

Dual-fast Greedy Heuristic Algorithm for Green ICT

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Abstract—The Internet power consumption represents 3.6% to 6.2% of the annual worldwide power consumption and is continually expanding. The awareness of this problem has increased, hence, a few strategies are being put into place to decrease the power consumption of the Information Communication Technology (ICT) sectors, in general. Backbone networks are the main part of the Internet power consumption because their line cards expend a lot of energy, also their links are commonly bundled and provide larger capacity than needed. Therefore, bundled links are partially shut down during times of low demand to reduce power consumption. Literature introduces a few heuristic algorithms that are run periodically to shut down bundled links partially. This paper proposes a Dual-Fast Greedy Heuristic algorithm (DGH), which significantly speeds up the power savings. DGH is examined on the topology and traffic of the Abilene backbone. The experimental results show that DGH provides competitive power savings with minimum execution time.

Keywords—Abilene backbone; backbone network; bundled link; capacity; Internet power consumption; power savings

I. INTRODUCTION

ICT (Information Communication Technology) handles the processes of communications such as telecommunications, broadcast media, intelligent building, network-based control, etc. [1, 2]. Green ICT is responsible for using computing resources efficiently and effectively with minimum impact on the environment, mainly by reducing their power consumption [2, 3]. Since the Internet is the pivot sector of ICT, network researches focus on reducing power consumption. The most popular power-saving technique is based on the power consumption of servers and wireless equipment [4]. However, reducing the power consumption of wired networks has been ignored, even though it is critical [5]. For example, powering the wired networks in the United States alone expenses an expected 0.5-2.4 billion dollars per year. Additionally, network architectures having better energy efficiency allow deploying networks in poor infrastructures [6].

The Internet has multiple backbone networks. Since a backbone network interconnects networks and provides paths for data exchange. Also, a backbone network is called a core network. Usually, the capacity of a backbone link is larger than the needs of backbone networks. The additional capacity is used to cover traffic shifts and to provide alternative paths for broken links [7]. For example, the average used capacity in backbone networks of big Internet service providers is no more than 30-40%, consequently, there are 70-60% extra capacities. Accordingly, using dynamic capacity instead of static capacity

for backbone networks will reduce the power consumption efficiently. The optimal technique to provide dynamic capacity is that the backbone links are partially shut down and powered as needed. Since the used capacity through off-peak hours is reduced to one-third or more of peak hours [5, 8].

A backbone link connects two routers and is structured as multiple physical cables that are dealt with as one logical bundled link [9]. Generally, a logical bundled link with all its physical cables is called bundled link, aggregate link, or composite link [9, 10]. Additionally, there is a line card at each end per physical cable to serve it. Nonetheless, bundled links are standardized by IEEE 802.1AX [10]. The capacity of a bundled link is the aggregate capacities of all its physical cables. Thus, to upgrade a bundled link i.e. increasing its capacity, you just add more physical cables to the existing cables. As a result, the capacity of a bundled link may exceed the capacity of the fastest physical cable. For example, given a bundled link of five OC-192 cables each with a 10 Gbps capacity, then the bundled link capacity is 50 Gbps.

The optimal power-saving approach shuts down and powers some physical cables of a bundled link as needed. In other words, this approach is an optimization problem that maximizes the power savings by shutting down the most possible physical cables of every bundled link, as it yet has enough capacity for future traffic. The physical cable selection is based on the current and expected traffic matrix, the network topology, and the bundled link capacity [11]. Thus, heuristic algorithms are used to find the optimal selection, which is an NP-complete problem [12]. Accordingly, these algorithms extremely vary in execution time, which increases the router overhead. However, the execution time of these algorithms is based on how they select physical cables of a bundled link to be shut down or powered [11].

This paper proposes the Dual-fast Greedy Heuristic (DGH) algorithm to reduce the power consumption of backbone networks with limited overhead on routers. DGH shuts down some physical cables and their corresponding line cards. Since line cards consume most of the router power consumption [8]. Moreover, DGH provides competitive power savings compared with other algorithms, in addition to its simplicity and high speed.

The rest of this paper is organized as follows; Section II describes the problem notations. Section III analyzes the literature review. Section IV portrays the proposed algorithm. Section V shows the experimental results. Finally, conclusions are shown in Section VI.

