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OPTIMIZING THE WAVELENGTH CONVERTER USING ADAPTIVE WAVELENGTH ROUTING IN OPTICAL NETWORKS

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ABSTRACT

This project analyses the Wavelength Assignment problem in Optical WDM Networks. The sparse Wavelength Conversion is compared with no Wavelength Conversion and Full Conversions. These comparisons are done on basis of blocking probability, the number channels and links are kept constant and response is calculated by varying the load per link and number of Wavelength Converters. In this work the graph is plotted for blocking probability V/S traffic (load) for both Dijkstra wavelength routing algorithm with existing first fit wavelength assignment and LORA wavelength routing algorithm with existing least loaded wavelength assignment and the results are compared with each other.

Keywords: Analysis, Wavelength Assignment, Wavelength Conversion, Blocking probability, Routing.

I. INTRODUCTION

The realm of telecommunications, the demand for faster, more efficient, and reliable data transmission has led to the development of Optical Networks. These networks leverage optical fibers to transmit data signals in the form of light pulses, allowing for high-speed transmission over long distances. As data traffic continues to grow exponentially, conventional all optical networks face challenges in effectively managing and routing the increasing volume of data. The key problems in optical networks is the Routing and Wavelength Assignment (RWA) problem. RWA involves determining the optimal path and assignment of wavelength for each data transmission to minimize blocking and maximize the utilization of network resources. Based on this real-time information, AWR dynamically adjusts the routing paths and wavelength assignments to ensure optimal data transmission. This adaptability allows the network to intelligently respond to changing traffic patterns and optimize resource utilization. The advanced control and management mechanisms employed in AWR play a crucial role in solving the RWA problem, such as optical switches, wavelength converters, and monitoring systems. These components facilitate the dynamic allocation of wavelengths and the rerouting of data flows, ensuring utilization of network resources efficiently while minimizing blocking and signal degradation. The Wavelength-routed Optical WDM network comprises of Optical Wavelength Routing nodes that is Wavelength routers interconnected by Optical fiber links is considered as the RWA problem.

II. OBJECTIVE

The objective of the project is to transfer information over an Optical network with the minimum number of Wavelength Conversions. To evaluate the Blocking Probability of the path.

- Reduction in the number of Wavelength Converters in the entire network.
- To determine the Optimal Placement of Wavelength Converters.
- Reduction in the overall Blocking Probability.

III. NETWORK MODEL AND ANALYSIS

The WDM Optical networks will be formulated for the Optimal Converter Placement Problem, and the network model is considered and it is a procedure for evaluating the Blocking Probability will be shown, and the exhaustive search Algorithm has also been discussed. The network model can be formulated to calculate the Success Probability and Blocking Probability. The Network model directed graph

$G = (V, L)$

Where, **G** = Network model directed graph

V - Vertices in the graph for network nodes

L - bidirectional optic fiber link between the edges in the graph of the network. The network model with the nodes are represented as 1,2,3,4........n .

$\mathbf{l_{ij}}$ - Node i to node j the directed link.

F - Each link Wavelength

$[\boldsymbol{\lambda_{ij}}]$- Utilization matrix, $\boldsymbol{\lambda_{ij}}, \mathbf{i} \neq \mathbf{j}$ denotes the node-pair load from node **i** to node **j** and $\boldsymbol{\lambda_{ii}} = 0$

$\boldsymbol{\rho_{ij}}$ - Link loads per Wavelength

$\boldsymbol{\lambda_{st}}$ - Represents the link from source to destination

fsi - function of Success Probability of the segment

p - Path on the network graph

k - the number of Converters placed on the nodes of the path p

The traffic model can be computed by Eqn. 1

$$\rho_{ij} = \frac{\sum_{\forall st} \lambda_{st}^{ij}}{W} \quad (1)$$

Under the condition that $\boldsymbol{\lambda_{st}^{ij}}$ is small such that $\boldsymbol{\rho_{ij}} < 1$. $(\mathbf{x_1}, \mathbf{x_2}, \ldots, \mathbf{x_n})$ is the state vector, indicating the Placement of Converters. $\mathbf{x_i}$ is defined as:

$$\mathbf{x_i} = \begin{cases} \mathbf{1} & \textbf{if node i is equipped} \\ \mathbf{0} & \textbf{otherwise} \end{cases}$$

