Static Multipoint to Multipoint Buses Placement in Transparent Optical Networks

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Abstract. We propose a node architecture supporting the packet-oriented multipoint to multipoint (MP2MP) transparent optical passive buses. The main goal of the bus concept is to minimize costs by maximizing resources utilization in transparent optical mesh networks. We first formulate the problem of MP2MP passive optical bus placement (OBP) as an ILP problem with linear constraints in case of static traffic demands. We propose next a heuristic named Maximizing Resources Utilization (MRU). We use further the MRU dimensioning with two traffic models. We compare the concept of MP2MP bus to the multipoint-to-point (MP2P) passive optical bus and an active MP2MP bus (MP2MP with online optical packet erasing) called also Optical Packet Switching (OPS). We finally derive conclusions from the numerical results on the performance of both the passive and active MP2MP optical and the MP2P bus as well as on the MP2MP passive bus and the OPS active one.

Keywords: Optical Bus, Dual Optical Bus, MP2MP, MP2P, OPS, packet-oriented, passive, active, bus placement, statistical multiplexing, ON/OFF traffic.

1 Introduction

In transparent optical networks, the bandwidth requested by a traffic stream can be much lower than the capacity of a lightpath [1], which may result in large underutilization of optical resources. Efficient grooming of low-speed connections onto high-capacity lightpaths may be therefore required to improve network throughput and reduce network cost.

Several approaches of intermediate grooming have been investigated for transparent optical networks with the general principle to allow intermediate nodes to access a light path in the optical domain, without re-passing through electronic domain. The first approach called optical packet switching (OPS) [2], supposes that an intermediate node on a lightpath is able to drop and erase, in the optical domain, packets destined to it. The second one called indifferently multipoint-to-point (MP2P) traffic aggregation, MP2P optical buses or distributed aggregation (DA) supposes that intermediate nodes are not able to erase packets in the optical domain but to only detect availabilities on the resource and fill it on the fly [3] leading to a set of

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multipoint-to-point (MP2P) unidirectional bus. Another approach named super lightpath or P2MP optical bus supposes that the edge node of a lightpath broadcasts its traffic to all intermediate nodes [4]. Finally, the approach called optical dual bus represents an optimal combination of MP2P and P2MP buses partially described in [5]. Intermediate electronic grooming is also a solution for the mentioned problem, but with this solution the network is no longer transparent.

In this paper, we evaluate the MP2MP optical bus concept [6] in transparent mesh networks. Another concept called "Light Trail", similar to a MP2MP bus and burst-oriented (not packet-oriented) was previously investigated [7]. The light trail concept uses a control channel to establish rapid connections and to avoid collision between nodes sharing a light trail. Therefore, the light trail is connection-oriented in contrast with a MP2MP bus, which is entirely connection-less and packet-oriented.

We propose a new ILP formulation of the MP2MP optical bus placement problem for minimizing the number of required wavelengths. Next, we propose a heuristic named MRU to solve this problem. For the evaluation and network dimensioning, we use two traffic models. The first model is a simple model taking into account the average bandwidth of traffic demands. The second model is the ON/OFF flow model [8] allowing taking into account the statistical multiplexing effect, when multiplexing individual traffic flows onto a single optical resource at different grooming places. We finally compare, for the two traffic models, the proposed MP2MP aggregation to the OPS and MP2P approaches according to the minimum number of resources (lightpaths, transmitters: Tx and receivers: Rx) required to route a given traffic through a given network. This minimum is the performance criterion used for the comparison of different types of optical buses in this paper. A theoretical framework to calculate the statistical multiplexing gain for a single bus in the case of uniform traffic demand is also proposed.

2 MP2MP Optical Bus

An optical bus is a lightpath that can be accessed by its intermediate nodes in the optical domain without passing through the electronic domain. An optical bus consists of a lightpath and intermediate nodes generating traffic (Ethernet frames for example) and accessing the lightpath.

The MP2MP optical bus feature enables full bus sharing among several access nodes. Instead of limiting access to the bus on intermediate nodes only for writing (as in MP2MP case), each node can have an access to a bus for both reading and writing according to the availability. In a MP2MP aggregation, the bus can be shared by multiple connections that have several destinations instead of a single destination for a MP2P bus. Intermediate nodes access the bus in a similar way as in MP2P and use a simple Medium Access Control (MAC) protocol based on void/null detection [9]. Figure (1) depicts different optical buses compared in this article.

