Experimental Demonstration of Elastic Optical Networking utilizing Time-Sliceable Bitrate Variable OFDM Transceiver

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Abstract: A cost-effective time-sliceable IM/DD OFDM transceiver using low-complex DSP is experimentally investigated. Slicing capabilities are tested for concurrently serving 12.5GHz channels running up to 10Gb/s variable bandwidth optical routes covering up to 185km.

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1. Introduction

Emerging cloud applications require more traffic being delivered between data centers [1]. To this end, it becomes necessary to deploy efficient network infrastructures, in terms of cost, energy consumption and reliability. Current optical networks are mostly based on dense wavelength division multiplexing, where each wavelength is used for transmitting data according a standard fixed grid [2]. However, this approach is not efficient when traffic does not occupy the whole allocated optical spectrum. An evolution is the elastic optical network that adopts the so-called flexi-grid, which uses 12.5GHz spectrum slices for adaptively allocating bandwidth variable connections and, thus, improves the spectrum usage [3]. An interesting approach is the combination of these elastic functionalities with time domain multiplexing (TDM) [4-5]. In this time-sliceable concept, several connections may share the same bandwidth and central wavelength, allowing to simultaneously serve several destinations from a single source. Thus, a unique transceiver could be sliced into several virtual transceivers, each for covering a different optical path [6].

From the data plane point of view, these functionalities are mainly enabled by transceivers featuring variable bandwidths and bit rates. Employing optical orthogonal frequency division multiplexing (O-OFDM) based on digital signal processing (DSP), the transceiver can be dynamically adapted to different modulation formats for different subcarriers, while achieving sub-wavelength granularity [7]. Among the reported DSP-based O-OFDM techniques, those based on intensity modulation and direct detection (IM/DD) constitute a cost-effective solution. Thus, an OFDM-based Flexi-grid TDM would provide enhanced networking capabilities also at a sub-wavelength level,

In this paper a hybrid time/bandwidth sliceable IM/DD OFDM transceiver is investigated across an experimental network testbed for enhancing the capabilities of flexi-grid networks. It is based on fast Hartley transform (FHT), working at different bitrates, and is capable to switch between different wavelengths in order to concurrently serve different destinations. BPSK and 4ASK modulation formats are assessed, achieving up to 2 bit per symbol for different time slots. Its performance is experimentally evaluated in the 4-node ADRENALINE network testbed, covering paths ranging from 50km to 185km.

2. Experiments and discussion

The paper proposes the use of a transceiver featuring a double sideband IM/DD with low-complex DSP based on FHT using M-ASK format, obtaining the same performance as those based on fast Fourier transform [8]. Taking it as a basis, several approaches to the flexi-grid time-sliceable networking concept are investigated.

