

Efficient Mixed Topology Configuration Algorithm for Optical Carrier Ethernet

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ABSTRACT

Carrier Ethernet, which extends the traditional Ethernet into backbone networks, has drawn a lot of attention. The algorithm based on constructing the mixed topology and performing link stretching, MT/s, has been proposed for designing cost-efficient Carrier Ethernet in optical network with multi-line-rate. However, the MT/s algorithm has high blocking ratio because the wavelength capacity is fully allocated without considering the load balance of network. In this paper, we propose an efficient mixed topology configuration (EMTC) algorithm by modifying MT/s algorithm. In order to reduce blocking ratio, we adapt a threshold for each link to restrict the link utilization so that traffic load can be distributed over whole network. We also apply the EMTC algorithm into optical hybrid switched network to evaluate the availability of our algorithm for different applications. The performance of the EMTC algorithm is compared with that of MT/s algorithm through OPNET simulation. The simulation results show that our algorithm achieve lower blocking ratio than the MT/s algorithm. Moreover, in hybrid switched network, our algorithm performs better than MT/s algorithm in terms of packet loss ratio and end-to-end delay.

Key Words : Carrier Ethernet, WDM, Mixed Topology

I. Introduction

Ethernet, which has achieved huge success in the Local Area Network (LAN), is now in process of extending to Metropolitan Area Network (MAN) and Wide Area Network (WAN). Because of simplicity, inexpensiveness and flexibility, Ethernet has proven itself a significant transport technology that can continually adapt to evolving market demand^[1,2]. Meanwhile, it has been proved that transmitting Ethernet frames directly over wavelength division multiplexing (WDM) channels (Ethernet-over-WDM) at high rates (e.g. possibly 100Gbps in near future) can minimize both Capital Expenditure (CapEx) and Operational Expenditure (OpEx)^[3-5]. To provide reliable services in backbone networks, Carrier Ethernet can be realized by

establishing a connection between source and destination nodes: Ethernet Tunnel (ET) consisting of one or several lightpaths, or Etherpaths (EPs) denoting lightpaths carrying Ethernet frames. Besides, the variation in bandwidth requirements of applications incurs the proposal of multi-line-rate network, in which links may operate at different rates. Accordingly, network needs more flexibility for provisioning traffic.

Study in [6] proposed the mixed topology (MT) based algorithm to design cost-efficient Carrier Ethernet using link stretching(LS), MT/s algorithm, to provision all traffic demands under the constraint of 3R (reamplification, reshaping and retiming) regeneration. The main objective is to minimize the number of Ethernet Interfaces (EIs). Thus, the algorithm fully allocates link capacity to the

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connection requests so as to minimize the number of EIs. This may result in high packet blocking ratio.

In order to combat this problem, we propose an efficient mixed topology configuration (EMTC) algorithm which considers load balance to distribute traffic through the whole network. And we also apply the EMTC algorithm into optical hybrid switched network consisting of optical packet switching (OPS) and optical circuit switching (OCS). The EMTC algorithm can achieve high throughput and guarantee the required QoS in optical hybrid switched network.

The remaining part of this paper is organized as follows: Section II describes the related work of MT/s Algorithm; Section III proposes EMTC algorithm and applies EMTC algorithm into hybrid switched network; Section IV shows the simulation results and analyzes the performance; Section V concludes this paper.

II. Related Work

2.1 Node Architecture

The node architecture of Ethernet-over-WDM is shown in Figure 1. The architecture consists of Ethernet Switch (ES) in electronic domain and optical cross connect (OXC) in optical domain. The ES initiates and terminates EPs by using EIs. ES performs the function of grooming traffic from metropolitan or access networks (Ethernet connection requests) onto EPs in electronic domain. The other function of ES is to regenerate signal if the EP traverses a long distance and the signal quality deteriorates to a level where 3R regeneration

