Energy Saving Algorithms for Electric Power Telecommunication in Smart Grids

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Abstract. The rapid growth of data service promotes the construction of the electric power telecommunication in smart grids. With the objective of energy savings, we determine the optimal location of the data center with the minimal energy cost within all possible positions. An Integer Linear Program (ILP) is formulated and we also propose the corresponding algorithms, mainly including Green Optical Bypass Energy Saving Grooming Algorithm (GOBEGA) and Green Non-Bypass Energy Saving Grooming Algorithm (GNBEGA). Simulation results demonstrate that the proposed algorithms have the good performance of energy savings, and GOBEGA has the lower energy cost compared with GNBEGA.

Introduction

The rapid growth of data service promotes the construction of the electric power telecommunication in smart grids, but it also increases the environment pressure. To protect environment and satisfy the people demand, the electric power telecommunication network should be optimized with the minimal energy consumption. On the other hand, increasing electricity prices, diminishing fossil fuels and putting attentions on Green House Gas (GHG) emissions all motivate the modernization of power grids, where Information and Communication Technologies (ICTs) play a key role. A comprehensive survey was summarized in [1] in terms of energy-efficient communications and data centers in smart grids, and proposed some approaches of minimizing energy cost and GHG emission in data centers.

These data centers place a heavy burden on both environment and energy resources [2, 3]. Recent studies showed that the large-scale data centers consumed about 1.3% of worldwide electricity, and 2% of all electricity used in USA during 2010 [4]. The EPA estimated that the annual electricity consumption of data centers would exceed 100 billion kWh at the cost of 7.4 billion dollars in 2011 [4]. The energy consumption of data centers can be reduced by using demand peak shaving, regulation services and frequency control programs [5].

In this paper, we achieve energy saving using optical bypass and traffic grooming technologies in smart grids. We construct the mathematical model to determine the optimal location of the data center, and then design the corresponding algorithms to solve the problem above in the large- scale topology. Finally, two algorithms are compared in simulations, which demonstrate that the different locations of the data center can lead to various levels of energy consumption. The energy consumption can be reduced by 4.5%, and changed with the increased scale of topology and traffic requests. In addition, compared with GNBEGA, GOBEGA can save more energy owing to optical bypass, and this advantage is more obvious in the larger-scale topology.

Network Architecture

Figure 1 shows the architecture of the electric power telecommunication network in smart grids. This network architecture consists of two layers: IP layer and optical layer. In IP layer, the core IP router is connected with an Optical Cross-Connect (OXC) via short-reach interfaces. IP router aggregates the traffic from low-end access routers. OXC nodes are connected by fiber links, which can provide high bandwidth provisioning for IP layer. In optical layer, several requests are aggregated into one lightpath to transport, which reduces the number of occupied transponders, IP router ports and other components, thus leading to the energy savings.

There are two methods for the transmission in the electric power telecommunication network: bypass and non-bypass. In the traditional network with non-bypass, all lightpaths passing through an intermediate node must be terminated. The reason is that the lightpath needs to process and forward the traffic when it goes through the IP router. In contrast, the bypass approach allows the lightpath, whose destination is not the intermediate node, directly bypass the IP router via the cut-through[6]. Using optical bypass, a lightpath can be regarded as a virtual link in the IP layer. It is notable that optical bypass can significantly reduce the number of IP router ports, which contributes to the energy savings.

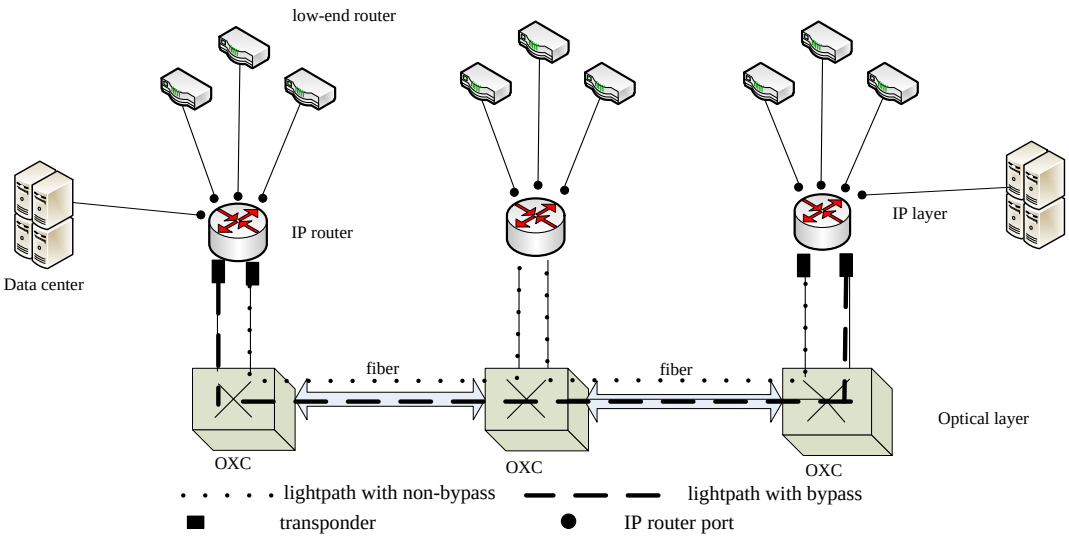

Fig. 1 Architecture of the electric power telecommunication network in smart grids

