Energy Efficiency Optimization in Wired Networks: Analysing the Impact of Smart Sleeping Techniques on OSPF Protocol Performance

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***Abstract*— This study explores the reduction of energy usage in wired backbone networks through the simulation of a simplified GÉANT Network. Using NetSim, the OSPF protocol is implemented under low and high traffic conditions, with an added layer of smart sleeping for routers. The performance metrics, along with energy consumption estimated through a proposed formula, are analysed. The results obtained from the four scenarios, which involved standard and smart sleeping under different traffic loads, underline the impact of strategic router inactivity on both network efficiency and energy consumption. These findings indicate that smart sleeping is a feasible method to regulate energy in the network.**

Key words: *Energy Consumption, Smart Sleep Scheduling, Network Performance Analysis, OSPF Routing.*

I. Introduction

The increasing digitalization of society has seen the backbone networks, which form the internet's infrastructure, come under analysis for their energy consumption, a growing concern given the climate challenges facing our world. This research explores innovative methods for improving the energy efficiency of wired backbone networks, with a particular focus on implementing smart sleeping methods into the OSPF routing framework. This study attempts to estimate the possible energy savings without affecting network performance by modelling a network model based on the simplified design of the GÉANT Network, which connects European research and education institutes. The analysis includes scenarios with low and high traffic loads, both with and without smart sleeping implementations. The research study assesses the efficiency of energy-saving measures for future sustainable network designs through a detailed analysis using a designed energy consumption model.

II. Estimating Energy Consumption in wired networks

According to (Gandotra, 2020), energy reduction methods are crucial since the Internet is anticipated to consume a significant portion of the energy footprint of the ICT sector as a whole. In this regard, the Internet's adoption rate, which stands at over 65.6% worldwide with 5.1 billion users, makes the energy problem worse. Implementing energy-efficient solutions in networks is vital to stop the upward trend in energy use and offset the environmental impact. This is because data traffic is growing at a faster rate than computer hardware efficiency advancements.

The study by (Gandotra, 2020) examines methodologies to reduce energy usage in wired networks, classifying research into sleeping of network elements, link rate adaptation, proxying, store and forward, and traffic aggregation. The thesis highlights the shift towards energy-aware network design and protocol design, suggesting these as key areas for innovation over system-oriented management.

A. Power-Proportional Networking and Traffic Optimization

To deal with the Power Efficiency Problem (PEP), it presents industry-standard power-proportional models. The study emphasises how carefully allocating network traffic can significantly lower power consumption by changing networking device activity based on load. When devices are permitted to go into sleep mode during times when demand is lower, this technique can result in significant power savings (Choudhury, 2021).

The research proposes strategies to efficiently distribute network traffic by examining several power models, potentially resulting in up to 20% reduction in power consumption. To achieve energy efficiency, the article underlines the significance of power-proportional networking devices and intelligent traffic engineering. By using these strategies, routers may adjust their operational states dynamically (refers to switching between active, idle, and sleep modes based on traffic load) to suit current traffic requirements, maximising the use of energy in network infrastructures (Choudhury, 2021).

B. Enhancing Network Energy Efficiency through Sleep-Scheduling

(Dabaghi, 2017) conducted an in-depth study of sleep-scheduling methods aimed at improving energy efficiency in wired networks. Their research provides a thorough analysis of different protocols designed to reducing energy usage by carefully switching network components between active and inactive states according to network demand. The authors classify these protocols into two categories: traffic-aware and traffic-unaware algorithms. They highlight the importance of combining sleep-scheduling with network traffic patterns in order to optimise energy efficiency. Additionally, they also explore the potential of sleep-scheduling in reducing the carbon footprint of network operations.

Furthermore, (Dabaghi, 2017) establishes a framework for evaluating sleep-scheduling protocols and their impact on network performance and energy consumption. This classification serves as a foundation for future improvements in energy-efficient network design, emphasising the need for achieving a balance between reducing energy usage and maintaining network performance.

