A Sleep Study for ISP Networks: Evaluating Link Sleeping on Real World Data

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ABSTRACT

Turning off under-utilized network links is a promising energy-saving technique. In this paper, we present Hypnos, a link sleeping system targeted at low-utilization wired networks and assess its efficiency using real-world data from two European ISPs. In those two case studies, we find that Hypnos can turn off more than a third of all links without congesting the network. This confirms the promise of link sleeping in low-utilization networks.

CCS CONCEPTS

• **Networks** → **Physical links**; • **Hardware** → *Power estimation and optimization*; • **General and reference** → Empirical studies.

KEYWORDS

Sustainable Networking, Link Sleeping

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1 INTRODUCTION

In recent years, transceivers have increased in both capacity and power demand. Energy efficiency improves when transceivers are at 100% utilization [6], but, in practice, network links are often underutilized, even in datacenter networks [4]. Unlike servers, today's wired networks do not reduce their power draw by a lot when the utilization is low [5]. As a result, [4] suggests the network could make up around 20% of the IT power in a datacenter. This fraction is likely much larger in low-loaded networks such as ISPs. Hence, one could achieve important energy savings by improving energy proportionality in wired networks.

Energy proportionality is well-studied topic in the networking literature. In short, there are two classes of approaches: sleeping, *i.e.*, turning things off whenever possible, or rate adaptation, *i.e.*, setting the links to lower bitrates [7]. Rate adaptation is potentially more practical as it does not affect the routing topology; however, the power savings are limited by the fixed power cost to keep the link up, which sometimes dominates the total port power [5]. Besides, not all transceivers and network devices support multiple bitrates, which limits the generality of the approach.

In this paper, we focus on link sleeping, *i.e.*, turning links off. In a prior poster [2], we observed that transceivers can take multiple seconds to turn on and off. This renders sleeping at the traffic scale (as suggested in [7]) unfeasible. However, we argued one could still put links to sleep at longer timescales (*e.g.*, a couple of times per day) and proposed a first system prototype. This system performs four main functions:

(1) Collect network state information
(2) Select links to put to sleep
(3) Turn links off
(4) Wake links up on demand

Intuitively, the potential savings from sleeping strongly depend on the network load and degree of connectivity. Moreover, one may be more or less aggressive in the selection of links to put to sleep; turning more links off improves energy savings but is more likely to create congestion events on the remaining links. The likelihood of creating congestion depends on how stable the traffic demand is; the more bursty it is, the likelier it is the system makes "mistakes," *i.e.*, it turned off links that would have avoided congestion.

[2] described a first prototype but lacked a fundamental part in its evaluation: without access to real-world traffic and topology information, it could not assess how efficient the system would be at putting links to sleep; *i.e.*, how many links would it turn off, and how often would sleeping decisions lead to congestion?

This paper fills this gap. We present a refined link sleeping system called Hypnos and evaluate its efficiency on real-world data from two ISPs. We show that, despite its simple logic, Hypnos is very efficient; more specifically,

- Hypnos turns off more than a third of links in two real-world case study of lowly-loaded networks; (§ 3.4)
- it does so without causing congestion; (§ 3.4)
- it adapts well to high-load scenarios; (§ 3.5, § 3.8)
- it can be configured to maintain link failure resilience. (§ 3.6)

2 HYPNOS

2.1 Overall Design

Hypnos aims to put as many links to sleep as possible without disrupting the network. In other words, it has three objectives.

- It must *not disconnect the network* by putting links to sleep.
- It must *decide which links to put to sleep* while minimizing traffic redirection and congestion.
- If congestion happens, it must *react quickly* and turn links back on to resolve the congestion.

While we aim to set as many links to sleep and keep them asleep for as long as possible, avoiding congestion takes priority. Hypnos' four main functions are described below and illustrated in Fig. 1.

