

# A Novel Reconfigurable Ring Architecture of Multiple Secure Private Networks over EPON Using OCDMA Code-Drop Units

Mohammad GHARAEI\*<sup>a</sup>, Catherine LEPELERS<sup>b</sup>, Ihsan FSAIFES<sup>b</sup> and Philippe GALLION<sup>a</sup>

<sup>a</sup> Institut TELECOM, TELECOM ParisTech, CNRS LTCI,

ENST, 46 rue Barrault, 75634 Paris Cédex 13, France;

<sup>b</sup> Laboratoire de Physique des Lasers, Atomes et Molécules, CNRS UMR 8523,

Université de Lille, 59650 Villeneuve d'Ascq, France

## ABSTRACT

A new architecture of multiple private networks independent of optical line terminal (OLT) over Ethernet passive optical network (EPON) using ring topology is proposed. This novel schema integrates the multiple private networks (PNs) with downstream/upstream EPON. Self determining private communications between optical network units (ONUs) are established using code-drop units. The use of optical code division multiple access (OCDMA) technique results in secure and reconfigurable PNs in the ring. Each ONU is assigned an appropriate codeword for private network communication and also the standard equipments for the up/downstream standard EPON communication. Using quadratic congruent (QC) codes with ( $p=5$ ) leads to four optical private networks in the ring. To demonstrate the integration feasibility of multiple 622 Mb/s PNs over 1.25 Gb/s EPON using implemented QC code-drop units, we analyze the network architecture by evaluating power budget, network dimensioning and BER performances.

**Keywords:** Access network, Ethernet PON- ring topology- private networks- optical CDMA

## 1. INTRODUCTION

Ethernet passive optical network (EPON) is an attractive solution to solve the problem of data traffic growth in future broadband access networks. Conventional passive optical network (PON) architecture consists of optical line terminal (OLT), star coupler (SC) and optical network units (ONUs) using tree topology. The transmission of data between OLT and multiple ONUs is performed at 1490 nm wavelength in downstream direction and at 1310 nm in upstream direction.

The significant applications of private networks such as peer to peer application, data communications between ONUs, sharing videos and data in the residence and the communications between different campus and branches of a university result in the development of private networks. EPON may support private network functionality by inserting a router in OLT as described in [1]. However, this solution reduces the available spectral efficiency of EPON and adds complexity to the data traffic management at OLT such as buffering, scheduling and routing. Therefore, different architectures have been proposed to build private networks independent of the OLT. One solution consists of reflecting private network data with fiber Bragg grating (FBG), placed before the PON star coupler, towards the entire ONUs of the network [2]. Disadvantages of this method are the interference between upstream and reflected private data from the ONU transmitter and disability of supporting different private networks in the same fiber. Furthermore, with this solution, no private data selection is carried out at different ONUs. Another solution suggests using optical switches in ONUs to separate private network data bit from EPON data bit; nevertheless it suffers from the low switching time of the devices [3].

The paper is structured as follows. In the second section, we present the architecture of a system supporting multiple Private Networks (PNs) over EPON using ring topology. Ring topology is attractive for its robustness and is often the building block behind many LAN and MAN architecture for reliable communications [4]. In the system considered here, self determining private communications between ONUs are established using optical CDMA technique. This technique permits to achieve to multiple secure private network communications independent of OLT which leads to better consumption of optical resources in OLT and also it does not add the additional traffic management. Thus different

\* E-mail: [Mohammad.Gharaei@telecom-paristech.fr](mailto:Mohammad.Gharaei@telecom-paristech.fr); phone: (+33) 145 818 085; fax : (+33) 145 804 036

ONUs belonging to the same private network, communicate with each other sharing the same codeword. The configurability of OCDMA technique consists of changing the codeword as it is required and a codeword is assigned to ONUs only if the private communication service is requested. In the third section, we demonstrate experimental temporal responses and autocorrelation functions of Quadratic Congruence (QC) optical codes used for different private network communications. In the fourth section, we analyze system integration feasibility and performances of private networks over EPON. In the last section, we present our conclusions.