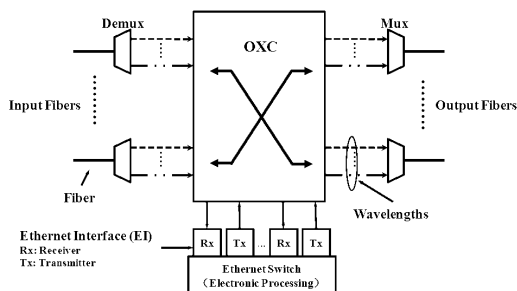


Fig. 1. Node architecture

is needed. The OXC is used to route lightpaths in optical domain. The OXC is supposed to have enough Input/Output ports, which are network line cards, to support fiber connections with neighbor nodes and for local traffic Add/Drop with ES^[6].

2.2 MT/s Algorithm

Given the traffic demand matrix which reflects the bandwidth requirement between each source-destination (s-d) pair in network, a logical topology can be constructed. The logical topology, also known as virtual topology, depicts the establishment of lightpaths as well as the status of network resource allocation^[7-8]. Study^[6] uses the terminology MT because the edges of MT might be physical links or virtual links (already established lightpaths). And the MT is constructed for each ET. In MT, all usable physical and virtual links can be included, i.e. any path in the MT is a viable route for current ET. The MT reflects the network's resource usage state by including/excluding appropriate edges. The physical or virtual links contained in MT include all but: 1) all links running at the link rate lower than the ET's rate; 2) all saturated EPs or EPs with free capacity below ET's rate; 3) all saturated links (all wavelengths on the link are used). According to certain order, the connection requests are provisioned one by one based on the MT.

In the multi-line-rate network, ETs could be served over EPs with different rates. For example, the bandwidth requirement for an ET is 5Gbps and there are two kinds of links running at 10Gbps and 100Gbps respectively. This ET can be carried over a 10Gbps EP or a 100Gbps EP. Obviously, EIs cost in two cases are two 10Gbps EIs or two 100Gbps EIs correspondingly. The cost of a 100Gbps EI is around five times the cost of a 10Gbps EI according to current industry trend^[9]. Moreover, the signal transmitted on 100Gbps channel is more likely to be interfered by physical impairment than that on 10Gbps channel. In other words, the optical reach of 100Gbps lightpath is shorter and more 3R regeneration might be needed which leads to higher CapEx and OpEx^[10].

To find the minimum-cost path which is

determined by EIs, the concept of LS is introduced. Usually, the distance of a link is viewed as link cost in a number of routing algorithms. But by LS, the link cost is determined by link distance as well as a factor α which depends on both the link rate and the ET rate. The factor α is defined as

$$\alpha = \frac{\text{Link Rate}}{\text{ET Rate}} \quad (1)$$

Obviously, it is possible to set heavier weights on the links which are running at higher rates in order to choose those higher-rate links with lower possibility, because the initiation and termination of a higher-rate EP need more expensive EIs and a higher-rate EP means more 3R regenerations required. Oppositely, establishing lower-rate paths means the EP scan have a longer transmission range and less 3R regenerations. In addition, each ET can be satisfied by being groomed onto existing EPs or establishing new EPs. If there need EPs to be setup, LS can guarantee that the most appropriate EP rate is chosen to provision the ET. Note that the cost of those already established lightpaths(virtuallinks) in MT is set to be zero. This could enable ETs to be groomed on to the established EPs In MT, that is, one EP can be shared by different ETs if the capacity is enough to pack them together. LS can be viewed as a kind of link cost assignment scheme which can affect the computing of routing.

With the concept of MT and the operation of LS, MT/s algorithm is proposed to minimize EI consumption. The number of lightpaths established and 3R regenerations needed are factors of the number of EIs consumed in network.

III. Proposed Algorithm

3.1 The Efficient Mixed Topology Configuration Algorithm

To achieve the least consumption of EIs, MT/s algorithm tries to groom as many ETs onto same wavelength as possible. However, this full allocation might result in a high connection blocking ratio which is a vital problem in backbone network.

