Optimum placement of optical amplifiers in a OTDMA/OCDMA based hybrid network topology

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The widely used erbium–doped fiber amplifiers (EDFA), instead of its numerous merits, are expensive and require maintenance, thus making network designers to recrudesce techniques to minimize the number of amplifiers in any optical networks. In this paper, the hybrid network topology (mesh-ring-bus) is proposed and further the count of amplifiers has been optimized to its minimum number. The used mixed integer linear program (MILP) solvers employ branch and bound strategies has been used to handle the linear constraints. On the other hand, last as soon as possible (LASAP) scheme has been used for amplifiers gain splitting and its placement.

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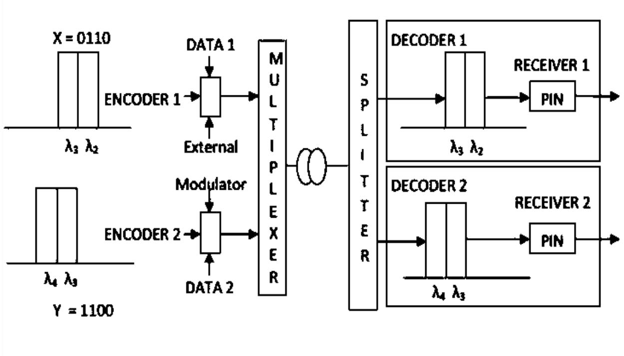
1. Introduction

The enormous demand of services in the field of communication made wavelength division multiplexing (WDM) one of the best alternative to achieve better spectral efficiency with enhanced performance. WDM has further elevated by using optical amplifiers [1-5]. Mostly, EDFA plays a key role as power boosters, optical repeaters and preamplifiers in long distance optical fiber communications systems. Despite of EDFAs advantages, they are very expensive and require maintenance. Because of these reasons various complex algorithms and schemes are used to optimize EDFA parameters and its placement [6,7]. Following expression is used to understand the amplifier model [8].

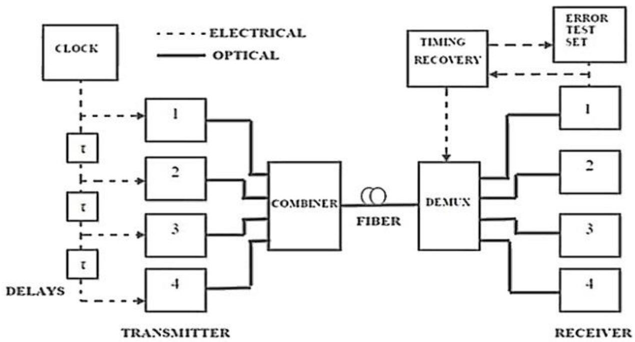
$$\frac{p_{in}}{p_s} = \frac{1}{(G-1)} \ln\left(\frac{G_0}{G}\right)$$

Where *Pin* is the total input signal power to the amplifier, $P_s$is internal saturation power, G_0 the small signal gain and G is gain. EDFA can be used in various types of multiplexing techniques to compensate the losses [9].

OCDMA is a multiplexing technique in which each communication channel is distinguished by a specific code rather than wavelength or time slots. The encoding operation optically remodels every data bit before transmission. In this paper, we use direct detection technique to enhance the security of the system [10]. Reverse decoding operation is needed to reacquire the original data. The same frequency component is directly detected at the receiver and due to this its circuitry is very simple and inexpensive as shown in Fig. 1 (a).



