High Performance Burst-Mode Upstream Transmission for Next Generation PONs

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Abstract *This paper presents the effective optical gain achieved with FEC in 1.25 Gbit/s GPON uplink yielding -36 dBm burst-mode receiver sensitivity and 25 dB dynamic range. A low cost embedded fiber monitoring system measures fiber attenuation and locates deteriorations without interference with TDM(A) network operation or power budget penalty. Finally, a 10 Gbit/s WDM/TDMA long reach PON system is introduced.*

Introduction

After the successful development of a burst-mode PMD (Physical Media Dependent) chip set [1]-[5], a 1.25 Gbit/s GPON (Gigabit Passive Optical Network) uplink has been integrated and validated at the UGent INTEC_design Lab. This was the first public demonstration of ITU-T GPON-compliant operation at 1.25 Gbit/s and has shown very promising performance [6] [7]. To further minimize the cost per subscriber, a FP (Fabry-Perot) laser is preferred for the ONT (Optical Network Termination). As the FP multimode spectrum causes MPN (Mode Partition Noise), the ITU-T Recommendation G.984.2 proposes to use FEC (Forward Error Correction) to reduce the associated penalty. The effective optical gain achieved with FEC allows for a longer physical reach or a higher split ratio. However, the effective optical gain G in burst mode operation was unknown and is not specified in G.984.2. The first part of this paper presents how we studied MPN in the GPON upstream channel and quantified the improvements after implementing FEC in burst-mode 1.25 Gbit/s transmission.

By sharing the OLT (Optical Line Termination) and the fiber plant between many subscribers, PONs are quite cost-effective in offering large scale broadband connectivity. Once the PON is in use however, an operator does not want to shut it down to locate a fiber plant irregularity. With increasing numbers of subscribers and services, and more fiber in the last drop, there is a growing need for low cost fiber plant monitoring. Many operators monitor the data traffic and BER (Bit Error Ratio) in optical fiber networks, but physical layer monitoring is not so widespread because of its hitherto high implementation and operation costs. Classic OTDR (Optical Time Domain Reflectometry) techniques are invasive, require the network to be shut down, and/or rely on expensive equipment that cannot be embedded in low cost ONTs. The second part of this paper reports an innovative FIBERMON™ system designed for low-cost physical layer monitoring in operational fiber networks. FIBERMON™ operates in the background, and can provide round-the-clock verification of the integrity of the fiber plant, and a quick and precise identification and localization of link deterioration without interference with ongoing services [8].

Finally, the EU-funded IST project PIEMAN (Photonic Integrated Extended Metro and Access Network) [9] is introduced. The project performs ambitious physical layer research into a future broadband optical access and metro system with capacity and reach well beyond what is achievable today.

GPON uplink performance with FEC

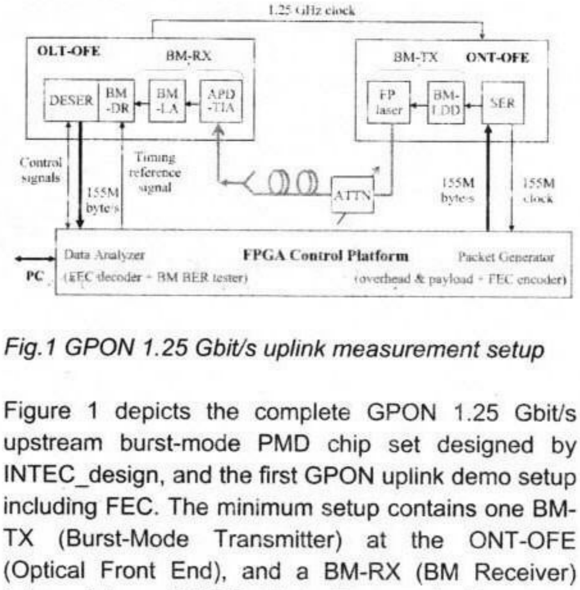

Fig.1 GPON 1.25 Gbit/s uplink measurement setup

Figure 1 depicts the complete GPON 1.25 Gbit/s upstream burst-mode PMD chip set designed by INTEC_design, and the first GPON uplink demo setup including FEC. The minimum setup contains one BM-TX (Burst-Mode Transmitter) at the ONT-OFE (Optical Front End), and a BM-RX (BM Receiver) followed by a BM-DR (Data Recovery) chip at the OLT. The BM-TX contains a cheap FP laser diode and a BM-LDD (Burst-Mode Laser Diode Driver) [5]. The ONT SER (Serializer) adds a programmable delay with bit accuracy to align the launched bursts with the ongoing traffic at the OLT. The 155 Mbyte/s parallel data outputs from an FPGA-based packet generator are serialized to generate a 1.25 Gbit/s burst-mode data stream after a FEC encoder with Reed-Solomon code RS (255, 239). The BM-RX contains a high sensitivity burst-mode APD-TIA (Transimpedance Amplifier) and a wide dynamic range BM-LA (Limiting amplifier) designed for instantaneous packet amplitude recovery [4]. The

BM-DR IC contains the high-speed blocks of the line termination and includes the DESER (Deserializer) function. It performs the upstream retiming i.e. the CPA (Clock Phase Alignment) and the burst alignment via delimiter detection. The FPGA-based data analyzer measures the BM-BER from recovered incoming packets after a RS (255, 239) decoder.