Problem Description and Algorithms

In this section, we first design an ILP model to optimize the location of data centers in the electric power telecommunication network, with the objective of minimizing the total energy consumption. Then, we propose two heuristic algorithms, i.e., GOBEGA and GNBEGA.

Problem description. The physical network topology is described as the graph $G(V,E)$, where V is the set of nodes, and E is the set of fiber links. f_{mn} is the number of fibers on the fiber link (m,n), W is set of wavelengths on the fiber link, EA_{mn} is the number of EDFAs on the fiber link (m,n), and $EA_{mn} = \lfloor L_{mn} / S - 1 \rfloor + 2$. Here, L_{mn} is the distance of the fiber link (m,n), and S is the distance between two adjacent EDFAs. Other notions are defined as follows.

s, d : source and destination regular nodes.

i, j : end nodes of the virtual link in IP layer.

T : set of time slots.

B : capacity of each wavelength.

P_R : power consumption of a router port.

P_T : power consumption of a transponder.

P_E : power consumption of an EDFA.

P_{O_i} : power consumption of an optical switch in node i.

N_{dc} : number of data centers.

w_{mn}^{t} : number of wavelength channels (integer) in the fiber link (m,n) at time t.

C_{ij}^{t} : number of wavelength channels (integer) in the virtual link (i,j) at time t.

W_{mnt}^{ij} : number of wavelength channels (integer) in the virtual link (i,j) traversing the fiber link (m,n) at time t.

q_i^t : number of ports (integer) used for data aggregation in node i at time t.

δ_i : binary variable taking 1 if node i is a data center, and 0 otherwise.

$\vartheta\_d_{ij}^{sdt}$: downlink traffic demand from data center s to regular node d traversing the virtual link (i,j) at time t.

$\vartheta\_u_{ij}^{sdt}$: uplink traffic demand from regular node s to data center d traversing the virtual link (i,j) at time t.

$\vartheta\_r_{ij}^{sdt}$: regular traffic demand from node s to node d traversing the virtual link (i,j) at time t.

The energy consumption of different components in the network at time can be represented by the following equation. The first and the second items of Eq. 1 indicate the energy consumption of all IP router ports in regular nodes and data centers ports; the third item indicates the energy consumption of all optical switches, and the forth item indicates the energy consumption of all transponders in regular nodes and data centers; the last item represents the energy consumption of all EDFAs. Our objective is to minimize the total energy consumption.

$$minimize \sum_{t\in T}(\sum_{m\in V}\sum_{\in V}P_R\cdot C_{ij}^t+\sum_i P_R\cdot q_i^t+\sum_{i\in V}P_{O_i}+\sum_{m\in V}\sum_{n\in V_m}P_T\cdot w_{mn}^t+\sum_{m\in V}\sum_{n\in V_m}P_E\cdot EA_{mn}\cdot f_{mn}) \quad (1)$$

The constraints such as flow conservation in IP layer and optical layer, capacity of the fiber link and virtual link, the number of data centers, and the number of data aggregation ports are not listed due to space limitation.

Heuristics

Since the proposed mathematical model is not adaptive to the large-scale network topology, we propose the heuristic algorithms, GOBEGA and GNBEGA, based on bypass and non-bypass approaches, respectively. For each candidate location of the data center, we can implement the GOBEGA algorithm to route the traffic demand at each time slot . Firstly, for each traffic demand from node s to node d, we use the Dijkstra algorithm to find the shortest path in the virtual topology. If the shortest path for is unavailable, we directly establish a new virtual link between the node pair s and d, and allocate wavelengths on this virtual link, in order to ensure the bandwidth requirement of λ^{sdt}. Otherwise, we will route λ^{sdt} through the shortest path. More specifically, we first allocate the bandwidth capacity to λ^{sdt} according to the minimum residual capacity m_r of the shortest path, i.e., $\theta_{allocate}\leftarrow\min\{\theta_{allocate}+m_r,\lambda^{sdt}\}$, and then update the residual capacity of each virtual link on the shortest path by subtracting the bandwidth capacity allocated to θ^{sdt}. In such way, we will route all traffic demands one-by-one until the virtual topology has been constructed. Next, we will compute the physical paths for all virtual links. Particularly, for any virtual link (i,j), the Dijkstra algorithm is first utilized to find the shortest path for the virtual link (i,j) on physical topology. Then, we allocate the wavelength channels for the virtual link (i,j) and update the wavelength number of each fiber link traversed by (i,j). After the iterations of all time slots, we can calculate the total energy consumption for each candidate location of data center. Finally, the best location of the data center with the lowest energy consumption is determined.

