Capacity optimisation for optical links using DMT modulation, an application to POF

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Abstract

The Levin-Campello algorithm optimises the capacity of communication links using DMT/OFDM modulation. We demonstrate its application to optical communications, transmitting 1Gbps through 50m 1mm step index POF.

Introduction

The ease of use of 1 mm core plastic optical fibre makes it an ideal candidate for setting-up economic, self-deployable, data communication links for residential or small business use. Several different types of 1 mm POF exist but the step index type which is the cheapest and most common exhibits bandwidth of 40 MHz x 100 m and is produced today at a price similar to that of CAT 5 cable. Products transporting Fast Ethernet over up to 100 m are now available [1] and higher data rates/distances have been demonstrated in the literature using different techniques all involving some kind of digital signal processing (equalisation, modulation, compensation) [2,3,4]. In this paper we propose to use the Levin-Campello (LC) bit loading algorithm [5] for capacity optimisation over Discrete Multi Tone (DMT) modulation to reach 1 Gbps over 50 m of 1 mm basic (single) step index POF. In severely bandwidth limited environment this algorithm is already used to adapt the capacity transmitted to the transmission media considered. This is for instance the case in Power Line Communications (PLC) [6] and Digital Subscriber Lines (xDSL) [7]. Its application to optical communications is considered here for the first time to our knowledge.

Levin-Campello bit loading algorithm

DMT modulation techniques allow for the transmission of a large number of independent sub-channels (here 511 are considered), each carrying a small fraction of the total data rate and covering a bandwidth where the propagation channel can be considered flat. Taking into account the system loss, non-linearity and bandwidth limitation, a given power budget is available, to be spread over the different channels, for reliable data transmission. Starting from a given set of powers per sub-channel P_n, the achievable total number of bits per DMT symbol is expressed as:

$$b = \sum_{n=1}^{N} \log_2\left(1 + \frac{P_n \cdot g_n}{\Gamma}\right)$$

The parameter g_n is the signal to noise ratio for a normalised transmit power equal to 1. The parameter Γ is the SNR gap to capacity associated with an error rate. The throughput can then be maximised under a constraint of a fixed power budget $P = \sum_{n=1}^{N} P_n$ through the use of optimal loading algorithms that approach the water filling solution expressed as [7]:

$$P_n + \Gamma / g_n = \text{constant}$$

Discrete loading algorithms allow parameters such as the granularity and the maximum allocated bit per sub-channel (bitcap) to be taken into account. Among these algorithms, LC algorithm [5] reaches a quasi-optimal solution with low complexity. Rate-adaptive LC algorithm starts with making an efficient bit distribution which guarantees that any other bit distribution with the same throughput requires more power. A second step consists in tightening the bit distribution which means that a bit increase cannot be fulfilled without raising the power budget. In order to implement this algorithm, an approximation of the gap Γ has to be made. The gap values given in table 1 are evaluated theoretically for different M-QAM constellations with a target symbol error rate (SER).

M	4	16	32	64	128
Γ(dB)	7.07	7.24	7.34	7.37	7.37

Table 1: Gap for a target SER=10^{-4}

The used gap within the loading algorithm here is chosen equal to 7.2 dB. The normalised SNR per sub-channel is computed from probed EVM values using an experimental set-up described below.

Experimental demonstration

An Arbitrary Waveform Generator (AWG) on a PCI card from GAGE generates the DMT signal with ~0.8 Vp-p with a sampling rate of 1 GS/s. This signal is first constructed mathematically on a PC using Matlab® and codes a PRBS sequence over a DMT modulated signal made of 512 symbols each carrying 511 carriers which can be independently modulated (BPSK to 64-QAM) and whose power can be set arbitrarily. The signal has a bandwidth of 250 MHz.

