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A Hop-by-Hop Energy Efficient Routing for Green Internet

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ABSTRACT: In Internet the energy consumption varies according to the different traffic volumes in a path and everywhere packets are travelling due to trunking (IEEE 802.1AX), adaptive link rates, etc. To overcome the problems in the present routing scheme introduce green Internet routing scheme, where the routing can lead traffic in a green way. Previous the line cards and routers are in the sleep mode, so we introduce concept of power model and validate it using real commercial routers. Instead of developing a centralized optimization algorithm, which requires additional protocols such as MPLS to appear in the Internet, we opt a hop-by-hop approach. We introduce three algorithms, there are loop-free, substantially reducing energy consumption and jointly consider green routing and QoS requirements such as path stretch. We further explore the power saving ratio, the routing dynamics, and the relationship between hop-by-hop green routing and QoS requirements. We systematically evaluate our algorithms through simulations on synthetic, measured, and real topologies, with synthetic and real traffic traces.

KEYWORDS: Energy conservation, Green routing, internet routing, hop-by-hop routing.

I. INTRODUCTION

Energy conservation is the main problem now a days and cost is increasing. The important issue now is that how to save energy in areas such as data centres, building management system (BMS).Data centres offer a tremendous opportunity for energy and cost savings. Data centre energy consumption can be reduced by 20% to 40% by applying best management energy-efficiency measures and strategies. In the Internet, routers and switches take the majority of energy consumption. More high performance routers are developed and deployed currently. In general, these studies switch network components, such as line cards and routers, into sleep mode and compute a topology with fewer nodes and links, which may decrease network resistance against failures. The network components to be turned off are watchfully selected and trade-offs are investigated to steadiness network performance. To recognize these approaches, MPLS or any previous required protocols are usually necessary.

Here "green" routing where we do not disturb the topology of Internet. A key observation that makes this possible is that the energy consumption for packet delivery can be different in different traffic volumes. Consequently, we can choose paths that consume less power while delivering traffic. Intrinsically, this is caused by technologies including trunking and adaptive link rates. Trunking is a method for a system to provide access to many clients by sharing a set of lines or frequencies instead of providing them individually. This is analogous to the structure of a tree with one trunk and many branches. Logical link in the Internet often reflects multiple physical links and when traffic volume is less, less physical links can be used and less energy is consumed. Adaptive Link Rate is an Ethernet technology where link rate and power dynamically extent with traffic volume. As such, even without changing the topology (i.e., by switching routers into sleeping mode), energy utilization can vary greatly given different routings that result in different traffic volume on the paths. Fundamentally, our work shows that there can be further refined control than an on-off (0-1) control of the routers in energy conservation.

In a network that includes many links with trunking or ALR, the energy conservation can be greater than that of topology pruning approaches. An approach without topology pruning can also be used in a network after pruning some

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links or nodes for further energy conservation. Instead of using hop-by-hop approach, each router can separately compute next hops, the same as what they do in Dijkstra today. We can then easily incorporate the routing algorithm into the OSPF protocol. Under this hop-by-hop design, we face the following challenges to be practical, the computation complexity should be comparable to that of shortest path routing and more importantly, the routing must be loop-free, maximize energy conservation; and important QoS performance of the network such as path stretch may be considered concurrently, and can be naturally adjusted.

We first develop an influence model and validate the model victimisation real experiments in industrial routers. we have a tendency to then develop principles and a baseline hop-by-hop inexperienced routing algorithmic program that guarantees loop-free routing. The algorithmic program follows the wide legendary routing pure mathematics with isotonic property. We have a tendency to any develop a complicated algorithmic program that well improves the baseline algorithmic program in energy conservation. We have a tendency to additionally develop AN algorithmic program that at the same time considers energy conservation and path stretch. Then, we have a tendency to discuss and analyse a number of problems associated with our approach. we have a tendency to discuss the ability saving quantitative relation of our approach and topology pruning approaches, analyse the routing dynamics and conduct an in-depth study on increasing energy conservation with QoS necessities. We have a tendency to evaluate our algorithms victimisation comprehensive simulations on artificial and real topologies and traffic traces. The results show that our algorithms may save quite fifty percentage energy on line cards.

