Energy Efficient Dynamic Virtual Optical Network Embedding in Sliceable-Transponder-Equipped EONs

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***Abstract*—We propose a novel energy efficient virtual optical network embedding (VONE) scheme over sliceable-transponder-equipped elastic optical networks (EONs). In the scheme, two energy-saving methods for data center (DC) and transponder (TP) are designed for node mapping and link mapping, respectively. During dynamic VONE, two schemes are developed: i) DC-EA scheme which only considers DC energy-saving in the node mapping; and ii) DC&TP-EA scheme which considers the energy saving for both the DCs and TPs, in the node mapping and link mapping, respectively. In order to evaluate the energy-saving performance of our proposed scheme, a benchmark algorithm is also realized which tries to maintain traffic-load balancing (TB) without any energy-saving consideration. The simulation results demonstrated that our proposed DC&TP-EA scheme achieves a maximum power saving, compared with the DC-EA and TB schemes. Also, the effect of the DC-EA gets very remarkable in terms of energy saving especially when the traffic load is smaller. With the increase of traffic load, the DC&TP-EA has higher energy-saving efficiency, due to the fact that the TP energy-saving plays a more and more important role.**

Keywords—Energy efficiency, Dynamic virtual optical network embedding, Data center, Sliceable transponder

I. Introduction

The recent booming of cloud-based applications has been stimulating the research and development on the on-demand provision of computing, storage and network resources over optical networks with geographically distributed datacenters (DCs) [1]. Consequently, with the exponential growth of Internet traffic, the energy consumption incurs a considerable increase. Estimates indicate that the annual energy bill paid by DC operators will exceed the cost of equipment [2]. Hence, building green and energy-saving substrate networks to reduce energy consumption has recently become the major concerns of internet service providers (ISPs).

Network virtualization is emerging as a promising solution to improve the flexibility and scalability of substrate networks. Specially, a virtual optical network (VON) can be constructed for each application, and multiple VONs share these resources in the same physical substrate network [3]. The process of the VON construction has been widely studied in the literature as VON embedding (VONE), which generally consists of two steps: 1) node mapping, which is placing virtual nodes (VNs) onto different substrate nodes (SNs), 2) link mapping, which is routing virtual links (VLs) onto physical links [4]. In the process of the VONE, energy savings is enabled by means of resource consolidation in the DCs [5-7]. More specially, these approaches try to turn idle resources as many as possible into sleep mode to reduce idle power consumption in the DCs.

Meanwhile, to future improve the flexibility of the optical network, elastic optical network (EON) has been considered as a promising enabler to satisfy the ever-increasing spectrum demand for the flexible physical substrate networks [8]. It allows the optical spectra to be allocated at the granularity of a few gigahertz (e.g.,12.5 GHz), which facilitates agile spectrum management in the optical layer. In the earlier stage, a bandwidth variable transponder (BVT) is designed as a single-flow transponder (TP) called as "non-sliceable transponder (NS-BVT)" [9]. Only one optical flow can be transmitted/ received by this BVT. Since most NS-BVTs are built with a maximal transmission rate to satisfy future demands, a NS-BVT may work inefficiently when transmission rate of the traffic is small and produce a large amount of unnecessary energy eventually. To improve the utilization and reduce the power consumption, sliceable bandwidth-variable transponder (SBVT) has been proposed [10]. Thus, a physical SBVT can be logically sliced into multiple sub-TPs, each of which can set up an independent lightpath for a connection without electrical processing at intermediate nodes. In SBVT-EON with optical traffic grooming, multiple sub-TP channels can be "groomed" optically onto one physical TP by using optical switching fabric, which would greatly reduce the number of active SBVTs. For instance, the authors in [9] investigate the energy-minimized traffic grooming problems with SBVT in IP over EONs.