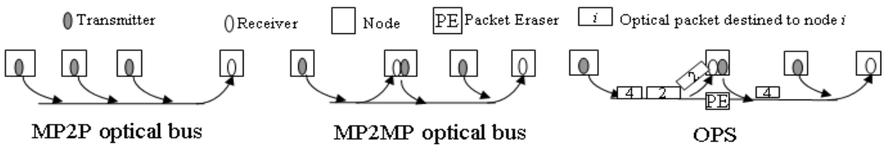

Fig. 1. An illustration of the compared optical busses

3 Node Architecture

3.1 Physical Layer

The node must allow wavelength routing and sharing in a MP2MP manner, controlling the access to the MP2MP bus and on demand MP2MP buses reconfiguration (Bus set up/tear down, add nodes to bus and delete nodes from bus). This architecture must also allow a fair access to the bus and finally, it must allow also classical point-to-point (P2P) lightpath [1] to establish circuit P2P connections if the flow value between two nodes is close to the bandwidth capacity C (Gb/s).

The node architecture comprises optical multiplexers (Mux) and de-multiplexers (Demux), tunable transmitters (Tx) and receivers (Rx), carrier sensing device (CS) or MAC introduced in [9], tunable burst mode receivers (BM-Rx) and transmitters (BM-Tx). Note that in appropriate cases, a burst mode receiver can be used both to receive and detect the void/null as a MAC device (BM-Rx/CS). The node architecture also comprises optical couplers, variable optical attenuators (VOA) to terminate optical MP2MP busses and 2×2 optical switches to reconfigure the busses (only slow reconfiguration is required). Figure (2) shows an optical node supporting MP2MP optical buses. This architecture can be implemented differently, but the more important is that such architecture should be more flexible to allow optical MP2MP buses setup and reconfiguration as well as optical circuit switching. The proposed architecture is scalable and extended easily to an *N* inputs and *N* outputs one.

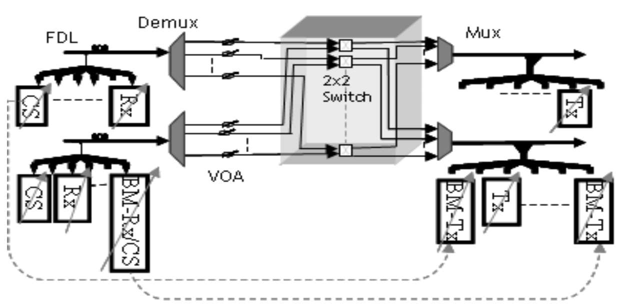

Fig. 2. A node Architecture supporting MP2MP optical buses

3.2 Data Link Layer

In the case of MP2MP bus, the access to the wavelength is controlled, as in MP2P bus, by a simple MAC layer presented in [9]. In addition to a simple Carrier Sense Multiple Access with collision avoidance, the bus fairness is controlled by the TCARD protocol [10]. In this paper, we do not propose any modification to these control mechanisms, as TCARD is also applicable for a fair access between nodes sharing an optical MP2MP bus.

4 Static Optical M2MP Bus Placement: An ILP Formulation

The problem of static optical bus placement is described in [6]. This problem is to find, for a given configuration of traffic, the optimal placement of the different buses. For our study, the cost function is supposed to be the number of buses (wavelengths) required to satisfy a given traffic configuration. The inputs of this problem are:

The physical topology (number of node (*N*) and physical shortest path between node *i* and *j*), the traffic matrix (*T*(*s*,*d*)) and the wavelength capacity *C*. The wavelength capacity *C* will be equal to 10 Gb/s in our study. From those inputs we define the parameters *L* and *H* as follow.

$$L(i,j,k)=\begin{cases}1\,\text{if node } k \text{ is an intermediate node of the bus } (i,j)\\ 0\,\text{otherwise}\end{cases}. \tag{1}$$

H(*s*,*d*): is the hop-distance (in number of links) of the shortest path between nodes s and d. The optical buses will be constructed in a shortest path manner.

We define the variable λ, that indicates if a MP2MP bus is used or not by a traffic demand, as follow.

$$\lambda(s,d,i,j)=\begin{cases}1\,\text{if the bus } (i,j) \text{ is used by the demand } T(s,d)\\ 0\,\text{otherwise}\end{cases}. \tag{2}$$

Under these assumptions, the OBP problem can formulated as follow:

$$\begin{aligned}
&\min_{\lambda(i,j,s,d)} \sum \lambda(i,j,i,j)\\
&\quad\text{Subject to :}\\
&\qquad (C1)\quad \sum_{s,d} \lambda(i,j,s,d)=\delta_{T(i,j)} \qquad \forall i,j\\
&\qquad (C2)\quad \lambda(i,j,s,d)=0 \qquad \text{if } (L(s,d,i)=0 \,\text{or}\, L(s,d,j)=0)\\
&\qquad (C3)\quad \lambda(i,j,s,d)=0 \qquad \text{if}\, H(s,i)\geq H(s,j)\\
&\qquad (C4)\quad \sum_{i,j} \lambda(i,j,s,d)T(i,j)\leq C \qquad \forall (s,d)\\
&\qquad (C5)\quad \lambda(i,j,i,j)\geq \lambda(s,d,i,j) \qquad \forall i,j,s,d
\end{aligned} \tag{3}$$
.

