Green Networks

IK2215
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Outline

- Energy savings in communication infrastructures
  - Why?
  - Saving opportunities?
- ”Greening of the Internet”
  - Positioning as of 2003—a starting point
- Node level power saving
- Link level power saving
- Network level power saving
- Concluding remarks

Green Networks—Energy Efficiency

Energy efficiency in wireless networks

Energy efficiency in optical networks

Energy efficiency in data center networks

Energy efficiency in ”wired networks”: Greening of the Internet

Several of the techniques we will look at can be exported across these areas

Why Save Energy?

Main reasons

- Support units with limited power supply
  - Sensors, mobile phones, etc—saving battery
- Reducing greenhouse gas emissions (EC climate action)
  - Requires clean technologies in all industrial sectors
- Network deployment in challenged environments
  - Electricity often a limited resource
- Power outages in conjunction with natural disasters
  - Communication may rely on battery to work
- Economic concerns
  - Operators reduce costs by consuming less power

Greening of the Internet

Device	Total (AEC) TWh
Hubs	1.6
LAN Switches	3.2
WAN Switches	0.15
Routers	1.1
Total	6.05

Worth bothering?
6 TWh ~ 1 billion $!
1 nuclear reactor unit!
Energy expenditure from network devices will increase!

From Gupta & Singh, 2003

- Annual Electricity Consumption in USA as of year 2000
  - Cost of cooling not included
  - UPS (Uninterruptable Power Supply) equipment not included
  - 0.07% of the total energy expenditure....

ICT and Sustainability

GeSI: Global e-Sustainability Initiative

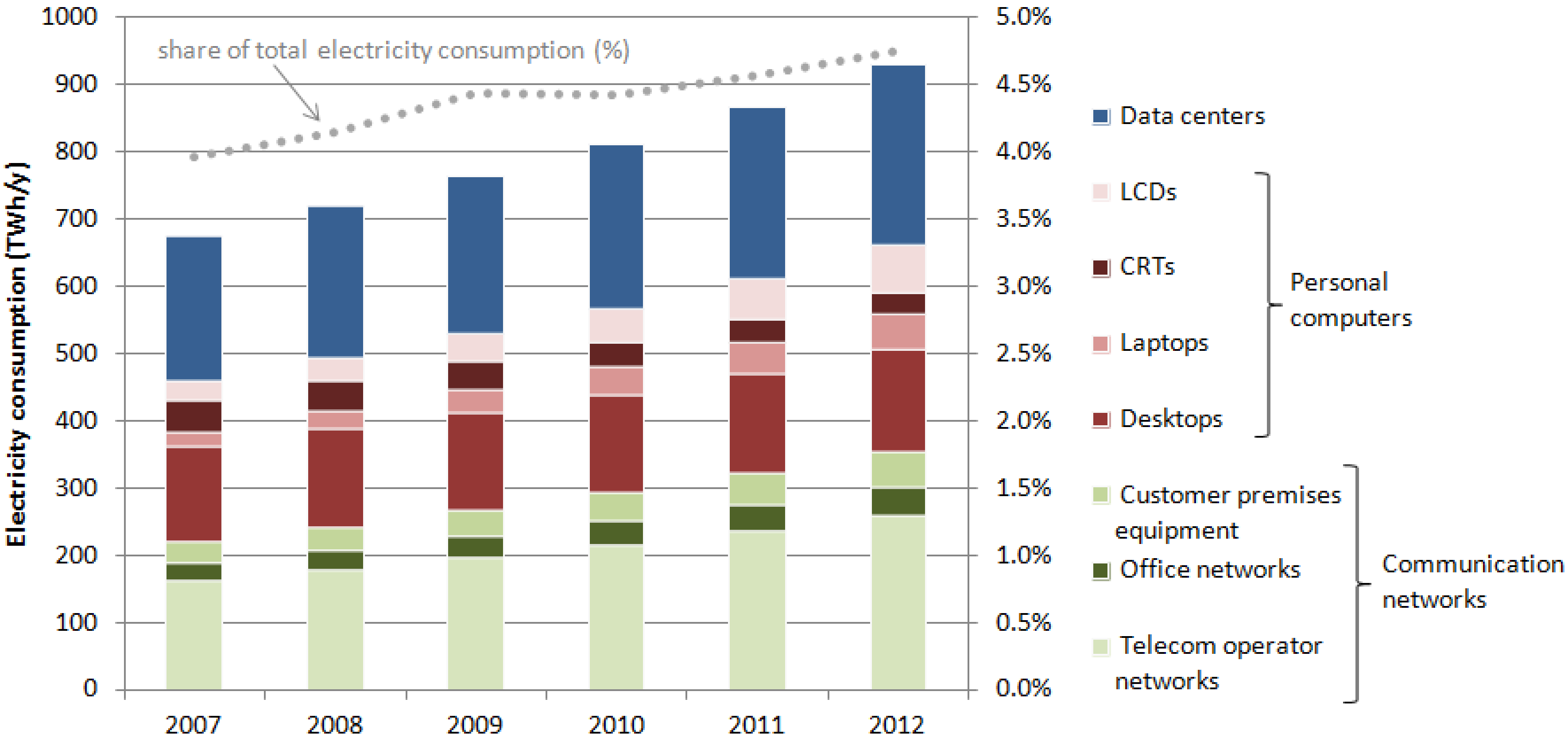
- Source for information on ICT and sustainability

GeSI's SMARTer 2020 report (published in 2012)

- Smart solutions to reduce green house gas emissions (GHG)
- 2% of global GHG emission from ICT today
- 3.8% increase per year is expected

