Design and Performance Evaluation of DWDM Links: The Case of Metropolitan Delta Network Extension for Research and Education in Mexico

Pedro Jesús Nájera-Chávez and Aida Huerta-Barrientos

***Abstract*—The Delta Metropolitan academic network is a fiber-optic networks that interconnects high performance supercomputing clusters of National Autonomous University of Mexico (UNAM), Autonomous Metropolitan University (UAM) and Center for Research and Advanced Studies of the National Polytechnic Institute (CINVESTAV-IPN). The aim of this paper is to design DWDM links and evaluate the optic receiver performance to connecting additional academic institutions as the Faculties of Higher Studies (FES) of UNAM to the Delta Metropolitan academic network. The four selected FES are Zaragoza, Aragon, Iztacala and Cuautitlan, so the DWDM links designed are FES Zaragoza-UNAM, FES Aragon-UNAM, FES Iztacala-UNAM and FES Cuautitlan-UNAM. We calculate the power budget for the four fiber-optic links. Then we analyze the DWDM receiver performance through the eye diagram tool. Our results show that from the technical perspective the four DWDM links designed are feasible to be installed.**

***Index Terms*—Delta network, DWDM design, DWDM performance evaluation, research and education network.**

I. Introduction

A network for research and education consists on a set of technological tools that interconnect different academic entities for the purpose of benefiting the research, the development of new technologies, the information exchange, and the information processing. Today, telecommunication networks of high transmission capacity let the objectives of academic networks to be viable. For example, in Latin America, the CLARA organization (Latin American Cooperation of Advanced Networks) develops and operates the only one Internet advanced network that exists in Latin America through which the development of science, education, culture and innovation is strengthened [1], [2]. On the one hand, Mexico is one full member connected to the CLARA network (see Fig. 1) by one of the ten main routing nodes located geographically in Tijuana, at the northern Mexico [3], [4]. The Mexican University Corporation for Internet Development (CUDI), manages the National Network for Research and Education (NREN), which uses the capacity of the NIBA network as part of its backbone. The NIBA Network (see Fig. 1) is a project of the Secretariat of Communications and Transportation that seeks to provide broadband connectivity to educational centers, health centers, government offices, universities, entities of the Federation and municipalities. Using the capacity is taken into the fiber optic infrastructure of the Federal Electricity Commission (CFE). The NIBA network is interconnected with the CLARA network, allowing the interconnection to the NRENs and members of CUDI also with the CLARA network [5], [6].

On the other hand, the Delta Metropolitan academic network, located in Mexico City, is a fiber-optic network that interconnects high performance supercomputing clusters of National Autonomous University of Mexico (UNAM), Autonomous Metropolitan University (UAM) and Center for Research and Advanced Studies of the National Polytechnic Institute (CINVESTAV-IPN). The Delta network also forms the National Laboratory for High Performance Computing (LANCAD). This lab was built with Xiuhcoatl, Yoltla and Miztli clusters, and provides services such as data processing, management training hardware and software configuration and access to shared resources to scientific communities [7]-[10]. The aim of this paper is to design four new DWDM links and evaluate the optic receiver performance for connecting Faculties of Higher Studies (FES) of UNAM to the Delta Metropolitan academic network.

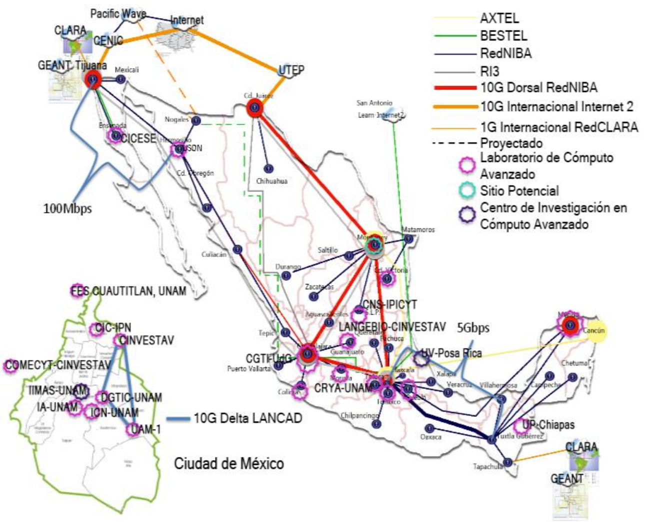

Fig. 1. Mexican e-infrastructure [10].