To minimize the energy consumption, the best approach is to switch off as many active resources (e.g., DCs and TPs) as possible, without compromising the application performance. Thus, the active resources in the substrate can be dynamically dimensioned for current traffic demand rather than for peak demand. In this paper, we focus on energy-saving methods in two aspects which may lead to unnecessary energy waste. i) A large amount of idle computing resources exist in each DCs within the substrate network, which leads to a lower resource utilization of DCs. ii) Much transmission resources within the SBVTs have not been used fully and stay idle state. Therefore, we proposed a novel energy-efficient VONE scheme over transparent EONs in a dynamic scenario. During the node mapping, we try to embed VNs onto those active SNs that are serving other VON requests and turn idle DCs as many as possible into sleep mode without affecting the performance of the VONs. In the process of the link mapping, we try to reduce

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the number of active SBVTs by using the optical traffic grooming, to save TP power consumption. In the following, two VONE algorithms (i.e., DC-EA and DC&TP-EA) are designed. The former only uses DC-aware energy-saving algorithm in the node mapping, while the latter simultaneously considers the energy-saving for both the DC and TP in the node and link mapping, respectively.

The paper is organized as follows. Section II describes the dynamic VONE problem and establishes power consumption model. In section III, several dynamic VONE algorithms are designed to evaluate the energy-saving performances of our proposed schemes. Simulation results are given out in section IV. We finally conclude the paper in Section V.

II. Problem Formulation

A. VONE Models

In order to make our model more concise, we come up the following definition. As emphasized in literature [11], DCs are built very close to substrate nodes (SNs) to benefit from the large bandwidth capacities available from such SNs. Here, we define that a SN is composed of a core optical node and a DC that connects to the SN. Thus, the computing resources within the DC can be represented as the CPU resources of the corresponding SN. When the DC in the SN is turned on, it can be viewed as active SN; otherwise, it is treated as inactive SN.

1) *Substrate Optical Network (SON)*: It can be modeled as an undirected graph, denoted as $G^s(\mathrm{N}^s,\mathrm{L}^s)$, where N^s is the set of SNs and L^s is the set of substrate fiber links (SFLs). Each SN $n^s \in N^s$ has a computing capacity of $c^s_{n^s}$. For simplicity, we define a bit-mask $b^s_{n^s}$ which contains B^s bits for each SFL $n^s \in N^s$, where B^s denotes the maximum number of frequency slots (FSs) that a SFL can accommodate. When $b^s_{n^s}[i]=1$, the *i*-th FS on the link l^s is occupied, otherwise $b^s_{n^s}[i]=0$.

2) *VON Requests*: A VON request can also be modeled as an undirected graph $G^v(\mathrm{N}^v,\mathrm{L}^v)$. We use notation $c^v_{n^v}$ to denote the computing capacity requirement of each VN $v^r \in V^r$ in the VON request. The bandwidth requirement of each VOL is $bw^v_{l^v}$ (Gb/s).

B. VONE Procedures

When a VON request arrives, a dynamic VONE procedure tries to assign the VNs to SNs which have enough computing resources in the node mapping. Then the procedure of the link mapping needs to select SFLs to realize the VOLs and make sure that all the VOLs in a VON occupy the same spectrum resource on SFLs with spectrum continuity and contiguous constraints. Specifically, for the transparent VONE, the block of one or more FSs that are available in the spectrum domain allocated to a VOL should be the same in terms of indices.

C. Power Consumption Model

The overall power consumption of the SON consists of the power consumption of DCs and TPs. According to [11], the power consumption of a DC can be derived as follows:

$$P_{DC} = \begin{cases} P_{idle} + P_l \cdot \mu, & \text{DC } \textit{is the} \text{ ON } \textit{state} \\ 0, & \text{DC } \textit{is the} \text{ OFF } \textit{state} \end{cases}, \quad (1)$$

where P_{idle} is the idle power consumption of DC. We define that P_m is the maximum power when the DC is serving at the maximum capacity. $P_l = P_m - P_{idle}$ denotes the energy proportion factor of DC concerning the CPU utilization μ .

For a TP, the power consumption can be expressed as:

$$P_t = 1.683 \times TR(\mathrm{Gb/s}) + 91.333(\mathrm{W}) , \quad (2)$$

According to [12], TR denotes the transmission rate of this TP and 91.333 W is the overhead power consumption.

D. Objective

The objective of the dynamic VONE scheme in our study is to minimize the power consumption of the SON. We consider the following two factors that would deteriorate the energy saving performance: i) the idle power consumption of DCs; ii) the overhead power consumption of TPs. Hence, eliminating power waste resulting from the above two factors as much as possible will help us to design an energy efficient dynamic VONE scheme.

III. Dynamic Transparent VONE Algorithm

In this section, we design two novel energy efficient node mapping and link mapping algorithms, respectively, to reduce unnecessary power consumption resulting from the above two factors for dynamic VONE scheme over transparent EONs.