(1) Collecting network state. One key design choice is how to decide whether one link can be safely turned off. To know exactly where the current traffic would be re-routed, one would need the flow-level traffic matrix and complete routing state, which is very challenging to collect and process in real time. Instead, Hypnos relies on a heuristic based on link loads (Fig. 1i), which are already commonly collected today at five-minute granularity via SNMP,

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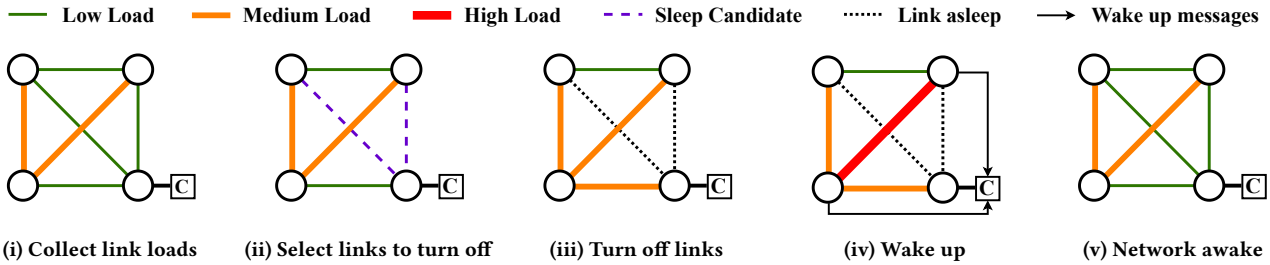


Figure 1: Visual representation of steps Hypnos performs to turn off and wake up the network

similar monitoring protocols. They may also be collected *e.g.*, via the OSPF TE Metric Extensions (RFC 7471).

(2) Selecting links to put to sleep. Link loads are aggregated to a centralized controller, which selects the links to turn off (Fig. 1ii). Hypnos uses a centralized controller to avoid accidental network partitions; the controller always knows which links are asleep and which must stay up to keep the network connected. In a decentralized system, guaranteeing connectivity becomes non-trivial.

Hypnos sets the total volume of traffic allowed to be rerouted with a *Reroute Budget* that lets the operator tune the acceptable amount of traffic moved to a different path due to sleeping.

(3) Turning links off. To limit traffic disruption, Hypnos turns links off in two stages: First, it increases the IGP link weight to drain all traffic from the link; then, if no congestion is observed on the other links, Hypnos turns the link off (Fig. 1iii).

(4) Waking up the network. Since avoiding congestion is prioritized over saving energy, Hypnos uses a conservative wake-up logic: if one of the network links becomes congested (Fig. 1iv), Hypnos immediately triggers the wake-up of all sleeping links (Fig. 1v).

2.2 Sleeping Decision Algorithm

The link sleeping decision algorithm is the core of Hypnos. It proceeds in three steps:

- defining sleeping link candidates;
- sorting candidates by increasing load;
- iteratively turning candidates off while checking connectivity and rerouting constraints.

To define link candidates, Hypnos checks all the link loads of the routers connected to a given link. As explained in § 2.1, we cannot easily know where the link traffic would be rerouted, so Hypnos uses the following heuristic. Take one candidate link and assume all of its traffic would be rerouted via the highest-loaded link on the same router; if that creates congestion, disregard the link as a sleeping candidate. Then, iterate over all links.

The second step sorts all candidate links by the traffic volume they carry, in bits per second. Using traffic volume instead of utilization (in %) is important in networks with different link capacities: turning off a 100G link at 1% results in a lot more rerouting than a 1G link at 50% utilization. Hence, Hypnos indirectly prioritizes turning off low-capacity links.

Finally, Hypnos iterates over the link candidates. It first checks that turning off the current candidate does not disconnect the network once accounting for the already turned-off links. If not, it then checks if there is enough Reroute Budget left for that link. The algorithm stops when one of the conditions no longer holds.

In addition, there is one special case that the algorithm handles first: Two routers are sometimes connected via multiple links, known as a bundle. Bundles are special because if one link is turned off, the link traffic is guaranteed to be rerouted to the remaining links from the bundle. Thus, Hypnos optimizes the sleeping of bundles by aggregating the bundle traffic over as few links as necessary to carry that traffic and putting all other links to sleep. Then, it aggregates the remaining links from the bundle as one virtual link and runs the link sleeping decision algorithm described above.

3 EVALUATION

We now thoroughly evaluate how efficient Hypnos is at putting links to sleep in realistic settings; *i.e.*, how many links would it turn off, and how often would sleeping decisions lead to congestion?

3.1 Dataset

Before diving into the evaluation, we present a short overview of the topologies we use to evaluate Hypnos' algorithm (Table 1).