II. PROBLEM NOTATIONS

The backbone network topology is described as a directed graph $G(V, E)$ as V is a set of routers and E is a set of links. Usually, links are bundled and every bundled link $(u, v) \in E$, such that (u, v) connects two routers; $u, v \in V$ and has a capacity $c(u, v)$. Every bundled link consists of B physical cables. For example, a bundled link (u, v) consists of five 10 Gbps physical cables. Then $B=5$, which is the bundle size, and $c(u, v)=50$ Gbps, which is the bundled link capacity. The demand i.e. traffic between a couple of routers is described as a row (s_d, t_d, h_d) in the traffic matrix D , where s_d is the source router, t_d is the destination router, and h_d is the amount of demand between s_d and t_d combination. Furthermore, let $f_d(u, v)$ be the flow of the bundled link (u, v) and d is a demand amount through a bundled link (u, v) [13]. The aggregate flow of a bundled link (u, v) is denoted as $f(u, v)$ and shown in Equation (1). Usually, the flow $f(u, v)$ of a bundled link (u, v) does not exceed its capacity $c(u, v)$ [14].

$$f(u, v) = \sum_D f_d(u, v) \quad (1)$$

Furthermore, the extra capacity concept is the aggregate capacity of all unused physical cables of a bundled link. For example, Fig. 1 shows a partial backbone network, assuming there is a demand $d=4.5$ Gbps between a source router $s_{4.5}$ and a destination router $t_{4.5}$. Assume that every bundled link has a capacity of 10 Gbps, which are the aggregate capacities of ten 1 Gbps physical cables. As shown in Fig. 1, there are two paths between s and t , either $(s, 1, 2, 3, 4, t)$ or $(s, 4, t)$. Even though the demand is the same for both paths, its corresponding total flow varies. The total flow through the $(s, 1, 2, 3, 4, t)$ path is 22.5 Gbps, so the total extra capacities among all bundled links are 37.5 Gbps. However, the total flow through $(s, 4, t)$ path is 9 Gbps and the total extra capacities among all bundled links are 51 Gbps. Therefore, to minimize the total flow and maximize the total extra capacities, you have to select the shortest paths.

Accordingly, to maximize the total extra capacities of all bundled links, the traffic is routed through the possible shortest paths. Thus, the total flow through all bundled links is reduced. In other words, routing traffic through shortest paths minimizes the total flow of all bundled links and maximizes the total extra capacities of all bundled links, as shown in Equation (2).

$$\min \sum_{(u, v) \in E} f(u, v) \quad (2)$$

The network-management system runs an optimization algorithm periodically to reduce power consumption. The inputs of an optimization algorithm are a network topology $G(V, E)$, a bundle size B , and a traffic matrix D . Then, the optimization algorithm defines a network setup that utilizes the least physical cables from all bundled links, with the end goal of fulfilling all demands. The number of powered physical cables in a bundled link (u, v) is denoted as $n_{u, v}$. In other words, the outputs of an optimization algorithm are the selected powered physical cables per bundled link and the rerouting paths that some demands may use to increase the utilization of powered physical cables in the network [14].

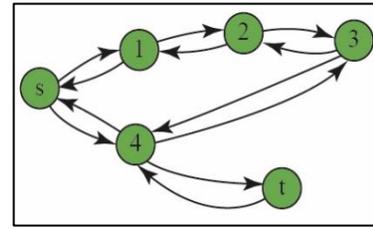


Fig. 1. Backbone Network using Hierarchical Topology.

III. LITERATURE REVIEW

To control power consumption in local-area networks, Ethernet cards utilize off-peak periods to work in low power consumption modes. For example, Broadcom and Intel produce network cards containing programmable rest clocks, that can be controlled by algorithms to shut down a link for a while [15]. Nonetheless, some approaches shut down a router totally including all its bundled links and their corresponding line cards at that router [11]. However, these approaches are not compatible with wide area networks, because shutting down the whole bundled link must produce a packet loss [15].

In wide-area networks, literature shows approaches to control power consumption. One approach uses a sleep mode, such that the system puts network cards into the sleep mode. However, how does the system deal with traffic through sleeping network cards? There are two solutions; either using coordinated sleeping routers or uncoordinated sleeping routers. The coordinated sleeping router is a centralized solution, that reroutes traffic through sleeping network cards into alternative active network cards as could reasonably be expected. The drawback of this solution is that the router needs a dynamic protocol [6, 16, 17].

