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Delay Constrained Bandwidth Utilization in Passive Optical Networks by Using Compensating Fiber and Butterworth Filter

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Abstract: This paper proposes the technique of compensating fiber on various numbers of channels by altering the bandwidth. By applying the filter we try to consume the energy to the extent as much as possible. We observe that the average energy consumption before filtering remains constant but as soon as on applying the filter the average energy consumption starts altering. Even the group delay remains constant for same bandwidth but as the value of bandwidth is increased the group delay drops off. The mathematical model is derived for the filter. Simulation tool MATLAB is used to verify the results.

Keywords: Average Energy Consumption, Bandwidth Utilization, Compensating Fiber, Group Delay, Passive Optical Networks

I. INTRODUCTION

In the foregoing years, the authentic users have enabled to increase the consideration of Passive Optical Networks. It ensures higher reliability, simpler maintenance and reduced power consumption because of the absence of active elements in the ODN, so implying lower operational expenditure [1]. Bandwidth Utilization is the percentage of bandwidth consumed off the total bandwidth available. In this paper, we analyze a novel model for bandwidth utilization that includes compensating fiber. This model calculates the average energy consumption and group delay. We improved our work from the previous work [2] and reduced the group delay. Through widespread simulations and implementation of diverse channels at different bandwidths we have investigated the model's behavior and obtained simulation results that validate the excellent performance of the presented model in terms of average energy consumption and group delay.

The paper is organized as follows. In Section II outline of related work is presented. Section III presents the algorithm of model. Section IV presents simulation experiments that are significant for studying the performance. Section V, shows the comparison between existing and proposed work. Section VI, concludes the work

II. RELATED WORK

In [2] the author proposed that the effect of sub channel delay on bandwidth synthesis eliminates the phase step phenomenon. Sub channel delay was compensated to zero by shifting calculated clock cycles of the attached data valid signals. The author of [3] analysed that in Time and Wavelength Division Multiplexed PON, energy savings at OLT were achievable by dynamically allocating the number of active wavelengths in the network. The impact of ONU on OLT energy savings and average frame delay was evaluated. The authors of [4] presented Dynamic Wavelength Priority Bandwidth Allocation with Traffic Class Hopping algorithm with Quality of Service support that incorporates both offline and online scheduling. The author of [5] discussed about a probability based Dynamic Bandwidth Allocation algorithm in optical networks that uses the latest polling table for the current allocation of the bandwidth among the ONU's dynamically. In [6] the author clarified the scalability of the hitless wavelength-tuning sequence for Dynamic Wavelength Allocation on a λ-tunable WDM/TDM-PON. The author in [7] presented the energy efficient framework for Time and Wavelength Division Multiplexed PON that optimized the number of active wavelengths and used sleep/doze mode to improve the energy savings. In [8] discussion of Synergized Adaptive Multi Gate Polling with Void Filling which reduce both the delay bound and packet loss rate by atleast 50% is made. The authors of [9] summarized the existing proposals for multi-channel EPON and proposed a scheme to enhance the scheduling efficiency by developing a Modified Stable Matching Algorithm. In [10] the author discussed about the resource management. he energy-saving mechanism was able to save energy at the OLT. Then, in [11] Energy-Saving Passive Optical Network that aims to incorporate ONU sleep/doze mode into Dynamic Bandwidth Allocation algorithms to reduce ONU energy consumption was proposed. The author presented a comprehensive survey on the dynamic bandwidth allocation schemes for Long Reach PONs [12]. The author of [13] investigated the difficulty of optimal scheduling and bandwidth allocation in next generation 10G-EPON coexisting with 1G WDM-PONs. By upgrading. the quality of service was improved. The author presented and analyzed the model for Wavelength and Bandwidth Allocation in hybrid TDM/WDM EPONs with full quality of service support, called the Dynamic Wavelength Priority Bandwidth Allocation with Fine Scheduling. The proposed concept reduces overall system cost and offers the superior network scalability and flexibility [14].