Table 1: Overview of the evaluation's topologies

Dataset	Nodes	Links	Avg. link load	Avg. node degree
ISP_1	143	230	2.1%	3.21
ISP_2	462	744	1.2%	3.22
Repetita [3] (avg)	38.9	54	32.5%	2.64

We obtained the topology, IGP weights, and link load information from the production network of two ISPs.[1] For our evaluation, we use the link load information of their internal links at a granularity of five-minute intervals.

To test against a more diverse set of topologies, we also use Repetita [3]: a collection of real topologies and synthetic traffic matrices that is meant to compare traffic engineering (TE) algorithms. Since it is used for TE algorithms, the average link load is much higher than for the ISP networks, making it almost impossible to turn any link off. The evaluation on Repetita aims to show whether Hypnos creates problems in high-load scenarios.

[1]The entire dataset will be published by the camera-ready.

Finally, we also use scaled versions of the traffic scenarios above. We scale the traffic matrix down for Repetita and scale up for the ISPs. For up-scaling, we set a cap on individual link loads to 70%.

3.2 Extracting the Traffic Matrix

Hypnos uses only network link loads as inputs (see § 2). However, to evaluate whether Hypnos creates congestion, we need the traffic matrix to compute accurately where traffic gets rerouted. To obtain this data, we use a technique called tomogravity [9] that approximates traffic matrices from the link loads.

As the tomogravity method scales quadratically with the number of links, it became a bottleneck for our evaluation of ISP_2, which is much larger than ISP_1 (Table 1). Thus, our evaluation uses 75 days of data for ISP_1 but only 14 days for ISP_2. Note that the bottleneck comes from the evaluation needs, not from Hypnos. Running on a single core, Hypnos' algorithm derives the list of links to turn off in less than 300ms for ISP_1 and less than 3s for ISP_2.

3.3 Metrics

This paper focuses on the Hypnos' algorithm for selecting links to put to sleep. Thus, the main performance metric we consider is the number of links that Hypnos turns off. This metric is upper bounded by the size of a network's spanning tree, since we want to maintain the network connected. Therefore, the maximum number of links that Hypnos can turn off is 88 for ISP_1 and 283 for ISP_2.

Conversely, Hypnos can create congestion in a network in two ways. The first case is when the link sleeping heuristic makes a bad decision, and too much traffic gets rerouted on a link that becomes congested. This can happen because the heuristic takes a local view on link loads (§ 2.1) while turning a link off can have global effects on routing. The second case is when turning a link off causes congestion on the *future* traffic demand; *i.e.*, when the demand changes significantly. This is a generic problem for any scheme that does not know nor predict future demands.

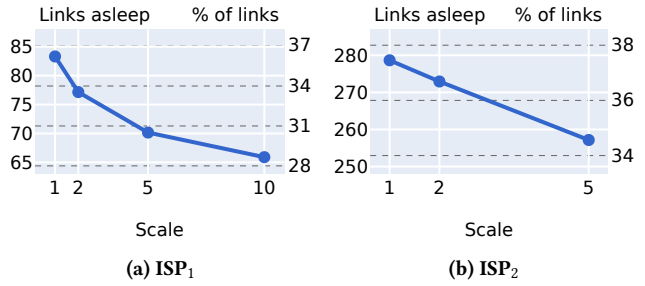
We measure Hypnos' negative impact as the number of 5-minute intervals where it leads to mild congestion (over 80%) or severe (over 100%) on at least one of the network links.

3.4 Performance on ISP Networks

How many links does Hypnos turn off? Fig. 2 shows the mean number of links that can be turned off over the entire dataset. When Hypnos creates congestion in one 5-minute interval, we count the number of links put to sleep as zero for that interval since the entire network is being woken up.

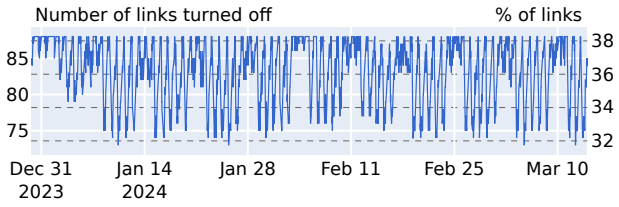
For ISP_1, Hypnos turns off 83 links on average, which is 36% of the network's links (Fig. 2a). As expected, when scaling the traffic up, the savings go down; but even at ten times the traffic, Hypnos still turns off around 68 links (28%). This is because many links are idling; scaling the traffic by a multiplicative factor does not change much for those links. The results are similar for ISP_2 (Fig. 2b).

