Abstract—This dissertation treats the grooming problem that arise in the new DWDM networks. Nowadays due the rapidly internet and data growth some operators are facing problems with expansion and provision due capacity and resources limitations. To address this question we developed two algorithms: The first is based on ILP and is used to obtain the optimal network configuration for routing and regenerators placement simultaneously with grooming cards, transponders and muxponders. This ILP formulations shows that allowing any node in the network be capable to perform grooming increase resource re-utilization such as wavelength and can decrease the initial investment. The ILP deals with the problem in large scale putting in the same environment the physical path restrictions, wavelength and regenerator placement problem with distance constrains. The second approach is an heuristic algorithm developed for the same purpose based on the results achieved with the ILP. The heuristic also proves that the grooming solution is better than just increase the number of wavelength for all cases studied in this research work.

Index Terms—Wavelength assignment, regenerator placement, traffic grooming, WDM, SDH, routing, muxponders, reachability graph.

I. INTRODUCTION

INTERNET and IP are the main drivers to network expansions. Today voice traffic either fixed or mobile are losing space in the world of packets. Mobile networks are shifting the attention from voice to mobile internet and swapping the old circuit switching to packet switch. Fixed network trends are in the battle for the best service related with VOD and other high deﬁnitions services. To accommodate all demands and costumers requirements SDH (Synchronous Digital Hierarchy) technology was deployed for access, convergence and transport layers. This technology as proved in the ﬁeld be reliable and still be deployed in many countries around the world. However, its working principle is seeded in 1310 and 1550 nm. This means that just two wavelength are allowed to carrier trafﬁc regarding the difference in planning phase due the difference in attenuation coefﬁcient, 0.35 dB/km and 0.25 dB/km respectively. To overcome SDH limitations ITU-T developed the OTN (Optical Transport Network) with four main tributaries; OTU1, OTU2, OTU3, OTU4 with 2.666, 10.709, 43.018 and 111.809 Gbit/s respectively for line rates with FEC (Forward Error Correction). This new tributaries can easily be used to carried any service with higher efﬁciency when compared with SDH. Moreover, OTN technology was design to reach large distances without regenerator with new complexes modulations schemes, and its ASON/GMPS in-built protection scheme suits in any topology deployed. Once we have two technologies both capable of grooming and routing we need a tool for planning WDM (Wavelength Division Multiplexing) networks effectively and efﬁciently where the services rates can vary between 2.5 and 40 Gbit/s and line rates can go up to 100 Gbit/s in order to improve the proﬁts and reduce the investments and operations costs.

In the next section, I, we present how to create the reachability graph and all possible paths. The section II describes the ILP based (Integer Linear Programming) formulation for grooming where the problem of grooming is solved just for source nodes. Section III presents the improvements made for achieve optimal grooming solution where any node can perform aggregation. In this section it’s showed that a trick modiﬁcation can be made to change the algorithm to a new type of aggregation called Hub. Section IV describes the heuristic derived from ILP where some assumptions were taken in account in order to produce a faster and reliable solution.

II. REACHABILITY GRAPH

• Definition: Let $G(N, E)$ be the physical topology graph where $N$ is the node set and $E$ the set of all connections between node pairs. $l_{i,j}$ identifies the connection between $Ni$ and $Nj$. $C_{i,j}^{(r)}$ is the set of all physical connections that can be used to establish a path between $Ni$ and $Nj$ at rate $r$ without regenerating the optical signal. Then, $C_{i,j}^{(r)}$ is a sub graph of $G(N, E)$ and $TI^{(r)}_{i}$ a sub graph of $G$ defined as:

$$TI^{(r)}_{i} = \bigcup_{j \in N} (C_{i,j}^{(r)}).$$

Lightpaths raised on $Ni$ at rate $r$ and travel to $Nj$ without regeneration belongs to $TI^{(r)}_{i}$. A second graph can be defined, i.e $G^{(r)}(N, A^{(r)})$, is used to represent the connectivity between nodes based on transparent island.

$$A^{(r)} = \bigcup_{i} \bigcup_{j \in N} A^{(r)}_{i,j}, \forall j \in TI^{(r)}_{i}.$$  

If $f_{i,j}^{(r)} \in \forall A^{(r)}$ then is possible to establish a lightpath from $i$ to $j$ at $r$ without 3R.