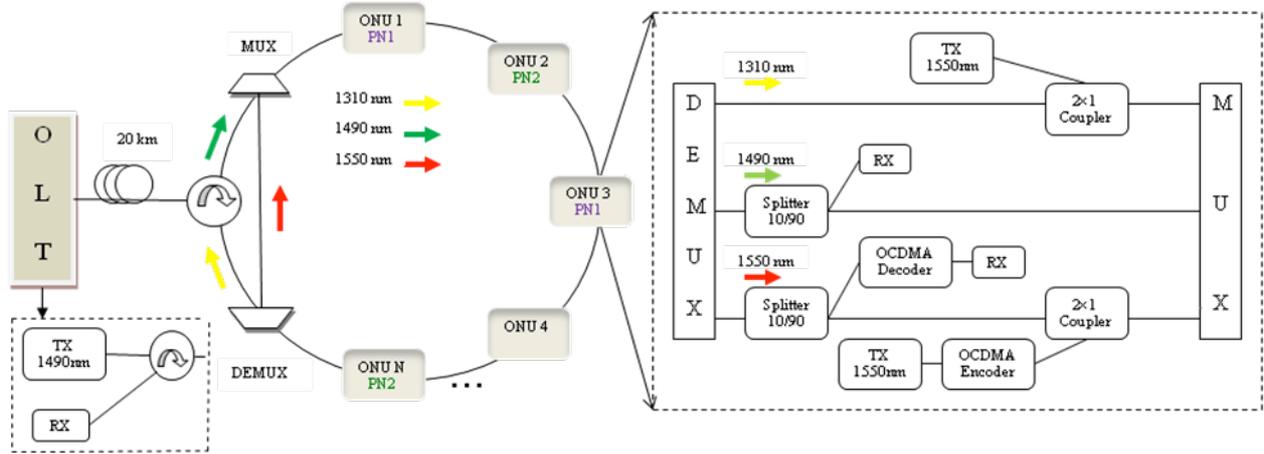


Fig. 1. Proposed system architecture of multiple secure ring private networks over EPON using OCDMA.

## 2. NETWORK ARCHITECTURE

The physical layer of the proposed system architecture based on multiple optical private networks over EPON in the ring topology is illustrated in Fig.1. In this schema, OLT is connected to ONUs via a 20 km feeder fiber, an optical circulator and a short distance distribution fiber ring (<3km). Upstream and downstream wavelengths are defined in standard EPON i.e. 1310 nm and 1490 nm respectively. Private networks are distinguished from EPON by a different wavelength selected as 1550nm.

At the entrance of each ONU, a demultiplexer splits the wavelengths of upstream EPON, downstream EPON and private networks transmission data bits. Then, the 1490nm optical downstream signal (respectively 1550nm private network signal) passes through a 10/90 splitter. Only 10 percent of optical signal power is received by photodetector and the rest (90 percent) is multiplexed with the other signal and is passed through the subsequently ONU. In the EPON upstream direction, the OLT allocates a special time slot to each ONU, and during each time slot an ONU can forward its data bit toward OLT. It means that, it is passed by other ONUs to reach to the OLT. After traversing the last ONU in the ring, the downstream wavelength is eliminated and upstream EPON and private network data are only permitted to circulate using multiplexers.

Since there are different private networks in the ring topology, the ONUs are separated using different codewords. Then the ONUs belonging to the same private network, receive the same codeword and they can communicate with each other in the ring with a high level of security. For example, the ONU1-PN1 and ONU3-PN1 belong to the same private network 1 (PN1) and consequently, possess the same codeword and the other ONUs are potentially unable to decode their private data (Fig.1). Moreover, in this architecture, it is possible to find an ONU for instance ONU4, which does not belong to any private network, with no assigned codeword.