Explicitly, the bandwidth requirements in traffic matrix are predicted as statistical average values. However, traffic in actual network is characterized of the self similarity which implies that traffic can be bursty instead of being stable^[9,10]. If we groom too many ETs onto a same wavelength so as to achieve the least EI consumption, many requests will be blocked when traffic is bursty. Additionally, the bandwidth requirement of a connection request is large and the request is serviced in a connection-oriented way in backbone network. Once a request is blocked, there will be a huge amount of data lost. Hence, we want to improve MT/s algorithm with the objective to reduce connection blocking ratio.

In order to reduce blocking ratio, we consider the load balancing scheme which can distribute traffic load through whole network. To achieve this, we propose to use partial allocation when configuring MT. We introduce a threshold, δ , which limits the ratio of usable capacity on a wavelength. The remaining $(1-\delta)$ part is reserved to avoid request blocking when bursty traffic arrives. This limitation guarantees that each link will not be over-loaded. As a result, blocking ratio will be reduced.

The problem of configuring an efficient MT which can achieve low blocking ratio is formulated as follows:

Given:

- G(V, E): graph that depicts the network physical topology, where V is the set of nodes and E is the set of links
- TM: traffic demand matrix consists of ETs with different bandwidth requirements

Transmission Constraints:

- Number of EIs at each node
- Number of wavelengths on a link and the wavelength capacity for different data rate
- Maximum distance that an EP can travel (data rate dependent), i.e., the signal's transmission range beyond which the 3R regeneration is necessitated
- For each EP, the wavelength-continuity constraint is assumed

Objectives:

- Provision all ETs in the TM
- Reduce the connection blocking ratio

The notations used in the EMTC algorithm are described as follows:

- $G'(V, E)$: Auxiliary graph that depicts the MT, where V represents the set of nodes and E represents the set of links
- $ET(s, d, BW)$: ET format, where s denotes the source node and d denotes the destination node and BW is the bandwidth requirement for ET
- v_j : A node in $G'(V, E)$
- $E_{j,k}$: Link connecting v_j and v_k which could be either a physical or a virtual link
- $D_{j,k}$: Distance of the link $E_{j,k}$
- $R_{j,k}$: Data rate of the link $E_{j,k}$
- R_i : Rate of $ET(s, d, BW)$
- δ : Threshold of usable capacity on a wavelength
- $NODE_NUM$: Number of nodes
- $WAVE_NUM$: Number of wavelengths on a link

Based on the assumption and notations mentioned above, we propose the EMTC algorithm, which is described as follows:

- Step 1. Store all the ET_s (according to the traffic matrix) into a list L in descending order.
- Step 2. From the i th ET, represented as $ET_i(s_i, d_i, BW_i)$, generate an auxiliary graph G_i' which is the MT associated with ET_i .
- Step 3. For node pair v_j and v_k , find the link $E_{j,k}(v_j, v_k)$, which is the connection between v_j and v_k .

A. If link $E_{j,k}$ is found:

1. If $E_{j,k}$ is a physical link, for the n th wavelength/channel λ_n ,
 - a) If the residual capacity is larger than or equals to $(1 - \delta)$ of λ_n 's total capacity after serving ET_i , reserve $E_{j,k}$ in the G' ; do LS, set $E_{j,k}$'s link weight as $D_{j,k} * \alpha$; go to step 3 with new $E_{j,k}$.
 - b) Else, $n++$, repeat Step3.A-1 with new λ_n .

If there is no wavelength can serve ET_i on link $E_{j,k}$, remove link $E_{j,k}$ from G' . Go to Step3 with new $E_{j,k}$.

2. Else, $E_{j,k}$ is a established virtual link, check:
 - a) If the residual capacity larger than or equal to $(1 - \delta)$ of $E_{j,k}$'s total capacity after serving ET_i , reserve E_c in the G' , go to step 3 with new $E_{j,k}$.
 - b) Else, remove link $E_{j,k}$ from G' . Go to step 3 with new $E_{j,k}$.

