# Energy-aware routing in IP networks

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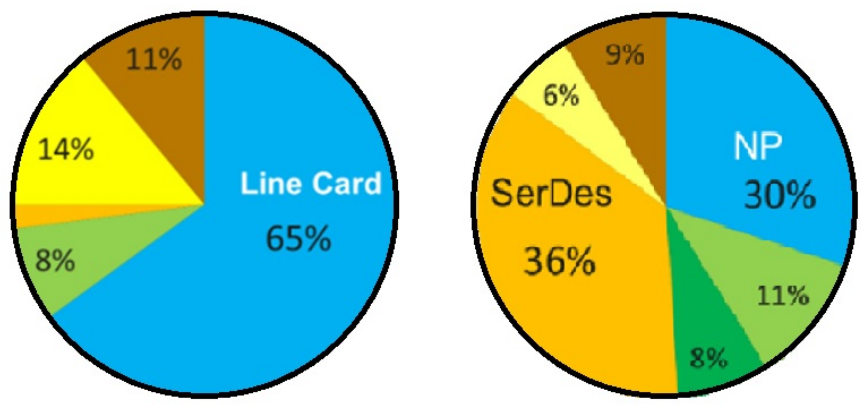
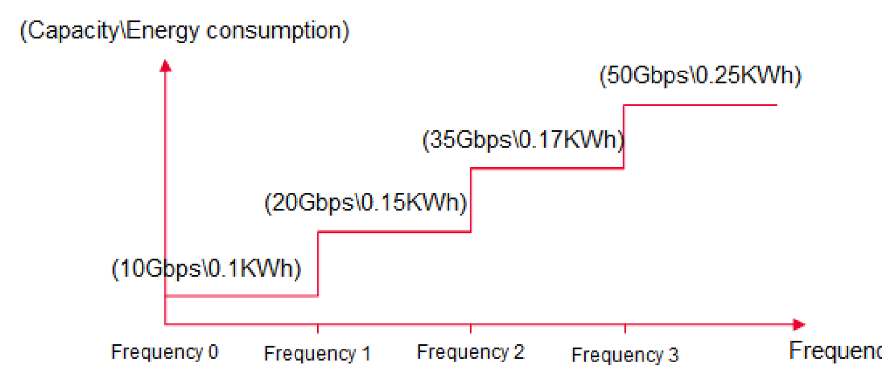
## Context & Motivations

- Information and Communication Technologies represent 10% of the global CO2 emissions
- 37% of these emissions are due to telecommunication infrastructures and their devices
- Networking devices are wasting a considerable amount of power
- Many resources (i.e., routers and links) are powered on without being fully utilized
- A node (router or switch) is composed of a set of boards. Each board has a set of chipsets an every chipset has a set of Serdes (= Port)
- We propose two methods to optimize the energy consumption

## Energy consumption of sub-devices

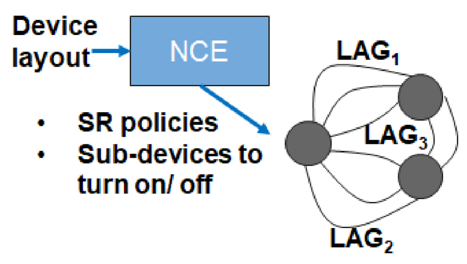



## (Method 1) Turning On/Off Boards, Chipsets & Ports

Select routing paths & sub-devices to turn-off such that:

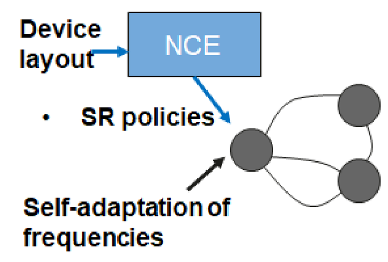
- Total saved energy is maximum
- The traffic demand is satisfied
- Keep at least 1 link in LAGs (avoid IGP disruptions)




## (Method 2) Multi-Frequency Chipsets & Serdes

Select routing paths such that:

- One frequency is selected for every Chipset and Serdes
- Total saved energy is maximum
- The traffic demand is satisfied




## (Method 1) Mathematical model

$$\max \quad \sum_{d\in D} e_d t_d - \sum_{k\in K}\sum_{p\in P^k} c_p x_p^k \qquad \leftarrow \text{Energy saving}$$