III. ALGORITHM

BW = 3Gb/s and 5Gb/s

Number of channels = 5 and 10

Step 1: Gamma index is calculated; transmitting fiber calculates the gamma index to get the average power, $G_{index} = \frac{2*\pi*I_{TF}}{(\lambda*A_{TF})10^{21}}$

Step 2: Compensating fiber length determination, $L_{comp} = \frac{Din-(D_{TF}*L_{TF})/10^{3}}{D_{CF}*10^{3}}$

Step 3: Amplification gain calculation; it amplifies the optical field,

$$G_{amp} = \frac{(\alpha_{TF} * L_{TF})}{10^8} + \frac{\alpha_{CF} * L_{CF}}{10^8}$$

Table 2. Parameters of Algorithm

PARAMETER	VARIABLE
Nonlinear index	I_{TF}
Effective area	A_{TF}
Central wavelength	λ
In line dispersion	D_{in}
Dispersion of transmitting fiber	D_{TF}
Length of transmitting fiber	L_{TF}
Dispersion of compensating fiber	D_{CF}
Attenuation of transmitting fiber	α_{TF}
Length of transmitting fiber	L_{TF}
Attenuation of compensating fiber	α_{CF}

Step 4: For modulation of signals, Cross Phase Modulation is left ON as it is a combination of dispersion and effective area.

Step 5: Calculation of group delay,
if (BW = 3Gb/s and No. of channels =10) then
group delay = 0.4509 ns
end
if (BW = 5Gb/s and No. of channels =10) then
group delay = 0.2706 ns
end

IV. SIMULATION RESULTS

In this section, the performance of model and analysis of the impact of different values of bandwidths on network has been studied. In the simulations, the average energy consumption before and after filtering and the group delay for different number of channels at two values of bandwidth were evaluated. The average energy consumption before filtering remained constant and after filtering fluctuates. The group delay is reduced on increasing the bandwidth.

A. Average Energy Consumption for Bandwidth = 3Gb/s and Number of Channels = 5

The average energy consumption before and after filtering for 5 channels at bandwidth 3 Gb/s is calculated.

Table 2. Average Energy Consumption of Scenario 1

SCENARIO1		
Bandwidth=3Gb/s	Number of Channels=5	
Channel Number	Average Energy Consumption Before Filtering(Joules)	Average Energy Consumption After Filtering(Joules)
Ch #1	0.5251	0.5095
Ch #2	0.5251	0.5088
Ch #3	0.5251	0.5087
Ch #4	0.5251	0.5094
Ch #5	0.5251	0.5093

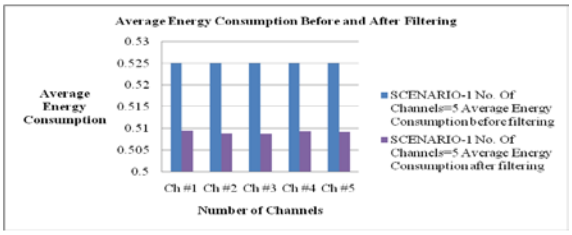

Figure.1. Average Energy Consumption for Channels=5 and Bandwidth=3Gb/s

As from the figure it is clear that average energy consumption before filtering remains constant but as soon as filter is applied average energy consumption starts varying.

B. Group Delay for Bandwidth = 3Gb/s and Number of Channels = 5

The group delay for 5 channels at bandwidth 3Gb/s is calculated at different channels and is tabulated in table.

Table 3. Group Delay of Scenario 1

Channel Number	Group Delay(ns)	Average Delay(ns)
Ch #1	0.4509	0.4509
Ch #2	0.4509	
Ch #3	0.4509	
Ch #4	0.4509	
Ch #5	0.4509	

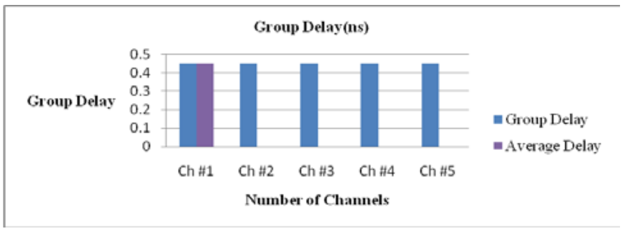

Figure.2. Group Delay for Channels=5 and Bandwidth=3Gb/s

As from the figure it is clear that group delay remains constant for all the 5 channels. But as compared to the existing work, the group delay has reduced.

C. Average Energy Consumption for Bandwidth = 3Gb/s and Number of Channels = 10

The average energy consumption before and after filtering for 10 number of channels at bandwidth 3Gb/s is calculated at different channels.

