Study of Orthogonal Modulation Schemes for Passive Optical Access Networks.

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Abstract. In this thesis, the potential of upgrading Passive Optical Networks in order to increase available bandwidth and expand in services and number of users is studied. The upgrade is feasible through the adoption of orthogonal modulation techniques –used in other types of networks- adapted adequately to the specific needs of a passive optical network. At first, it is investigated and recorded the status of access networks and the technologies used so far as well as the benefits of fiber optics in the access "part" of a network. Furthermore, we evaluated through numerical simulations the use of orthogonal modulation techniques in future passive optical networks. The results of the simulation process lead to the experimental investigation of the transportation of two optical signals on the same optical carrier. Laboratory experiments showed that the use of orthogonal modulation in future passive optical networks is feasible and help us upgrade the already installed networks. Finally, the technological and economical aspects of the passive optical networks upgrade has been investigated and cost elements of this upgrade has been reported, based on the use of IM/FSK technique.

Keywords: Passive optical networks, orthogonal modulation technique, extinction ratio, bandwidth, optical carrier.

1. Introduction

Passive optical network (PON) is emerging as the most promising FTTH technology to meet the ever-increasing bandwidth demand, by using the minimal number of optical transceivers and fiber deployments. Depending on bandwidth and network requirements, several access techniques have been proposed so far. The majority of these PON architectures, is based on wavelength-division-multiplexing (WDM) [1] and/or time-division-multiplexing (TDM). In conventional WDM-PONs, each ONU (Optical Network Unit) requires a fixed specific wavelength

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∗ Dissertation Advisor: Dimitris Syvridis, Professor laser or a tunable one increasing the cost and the complexity of the PON implementation. On the other hand in TDM-PONs all ONUs are sharing one laser making this architecture cost-effective but at the same time restrictive and power sensitive due to the use of an optical splitter. Recently a hybrid WDM/TDM PON scheme has been proposed [2] in order to make more efficient use of advantages offered by different architectures.

Formulating a PON deployment strategy to satisfy varying service requirements can be a complex undertaking. Multiple PON technologies [3] such as Broadband PON (BPON), Gigabit PON (GPON), and Ethernet PON (EPON) currently exist or are near standardization, and multiple deployment models are possible. Technology maturity, system availability, operational considerations, video compression performance, service requirements, engineering rules, and business impacts all need to be taken into account in order to deploy PON.

Moreover, the continuously increasing need for more services and quality of service as well, increase bandwidth requirements. Service providers throughout the world are recognizing that a competitive triple play (voice, high-speed data, and video) service offering is essential in order to offset declining voice revenues and enhance profitability. In the near future [4] the guaranteed bandwidth per user is estimated to be more than 75 Mbps. Therefore, we need to expand and upgrade network capabilities of an already existent optical access network in order to support the increasing subscribers needs, ensure higher bandwidth utilization and at the same time, more efficient use of resources.

In this thesis, a new PON architecture based on the use of orthogonal modulation formats in a standard passive optical access network, offering an additional data stream, without increasing the cost and the complexity of the existent network, is presented. The proposed system architecture is analyzed and investigated through numerical and experimental evaluation. In the numerical evaluation two implementation schemes are examined. The first one, combines intensity modulated (IM) information along with FSK and the second one IM with DPSK modulated bit streams. Concerning the experimental investigation the tested scheme combines IM and FSK modulated information. The results of the numerical evaluation and the experimental investigation prove the feasibility of the proposed scheme. Finally, in this thesis the economic aspects of the passive optical network upgrade have been evaluated.

2. Proposed Architecture System Description

A schematic diagram of the proposed architecture is shown in figure 1 illustrating the main functional blocks of the optical line terminal (OLT) and the optical network unit (ONU) which consist the investigated passive optical network. The aforementioned proposed architecture is implemented incorporating two schemes. Both schemes, introduce the idea of two orthogonally modulated bit streams on the same optical carrier for the downstream direction path. The first one is a combination of IM information with FSK modulated bit stream and the second one is IM combined with DPSK. The OLT, in both cases (IM/FSK and IM/DPSK), has a simple configuration making it an attractive solution for the implementation, or future upgrade of a passive optical network. In the IM/FSK case, it consists of a directly modulated DFB laser (~5mW average optical power). The FSK is realized by chirping, through direct modulation, the laser transmitter according to the typical OFSK transmitter realization approach [5]. Additionally an already proposed [6] FSK compensation scheme incorporating an electroabsorption modulator (EAM), has been applied in order to remove the residual intensity modulation at the output of the DFB laser. At the output of the EAM the FSK signal is fed to a Mach Zehnder (MZ) amplitude modulator working at a low extinction ratio, in order for the second bit stream to be IM encoded along with the FSK on the same optical carrier. The DFB laser basic parameters are shown in table 1.