Does Hypnos adapt to changing load conditions? Fig. 3 shows that Hypnos' algorithm adapts nicely to the daily and weekly load patterns seen in the network and adjusts the number of links that can be turned off accordingly.

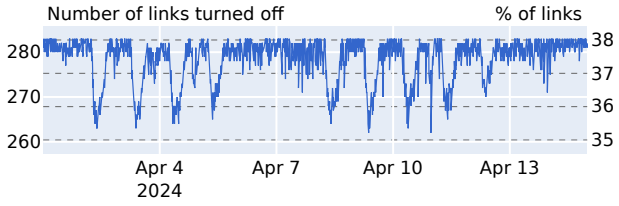


(a) ISP_1 **(b) ISP_2**

Figure 2: Hypnos turns off more than 30% of the links, even when we artificially scale up the traffic load.



(a) ISP_1



(b) ISP_2

Figure 3: Hypnos adapts to daily and weekly load patterns.

How stable is the list of sleeping links? Even if Hypnos limits the volume of rerouted traffic, one does not want links flapping on and off all the time. Fig. 4 shows the percentage of links that turn on or off in every timestep for ISP_2. We find that most of the 278 sleeping links stay asleep, and only around 5% of those have to change their state. We observe similar results for ISP_1 (not shown), where around 10% of links change their state between two intervals. This shows that most links remain stable; the routing protocol needs to handle only a few link state changes in every five-minute interval.

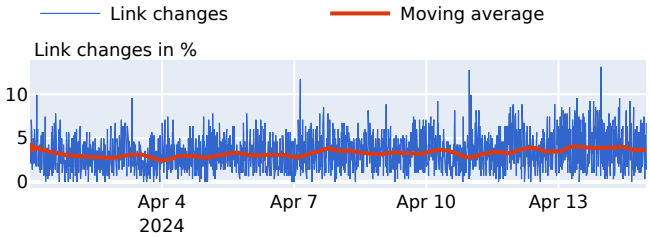
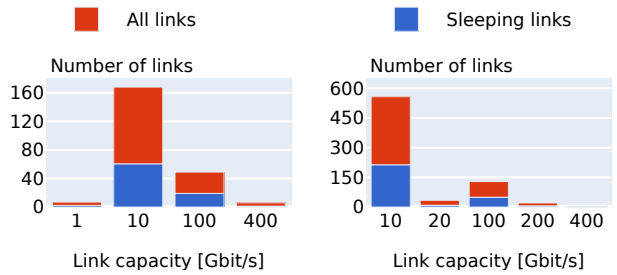


Figure 4: Only a fraction of links change their state between intervals, reducing the amount of rerouting that is necessary.

Which links are put to sleep? Since we have links with different capacities, one might expect Hypnos' algorithm to turn off only the low-capacity ones. We found that this is not the case; as shown

in Fig. 5, Hypnos also turns off high-capacity links when possible. For ISP_1, it turns off two out of the six 400 Gbps links on average without creating congestion. The results are similar for ISP_2.[2]

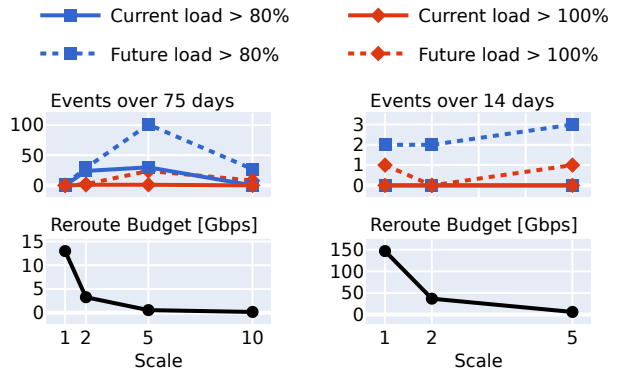


(a) ISP_1 **(b) ISP_2**

Figure 5: Hypnos does not just turn off low-capacity links.

How many mistakes does Hypnos make? Hypnos never creates congestion directly when putting links to sleep with unscaled traffic load (Fig. 6). A few times, traffic demand changes sufficiently during the next five-minute interval to result in congestion. This is not an issue if the traffic changes gradually since the algorithm can wake up the network if the load starts building up.