A. Layered Auxiliary Graph (LAG)

For clarity, a LAG approach is first introduced [17]. It transforms the substrate network into several layered graphs, according to the bandwidth requirement of the VON request. Specially, when a VON request arrives, the approach first transforms the bandwidth requirement $bw^v_{l^v}$ into the number of required FSs n^r according to the bandwidth of each FS. Then, we decompose the SON topology into several layers by scanning the spectrum utilization of all the SFLs. For *i*-th layer, the approach checks whether the contiguous slot-block covering *i*-th to (k+ n^r -1)-th FS exists on each SFL $e^s \in E^s$. If the contiguous slot-block exists on an SFL e^s , e^s is inserted into the i-th layer denoted as G^{sub}_i .

B. Node Mapping

Node mapping can be achieved with the aid of the local resource capacity (LRC) [13] including computing and network resources. The local information of a SN n^s contains its available computing resource capacity $c^s_{n^s}$ within its DC and node degree $d^s_{n^s}$. We define the LRC of a SN as follows

$$h_{n^s}^s = c_{n^s}^s \cdot d_{n^s}^s \quad (3)$$

Intuitively, a larger value of $h_{n^s}^s$ means that the node n^s has more computing resource and physical links attached.

According to [17], for each VON request, its required resource capacity (RRC) can be defined as

$$h_{n^v}^v = c_{n^v}^v d_{n^v}^v \quad (4)$$

where $d_{n^v}^v$ denotes the node degree of the VN n^v in the VON.

To alleviate idle power consumption of DCs as much as possible, we design the node mapping algorithm which seek to map VNs onto active SNs as few as possible, to minimize the number of active SNs. A new DC should be activated unless the all active nodes can't accommodate the VN. The following algorithm 1 gives out the details of the node mapping.

C. Link Mapping

After all the VNs are embedded successfully into SONs, we use the shortest-path routing for link mapping. Similar to routing and spectrum assignment (RSA) problem described in [14], link mapping needs to decide how to embed each VOL onto the SFLs and how to assign certain number of contiguous slots to each SFL under the spectrum contiguous constraints.

```
Algorithm 1 : Node Mapping
Input   : G^s , G^r
Output : VON node mapping status F and substrate network
         G^s within traffic demand matrix T(s,d,b)
calculate h^s_{n^s} for each n^s ∈ N^s in G^s ;
calculate h^v_{n^v} for each n^v ∈ N^v in G^v ;
for all VNs n^v in descending order of their h^v_{n^v} do
  F = FAILED;
  set a flag bit K_{n^s}=1 for each n^s ∈ N^s ;
  for all active SNs n^s in descending
    order of their h^s_{v^s} do
     if c^s_{n^s} > c^v_{n^v} AND d^s_{n^s} > d^v_{n^v} AND K_{n^s}=1 then
       map n^v on to n^s ;
       K_{n^s}=0 ;
       F = SUCCEEDED;
       break;
     end
  end
  if F == FAILED then
   for all inactive SNs n^s in descending
     order of their h^s_{v^s} do
      if c^s_{n^s} > c^v_{n^v} AND d^s_{n^s} > d^v_{n^v} AND K_{n^s}=1 then
        map n^v on to n^s ;
        K_{n^s}=0 ;
        F = SUCCEEDED;
        break;
      end
   end
  end
  if F == FAILED then
    return (F);
  end
end
return (G^s AND traffic demand matrix T(s,d,b));
```