By using variables $\mathbf{x_i}$ where, $(\mathbf{i} = \mathbf{1}, \mathbf{2}, \ldots, \mathbf{n})$, and the given **k** Converters, the values in $(\mathbf{x_1}, \mathbf{x_2}, \ldots, \mathbf{x_n})$ can be determined**,** such that the overall Blocking Probability of the network is minimized. The path from **s** to **t** includes link $\mathbf{l_{ij}}$**,** provided $\boldsymbol{\lambda_{st}}$ is small such that $\boldsymbol{\rho_{ij}} < \mathbf{1}$**.** The load on a link for a given Wavelength is statistically independent of the link loads of other Wavelengths. The path **p** of an end-to end call from a source node s to a destination node **d** in the network is considered. A segment to be the set of links on the path between two consecutive Converter nodes or between the source (or destination) and a Converter node is considered. A single segment exists between the source and destination, if the path contains no Converter nodes. Then,

$$\mathbf{f\,(\,i\,,j\,)\; = \;1\; - \;(1 - \rho_{ii_1}, \rho_{i_1 i_2}, \ldots\ldots\ldots \rho_{i_n j})^{\,F}} \quad (2)$$

where $\mathbf{f\,(\,i\,,j)}$ is the Success Probability in the segment from node i to node j on the path. Let the number of Converters placed on the nodes (not including the source and destination nodes) of the path **p** be **k**, where $\mathbf{0 \leq k \leq K}$**.** Hence the Success Probability of the end-to-end call with the Converter Placement vector being **C** is given by

$$\mathbf{S_{st}\,(C) = \prod_{i=0}^{k} (f(s_i))}$$

Where,

$$\boldsymbol{f\,(si) = f(t(i)\,,t(i+1)\,)\,, 1 \leq i \leq k - 1,} \quad (3)$$

Corresponds to the Success Probability of the segment si between the Converter nodes $\boldsymbol{t(i)}$ and $\boldsymbol{t(i+1)}$. The Blocking Probability for the path is then obtained as,

$$P_{st}\,(C) = 1 - S_{st}\,(C) \quad (4)$$

Thus Blocking probabilities can be computed for all the paths in the network. The formula for the Success Probability for determining the Optimal Converter Placement. The end-to-end Success Probability of a call on path $\boldsymbol{P_{st}}$, $\boldsymbol{S(P_{st})}$ is formulated, under the Converter Placement state $(\boldsymbol{x_1}, \boldsymbol{x_2}, \ldots, \boldsymbol{x_n})$, as follows. When $\boldsymbol{d = 1}$,

$$\boldsymbol{S(P_{st}) = 1 - (1 - q_{i_0 i_1})^F} \quad (5)$$

When $\boldsymbol{d = 2}$

$$\mathbf{S(P_{st}) = (1 - (1 - q_{i0i1})^F)^{x_{i1}}\,(1 - (1\,q_{i1i2})^F)^{x_{i1}}\; \boldsymbol{x}\; (1 - (1 - q_{i0i1}\,q_{i1i2})^F)^{(1-xi1)}} \quad (6)$$

In order to formulate the overall Success Probability, geometrical average of all end-to-end Success probabilities in the system has been considered, which is defined as:

$$\boldsymbol{max\left(\prod_{\forall s,t} S(P_{st})^{\lambda_{st}}\right)^{e^{\left(\frac{1}{\sum_{\forall s,t}\lambda_{st}}\right)}}} \quad (7)$$