III. NETWORK ELEMENTS

In this section we brieﬂy describe transponders and muxponder cards. Transponder cards are used to adapt the incoming trafﬁc from the services channels to line side. If a signal

1In order to use 2.66, 43.018 and 111.809 Gbit/s the values 2.5, 40 and 100 Gbit/s are used as market rates
is not in OTN format then it must go through this transponder card. Muxponder cards are deployed when traffic granularity are very small in comparison with channel capacity in order to increase network efficiency and reduce the amount of lambdas in service. In this work we won’t use regenerators since the cost and the principle are the same and is not possible access the traffic through the backplane. The difference between muxponder and multiplexer is that one put in the same lambda more than one service and the other use one fiber to send many lambdas. Some routers are been manufactured with OTN interfaces to reduce or avoid transponder cards which have a huge impact in the network total cost. Picture retrieved from [1] shows the next step in the combination of routers and transport equipments.

IV. PROBLEM DEFINITION

The problem we try to solve is regarding with network resource waste and investment cost. Nowadays mostly services are based on IP and this traffic is characterized as non uniform traffic in time domain with rates in the range from 10 Mbit/s to 1000 Mbit/s. Once most of networks use IP over SDH over WDM (see figure [2]), the rate arrived at transponder and muxponder cards on WDM equipment coming from client side, was groomed at least in first stage by SDH cards. Normally, SDH groom 10 × 100 Mbit/s and 10 × 1000 Mbit/s and if the rates are 1 Gbit/s then SDH layer is no need and we plug the router directly to WDM equipment. This means WDM is designed to work with clients rates from 1 Gbit/s. In this investigation we study how to optimize the network to carry all types of traffic using the minimum wavelength and equipment resources. To simplify the problem that we are addressing we set three main clients rates: 2.5, 10 and 40 Gbit/s from client side and three types of Muxponders cards with this input ports configuration: 4 × 2.5 Gbit/s, 4 × 10 Gbit/s and the last one is 2 × 40 Gbit/s. The problem is to find the best network configuration to satisfy all traffic request.

V. ILP FORMULATION

A. Source Grooming Problem

In this section we present the first solution for traffic grooming based on source grooming approach with muxponders deployed in cascade configuration. In this formulation we can introduce one muxponder next to other increasing the line rate and groom more traffic request from same source destination pair.

The following formulations simplifies the ILP model presented on [2] and introduces the cascade concept with muxponders at source or intermediate nodes.

Parameters:

- $G(N, E)$: Physical topology graph, $N$ set of nodes and $E$ set of link connection. $(i, j) \in N$.
- $\Lambda_{sd}$: Traffic demand matrix from $(s, d)$ for each rate $r$:
- $r$: line rate identifier. $r \in [0, 1, 2, 3] \Rightarrow \{2.5, 10, 40, 100\}$ Gbit/s.
- $T^{(i,j),r}_{Kth}$: Boolean matrix with information about $k$ disjoint possible paths from $i$ to $j$ at line rate $r$ without be necessary bring the signal to electrical domain.
- $T_{i}^{(r)}$: Contém todos os nós $j \in N$ alcançáveis a partir de $i$ sem ser necessário efectuar regeneração do sinal óptico.
- $C_{TX, CM_{K}}$: Transponder cost for each line rate $r$ respectively and muxponder cost for each client side rate $r$ and line rate $r + 1$.
- $C_{IM_{K}}$: Residual cost to be add in if internal muxponder is used in grooming process.
- $\delta_{i,m,n,k}^{(i,j)}$: Constant. Takes value 1 if the physical connection $(m, n)$ belongs to $K$th path between $(i, j)$ from the logical topology at rate $r$. 0 otherwise.
- $P^{ij}_{r}$: Indicates how many physical paths from $i$ to $j$ are possible to used without 3R.