II. RELATED WORK

As one with the world-wide intention to build a greener globe, added and more computing systems consist of energy conservation into their design principles and readily available are efforts to develop a greener Internet. First one is saving energy of the routers. Second, there are studies on energy conservation of the Internet from upper layers point of view. For instance, Energy Efficient TCP is proposed to perform congestion control with dynamic bandwidth modification. Note that the energy saving of such upper layer performance control is realized by converted into better router control in the network layer. Third, save energy from a network routing point of view. GreenTE is proposed to aggregate traffic using MPLS tunnels, so as to control the underutilized network components hooked on sleep mode and therefore save energy. Response is proposed to identify energy critical and on-demand paths offline. The packets are delivered online also with the aim to effectively aggregate traffic and switch more network components into sleep mode. An energy efficient routing method that jointly considers admission control is projected. These approaches use sleep mode to save energy. Also, there are studies to save energy without sleep mode.

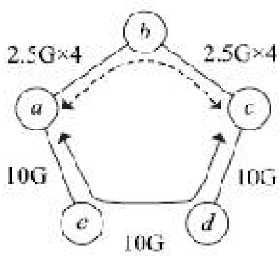

Fig.1. Example of Green Routing with Adaptive Link Rates

They leverage bundled links or speed scaling model. These approaches all need centralized computing and use MPLS to build routing paths. For distributed or hop-by-hop power efficient routing approaches, Green OSPF is proposed to aggregate traffic and switches the network components into sleep mode. However, to achieve good performance, a centralized algorithm is still needed to assign sleeping links. ESACON is proposed to collaboratively select sleeping links with special connectivity properties. Routing paths are then work out after these links is removed. A set of completely distributed approaches is proposed in and which collects global traffic information and aggregates traffic to switch appropriate network components into sleep mode

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. There is a set of other works with various considerations. These works use sleep mode to save energy. A hop-by-hop approach that does not use sleep mode is proposed. The approach considers a power model similar to the speed scaling model, which does not capture the properties of trunking. Further, the routing protocol needs to be changed largely, e.g., multipath needs to be supported. Our approach falls into the third category discussed above, yet it differs from the aforementioned schemes in the following aspects. First, most previous proposals switch network devices or links into sleep mode and prune the network topology. Our design is based on the observation that the energy consumption of a link can be dependent on the traffic volume. A routing algorithm may take this into consideration. Second, though some previous schemes compute the network components to be shut down in a distributed fashion, great changes to the current routing protocols are still needed. Our routing working out hop-by-hop and Dijkstra oriented, which we believe is easier to be incorporated into the current routing architecture. We note that using sleep mode for energy conservation is preferred in certain scenarios, specifically, in networks where the link power changes little with the traffic volume, such as a data centre network. However, techniques of trunking and ALR are deployed more and more in the Internet, and there are increasing efforts recently in developing power-proportional routers. Existing approaches for such a situation are centralized or change current routing protocols greatly. Thus, a hop-by-hop and practical approach is needed, and this motivates our work. We may consider green as one type of services that the Internet should provision. There are many studies on Internet Quality of Service (QoS). There were two different approaches in Internet QoS support beyond shortest path routing. One is centralized computation. The advantage is that since different types of services usually introduce conflicts, a centralized scheme can compute optimal or near optimal solutions. But the drawback is that centralized computation requires additional protocols, which is a nontrivial overhead. The other is to maintain hop-by-hop computation by managing different types of services into a singular link weight.

III. POWER MODEL

A. ROUTER OPERATION AND POWER MODELLING

A link between two routers is actually connected with two line cards, and the line cards consume the commonly power of the routers and use link power consumption to abstract the power consumption of the line cards.