### 3. CODE-DROP UNITS

In this section the characteristics of implemented encoders and decoders used in private networks (PNs) as code-drop units are described. Only the ONU with code-drop unit can participate in internetworking. Direct sequence optical code division multiple access (DS-OCDMA) which each user data bit is encoded with a given sequence of pulses is used as an OCDMA technique for encoding/decoding data in a code-drop unit. Superstructured fiber Bragg gratings (S-FBGs) are used to generate an on-off keying (OOK) codeword. Each “1” chip of a user-data (50 ps) is reflected by a FBG, and an optical fiber length ( $\Delta L$ ) between two successive FBGs represents the number of “0” chips. Encoder–decoder technological realization is achieved by UV photoinscription of in-fiber Bragg gratings with the phase mask method.

The main performances of OCDMA are related to the correlation properties of used code family. Superstructured fiber Bragg grating behaves as multipath interferometers. In this condition, optical interference impairments occur and to minimize these effects, non-periodic, sparser and longer QC codes are used [5]. The nonperiodic QC code specifications for  $p=5$  considered here, are given in Table 1.

Table. 1. FBG specification of QC codes.

	FBG1	FBG2	FBG3	FBG4	FBG5
$R_i$	10%	12%	16%	23%	38%
$L_i$	830 $\mu\text{m}$				

where  $R_i$  represents the reflectivities of FBGs, and  $L_i$  is the length of fiber taking into the consideration.

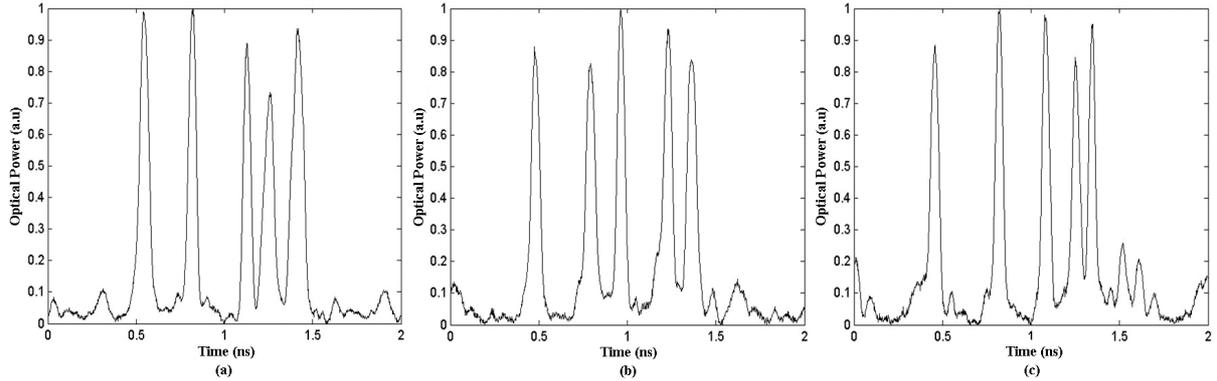


Fig. 2. Experimental temporal response of a) PN1 code (1000001000000100100010000), b) PN2 code (100000001000100000010010000) and c) PN3 code (100000000100000010001010000).

The QC temporal responses of the encoder/decoder are measured using a full-width at half-maximum (FWHM) pulse train of 50 ps generated by an ILM (DFB laser integrated with an electro-absorption modulator) (Fig.2). The pulses are modulated by user data and then coded with QC code ( $p = 5$ ) in order to supply at maximum four different code-drop units. The reflected pulse trains coming from different users are combined and transmitted to the network. We carry out experiment for the decoding operation at photodetector, which decodes the desired user and considered the other users data as multiple access interference (MAI). The main peak of the auto-correlation functions surrounded with weak sidelobes is shown in Fig.3. Finally these encoded data with three codes are broadcast at  $\text{ONU}_i\text{-PN}_i$ , circulate into the ring and decode by the matched decoder  $\text{ONU}_i\text{-PN}_i$ .