This paper is prepared as follows: the Metropolitan Delta network structure is described in Section II. The optical power budget of for new DWDM links of the Metropolitan Delta network is evaluated in Section III. The receiver performance of DWDM links is analyzed in Section IV. Concluding remarks are draw in Section V.

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II. Delta Metropolitan Academic Network

A. Network Description

The Delta Metropolitan academic network has been built through the Mexico City subway infrastructure: the subway-line 3 (from University station to Green Indians station), the subway-line 4 (from Martin Carrera station to Santa Anita station), the subway-line 5 (from Pantitlan station to Polytechnic station), the subway-line 8 (from Garibaldi station to Constitution of 1917 station) and the subway-line 9 (from Tacubaya station to Pantitlán station) (see Fig. 2).

The last mile between Xiuhcoatl (CINVESTAV), Yoltla (UAM) and Miztli (UNAM) clusters, and the nearest subway stations is terrestrial by subterranean channels. Currently, the Delta network is connected to NIBA network through CFE fiber-optic network so it can be connected to other networks at global level [11]. The Delta Metropolitan academic network has a total length of 108,457 km. [12]-[15] and was built with 72 optical fiber yarns with counts considering a duplex dedicated link between each institutional cluster with a current capacity of up to 10 Gbps using DWDM technology at the optical layer, summarizing a total capacity of up to 720Gbps.

Fig. 2. Delta metropolitan academic network structure based on the subway network of Mexico City [14].

The FES of UNAM are geographically located outside of Mexico City and also develop scientific research, generating scientific knowledge but have not a high capacity connection to the Delta Metropolitan academic network so their access to computational resources of high capacity are limited. To integrate FES to the Delta network we visualize two options. The first one option (see Fig. 3), considers the design of four fiber-optic point-to-point links, each one between a FES and the central node geographically located in the Miztli (UNAM) cluster, using DWDM technology at the optical layer. Each one of the links needs to have its own DWDM multiplexer and demultiplexer at the terminal points. This option would let to exploit the network capacity and resources optimally. The second one option, considers the design of a fiber-optic ring to connect the FES and using crosconectors (OXC) to join both rings: the Delta Metropolitan academic network and the new ring at one point geographically located at North-East Mexico City. The difference between the two options is basically the implementation cost taking into account the future extension in terms of network coverage and capacity. In this study we consider the first option so we propose the design of four DWDM links based on the configuration point-to-point.

B. Additional DWDM Links to the Delta Metropolitan Academic Network

UNAM has six FES but in this study we selected just four according with the following criteria: activities of research, the infrastructure of a computer center, the proximity to a subway or suburban station. So, the four FES selected are Zaragoza, Aragon, Iztacala and Cuautitlan. Three of these four FES are geographically located outside of Mexico City but inside the Metropolitan area (see Fig. 4).

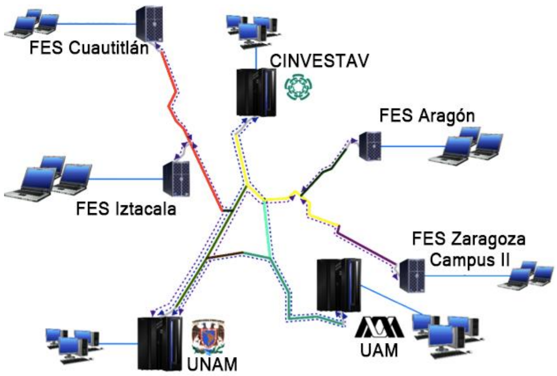

Fig. 3. Diagram of fiber-optic links that connect four FES to Metropolitan Delta Academic network.

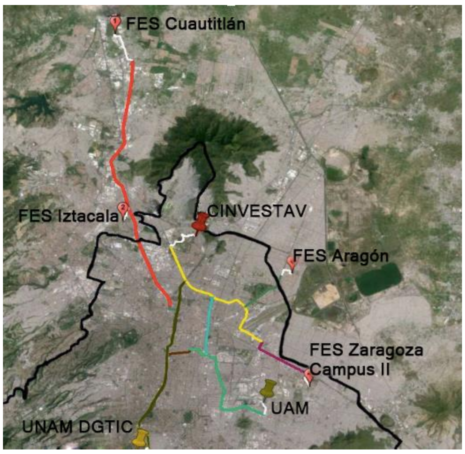

Fig. 4. Geographical location of additional fiber-optic links to the Metropolitan Delta academic network.