We can classify two types of links:

1) Trunk links where advanced technologies are adopted and line cards in a logical link can be independently turned off, resulting in a stair like behaviour in power consumption

2) Non-trunk links. We first model the non-trunk links and divide the power consumption into three categories:

a) Power consumed by OS and control plane.

b) Power consumed by line card CPU processor

c) Power consumed by operations like buffer I/O, packet lookup, etc.

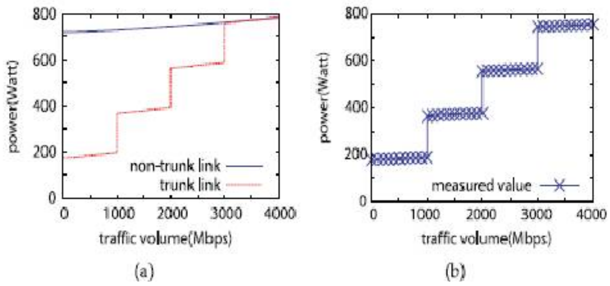

Fig 2: (a)The power-traffic curves by eq.1 and eq.4 (b) The measured power-traffic curve.

Finally, the total power consumption of a non-trunk link, and then we have

$$P_l^{no}(x_l) = 2n_l \times \left(\delta_l + \rho_l \frac{x_l}{n_l} + \mu_l \left(\frac{x_l}{n_l} \right)^{\alpha_l} \right). \qquad (1)$$

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Here $2n_1$ denotes the fact that the power is consumed by the line cards on both ends of the link. 2) Trunk links. For a trunk link, the difference is the discrete stair-like behaviour. We replica two intrinsic reasons for the discrete stair-like behaviour:

1) Physical links can be powered off in different traffic volumes

2) Different components in line cards can be turned-off in different traffic volumes. There are many components in a line card. With advanced technologies, many components can individually change to low-power states or be turned off after the traffic volume is reduced below different levels of thresholds. For instance, an Intel processor has active state C0, auto halt state C1, stop clock state C2, deep sleep state C3 and deeper sleep state C4,all with different power consumption. Similarly, a PCIe bus which connects the chips has the states D0, D1, D2, D3hot and D3cold.4 Turning on/off of these components is discrete in general.

$$n_c = \begin{cases} n_l - 1, & \text{if} \quad r_0 \le x_l < r_1 \\ n_l - 2, & \text{if} \quad r_1 \le x_l < r_2 \\ \dots, & \dots \\ 0, & \text{if} \quad r_{n_l-1} \le x_l. \end{cases} \tag{2}$$

$$\delta_c = \begin{cases} \delta_{n_s-1}, & \text{if} \quad r'_0 \le \frac{x_l}{n_l - n_c} < r'_1 \\ \delta_{n_s-2}, & \text{if} \quad r'_1 \le \frac{x_l}{n_l - n_c} < r'_2 \\ \dots, & \dots \\ \delta_0, & \text{if} \quad r'_{n_s-1} \le \frac{x_l}{n_l - n_c}, \end{cases} \tag{3}$$

$$P_l^a(x_l) = 2(n_l - n_c)\left(\delta_l - \delta_c + \frac{\rho_l x_l}{n_l - n_c} + \mu_l \left(\frac{x_l}{n_l - n_c}\right)^{\alpha_l}\right). \tag{4}$$