Table 4. Average Energy Consumption of Scenario 2

SCENARIO2		
Bandwidth=3Gb/s	Number of Channels=10	
Channel Number	Average Energy Consumption Before Filtering(Joules)	Average Energy Consumption After Filtering(Joules)
Ch #1	0.5251	0.5095
Ch #2	0.5251	0.5087
Ch #3	0.5251	0.5084
Ch #4	0.5251	0.5088
Ch #5	0.5251	0.5084
Ch #6	0.5251	0.5089
Ch #7	0.5251	0.5086
Ch #8	0.5251	0.5088
Ch#9	0.5251	0.5091
Ch #10	0.5251	0.5089

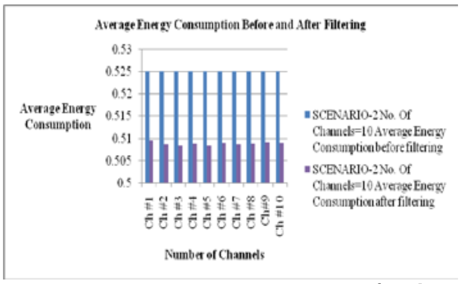

Figure.3.Average Energy Consumption for Channels=10 and Bandwidth=3Gb/s

As from the figure it is clear that average energy consumption before filtering remains constant but as soon as filter is applied average energy consumption starts varying.

D. Group Delay for Bandwidth = 3Gb/s and Number of Channels = 10

The group delay for 10 channels at bandwidth 3Gb/s is calculated at different channels.

Table 5. Group Delay of Scenario 2

Channel Number	Group Delay(ns)	Average Delay(ns)
Ch #1	0.4509	4.10319
Ch #2	0.4509	
Ch #3	0.4509	
Ch #4	0.4509	
Ch #5	0.4509	
Ch #6	0.4509	
Ch #7	0.4509	
Ch #8	0.4509	
Ch #9	0.4509	
Ch #10	0.4509	

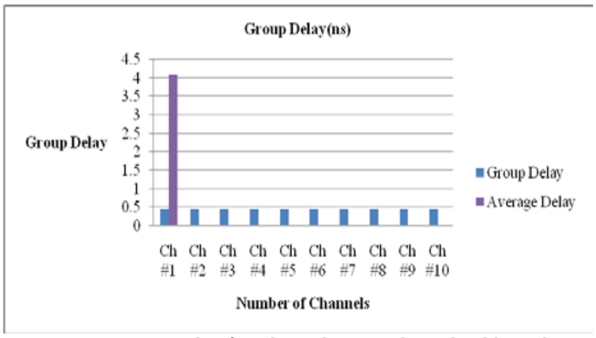

Figure.4. Group Delay for Channels=10 and Bandwidth=3Gb/s

The group delay will not change, there will be effect only on average delay as the no. of channels vary.

E. Average Energy Consumption for Bandwidth = 5Gb/s and Number of Channels = 5

The average energy consumption before and after filtering for 5 channels at bandwidth 5Gb/s is calculated at different channels and is tabulated in table.

Table 6. Average Energy Consumption of Scenario 3

SCENARIO3		
Bandwidth=5Gb/s	Number of Channels=5	
Channel Number	Average Energy Consumption Before Filtering(Joules)	Average Energy Consumption After Filtering(Joules)
Ch #1	0.5251	0.5203
Ch #2	0.5251	0.5199
Ch #3	0.5251	0.5201
Ch #4	0.5251	0.5202
Ch #5	0.5251	0.5204

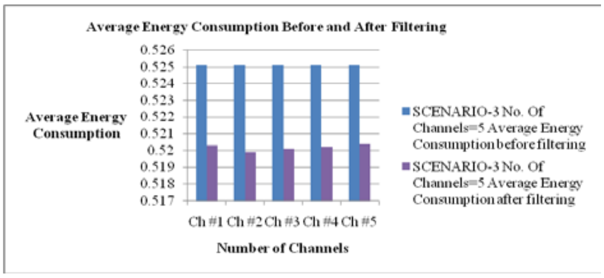

Figure.5. Average Energy Consumption for Channels=5 and Bandwidth=5Gb/s

As from the figure it is clear that average energy consumption before filtering remains constant but as soon as filter is applied average energy consumption starts varying.