(a)



(b)

Fig. 1. (a) Direct Detection Technique for OCDMA[9] (b) Optical Time Division Multiplexing (OTDM)

In time division multiple access (TDMA) technique, every baseband data streams are provided an array of time slots on the multiplexed channel. In Fig. 1 (b), a schematic diagram of an *N* channels OTDM transmission system is shown in which optical pulse from a laser diode is splits into *N* paths. In each path, the pulse train is independently modulated by an electrical data signal forming$N$ optical RZ format data channel. All the branches are delayed by a fraction of the clock period and synchronized to allow multiplexing to sum up an independent data stream, where $\Delta\tau$ is the time delay

OCDMA is more adequate than OTDM is many aspects. Fadhil *et al.* [10] studies the performance analysis SAC-OCDMA system using spectral direct detection approach. It was described that, with the use of direct detection approach, complexity is reduced because less number of filters are required.

Mohammed *et al.* [11] investigates the performance of the four users Optical Time Division Multiplexing for different lengths for single mode fiber SMF at different bit rate. The capability of EDFAs was investigated for diminishing the effect of performance degradations due to noises and attenuation. Randhawa *et al.* [12] resolved the designing issues in hybrid optical or wireless networks. The objective was to minimize the network's deployment costs, while taking care of traffic or links capacity for different hybrid topologies like - ring, star, bus and mesh topologies.

Till now, various placements techniques are implemented, but these are limited to single type of topology only which is not practical for large geographical area. Currently, the users in large cities are connected with more than one topology (called hybrid topology) having different type of multiple access techniques. Moreover, the investigated topologies are limited to the number of users and wavelengths which disregards the bandwidth of optical fiber. In this paper, we have extended the previous work by optimizing amplifier placement considering more noises with increased capacity and span distance with OCDMA and OTDMA. The novelty of this work is that the optical network is investigated with OCDMA technique which make the data secure.

This paper is organized into five sections. In Section 2 and Section 3, the problem formulation, system setup with solution approach is described. In section 4, results have been reported of the different end nodes and finally in Section 5 the conclusions are made.

2. Problem formulation

We used certain steps to minimize the number of optical amplifiers, these are explained as : 1) To determine whether or not it is possible to design the network by considering the limitations of the devices (e.g., the power budget of the amplifiers), 2) then generate a *linear* set of constraints to describe the problem settings, 3) use a MILP solver to determine the minimum number of amplifiers needed in proposed network, and 4) determine the exact placements of the amplifier in the network by using LASAP.

3. Sample Network

The network consist of broadcast type X stations and Y optical nodes. Transmissions of a station are received by every other station, which experiences losses as the signal pass through the network. Each transmitted signal has to be reached to receivers at the power level greater than the sensitivity level, denoted by $P_{s.}$ Attenuation on fiber is given by the parameter "α". Table 1 describes the parameters and its values used for the simulating an OCDMA system. The other used parameters are described in Table 2. As shown in Fig. 2, the aggregate link 11-12 and 15-16 uses star topology and nodes 1,2,3 and 4 used as a ring together.

The ITU-T G.652 standard single mode optical fiber is used for the simulation.

Table 1. Parameters used for OCDMA

PARAMETER	VALUE USED
Bit rate	622 Mbps
Wavelength	1550nm
Polarization mode Dispersion coefficient	0.07ps/ √km
Dark current	5nA
Thermal noise coefficient	1.8×10^{-23} W/Hz

SOLUTION APPROACH

Our solution approach consists of four steps:

- STEP 1 - Test the viability of the network.
- STEP 2 - Formulate the constraints
- STEP 3 - Solve the mixed integer linear program
- STEP 4 - Placement of amplifiers