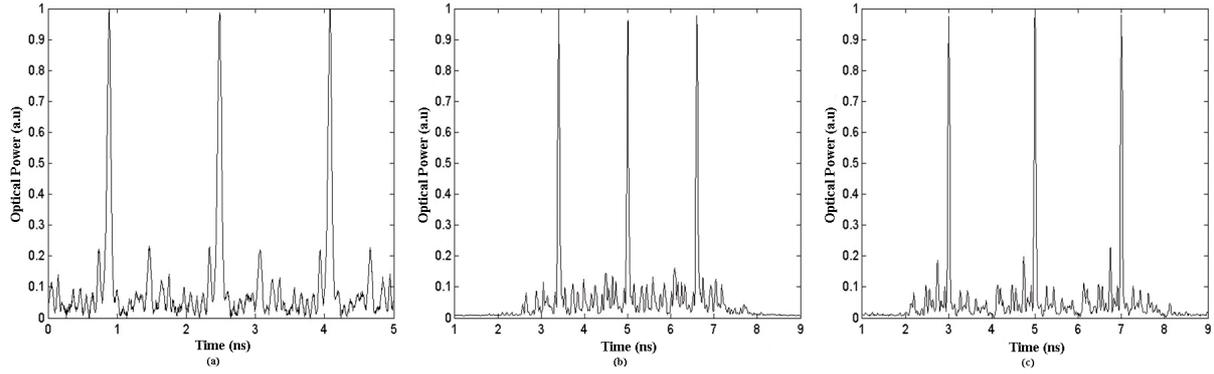


Fig. 3. Experimental autocorrelation function of a) PN1 code, b) PN2 code and c) PN3 code.

## 4. NETWORK ANALYSIS AND PERFORMANCE EVALUATION

In order to demonstrate the feasibility of the proposed network and to verify the integration of multiple private networks with EPON the network simulation is carried out to measure and to analyze the transmission losses and to confirm the proposed system architecture. We consider eight ONUs connected to the OLT via 20 km trunk feeder fiber supporting three different private networks in the ring as it has been presented in Fig.1. A typical 100m fiber length is taken into consideration between each ONU in the ring which makes the last ONU (ONU8), 20.8 km away from the OLT in downstream direction. Here we analyze the network architecture by means of power budget, network dimensioning and BER performances.

### 4.1 Optical power budget

Using the ring topology leads to limited power budget (PB) problem, since downstream, upstream and Internetworking signals are regenerated at every node (ONUs). In addition the ring topology eliminates the receiver dynamic range problem and near-far path effect encountered in a tree topology.

Optical distribution network (ODN) losses are due to fiber, circulator, multiplexer and splitter losses. With the purpose of evaluating the downstream power budget, we consider commercial device losses. We take into account 0.2 dB/km SMF fiber losses at 1490 nm. The 90% of the signal with 0.45 dB penalty is regenerated at each ONU. Table 2, summarizes the whole optical losses in the proposed network architecture.

Table 2. Power budget of downstream signal.

Type of Loss	dB
Splitter 10/90	9.55/0.45
Circulator	1.4
Connectors	2
MUX/DEMUX	0.7
ONU loss	1.87

In the downstream direction, the ODN loss for the first ONU in the ring is measured 15.42 dB. The power penalty of the passing signal through the ONU is measured 1.87 dB respectively. As a result the ODN loss for the eighth ONU (ONU8) is calculated 28.42 dB. On the contrary, the first ONU (ONU1) in upstream direction to OLT has approximately the same ODN loss as the ONU8 in downstream direction.

## 4.2 Network dimensioning

The number of ONUs is an important factor in terms of network performances since it determines the total network capacity. In tree topology the network capacity is highly dependent to the splitting factor of star coupler (SC). However in ring topology, the power budget is more critical since there is an additional loss from passing each node. Standard ITU/IEEE recommendation values of power budget, proposes PB=20 dB for Class A, PB=25 dB for Class B and PB=30 dB for Class C equipments.