B. SIMULATION AND EXPERIMENTAL VALIDATION

Equations (1) and (4) are abstract for the illustration purpose, we plot numerical examples. We set the link to consist of four 1 Gbps physical links. The idle power dl for each physical link is set to 180 Watt. These are based on suggested values and We set r0;r1;r2;r3;r4 to 0;1;000;2;000;3;000;4;000 Mbps. We assume that there are five states for the line card components, which can reduce power by 5; 3:5; 2; 1; 0 watt respectively. We obtain these thresholds from our experiments. We see that for a non-trunk link, the power consumption is slightly super-linear to the traffic volume. For a trunk link, the power consumption shows a much bigger difference and a discrete stair-like behaviour. This means that smaller traffic volume leads to more energy conservation for a trunk link if appropriately managed. Another observation is that the power consumption changes little when the line card components change power state; the slope of each step of the trunk link curve is similar to the slope of the non-trunk link curve. This is because the idle power of a line card is a dominant factor in current stage. We further validate this power model with experiments using a real commercial router. We set up the experiment by generating packets of 64 bytes with a PC and sending the packets to a commercial BitEngine12000 router,5 through four 1 Gbps Ethernet links. The traffic volume varies from 1 to 4,000 Mbps. The router has four 4 GE line cards and powers on a proper number of line cards to forward the traffic. We measure the power of the 4 GE line cards by connecting an AC ammeter with the AC-input power supply circuit. We can read the electric current value from the ammeter. The results are shown in Fig. 2b. We see that the curve matches our model closely. As an example, when we increase the traffic from 1,000 to 1,100 Mbps, the power consumption shows a sharp increase from 210 to 380 Watt. The power model we proposed is based on analysis and measurements on real routers. Similar results are reported in a recent independent work. The main difference we made is the stair-like behaviour when line cards in a trunk link can be switched off individually. Again, we emphasize that we focus on network layer devices (routers) in this paper. Although routers made by different vendors have different power consumptions, we believe that the stair-like relationship between power consumption and traffic holds for modern routers that operate in a modular fashion. In this paper, we will focus on the power consumed by traffic. Therefore, we subtract the idle power.

$$P_l(x_l) = \begin{cases} P_l^a(x_l) - P_l^a(0) & \text{trunk link } l \\ P_l^{na}(x_l) - P_l^{na}(0) & \text{non-trunk link } l. \end{cases} \tag{5}$$

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IV. OVERVIEW AND PRELIMINARIES

The objective of green Internet routing is to minimize the total energy consumption in the network. We choose a hop-by-hop approach since it can be easily integrated into existing Internet routing architecture. Officially, a network is modelled as G(V,E) where V denotes the set of nodes and E the set of links.

Fig. 3: An example of routing loops.

For a hop-by-hop approach, simply computing the "greenest" path (i.e., with the smallest energy consumption) for each s-d pair may not minimize the total energy consumption. The traffic of different paths together increases the consumption ratio of links, and leads to greater energy consumption. This is a standard local vs. global optimal problem. One possible solution is to let each router compute routing based on global traffic matrices that reflect the volume of traffic flowing between all possible source and destination pairs. However, it is not easy to obtain a traffic matrix, because 1) direct measurements to populate a traffic matrix is typically prohibitively expensive and 2) the procedure to estimate a traffic matrix from partial data is of high complexity, since the associated optimization problem is non-convex. Thus, for a hop-by-hop scheme whose complexity is comparable to that of Dijkstra, we design a path weight similar to the path weight used by Dijkstra, where the weight reflects the total energy conservation based on partial traffic data. The path weights must be carefully designed to make sure the hop-by-hop routing is loop-free.

V. GREEN-HR ALGORITHMS

In Green routing path weight and a baseline algorithm Dijkstra-Green-B to achieve loop-free then study some fundamental relationships between link weights and power consumption, and develop an advanced algorithm Dijkstra Green-Adv that improves energy conservation.

A. DIJKSTRA-GREEN-B ALGORITHM

The key is to develop an appropriate weight for a path so that it incorporates "green" and holds is tonicity. A Dijkstra-oriented algorithm can then be developed to achieve loop-free hop-by-hop routing. A initial observation is that though we cannot choose the "greenest" paths, for energy conservation from the whole network point of view, we should not choose a path that is too long either, since it accumulatively consumes more energy. We thus set the weight as follows. For each link in the path to destination node d, we assign an estimated traffic volume or "virtual traffic volume". We compute the virtual traffic volume by posing an exponential penalty to a start traffic volume for each additional hop. Then, with the virtual traffic volume, the link power is computed following the power function.