CO_2 emission comparable to aviation industry

Worldwide ICT Electricity Consumption



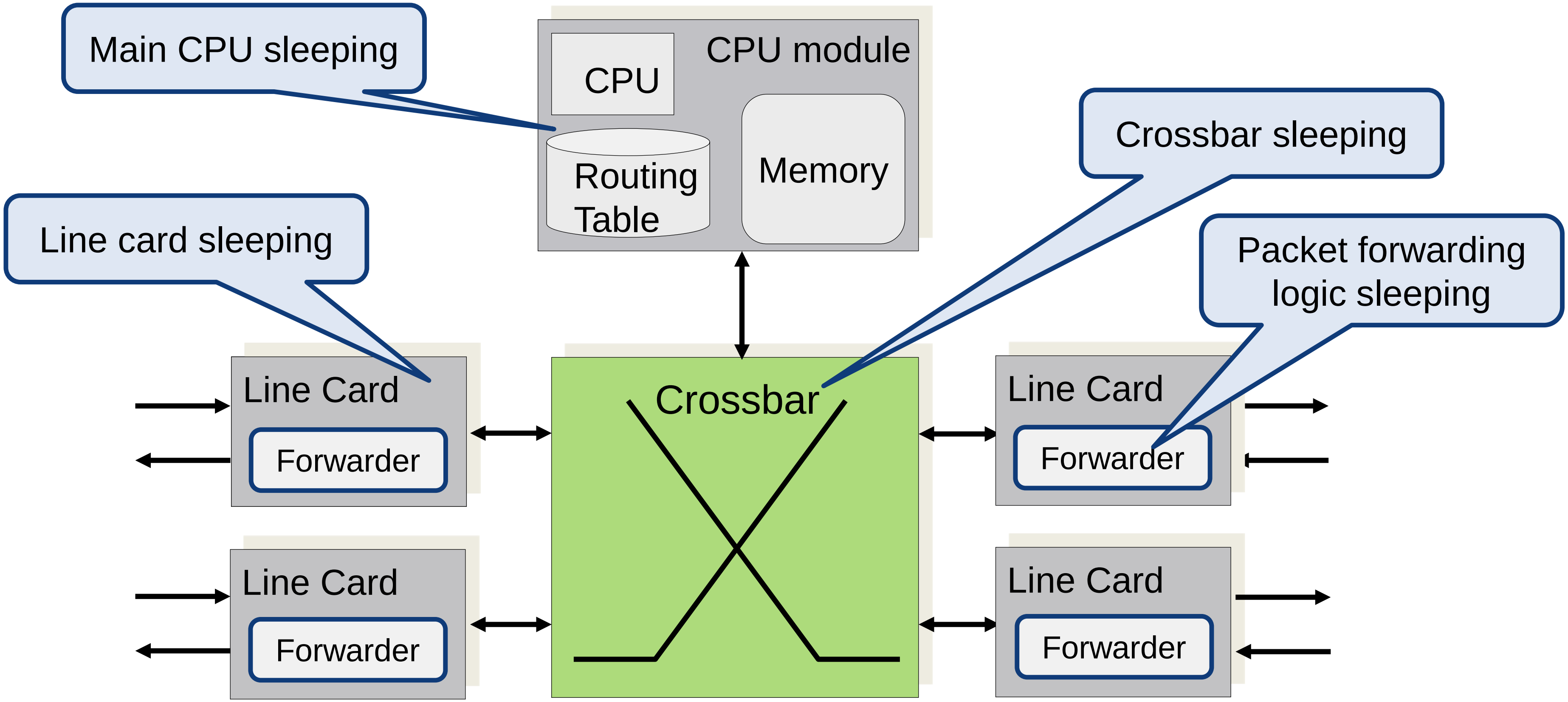
Overview of ICT energy consumption, FP7-288021, 2013

Greening of the Internet, cont'd

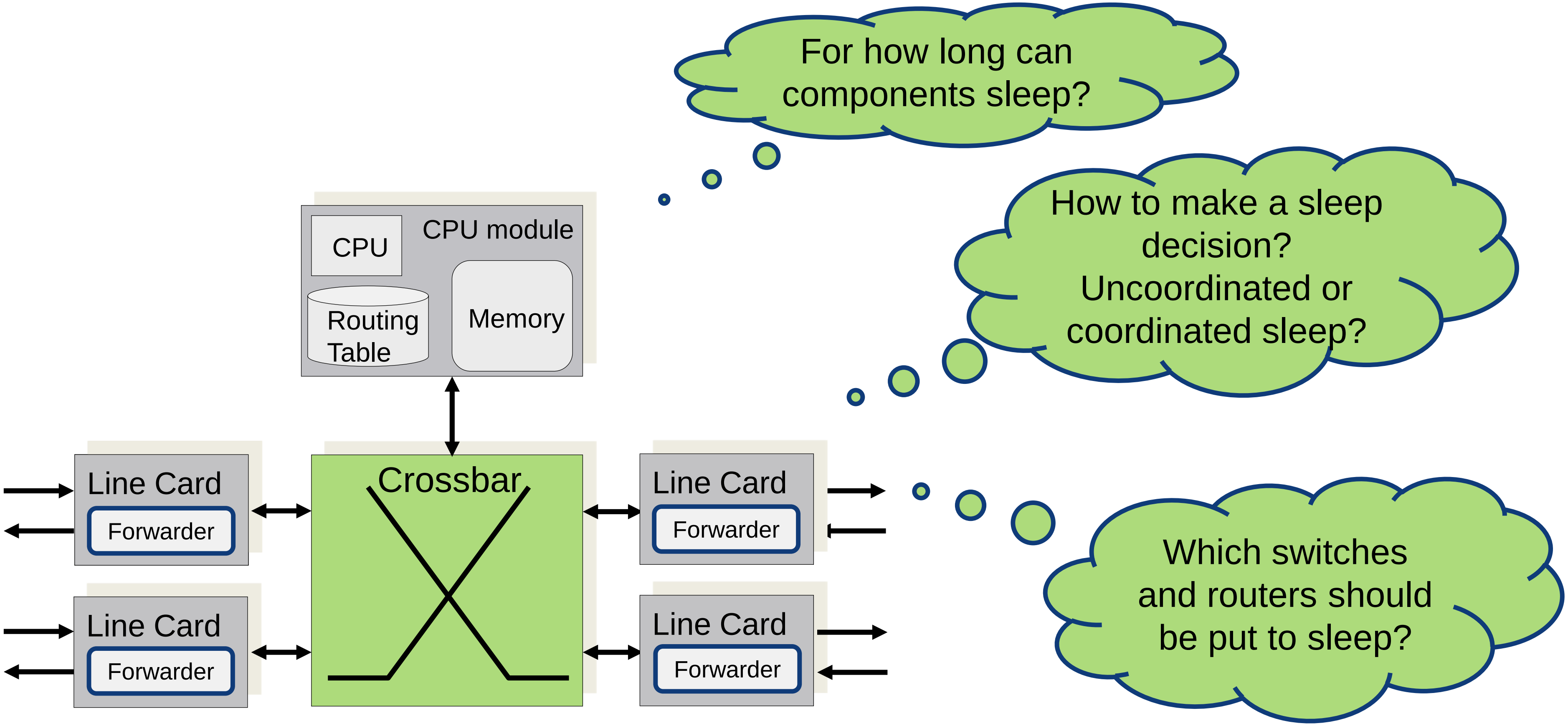
Algorithms for sleeping to maximize energy conservation require:

- Design hardware for software-enabled sleeping
- Modify routing protocols to deal with load aggregation and sleeping
- Internet topology amendments to support sleeping, aggregation, and route selection
- Changing protocols (like TCP) to adapt to sleeping modes

Power Saving Opportunities in Routers



How and When to Sleep?

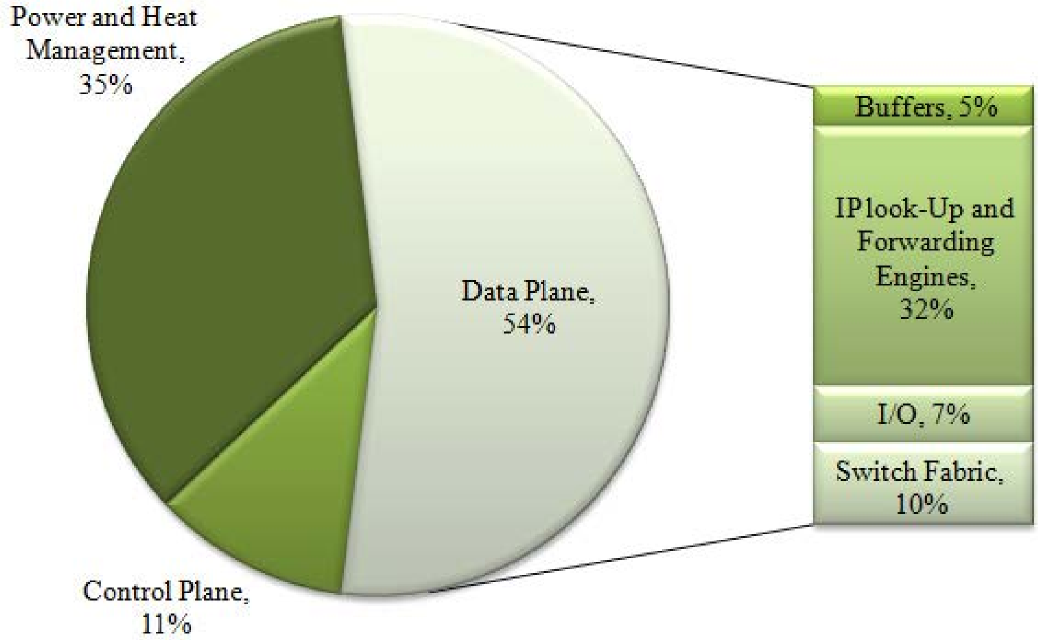


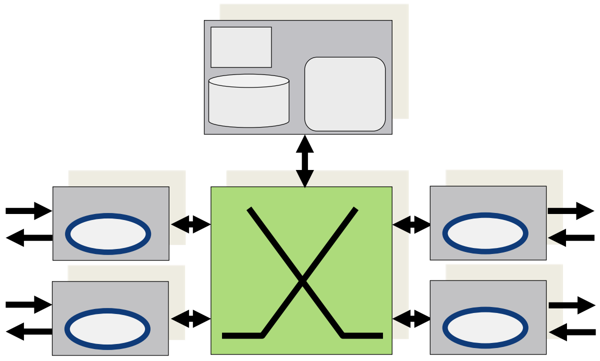
Node Level Power Saving

Power efficient node design

Power Consumption in High-end Routers

- An example:





Bolla et al., 2011

Network Devices

Energy-Efficient components

- Power-adjustable components (CPU, memory, crossbars)
- Energy-efficient silicon (ASICs, FPGAs, NPUs)
  - CMOS improves energy efficiency
    - By a factor of 1.65 every 18 months
- Optical components
- Modular design

Complexity Reduction

- Reduce/remove functionality
- ”Turn off” unused modules

Dynamic Voltage Scaling

- Power management technique in computer architectures
- Undervolting to conserve power
- Reducing the voltage and/or frequency:
  - reducing the maximum frequency at which the circuit can operate
  - CMOS power consumption roughly:

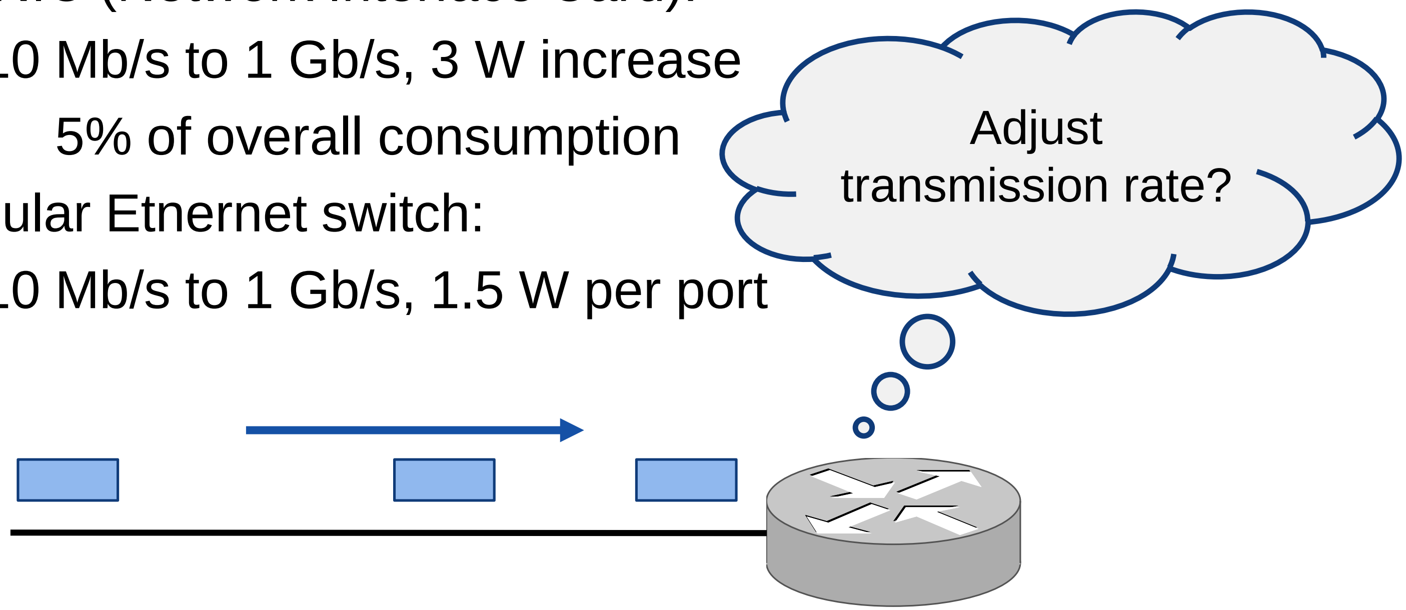
$P = CV^2f$
C – capacitance
V – voltage
f – frequency

Link Level Power Saving

Adaptive Link Rate (ALR)
Uncoordinated Sleeping

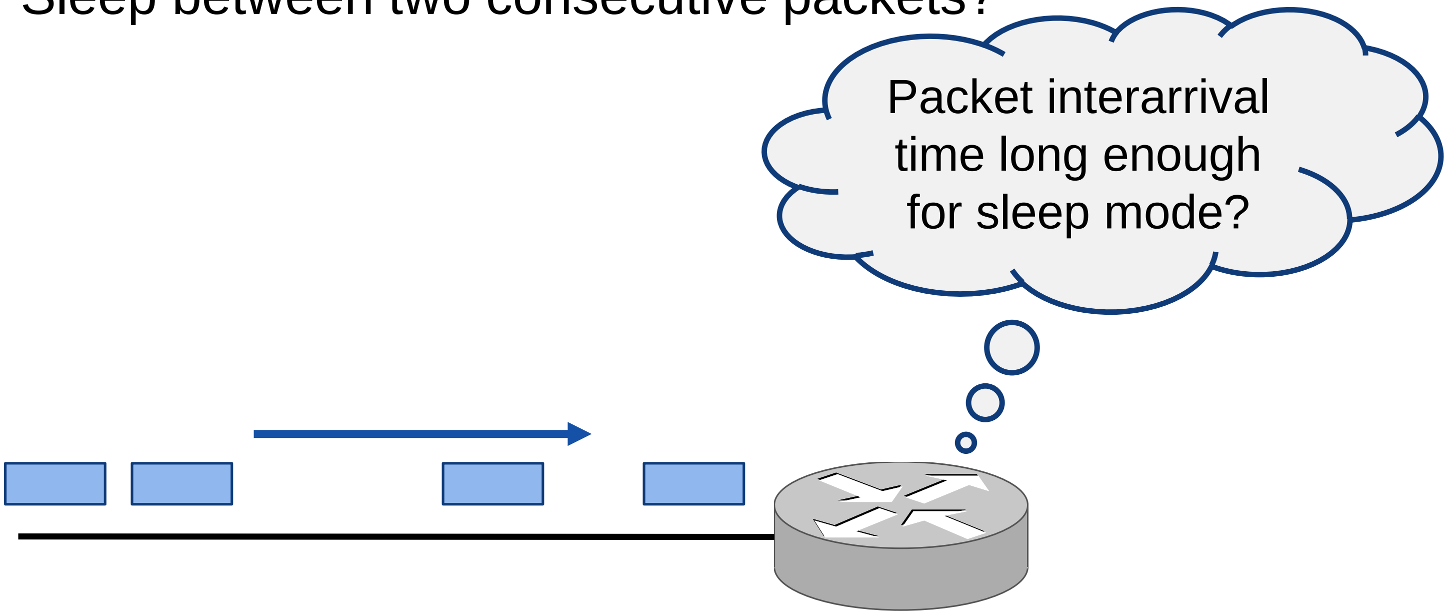
ALR—Rate Switch

- Configurable transmission rates
  - Ethernet transmission rates: 10 Mb/s – 10 Gb/s
- PC NIC (Network Interface Card):
  - 10 Mb/s to 1 Gb/s, 3 W increase
    - 5% of overall consumption
- Regular Etnernet switch:
  - 10 Mb/s to 1 Gb/s, 1.5 W per port