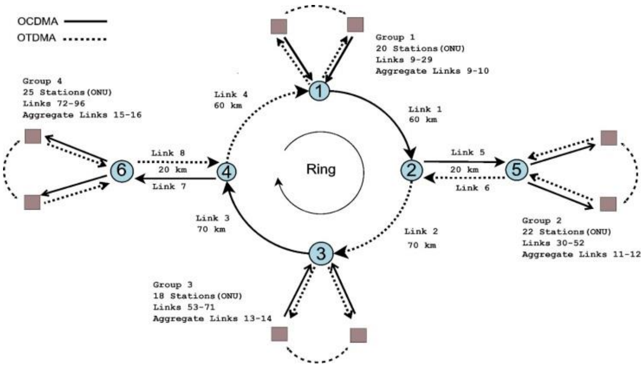


Fig. 2. Sample of Passive OCDMA - OTDMA based optical metropolitan area network

Table 2. Parameters used in network

Parameter	Description	Value & Units Used
p_s	Minimum signal power at receiver or the amplifier sensitivity level	-30 dBm
G_m	Maximum small signal gain	20 dB
P_m	Maximum output power of amplifier and transmitter	0 dBm
α	Fiber attenuation	0.2 dB / km
P_s	Internal saturation power of amplifier	1.55 dBm
P_{max}	Maximum total output power in fiber	10dBm
D_p	Dispersion penalty	0.5dB/20km
L_l	Length of link *l*	km
Gs_l	Total gain required on link *l*	dB
M	Link loss Margin	3dB
X	Number of stations or wavelengths in the network	-
Y	Number of stars in the network	-
L	Number of links in the network	-
A	Number of amplifiers in the network	-
λ_l	Number of wavelengths	-
n_l	Number of amplifiers on link *l*	-
D_a	Degree of star *a*	-
P_a	Output power of star *a* on each wavelength	-
Q	Number or nodes on the network	

- *Test the viability of Network*

The feasibility has been checked in the term of receiver sensitivity, means the power level at the receiver side should be higher than the threshold value to efficiently recognize the data signal. The feasibility has been checked as follows:

For each star in the network $1 \leq a \leq$ Q and for each input link *j* into the star *i*,

$$P_m + P_s \geq 10\ log_{10}\ (D_a - 1) + 10 log_{10}\ (|\lambda_b|) \quad (1)$$

Then the network has viable amplifier placement else it is not acceptable.

- Formulate the constraints

To calculate the linear constraints on various links or paths, it is required to determine the value of wavelength, fiber length, added noises, dispersion etc.

1. LINKS BETWEEN NODES

Here, two nodes *a* and *b* are connected to each other by using link *l*, then the power can be represented as:

$$P_a - \alpha.L_1 - 10\ log_{10}\ (D_b - 1) - D_p - M + Gs_l = P_b \quad (2)$$

$$G_m + Gs_l \leq 0 \quad (3)$$

$$G_m + Gs_l \geq - G_m\ (n_l) \quad (4)$$

Where $(D_b - 1)$ is splitting loss at the node and G_m is based on the total input power via all wavelengths and total saturation power of an amplifier. G_m can be at its maximum when the input are at their lowest level i.e. p_s and the number of wavelength on that link i.e. $\lambda_l$so $G_m$for node to node is:

$$G_m = - p_s + 10\ log_{10}\ (\ |\ \lambda_l |\ ) \quad (5)$$

But here as we are using OTDMA and OCDMA, we are using a different wavelength for each group and in this whole network we are using four groups so we are using four wavelengths.

2. LINK FROM STATION (ONU) TO NODE

Now a link *l*is used to connect any station *k* with node *b* and available gain on the transmitter on link *l* is given as;

$$P_m - \alpha.L_1 - 10\ log_{10}\ (D_a - 1) - D_p - M + n_l\ (G_m\ ) \geq p_b \quad (6)$$

Here, as we know that from ONU to node, a different frequency is used for every ONU and here only one frequency is used. So by putting λ_l=1 in (5), max gain available will be equal to the min received power i.e$p_s$then G_m will be shown as:

$$G_m = p_s \quad (7)$$

3. LINK FROM NODE TO STATION (ONU)

Link $l$is used to connect a node a to station k, we require that the necessary power on station for eachwavelength will be at least equal to or greater than sensitivity level p_s

$$p_i - \alpha.L_1 + p_s\text{-}D_p - M + n_i\,(G_m) \geq p_s \quad (8)$$

The maximum gain can be calculated as:

$$G_m = p_s + 10\,log_{10}\,(N\text{-}1) \quad (9)$$

4. NODE CONSTRAINTS

For any node a, 1 ≤ a ≤ Q, the necessary power on station for eachwavelength should be at least equal to or greater than sensitivity level p_s,

$$P_a \geq p_s \quad (10)$$

To solve our formulation it is necessary that, for any star a via link l into star b, it should beensure that the necessary output power p_j is acceptable, which is:

$$P_m - 10log_{10}\,(D_b\text{-}1) \geq P_b \quad (11)$$

5. MILP FORMULATION

For any link l, n_l is a integer. To minimize the number of amplifiers the objective function is given as:

$$\text{Minimize A} = n_l \quad (12)$$

- Solve the Mixed-Integer Linear Program (MILP)

Now the variable or constraints presented in equations (1 to 12) are fed into MILP solver [13] i.e. mixed integer linear program. Then as a results we have found the number of amplifiers for the considered link.

- Place the Amplifier

For the placement of optical amplifiers LASAP algorithm is used. In this method, the N-1 first amplifiers are placed in the same way as in the (as soon as possible) ALAP scheme, but the last one is placed as soon as it is possible for it to give the remaining gain [14]. The best noise performance is obtained when LASAP method is used as compared to ALAP, it provides around 26.8 % better noise performance as compared to ALAP.

4. Result and discussion

Consider the sample network shown in Fig. 1. The network has N = 96 stations and M = 6 passive nodes. After the formulation of all constraints in MILP, number of amplifiers are n = 96 and the maximum gain and per wavelength power is also acquired.

Placement of amplifiers on link 1 between nodes 1 and 2 is shown in Fig. 3. The black triangles shown in Fig. 4 are the amplifiers located at its optimum place. The gain and distance of each amplifier is shown in Table 3. Fig. 5 shows the block diagram of users using bus topology at nodes B1, B22, B23 and B48.

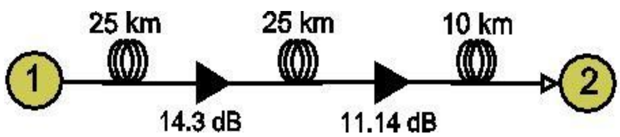


Fig. 3. Placement of amplifier at Link 1

To validate the results from the proposed hybrid network the simulation is also done by the mean to evaluate the performance in the term of BER, received power etc. After the placement of amplifiers and to understand the performance of the network, the graph between BER and input power is plotted as shown in Fig. 6 for aggregate links 9 (group 1 user) and 13 (group 3 user), at these link OTDMA signals are received via nodes 1 and 3, the bit error rate is low which indicates the best performance. It is also observed that when power increases from -5 dBm to 3 dBm, its bit error rate decreases upto 10^{-20} for aggregate links 9 and 10^{-19} for aggregate links 13 which is acceptable for optical transmission.

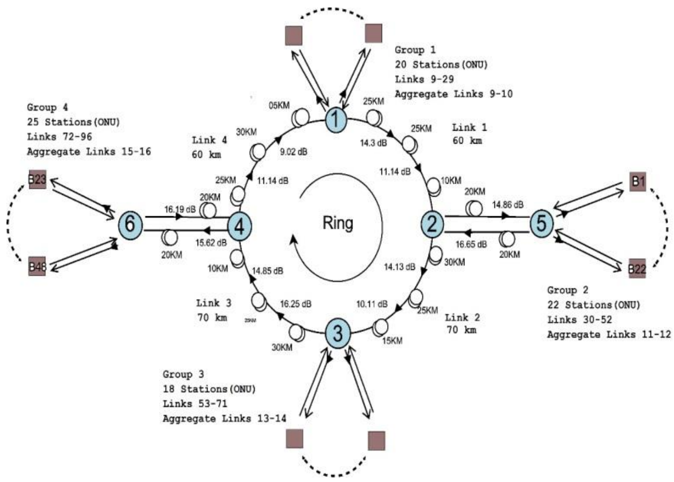


Fig. 4. Amplifier placement in OTDMA-OCDMA based network by using LASAP [8]