III. Calculating Optical Power Budget

The design of a fiber-optic communication system as DWDM requires the understanding of limitations imposed by the medium, as for example loss, dispersion and nonlinearity of the fiber [16]. In this section we evaluate the power budget whose purpose is to ensure that enough power will reach the optical fiber receiver to maintain reliable performance ensuring the optic system lifetime.

A. Optical Power Budget Formula

As [16] suggests, the minimum average power required by the receiver is the receiver sensitivity P_{Rec}. While the average launch power P_{Tr} is generally known for any transmitter. So, the optical power budget takes a form in decibel units as in (1) with optical powers expressed in dBm.

$$P_{Tr} = P_{Rec} + C_L + M_s. \tag{1}$$

where C_L represents the total channel loss and M_s is the system margin. The channel loss C_L (2) takes into account all possible sources of power loss, including connector and splices losses. Assuming α_f as the fiber loss in decibel per kilometer, the channel loss is calculated as follows.

$$C_L = \alpha_f L + \alpha_{con} + \alpha_{splice.} \tag{2}$$

where α_{con} account the connector losses and α_{splice} the splice losses throughout the fiber-optic link.

In this study, for the four DWDM links proposed, we consider a G.652.D UIT recommendation optic fiber [17]-[19]. In the case of a transmission rate of 1 Gbps, BER= 10^{-12} and a wavelength= 1550 nm, the parameters values to calculate the power budget are shown in Table I.

TABLE I: TYPICALLY ACCEPTED VALUES IN THE POWER BUDGET CALCULATION

Parameter	*Values*
α_f	0.3 dB/km
α_{con}	0.75 dB/connector
α_{splice}	0.1 dB/splice
P_{Tr}	0 dBm
P_{Rec}	-28dBm

We consider a system margin of 4-6 dB that is typically allocated. The typical distance between splices is 6 Km.

B. Evaluation of optical power budget for FES Cuautitlan-UNAM, FES Aragon-UNAM, FES Iztacala-UNAM and FES Zaragoza-UNAM fiber-optic Links

1) FES Cuautitlán – UNAM fiber optic link

The total length of FES Cuautitlán-UNAM point-to-point link is 47.689 km.

TABLE II: CHANNEL LOSSES FOR FES CUAUTITLAN-UNAM LINK

Channel losses	Values		
	Parameter 1	*Parameter 2*	*Total*
$\alpha_f L$	L = 47.689 km	α_f = 0.3 dB/km	14.3067 dB
α_{con}	Connectors =2	0.75 dB/connector	1.5 dB
α_{splice}	Splices= 10	0.1 dB/splice	1 dB

From Table II, total channel losses are 16.8067 dB. While, from (1), the system margin is calculated as follows.

$$M_s = P_{Tr} - P_{Rec} - C_L \tag{3}$$

So, the system margin for the FES Cuautitlan-UNAM fiber optic link is calculated as

$$M_s = 0 - (-28 \text{ dBm}) - (16.8067 \text{ dB}) = 11.1933 \text{ dB}$$

2) FES Iztacala – UNAM fiber optic link

The total length of FES Iztacala-UNAM point-to-point link is 30.525 km.

TABLE III: CHANNEL LOSSES FOR FES IZTACALA-UNAM LINK

Channel losses	Values		
	Parameter 1	*Parameter 2*	*Total*
$\alpha_f L$	L = 30.525 km	α_f = 0.3 dB/km	9.1575 dB
α_{con}	Connectors =2	0.75 dB/connector	1.5 dB
α_{splice}	Splices= 7	0.1 dB/splice	0.7 dB

From Table III, total channel losses are 11.3575 dB. From (3), the system margin for FES Iztacala-UNAM fiber optic link is calculated as follows.

$$M_s = 0 - (-28 \text{ dBm}) - (11.3575 \text{ dB}) = 16.6425 \text{ dB}$$

3) FES Aragon – UNAM fiber optic link

The total length of FES Aragon-UNAM point-to-point link is 32.194 km.

TABLE IV: CHANNEL LOSSES FOR FES ARAGON-UNAM LINK

Channel losses	Values		
	Parameter 1	*Parameter 2*	*Total*
$\alpha_f L$	L = 32.194 km	α_f = 0.3 dB/km	9.6582dB
α_{con}	Connectors =2	0.75 dB/connector	1.5 dB
α_{splice}	Splices= 8	0.1 dB/splice	0.8 dB

From Table IV, total channel losses are 11.9582 dB. From (3), the system margin for FES Aragon-UNAM fiber optic link is calculated as follows,

$$M_s = 0 - (-28 \text{ dBm}) - (11.9582 \text{ dB}) = 16.0418 \text{ dB}$$

4) FES Zaragoza – UNAM fiber optic link

The total length of FES Zaragoza-UNAM point-to-point link is 37.683 km.