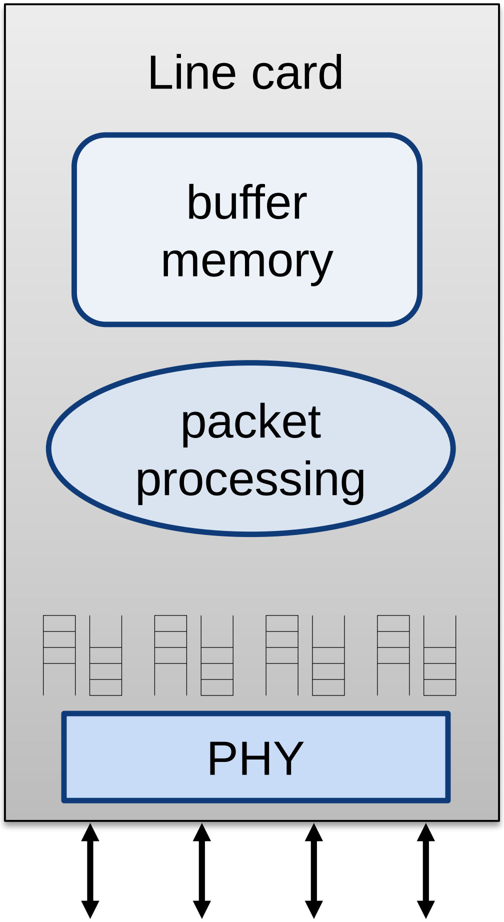
ALR—Uncoordinated Sleeping

- Router/switch monitors traffic on its interfaces
  - Estimate packet interarrival time
  - Sleep between two consecutive packets?



ALR—Types of Sleeping Modes

- Deep idle/sleep
  - Drop packets when sleeping
- Idle/sleep and buffer packets
  - Store packets in buffer when sleeping
- Idle/sleep and fully awake
  - If sleeping, wake up for every packet



ALR—Practical Considerations

- How trigger adaptation of transmission rates?
  - Buffer size and dual thresholds
- Negotiating transmission rates is time-consuming
  - About 256 ms at 1 Gb/s....
- Synchronization between link end-points
  - Sleeping mode on both sides of the link
- How will sleep mode influence routing and switching?
  - triggering routing protocols and spanning tree operations

Energy Efficient Ethernet (EEE)

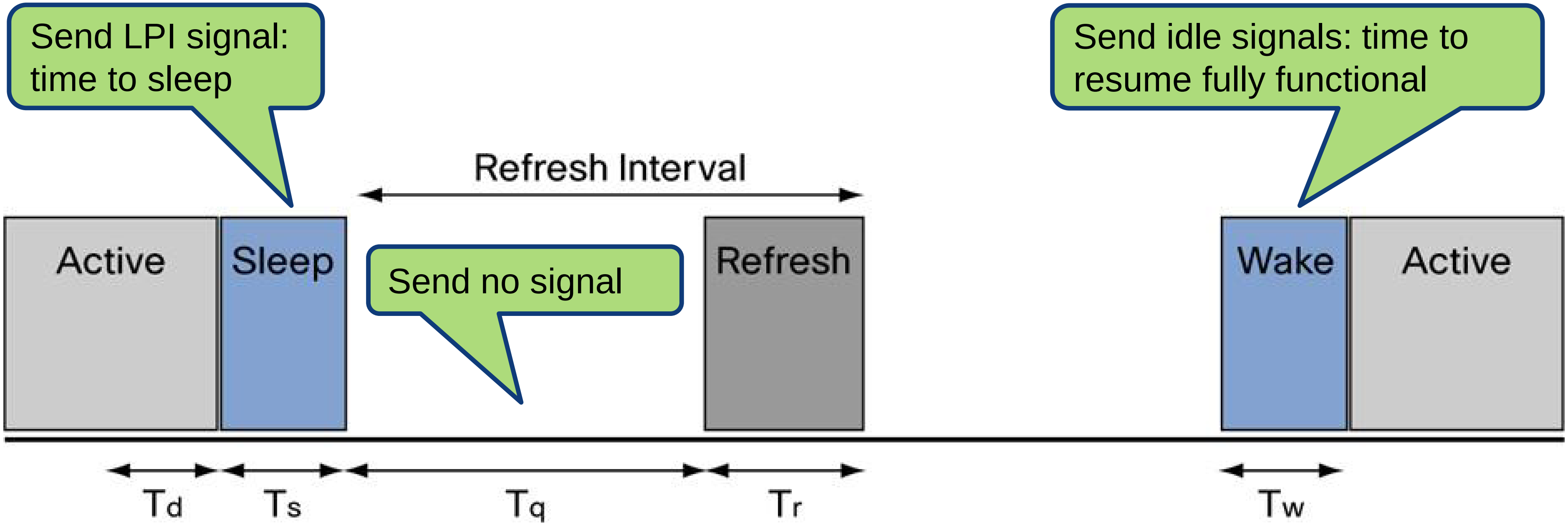
IEEE 802.3az Energy Efficient Ethernet
Standard for reducing energy usage

Work started in Nov 2006, standard as of Nov 2010
Focus on mainstream Base-T interfaces (twisted pair)

Fundamental idea: LPI (Low Power Idle)–consume power only when data is being sent

Low Power Idle and not Rate Switching!

Energy Efficient Ethernet—Protocol



Cisco | Intel, White Paper, 2011

Designed not to affect higher layer services
Default wake-up time similar to the delay of a maximum packet at the target link speed (store and forward)

T_W: 3 µs for 10 Gb/s link

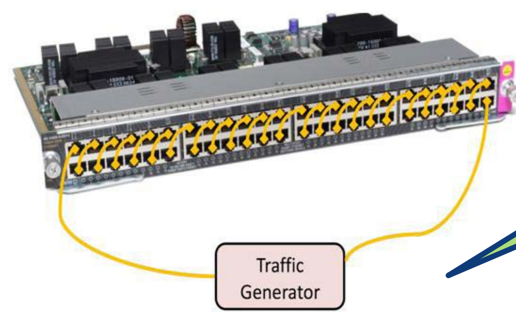
Energy Efficient Ethernet, cont’d

- Many policies possible for how to use LPI
- Backward compatible
  - EEE advertises capability through auto-negotiation
    - If no support on other end, operate in legacy mode
  - Gradual roll-out possible
- Extensions for sophisticated use
  - Deeper sleep negotiation
    - Take longer time to wake up
  - For polices driven from network energy management

EEE Standard in Network Products

- Example: fully loaded Cisco Catalyst 4500E Switch
  - 384 1000Base-T ports
  - Traffic generator sending bursty traffic with low link utilization
- 141 W (16%) reduction in power consumption