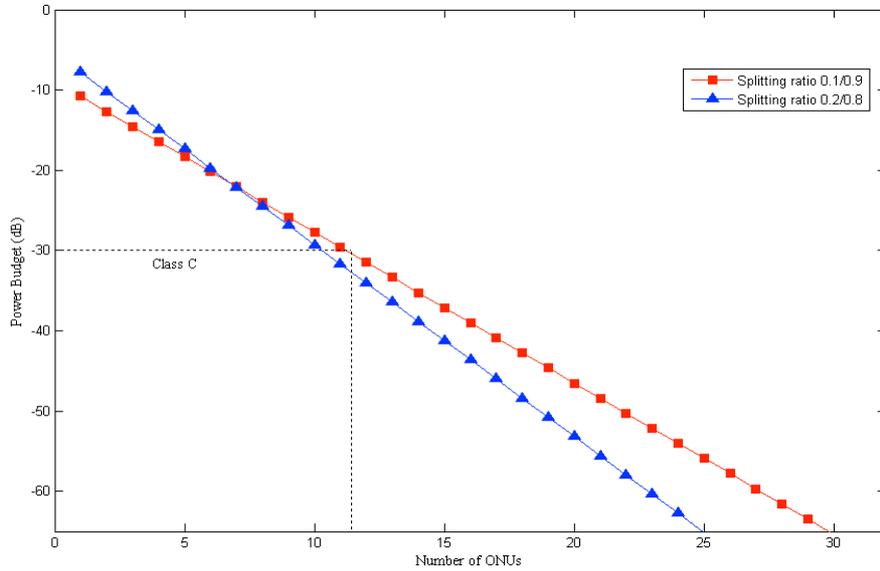


Fig. 4. Power budget as a function of the total number of ONUs for two different splitting ratios.

One of the limiting factors in the proposed architecture which impacts directly to the power budget and the capacity of network is the splitting ratio. Fig. 4 shows the different splitting ratio in relation with the number of ONUs in the ring. The linear ONU losses from 1.87 dB in 10/90 splitter to 2.49 dB in 20/80 splitter determine the number of active OCDMA code-drop units in the proposed ring network. The result shows that using 10/90 splitting ratio allows to achieve higher network capacity i.e. 12 ONUs without any optical amplifier in the ring.

The points which are above the class A/B/C lines correspond to combinations that can be deployed using A/B/C equipments. It is worth to notice that the class C equipments offer a vast combination, yet these equipments are also more expensive than class A devices.

Finally to find the number of optimal ONUs in designing a network deployment, a compromise should be made between optimizing power losses and optimizing network performances.

## 4.3 BER performances

In this subsection we simulate the optical bit-error rate performances of downstream/upstream transmission on EPON and BER performances of one, two or three active simultaneous private networks in the ring.

The private network data for example PN1 is coded using the first QC code 1 and forwarded toward ring to arrive to the destination. Simultaneously the other private networks i.e. PN2 and PN3 could transmit their data bit using the second and third QC codes in the ring. Each bit is composed of 25 chips of 50 ps full width half maximum (FWHM) which creates a train of 1.25 ns bit time without side lobes. Thus the data rate of private networking using the QC codes ( $p=5$ ) with theoretical four users is calculated to be around 622Mb/s. However the shorter code length provides with the better data rate. But it is worth noticing that there is a power penalty with increasing the data rate. In this simulation all the noise sources generated by receiver such as thermal noise, beat noise, dark current, and shot noise are considered as Gaussian noises. The multiple access interference (MAI) noise is the main cause for the degradation of OCDMA system performances. Therefore, the penalty caused by MAI noise will dominate the system performances. Fig.5 shows the BER

degradation as a function of active private network number in the ring and BER curve of the downlink transmission on EPON in the worst scenario (ONU8) at 1.25 Gb/s. The receiver sensitivity for 1.25 Gb/s data rate in ONU8 at BER =  $10^{-9}$  is measured -25 dBm. The simulated BER characteristics and clear eye diagram in Fig.5 show the integration feasibility of private networks over EPON.