Variables and constants:

- $\lambda^{sd,r}_{i,j}$: Integer variable. Number of requests $r$ for $(s, d)$ to be groomed before send to the line.
- $\lambda^{sd}_{i,j}$: Binary variable. Takes value 1 if a lightpath from $i$ to $j$ at rate $r$ using transponder is established in the logical topology with wavelength $w$.
- $M^{sd}_{i,j,w}$: Binary variable. Takes value 1 if a lightpath from $i$ to $j$ at rate $r$ using Muxponder is established in the logical topology with wavelength $w$.
- $IM_{s,d,r}$: Integer variable. Stores quantity of muxponders used in cascade to satisfy all $(s, d)$ traffic requests. We refer this variable as Internal Muxponder due the way it is connected in the network.
- $\gamma^{(r)}$: Binary variable, changes according the rate. 2 if $r = 40$ Gbit/s and 1 otherwise.
- $P_{ij,k}$: Binary variable. Assume value 1 if for $K$th physical path between $(i, j)$ is assigned the wavelength $w$.
- $V_{i,j,k}^{w}$: Integer variable. Counts the number of lightpaths created in the logical topology with same wavelength $w$.

(i) Objective Function: The goal is minimize the network total cost for a given traffic matrix using the minimum
number of wavelengths, transponders and muxponders.

\[
\min \sum_{s} \sum_{d} \sum_{i} \sum_{j} \sum_{r} \left( \lambda_{sd,r}^{i,j,w} \cdot C_{TX}^{i,j,r} + M^{i,j,w} \cdot C_{r}^{r} \right) + \sum_{s} \sum_{d} \sum_{r} \sum_{i} \left( I M^{i,j,w} \cdot C_{IMX}^{r} \right)
\]

\text{(3)}

(ii) \textbf{Routing restrictions:} Equations (4) ensures that each request is send to the line using transponder or queued for groom. If the request is in groom mode than equations (5)-(6) will make sure it is forward toward one of adjacent nodes in the logical topology than (7) ensures the route to the sink node. For transponder or muxponder direct lightpath with a wavelength assigned, (8)-(9) guarantee its conservation while the signal cross all intermediate nodes.

\[
\sum_{j} \sum_{w} \lambda_{sd,r}^{i,j,w} + \lambda_{sd,r}^{i,j,k} = \Lambda_{sd}^{i,j} \quad \forall_{sd,r} : j \in T_{s}(r)
\]

\text{(4)}

\[
\sum_{i} \sum_{w} \lambda_{ij,w}^{i,j,k} = \sum_{k} \sum_{w} \lambda_{ij,w}^{i,j,k} \quad \forall_{sd,r,j} : j \in T_{s}(r), j \in T_{k}(r)
\]

\text{(5)}

\[
\sum_{i} \sum_{w} M_{ij,w}^{i,j,k} = \sum_{k} \sum_{w} M_{ij,w}^{i,j,k} \quad \forall_{sd,r,j} : j \in T_{s}(r)
\]

\text{(6)}

\[
\sum_{i} \sum_{w} \lambda_{id,w}^{i,j,k} + \lambda_{id,w}^{i,j,k} = \Lambda_{sd}^{i,j} \quad \forall_{sd,r} : d \in T_{s}(r)
\]

\text{(7)}

(iii) \textbf{Traffic Grooming:} All requests in the grooming state are grouped either with same rate requests or with upper level request using internal muxponders, (8). Equation (9) is used to align different signals at higher level and send to the line or to another grooming stage.

\[
\frac{1}{4} \lambda_{sd,r}^{i,j,k} \leq \sum_{j} \sum_{w} M_{s,j,w}^{i,j,k} + \sum_{i=0}^{\theta} I M_{s}^{i,j,k} \quad \forall_{sd,r} = 0
\]

\text{(8)}

\[
\gamma \left[ \frac{1}{4} \lambda_{sd,r}^{i,j,k+1} + \frac{1}{4} \sum_{i=0}^{\theta} I M_{s}^{i,j,k} \right] \leq \sum_{j} \sum_{w} M_{s,j,w}^{i,j,k+1} + \sum_{i=0}^{\theta} I M_{s}^{i,j,k+1} \quad \forall_{sd,r}
\]

\text{(9)}

(iv) \textbf{Physical path restrictions:} For all lightpaths created in the logical topology must exists one corresponding physical path to carrier the signal. For example, if two lightpaths in the logical topology are assigned the same wavelength than on the physical side we must have at least two disjoint path to ensures no wavelength conflicts during the route. These restrictions are verified in equations (10) - (13).