Before enabling EEE: 892 W



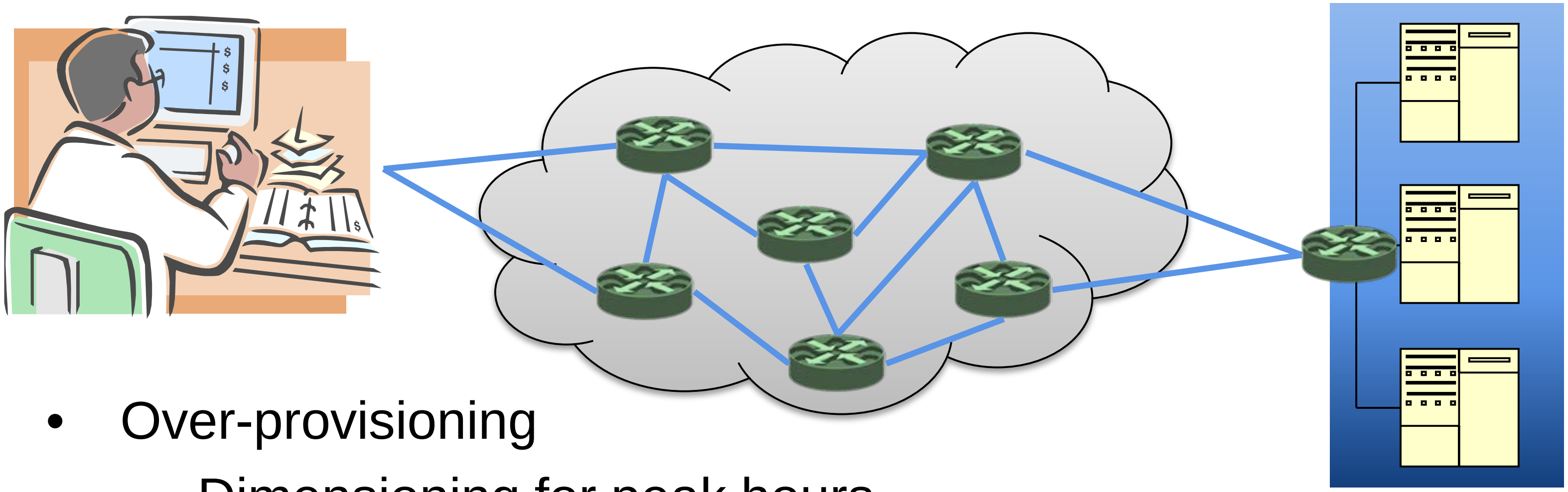
After enabling EEE: 751 W

Cisco | Intel, White Paper, 2011

Network Level Power Saving

Energy-aware network control
Coordinated Sleeping

Traditional Networking Objectives



- Over-provisioning
  - Dimensioning for peak hours
- Redundancy
  - Always on to support mission-critical applications

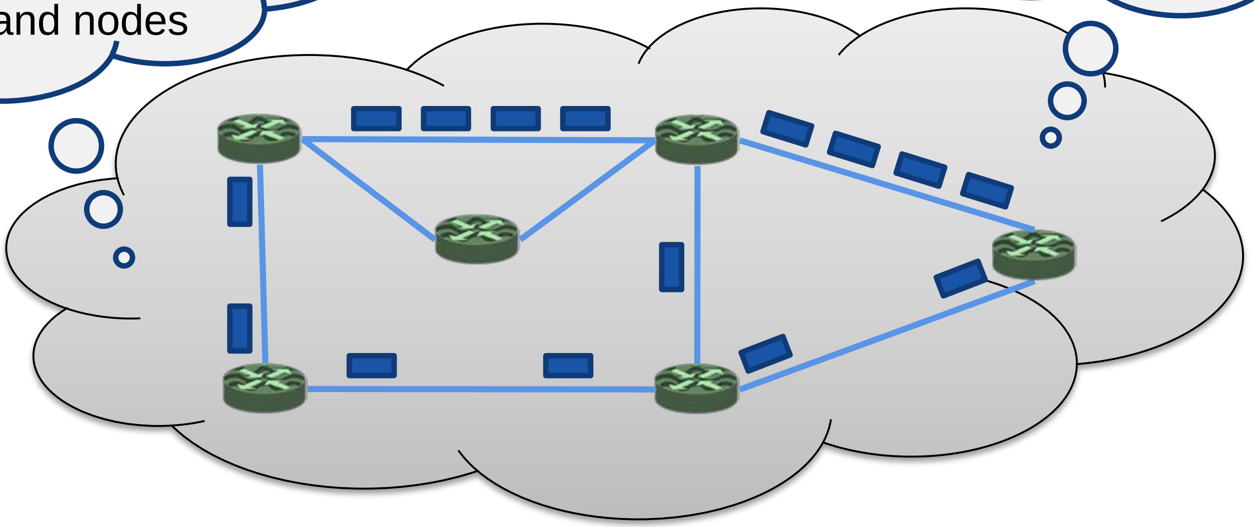
As opposed to objectives with green networking and energy-awareness!