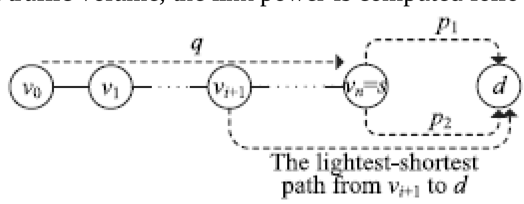

Fig.4: The topology used to prove the strict left-istonicity of the path weight structure defined by Eq. (6).

For the path,

$$w_b(p) = \sum_{i=0}^{n-1} P_{(v_i,v_{i+1})}\left(x_0^v \cdot \beta^{\mathrm{Hops}(p_b(v_{i+1},d))}\right). \qquad (6)$$

Here function returns the hop number of path p. Note that a link's weight is not a static value, and may vary with path p and destination node d. However, we can prove the strict left- isotonicity of this path weight structure.

The computation complexity of Dijkstra-Green-B is the same as that of the standard Dijkstra in the worst case, i.e., O(|E|+|V |log |V|). However, the algorithm can stop once the path from s to d is finished so the complexity in the best case is O(1).Dijkstra-Green-B computes the routing for one destination. Though routings of different destinations are independent from each other, so parallel processing can be used to accelerate the computing. We can expect that the running time is less than that of Dijkstra.

B. LINK WEIGHTS VS. ENERGY CONSERVATION

In order to achieve greater energy conservation, we take a closer look at two main factors affecting power consumption.

B.1 LINK WEIGHTS VS. POWER PER UNIT TRAFFIC VOLUME

Recall the power-traffic functions the power consumption of a link enhanced. The topology used to prove the strict left-isotonicity of the path weight structure defined with the rise of the traffic volume. The link weight should reflect this. We consider an extreme case that the power consumption is proportional to traffic volume X_1. Such an assumption is a special case of our power model. Though the assumption is ideal, it is reliable with the trend of developing power-proportional routers.

B.2 LINK WEIGHT VS TRUNK LINK

For trunk link, if the traffic volume results in a leap to a higher "stair", there can be a great power loss. We tend to assign a higher weight for a trunk link to reduce its traffic volume. Generally, we take a heuristic by multiplying the weight of a trunk link with a factor. However, the factor for different trunk links should not be the same. On one hand, if we put a big traffic volume on a trunk link, the power consumption is likely to leap to a higher stair. In this case, we need a big factor for the link, such that the traffic volume can be reduced. On the other hand, if a small traffic volume can cause the power consumption to leap to a higher stair, we also need a big factor for the link. Formally, we define the factor k_l as

$$k_l = \gamma\sqrt{\frac{x_0^v}{r_u - r_d}}, \qquad (7)$$

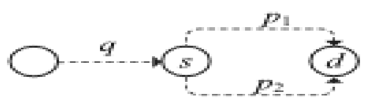

Fig.5: The topologies used to prove the strict isotonicity of the path weight structure

C. DIJKSTRA-GREEN-ADV ALGORITHM

Now we develop the Dijkstra-Green-Adv algorithm based on the improvements above. Note that Dijkstra Green-B is a baseline algorithm, which focuses on loop-free hop-by-hop routing while considering energy conservation. Dijkstra-Green-Adv focuses on achieving more energy conservation, and follows the principles of Dijkstra-Green-B to guarantee loop-free routing.