Constraint *C*1 explains the fact that a traffic demand *T*(*i*,*j*) use one and only one optical bus. *C*4 is the bus capacity constraint and *C*5 explains the fact that if an optical bus (*i*,*j*) is used, it is necessarily used by the traffic demand *T*(*i*,*j*). *C*2 and *C*3 are considered as inputs constraints of the problem, because C2 explains that, if a node i or a node j is not an intermediate node to the optical bus (s,d), the traffic demand T(i,j) will not use the bus (s,d) and C3 is the constraint explaining that if the orientation of the demand T(i,j) is opposite to the bus (s,d), this demand will not use the bus (s,d).

Theorem 1. The OBP problem is NP-hard.

Proof 1. The Bin Packing Problem (BP) can be reduced to the OBP since the OBP has more constraints (BP has only the two constraints C1 and C4). Hence the OBP problem is NP-Hard.

Since, the OBP is NP-hard, the complexity of an exact resolution algorithm is exponential and the problem is inaproximable. This complexity is one of the key motivations for a heuristic approach to solve the static MP2MP OBP problem.

We propose a heuristic that we name MRU (Maximizing resource utilization). The pseudo-code of the MRU is described by the Algorithm 1. The principle of this heuristic is to prioritize the flows T(s,d) which have the farthest hop-distance H(s,d) between their nodes source and destination. Unlike the MTA algorithm used for MP2P buses [11], MRU allows intermediate nodes to receive data in a given lightpath, it can assign, therefore, a traffic demand T(i,j) to a lightpath (s,d) even if j is not equal to d.

Algorithm 1 The pseudo-code of the heuristic MRU

1. Reorder the connection requests $T(s,d)$ in descending order of $H(s,d)$.
2. For each connection request $T(s,d)$:
   (a) If T(s,d) is not satisfied :
      i. Establish the bus (s,d) to satisfy $T(s,d)$.
      ii. Insert the intermediates MP2P connections $T(i,d)$ in the bus (s,d) in descending order of $H(i,d)$.
      iii. Insert, in the bus (s,d), the others intermediates connections $T(j,k)$ if there is sufficient bandwidth (in descending order of $H(j,k)$).
3. Route the traffic requests in the constructed topology.

5 Network Dimensioning, Results and Comparison

5.1 MRU Compared to Optimal Solution

In this part, we compare the performance of the heuristic MRU to the optimum obtained by the numerical solver CPLEX [12]. We use the 6-nodes network (small

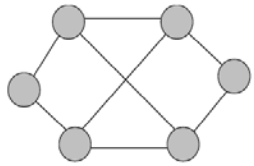

Fig. 3. A six node network

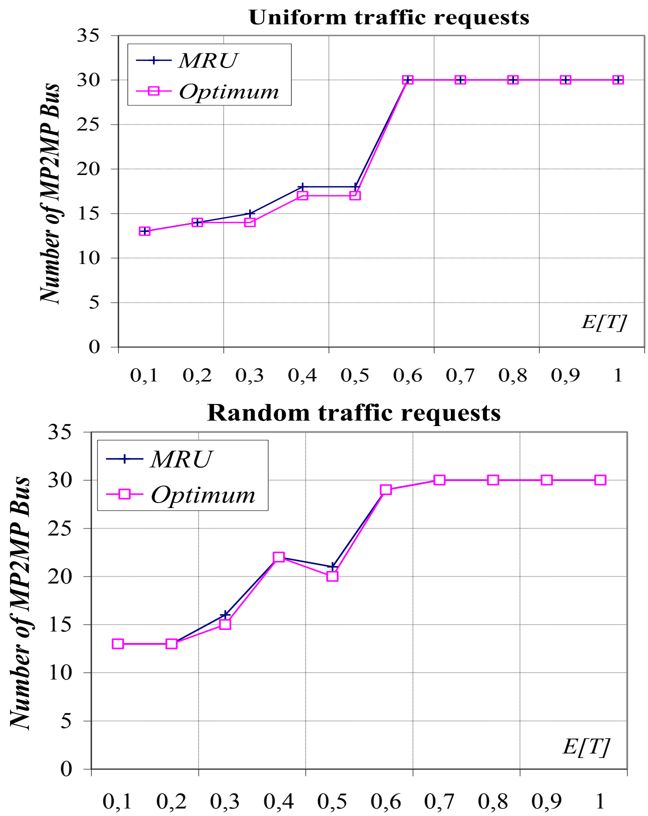

Fig. 4. A six node network (b) MRU and Optimum performance in number of required MP2MP buses

size) network presented on figure 3. We consider a traffic model based in the average bandwidth of each demand T(s,d). It means that the value T(s,d) gives the time-averaged bandwidth of the demand T(s,d). We define the parameter $\overline{T}$ as the averaged and normalized (to the wavelength capacity C) bandwidth value of all the traffic demand:

$$\overline{T} = \frac{\sum_{s,d} T(s,d)}{(Number\ of\ non-zero\ traffic\ demands\ T(s,d)) \times C}. \quad (4)$$