Length	270 μm
Width	3 μm
Height	0.2 μm
Confinement factor (Γ)	0.3
Electron Lifetime (τ_e)	2.1ns
Linewidth enhancement factor	6.0
Group refractive index	4.0
I_{th}	22mA
I_{bias}	45mA
I_{mod}	6mA

Table 1. Basic parameters of the FSK transmitter DFB laser

On the other hand in the setup consisting of IM along with DPSK, instead of using a DFB directly modulated laser, it uses CW laser (~5mW average optical power) followed by a phase modulator with π as modulation depth. As in the IM/FSK case, the DPSK signal is fed to a MZ amplitude modulator for the combination of the two orthogonally modulated bit streams.

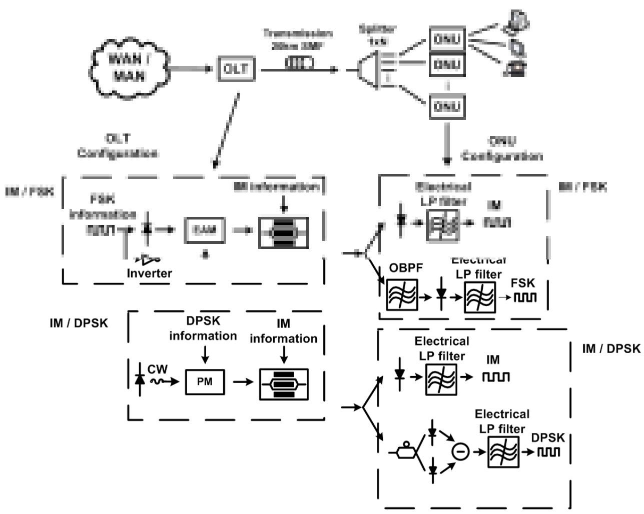


Fig. 1. Schematic diagram of the proposed architecture.

Finally concerning the transmission of the signal form the OLT to the ONUs, a standard 20km single mode fiber is used.

attenuation	0.2dB/km
Dispersion	16ps/nm/km
Dispersion slope	80fs/km/nm^2

Table 2. Basic parameters of the transmission standard single mode fiber

In both schemes (IM/FSK and IM/DPSK), one of the most crucial parameters that determines the performance of the system is the extinction ratio (ER) of the intensity modulated signal. The ER of the IM bit stream must be kept at a low value (around 3dB in our simulation models) in order for the orthogonal to the IM bit streams (DPSK or FSK) to have satisfactory BER performance. This has a detrimental effect on the IM signal especially in the case when the received power is in the range of receiver sensitivity, where the thermal and shot noises of the photodiode become critical concerning the IM performance.

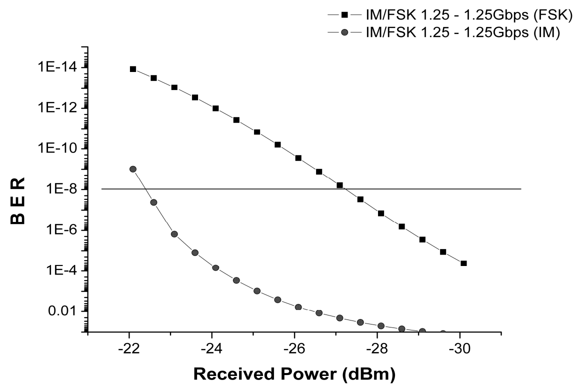
At the ONU side (receiver), part of the signal is fed to a square law detector in order to read the IM modulated information and the rest of the signal is either filtered by a Gaussian 10GHz optical bandpass filter and then detected by a direct detector in the case of FSK, or detected by a differential detector in the case of DPSK followed by the appropriate electrical low pass.