Algorithm for Dijkstra-Green-Adv ()

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Input: G(V, E), s, d, P, x_0^v, x̄;
Output: the advanced green path from s to d stored in φ[];
for each node v ∈ V
    w[v] ⇐ ∞; φ[v] ⇐ null;
Q ⇐ V; w[d] ⇐ 0;
while Q ≠ ϕ
    u ⇐ Extract_Min(Q);
    if u = s
        return φ[];
    for each node v ∈ N(u)
        ϖ ⇐ P_(u,v)(x̄(u, v) + x_0^v) − P_(u,v)(x̄(u, v));
        ϖ ⇐ ϖ · k(u, v);
        if w[u] + ϖ < w[v]
            φ[v] ⇐ u;
            w[v] ⇐ w[u] + ϖ;
return;
```

The algorithm makes only a few medications to the standard Dijkstra algorithm.

D. DIJKSTRA-GREEN ALGORITHM

The balance between green and normal QoS requirements for the routing paths are find out and investigate whether the pursuit of green may give up distinctive routing metrics such as end-to-end delay or bandwidth. How a balance can be made, we will develop an algorithm that jointly consider green and path length. Note that our earlier algorithms think about path length in the sense to make the paths greener. Here the path length is considered as a separate parameter that reflects end-to-end delay. Obviously, the green paths and the shortest paths cannot be simultaneously achieved. A typical metric to evaluate how a computed path differs from shortest path is path stretch: the ratio of the length of an s-d path to that of the shortest path between this s-d pair. We analyze the path stretch of $w_{adv}(p)$ and find that the path stretch is small for most paths there exists some big stretch when the length of the shortest path is small. Thus, we develop an algorithm which takes additional considerations for the “short” paths. Specifically, let Len(p) be the length of path p. We divide the link length by the root of the shortest path length to node d. In this way, path length will dominate in the weight for short paths, and power consumption will dominate for long paths. The weight of path is defined by

$$w_g(p) = w_{adv}(p) + \sum_{i=0}^{n-1} \frac{\kappa \cdot Len(v_i, v_{i+1})}{\sqrt{Len(p_s(v_{i+1}, d))}}, \qquad (9)$$

VI. PERFORMANCE EVALUATION

A. METHODOLOGY

We evaluate our algorithms using synthetic, measured, and real topologies. First, we generate synthetic network topologies, and we set the parameters following, which captures certain properties of real networks, such as the power law node degree. Each synthetic topology has 100 nodes, and the link density changes from 2 to 5. Each dot in our figures is an average on 1,000 random and independent synthetic topologies. Second, we use the six measured intra-domain topologies provided by the Rocket fuel project. Third, we have two real topologies:

1) The Abilene backbone with 12 nodes and 15 two-directional links,7 and

2) The China Education and Research Network backbone, with 8 nodes and 12 links

The link capacities of the synthetic and measured topologies are resolute based on the fact that a node with a big degree is likely to hold links with a large capacity. We set a link’s capacity to 9,953.28 Mbps, if both end nodes of the link have a degree greater than 5. The capacity is set to 2,488.32 Mbps if one end node has a degree greater than 5 and the other has a degree less than 6 but greater than 2. Finally, the other links’ capacities are set to 622.08 Mbps. For the synthetic topologies, the measured topologies, we create traffic matrices according to the gravity model.

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$$f(s,d) = \frac{\eta \cdot \sum_{v \in N(s)} c(s,v) \cdot \sum_{u \in N(d)} c(u,d)}{(\text{Hops}(p_s(s,d)))^2}, \qquad (12)$$

B. RESULTS IN SYNTHETIC TOPOLOGIES

B.1. RESULTS ON DIFFERENT TRAFFIC LEVELS

