Xarxes de computadors II

Temas de investigación

Temas

- 1) Introducción
- 2) Arquitectura y direccionamiento en Internet
- 3) Encaminamiento intra-dominio
- 4) Encaminamiento inter-dominio
- 4) Conceptos avanzados de red
- **6) Actividad complementaria:**
  Temas de investigación

Research

- Presentation of some researches in
  - OSPF
  - BGP
  - Sustainable Internet

- Your presentation (20 minutes)
  - December 17 (2 hours) and 18 (1 hour)
  - Either select one of these topics or one you prefer
  - Recommended structure
  - Provide references

Some recent researches

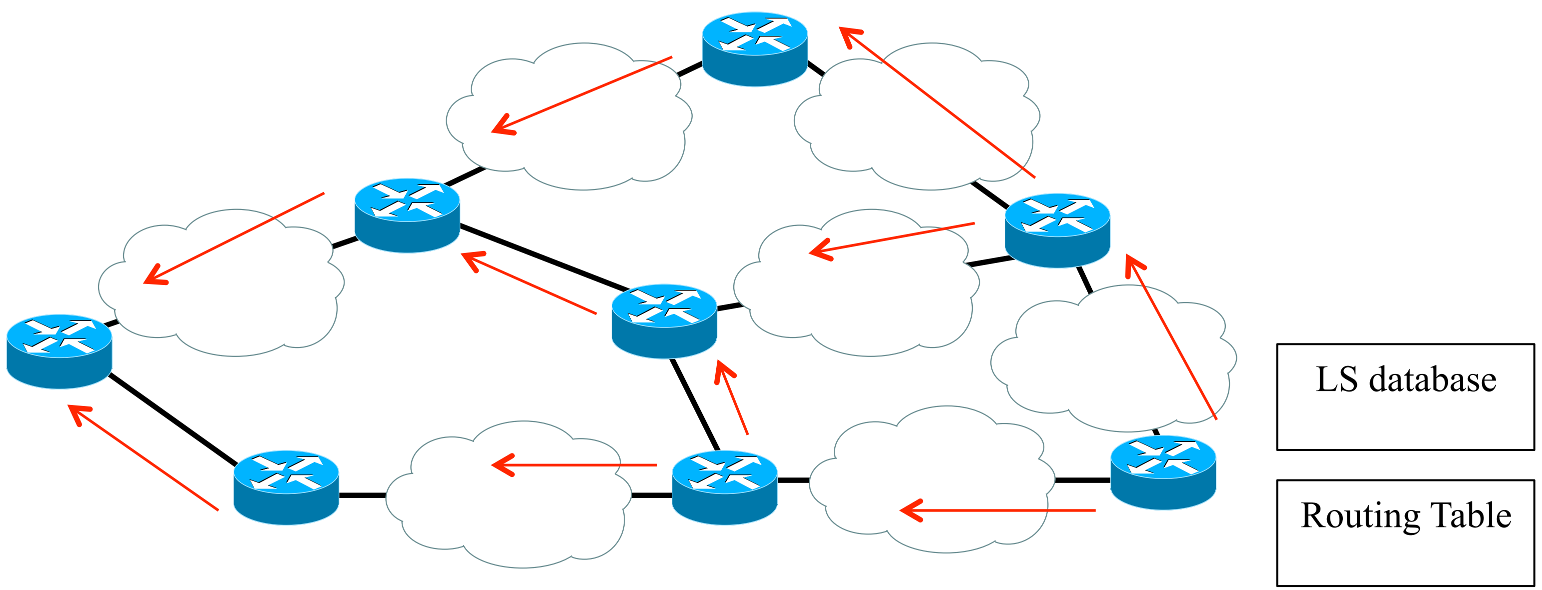
- Routing and OSPF
  - Quality of Service (QoS) routing and global knowledge of the network status
  - Application to optical networks
- BGP
  - Identification of the problems
  - Short-term improvements
    - Geographical routing
    - LISP protocol
  - Revolutionary approaches
    - Compact routing
    - Greedy routing
- New Internet model
  - Energy-oriented model
  - RINA architecture