3. Simulation Results

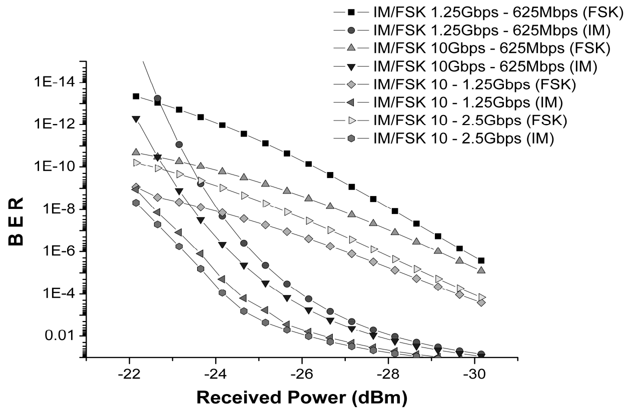
The performance of the aforementioned architecture using two orthogonal modulation schemes has been evaluated for various combinations of bitrates. In order to achieve satisfactory results and prove the feasibility of this architecture and to determine the parameters of the system, numerous simulations have been carried out. Concerning the IM modulated information 1.25Gbps and 10Gbps modulation bitrates were examined, while on the other hand, concerning the DPSK and FSK information the investigated bitrates were 625Mpbs, 1.25Gbps and 2.5Gbps. The transmission module consists of 20km of SSMF. Following the SSMF a star coupler splitting the signal to 128 parts, is used in order for the signal to be distributed to different ONUs. Due to the fact that both schemes have identical behavior, the simulation results presented in this document refer to the IM/FSK scheme.

3.A. IM/FSK scheme

The bitrates that were simulated are 1.25Gbps and 10Gbps for the IM information and 625Mbps, 1.25Gbps and 2.5Gbps for the FSK modulated information. Using combinations of the aforementioned bitrates, numerous simulations have been performed in order to evaluate system's feasibility, performance and limitations. System's performance has been tested in respect with the received optical power at the ONU and the crosstalk induced to the IM signal by the FSK one and vice versa.



a)



b)

Fig. 2. BER of IM and FSK modulated signals vs. received power. a) for IM/FSK with the same bitrates (1.25Gbps), b) for various bitrate combinations.

Figure 2 illustrates BER performance of the IM and FSK signal versus the received optical power at the ONU. The performance of the IM signal (in both figures 2a and 2b) is heavily degraded as the received power decreases. This is attributed to the low extinction ratio value of the IM (around 3dB) needed, in order to preserve satisfactory results for the FSK modulated signal and reduce the crosstalk caused by the IM information (as it is illustrated in the following figures). On the other hand, the performance of the FSK modulated signal decreases gradually by decreasing the received optical power, however it maintains the BER performance above 10^{-9}. The power penalty induced between the two signals (at BER 10^{-9}) is approximately 5dB, especially in the case where the IM and the FSK have the same bitrate. This is also illustrated in figure 3, where the eye diagrams of the IM and the FSK signal are presented.

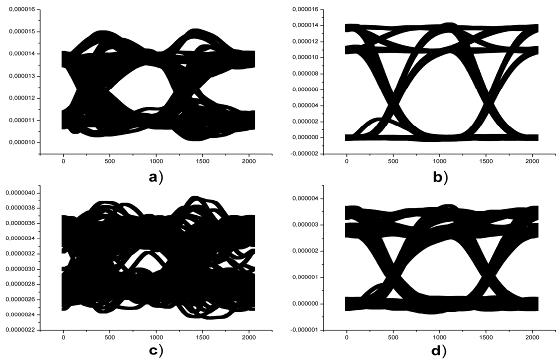


Fig. 3. Eye diagrams of the intensity modulated and the FSK modulated signals in two received power levels: a) IM eye diagram at 10dB above receiver sensitivity, b) FSK eye diagram at 10dB above receiver sensitivity, c) IM eye diagram near receiver sensitivity, d) FSK eye diagram near receiver sensitivity.

In 3a and 3b the eye diagrams correspond to received power around 10dB above receiver sensitivity ensuring BER performance above 10^{-9}, while on the other hand 3c and 3d, correspond to optical power around receiver sensitivity.

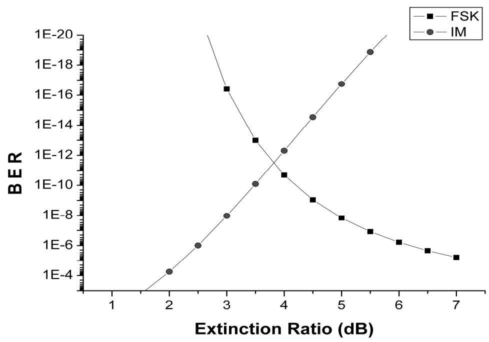


Fig. 4. BER performance of the IM and FSK signal vs. extinction ratio in the IM/FSK scheme with bitrates 10Gpbs and 625Mbps respectively.