F. Group Delay for Bandwidth = 5Gb/s and Number of Channels = 5

The group delay for 5 channels at 5Gb/s bandwidth is calculated and is tabulated in table.

Table 7. Group Delay of Scenario 3

Channel Number	Group Delay(ns)	Average Delay(ns)
Ch #1	0.2706	0.2706
Ch #2	0.2706	
Ch #3	0.2706	
Ch #4	0.2706	
Ch #5	0.2706	

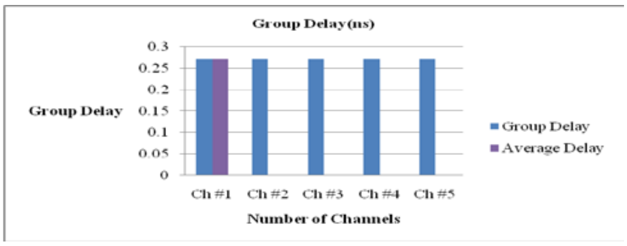

Figure.6. Group Delay for Channels=5 and Bandwidth=5Gb/s

The group delay will not change, there will be effect only on average delay as the no. of channels vary.

G. Average Energy Consumption for Bandwidth = 5Gb/s and Number of Channels = 10

The average energy consumption before and after filtering for 10 channels and bandwidth 5 Gb/s is calculated at different channels.

Table 8. Average Energy Consumption of Scenario 4

SCENARIO4		
Bandwidth=5Gb/s	Number of Channels=10	
Channel Number	Average Energy Consumption Before Filtering(Joules)	Average Energy Consumption After Filtering(Joules)
Ch #1	0.5251	0.5203
Ch #2	0.5251	0.5199
Ch #3	0.5251	0.52
Ch #4	0.5251	0.5201
Ch #5	0.5251	0.5199
Ch #6	0.5251	0.5198
Ch #7	0.5251	0.5198
Ch #8	0.5251	0.5199
Ch#9	0.5251	0.5198
Ch #10	0.5251	0.5202

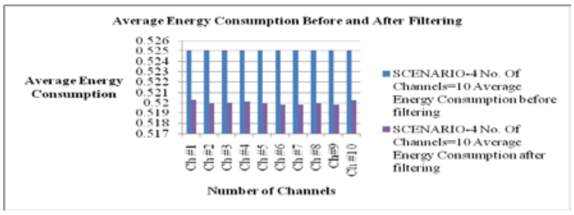

Figure.7.Average Energy Consumption for Channels=10 and Bandwidth=5Gb/s

As from the figure it is clear that average energy consumption before filtering remains constant but as soon as filter is applied average energy consumption starts varying. It is maximum at Ch#1.

H. Group Delay for Bandwidth = 5Gb/s and Number of Channels = 10

The group delay for 10 channels at bandwidth 5Gb/s is calculated at different channels and is tabulated in table 8.

Table 9. Group Delay of Scenario 4

Channel Number	Group Delay(ns)	Average Delay(ns)
Ch #1	0.2706	2.46246
Ch #2	0.2706	
Ch #3	0.2706	
Ch #4	0.2706	
Ch #5	0.2706	
Ch #6	0.2706	
Ch #7	0.2706	
Ch #8	0.2706	
Ch #9	0.2706	
Ch #10	0.2706	

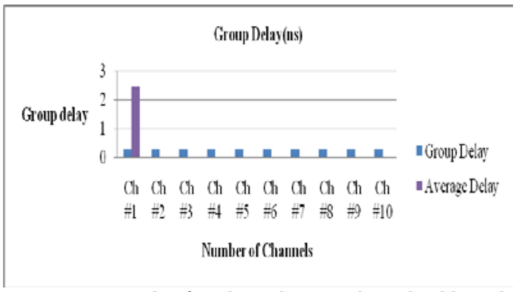

Figure.8.Group Delay for Channels=10 and Bandwidth=5Gb/s

The group delay will not change, there will be effect only on average delay as the no. of channels vary.

I. Analysis of Bandwidth and Average Delay

It is analyzed from all scenarios of average energy consumption and group delay that delay vary with bandwidth.