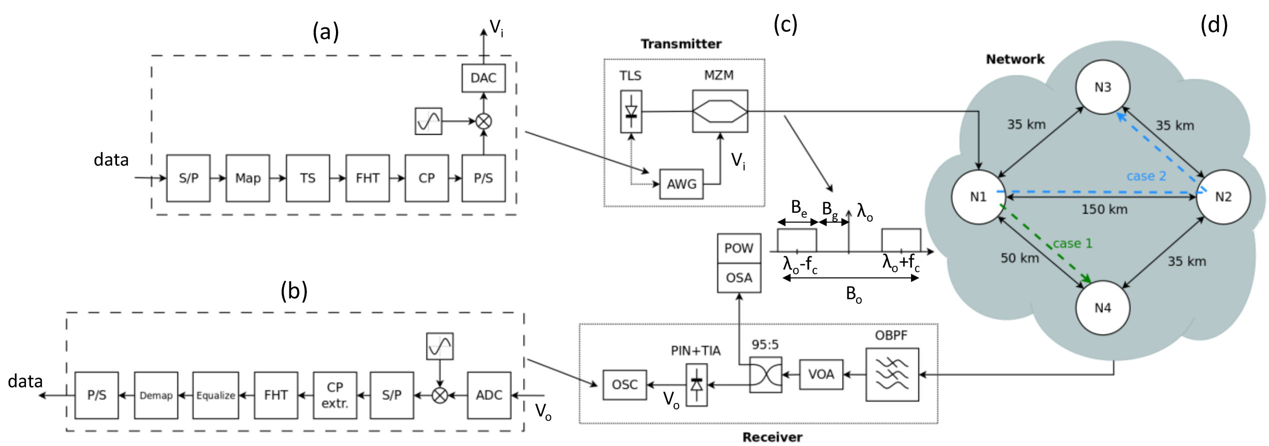

Figure 1 DSP schemes of (a) the transmitter and (b) the receiver . (c) Experimental setup. (d) Network scheme.

The basic transmission scheme is shown in Fig. 1. The DSP and electrical up/down conversion at the transmitter/receiver are performed off-line, following the steps detailed in Figs.1a-b. At the transmitter, randomly generated data are mapped into the corresponding constellation (BPSK/4ASK) and modulated by an FHT, with 64 subcarriers. The system is intended for occupying a 12.5GHz channel and, consequently, the total bandwidth of the generated optical spectrum is set to B_o=11GHz. A small guard band of B_g=±500MHz around the optical carrier λ_o is set for avoiding undesired effects from the laser emission profile. Thus, the considered electrical bandwidth occupancy for the OFDM signal is B_e=5GHz, leaving two possible gross bit rates: 5Gb/s using BPSK and 10Gb/s at 4ASK. The obtained real-valued OFDM symbols are then serialized. The digital OFDM signal is clipped and upconverted to an intermediate frequency (f_c=3GHz) by mixing with a digital oscillator. The resulting signal is converted to the analog domain by an arbitrary waveform generator (AWG) running at 12GSa/s. This analog signal is conditioned and injected to a Mach-Zehnder modulator (MZM) biased at the quadrature point and excited by a tunable laser source (TLS). The network where the experiments are carried out is the data plane infrastructure of the ADRENALINE testbed [9], whose scheme is shown in Fig.1d. There, four nodes are interconnected with 5 different links with lengths ranging from 35km up to 150km. At the receiver, the incoming signal passes through an optical bandpass filter (OBPF), for filtering out the optical noise, and a variable optical attenuator (VOA). After the VOA, a 95:5 optical coupler is placed for taking power/sensitivity measurements (POW) and for spectrum monitoring purposes with an optical spectrum analyzer (OSA). Next, the optical signal is detected by a PIN+TIA module. The detected current is IF sampled by a real-time oscilloscope (OSC) running at 50GSa/s. The OFDM baseband signal is then recovered after downconverting and low pass filtering in the digital domain. The recovered signal is off-line demodulated, equalized and demapped. Every 2048 OFDM frames, 8 training symbols are inserted for synchronization and further equalization. Bit error ratio (BER) measurements are obtained by statistical bit error counting up to obtain 10^3 errors.

The TLS employed in scenario 1 is a standard integrable tunable laser assembly (iTLA) [10], controlled by an embedded computer through RS232 bus, for generating the TDM bursts at different wavelengths. The embedded computer also gives the trigger signals to the AWG and the oscilloscope for synchronizing the data bursts. Because of RS232 bus speed, the burst time duration is limited to 30ms.