The uncoordinated sleeping router is an uncentralized solution. Every network card notifies its neighboring network cards before going to the sleep mode, which is allowable at low demand periods. Thus, an active network card wakes up the sleeping network card as needed by sending a wake-up packet. The drawback of this solution is the latency because of wake-up time and neighboring processing [6]. Furthermore, the authors of [15, 19] recommend an extreme suggestion as all network equipment should support a slow-speed mode to reduce power consumption.

Nevertheless, literature shows that the optimal power-saving approach shuts down and powers some physical cables of a bundled link according to the low demand time. This approach uses the extra capacities, which are determined by the traffic matrix of all bundled links. Generally, this approach maximizes the total extra capacities of all bundled links since the traffic is routed through the possible shortest paths. As mentioned in the Introduction Section, this approach uses heuristic algorithms to find a possible optimal selection among physical cables of a bundled link [6]. This section presents the most known heuristic algorithms, which utilize the unused capacity of powered physical cables. These algorithms are the Fast Greedy Heuristic algorithm (FGH), Exhaustive Greedy Heuristic algorithm (EGH), and Bi-level Greedy Heuristic algorithm (BGH) [19].

A. Fast Greedy Heuristic Algorithm

FGH is the fastest and simplest algorithm compared with EGH and BGH. Initially, FGH minimizes the total flow of all bundled links to maximize the total extra capacities of all bundled links, as shown in (2). Then FGH shuts down all extra capacities such that the remaining powered physical cables can serve all the network traffic. After that, FGH finds the physical cable with the largest unused capacity by using (3) [14].

$$f(u,v) \leq (n_{uv} \div B) c(u,v) \quad \forall (u,v) \in E$$

such that,

$$\max_{(u,v)} ((n_{uv} c(u,v) \div B) - f(u,v)) \quad (3)$$

Periodically, FGH attempts to shut down the physical cable having the largest unused capacity and reroutes its corresponding flow. According to the example in Section II, if you shut down one out of the remaining five physical cables, that carry out the demand $d=4.5$ Gbps, you have to reroute a demand $d=0.5$ Gbps into alternative paths. Then, FGH examines (2). If it is not satisfied anymore, FGH powers the shutting down physical cable and marks its bundled link (u, v) as “final”, so no more future attempts to shut down any of its physical cables. As long as (2) is satisfied, the shutting down physical cable is confirmed and (3) is calculated. FGH repeats until all bundled links are marked as “final” [14].

However, FGH has drawbacks; such as if FGH shuts down a physical cable that produces a suboptimal solution, it will never backtrack to revise the selection.

B. Exhaustive Greedy Heuristic Algorithm

EGH performs as FGH using different conditions to shut down a physical cable. EGH calculates a penalty value for every candidate-physical cable. Such that, EGH shuts down the physical cable having the smallest penalty. Nevertheless, the penalty for a physical cable is calculated based on the flow distribution before and after shutting down the physical cable. Thus, the penalty allows the algorithm to do a “look-ahead” decision on each physical cable before removing it. Usually, EGH finds an optimal selection consuming a larger execution time and increasing the router overhead because of penalty calculations [14].

C. Bi-level Greedy Heuristic Approach

BGH performs as EGH using the penalty condition, but in a different manner. BGH applies a penalty on a pair of physical cables and shuts down the pair having the smallest penalty. However, the penalty for a pair of physical cables is calculated based on the flow distribution before and after shutting down the physical cables. Therefore, BGH finds the optimal selection, consuming unreasonable execution time to make a removal decision [14]. Accordingly, the router overhead extremely increases because of the double penalty calculations per selection.

IV. PROPOSED ALGORITHM

As we mentioned previously, FGH is fast and simple. Literature shows that the three heuristic algorithms (FGH, EGH, and BGH) are close to each other in terms of power-saving amount, but they extremely vary in execution time.

Moreover, a network operator runs one of these algorithms very often to control the power consumption. Thus, it is essential to reduce the execution time, which is varied from a few minutes using FGH, a few hours using EGH, and countless times using BGH. Their execution times vary because of the (2) complexity, which is $O(|E|^2)$ for both FGH and EGH as is $O(|E|^3)$ for BGH. On the other hand, FGH and EGH are different in selecting a physical cable to be shut down. FGH selects a physical cable having the maximum unused capacity, as EGH selects a physical cable having the minimum penalty. However, penalty calculation is harder and consumes more time than unused capacity calculation. As a result, execution times of FGH and EGH are different, even though they have the same complexity of (2) [14].