Green Network Control—Basic Idea

Adapt network capacity in terms of active nodes and links to actual traffic volumes

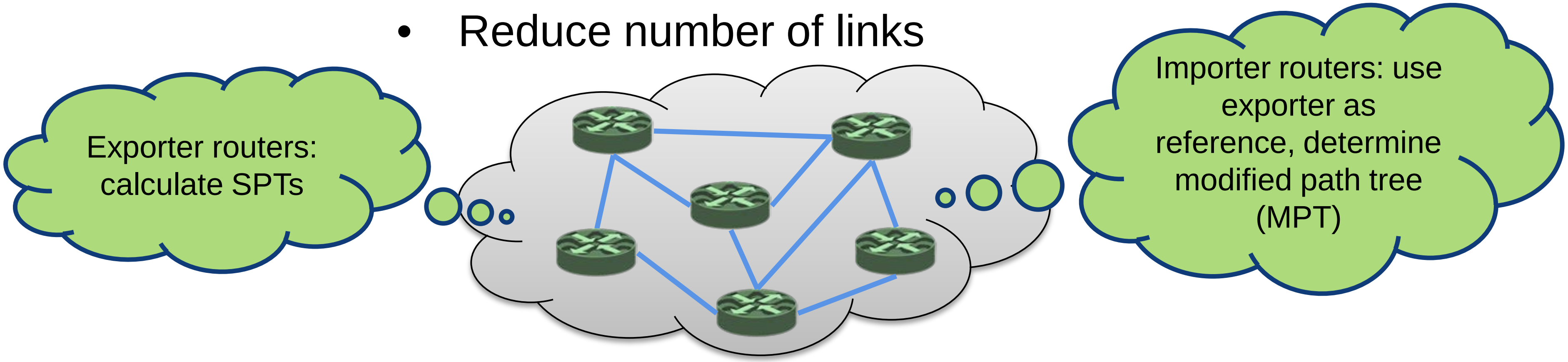
Move traffic flows among network nodes—”switch off” unused links and nodes

Guarantee best trade-off between performance and power consumption!



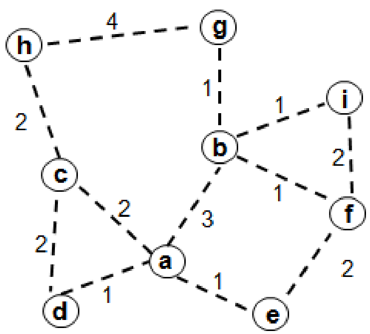
Green OSPF—EAR (Energy-Aware Routing)

- Energy saving routing solution compatible with OSPF
  - Open Shortest Path First—link state routing
  - Each router calculates its shortest path tree (SPT)
    - Using Dijkstra's algorithm
  - EAR algorithm: use subset of SPTs to select paths
    - Reduce number of links

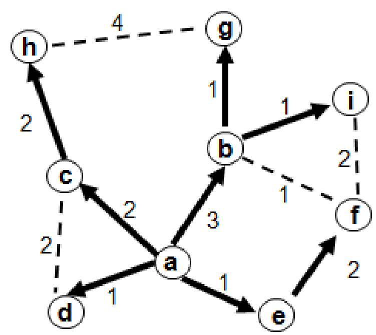


Energy-Aware Routing (EAR), cont'd

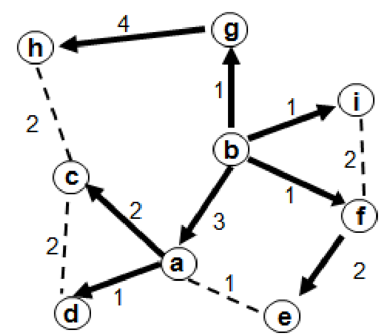
Graph with OSPF weights



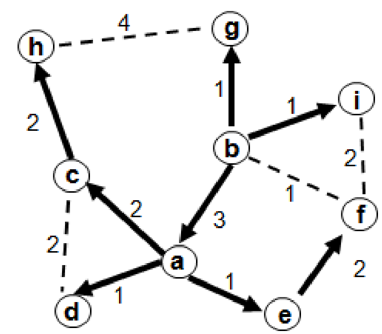
SPT computed by ***a***, SPT(a)



SPT computed by ***b***, SPT(b)



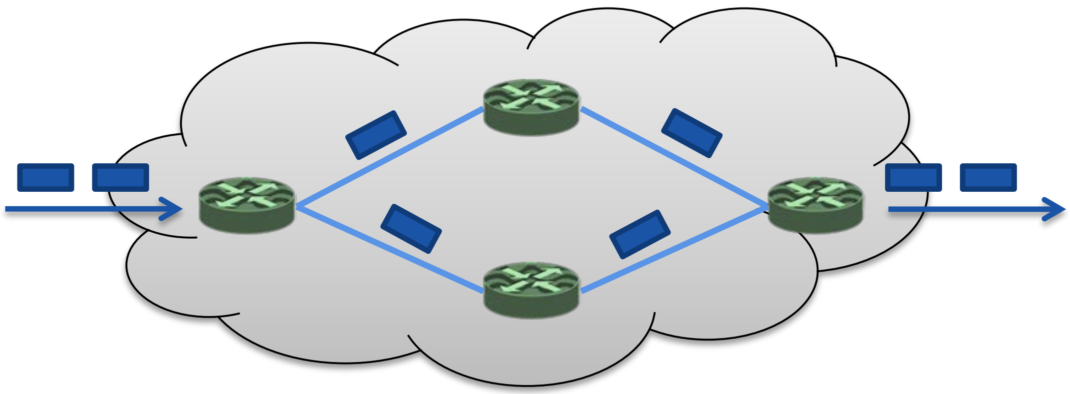
EAR performed by ***b***, if ***a*** exporter, MPT(b, a)



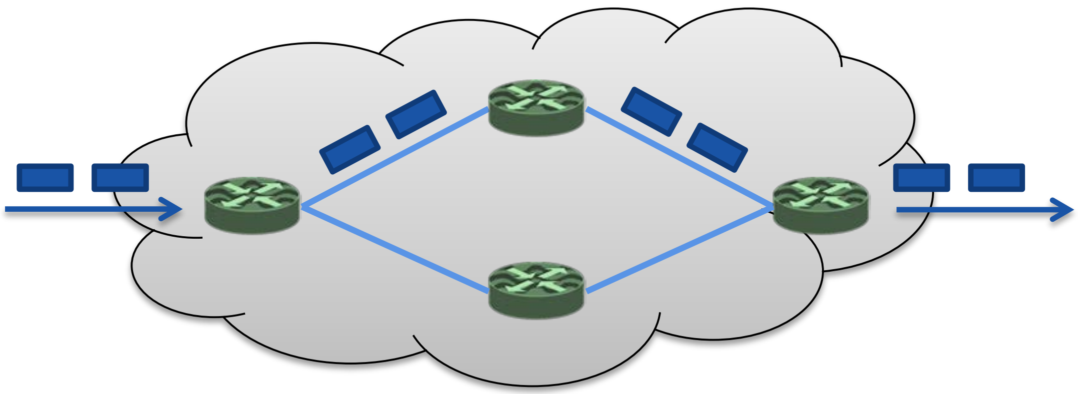
Cianfrani, et. al., IEEE INFOCOM 2010

- Packets can be deflected and links put in sleep mode
  - Like ***b*** can do with link ***b-f*** above
- Performance evaluation on real network topologies
  - Exodus: 244 routers, 1080 links
  - Up to 60% of links could be "turned off"