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Algorithm 2: Link Mapping
Input : substrate network G^s within traffic demand matrix
        T(s,d,n^r)
Output : G^s after link mapping
get traffic demand matrix T(s,d,n^r) in G^s and store them
in group Q;
create a group R to store the information of traffic route
r(t(s,d,n^r)) for demand t(s,d,n^r);
  for i=1 to B^s − n^r +1 do
    for all demands t(s,d,n^r) in group Q do
      build the i−th LAG G_i^{sub} with Algorithm 1;
      find the shortest path from s to d in G_i^{sub} for traffic
      route r(t(s,d,n^r));
      if the path can be found then
        generate a traffic route r(t(s,d,n^r)) according to
        the path in G^s and Store r(t(s,d,n^r)) in group R
        remove all SFLs of the path in G_i^{sub}
      else
        clear out the group R;
        break;
    end
    for all traffic routes r(t(s,d,n^r)) in group R do
      optical traffic grooming 1 or
       optical traffic grooming 2 ;
      if traffic grooming 1 or 2 succeed then
        update transponder status (e.g., capacity and
        number of available sub-transponders) and
        capacity of all SFLs in G^s.
      else
        do traffic process 1 and update transponder status
        and capacity of all SFLs in G^s.
    end
    return G^s after mapping G^v successfully;
  end
return G^v as blocked;
```

Additionally, we need to assign the same set of subcarrier slots to each VOL with the spectrum continuity constraints. More specifically, the proposed link mapping algorithm first sets up a lightpath in an LAG in the substrate network using the shortest-path routing for a VOL, and then removes the links in the lightpath from the LAG. Since the construction principle of the LAG makes sure that both the routing path and the FS' on them are available for a VOL, we achieve integrated RSA. These procedures are done sequentially until the lightpaths of all VOLs have been set up successfully. The details of the link mapping is shown in following algorithm 2.

To mitigate as much overhead power consumption of TPs as possible, we will use optical traffic grooming to aggregate multiple optical flows into one SBVT, in order to decrease active TPs as few as possible during setting up lightpaths. Generally, there are three possible operations to accomplish a new VOL connection request.

Operation 1: Establish a new lightpath using a sub-SBVT both in its source and destination nodes by grooming the VOL request onto existing active SBVTs.

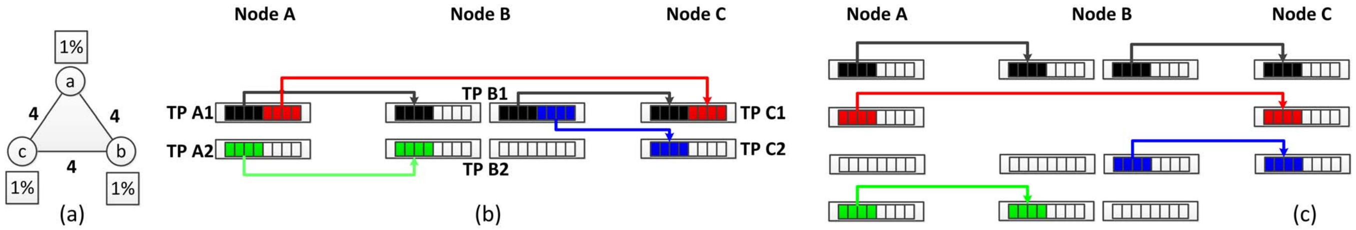


Fig. 1 (a) VON request with three VOLs, (b) Optical traffic grooming using SBVT, (c) No optical traffic grooming with NS-BVT

Operation 2: Establish a new lightpath using a sub-SBVT in its either source or destination node by grooming the VOL request onto an existing active SBVT.

Operation 3: Establish a new lightpath for the VOL request using two new-activated SBVTs both in its source and destination nodes.

