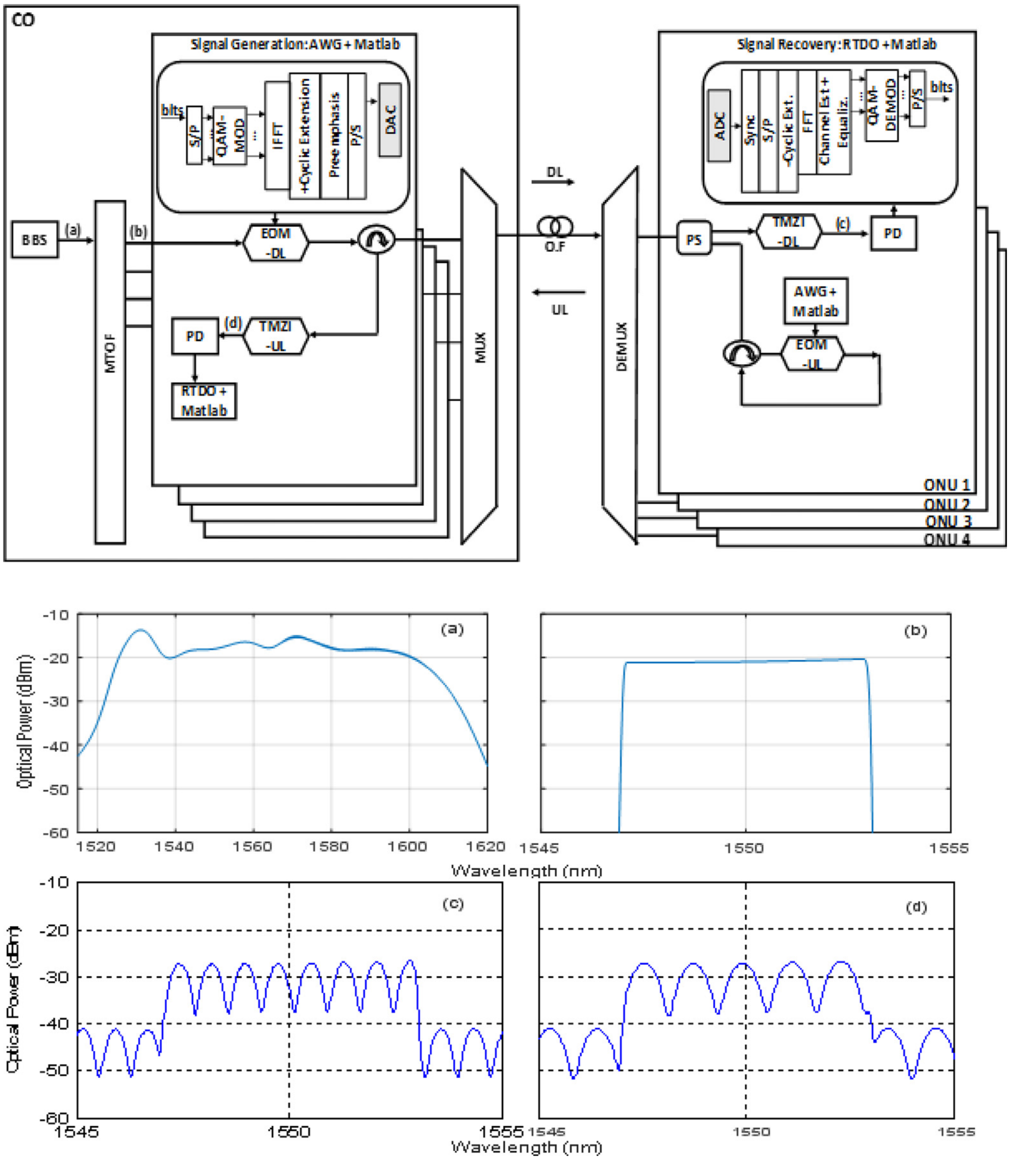

Fig. 1. Centralized bidirectional OOFDM-WDM network. Insets: Optical spectra at different marked positions along the network: (a) BBS output signal, (b) MTOF output at port 1, (c) DL-TMZI-VDL output signal and (d) UL-TMZI-VDL output signal. BBS: BroadBand Source (Optical), MTOF: Multiport Tunable Optical Filter, EOM: Electro-Optical Modulator, MUX: Multiplexer, DEMUX: Demultiplexer, PS: Passive splitter, TMZI: Tunable Mach-Zehnder Interferometers, DL: Downlink, UL: Uplink, OF: Optical Fiber, PD: Photodetector, AWG: Arbitrary Waveform Generator (RF), RTDO: Real Time Digital Oscilloscope, CO: Central Office, ONU: Optical Network Unit.

Table 1
Specifications of the required equipment in the OOFDM-WDM proposed network.

	Model	Characteristics
AWG	AWG7122C, Tektronix	Sampling rate = 24 GS/s
BBS	NP Photonics C&L Band ASE Source	Optical Power = 19.5 dBm Wav. Range = 1525–1610 nm
MTOF	Finisar WaveShaper 4000S	Wav. Range = 1527–1568 nm Steps of 77 pm Roll-off value of 0.06 dB/pm
EOM	Avanex	$V\pi$ = 5 V Insertion loss ($V\pi$) = 3.5 dB
PS	Fibercore	Insertion losses = 0.5 dB
RTDO	DPO72004C, Tektronix	Sampling rate = 50 GS/s
TMZI	Fiberco 50:50 couplersGeneral Photonics Variable Optical Delay Line (VDL)Fiberpro polarization controller	Total Insertion Losses = 4 dB Max. delay between TMZI arms = 300 ps
PD	u2t photonics BPDV2020R	Bandwidth = 40 GHz Responsivity = 0.55 A/W

for higher performance [19].

Spectrum-slicing of super-luminescent diodes (SLDs) or optical amplifiers was proposed several years ago [20,21] towards a cost-effective solution for colorless WDM-PONs besides the operating bandwidth limitation induced by the chromatic dispersion and the tradeoff between the loss budget and the sliced bandwidth.

More recently, the utilization of a tunable Mach-Zehnder interferometer (TMZI) allowed to demonstrate an OOFDM access network based on a single optical broadband source (BBS) to transmit moderate bitrates with low cost, high stability, low crosstalk operation [22] and also allowing multiband OFDM transmission in WDM networks [23]. A theoretical analysis in [24] details the potential of this optical BBS-based transmission system over a radio frequency band, also free from carrier suppression effect for any amplitude modulation format. In this paper, we explore the large potentiality offered by the BBS to implement a bidirectional reconfigurable network with dynamic bandwidth allocation, multiple bands operation and multiple users.

The paper is structured as follows: section II describes the proposed network description, section III presents the experimental results on the network performance and finally, section IV summarizes the main conclusions of the paper.

2. Network description

The proposed network employs IM-DD for both the DL and UL,