\[
V_{w}^{i,j,r} = \sum_{s} \sum_{d} \left( \lambda_{ij,w}^{i,j,w} + M_{ij,w}^{i,j,w-1} \right) \quad \forall_{i,j,w,r}
\]

\text{(10)}

\[
P_{r}^{i,j} \geq V_{w}^{i,j,r} \quad \forall_{i,j,w,r}
\]

\text{(11)}

\[
V_{w}^{i,j,r} = \sum_{k} P_{k,w}^{i,j,r} \quad \forall_{i,j,w,r}
\]

\text{(12)}

\[
\sum_{i} \sum_{j} \sum_{r} \sum_{k} P_{k,w}^{i,j,r} \cdot \delta_{i,j,k,w}^{i,j,r} \leq 1 \quad \forall_{m,n,w}
\]

\text{(13)}

(v) \textbf{Line rate restrictions:} The following restrictions limit internal groom to 40 Gbit/s and line groom to 100 Gbit/s. Moreover, it's avoid incompatible inputs rates at muxponders ports.

\[
\lambda_{sd,r}^{i,j,k} = 0 \quad \forall_{sd,r>2}
\]

\text{(14)}

\[
I M_{sd,r}^{i,j,k} = 0 \quad \forall_{sd,r>2}
\]

\text{(15)}

\[
M_{sd,r}^{i,j,k} \leq \sum_{w} \sum_{d} \left( I G_{j}^{sd,r} \cdot C_{r}^{r} + I G_{j}^{sd,r} \cdot C_{TX}^{r} \right)
\]

\text{(17)}

\text{B. Intermediate Grooming}

This algorithm is an upgrade to the former with two new variables and the same number of restrictions turning the ILP more reality close. \( I G_{j}^{sd,r} \) represents all lightpaths using transponder/muxponder card that were dropped in the intermediate \( j \) and \( \lambda_{sd,r}^{i,j,k} \) represents all lightpaths with same sink node \( d \) and different source \( s \). The grooming concept remains at equations (8) and (9) and now each node can mixture its own demands with others nodes demands or just behave as hub node for the crossing traffic. The new falling new variables and restrictions describe the new algorithm:

- \( I G_{j}^{sd,r} \): Integer variable. Number of lightpaths created with transponder at node \( s \) and dropped at node \( j \) for grooming with other lightpaths with same sink node \( d \).
- \( I G_{j}^{sd,r} \): Integer variable. Number of lightpaths created with muxponder at node \( s \) and dropped at node \( j \) for grooming with other lightpaths with same sink node \( d \).

(i) \textbf{Objective Function:} Same objective as source grooming with the variables.

\[
min \sum_{s} \sum_{d} \sum_{i} \sum_{j} \sum_{r} \left( \lambda_{sd,r}^{i,j,w} \cdot C_{TX}^{i,j,r} + M^{i,j,w} \cdot C_{r}^{r} \right) + \sum_{s} \sum_{d} \sum_{r} \sum_{i} I M_{s}^{i,j,w} \cdot C_{IMX}^{r} + \sum_{s} \sum_{d} \sum_{j} \left( I G_{j}^{sd,r} \cdot C_{TX}^{r} + I G_{j}^{sd,r} \cdot C_{TX}^{r} \right)
\]

\text{(17)}

(ii) \textbf{Routing Equations:} Constrains (15) route connections to adjacent nodes in the transparent island or send the requests to constrains (19) - (20) for grooming. In the other and, constrains (19) - (20) ensures that all traffic routed in the network will reach the sink node over the intermediate nodes on the logical topology, changing or
note its assigned wavelength, or dropped at one middle node \( j \) to be groomed with others requests. The decisions how groom all traffic is made in equations (22)-(23).

\[
\sum_j \sum_w \lambda_{s,j,w}^{sd,r} + \lambda_{s,j,w}^{sd,r} = \Lambda_{sd}^r \quad \forall s, d, r : j \in T_s^r \quad (18)
\]

\[
\sum_i \sum_w \lambda_{i,j,w}^{sd,r} = \sum_k \sum_k \lambda_{j,k,w}^{sd,r} + IG_{j}^{sd,r} \quad \forall s, d, r, j \quad (19)
\]

\[
\sum_i \sum_w M_{i,j,w}^{sd,r} = \sum_k \sum_k M_{j,k,w}^{sd,r} + IGG_{i}^{sd,r} \quad \forall s, d, r, j \quad (20)
\]

\[
\sum_i \sum_w \lambda_{i,j,w}^{sd,r} + \lambda_{s,j,w}^{sd,r} + \sum_j IG_{j}^{sd,r} = \Lambda_{sd}^r \quad \forall s, d, r \quad (21)
\]