FP lasers (wavelength around 1310 nm) were used for experiments to investigate the effective optical gain with FEC. The effective optical gain G of the system employing FEC is defined as the difference of optical power at the receiver input, with and without FEC, for a BER = 1×10^{-10}. No notable MPN penalty is observed even with 20 km G652 fiber, when the central wavelengths of the FP lasers used are within the zero dispersion window of the fiber (1302~1322 nm). However, ITU-T G.984.2 specifies the ONT transmitter operating wavelength in the range of 1260-1360 nm, so in worst case the MPN penalty cannot be negligible. To emulate such a condition by lack of a suitable 1360nm FP laser, 3.1 km of G653 DSF (Dispersion Shifted Fibre) with dispersion of -20 ps/nm.km at 1307 nm was inserted into the uplink. This is equivalent to the dispersion of a 1360 nm FP laser over 12 km G652 fibre with dispersion of 5 ps/nm.km. Fig. 2 plots the measured BM-BER (at APD gain=6) of the GPON uplink with 3.1 km DSF fiber where B1 and B2 denote OLT-OFE Board #1 and Board #2 respectively. This illustrates the penalty caused by the MPN, and also the error correction capability of the RS (255, 239) code.

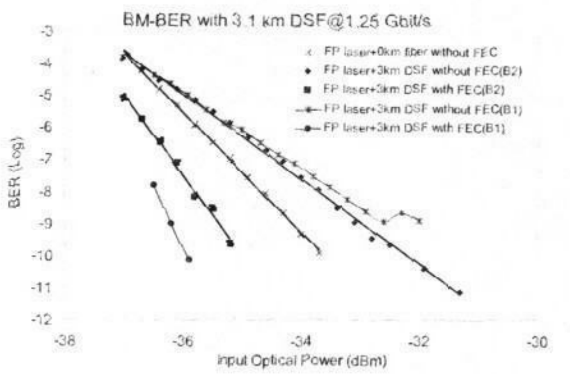

Fig.2 Measured BM-BER with & without FEC

Table 1 Different effective optical gain G

Fibre (km)	FEC gain	RX sensitivity (dBm)
20km (G652)	no FEC	-33.6 (DFB)
20km (G652)	G=2.6 dB	-36.2 (DFB+FEC)
20km (G652)	no FEC	-33.0 (FP)
20km (G652)	G=2.7 dB	-35.7 (FP+FEC)
3.1 (G653 DCF)	no FEC	BER floor > 10^{-9} (B1)
3.1 (G653 DCF)	G >> 3 dB	-36 (OLT #B1)
3.1 (G653 DCF)	no FEC	-32.1 (OLT #B2)
3.1 (G653 DCF)	G=2.9 dB	-35 (OLT #B2)

Table 1 summarizes the measured effective optical gain G on the GPON uplink. A gain of 2.6~2.9 dB was found which depends on two factors: the slope of the BM-BER curve and the distribution of the errors (burst or discrete). Note that the slope of the BM-BER curve is very sensitive to the performance of the upstream PMD components such as the BM-LA and BM-DR. Any small difference due to settings, tolerances and DC offset will have influence on the characteristic of the error distribution. To conclude, experiments prove that the FEC with RS (255, 239) code can reduce the penalty due to MPN when using a cheap FP laser in the upstream direction. However the BM-RX overload specification is not altered by FEC gain. This guarantees both the high sensitivity and wide dynamic range of the BM-RX, which allows to extend the PON reach or to nearly double the number of subscribers in a given PON network.

A low cost fiber monitoring system

An embedded, non-intrusive fiber monitoring system called FIBERMON™ [8] has been developed for low-cost physical layer monitoring in operational fiber networks. Two major benefits that cannot be met by classic OTDR, nor by any alternative "embedded" OTDR system that was published, are:

1). The cost of the FIBERMON™ system is low. This is especially critical for PON ONTs. The analog front-end electronics of FIBERMON™ can be embedded inside every subscriber ONT as shown in Fig. 3, and there is no need for additional optical components such as an optic coupler or an OTDR PIN photodiode.

2). The presence of the FIBERMON™ system does not have any negative impact on the upstream optical power budget and network/system performance. The FIBERMON™ system measures and detects optical reflections but it does not interfere with the data traffic carried by the optical fiber plant, nor with the MAC (Media Access Control) functionality.