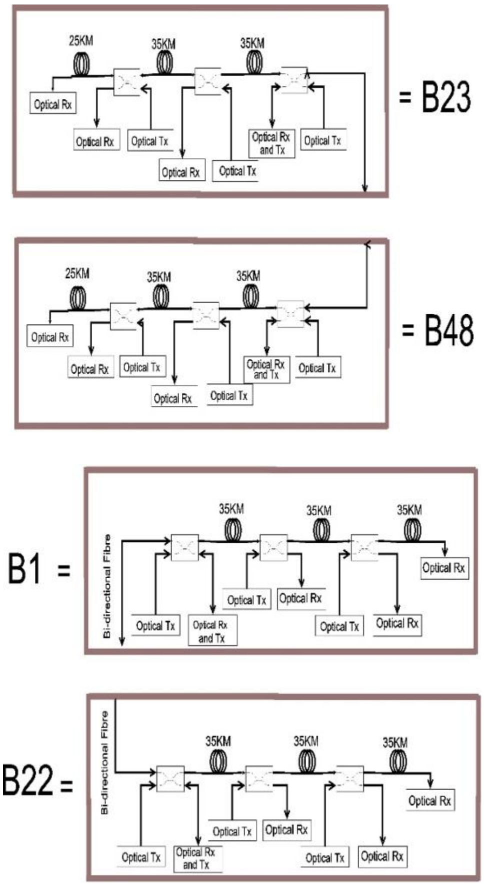


Fig. 5. Diagram of bus topology used at nodes B1, B22, B23 and B48

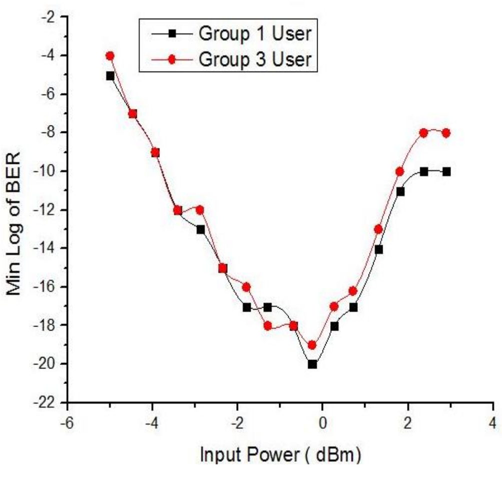


Fig. 6. Input power vs. bit error rate graph for link 9-10 and 13-14

Fig. 7 show the bit error rate vs. input power graph for aggregate links 11 (group 2 user) and 15 (group 4 user), at these links OCDMA signal is received via nodes 5 and 6. Now it is observed from graph that when the power increases from -5 dBm to 4 dBm, the bit error rate decreases up to 10^{-30} for aggregate links 15 and 10^{-26} for aggregate links 11 which is a quite sufficient for optical transmission.