TABLE V: CHANNEL LOSSES FOR FES ZARAGOZA-UNAM LINK

Channel losses	Values		
	Parameter 1	*Parameter 2*	*Total*
$\alpha_f L$	L = 37.683 km	α_f = 0.3 dB/km	11.3049 dB
α_{con}	Connectors =2	0.75 dB/connector	1.5 dB
α_{splice}	Splices= 9	0.1 dB/splice	0.9 dB

From Table V, total channel losses are 13.7049 dB. From (3), the system margin for FES Zaragoza-UNAM fiber optic link is calculated as follows,

$$M_s = 0 - (-28 \text{ dBm}) - (13.7049 \text{ dB}) = 14.2951 \text{ dB}$$

As noted, the system margin in the four links is bigger than the system margin typically allocated.

IV. RECEIVER PERFORMANCE ANALYSIS

The optic receiver performance can be monitored in a visual way using the eye diagram tool. Closing the eye is an indication that the optic receiver is not performing properly [16]. Fig. 5 shows an ideal eye diagram together with a degraded one affected by the noise and the timing jitter, causing a partial closing of the eye.

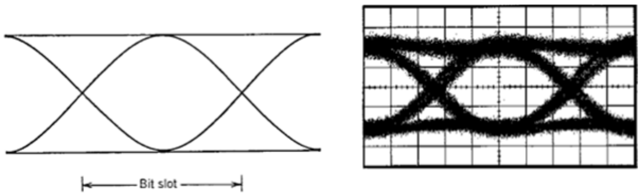

Fig. 3. Ideal and degraded eye diagram [16].

We use Optisystem™ software to evaluate the receiver performance and to show there are not amplifier requirement in the four fiber-optic links under study using the eye diagram. We propose the connections showed on Fig. 6. We took a single channel of each fiber-optic links.

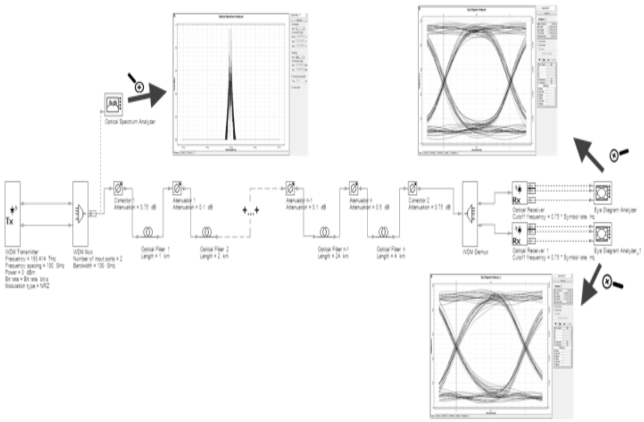

Fig. 4. Diagram to evaluate the receiver performance using Optisystem™ software.

To each fiber-optic point-to-point link, we propose to use a DWDM transmitter and a DWDM multiplexer in one side, in the other side a DWDM demultiplexer and an Optical receiver. A multichannel fiber-optic point-to-point link in which every 6 Km was inserted a splice like the recommendation says or in less depending on the fiber-optic haul or the Mexico City subway infrastructure.

A. Eye Diagram of FES – UNAM Fiber Optic Links

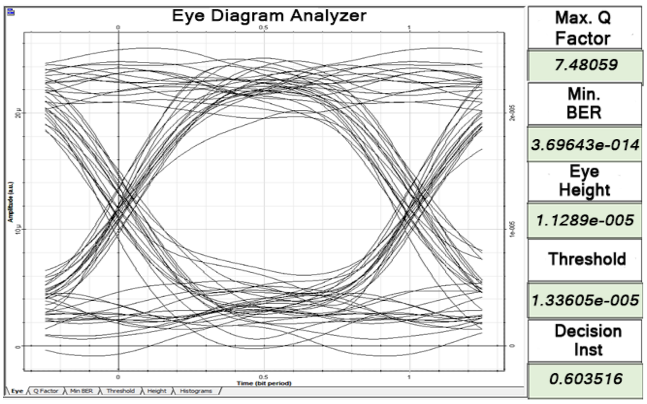

Fig. 5. Eye diagram of FES Cuautitlan - UNAM link.