Interestingly, we see that increasing the network load makes it harder for Hypnos to turn off links without making mistakes. However, once we scale up the load even more, the number of mistakes decreases again, as Hypnos can put fewer links to sleep.



(a) ISP_1 **(b) ISP_2**

Figure 6: Hypnos has to be more cautious for higher loads.

This behavior is partly due to the dynamic nature of the Reroute Budget (§ 3.5). When the load in the network increases we decrease the Reroute Budget as it is easier to make mistakes at higher loads. For ISP_1, it looks like the decrease does not happen fast enough, so we have fewer mistakes at scale 10 than at scale 5. This result suggests that it might be possible to tune the Reroute Budget to avoid creating congestion regardless of the load.

[2]One may note some unusual link speeds in Fig. 5b. This is because we do not have data on each physical link for ISP_2; some of the link data are bundled, resulting in capacities of, *e.g.*, 20 Gbps, which are just two 10 Gbps interfaces bundled together.

3.5 Reroute Budget

The Reroute Budget is a key parameter of Hypnos. If we set the budget too low, there are no savings because Hypnos has no leeway to turn any links off. If we set it too high, Hypnos turns off too many links and is more likely to cause congestion in the network.

In this paper, we set the Reroute Budget as follows.

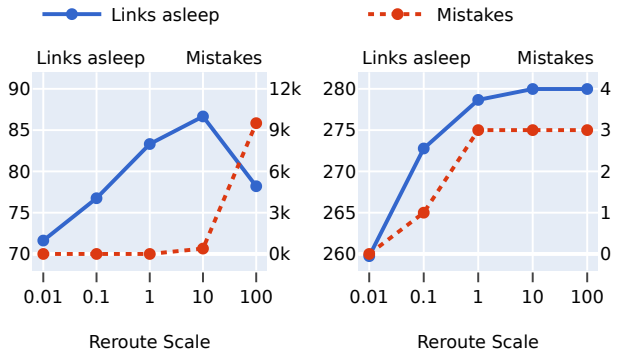
$$reroute\_budget = \frac{sum\_link\_capacity}{500} * \frac{0.0001}{network\_util^2} \quad (1)$$

The first term of the formula estimates the order of magnitude of traffic the network experiences. A Reroute Budget of 10 Gbit might be acceptable for a network with terabits of traffic but is probably not ideal for a network only with a few gigabits of traffic.

The second term captures the network load; we want the Reroute Budget to be small if the load is high and vice versa. If the network's average network utilization is 1%, the second factor becomes 1.

The Reroute Budget defined in Eq. (1) is not meant to be optimal; we found it to work well for our case studies, but it might not work in other scenarios.

Fig. 7 shows how Hypnos behaves if we scale up or down the Reroute Budget. For ISP_1, we can clearly see that increasing the budget causes Hypnos to make many more mistakes while reducing it limits the savings. Interestingly, for ISP_2, we only see similar behavior when reducing the Reroute Budget; when increasing the Reroute Budget, nothing really changes. We believe this is due to the lower load of ISP_2, which means the algorithm is not limited by the Reroute Budget but by the connectivity constraint.



(a) ISP_1 **(b) ISP_2**

Figure 7: ISP_1 is more sensitive to budget changes.

It is not clear how to optimally set the Reroute Budget for a given network and traffic load. Currently, the simplest approach is to simulate the sleep decision algorithm's behavior over common load scenarios and tune the Reroute Budget accordingly.

3.6 Two connectedness

Until now, we only considered that the network should remain connected. Since the traffic load is very low (Table 1), Hypnos almost reduces the active topology to a spanning tree. This might be considered an overly aggressive sleeping strategy, as any failure could momentarily disconnect the network.

Therefore, we also evaluate a version of Hypnos that aims to keep the network 2-connected at all times. However, since ISP_1 and ISP_2 networks are not 2-connected to begin with, we constraint Hypnos to keep the largest component of the network 2-connected. The results are summarized in Table 2.

Table 2: Hypnos can still turn some links off even with a 2-connectedness constraint.

Constraint	1-connected (default)	2-connected
ISP_1	83 (36%)	41 (18%)
ISP_2	278 (37%)	51 (7%)

For ISP_1, enforcing 2-connectedness reduces the number of sleeping links from 85 down to 41 and, for ISP_2, from 278 to 51 (Table 2). Thus, even with a 2-connectedness constraint, Hypnos can still turn off a few percent of the network links.

