High bit rate Transmission for NG-PON by Direct Modulation of DFB Laser using Discrete Multi-Tone

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Abstract *A bit rate as high as 19Gbit/s transmission was experimentally demonstrated for NG-PON without chromatic dispersion compensation by direct modulation of DFB laser using DMT signal combined with adaptive power-bit loading algorithm.*

Introduction

Fuelled by an exponentially growing demand for broadband services, a further increase of transport capacity in optical access network has to be considered. However, this implies an increase of cost of equipment with presently available technology.

Advanced modulation formats are promising for transmission bit rate increase while maintaining an acceptable cost of deployment. Recently, orthogonal frequency division multiplexing (OFDM) has been receiving enormous interest from the optical fiber transmission community. Already widespread in mobile communications, this multi-carrier modulation technique is now being proposed for optical communication in multimode fiber [1] as well as single mode fiber [2] due to its high spectral efficiency and robustness to fiber dispersion. In addition, OFDM has become extremely popular due to its efficient implementation using Fast Fourier Transforms (FFTs) to modulate and demodulate data. Furthermore, it offers the prospect of integrating forward error code (FEC) for improved transmission.

Derived from the more general OFDM modulation, discrete multi-tone modulation (DMT) is a baseband version that is already applied in large scale in xDSL (Digital Subscriber Line) and PLC (Power Line Communication) systems. We implemented DMT modulation in our recent research work, and demonstrated high bit rate transmission over SMF link for NG-PON (Next Generation Passive Optical Network) using a combination of modulation and digital signal processing techniques [3]. The bit rate was further maximized by using Levin-Campello adaptive power-bit loading algorithm [4, 6]. In this paper, we report the transmission of 19Gbit/s over 25 km and 9.7Gbit/s over 100 km of SMF fiber without dispersion compensation for NG-PON by directly modulated DFB laser. This laser is a prototype developed by 3SPhotonics and has linear properties to meet the requirements for analogue transmission.

DMT using adaptive power-bit loading

The main difference between DMT and OFDM is the possibility to adapt the modulation order as well as the power level per sub-carrier according to the corresponding channel state information (CSI) for each sub-carrier. The CSI can consist of Signal-to-Noise ratio (SNR) per sub-carrier that can be measured at the receiver side using probing signals. As a result, sub-carriers with a high SNR will be assigned more bits to transmit than sub-carriers with a lower SNR. However, the same quality in terms of bit error rate will be targeted.

In the case of PON transmission based on DMT modulation, rate-adaptive loading algorithms are appropriate to meet the constraint of the required power to modulate the laser. They consist in finding the best power combination (P_n, n=1:N) that maximizes the aggregate throughput ***b*** over the used frequency band: $b=\sum_{n=1}^{N}\log_2\left(1+\frac{P_n\cdot\mathrm{SNR}_n}{\Gamma}\right)$

where SNR_n is the signal-to-noise ratio for sub-carrier n, N is the number of sub-carriers, $\sum_{n=1}^{N} P_n$ is the fixed power budget constraint and Γ is the SNR gap to capacity inherent to the used modulation and the target symbol error rate (SER). When *m-QAM* modulation is used, the gap **Γ** can be approached by [5]: $\Gamma = \frac{1}{3}\left[Q^{-1}\left(\frac{SER}{4}\right)\right]^2$

Levin-Campello (LC) loading method [6] has proved to give a quasi-optimal solution to the optimization problem with low complexity. It takes into account the granularity and the maximum allocated number of bits per sub-channel (bitcap) requirements. Rate-adaptive LC algorithm starts with making an efficient bit distribution. This step ensures that any other bit distribution with the same throughput will require more power. A second step is margin-adaptive which consists in tightening the bit distribution. This step ensures that a bit increase cannot be fulfilled without raising the power budget.

Experimental set up and results

Fig. 1 shows the measurement set up of the DMT transmission system based on TDM-PON architecture. The DFB laser from 3SPhotonics has a bandwidth of 6.9 GHz. The laser emitted at a wavelength of 1550 nm and was modulated at 2 V_{pp}. The laser output power was 7 dBm at a voltage bias of 2.7 V. The transmission link consists of SMF fiber and a variable optical attenuator (VOA) that is used to control the received signal power and also to simulate the losses of a coupler. At the receiver, the optical signal was detected by an avalanche photodiode (APD) having a bandwidth of 8.4 GHz.

For DMT transmission, the digital DMT signal was constructed mathematically using MATLAB^{TM}. 300 DMT symbols were injected into an arbitrary waveform generator (AWG) which is used to generate the corresponding analog DMT signal at a sampling speed of 10 GS/s. The DMT signal contains 255 sub-carriers spread over 5 GHz. To overcome link dispersion, the cyclic prefix in time domain is taken to be 1/64 (8 samples). Based on the aforementioned parameters, we have a sub-carrier bandwidth of 19.23 MHz, a total symbol length of 52 ns of which 0.8125 ns is occupied by the cyclic prefix. At the APD receiver, the analogue DMT signal is captured with a real- time oscilloscope at 10 GS/s and demodulated to estimate the BER.