GreenTE: Power-aware Traffic Engineering



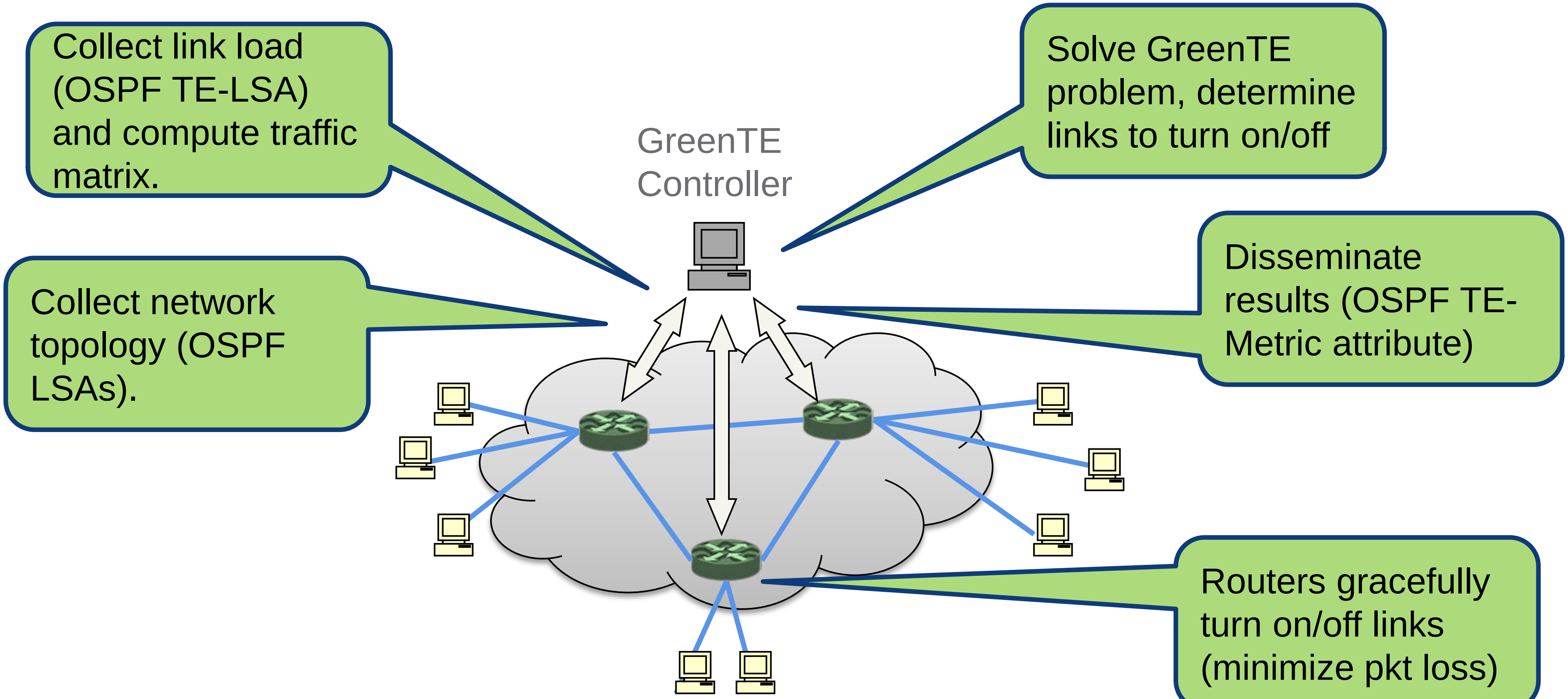
Traditional traffic engineering goals



Power-aware traffic engineering goals

GreenTE Operation

Uses existing protocols (OSPF and MPLS) and rely on centralized controller



GreenTE Evaluation

Network	Nodes	Links
Abilene	12	30
GÉANT	23	74
Sprint	52	168
AT&T	115	296

Line card	Power (W)
1-port OC3	60
8-port OC3	100
1-port OC48	140
1-port =C192	174

- Based on real network topolgies and measured traffic matrices (when available)
- Power saving model
  - Line cards > 40% of total router power budget
  - Power saving ratio: P(all sleeping LCs)/P(all LCs)
- Power saving potential of 20-40%

Concluding Remarks

Other Energy Efficiency Techniques

Energy-aware proxies

- End-systems in sleep mode despite background traffic
- Interface proxying—offload network chatter from power-hungry motherboards to NIC
- External proxying—offload traffic filtering and processing to external unit

Energy-aware software and applications

- telnet client in sleep mode
- Green BitTorrent peers prefers active peers—don’t wake up sleeping peers
- Modified TCP for greener sockets

Operators and Energy Consumption

Telecom Italia
2 TWh (2006)

British Telecom
2.6 TWh (2008)

France Telecom
2 TWh (2006)

Deutsche Telecom
3 TWh (2007)

Verizon
8.9 TWh (2006)

EC INFSO report 2008, European telcos & operators:
14.2 TWh 2005, 21.4 TWh 2010, 35.8 TWh 2020
If no green network technologies will be adopted

Summary

- Green networks—energy-efficient networks
- Lots of opportunities for power-saving in the Internet
- Three categories of power-saving techniqus
  - Node level
  - Link level
  - Network level
- Still rather young research field currently gaining much attention!

Thanks for your attention!