III. Critical evaluation

The network topology in figure 1, which is based on a simplified version of the GEANT network, consists of 20 routers connected by wired point-to-point links at a constant 100 Mbps speed. This setup ensures network data transmission reliability. The Open Shortest Path First (OSPF) protocol is employed to facilitate efficient packet routing. OSPF, a dynamic routing protocol that employs a link-state routing algorithm, is pivotal in managing network paths in an IP environment. Its purpose is to efficiently offer support to large and diverse network topologies.

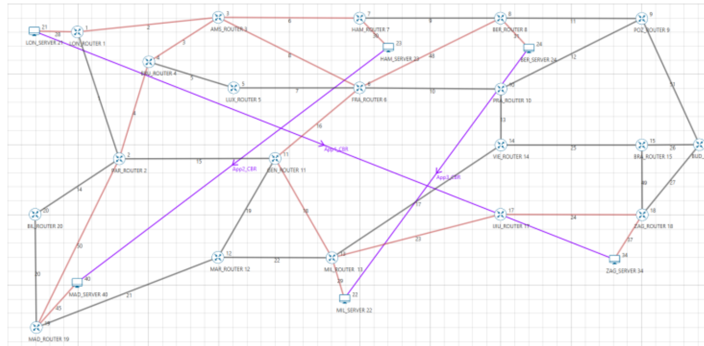

Figure 1: Simplified version of the GEANT Network Topology

Furthermore, the topology is engineered without a single point of failure, enhancing its resilience against network issues. Every router is strategically interconnected with multiple others, ensuring there is no isolated node. This interconnectivity not only supports no redundancy but also promotes uninterrupted network service, as alternative paths can be rapidly recalculated and deployed by OSPF in the event of a link or node outage.

Across all four scenarios within the network topology, in figure 1, three CBR applications are consistently deployed:

- App1_CBR: Routes from LON_SERVER 21 to ZAG_SERVER 34.
- App2_CBR: Transfers data from HAM_SERVER 23 to MAD_SERVER 40.
- App3_CBR: Connects BER_SERVER 24 to MIL_SERVER 22.

The topology shows the specific routes packets travel, highlighted in red. These applications serve as the simulation's main source of traffic generation, making it possible to evaluate network performance consistently across a range of traffic scenarios.

Traffic Configurations:

Low Traffic Scenario - Each application's packet size is standardised at 1500 bytes, which is the size of a regular internet packet. Best Effort is the Quality-of-Service configuration, which reflects the most typical internet traffic scenario. A consistent inter-arrival time of 20,000 microseconds is maintained to ensure a steady and consistent flow of traffic. Throughout the experiment, this uniform distribution guarantees a steady and predictable network load.

High Traffic Scenario - The packet size is increased to 3500 bytes in the high traffic scenario to simulate a larger load and evaluate the network's capacity to handle it. All other traffic configuration settings remain the same.

Low Traffic Smart Sleeping Scenario - The network configuration is the same as the basic low traffic setup in the low traffic scenario with smart sleeping enabled; however, a smart sleep schedule is implemented for specific routers.

High Traffic Smart Sleeping Scenario - In the smart sleeping high traffic case, the network configuration is in line with the basic parameters defined in the high traffic configuration. The difference is in how specific routers are used to provide a smart sleep schedule that optimises energy efficiency while handling increased data loads.

Smart Sleeping Schedule implemented on routers that handle the greatest traffic:

- FRA_ROUTER 6 has active periods at 0s to 14s, 50s to 79s, and 90s to 100s, and enters sleep mode at 15s to 49s and 80s to 89s.
- PAR_ROUTER 2 remains operational at 15s to 49s, 60s to 69s, and 80s to 100s, with downtime starting at 0s to 14s, 50s to 59s, and 70s to 79s.
- GEN_ROUTER 11 is up at 15s to 49s and 80s to 89s, with rest periods at 0s to 14s, 50s to 79s, and 90s to 100s.
- VIE_ROUTER 14 maintains uptime at 15s to 49s and 60s to 100s, with off times at 0s to 14s and 50s to 59s.

This sleep scheduling aims to conserve energy by deactivating routers during predicted periods of low and high usage while maintaining network integrity and performance.