Fig. 1 indicates the examples of the link mapping for three VOL requests using different types of TPs (i.e., SBVT, NS-BVT). Fig. 1(a) gives out a VON request with three VNs and three VOLs, where the numbers in the boxes around the VNs are their computing resource requirements and the numbers on the VOLs are the bandwidth requirements n^r. We assume that the underlay SON is an interconnection bidirectional network of three-node topology. Thus, the node mapping is [a→A, b→B, c→C] and the link mapping is [(a, b) → (A, B), (a, c) → (A, C), (b, c) → (B, C)]. In Fig. 1(b) and Fig. 1(c), we only focus on the utilization of TPs for VOL requests. In Fig. 1, the black boxes indicate the unavailability part within the TP; and the black arrowed lines represent the existing lightpaths. We assume that there are eight sub-SBVTs in each SBVT.

In Fig. 1(b), for the VOL request [(a, c) → (A, C)], a new lightpath can be established successfully using *Operation 1*. Four free sub-SBVTs within A1 in node A and four free sub-SBVTs within C1 in node C can be used by optical traffic grooming for the VOL request. For the VOL request [(b, c) → (B, C)], we can use *Operation 2* to groom the request onto sub-SBVTs in an existing active B1 in the source node, while a new SBVT has to be activated at destination node C. For the VOL request [(a, b) → (A, B)], because no free sub-SBVTs is available under the spectrum constraints, we must adopt *Operation 3* to activate two new SBVTs both in the source and destination nodes, for establishing a new lightpath. Therefore, we just need to active three new SBVTs for the VON request, by using optical traffic grooming. We can find from Fig. 1(c) that without optical traffic grooming, each SN activates one more NS-BVT in each node, compared with the scenario in Fig. 1(b). It is because that a NS-BVT is a single-flow TP, and we have to turn on a new TP for each VOL both in source and destination nodes respectively.

IV. Performance Evaluations

A. Simulation Setup

We design simulations to evaluate the performance of the proposed algorithms with a realistic Deutsche Telecom (DT) topology with 14 nodes and 23 links [15], over a Java-based simulation platform. The number of VNs in each VON request is randomly taken in an integer set [3, 4] and the probability that a VN-pair is directly connected equals 0.5. The arrival of the VON requests follows the Poisson traffic model.

We design that each DC in the SN contains 50 Dell Power Edge R720 Servers [16], each with idle power rated at 112W and 365W at full load. Thus, the idle power of the DC is 5600W. We also assume that whole CPU capacity of a DC is unit 1. $c_{v^r}^r$ represents computing resource requirement of the VN $n^v \in N^v$, which is uniformly distributed between 0.2% and 2%. Bandwidth capacity of each SFL are 320 FSs and slot requirement of each VOL is evenly distributed between 1 and 8. To improve the transmission quality, an EDFA is essential every 80 km fiber link and its power consumption is 8W [3].