so that

$$\sum_{i=1}^{n} x_i = k \quad (8)$$

$$x_i \in \{0,1\}, \quad i = 1, 2, \ldots, n \quad (9)$$

where λ_{st} is the traffic flow from s to t. Note that the traffic between two end-nodes to take the same path has been assumed. Substituting equations (6) – (7) into Eq. (8), the overall Success Probability becomes a function of variables $x_1, x_2, \ldots, x_n$. Eq. (9) represents the binary constraint variable, which is limited to a given k Converters in the system. The optimization goal is to find an Assignment of binary variables $x_1, x_2, \ldots, x_n$ such that the objective function in Eq. (8) is maximized. Thus, the overall Success Probability objective function after taking the logarithm of Eq. (8) will be:

$$f(x_1, x_2, \ldots, x_n) = max \frac{\Sigma_{\forall s,t} \lambda_{st} lg(S(P_{st}))}{\Sigma_{\forall s,t} \lambda_{st}} \quad (10)$$

Equation (10) is a polynomial function of binary variables $x_1, x_2, \ldots, x_n$, which can be more easily optimized than equation (9) since it presents a summation instead of the originally function in the equation (9). Moreover, equation (7) is equivalent to equation (9), because a logarithm function is monotone, which means that an Assignment of binary variables is an Optimal solution.

The Blocking Probability over the entire network with Converter Placement C is given by,

$$\Gamma(C) = \frac{\Sigma_{s,t \in V} \lambda_{st} \ log(P_{st}(C))}{\Sigma_{s,t \in V} \lambda_{st}} \quad (11)$$

This formula is used to select the Optimal C that minimizes $\Gamma(C)$ in the Genetic Algorithm.

Finally, the efficiency of the Algorithm is calculated using

$$\eta = \frac{C_k^N - \alpha}{C_k^N} \times 100\% \quad (12)$$

Where, C – Combination;

α – Number of trials;

N – Number of nodes in the network considered for converter placement;

k – Number of converters to be placed

IV. NETWORK TOPOLOGY

The validity of the proposed Differential E Algorithm in four real sized networks, EON (European Optical Network) with N=20 nodes and L=39 links, topologies are shown Figures respectively

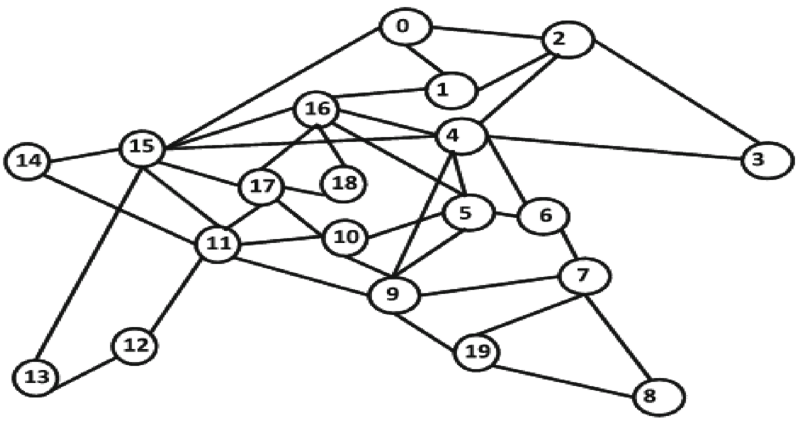

Figure 1: 39 links EON topology

Specifically, focused the analysis in 19-nodes EON, because these network offer the advantage of being big and complex enough to show the advantages and subtleties the algorithm and at the same time, allow us to perform a higher number of tests, which gets cumbersome with larger networks. Furthermore, for comparison purposes we had to consider that most of the studies are done.

V. RESULTS AND DISCUSSION

The results of the mathematical modelling when 7 converters are placed are shown in table 1. The range of wavelength that has been used for this is from 0.3 to 0.37 by increasing 0.05 for each trial. Totally, the Blocking Probability and the Optimal Placement for 7 converters are calculated for 15 trials to obtain the best or optimized value.