B. Else, the link $E_{j,k}$ is not found;
repeat step 3 with new $E_{j,k}$.

- Step 4. Generate SR, a route set containing all candidate routes for ET_i based on MT and LS.
- Step 5. Find a set of K Minimum-Weight Paths (KMWP) over the established MT for ET_i with new link weight after LS.
- Step 6. For each path in KMWP, calculate the cost of using that path

$$PathCost = \sum_{m=1}^2 n_m \times c_m \quad (2)$$

where n_m is the number of EIs at data rate r_m , c_m is relative unit cost of the EI operating at r_m . Note that the EIs may operate at data rate $r_1 = 10\text{Gbps}$ or $r_2 = 100\text{Gbps}$ and they have different costs.

- Step 7. Choose the path with the minimum cost from the KMWP set. Provision the ET_i and update network resource information. If ET_i is the last ET, finish. Else, $i++$, go to Step 2.

Following, we will describe how the proposed EMTC algorithm works and compare it with MT/s algorithm. The network physical topology is shown in Figure 2. The links drawn in thin and thick lines represent that they operate at 10Gbps and 100Gbps, respectively. The links are bidirectional. The number of wavelengths on each link is two for simplifying illustration, one for each direction. It is assumed that there are two ETs to be provisioned in the order: $ET_1(2,5,70)$, $ET_2(1,5,5)$, which corresponds with the notation aforementioned and the unit of bandwidth is

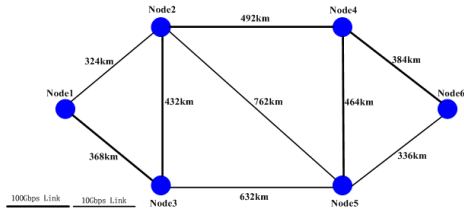


Fig. 2. Network physical topology

Gbps. The threshold δ is set to be 0.7.

Comparing the two algorithms, we can get that the routing and wavelength assignment (RWA) solutions for ET_1 are the same: route for ET_1 is {2->4->5} and λ_0 on both link 2-4 and link 4-5 are allocated to ET_1 . After provisioning ET_1 , the RWA solutions for ET_2 are different. According to MT/s algorithm, ET_2 can be provisioned like this: establish a new EP from node1 to node2 (EP_{1-2}) on link connecting these two nodes and groom ET_2 onto EP_{2-4} , EP_{4-5} because the link costs of existing EP_{2-4} and EP_{4-5} are set to be 0. The route for ET_2 is {1->2->4->5}. Otherwise, if we implement EMTC algorithm, although EP_{2-4} , EP_{4-5} have been established and their costs have been set to 0, the RWA solution for ET_2 will be to establish a new EP_{2-5} since the residual 30% capacity (30Gbps) on EP_{2-4} , EP_{4-5} cannot be allocated anymore. On the other hand, the total EI consumption is four 100Gbps EIs and two 10Gbps EIs based on MT/s algorithm. Although EMTC algorithm consumes the same amount of EIs it occupies one more wavelength on link 2-5. As a result, by implementing EMTC algorithm, the traffic can be distributed more evenly and thereby the blocking ratio on the links which endure heavy traffic can be reduced.

After serving the ETs mentioned above, the MTs

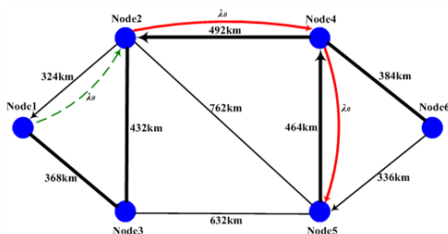


Fig. 3. MT constructed by MT/s algorithm

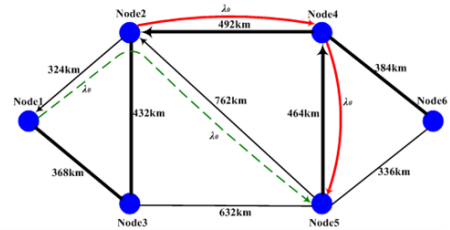


Fig. 4. MT constructed by EMTC algorithm

constructed based on MT/s algorithm and EMTC algorithm are shown in by Figure3 and 4, respectively. In both figures, the solid red lines represent EPs running at 100Gbps while the dashed green lines represent those 10Gbps EPs.