One of the most critical parameters of an orthogonally modulated scheme is the ER value of the IM signal, as already mentioned. Figure 4 illustrates the BER performance of both IM and FSK signal versus the ER value of the IM. As the ER value increases the performance of the IM signal is getting better while on the other hand the one of the FSK deteriorates due to the amplitude noise (crosstalk) induced to the signal by the IM information.

Concerning the crosstalk induced to the IM signal by the FSK one, in order to eliminate it, an already proposed FSK compensation scheme [6], has been applied on the FSK transmitter, as already mentioned. According to this scheme (see fig. 1), the optical FSK data are fed to an external electroabsorption (EA) modulator, which accepts the optical FSK data, while at the same time is driven with the inverse electrical data, thus removing the intensity variations at the output of this transmitter and minimizing the residual intensity modulation effect (crosstalk) on the IM signal when they are coupled together. The effect of the residual intensity modulation of the FSK signal, is illustrated in figure 5, where the time traces of the two bit streams (FSK and IM) are shown with and without the compensation scheme along with eye diagrams for the IM in both cases.

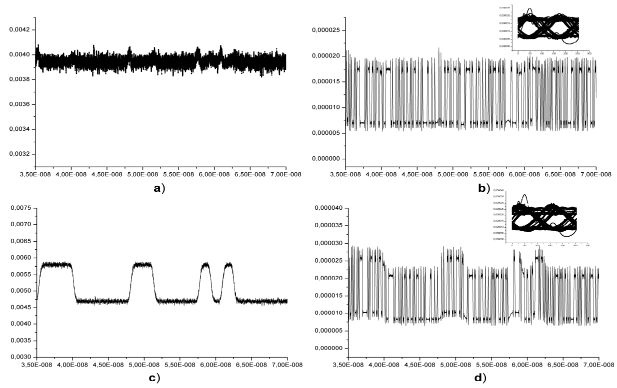


Fig. 5. Time series of a) FSK signal with the compensation scheme, b) IM signal with compensation scheme, c) FSK signal without compensation scheme and d) IM signal without compensation scheme.

4. Experimental Investigation

A long with the simulation, the proposed method has been experimentally investigated. A schematic diagram of the experimental setup is shown in the following figure.

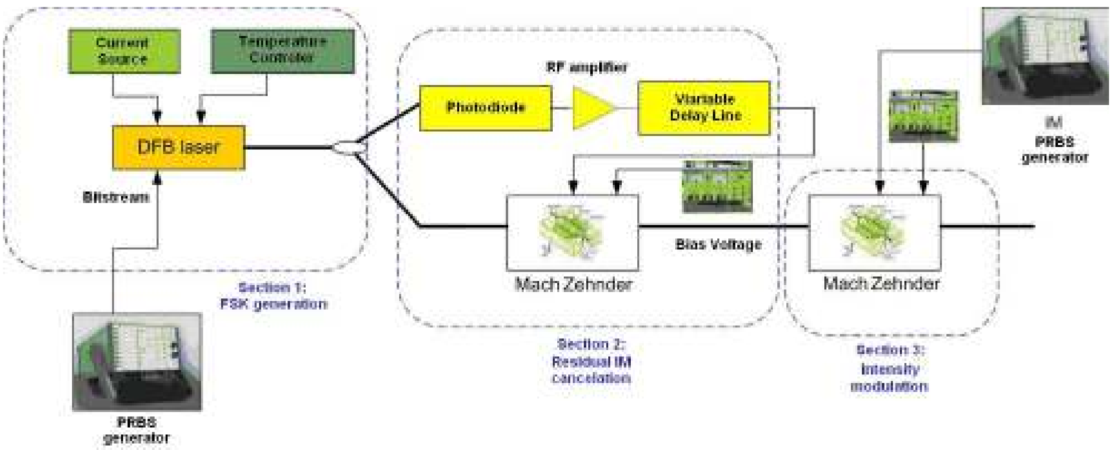


Fig 6. Schematic diagram of the experimental setup transmitter

illustrating the main functional blocks of the investigated scheme. The transmitter (OLT) consists of a directly modulated DFB laser. The bias current is 60mA and the modulation current 40mA ranging from 40 to 80mA. Following the DFB diode, is the block used for the compensation of the residual intensity modulation. This block consists of an optical coupler, a photodiode, an RF amplifier followed by the appropriate filter and an external modulator. The optical signal at the laser output is split into two signals. One part of the signal is fed to the input of the external modulator, and the other part is demodulated, amplified and finally used as a drive signal to the external modulator. Depending on the bias voltage of the modulator, we can use as drive signal either the initial bit sequence or the inverted one.