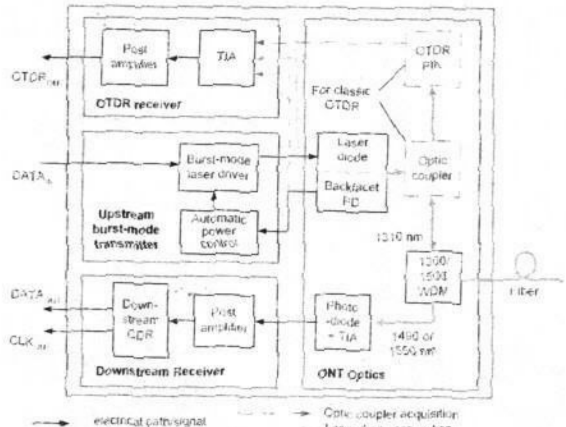

Fig.3 OTDR receiver integrated into an ONT without additional optical components

The FIBERMON™ system can make full use of resources that are already available in an operational fiber network, such as the data laser diode(s), and the data light bursts themselves. An optical echo signal caused by an optical burst or pulse can be extracted electronically from both a laser diode or a laser back facet photodiode, without any need to physically interrupt the optical link or to introduce extra optical components. For this purpose, dedicated OTDR RX front-end electronics (a slow speed TIA and a post amplifier) can be integrated into the burst-mode laser driver chip, feeding a small off-chip DSP (Digital Signal Processing) unit. The OTDR measurements are performed at the exact wavelength and modal distribution of the data pulses, and so can be very accurate.

The complete OTDR measurements can be performed passively, without the need to inject specific OTDR signals into the network. As is proven by recent INTEC_design research, the optical echo's caused by ongoing burst-mode data transmissions contain suitable information to perform OTDR measurements. Innovative FIBERMON™ signal processing allows one to extract complete OTDR curves by combining optical reflection measurements taken in different time windows and originating from different data bursts. In the background, and completely transparent for any MAC function, FIBERMON™ composes valuable information such as the fiber attenuation as a function of distance, the location of abrupt changes in the optical attenuation or reflection as caused by connectors, breaks, fiber joints, stress points etc., and the strength and nature of such changes. The only requirement on the system is the occasional occurrence of a "dark" time window after data transmission, during which optical reflections can be observed.

Next generation 10 Gbit/s WDM/TDMA PON

The PIEMAN project proposes a new photonic communication system [10] integrating access and metro into a single network with a reach of 100 km between customers and the major service node. PIEMAN is aiming at 32 wavelength channels and symmetric 10 Gbit/s data rates in both downstream and upstream direction. EDFAs (Erbium-Doped Fiber Amplifiers) will be employed at the local exchange and as a preamplifier in front of the PON OLT as shown in Fig. 4, to achieve the required optical power budget. Up to 512 customers will share each 10 Gbit/s wavelength. Currently a 10 Gbit/s BM-TIA and a BM-LA with high sensitivity and wide dynamic range are under development (by IMEC / INTEC_design). A major challenge is achieving upstream burst mode operation of a high-split, amplified PON at 10 Gbit/s with 100km reach.

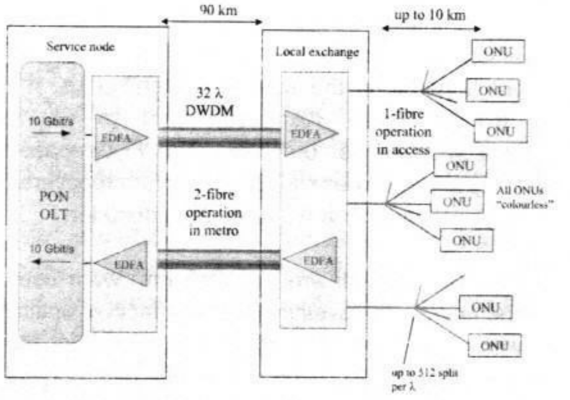

Fig.4 The PIEMAN WDM/TDMA system architecture

Conclusions

Several advanced techniques are presented in this paper to improve the performance of next generation high speed high split PONs. We demonstrated for the first time that an APD based BM-RX can simultaneously achieve -36 dBm sensitivity and 25 dB dynamic range by employing FEC with RS (255, 239) code when a cheap FP laser is employed. Secondly, the low cost, embedded FIBERMON™ system is introduced, designed for non-intrusive fiber plant monitoring, especially in PON drop sections after the split. Finally, an ultra high capacity hybrid WDM/TDMA network is introduced with 100km reach, based on 32 DWDM wavelengths. Each wavelength is shared by up to 512 customers and carries 10 Gbit/s, yielding an aggregate 320 Gbit/s data rate and connecting up to 16384 subscribers.

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