EXPERIMENTAL INVESTIGATION OF RE-MODULATING
UPSTREAM OOK DATA ON DOWNSTREAM OFSK SIGNAL IN A
TWO-WAY WDM ACCESS NETWORK

Ning Deng, Chun-Kit Chan, Lian-Kuan Chen, Frank Tong
Department of Information Engineering, The Chinese University of Hong Kong, Shatin, N.T., HONG KONG.
Tel: +852-2609-8385, Fax: +852-2603-5032, Email: ndeng2@ie.cuhk.edu.hk

Abstract – We propose and demonstrate a WDM access network with downstream OFSK data and
upstream OOK data. A simple and low-cost optical network unit is realized by re-modulating the downstream
optical signal power with the upstream data; and the transmission performance is experimentally characterized.

INTRODUCTION

Wavelength division multiplexing passive optical network (WDM-PON) is a promising access technology to
deliver high capacity data to the subscribers. To facilitate the wavelength management and maintenance, a
centralized light source approach at the optical line terminal (OLT) has been previously proposed [1-3], such
that no light source was incorporated at the optical network unit (ONU). At the ONU, the upstream data
transmitter was realized by re-modulating part of the received downstream signal power. However, if the
downstream data was in on-off keying (OOK) format [2], it might induce crosstalk and degraded the
re-modulated upstream signal. Therefore, constant-intensity downstream signal is desirable for such
re-modulation scheme. In [3], optical differential phase shift keying (DPSK) modulation format was exploited in
the downstream traffic. The quality of the upstream signal was greatly improved as compared to the downstream
OOK signal case.

In this paper, we propose and investigate using optical frequency shift keying (OFSK) as the downstream
modulation format to facilitate upstream data re-modulation. A binary OFSK signal exhibits constant light
intensity with the data being carried by two closely-spaced optical carrier frequencies, each of which is intensity
complementarily modulated. With proper dispersion compensation, constant intensity can be preserved before
feeding part of the downstream signal power into the optical modulator at the ONU for data re-modulation.
Moreover, this scheme only simply requires an optical filter for downstream data demodulation. Besides, the
transmission characteristics of both the upstream and the downstream signals over a 40-km WDM-PON testbed
have been experimentally investigated and this proved the feasibility and effectiveness of the proposed scheme.

USE OF DOWNSTREAM OFSK SIGNAL FOR UPSTREAM REMODULATION

In a typical WDM-PON, traffics from the OLT are routed by one or more array waveguide gratings (AWGs)
at the remote node (RN) to different ONUs. Several approaches to realize an OFSK data transmitter have been
proposed. They include electro-absorption (EA) integrated distributed feedback (DFB) laser [4], dual-input
Mach-Zehnder modulator (MZM) with two wavelengths injection from a wide-spectrum light source, etc.
Another simple method is to employ two discrete DFB laser diodes of relatively closely-spaced wavelengths,
each of which is externally modulated by a complementary electrical data signal. By appropriately adjusting the
electrical tunable delay lines to synchronize the two complementary electrical data signals, the combined
modulated light output will be a downstream OFSK signal, which has constant light intensity.

The two wavelengths used in each OFSK signal should be chosen to be within the same passband of the
AWG at the RN, where the downstream OFSK signal is routed to a respective ONU. At the ONU, the received
downstream signal is split into two parts, in which one is fed into the OFSK receiver for downstream data
detection and the other for upstream data re-modulation. The OFSK receiver consists of a narrowband optical
bandpass filter (OBPF) followed by a photodetector. Such receiver is much easier to implement compared with
that of differential phase shift keying (DPSK) signal [3], which requires either coherent detection or optical
interferometric demodulation before direct detection. Moreover, phase information is more sensitive to
environmental changes, which makes the DPSK receiver unstable. The other part of received downstream signal
power is re-modulated with the upstream OOK data via an optical intensity modulator at the ONU, and is then
transmitted back to OLT. The two carrier frequencies of the OFSK signal, due to different group velocities in
the fiber link, may experience walk-off and the total intensity may not be kept constant after traveling for some
distances. This may induce crosstalk to the re-modulated upstream signal. In order to maintain the
synchronization between the two complementarily modulated wavelengths in the downstream OFSK signal and
to maintain the constant intensity property of the received light at the ONU, proper dispersion compensation has
to be carried out. This can improve the transmission performance of the re-modulated upstream OOK data.
We have experimentally demonstrated the proposed scheme on one particular channel in a WDM-PON for simplicity, to prove the feasibility and the effectiveness. Fig. 1 shows the experimental setup. Two light beams emitting from a DFB laser at 1553.39 nm and from a tunable laser initially at 1553.71 nm were modulated by a 10 Gb/s 2\(^{23}\)-1 pseudo random bit sequence (PRBS) and its complementary signal via their respective Mach-Zehnder modulators. The purpose of using the tunable laser for one optical carrier was to facilitate the investigation of the dependence of the transmission performance on the wavelength spacing of the OFSK signal. The wavelength difference between the two optical carriers was 0.32 nm which was much less than the channel spacing of a typical AWG with 100 GHz channel spacing. By properly adjusting the electrical delay lines, the output of the OFSK transmitter had constant intensity and it was optically-amplified to about 8 dBm, via the EDFA, prior to downstream transmission. Fig. 2 shows the respective waveforms of the OFSK signal (a) before downstream transmission, (b) after 40-km single mode fiber (SMF) transmission without dispersion compensation, and (c) after 40-km SMF transmission with pre-compensation by a piece of dispersion compensating fiber (DCF). This proved the effectiveness of using pre-compensation in maintaining the constant intensity at the ONU.