$s.t.$

$$t_d + t_{c_d} + t_{b_d} \le 1, \qquad \leftarrow \text{Cannot turn-off more than 1 nested sub-device}$$

$$\sum_{p\in P^k} x_p^k \ge 1 \qquad \forall k \in K, \qquad \leftarrow \text{Demand constraints}$$

$$\sum_{k\in K} b(k) \sum_{p\in P^k | e\in p} x_p^k \le c_e(1-(t_u + t_{c(u)} + t_{b(u)})), \qquad \forall e \in E \qquad \leftarrow \text{Capacity constraints}$$

$$\sum_{uv\in T}(t_u + t_{c(u)} + t_{b(u)}) \le |T| - 1, \qquad \forall \text{trunk } T \subseteq E, \qquad \leftarrow \text{Trunk constraint}$$

$$t_u + t_{c(u)} + t_{b(u)} = t_v + t_{c(v)} + t_{b(v)}, \qquad \forall uv \in E \qquad \leftarrow \text{Link constraints}$$

$$t_d \in \{0,1\}, \qquad \forall d \in D, \qquad \leftarrow \text{Integrality constraints}$$

$$x_p^k \in \{0,1\}, \qquad \forall k \in K, \forall p \in P^k. \qquad \leftarrow \text{Trivial constraints}$$

## (Method 2) Mathematical model

$$\max \quad \sum_{\text{chipset } d\in D}\sum_{l\in L_d} e_d^l t_d^l - \sum_{k\in K}\sum_{p\in P^k} c_p x_p^k \qquad \leftarrow \text{Energy saving}$$

$s.t.$

$$\sum_{p\in P^k} x_p^k \ge 1 \qquad \forall k \in K, \qquad \leftarrow \text{Demand constraints}$$

$$\sum_{l\in L_d} y_d^l = 1 \qquad \forall d \in D, \qquad \leftarrow \text{Frequency selection constraint}$$

$$\sum_{k\in K} b(k) \sum_{p\in P^k | T\cap p=\emptyset} x_p^k \le \sum_{l\in L_d}\sum_{(p_1,p_2)\in T} c_{p_1}^l t_{p_1}^l, \qquad \forall \text{trunk } T \subseteq E \qquad \leftarrow \text{Serdes Capacity constraint}$$

$$\sum_{l\in L_d} b(k) \sum_{\text{serdes } p\in d} c_p^l t_p^l \le \sum_{l\in L_d} c_d^l t_d^l, \qquad \forall \text{chipset } d \subseteq D \qquad \leftarrow \text{Chipset Capacity constraint}$$

$$t_d^l \in \{0,1\}, \qquad \forall d \in D, l \in L_d, \qquad \leftarrow \text{Integrality constraints}$$

$$x_p^k \in \{0,1\}, \qquad \forall k \in K, \forall p \in P^k. \qquad \leftarrow \text{Trivial constraints}$$

## (Method 1) Advantages

- Compatible with current routers
- More energy saving thanks to the shut-down of sub-devices (even boards)

## (Method 2) Advantages

- Fast adaptation to traffic in all scenarios
- Local energy saving mechanism (not controlled by NCE)

## (Method 1) Drawbacks

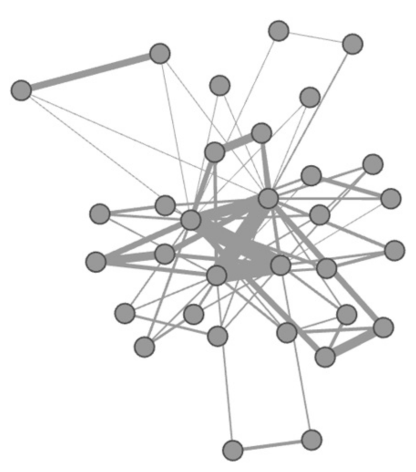
- Needs accurate traffic predictions
- Works mainly for networks with lots of LAGs
- Large reaction time in case of anomalies (wake-up time)

## (Method 2) Drawbacks

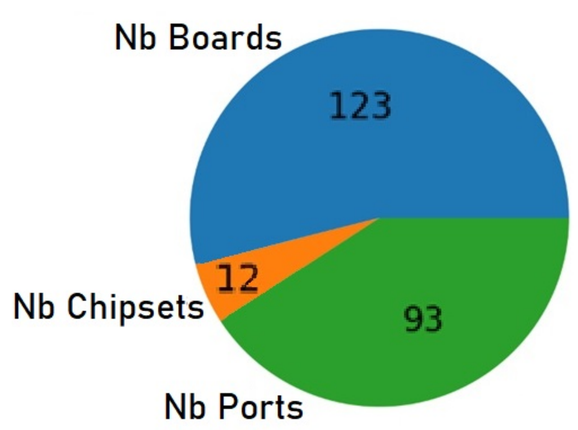
- Sub-devices cannot be shut-down totally
- Needs frequent accurate traffic measurements
- Compatible only with last generation Chipsets and Serdes (does not work with boards)