3.2 Implementing EMTC Algorithm in Optical Hybrid Switched Network

In order to guarantee reliable service, traditionally, backbone network was optical circuit switched. Additionally, the fixed routing and wavelength assignment scheme was considered. With the analysis in previous section, we find that much network resource remains after the MT is configured. Obviously, the residual high-speed wavelengths mean a huge amount of network capacity waste and low resource utilization.

With the development of optical technology, nowadays, implementing optical switches with microsecond switching time is becoming feasible^[9]. To resolve the problem brought by pure OCS way, we can consider an optical hybrid switching method which combines OPS and OCS to provide more efficient service in backbone network. Table 1 compares the basic properties of OPS, OCS and optical hybrid switching, aiming at identifying the main characteristics of each switching scheme. It is easy to be found that the hybrid switching scheme possesses distinguishable improvement of efficiency and flexibility compared with pure OPS and OCS schemes.

In order to evaluate EMTC algorithm in different application, we can implement it in the network supporting optical hybrid switching. Then we can divide the traffic into two parts, OCS part and OPS part, that is, there are two kinds of traffic generated

Table 1. Main properties OPS, OCS, and optical hybrid switching paradigms

	OCS	OPS	Hybrid
Recommended size of transfer unit	> GB	~40 to 1500 B	~40B to > GB
Explicit transfer guarantee	Yes	No	Yes (OCS part)
Loss type	Connection rejection	Packet loss	Packet loss (OPS)
Control	Out-of-band	In-band	Out-of-band (OCS) In-band (OPS part)
Latency usually	~3*prop. delay	~ Prop. delay	~Prop. Delay
Control overhead from	Connection set-up	Packet header	Conn. set-up (OCS) Packet header (OPS)

in network: one is serviced in OCS way and the other is serviced in OPS way. Correspondingly, the traffic matrix (TM) is divided into two sub-TMs. Here we use an example to describe how to implement EMTC algorithm in a network that supports optical hybrid switching. First, we establish EPs according to the sub-TM of OCS part. It is assumed that the configured MT is illustrated in Figure 5. Then we can separate a residual physical topology from the MT. This residual physical topology only includes those un-assigned links and wavelengths after provisioning all OCS requests. These links or wavelengths can be used for provisioning the traffic serviced in the OPS way. The separated residual physical topology is given in

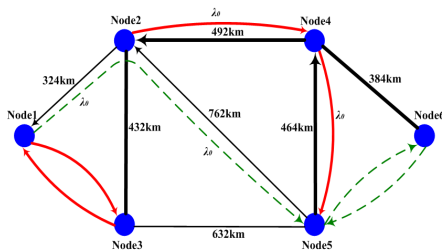


Fig. 5. MT constructed by EMTC algorithm

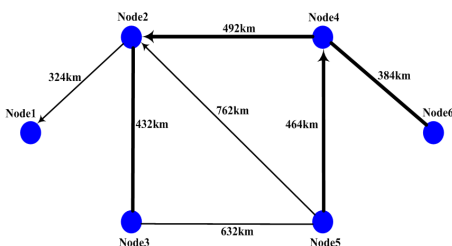


Fig. 6 Residual physical topology for Fig. 5

Figure 6.

IV.Simulation Results

The proposed EMTC algorithm is compared with MT/s algorithm by simulations. The physical topology of network used in simulation is as shown in Figure 2 where the thin links operate at 10Gbps and those bold links operate at 100Gbps. The experimental assumptions for the network are described as follows: the number of wavelengths on each 100 Gbps link is 4, and the number of wavelengths on each 10 Gbps link is 8; links are bidirectional; a link has a single rate, same in both directions; link length is in unit of kilometers; EPs are unidirectional; EPs running at 10 and 100 Gbps have maximum transmission distances of 3000 and 500km, respectively, after which regeneration is required; based on current industry trends, EI rates of 10 Gbps and 100 Gbps have relative costs of 1 and 5, respectively^[6], network cost equals to the number of EIs for each rate times the corresponding cost of EI for that rate.