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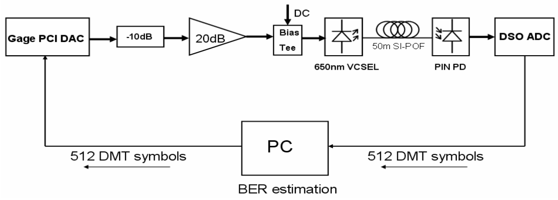

Figure 1: Experimental set-up

To avoid clipping by the D/A converter, the requested output RF power of the generator is set to -16 dBm. Once generated, the DMT signal is amplified to -6 dBm and drives a 650 nm VCSEL whose modulation bandwidth is around 1 GHz. The optical signal then passes through 50 m of Eska-Premier fibre and is detected using a standard 650 nm analogue PIN receiver. The overall 3 dB bandwidth of the system is 40 MHz. The electrical signal is subsequently captured using an Agilent DSO6104A at 2 GS/s. 968 symbols are captured (limited by the internal memory of the DSO) and post processed on a PC. BER is evaluated from the computation of the Error Vector Magnitude (EVM) of the different sub-carriers [8]. The optimisation of the system capacity via the bit loading algorithm is a two step process. First, a test signal using only QPSK modulation on all sub-carriers and where all sub-carriers have the same power is generated to probe the propagation channel. The resulting EVMs (figure 1) serve as an input to the LC algorithm which is used with a requested error rate of 10^{-4}. Then, the optimised signal is generated using the recommendation of the optimisation algorithm in terms of modulation and delta power level for each sub-carrier (figure 2). The average delta power requested is null. This signal is tested and results reported (figure 3).

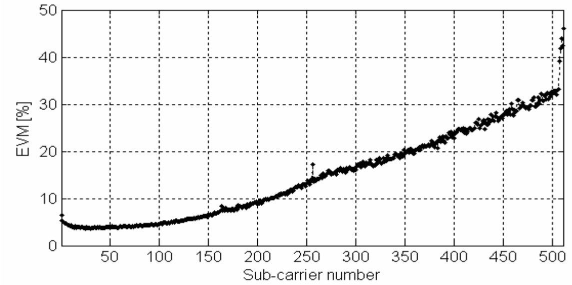

Figure 1: Probing signal EVM results

The resulting modulation levels varied from BPSK to 64-QAM. Total data rate is 1000.9 Mbps. All sub-carriers have a BER between 10^{-3} and 10^{-5} (figure 3 bottom). Average data rate is computed to be 1.2×10^{-4}.

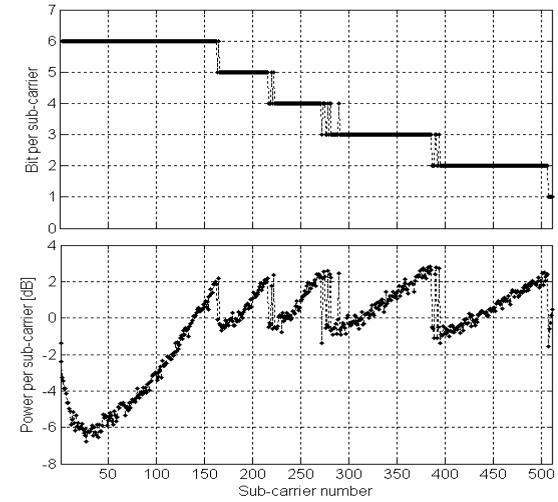

Figure 2: Optimisation results, modulation level (top) and delta power (bottom).

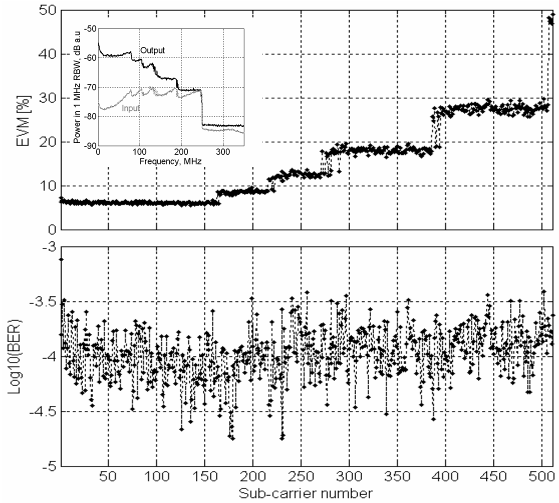

Figure 3: Optimised signal Results. EVM (top) and BER (bottom). Inlay: input and output spectra.

Conclusions

Levin-Campello bit loading technique is for the first time applied to an optical communications link. It allows the optimisation of the capacity transported under constraints of a given power budget and a target BER. 1 Gbps transmission is achieved over 50 m of 1 mm SI-POF (40 MHz 3 dB bandwidth overall).

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