We consider uniform and random traffic scenarios. In the uniform scenario, the demand T(s,d) have the same value for all (s,d) ($s \neq d$). And in the random one, demands T(s,d) are randomly generated following an uniform distribution.

It is noteworthy that all traffic demand will be considered sub-lambda ($T(s,d)<C$) in this part to be accommodated in an optical bus. Because if a traffic demand is non sub-lambda ($T(s,d) \geq C$) we can not accommodate it in an optical bus, but in this case we can break it into two components: the first one is composed of static lightpath while the second one is sub-lambda (part 5.3.4) . From any traffic demand matrix T we can create a traffic demand matrix T_1 that all its elements $T_1(s,d)$ are sub-lambda.

Figure 4 shows that, in this case, the performance of the heuristic MRU are very close to the optimum. In both uniform and random traffic scenarios, the relative error of MRU does not exceed 7%. We conclude that the heuristic MRU can be used to achieve near-optimum performance and thus, we will use it in this paper to map the demands to different MP2MP approach.

5.2 Average Bandwidth Model Network Modeling

In this part, we consider, as in part 5.1, an unicast traffic matrix *T* and only the “random” scenario. It is noteworthy that the MP2MP architecture will have additional benefits in case of multicast traffic, thanks to its full drop and continue feature. The network dimensioning is achieved by evaluating the saving rate of the minimum required resources (Tx, Rx and lightpath) to satisfy a given traffic demand in each approach compared to the classical transparent P2P networks.

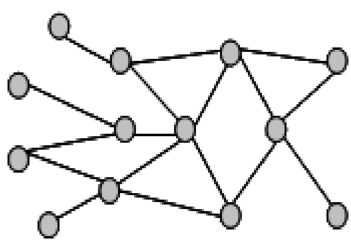

Fig. 5. Network Topology

In our simulation, we use a topology representative of a typical metropolitan network Fig 5. Fig 6. reports the proportion of transceiver saving per node and the reduction of the number of lightpaths in the different approaches compared to the classical transparent case.

$\overline{T}$	percent transceivers per node saving			percent reduction of light path number		
	MP2P	MP2MP	OPS	MP2P	MP2MP	OPS
0.05	25%	50%	50%	49%	77%	77%
0.1	25%	48%	50%	49%	76%	77%
0.15	25%	43%	47%	49%	73%	75%
0.2	25%	38%	43%	49%	70%	73%
0.25	24%	34%	39%	48%	65%	69%
0.3	23%	30%	34%	46%	60%	65%
0.35	21%	26%	29%	42%	53%	58%
0.4	18%	22%	25%	36%	46%	52%
0.45	16%	19%	22%	32%	41%	46%
0.5	14%	17%	19%	27%	36%	40%
0.55	8%	10%	11%	16%	22%	26%
0.6	4%	6%	6%	9%	13%	16%
0.65	2%	3%	3%	4%	7%	8%
0.7	1%	1%	1%	1%	2%	2%
0.75	0%	0%	0%	0%	0%	0%

Fig. 6. Results and comparison

The performance results show that, an average transceivers saving of 15%, 23% and 25% compared to the classical approach is obtained by the MP2P, MP2MP and OPS approaches respectively. We have also an average number of lightpaths reduction of respectively of 31%, 43% and 46%. Furthermore, given the properties of the MP2MP and OPS architecture, where connections to different destinations could be aggregated in the same lightpath on the contrary to the MP2P approach, the number of transceivers and lightpaths required to satisfy all traffic requests is reduced, for all $\overline{T}$ values (Fig 6.).

It is very important to note that, despite the lack of on line packet erasing features in MP2MP approach, its performances are close to those of the OPS. In general, Fig 6. shows average savings of 2% on the number of transceivers and 3% on the number of lightpaths comparing MP2MP and OPS, while the maximum difference is 5% on both criteria. As a result, the proposed MRU algorithm has a resources saving efficiency close to the OPS case without using optical erasing devices that require very faster re-configurability and more complex control [2].