Table 10. Average Delay at Different Bandwidths

Number of Channels	Bandwidth(Gb/s)	Average Delay(ns)
5	3	0.4509
5	5	0.2706
10	3	4.10319
10	5	2.46246

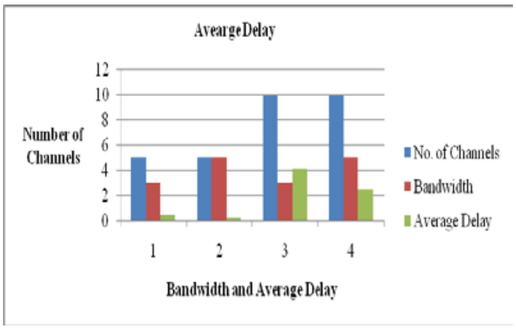

Figure.9.Average Delay for Different Bandwidths

It can be concluded that delay reduces to 0.2706 from 4.10319. As the bandwidth increases and the number of channel decreases, there is a reduction in delay.

V. COMPARISON OF EXISTING AND PROPOSED WORK

The comparison of work is as under:

A. Group Delay of Existing Work

In this sub channel delay compensation method was used [2].

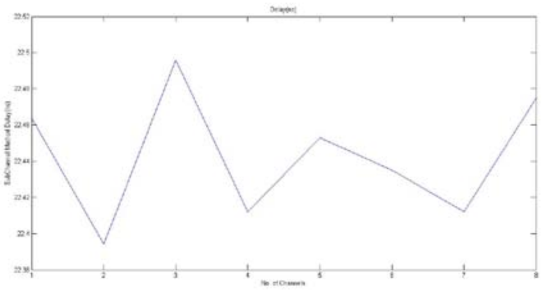

Figure.10.Group delay of existing work

In this delay varies in nano second when the sub channel delay compensation method is applied.

VI. GROUP DELAY OF EXISTING AND PROPOSED WORK

As we compare group delays of existing and proposed work, we analyzed that group delay reduces to 0.2706ns from 22.464ns. In existing work, sub channel delay compensation method is used to calculate group delay and in proposed work, compensating fiber technique along with Butterworth filter is used.

Table 11. Group Delay at Different Channels

Channels	Existing-group delay (ns)	Proposed group delay (ns) with bandwidth 3Gb/s	Proposed group delay (ns) with bandwidth 5Gb/s
ch #1	22.464	0.4509	0.2706
ch #2	22.394	0.4509	0.2706
ch #3	22.496	0.4509	0.2706
ch #4	22.412	0.4509	0.2706
ch #5	22.453	0.4509	0.2706
ch #6	22.435	0.4509	0.2706
ch #7	22.412	0.4509	0.2706

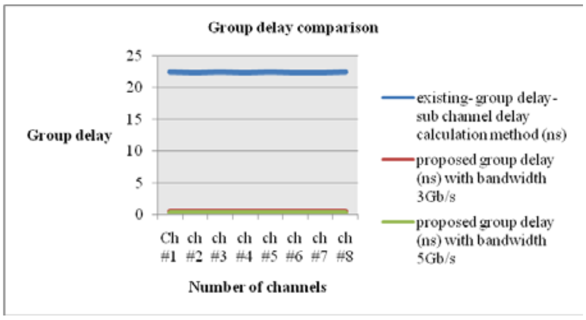

Figure.11.Group Delay Comparison

The figure shows the comparison of group delay of existing and proposed work in nanoseconds. Group delay of existing work is 22.464 ns and group delays of proposed work are 0.4509 ns and 0.2706 ns respectively. The group delay of proposed work varies at 5Gb/s and 3Gb/s.

VII. CONCLUSION

The algorithm worn and parameters evaluated are concluded in brief. The mathematical model is developed to calculate different parameters like Gamma Index, Length of Compensating Fiber, Amplification Gain. After the calculation, filtering of the channel is done by using Butterworth filter. The filtering process is applied to consume the average energy. Main focus is to reduce the group delay. These evaluations have been done by varying the number of channels and bandwidth. The group delay is reduced through compensating fiber. That is how the bandwidth is utilized because the average energy is consumed and group delay is reduced.

Difference in group delay = $D_{existing} - D_{proposed}$

Therefore, difference = 22.1934ns.

Group Delay is reduced to 98%.

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