In FES Cuautitlan-UNAM DWDM link (see Fig. 7), the eye diagram is gradually closed, affected by noise and timing jitter due the distance between transmitter and receiver. This is the only case in which we could consider use an amplifier.

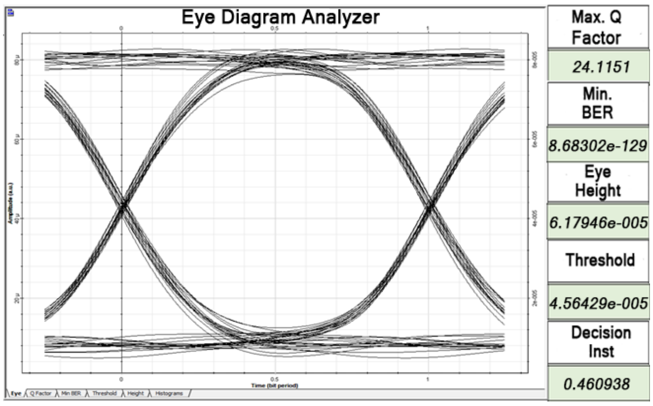

Fig. 6. Eye diagram of FES Iztacala - UNAM link.

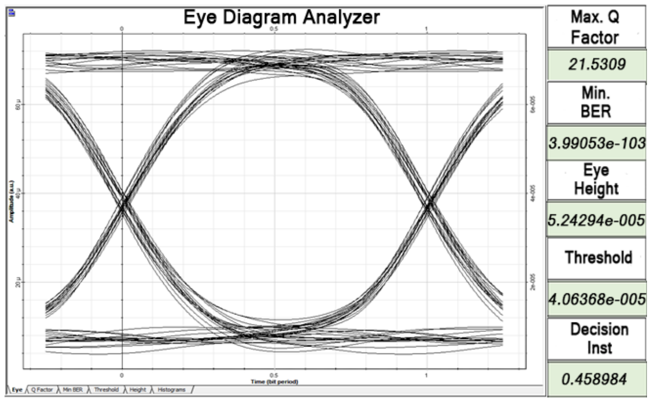

Fig. 7. Eye diagram of FES Aragon - UNAM link.

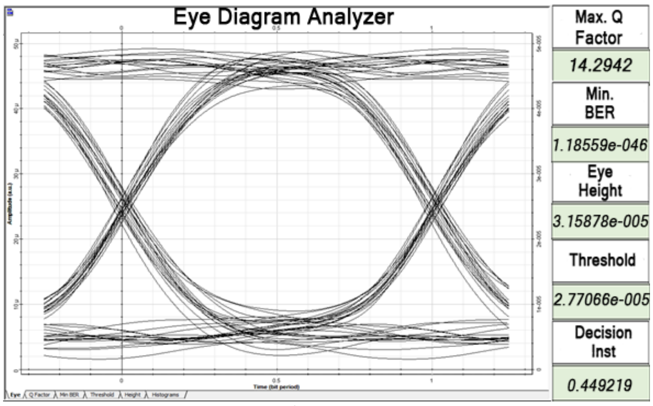

Fig. 8. Eye diagram of FES Zaragoza - UNAM link.

The eye diagram for FES Iztacala-UNAM (see Fig. 8), FES Aragon-UNAM (see Fig. 9) and FES Zaragoza-UNAM (see Fig. 10) DWDM links is considerably open so we can conclude that the optical receiver is performing properly.

V. Conclusions

We proposed the design of four new DWDM links and evaluated the optic receiver performance to connecting Faculties of Higher Studies (FES) of UNAM to the Delta Metropolitan academic network. We calculated the power budget of the new four fiber-optic links FES Zaragoza-UNAM, FES Aragon-UNAM, FES Iztacala-UNAM and FES Cuautitlan-UNAM. The system margin of each fiber-optic link was higher than 4-6 dB, value that is typically allocated. Then, we analyzed the DWDM receiver performance through the eye diagram tool. The FES Cuautitlan – UNAM DWDM link presented the eye diagram affected by the noise causing a partial closing of the eye. While the eye diagram for FES Iztacala-UNAM, FES Aragon-UNAM and FES Zaragoza-UNAM DWDM links was considerably open so the optical receiver was performing properly in these cases. We conclude that from the technical perspective the four DWDM links designed are feasible to be installed to extend the coverage area of the Delta Metropolitan academic network.

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