Analyzing results of the Fig 6., we can define three different areas: In the case of a small E[T] (less than 20%), OPS and MP2MP have similar performance, and gains compared to MP2P are very significant (around 50% on transceivers and 25% on lightpaths). In this optimistic case, MP2MP advantageously compete with OPS, having similar performance and a reduced complexity. In the pessimistic case ($\overline{T}$ higher than 60%), the performance of all approaches compared to the classical transparent network becomes low, and those approaches may be more questionable. Typical such case may occur in core networks where previous metro network segments enabled to bundle enough traffic to effectively have traffic demands close to the wavelength granularity. In the intermediate case ($\overline{T}$ is in the interval [25%, 55%]), which is a probable scenario in a metropolitan network, a difference arises between OPS and MP2MP, but this difference remains limited and not exceeds 5%. As a result, the simplicity of passive devices and control mechanisms of the MP2MP approach make it very competitive.

5.3 The Flow Model

In this part, we use the "buffer-less" flow model based on two-states (ON/OFF) Markov sources described in [8]. Each source is described by its utilization ratio (or activity rate) ρ and its peak rate a. The overall traffic model is then characterized by the wanted Grade of Service (GOS) determined by the expected overflow probability ε. Under those assumptions, we can fully characterize a traffic demand T(s,d) by the number N(s,d) of ON/OFF sources, supposed to be identical and independent, that compose it. We consider the two previous traffic scenarios (Uniform and Random).

5.3.1 Inputs and Performance Metrics

The inputs will be the same as in the part 5.2, but we will define another parameter $\overline{m}$, that will replace the parameter $\overline{T}$, as the averaged (to the number of traffic demand T(s,d)) number of N(s,d) multiplied by $a\rho$ to obtain the average network throughput and normalized by the wavelength capacity :

$$\overline{m} = \frac{\sum_{s,d} N(s,d)}{(Number\ of\ non-zero\ traffic\ demands\ T(s,d))} \times \frac{a\rho}{C}\ . \tag{5}$$

In the uniform traffic scenario, $\overline{m}$ becomes equal to (N(s,d)aρ/C). In both scenarios m=$\overline{m}$ C.

Some useful parameters for uniform traffic scenario:

- N(C,m) : Represents the maximum number of demands T(s,d) having each one an average rate of m that can be multiplexed in a wavelength.
- K(m): Represents the number of demands T(s,d) having each one an average rate of m that are effectively multiplexed in a given bus.
- Ke(m): The number of demands T(s,d) having each one an average rate of m passing through the link number #e. This parameter is considered only for the OPS case.

We will define also some performance metrics to compare the three bus concepts:

- ΔG1 (resp ΔG2): The difference between the gain obtained with MP2MP and MP2P (respectively OPS and MP2MP) compared to the classical transparent point to point (P2P) lightpaths networks. Those gains are expressed in percent and represent the savings in terms of transceivers and lightpaths. ΔG1 and ΔG2 are simulated for two dimensioning scenarios (statisical and deterministic multiplexing) combined with two traffic scenarios (uniform or random traffic). The deterministic multiplexing allocates an amount of resource equal to the sum of bandwidths required for each demand and thus causes an over dimensioning of the network. The deterministic multiplexing is similar to a perfect circuit dimensioning. The statistical multiplexing corresponds to a dimensioning that takes into account the effect of traffic burstiness when a bus is shared between several nodes.

- g(K(m)): the statistical multiplexing gain obtained for K(m) traffic demands multiplexed on a given bus and having each one a mean bit rate of m (in Gb/s). The statistical multiplexing gain represents the percent of bandwidth gained when the spatial reuse (statistical multiplexing) is taken into account. In practice, this gain is very difficult to formulate. So, this gain will be formulated, for each type of bus, as the relative bandwidth gain of a statistical dimensioning compared to a deterministic dimensioning. Let $BW_{det}(K(m))$ be the bandwidth reserved in the bus for K(m) traffic demands when a deterministic multiplexing is made, and $BW_{stat}(K(m))$ the same value of bandwidth but in case of a statistical dimensioning, the gain g(K(m)) can thus be expressed as:

$$g(K(m)) = 1 - \frac{BW_{stat}(K(m))}{BW_{\det}(K(m))}. \qquad (6)$$

The statistical multiplexing gain is not used to compare the three buses, but only to compare, for a given bus, a statistical and a deterministic multiplexing. The criteria used to compare the three bus concepts are only the difference of gain ΔG1 and ΔG2.

5.3.2 Buses Modeling

The optical buses MP2P and MP2MP will be modeled by a single resource shared between K(m) traffic demands. But for the OPS, because of existence of online optical packets erasing devices, a bus can't be modeled by a single resource, in this case we will model each link e by a single resource shared between Ke(m) traffic demands. Figure 7 highlights the different bus modeling.