3.7 Power savings

Ultimately, Hypnos aims to save energy. While estimating the effect of link sleeping on router power is not trivial [8], we can approximate the potential gains on transceiver power rather easily. Table 3 lists datasheet power numbers for different speeds of optical LR transceivers.[3]

Table 3: Approximate power numbers for LR transceivers

Capacity	1G	10G	100G	400G
Power	1W	1W	4W	10.5W

Multiplying the power numbers from Table 3 with the number and types of links that Hypnos turns off (Fig. 5), we find that ISP_1 and ISP_2 could save on average 320W and 960W on transceiver power, respectively. This translates into energy savings of 2.8MWh and 8.4MWh per year, respectively.

3.8 Performance on Repetita

To show that Hypnos is not overfitted to our ISP case studies, we evaluate its performance on Repetita [3], which provides around 250 different test scenarios. It consists of real network topologies with synthetic traffic matrices intended to benchmark traffic engineering (TE) algorithms. For our evaluation, we let Hypnos' algorithm run on all topologies and traffic matrices to determine how many links can be turned off and, more importantly, how often sleeping is causing congestion.

Table 4: Hypnos saves little but does no harm under high load.

Scale	Avg. link load	Links turned off	Link loads over 80%	Link loads over 100%
10%	3.3%	7.25	0	0
50%	16.3%	1.37	0	0
100%	32.5%	0.53	0	0

We find that for all the topologies, Hypnos does not make any mistakes (Table 4). Hypnos does not cause any additional congestion in the network, even though the dataset provided is specifically highly loaded to allow for comparing traffic engineering algorithms (Table 1: Repetita's average load is about 15 times higher than that of ISP_1). While there is not much saving possible at those loads,[4] Hypnos adapts well to high loads and does not cause problems.

[3]We use the power numbers of Flexoptics LR transceivers [1] because they are the most common type of transceiver used in ISP_1.

4 CONCLUSION AND FUTURE WORK

With this paper, we confirm that, in lowly loaded networks such as ISPs, it is possible to turn off a large number of links (§ 3.4 : >30%). We show that a simple heuristic (§ 2.2) to select the links to put to sleep appears good enough to avoid creating congestion on realistic network topologies and traffic demands. We materialize these observations with a link sleeping system prototype called Hypnos. The potential energy savings from link sleeping appear modest (§ 3.7), but we argue that any savings should be considered if they come with minimal downsides.

Hypnos appears already very effective at putting networks to sleep. However, several design points must be optimized further to make link sleeping really *too-easy-not-to-do-it*.

Optimizing the Reroute Budget The Reroute Budget is a key parameter of Hypnos that must be tuned to a given network capacity and traffic load (§ 3.5). How to optimally set it is an important question that deserves further attention.

Predicting traffic demands Most of the congestion events triggered by Hypnos result from assuming that traffic demands remain constant over the next five-minute interval. It would be natural to enhance the system with some mechanism to predict future demands and/or learn from past mistakes.

Optimizing link state stability Currently, Hypnos starts every link decision-making process anew; *i.e.*, it does not consider which links are already asleep. Because the algorithm is deterministic and the link loads are fairly stable in our case studies, this leads to a few links changing state at each iteration (Fig. 4). It should be straightforward to extend Hypnos to minimize the number of state changes, which would help make the system more practical.

Quantifying the latency cost In this paper, we only consider the "cost" of link sleeping in terms of congestion events. However, there can also be a latency cost for traffic that gets rerouted along a longer path. Estimating the impact of sleeping on latency is challenging and its practical relevance for ISP traffic is unclear. Nonetheless, latency should be considered.

Optimizing the transient While this is beyond the scope of this paper, an important aspect of a link sleeping system is managing the transient network state; *i.e.*, what happens while links are being turned on or off. To turn off links we just need to wait until the IGP has drained the link of traffic. When turning a link back on, we try resolving an issue as quickly as possible, which is time sensitive. In [2], we showed that transceivers can bottleneck the wake-up time of the network. To improve the transient, one needs to look at improving the turn-on time of transceivers.

Hence, we showed that link sleeping is feasible in real-world scenarios and worth future work to optimize its performance further.

[4]Another reason for the smaller savings is that many of the networks in Repetita are not well connected, so there is not as much potential to turn links off. Even without any traffic, the maximum number of links one could turn off is 16.2 out of 54.2.

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