The power saving ratio as against of traditional Dijkstra, We see that the power saving ratio of Green-HR can be as much as 55 percent, when the average link consumption is low. The power saving ratios was decreased when the average link utilization ratio increases. Yet we still see a power saving ratio of 38 percent when the average link utilization ratio is 65 percent. Dijkstra-Green-Adv is better than Dijkstra-Green-B as its design takes more factors that affect power consumption into consideration. Also see that Dijkstra-Green is slightly worse than Dijkstra-Green-Adv, mainly when the network is in high utilization. DLF and DMP save more power than Green-HR when the network is underutilized, but they save less power than Green-HR when the average link utilization is larger than 25 percent. This is because in a network with a large traffic, the link utilization will increase largely when switching links into sleep mode. In this case, Green-HR can save more power than topology pruning approaches. Fig.8showsthe average path stretch of the algorithms. We see that the path stretch of Green-HR is consistent and relatively low under any link utilization ratio. The average path length of Dijkstra-Green-Adv is about 1.22 times to that of the shortest path. We consider such a stretch to be a fine value in most cases. The path stretch of Dijkstra-Green is only 1.04. It successfully considers path length when saving energy. The average path stretches of DLF and DMP are much larger than those of Green-HR whenthe link utilization is low. For example, the path length of DLF is two times to that of the shortest path when the link utilization ratio is 10 percent. This is because packets have to be delivered in a long path to detour around the sleeping links. The path stretches of DLF and DMP decreases with the increment of the link utilization, because less links can be switched into sleep mode when the traffic is larger, since a link may be overloaded easily.

C. RESULTS IN MEASURED TOPOLOGIES

The average power saving ratios in the Rocket fuel topologies and Dijkstra-Green saves about 55 percent of the power in all the six topologies, which implies that GreenHR has a good scalability in networks with different sizes. DLF saves more power because the synthetic traffic is small. However, the difference is small. We consider the power saving ratio of Green-HR to be fine, since DLF induces larger path stretches and degrades the network resilience against failures, as presented below. DMF has similar results as DLF in the measured and the real topologies, so we do not plot the results.

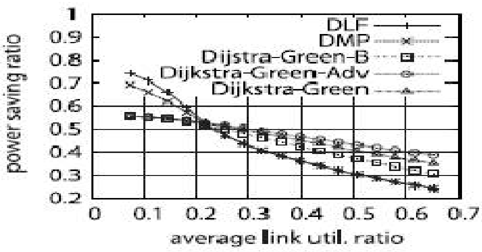

Fig. 4. Power saving ratio as a function of trunk link ratio

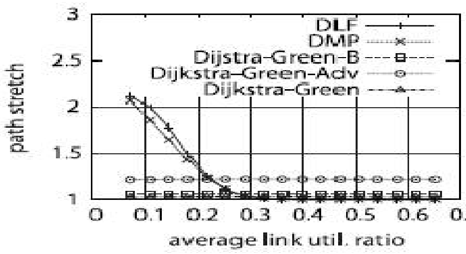

Fig.5. Path stretch as a function of avg. link utilization ratio

Our algorithms do not need to turn link/node level component off in the Internet. This is also useful when a failure occurs, as pruning links easily makes the Internet more stressful in connectivity and traffic support**.** The x-axis is the index of the failed link, sorted in increasing order according to the corresponding disruption time. We see that a few link failures induce the most disruption time. Dijkstra-Green induces much less disruption time than DLF, and for 99.2 percent of the link failures the time is less than 5 seconds. This is because we do not prune links from the topology and less sd paths are disrupted by a link failure. DLF results in a longer disruption time because it prunes links from the topology, and more paths are disrupted by a link failure, until some sleeping links are wake up and the routing is rebuilt. Note that DLF is distributed and the computation time is reasonable. We conjecture that centralized approaches such as GreenTE may have even longer disruption time.

VII. CONCLUSION

We presented Green internet routing and a power model that quantises the relationship between traffic volume and power consumption. The model is validated our real experiments. We presented a hop-by-hop approach and progressively developed algorithms that guarantee loop-free routing, significantly reduce energy footprint in the Internet, and jointly consider QoS requests such as path stretch. It is useful when MPLS can be applied, and may provide theoretical bounding for the possible highest power conservation.

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