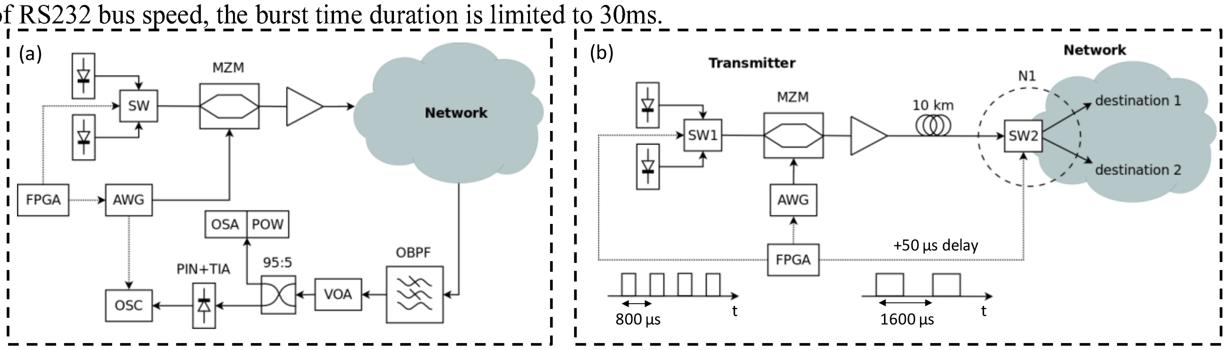

Figure 2 (a) Scheme of the experimental setup featuring the fast optical switching, controlled by an FPGA. (b) Scheme of the sliceable transmitter and the first node of the network for implementing the hybrid wavelength/time-switching networking

In scenario 2, the TLS source is substituted by an array of lasers, set at different wavelengths, which are properly combined by a 10ns PLZT optical switch (SW) for generating the desired TDM bursts [4]. This is shown in Fig.2a. An FPGA is used for delivering the control signals to the whole updated setup, including the fast optical switch and the AWG that, in turn, controls the OSC. An optical amplifier is set at the output of the transmitter for compensating the increased insertion losses. With this implementation, the duration of each burst is reduced down to 400µs.

For scenario 3, the target is to demonstrate the possibility of integrating this last approach of sliceable transceiver with a hybrid wavelength/time routed network. To that extend, a second fast switch (SW2) is integrated into the node N1 of the ADRENALINE testbed. This switch is controlled to route time slots of traffic to different destinations in the network. Furthermore, a 10km fiber spool is placed after the transmitter in order to emulate a first optical link (hop) prior to that node. The experimental setup is tuned so that the FPGA is controlling synchronously both switches and providing the trigger signal to the AWG. This is shown in Fig.2b. The switching period of SW1 is 800µs, while the signal controlling SW2 has a period of 1.6ms. This variable timing control of the switches allows for directing single or multiple time slots with arbitrary modulation formats to different destination nodes; i.e. the transceiver is able to transmit mixed BPSK/4ASK signals to different end nodes. A 50µs delay between both switching signals for compensating propagation through the 10km spool is taken into account by the FPGA.

Using the described experimental scenarios, the performance at BPSK and 4ASK formats is evaluated for specific cases. The measured figure of merit is BER versus the received power at the input of the photodetector.

First of all, scenario 1 is evaluated. Its back-to-back (B2B) performance is analyzed when switching between ITU-T channels 32 and 33 (1551.72nm and 1550.92nm). Results are shown in Fig.3a. Sensitivity values at BER 10^{-3} for channel 33 are -17.8dBm (BPSK, 5Gb/s) and -13.9dBm (4ASK, 10Gb/s). Regarding channel 32, the sensitivity values at 10^{-3} BER are less than 0.6dB away from results of channel 33. Afterwards, the transmitter is kept switching between channels 32 and 33, and the transmitter output is injected into node N1 of the ADRENALINE testbed. There, two lightpaths are simultaneously established for serving two different locations of the network. Precisely, channel 32 is routed through the link between N1 and N4, which covers a distance of 50km (case 1); while channel 33 is routed towards node N3, passing through node N2, giving a path length of 185km (case 2). For both lightpaths, all the remaining channels corresponding to the 100GHz grid are filled with CW optical sources. Results are also depicted in Fig.3a. At 10^{-3} BER for BPSK, sensitivity penalties with respect to the B2B are 1.5dB (case 1) and 2.1dB (case 2). Regarding 4ASK, sensitivity penalty at 10^{-3} BER with respect to B2B is 3.2dB for case 1, while for case 2 such BER could not be achieved. Thus, for a short distance path (case 1), both modulation formats can be transmitted successfully. For the longer path, the format is limited to BPSK and the granularity only based on the time slicing.

