Energy efficient networking

Modelação e Desempenho de Redes e Serviços

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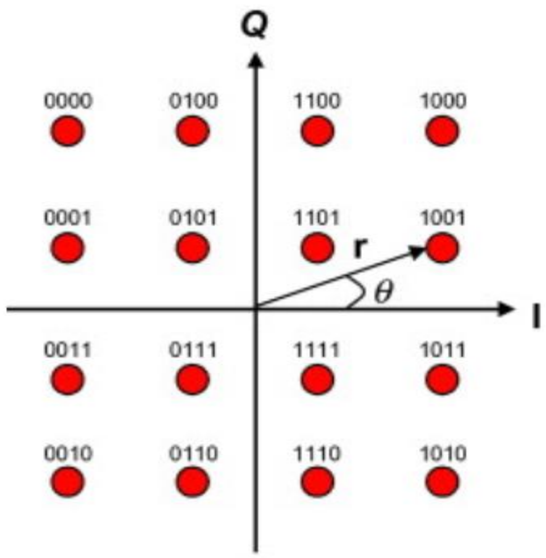
Energy consumption of network links

- Consider a network modelled by a graph G=(N,A)
  - Set N is the set of network nodes.
  - Set A is the set of network links: the arc $(i,j) \in A$ represents the link between nodes $i \in N$ and $j \in N$ from i to j whose capacity is given by c_{ij} in bps (with $c_{ij} = c_{ji}$).
- In wide area networks, network links are optical transmission systems. Energy consumption of network links is related with two factors:
  - *Transmission factor*: the energy required in the NICs (Network Interface Cards) for the conversion of the digital information from the electronic domain to the optical domain (in the transmitter side) and from the optical domain to the electronic domain (in the receiver side);
  - *Progapagion factor*: the energy required in the transmission lasers to send the optical signal with enough strength (i.e., enough optical power) so that the signal-to-noise ratio at the receiver is enough to recover the transmitted information.

Modulation formats in optical transmission systems

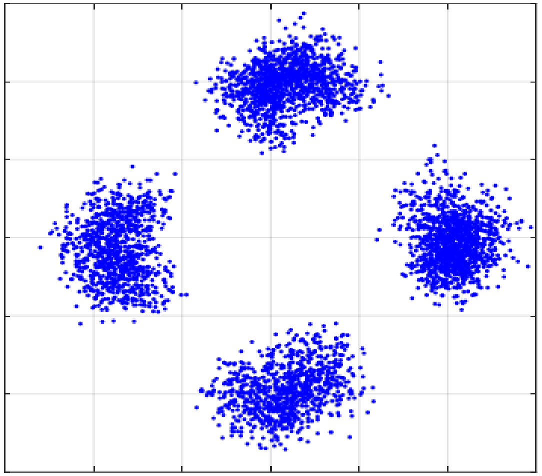
16-QAM at the transmitter side

- Each optical symbol represents a different combination of 4 bits
- There is a total of 16 possible combinations
- The resulting symbol rate (also known as baud rate) is ¼ of the bit rate



QPSK at the receiver side

- Each optical symbol represents a different combination of 2 bits
- Due to the impairments of the light propagation in fibers, the symbols are received distorted
- A higher transmitted optical power enlarges the amplitude distances between symbols



Operation modes of optical links

Consider that the network links can be put in a sleeping mode if they do not support traffic in none of its two directions.

<u>When a link is in full operational mode</u>, i.e., the link is supporting one or more traffic flows, the energy consumption of the link is:

- *Transmission factor*: the energy required on each of the two end NICs is a value which depends on the link capacity.
  - The modulation format order (defining the number of bits coded by each transmission symbol) and the baud rate (defining the number of transmitted symbols per second) determines the capacity of the link.
  - The higher both parameters are, the more energy they require for the electrical-optical and optical-electrical conversion.
- *Propagation factor*: the energy required in the transmission laser of each NIC is a value which depends on the modulation format order, baud rate and length of the link.
  - The longer the link is, the higher the optical power of the laser needs to be so that the signal-to-noise ratio at the receiver is enough to recover the transmitted information.

Operation modes of optical links

Consider that the network links can be put in a sleeping mode if they do not support traffic in none of its two directions.