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Table 1. Blocking Probability for 7 converters

Wavelength (λu)	Blocking Probability ($\times 10^{-10}$)	Optimal Placement (Γ(C))
0.3	2.6555	9.575853694
0.305	2.9813	9.52559432
0.31	3.3407	9.476162523
0.315	3.7366	9.427523391
0.32	4.1721	9.379645291
0.325	4.6504	9.33250969
0.33	5.1750	9.286089646
0.335	5.7494	9.240377475
0.34	6.3777	9.195335913
0.345	7.0639	9.150955457
0.35	7.8125	9.10720997
0.355	8.6280	9.064089864
0.36	9.5154	9.021572951
0.365	10.480	8.979638717
0.37	11.5272	8.938276172

A graph has been plotted for the obtained values of Blocking Probability versus the Wavelength from table 1 and is shown in fig. 4. It is seen that there is a slight increase in the Blocking Probability as the wavelength increases.

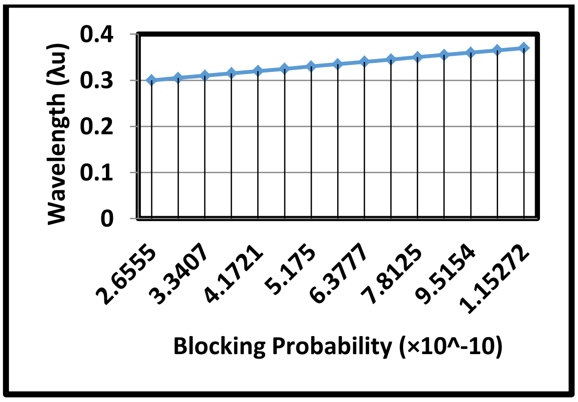

Fig 2. Blocking Probability versus Wavelength for 7 Converters

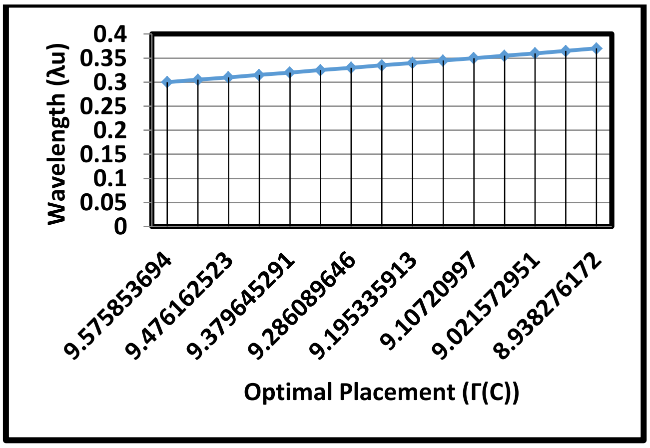

Fig 3. Optimal Placement versus Wavelength for 7 Converters

The graph has been plotted for the obtained values of the Optimal Placement versus their corresponding Wavelengths from table 2 has been plotted and shown in fig. 3. This increases with the increase in Wavelength.

Table 2. Blocking Probability for 8 converters

Wavelength (λu)	Blocking Probability ($\times 10^{-10}$)	Optimal Placement (Γ(C))
0.45	1.00225	9.998915619
0.455	1.0941	9.960942982
0.46	1.1949	9.922668439
0.465	1.3021	9.88512225
0.47	1.41926	9.847938037
0.475	1.54464	9.811172723
0.48	1.6796	9.774794134
0.485	1.8247	9.738808528
0.49	1.98083	9.703159373
0.495	2.1484	9.667884856
0.5	2.3283	9.632961062
0.505	2.5212	9.598392702
0.51	2.7279	9.564171554
0.515	2.9494	9.530266324
0.52	3.18644	9.496694255

The mathematical modeling when 8 converters are placed are shown in table 2. The range of wavelength that has been used for this is from 0.45 to 0.52 by increasing 0.05 for each trial. Totally, the Blocking Probability and the Optimal Placement for 7 converters are calculated for 15 trials to obtain the best or optimized value.

VI. CONCLUSION

This method has been tested to obtain the Optimal Converter Placement for the network examples consisting of major cities in USA (NSFNET) and Europe (EON) areas. The GA performance (accuracy and computational time) with the simulation is compared.

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