At the ONU, the received downstream power was split by a 40:60 fiber coupler, of which one output branch was connected to an OBPF, followed by a 10-GHz PIN detector. As shown in the insets of Fig. 1, the OBPF largely suppressed one of the optical carriers. The remaining optical carrier became a 10-Gb/s OOK signal and was detected with a receiver sensitivity of -17.9 dBm, which only had about 0.4-dB power penalty compared with the back-to-back 10-Gb/s downstream OOK transmission. The other part of the received downstream signal power was fed into a low-cost external modulator, driven by a 2.5-Gb/s 2\(^{23}\)-1 PRBS. The re-modulated upstream OOK signal was then fed into the upstream fiber link. We used a 40-km dispersion-shifted fiber (DSF) and operated in non-zero dispersion region to emulate the SMF link with non-fully dispersion compensation. At the OLT, the received upstream data was detected by a 2.5-GHz APD receiver. Fig. 3 also shows the measured bit error rate (BER) of the upstream data transmission. Due to the relatively small dispersion at the wavelengths around 1553 nm in the DSF, the two optical carriers did not experience too much walk-off and the upstream data only suffered from a very small power penalty (~1-dB), compared with the case of using CW laser as the optical carrier. It could be expected that if SMF had been employed as the upstream fiber link, the upstream signal quality could have been kept good provided that proper dispersion compensation was carried out.

To further characterize the OFSK signal transmission, the wavelength spacing of the two optical carriers per OFSK signal was varied and the signal quality of both the downstream and the upstream signals was examined. Such wavelength spacing (\(\Delta \lambda\)) had an upper bound (nominally, \(\Delta \lambda < 0.35\) nm), which should correspond to the passband of the common AWGs (100-GHz spaced) or similar types of wavelength demultiplexers. On the other hand, if \(\Delta \lambda\) was too small, a very narrowband OBPF might be needed. In addition, due to the non-zero rise/fall time and the non-ideal signal extinction ratio, the data spectra of the two optical carriers overlapped and interfered with each other. This greatly deteriorated the signal quality of each optical carrier, especially when \(\Delta \lambda\) was very small and the bit rate was high. Fig. 4 shows the measured BER performance as well as the power penalty curve (at BER=10\(^{-9}\)) of the downstream OFSK signal when \(\Delta \lambda\) varies. When \(\Delta \lambda\) was less than 0.24 nm, poor transmission performance in the 10-Gb/s downstream signal was resulted, mainly due to the spectral overlapping between the two optical carriers. Such spectral overlapping also led to intensity fluctuation at the ONU and thus degraded the upstream signal quality.
Fig. 2. Waveforms of downstream signals. (a) the output of OFSK generator, (b) the OFSK signal after 40-km SMF transmission without dispersion compensation, (c) the OFSK signal after 40-km SMF with DCF pre-compensation. (+ indicates zero level)

Fig. 3. BER measurements of downstream OFSK data (•), upstream OOK data re-modulated with downstream light (○) and upstream OOK data modulated with CW carrier (◦), after respective 40-km transmission.

Fig. 4. BER performance of downstream/upstream transmission and power penalty curve of the downstream OFSK signal versus the wavelength spacing between the two optical carriers of the downstream OFSK signal. Left y-axis is BER of downstream/upstream transmission and the right one is the downstream signal power penalty at BER=10⁻¹⁰.

SUMMARY

We have experimentally demonstrated a WDM-PON with 10-Gb/s downstream OFSK data and 2.5-Gb/s upstream OOK data. By re-modulating the constant intensity of the downstream OFSK signal with the upstream data, a simple and low-cost ONU was realized and good upstream signal quality was achieved. Furthermore, the OFSK signal requires much simpler receiver than the DPSK signal. Besides, the transmission performance of both the upstream and the downstream signals in relation to the wavelength spacing of the two optical carriers of the downstream OFSK signal has been experimentally investigated and the results proved the feasibility and effectiveness of the proposed scheme. This work was partially supported by a research grant from the Hong Kong Research Grants Council (Project No. CUHK4191/01E).

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