For evaluating scenario 2, the B2B performance is first assessed for the same channels. Results are shown in Fig.3b. Sensitivity values at 10^{-3} BER for channel 32 are -17.0dBm for BPSK and -11.6dBm for 4ASK. Note that 4ASK sensitivity is 5.4dB away from BPSK sensitivity, while for scenario 1 this difference is of 3.9dB. This is due to the additional noise introduced by the optical switch and the additional optical amplifier needed in the setup. Regarding channel 33, the sensitivity value at 10^{-3} BER for BPSK is 1.5dB away from the results obtained for channel 32, while 4ASK has a penalty of only 0.6dB. Similarly to scenario 1, a second round of experiments is performed including the ADRENALINE network. The corresponding results are also depicted in Fig.3b. The obtained sensitivities at 10^{-3} BER for BPSK exhibit a penalty of only 0.1dB (case 1) and 2dB (case 2) from the same cases reported in scenario 1. Regarding 4ASK, sensitivity at 10^{-3} BER for case 1 is 1.7dB away from the same case for scenario 1; whereas for case 2 such BER could not be achieved, limiting this modulation format to short paths.

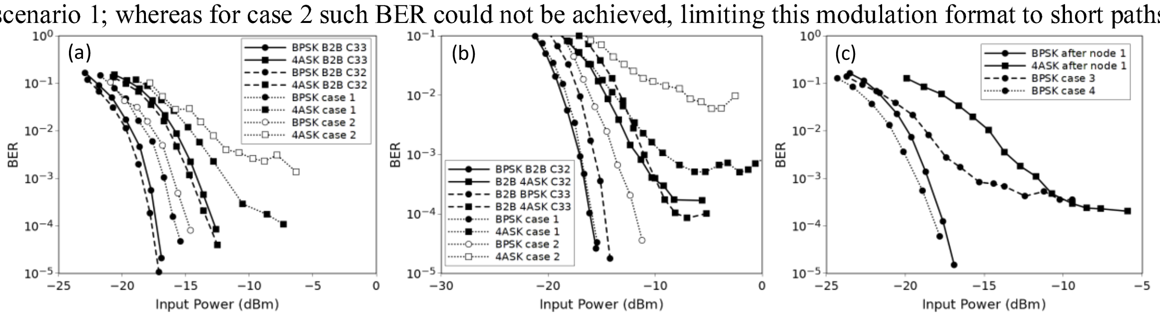

Figure 3 BER vs received power for (a) scenario 1, (b) scenario 2, and (c) scenario 3.

Experiments for scenario 3 start by characterizing both modulation formats just after SW2 for channel 33. Results are shown in Fig.3c. Sensitivity values at 10^{-3} BER are -18.4dBm for BPSK and -11.6dBm for 4ASK. Note that 4ASK sensitivity is 6.8dB away from BPSK sensitivity, 1.4dB increase with respect to B2B of scenario 2. Next, two lightpaths are established at different time slots of 800μs each, for serving two different locations of the network. Precisely, on the first time slot the signals are routed towards node N3, passing through node N2 (case 3, 10+185km); whereas on the second time slot the route through the link between N1 and N4 is established (case 4, 10+50km). In order to assess the functionality of sharing the same wavelength between two possible destinations, channel 33 is used for both the time slots transmitted towards the two different nodes. Results are depicted in Fig.3c. BPSK sensitivities at BER of 10^{-3} exhibit a penalty with respect to the characterization after SW2 of 2.9dB for case 3, while for case 4 is very similar (<0.7dB difference). 4ASK could not be successfully transmitted for both cases.

4. Conclusions

It has been experimentally investigated a time-sliceable O-OFDM system based on FHT processing, tailored for next generation elastic optical networks. Its transmission performance has been assessed in a realistic environment emulating a photonic mesh network. Results from the different approaches show successful concurrent transmission from the same source and through different routes, covering distances up to 185km.

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