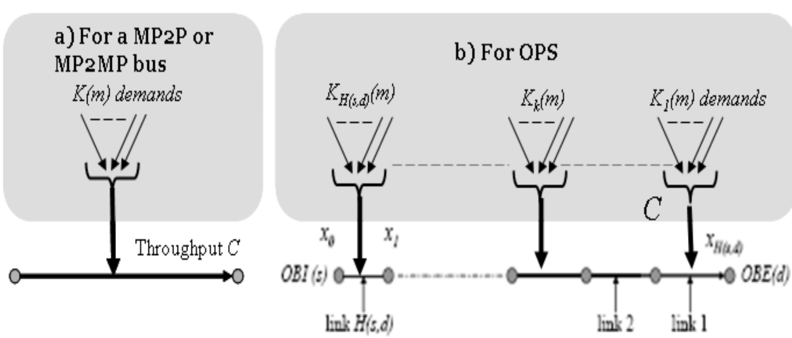

Fig. 7. Buses and traffic demands modeling

5.3.3 Local Derivation of Performance

In this part, we propose a theoretical approach to compute the defined performance metrics for one optical bus (MP2P, MP2MP or OPS), in the case of uniform traffic scenario. This theoretical approach will help us to understand the performance obtained by simulation. We will compute, the performance criteria g(K(m)) for the three bus MP2P, MP2MP and OPS.

K(m) and Ke(m) derivation:

To compute the value of K(m) and Ke(m) for a given bus, we'll start by computing the value of N(C,m) for both deterministic multiplexing (Circuit multiplexing) and statistical multiplexing case. Let BWeq(m) be the bandwidth required by a traffic demand having an average throughput m. BWeq(m) is the equivalent bandwidth given by the Guérin's formula:

$$BW_{eq}(m) = m + \alpha(\varepsilon)\sqrt{ma(1-\rho)}\,. \tag{7}$$

With α(ε) is given by the following approximation:

$$\alpha(\varepsilon) \approx \sqrt{-2\ln(\varepsilon) - \ln(2\pi)}\,. \tag{8}$$

In the deterministic multiplexing case (Circuit), the bandwidth required for a number of traffic demands is the sum of bandwidth required by each demand. Therefore, for an uniform traffic, the maximum number (N(C,m)) of traffic demand that can be multiplexed in a wavelength having a capacity C is:

$$N(C,m) = \left[\frac{C}{BW_{eq}(m)}\right]. \tag{9}$$

where [x] is the integer part of x.

In the statistical multiplexing case, N(C,m) is computed differently. The bandwidth required for q traffic demands having each one an average throughput of m is BWeq(mq):

$$BW_{eq}(mq) = mq + \alpha(\varepsilon)\sqrt{mqa(1-\rho)}\,. \tag{10}$$

And since the value of the required bandwidth of q traffic demands should be lower than C (BWeq(mq)≤C) , the value of N(C,m) is thus, the maximum value of q with BWeq(mq)≤C:

$$N(C,m) = \max\{q / BW_{eq}(mq) \le C\}$$
$$= \left\lfloor \frac{\left(\sqrt{4C + \alpha(\varepsilon)^2 a(1-\rho)} - \alpha(\varepsilon)\sqrt{a(1-\rho)}\right)^2}{4m} \right\rfloor . \quad (11)$$

Once the value of N(C,m) is obtained, we can now compute the value of Ke(m) and K(m) for the three buses concepts:

- • For a MP2P bus (s,d) having a distance H(s,d), there are H(s,d) traffic demands having d as destination. So, since the number of traffic demands K(m) multiplexed in a MP2P bus should not exceed N(C,m) we have :

$$K(m) = \min(N(C,m), H(s,d)) . \quad (12)$$

- In the MP2MP bus, the number of traffic demands (uniform traffic demands) that belong to the bus is:

$$\binom{H(s,d)+1}{2} = \frac{(H(s,d)+1)H(s,d)}{2} . \quad (13)$$

So, in this case K(m) is expressed as follow :

$$K(m) = \min\left(\binom{H(s,d)+1}{2}, N(C,m)\right) . \quad (14)$$

- In the OPS case, only Ke(m) will be computed. Let Ne be the number of possible traffic demands in link e. Ne is computed as follow: While this origin of link #e is node $x_{H(s,d)-e}$ and its destination is $x_{H(s,d)-e+1}$ (Fig. 7), Ne is the sum of the number of demands destined to each node belonging to { $x_{H(s,d)-e+1}$, …, $x_{H(s,d)}$} and having an origin located upstream to $x_{H(s,d)-e}$ (in Se = {x_0 , x_1 ,…, $x_{H(s,d)-e}$}):

$$\begin{aligned} N_e &= size(S_e) \times size(D_e) \\ &= e(H(s,d) - e + 1) \end{aligned} . \quad (15)$$

were size{X} is the number of elements of set {X}. Once the number of possible traffic demands in a link e, Ne, is computed, we can now give easily the number Ke(m):

$$K_e(m) = \min(N(C,m), eH(s,d) - e + 1) . \quad (16)$$

Bus statistical multiplexing gain g(K(m)) computing:

In this part we will represent two statistical multiplexing gains. The first one, *Local gain*, is the gain obtained by multiplexing individual flows (ON/OFF sources) in the node level. This is independent of the fact that an optical bus concept is used or not. The second gain, g(K(m)), defined previously, is the gain obtained by the multiplexing of K(m) traffic demands on the bus. To compute the Local gain for M(M>>1) multiplexed individual ON/OFF source, we use the same formula as in (1), but the sum of bandwidth required for each ON/OFF source ($BW_{det}(M)$) will be only Ma (Number of ON/OFF source × peak rate). The bandwidth required $BW_{stat}(M)$ in the statistical multiplexing for M ON/OFF sources is given by the Guérin's formula: $BW_{stat}(M)=BW_{eq}(Ma\,\rho)$, now the Local gain is:

$$Local\ gain = 1 - \frac{BW_{eq}(Ma\rho)}{Ma}. \tag{16}$$

To compute the gain g(K(m)) we will distinguish two cases:

- Case of MP2P or MP2MP bus: In this case we use the formula (6), with $BW_{det}(K(m))$ and $BW_{stat}(K(m))$ are expressed as follow:

$$\begin{aligned} BW_{stat}(K(m)) &= BW_{eq}(K(m)m) \quad and \\ BW_{\det}(K(m)) &= \sum BW_{eq}(m) = K(m)BW_{eq}(m) \end{aligned}. \tag{17}$$

- Case of OPS: In this case, formula (6) is also used but $BW_{det}(K(m))$ and $BW_{stat}(K(m))$ will be expresses as follow:

$$\begin{aligned} BW_{stat}(K(m)) &= \sum_{e=1}^{H(s,d)} BW_{eq}(K_e(m)m) \quad and \\ BW_{\det}(K(m)) &= \left(\sum_{e=1}^{H(s,d)} K_e(m)\right) BW_{eq}(m) \end{aligned}. \tag{17}$$

Results of figure 8 show that the bus statistical multiplexing gain is better for a MP2MP bus, but it becomes quickly the same for all buses type and becomes low when $\overline{T}$ >25%. The reason is that, when the requested bandwidth per traffic demand increases, the number of traffic requests K(m) (resp Ke(m)) that can be multiplexed in a bus (resp in a link) decreases until being the same for the three buses types. We conclude from those results that, the statistical multiplexing in the optical layer has significant benefits in sparse areas and limited benefits in dense ones.

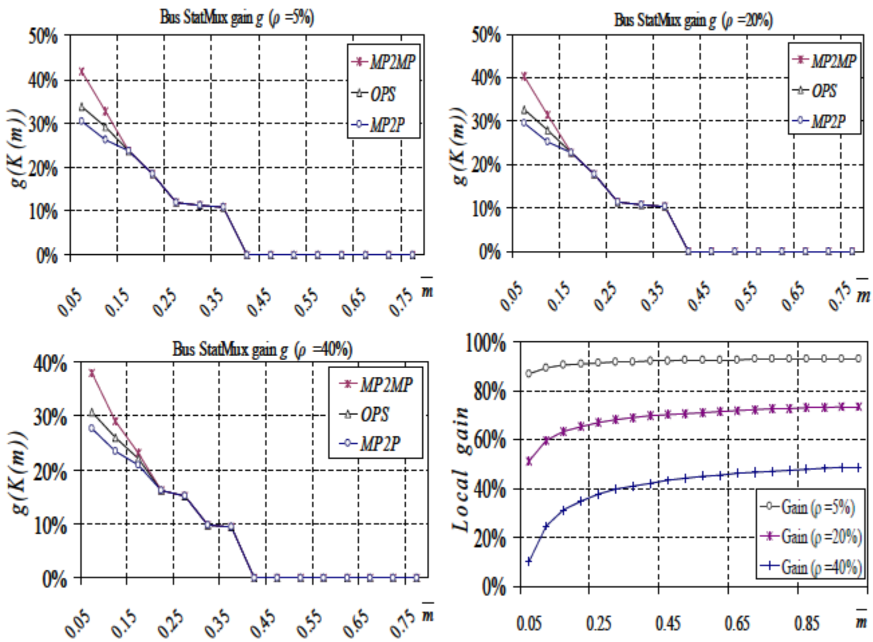

Fig. 8. Local and Bus statistical multiplexing gain (H(s,d)=4, ε=10^{-6} and a=50Mb/s)

Results show also that the variation of the utilization ratio of the ON/OFF sources ρ, that characterizes the traffic burstiness, does not significantly affect the bus statistical multiplexing gain g(K(m)). For example, when ρ passes from 40% to 5%, the bus statistical multiplexing gain increases very slightly (~3%). The reason for this is that the gain obtained from the traffic burtiness variation is mainly represented in the local gain (for example, when ρ passes from 40% to 5%, the local multiplexing gain increases significantly of about 77%).