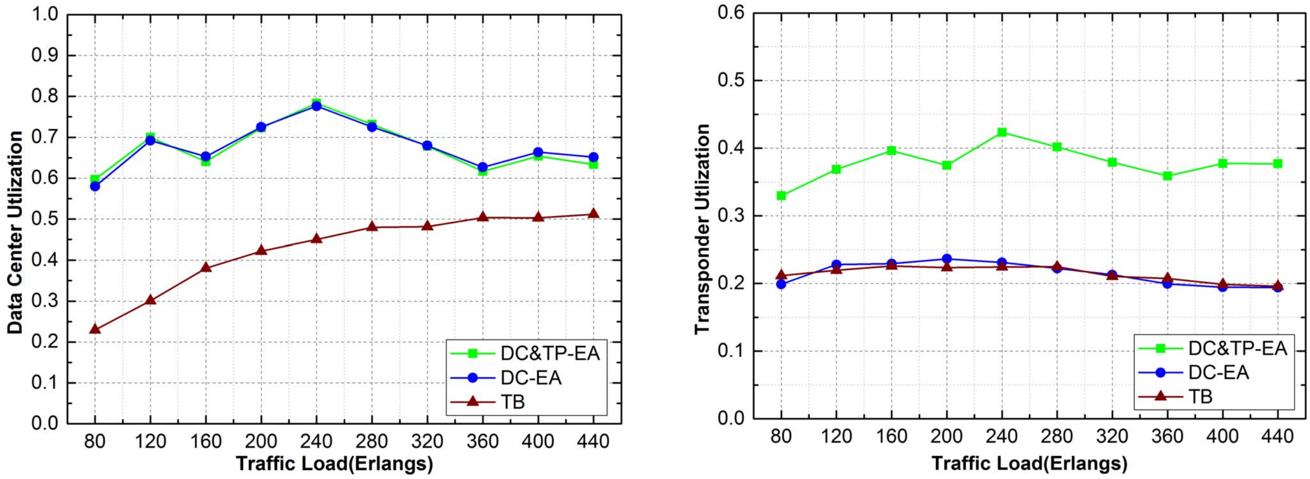
We assume that the bandwidth of one FS is 12.5GHz. For simplicity, the same modulation format of BPSK (Binary Phase Shift Keying) is set for all VOLs, and a single BPSK FS can carry 12.5Gb/s capacity. We consider 100Gb/s SBVTs for lightpath provisioning and each SBVT has 8 sub-SBVTs, each of which can carry a 12.5Gb/s signal with BPSK modulation format. In other words, for each SBVT, the maximal number of sub-SBVTs is 8.

Benchmark Algorithm: we adapt the algorithm in [17]. Since the benchmark algorithm tries to map the VNs to the SNs evenly to maintain traffic-load balancing, named as TB. The TB scheme is not energy-efficient without any energy-saving consideration.

In our simulations, we design two VONE schemes. The first scheme just consider the DC energy-saving in the node mapping, and it uses NS-BVT without optical grooming. We denote it as "DC energy aware" scheme (DC-EA). So the DC-EA scheme has no attempt for TP energy-saving in the link mapping, as same as the TB scheme. The second scheme considers the energy saving method both for the DCs and TPs, in the node mapping and link mapping, respectively. We name it as "DC and TP energy aware" scheme (DA&TP-EA).

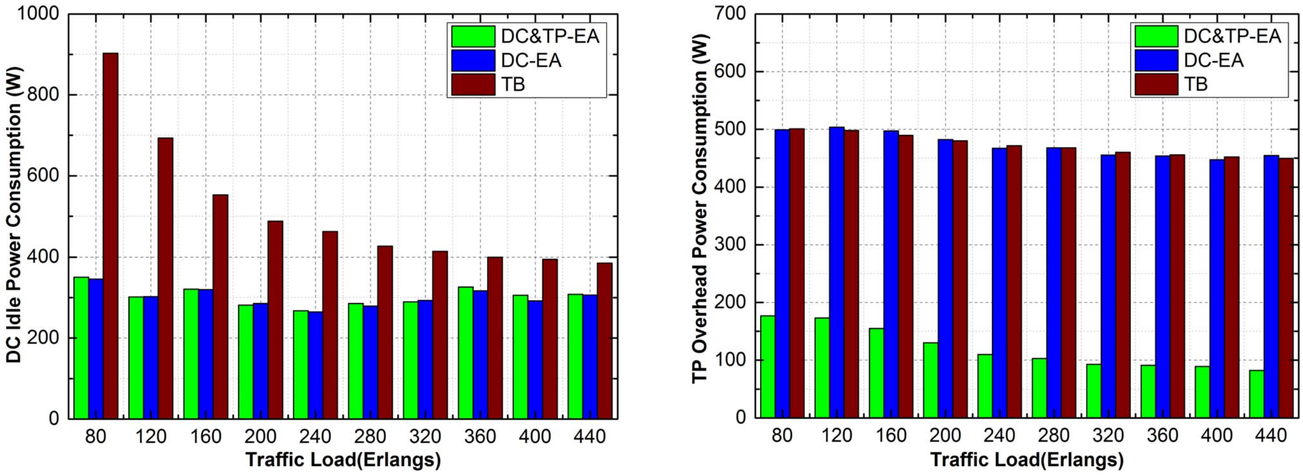
B. Simulation Results

Fig. 2 shows the resource utilization of the DCs and TPs in the substrate network. In Fig. 2(a), we can see that the DC-EA and DA&TP-EA achieve higher DC utilization than TB due to the fewer DCs activated, which results from using resource consolidation of the DCs in the node mapping (see Algorithm 1). With the increase of traffic load, the DC utilization of TB shows a growing trend. It is because that more and more DCs are activated to satisfy VON requests. But the DC utilization of the DC-EA and DA&TP-EA fluctuations up and down in



(a) (b)

Fig. 2 Results on utilization of data center and transponder



(a) (b)

Fig. 3 (a) Data center idle power consumption per accommodated VON, (b) Transponder overhead power consumption per accommodated VON

the range from 0.6 to 0.8. The up-trend line indicates that more VON requests can be accommodated into the existing active DCs, while the down-trend line presents more new DCs are activated with the increase of traffic load. In Fig. 2(b), it is observed that the TP utilization of DC&TP-EA is much better than that of the DC-EA and TB. The main reason is that the DC&TP-EA with SBVT tries to groom more VOL requests into the one activated TP with optical traffic grooming during link mapping procedure. For the DC-EA and TB with single-flow NS-BVT, the TP works inefficiently. For instance, only one VOL request that requires 25Gb/s traffic is running on the 100Gb/s NS-BVT.