The traffic matrix in Table 2 is used as the base matrix. The traffic matrix is scaled (multiplied) by a

Table 2. Traffic matrix for the network in Fig. 2 (in Gbps)

s \ d	Nd1	Nd2	Nd3	Nd4	Nd5	Nd6
Nd1	0	5	10	9	2	5
Nd2	5	0	20	8	70	7
Nd3	10	20	0	6	30	4
Nd4	9	8	6	0	7	10
Nd5	2	70	30	7	0	3
Nd6	5	7	4	10	3	0

factor from the set {0.25, 0.5, 0.75, 1.0}. Hence, the aggregate traffic corresponding to the scalars (sum of all entries in the scalar traffic matrix) is: {98, 196, 294, 392}Gbps. The traffic matrix is assumed according to the distance and the data rate of links between source and destination nodes.

The constructed MTs are illustrated in Figure 7 and 8, based on MT/s algorithm and EMTC algorithm, respectively. The removal of some original physical links depicts that all wavelengths on those links are configured to establish EPs and no more resource left on those links.

Comparing Figure 7 and Figure 8, it can be found that there are more 10Gbps EPs established in the MT based on MT/s algorithm than the other one. On the contrary, the 100Gbps EPs in EMTC algorithm-based MT are more than those in MT/s algorithm-based one.

Figure 9 shows the EIs consumption for MT/s and EMTC algorithms. It is shown that the EI consumption used by EMTC algorithm is slightly higher than MT/s Algorithm. The reason is that with the limitation of wavelength resource usage, it needs to leave some capacity to prevent the situation that

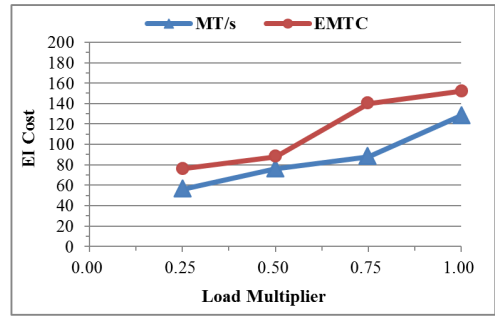


Fig. 9. Ethernet interface cost comparison

too many service requests are intended to be groomed on the same wavelength. As a result, there are more EPs need to be established to provision all the traffic demands in TM, especially some 100Gbps EPs, which account for more in EI consumption. However, the increment of EI cost is not too much and considerable.

In our consideration, the generated requests are serviced in the connection oriented way. So the connection blocking ratio is a very important metrics to evaluate network performance. Here, the connection blocking ratio is defined as:

$$Blocking\ ratio = \frac{no.\ of\ the\ blocked\ requests}{total\ no.\ of\ requests} \quad (3)$$

Figure 10 clarifies the blocking ratio in network versus different traffic load for MT/s and EMTC algorithms. Obviously, EMTC algorithm can achieve much lower blocking ratio in all load multiplier except in the case that the traffic load multiplier equals to 0.25. This is because in this case the