A formula, in figure 2, is used in the critical evaluation of the energy efficiency of the network to calculate the overall energy consumption for a single router:

$$\begin{aligned} \mathit{Total\ Energy\ Consumed\ for\ one\ router} &= \mathrm{P_{idle}} * T_{idle} \\ &+ \mathrm{P_{sleep}} * T_{sleep} \\ &+ \left(\sum_{z} (N_{receive}(z) * P_{receive}(z)) \right) * T_{receive} \\ &+ \left(\sum_{z} (N_{transmit}(z) * P_{transmit}(z)) \right) * T_{trasmit} \end{aligned}$$

Figure 2: Router Energy Consumption Formula

By including specific energy costs into this formula, it is determined that the power required by a router in idle mode ($\mathrm{P_{idle}}$) is 23 millijoules, while in sleep mode ($\mathrm{P_{sleep}}$), it is 15 millijoules (CISCO, 2024). Control packets consume 5 millijoules for traffic creation, while data packets (CBR) consume 10 millijoules (NETSIM, 2024), power usage varies for transmitting ($P_{transmit}(z)$) and receiving ($P_{receive}(z)$) packets of size (z).

By applying this formula alongside the network's smart sleep scheduling algorithm, it becomes possible to evaluate energy efficiency. Routers are activated or put to sleep according to a predetermined schedule that aligns with the network's times of low and high usage. This ensures that energy consumption is optimised while maintaining network reliability and efficiency.

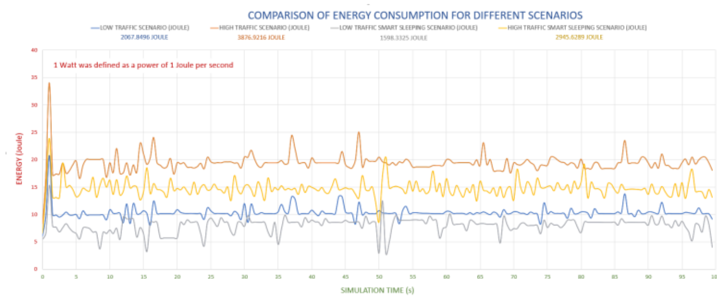

Figure 3: Comparative Energy Consumption in Different Network Traffic Scenarios

In the figure 3, the simulation results show in the graph demonstrate the impact of smart sleeping strategies on energy consumption in both low and high traffic scenarios within a network. The results show a clear correlation between traffic volume and energy use, as well as the efficiency of "smart sleeping" in reducing energy usage during periods of both high and low traffic.

In the low traffic case, the implementation of smart sleeping reduces energy consumption from 2,067.8496 Joules to 1,598.3325 Joules, a substantial reduction of approximately 22.7%. For the high traffic scenario, smart sleeping brings down the energy usage from 3,876.9216 Joules to 2,945.6289 Joules, achieving a 24% decrease.

These reductions highlight how smart sleeping can save energy without negatively affecting network performance. In low traffic conditions, where the demand on the network is naturally less, smart sleeping contributes to significant energy savings while maintaining optimal network performance. In high traffic situations, despite the larger load, smart sleeping still significantly reduces energy consumption without negatively impacting network performance.

Overall, smart sleeping shows potential as an effective method for reducing energy usage in wired networks. It maintains an optimal balance between operational effectiveness and energy conservation. Although the focus of this section has been on energy conservation, the study will also discuss the effects of smart sleep on network performance metrics, such as latency. This analysis will determine whether the improvements in energy efficiency are accompanied by any negative effects on data transmission times or reliability.