## Column generation based heuristic


## Telecom operator A (32 nodes, 992 demands, 40% of maximum traffic)

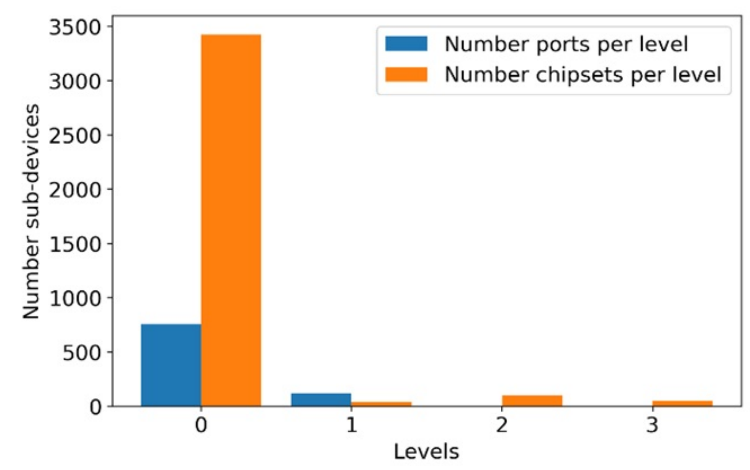


### Turning On/Off Boards, Chipsets & Ports




- Initial energy consumption: 323500.0 W
- Total saved energy: 55210.4 W
- Energy saved Gap: 17.07%
- Number of turned-off links: 274
- France: 48.36 Tons CO2/y
- Europe: 217.64 Tons CO2/y
- China: 464.30 Tons CO2/y

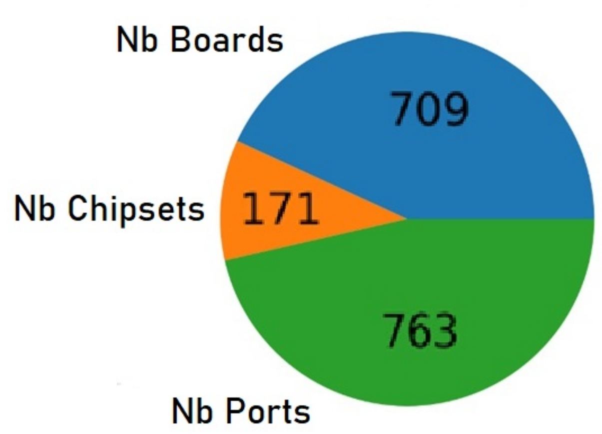
### Multi-Frequency Chipsets & Serdes




- Initial energy consumption: 323500.0 W
- Total saved energy: 37057.2 W
- Energy saved Gap: 11.46%
- Number of turned-off links: 0
- France: 32.46 Tons CO2/y
- Europe: 146.08 Tons CO2/y
- China: 311.64 Tons CO2/y

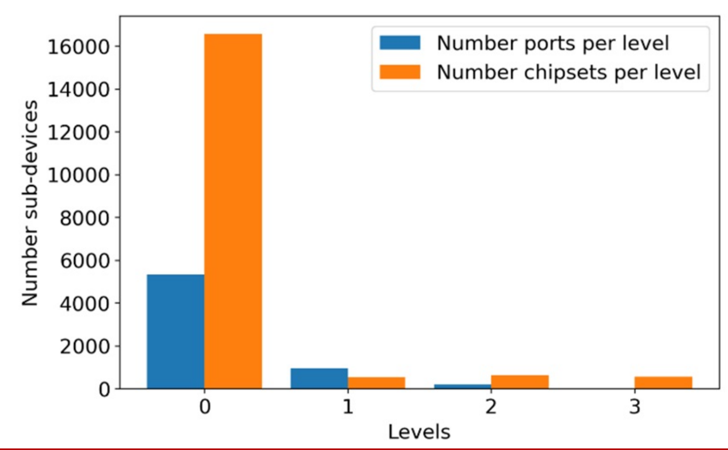
## Telecom operator B (143 nodes, 20306 demands, 40% of maximum traffic)

### Turning On/Off Boards, Chipsets & Ports




- Initial energy consumption: 2408870 W
- Total saved energy: 361128.0 W
- Energy saved Gap: 14.99%
- Number of turned-off links: 2292
- France: 316.35 Tons CO2/y
- Europe: 1423.57 Tons CO2/y
- China: 3036.94 Tons CO2/y

### Multi-Frequency Chipsets & Serdes




- Initial energy consumption: 2408870 W
- Total saved energy: 300851.0 W
- Energy saved Gap: 12.49%
- Number of turned-off links: 0
- France: 263.55 Tons CO2/y
- Europe: 1185.95 Tons CO2/y
- China: 2530.04 Tons CO2/y