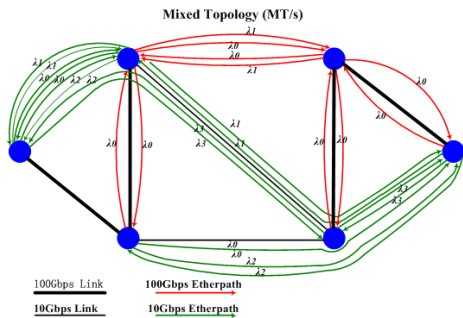


Fig. 7. Mixed topology for the MT/s algorithm

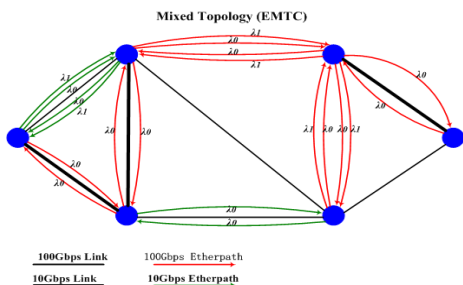


Fig. 8 Mixed topology for the EMTC algorithm

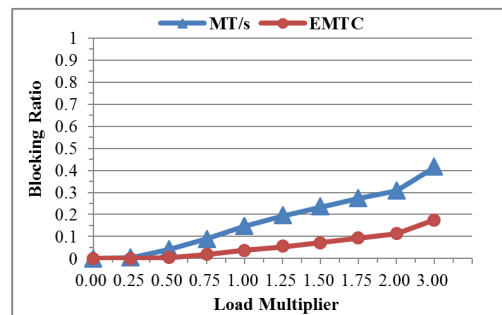


Fig. 10. Connection blocking ratio comparison

traffic load is too low so that both MT/s and EMTC algorithms can perform very well with the blocking ratio approaching to 0. Besides, it can be found that by using EMTC algorithm the blocking ratio can be reduced by more than 50% compared with that of MT/s algorithm. This unignorable reduction proves that EMTC algorithm can avoiding connection blocking apparently.

Based on the configured MT shown in Figure 7 and Figure 8, we regulate that those residual un-allocated wavelengths in MT will be used to service OPS traffic. The residual physical topology is separated and shown in Figure 11 based on MT/s algorithm and Figure12 based on EMTC algorithm. Note that the value in the bracket adjacent to a link means the number of residual wavelengths on that link. The total remaining capacity in network can be calculated by summing the respective remaining capacity on each link. In Figure 11, there are 10 wavelengths operating at 100Gbps and 8 wavelengths operating at 10Gbps left. Hence the total remaining capacity is $100\text{Gbps} \times 10 + 10\text{Gbps} \times 8 = 1080\text{Gbps}$. Calculated in the same way, 860Gbps is left in the case of EMTC algorithm as shown in Figure 12. From the comparison of Figure 11 and Figure 12, it is easy to find that EMTC algorithm can generate a more flexible residual physical topology for OPS traffic, although there are more low-speed links.

To apply EMTC algorithm into optical hybrid switched network, we use a new traffic matrix here. For the OCS part, the sub-TM is shown as Table 2. For the OPS part, it is assumed that each s-d pair has the uniform traffic demand of 2Gbps. The load multiplier is defined as mentioned before. With

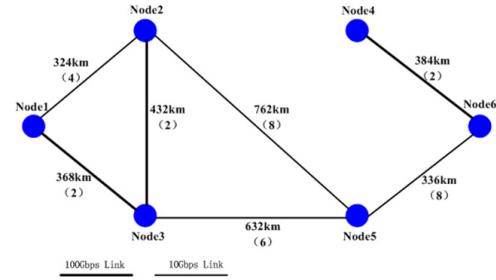


Fig. 12. Residual physical topology based on EMTC

different scalar, we can generate proportionate traffic amount. Otherwise, the packet (Ethernet frame) length is set to be 700Byte, which is less than the maximum transmission unit 1518 Byte^[10]. The routing algorithm for OPS traffic we use is the shortest path algorithm based on link distance and the route is fixed. In wavelength allocation process, we choose the usable wavelength randomly.

Figure 13 shows the average end-to-end delay of all transmitted packets. The end-to-end delay is generated because of the transmission time at each node. Obviously, the end-to-end delay based on EMTC algorithm becomes unacceptable after load multiplier reaches 2.0, while the end-to-end delay based on MT/s algorithm becomes unacceptable after load multiplier is larger than 0.75. This is because EMTC algorithm can configure an MT with more wavelengths in the residual physical topology. Then each node can transmit packets with less collision and shorter transmission time. Additionally, the residual physical topology brings less average hops for all s-d pairs. Hence, the end-to-end delay of packets based on EMTC algorithm is shorter than that based on MT/s algorithm.