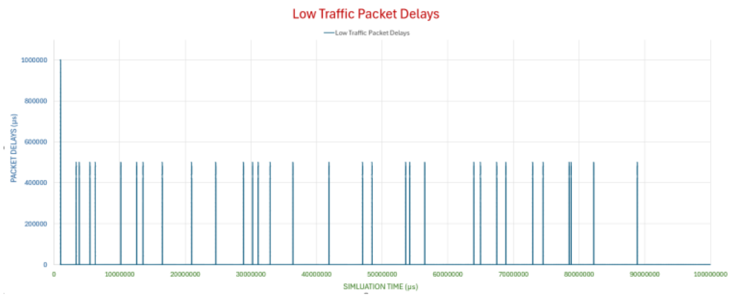

Figure 4: Latency of Low Traffic Scenario

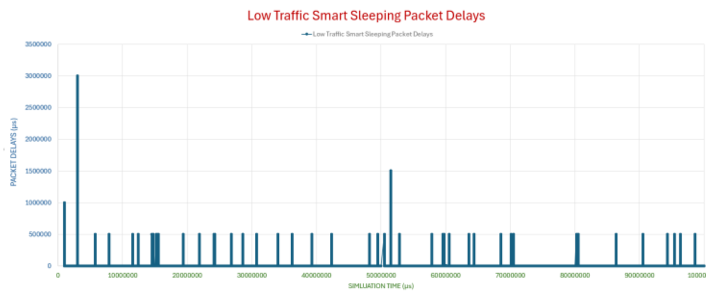

Figure 5: Latency of Low Traffic Smart Sleeping Scenario

The graphs in figure 4 and 5, compare standard low traffic conditions and smart sleeping conditions for packet latency. In the standard low traffic scenario, packet delays are consistent, showing a uniform pattern without significant spikes. However, smart sleeping causes an initial peak, which may indicate router wake-up latency as they switch from sleep to active state. After this peak, delays stabilise and resemble the standard scenario. Smart sleeping may cause some initial delay due to state transition, but once the routers stabilise, it doesn't significantly affect network latency. If the network can handle the initial wake-up latency, smart sleeping strategies can reduce energy consumption without affecting network performance.

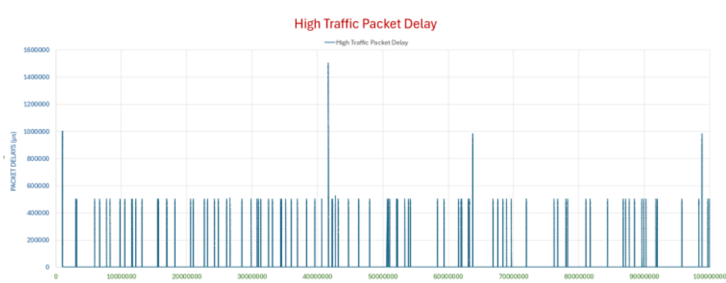

Figure 6: Latency of High Traffic Scenario

Figure 7: Latency of High Traffic Smart Sleeping Scenario

The latency graphs in figure 6 and 7 for high traffic and high traffic with smart sleeping show that smart sleeping may reduce delays in high-traffic networks. In the smart sleeping scenario, there are fewer significant delay spikes than in the high traffic scenario, suggesting that effectively handling router operational states does not affect network performance and can maintain service quality under heavy load. This allows smart sleeping on high traffic networks to save energy and maintain performance.

IV.Conclusions

The study shows that smart sleeping approaches can reduce energy usage in wired networks without affecting performance. Smart sleep schedules in routers based on traffic load show potential for energy efficiency. Future research may examine the long-term effects of these strategies on network hardware and develop dynamic power-saving measures to optimise sustainability in large-scale network operations.

References

Choudhury, M. a. L. G. a. L. J. a. Z. K. a. D. M. a. H. K., 2021. Power Efficiency in Communication Networks with Power-Proportional Devices. *2021 IEEE Symposium on Computers and Communications (ISCC),* pp. 1--6.

CISCO, 2024. *Cisco Meraki.* [Online]
Available at:
https://documentation.meraki.com/MX/MX_Overviews_and_Specifications/MX67_and_MX68_Datasheet
[Accessed 21 Feb 2024].

Dabaghi, F. a. M. Z. a. L. R., 2017. A survey on green routing protocols using sleep-scheduling in wired networks. *Journal of Network and Computer Applications,* Volume 77, pp. 106--122.

Gandotra, R. a. P. L., 2020. A comprehensive survey of energy-efficiency approaches in wired networks. *University of Colorado, Boulder.*

NETSIM, 2024. *NetSim.* [Online]
Available at:
https://support.tetcos.com/support/solutions/articles/14000145697-estimating-energy-consumption-for-wireline-routers-in-netsim
[Accessed 16 Feb 2024].