(iii) **Traffic Grooming restrictions** Restrictions (22)-(23) determine which grooming combination meets all restrictions.

\[
\frac{\sum_i IG_{i}^{sd,r} + \lambda_{sd,r}}{4} \leq \sum_j \sum_w M_{s,j,w}^{sd,r} + \sum_{i=0}^{\theta} IM_{i}^{sd,r} \quad \forall s, d, r = 0 \quad (22)
\]

\[
\gamma \left[ \frac{\lambda_{sd,r} + 1}{4} + \sum_i IG_{i}^{sd,r} + \frac{1}{4} + \sum_{i=0}^{\theta} IM_{i}^{sd,r} \right]
\]

\[
\leq \sum_i \sum_w M_{s,j,w}^{sd,r} + \sum_{i=0}^{\theta} IM_{i}^{sd,r} \quad \forall s, d, r \quad (23)
\]

These are the equations modified from the source grooming ILP algorithm others equations remain the same.

VI. **HEURISTIC APPROACH**

We propose a heuristic that chose the best path in terms of distance and number of regenerators such the total network cost in minimized. In the heuristic we assume one to three shortest path for routing for each rate since it meets the distance requirements. The proposed heuristic is based on reachability graph constructed for each node. If a link in the reachability graph exist from \( i \) to \( j \) then the signal can travel from one to another without any signal regeneration. Notice that, once link in the reachability graph can correspond to many links (or a path) in the physical topology, if \( j \) needs to reach \( j \) but \( j \) is not in the reachability graph of \( i \) than to establish a connection the signal must travel first to one node that is part of \( i \) and \( j \) reachability graphs or another intermediate node \( n \) until a connection be establish.

The algorithm star checking for all traffic demand if is possible to establish a lightpath. Is is useful because in the auxiliary graph process is possible to have unreachable nodes in the network for a given rate, normally this happens for higher rates. In this cases all demands in this situation will moved lower traffic demand from this unreachable node pair. The second and third algorithm computes the best muxponder configuration at source for all node pair requests. The fourth algorithm use the slacks left and tries to find the best path in order to use the demand form the intermediate nodes to full fill the lightpath and minimize the total network cost.

This heuristic don’t used cascade grooming at intermediate nodes and don’t allows grooming with non uniform traffic requests.

A. **Construction auxiliary graph**

The impairment constraint can be addressed by an auxiliary graph \( G'(V, L) \), where \( N \) is the set of auxiliary graph nodes and \( L \) is set of auxiliary links. In the auxiliary graph, the set of nodes \( V \) is the same as the set of nodes \( N \) in the physical topology. \( G(N, E), N = V \). The set of links \( L \) in the auxiliary graph can be constructed as fallows.

- **Step 1**: Find, if possible, the three shortest paths between all pairs of nodes using the Hoffman-Pavlet Ranked Shortest Path algorithm.
- **Step 2**: For all node pairs and all shortest paths ,
  IF The distance in terms of number of hops between a pair of nodes is smaller than the number of hops that the signal can propagate without regeneration, then establish an auxiliary link between the pair of nodes,
  ELSE do nothing.
- **Step 3**: For all node pairs,
  IF a lightpath exist between a pair of nodes, then establish a virtual link between the pair of nodes,
  ELSE do nothing.

B. **Pseudo-code for algorithm**

Below we provide pseudo-code for our proposed heuristic. For better understanding we divide the heuristic in four sub-algorithm.