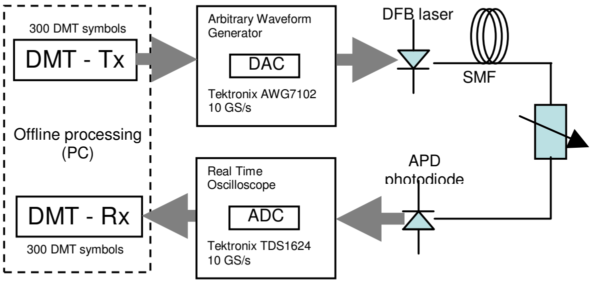

Figure 1: Experimental setup for DMT over SMF fiber. DAC: Digital-to-Analogue Converter; ADC: Analogue-to-digital Converter

The Levin-Campello algorithm implemented is described in this part. Firstly, a probing DMT signal which used only QPSK modulation with an equal power on all sub-carriers was created. This probing signal was sent through the system under test and the EVM was computed (Fig. 2(a)). The EVM result then served as an input to the LC algorithm (for a target SER = 10^{-4} which is equivalent to a bit error rate BER of $2.5\text{x}10^{-5}$ for 16-QAM). The optimized signal was then generated using the results of the optimization algorithm in terms of modulation and power level variation for each sub-carrier (Fig. 2 (b) and 2(e)). After propagation through the link, the signal performance was measured (Fig. 2(c) and 2(d)).

Fig. 3 shows the bit rate curve as a function of optical budget on the link for different transmission distances. A maximum bit rate of 19.7Gbit/s was achieved for back to back (BTB) transmission and 19Gbit/s after propagation through 25 km using DMT with power-bit loading. This bit rate decreased to 10.7Gbit/s after 75km link due to chromatic dispersion penalty. For 100km of fiber, the same bit rate as 75 km is expected if we have more optical budget to compensate for fiber losses since the two curves are superposed. The attained bit rates reported in this paper assume a target BER of 10^{-4} for all sub-carriers. Fig 3(right) depicts the received constellation diagram of 64-QAM after transmission over 40 km SMF, as an indication of the signal quality.

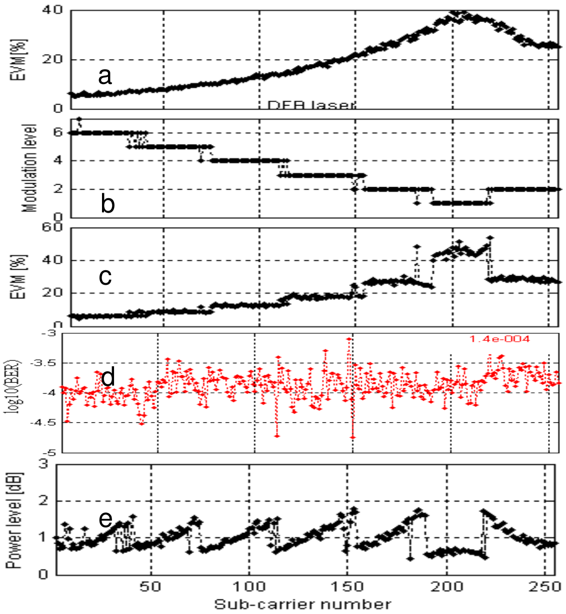

Fig. 2 Transmission results with 16.44-Gbit/s throughput for a target BER of 10^{-4} on 40 km SMF. (a): Probing EVM results (b): Bit allocation (c): Power allocation (d): EVM results of optimized signal (e): BER results of optimized signal.

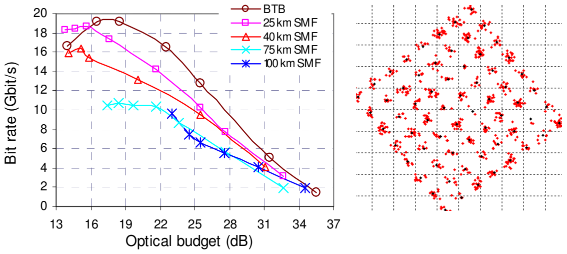

Fig. 3 Bit rate as function of optical budget for different transmission distances

Conclusions

We experimentally demonstrated high bit rate transmission using DMT modulation with adaptive power-bit loading algorithm over a linear DFB laser prototype. A bit rate of 19 Gbit/s was possible over 25km with a 5 GHz signal. Furthermore, transmission at 9.7 Gbit/s over 100 km could also be achieved without dispersion compensation. This proves that DMT technique, combined with the availability of an analogue laser is a promising solution for NG-PON.

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