Accordingly, this paper proposes a Dual-Fast Greedy Heuristic algorithm (DGH) to speed up the power-saving process consuming limited overhead on routers. Initially, DGH minimizes the total flow of all bundled links to maximize the total extra capacities of all bundled links. Then, DGH shuts down all extra capacities from all bundled links. After that, DGH randomly shuts down a physical cable from a bundled link (u,v) and reroutes the flow of the shutting-down physical cable into alternative shortest paths. As a test for optimality, DGH examines (2). If it is not satisfied, DGH powers the shutting down physical cable and marks its bundled link (u,v) as “final” to prevent future shut-down attempts on (u,v) . Otherwise, the shutting down physical cable is confirmed. Moreover, DGH repeats selecting a random physical cable from a random unmarked bundled link until all bundled links are marked as “final”.

DGH reduces the power-saving cost to the minimum because there is no calculation per selecting a physical cable. On the other hand, DGH could result in a suboptimal solution, since DGH randomly selects a physical cable. In other words, DGH is similar to other heuristic algorithms in the first part, which is shutting down all extra capacities from all bundled links. Then DGH randomly selects a physical cable to shut down without any extra calculations. Consequently, DGH provides power savings similar to FGH, EGH, and BGH, because of the first common part. Additionally, DGH consumes a lower execution time, because all further shutting down physical cables, after the first common part, are selected randomly.

V. EXPERIMENTAL RESULTS

The proposed algorithm DGH is examined using AMPL/CPLEX solver. CPLEX is an optimization package for linear, network, and integer programming. AMPL is an algebraic modeling language, which stands for A Modeling Language for Mathematical Programming. Generally, AMPL utilizes an optimization package such as CPLEX to solve optimization problems [20, 21]. As an experimental backbone network, the Abilene backbone network of 39 nodes is used. The experimental Abilene is examined using two topologies; Waxman and hierarchical topologies, as Table I presents their parameters, which are the number of bundled links as shown in “#Bundled links” column and the requested demands between any two nodes as shown in “Demands” column. The key difference between both topologies is connectivity. Such that

every existing bundled link between any two nodes is doubled to be in both directions for the hierarchical topology. However, some existing bundled links are doubled to be in both directions for the Waxman topology. Fig. 2 and 3 show examples of Waxman and hierarchical topologies, respectively. Results were collected on the Intel Core 2 processor running Ubuntu server 14.04.

TABLE I. PARAMETERS OF ABILENE TOPOLOGIES

Topology	#Bundled links	Demands
Hierarchical	148	2.450
Waxman	169	2.450

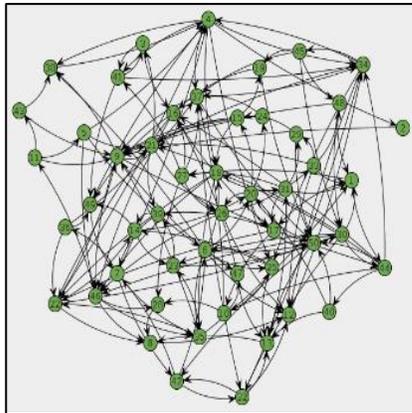


Fig. 2. Waxman Topology.

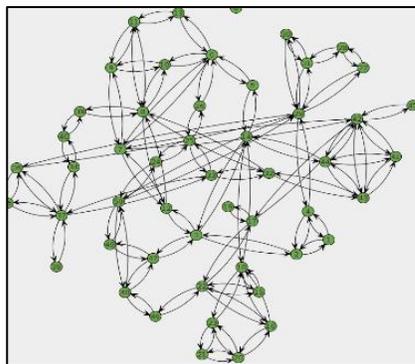


Fig. 3. Hierarchy Topology.

In the Waxman topology, the likelihood that two nodes are directly connected by a bundled link increases as the distance between them decreases. The hierarchical topology was created by GT-ITM [18]. Moreover, real demands were estimated by traditional entropy for urban traffic [22]. However, DGH is compared with FGH because it is the fastest algorithm.

Experimental results show that FGH and DGH provide similar power savings. Because both of them shut down all extra capacities from the beginning, also both of them fell into suboptimal solutions during the further steps. However, DGH outperforms FGH in terms of execution time. Fig. 4 shows the execution time of both FGH and DGH on Waxman topology. DGH outperforms FGH irregularly because of irregular topology. While Fig. 5 shows the execution time of both FGH and DGH on hierarchical topology. The curves of Fig. 5 reflect

the regular and little improvement of DGH due to the regular topology.