When a link is in sleeping mode, i.e., the link is not supporting any traffic flow, the energy consumption of the link is:

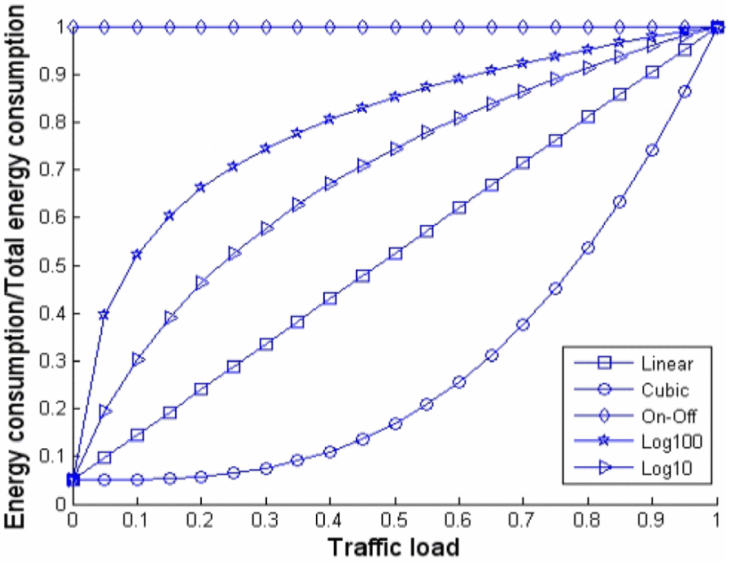
- *Transmission factor*: the energy required in each of the end NICs is a value to maintain the interface cards in a state that allows the card to be quickly activated.
- *Propagation factor*: the energy required in the transmission laser of each NIC is a value to maintain the laser in a state that allows the laser to be quickly activated.

Energy consumption of network nodes

As illustrated in the picture below[1], depending on the equipment (switching architecture, energy reduction techniques, cooling system, etc), the energy consumption of the nodes might depend on its total traffic load (sum of all flow demands crossing it).

- The On-Off model is when the router is always consuming its maximum energy (independently of its load).
- Other energy consumption models depend on each particular router equipment.

[1] J. C. Cardona Restrepo, C. G. Gruber and C. Mas Machuca, "Energy Profile Aware Routing," *IEEE Int. Conf. on Communications Workshops*, pp. 1-5, 2009



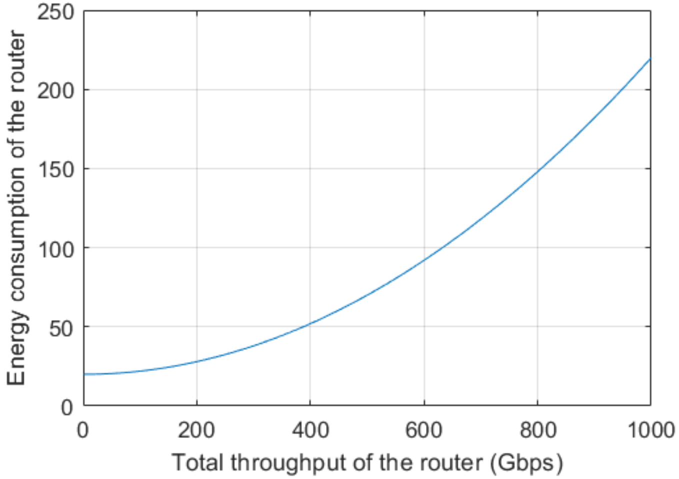
Energy consumption of network nodes - example

Consider a router equipment with a throughput capacity of 1 Tbps (= 1000 Gbps). The energy consumption of the router equipment is $E = 20 + 200 \times t^2$, where t is the total throughput supported by the router divided by its capacity.

1. Determine the energy consumption of the router when it is supporting a total throughput of 400 Gbps.

$$E = 20 + 200 \times t^2 = 20 + 200 \times \left(\frac{400}{1000}\right)^2 = 52$$

2. Draw a plot of the energy consumption of the router as a function of its supported throughput.



Single layer energy efficient routing

Consider that the energy consumption of each link is known when it is in full operational mode and when it is in sleeping mode.

The aim is to route the flows through routing paths so that:

- the set of non-used links (and, therefore, that can be put in sleeping mode) minimizes the energy consumption of all links;
- the set of full operational links has enough capacity to support the demand of all flows.

If the energy consumption of nodes is not the On-Off model, the energy consumption must also consider the total traffic load of each node and the aim is to minimize the network energy consumption (links + nodes).

Why links in sleeping mode are not removed from the network?

- Traffic flows of supported services can change over time.
- New services (with new traffic flows) can be introduced
- Failures in full operational links can require the activation of links in sleeping mode to maintain the services