After the external modulator used for the residual IM compensation, the signal is fed to another amplitude modulator (a Mach Zehnder interferometer) driven by the second bit stream in order to combine both signals onto the same optical carrier.

The optical signal combining the orthogonally modulated bitstreams is transmitted over a 25km standard single mode fiber without using dispersion compensation and split into 8 ONUs. At the receiver side, the optical signal is split into two signals using a passive optical coupler. One part of the signal is fed to a square law detector in order for the IM information to be demodulated, and the other part, after being filtered by an optical bandpass filter to convert the FSK signal into IM, is driven to a photodiode in order to demodulate it. The BER of the two signals is show in the following figure

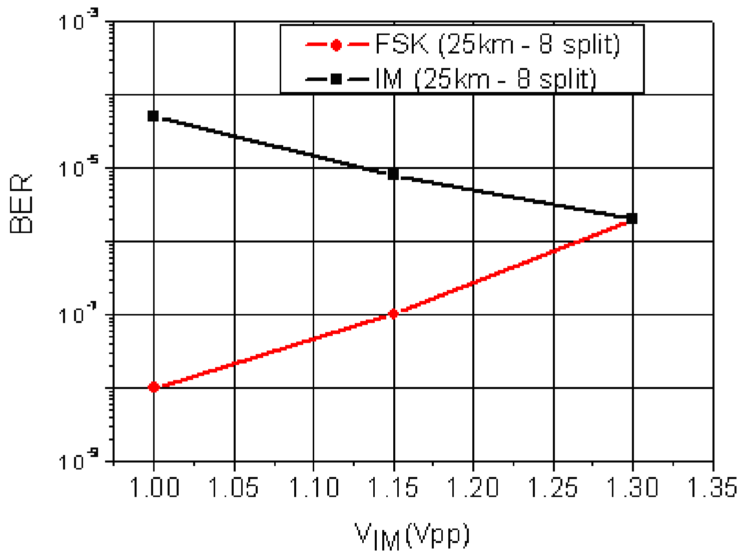


Fig. 7. BER performance of IM and FSK vs the IM modulation depth (extinction ratio)

where the BER performance of the IM and FSK signal is displayed vs the IM extinction ratio (IM modulation depth).

5. Applicability In Optical Access Network

Within this framework, of the ever increasing needs in services as well as number of subscribers, the proposed PON implementation architecture which is based on the use of orthogonal modulation formats can be a cost effective and efficient solution for the upgrade of an already established PON or for the development of a future access network. As it has already shown the proposed PON implementation structure, displays remarkable operating properties under a wide bit rate region and it can support sufficiently a large number of ONUs.

In a passive optical network like the proposed one and in case there is a need to add broadband, high quality services, the IM encoded information transfers the time division multiplexed high bitrate internet traffic (10Gbps), while the orthogonal to the IM (FSK or DPSK) additional bitstream, services like Video on Demand, Video Broadcast services, HDTV etc.

Apart from the transmission of new services, like the aforementioned ones, the already established passive optical networks have to address the ever increasing need to serve more subscribers. In that case, the orthogonal to the IM bitstream is able to provide the required additional bandwidth and relax the network expanding requirements, incorporating a simple and cost effective implementation for PON scalability. In either case, whether there is a need for more services or more subscribers the aforementioned proposed architecture constitute a simple and cost efficient solution for the implementation or for the upgrade of passive optical networks. Moreover its characteristics makes the presented technique competitive against the already WDM proposed technologies presented in [7]-[10]. The proposed technique compared with the aforementioned ones presented in the literature, has better bandwidth utilization, more efficient use of network resources.

6. Conclusion

In this thesis, it is presented a Passive Optical Network architecture based on the combination of orthogonally modulated bit streams on the same optical carrier. The feasibility of the proposed architecture along with its performance have been proven via numerical simulations and experimental investigation. The simplicity of their implementation makes them an attractive solution for the realization of future broadband optical access networks or for the upgrade of the already existing ones, being able at the same time to provide triple play services, increased bandwidth utilization and subscribers' upgradeability.

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