To translate the shown improvement into numbers, the improvement ratio is calculated using Equation (4):

$$IR = \text{avg}(T_{FGH}) - \text{avg}(T_{DGH}) \quad (4)$$

Where IR is the improvement ratio, as T_{FGH} and T_{DGH} are the execution time using FGH and DGH algorithms, respectively. Thus, DGH outperforms FGH in both topologies with improvement ratios of 18% and 36.17% on hierarchical and Waxman topologies, respectively.

Moreover, both Fig. 4 and 5 show that the bundled link size and the execution time are almost independent, because both DGH and FGH shut down all extra capacities in the first step.

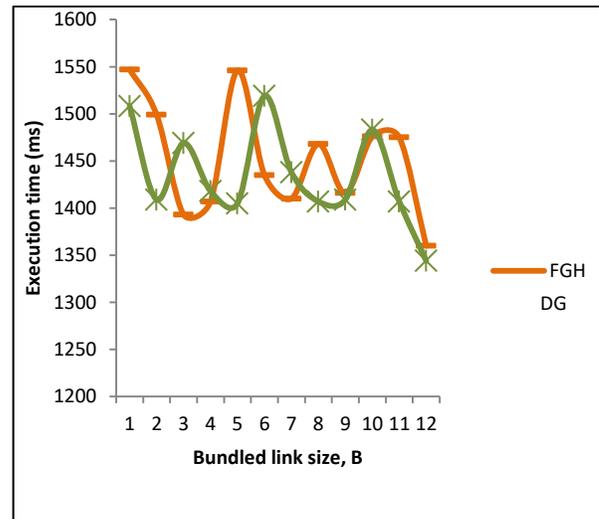


Fig. 4. The Execution Time of FGH and DGH Algorithms Applied on Waxman Topology.

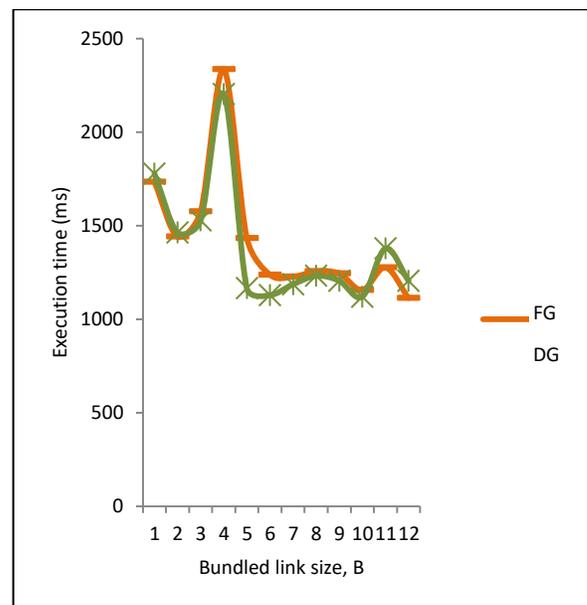


Fig. 5. The Execution Time of FGH and DGH Algorithms is Applied to Hierarchical Topologies.

VI. CONCLUSION

Green ICT is responsible for reducing the power consumption of computing resources to minimize their impact on the environment. The Internet represents up to 10% of the worldwide power consumption and is continually expanding. Furthermore, backbone networks are the main part of Internet power consumption. Since links of these networks are commonly bundled and provide larger capacity than needed.

A few approaches are proposed to reduce power consumption in the Internet backbone. One of them depends on shutting down individual cables of bundled links during times of low demand. However, optimal shutting down physical cables is an NP problem. Therefore, algorithms compete for increasing shutting-down cables in a reasonable time to provide more power savings. Accordingly, this paper proposes a dual-fast greedy heuristic algorithm (DGH), which shuts down all extra capacities from all bundled links. Then, DGH randomly shuts down a physical cable having an unused capacity. Also, DGH reroutes the flow of the shutting-down physical cable.

To assess DGH, the AMPL/CPLEX solver is utilized on the Abilene backbone. DGH is compared with the fastest algorithm, which is FGH. The experimental results show that DGH is faster than FGH and provides similar power savings as FGH. Nonetheless, the improvement ratios in terms of execution time are between 18% and 36.17% for Waxman and hierarchical topologies, respectively. The drawback of DGH is the suboptimal solution, which does not affect the power savings because DGH shuts down all extra capacities from the beginning. In a conclusion, DGH gets suboptimal selection to reduce the router overhead, which in turn reduces the power consumption. For future works, DGH could be examined using various backbone networks and various sets of parameters.

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