Simulation Result and Discussions

To evaluate the performances of our approach, we first compare the simulation results of heuristics in the small-scale topology including six nodes and 8 bidirectional fiber links. Then, we test the performances of the heuristics in the large-scale NSFNET including 14 nodes and 21 bidirectional fiber links. The regular traffic demand between each node pair is determined randomly from 20Gbps to 120Gbps. Assuming the traffic demand between data center and regular node is generated based on the regular traffic demand[7].

Figure 2 shows the total energy consumption under the small-scale topology. It indicates that the GOBEGA can reduce more energy compared with GNBEGA, and the improvement ration can arrive up to 22%. Due to the difference of ordinates, we can clearly note that the different locations of the data center lead to various levels of energy consumption, and these two heuristics reduce the total energy consumption up to 4.5% and 1.6%, respectively.

Figure 3 shows the total energy consumption under the large-scale NSFNET. It also indicates that the GOBEGA can decrease more energy compared with GNBEGA. We also can see that the different locations of the data center lead to various levels of energy consumption, meanwhile, GNBEGA and GOBEGA can reduce the total energy consumption up to 4.5% and 1.6%, respectively.

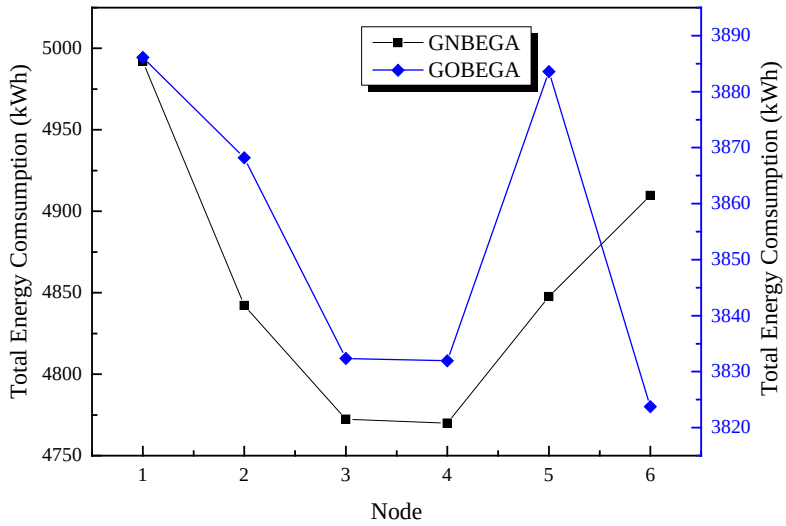

Fig. 2 Comparison of the total energy consumption between GOBEGA and GNBEGA in the small-scale topology

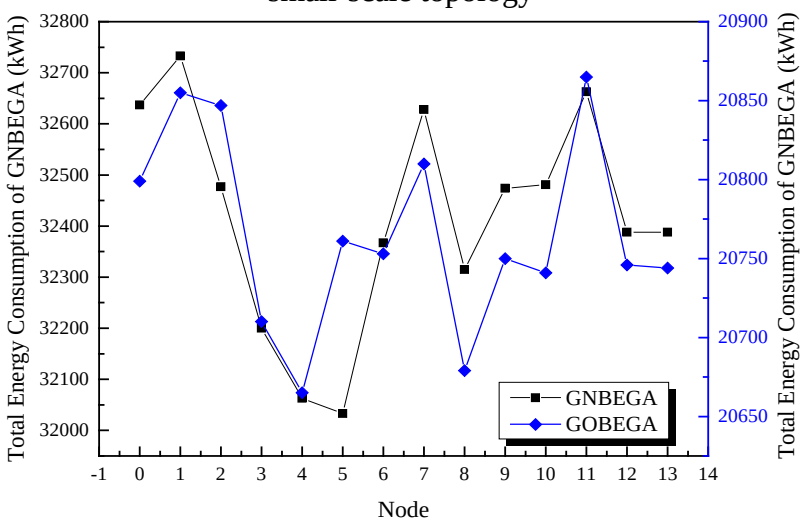

Fig. 2 Comparison of the total energy consumption between GOBEGA and GNBEGA in the large-scale topology

Summary

In this paper, we utilized the bypass and traffic grooming technologies to reduce the energy consumption of the electric power telecommunication network in smart grids. We also have determined the optimal location of the data center by calculating the total energy consumption at different nodes. The mathematical model and the corresponding heuristics were thus designed. The simulation results demonstrated that compared with GNBEGA, GOBEGA saves more energy, and the advantage is more obvious in larger-scale topologies.

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