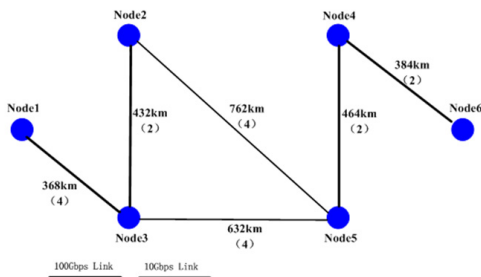


Fig. 11. Residual physical topology based on MT/s

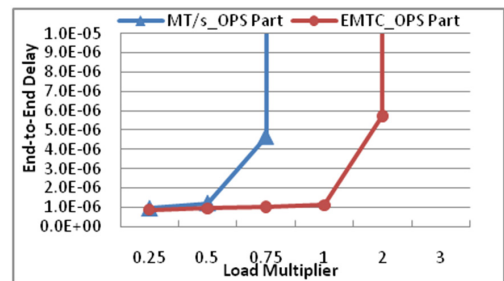


Fig. 13. End-to-end delay

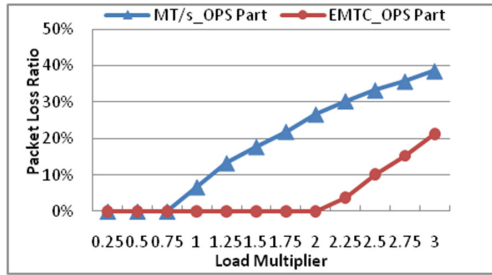


Fig. 14. Packet loss ratio

Figure 14 gives the simulation result of packet loss ratio versus the load multiplier. The packet loss ratio is defined as follows:

$$\text{packet loss ratio} = \frac{\text{no. of lost packets}}{\text{no. of total sent packets}} \quad (4)$$

The packets are lost when there are too many packets trying to transmit onto the same channel simultaneously. Obviously, the MT generated by EMTC algorithm achieves lower packet loss ratio, comparing to MT/s algorithm. At low traffic load, from 0.25 to 0.75, two algorithms don't show distinguishable difference. At the point of load multiplier 1, MT/s resulted in 6.7% packet loss ratio while EMTC algorithm could still keep nearly zero packet loss ratio till load multiplier 2. In the heavy traffic load situation (load multiplier 1.0 and above), EMTC algorithm performed much better than MT/s algorithm. Although EMTC algorithm occupied more network capacity to avoid connection blocking when determining the fixed routing for s-d pairs in OCS part, especially more high-speed wavelengths than MT/s algorithm, there are more wavelengths and links left for OPS part. The extra wavelengths mean that packets have more choices of output channels, resulting in a lower packet loss ratio even when we choose wavelength randomly.

V. Conclusion

Nowadays, many researchers has put in much effort to extend Ethernet into MAN and WAN. The huge profit advantages motivate service providers to implement "Ethernet-over-WDM" for Carrier

Ethernet. In this paper, we modified the MT/s algorithm and proposed EMTC algorithm in optical network with multi-line-rate. And we also applied it into the optical hybrid switched network to validate its availability in different network environment.

EMTC algorithm was evaluated by OPNET simulation. The simulation results showed that EMTC algorithm led to slightly higher EI cost than MT/s algorithm. However, EMTC algorithm could reach much lower blocking ratio for nearly all traffic load. In optical hybrid switched network, simulation results also proved that EMTC algorithm could achieve both lower end-to-end delay and packet loss ratio. In conclusion, the proposed EMTC algorithm, compared with previous MT/s algorithm, can configure more flexible virtual topology and utilize network resources efficiently.

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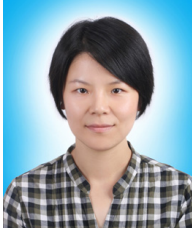
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