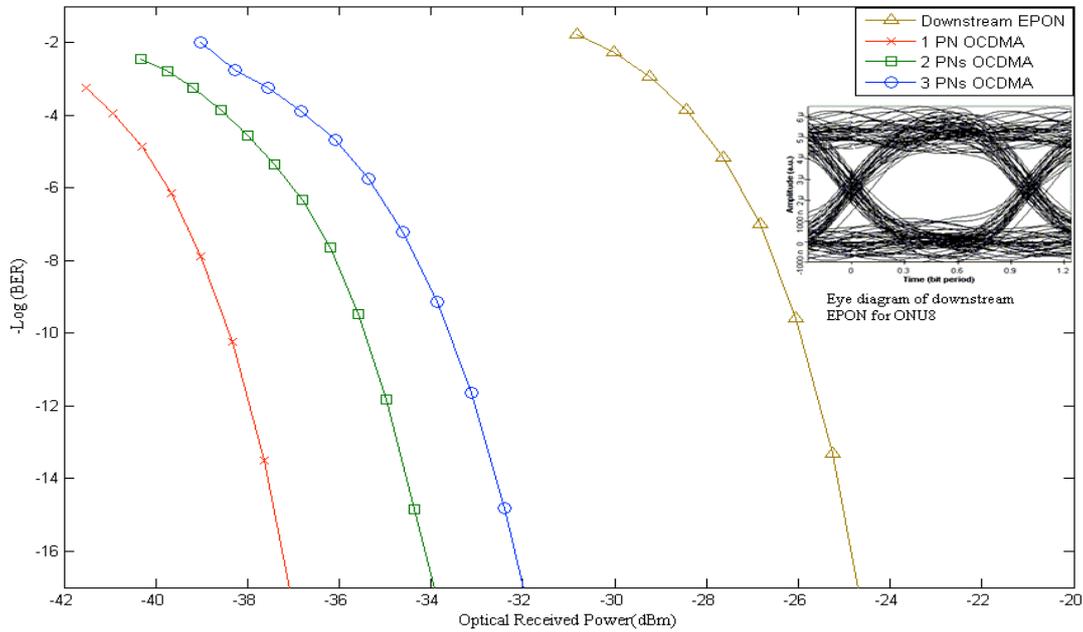


Fig. 5. BER performances of multiple private networks over EPON as a function of active PN number with Eye diagram of the downstream transmission on EPON for ONU8.

## 5. INTRODUCTION

This paper presented novel ring architecture of multiple private networks over EPON by means of OCDMA codes. The OCDMA technique supplies secure and configurable transmission in the different multiple private networks. The private networks are demonstrated to be independent of OLT which does not add any supplement traffic management at OLT. Network analyses such as power budget, network dimensioning and BER performances of private networks with downstream EPON have been simulated and confirm the feasibility of the proposed system architecture. Also we have demonstrated that it is possible to integrate up to 12 ONUs in the architecture of multiple PNs over EPON.

## REFERENCES

- [1] IEEE 802.3ah Ethernet Standard for Information Technology, 2004.
- [2] C.J. Chae, S.-T. Lee, G.-Y. Kim and H. Park, "A PON System Suitable for Internetworking Optical Network Units using a Fiber Bragg Grating on the Feeder Fiber," *IEEE Photonics Technology Letters*, vol. 11, no. 12, pp 1686-1688, (1999).
- [3] A.V. Tran, C.J. Chae and R.S. Tucker, "Bandwidth- Efficient PON System for Broad-Band Access and Local Customer Internetworking," *IEEE Photonics Technology Letters*, vol. 18, no. 5, pp 670-672, (2006).
- [4] M. Médard, S. Lumetta, "Architectural Issues for Robust Optical Access," *IEEE Commun. Magazine*, pp 116-122, (2001).
- [5] I. Fsaifes, C. Lepers, M. Lourdiane, P. Gallion, V. Beugin and P. Guignard, "Source Coherence Impairments in a Direct Detection DS-OCDMA system," *Applied Optics*, vol. 46, no. 4, pp 456-462, (2007).