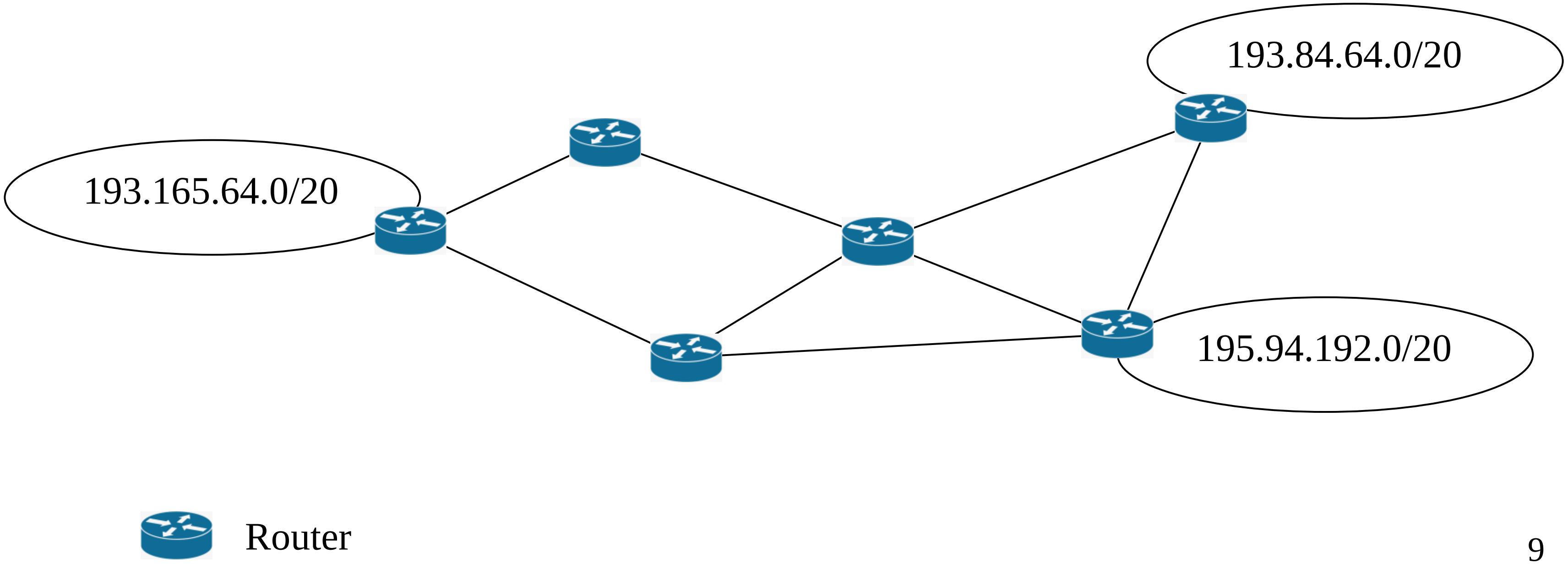
Single layer energy efficient routing

Consider the network below supporting one unicast service with the following traffic flows:

193.165.60.0/20 ↔ 193.84.64.0/20: 100 Gbps

193.165.60.0/20 ↔ 195.94.192.0/20: 100 Gbps

193.84.64.0/20 ↔ 195.94.192.0/20: 200 Gbps



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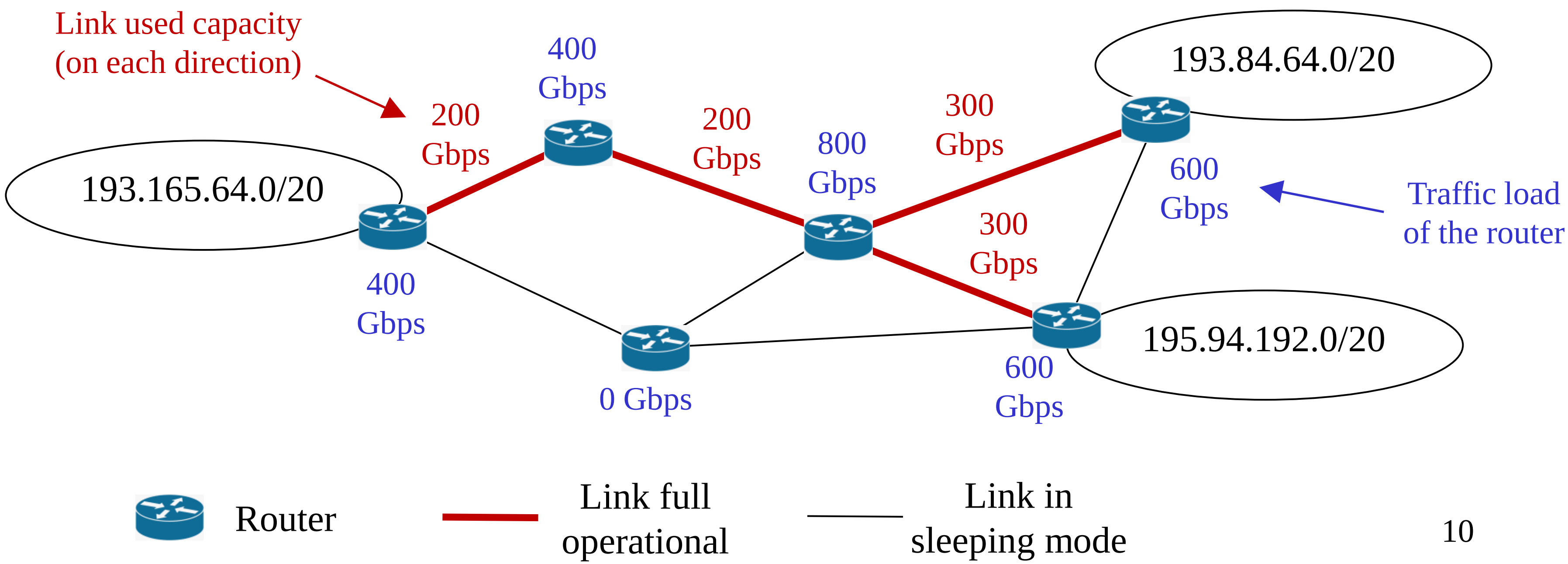
A possible solution:



Two-layer networks

Recently, the wide area networks have evolved to have two layers:

- A top layer network composed by routers operating in the electronic domain.
- A bottom layer network composed by optical nodes (named OXCs – Optical Cross Connects) operating in the optical domain, and fibre links between them.

Switching optical signals (known as lightpaths) from input ports to output ports in OXCs require much less energy than routing traffic flows from input NICs to output NICs in routers.

The lightpaths' capacity depends on the length of the routing paths[2]:

Modulation Format	BPSK	QPSK	8-QAM	16-QAM
Transmission reach (km)	6300	3500	1200	600
Bitrate capacity (Gbps)	50	100	150	200

[2] F. Barbosa, A. de Sousa, A. Agra, K. Walkowiak, R. Goścień, RMSA algorithms resilient to multiple node failures in dynamic EONs, *Optical Switching and Networking*, Volume 42, 2021

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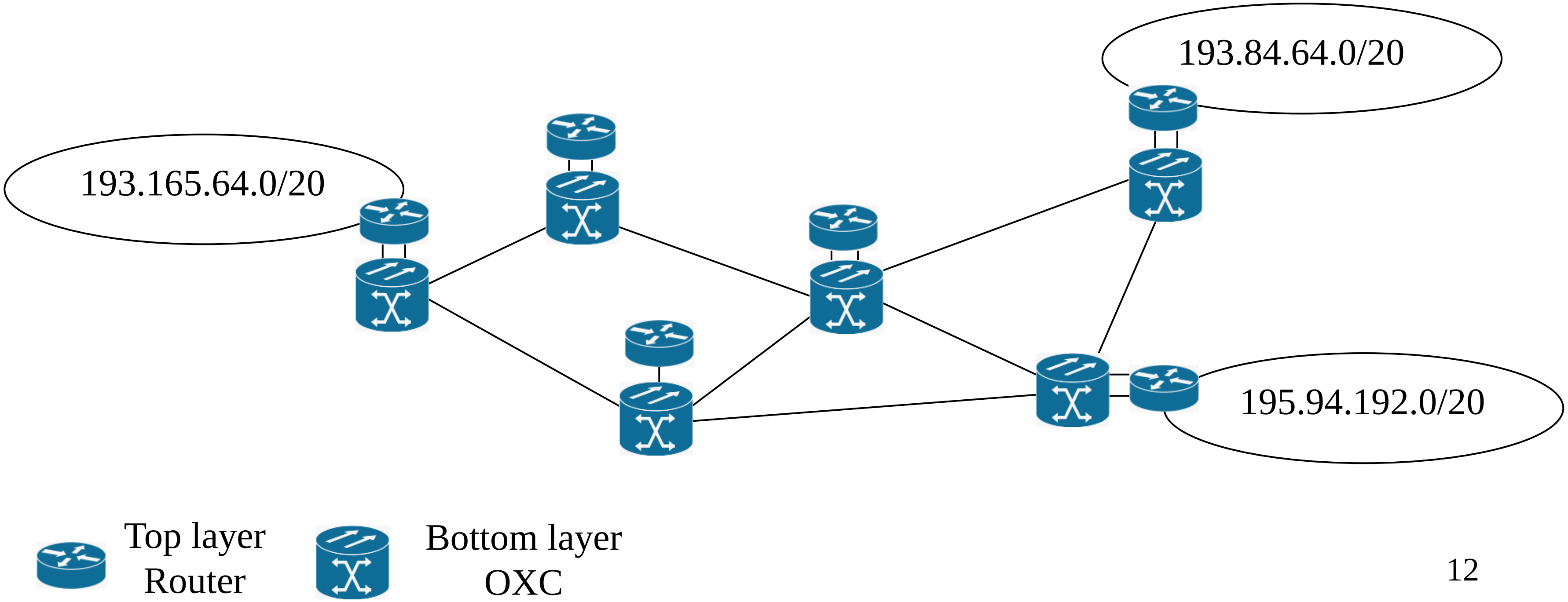

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