5.3.4 Network Dimensioning

This part is independent from the local computing, but some conclusion from the local computing part will be used to explain some simulation results. For this part we keep the same network topology as in 5.2. We represent in this part the variations of the difference of gain ΔG1 and ΔG2 for different scenarios as a function of $\overline{m}$. The algorithm used in the MP2MP dimensioning is the heuristic MRU. This part compares effectively the three buses performance (Costs saving: number of buses (lightpath) and transceivers).

Figure 9 shows that, the difference between MP2MP and MP2P is significant in some cases, but the difference between OPS and MP2MP remains always limited. It is also shown that, when the statistical multiplexing effect is taken into account, the difference between MP2MP and MP2P increases slightly but the difference between OPS and MP2MP decreases slightly compared to a deterministic multiplexing.

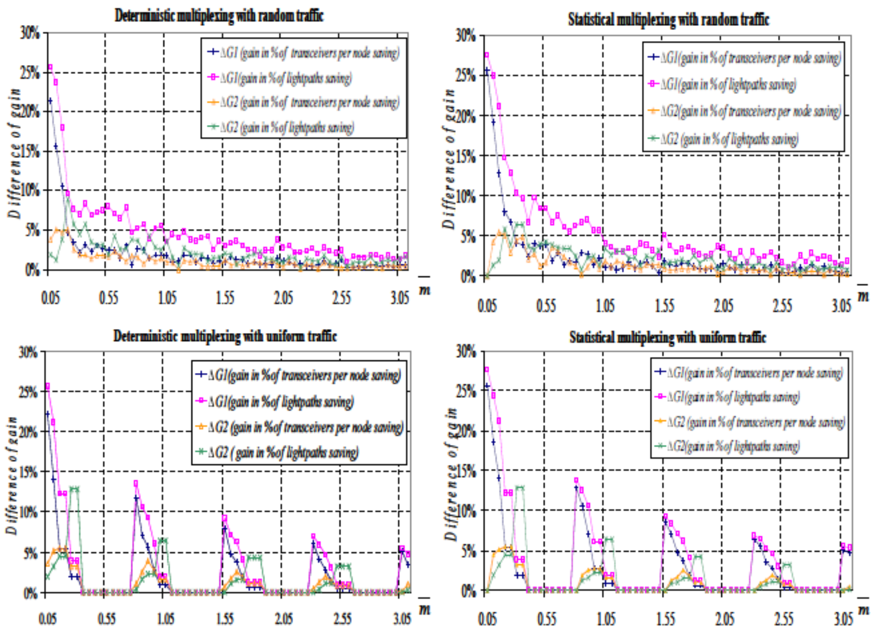

Fig. 9. Difference between the three buses (a=50 Mb/s, ρ=40% and $\varepsilon=10^{-6}$)

The explication is the fact that, the statistical multiplexing effect is more favorable to MP2MP (figure 8). So, the conclusion given with an average bandwidth traffic model in part 5.2 remains valid and is consolidated with a flow model. Results show also that the difference between the three approaches decreases as the average bandwidth $\overline{m}$ requested by traffic demands increases, because when the bandwidth requested by a traffic demand becomes high, only a small number of demands can be placed in a bus in all cases and thus the difference between the buses decreases.

6 Conclusion

In this paper we investigate the problem of minimizing cost while maximizing resource utilization in transparent optical networks. We proposed an architecture supporting MP2MP packet-oriented optical bus to address this problem. Next the problem of MP2MP bus placement and planning has been investigated and a heuristic was introduced to solve it. This heuristic has been evaluated and compared to the optimal solution under a small size topology.

MP2MP passive bus placement heuristic has been implemented and evaluated trough simulations in a more realistic transparent optical network topology. Simulation results show that the MP2MP bus combined with the proposed heuristic algorithm leads to significant optimization with respect to the MP2P approach.

MP2MP approach can also achieve performance close to those of the OPS, and thus remains very competitive compared to OPS thanks to its passives and simple devices. A further work is to compare it to all the existing buses and evaluate it in a multilayer network.

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