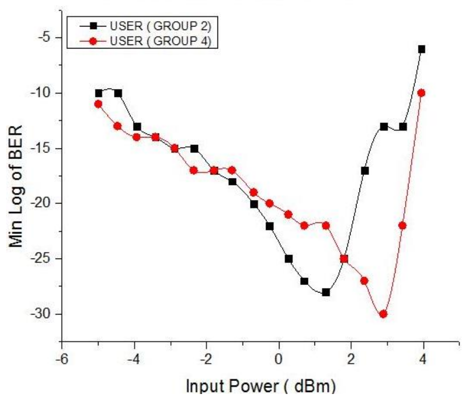
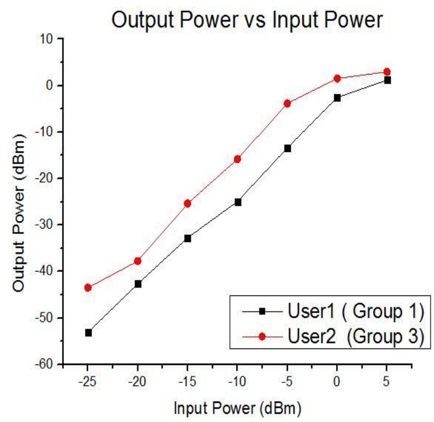
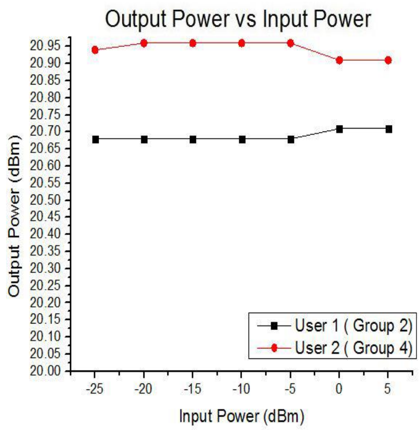


Fig. 7. Input power vs. bit error rate graph for link 11-12 and 15-16

Fig. 8(a) shows the change in output power with respect to the change in input power. Users in group 1 and 3 receive OTDMA signal via nodes 1 and 3 and it is observed when the power increases from -25 dBm to 5 dBm the output power also increases. Fig. 8(b) shows the graph for group 2 and 4 user's receiving OCDMA signals and it is observed that user at group 2 receive sufficient output power as compared to user at group 4.



(a)



(b)

Fig. 8. (a) Input power vs. output power graph for group 1 and 3 user i.e. OTDMA (b) Input power vs. output power graph for group 2 and 4 user i.e. OCDMA

Table 3. Location and gain of amplifiers

Link Number	Number Of Links	Amplifier	Gain of Amplifier's	Distance
1 NODE 1 to NODE 2 120 KM	1	1	14.3 dB	25 km
		2	11.14 dB	50 km
2 NODE 2 TO NODE 3 100 KM	1	3	14.13 dB	30 km
		4	10.11 dB	55 km
3 NODE 3 TO NODE 4 120 KM	1	5	16.25 dB	30 km
		6	14.80 dB	55 km
4 NODE 4 TO NODE 1 100 KM	1	7	15.828 dB	25 km
		8	11.9765 dB	55 km
5 NODE 2 TO NODE 5 30 KM	1	9	14.86 dB	20
6 NODE 5 TO NODE 2 30 KM	1	10	16.65 dB	20 km
7 NODE 4 TO NODE 6 30 KM	1	11	14.522 dB	20 km
8 NODE 6 TO NODE 4 30 KM	1	12	11.0102 dB	20 km
9 GROUP 1 TO NODE 1	20	--	--	--
10 NODE 1 TO GROUP 1	20	1	1.32 dB	
11 GROUP 2 TO NODE 5	22	--	--	--
12 NODE 5 TO GROUP 2	22	1	1.23 dB	
13 GROUP 3 TO NODE 3	18	--	--	--
14 NODE 3 TO GROUP 3	18	1	1.28 dB	
15 GROUP 4 TO NODE 6	24	--	--	--
16 NODE 6 TO GROUP 1	24	1	1.43 dB	

5. Conclusion

The problem of optical amplifier placement is to minimize the amplifier's count in network has been examined. The placement scheme used is LASAP. After examining the network performance on various aspects with added noises resulted in a bit error rate of up to 10^{-31} for OCDMA and $10^{-20}$for OTDMA.The maximum transmission distance observed is 90 km for twain modulations. The proposed setup is recommended for high speed and secure all optical network over which the users can transmit the data without fear of hacking and jamming. OFDMA technique is planned to be worked upon in future, assuming more noise and increasing transmission distance with more network topologies.

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