Fig. 3 shows idle/overhead power consumption of DCs and TPs per accommodated VONs, respectively, which is common source of the energy waste. In Fig. 3(a), we can see that DC idle power consumption of both DC-EA and DC&TP-EA is much smaller than that of TB. However, with the increase of traffic load (proportional to DC utilization), idle power that TB consumes becomes less and less. It also gets gradually to that of DC-EA and DC&TP-EA, since more and more DCs are activated to satisfy VON requests. It should be noted that the DC&TP-EA performs much better than two other schemes in terms of TP overhead power consumption (see Fig. 3(b)). Moreover, with the increase of traffic load, it is possible that more VOL requests can be groomed into one physical SBVT, which improves the TP utilization. Consequently, the DC& TP-EA consumes less overhead power, based on Eq. (2).

Fig. 4 shows the percentage of traffic dependent power consumption to total power consumption per accommodated VON under different VONE schemes. The larger value of the percentage means that more power consumption is used for VON requests rather than for waste. Due to the higher DC and TP utilization in the DC&TP-EA, it performs the best among three schemes. The performance of DC-EA comes second, because that it just realizes resource consolidation of the DCs in the node mapping. It is also found that with the increase of traffic load, tow curves of the DC-EA and TB gets closer. It indicates that the effect of DC-aware energy-saving method becomes smaller when the traffic load is larger.

Fig. 5 gives out important results on the average power consumption per accommodated VON request for above three schemes under different traffic loads. It is observed that the DC&TP-EA results in the minimum power consumption. Compared with the TB, the DC&TP-EA can save up to 37% power consumption per accommodated VON request, while

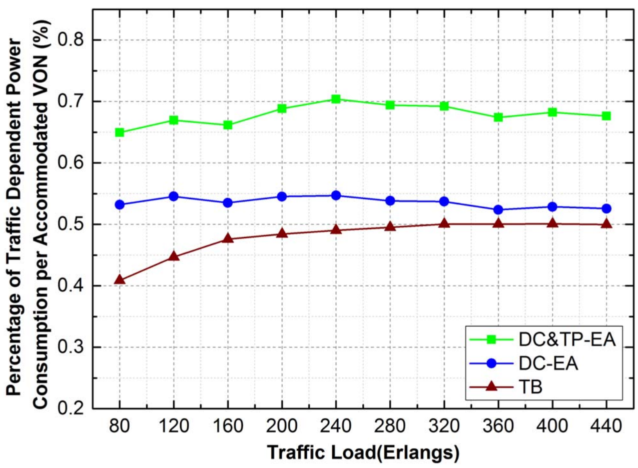


Fig. 4 Percentage of traffic dependent power consumption

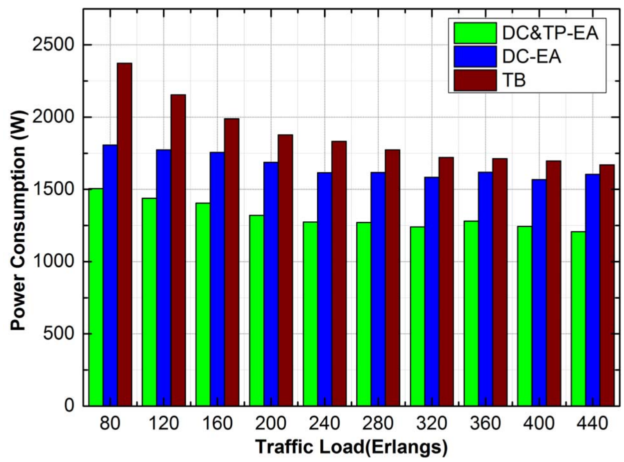


Fig. 5 Power consumption per accommodated VON

30% in average. The DC-EA can save maximum 24% power consumption compared with the TB. Additionally, with the increase of traffic load, the power consumption gap between the DC-EA and TB becomes smaller. It is because that more and more DCs need to be activated for more VON requests.

V. Conclusion

We investigated novel energy efficient dynamic VONE schemes over transparent EONs equipped with SBVTs. Two algorithms regarding to the DC-aware and TP-aware energy-saving are proposed in the node and link mapping procedures, respectively. In our simulations, a DC-EA scheme is designed, which simultaneously consider the energy-saving methods for both DCs and TPs. The results show that the DC&TP-EA achieves a maximum power saving of 37% compared with the TB, whose aim is to maintain traffic-load balancing without any energy-saving consideration. Moreover, the effect of the DC-EA is significant especially in the case of lower traffic load. With the increase of traffic load, the DC&TP-EA become more superior in terms of the energy-saving efficiency, due to the fact the TP energy-saving plays a more and more important role.

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