**Algorithm 1:** Inverse Multiplexing

**Input:** Set of traffic demands matrices  
**Output:** Set of traffic demands, muxponders, transponder and stuffing matrices

while \( r \geq 2.5 \) Gbps do  
  foreach Traffic matrix \([., r]\) do  
    foreach element at \([i, j]_r\) do  
      if \((([i, j]_r \geq 0) \text{ and ( not } \exists \text{ one physical path at } r \text{ connecting } (i, j))\) then  
        \([i, j]_r = 0;\)  
        \([i, j]_{r-1} = [i, j]_r \times 4;\)  
      end  
  end  
end
Algorithm 2: Directly multiplexing without cascade.

Input: Set of tasks and processors
Output: Mapping of tasks to processors
foreach Traffic matrix $[r]$ do
  foreach element at $[i,j]$, $r$ do
    oldcost $\leftarrow$ $COST()$;
    muxponder$[i,j]$, $r$ $\leftarrow$ $\left\lceil \text{demand}[i,j], r \right\rceil$ ;
    transponder $\leftarrow$ demands not counted for mux operation ;
    stuffing$[i,j]$, $r$ $\leftarrow$ slacks left;
    newcost $\leftarrow$ $COST()$;
    if newcost $\leq$ oldcost then
      continue;
    else undo $[i,j]$ operations;
  end
end

Algorithm 3: Directly multiplexing with cascade.

Input: Set of tasks and processors
Output: Mapping of tasks to processors
foreach $r$ do
  oldcost $\leftarrow$ $COST()$;
  demand$[i,j]$, $r+1$ $\leftarrow$ muxponder$[i,j]$, $r$;
  muxponder$[i,j]$, $r+1$ $\leftarrow$ $\left\lceil \text{demand}[i,j], r+1 \right\rceil$ ;
  transponder$[i,j]$ $\leftarrow$ demands not counted for mux operation ;
  stuffing$[i,j]$, $r+1$ $\leftarrow$ slacks left;
  newcost $\leftarrow$ $COST()$;
  if newcost $\leq$ oldcost then
    continue;
  else undo $[i,j]$ operations;
end

Algorithm 4: Intermediate grooming.

This last algorithm will fill the slacks left by the lightpath.
It seeks all paths and check for all intermediates nodes if they have request to send to the sink node. After all nodes it changes the behave and check if the intermediates node have requests to send to another intermediate node the the path. All verifications are made in the logical topology and all intermediates node are Regenerator nodes for the crossing lightpath. Notice that, when a muxponder with a slack is moved to another step for internal grooming, this slacks is lost and the intermediates nodes can not access.

VII. RESULTS

In this section, we evaluate the performance of the ILP, source and intermediate grooming, and the heuristic approach. First we start with a comparison between all ILP approaches. Since the ILP can not achieved results with dense networks we compare heuristic and ILP for small network with sparse demand matrix.

2.5G =

\[
\begin{bmatrix}
0 & 6 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
\]

10G =

\[
\begin{bmatrix}
0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
\]

40G =

\[
\begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
\]

Fig. 3: Sparse matrices used for test.

<table>
<thead>
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<th>$W_{MAX}$</th>
<th>Cost</th>
<th>Time (sec)</th>
</tr>
</thead>
<tbody>
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<td>$\infty$</td>
</tr>
<tr>
<td>2</td>
<td>$\infty$</td>
<td>$\infty$</td>
</tr>
<tr>
<td>3</td>
<td>$\infty$</td>
<td>$\infty$</td>
</tr>
<tr>
<td>4</td>
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<td>8</td>
</tr>
<tr>
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<td>34.5</td>
<td>14</td>
</tr>
<tr>
<td>7</td>
<td>34.5</td>
<td>18</td>
</tr>
</tbody>
</table>

TABLE I: ILP without grooming
VIII. CONCLUSION

The results shows that with grooming is possible to have more traffic with less wavelengths. Due the complexity and time consume for ILP algorithm is not possible to get results for large network even for the six node network the computation time is to high. The Heuristic approach shows better results if we choose to groom the traffic than taken no action to optimize the network. The algorithm designed, in all cases push lower rates in order do maximize wavelength utilization. For intermediate grooming we can see some improvements for large network and for the second and third path mainly because from a node pair using the first shortest path the probability for the signal travel from one to another in the optical domain is to high, this provability decreases when we move from the first to third shortest path.

For future work we suggest improvements in the heuristic approach for adding wavelengths constraints in the physical path and the possibility for cascade grooming at any node as ILP does.

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