OSPF: QoS routing

- Scenario
- Problem formulation
- Some solutions
- Some bibliography

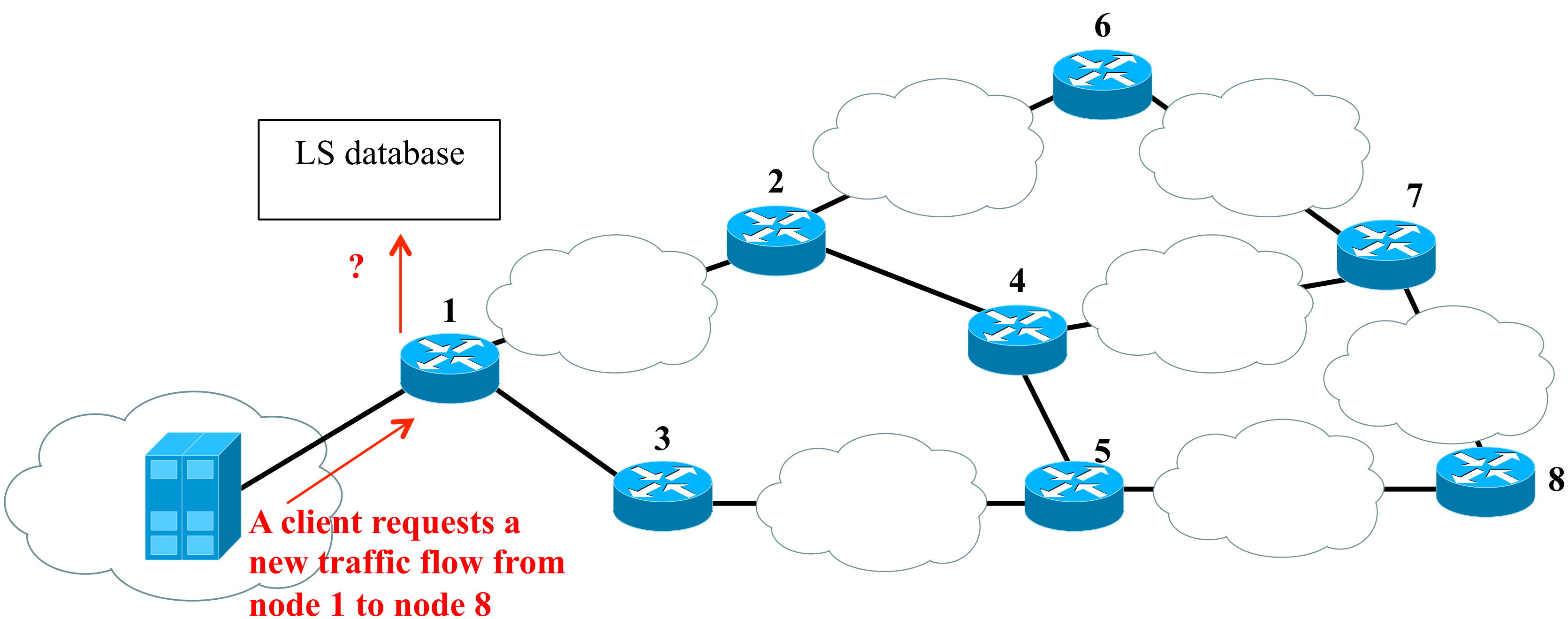
Scenario (1/3)

- A network operating OSPF
  - link-state routing algorithm
  - flooding mechanism to have global network knowledge at each node



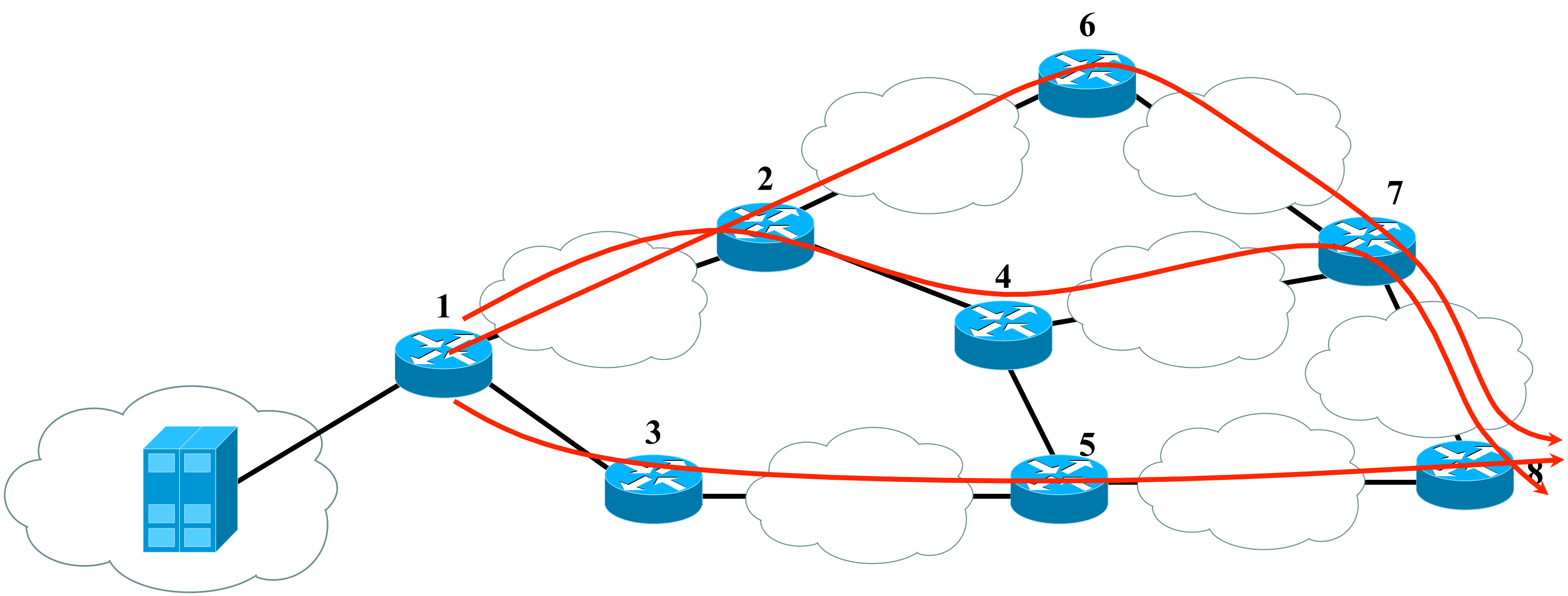
Scenario (2/3)

- A traffic flow from one node to another



Scenario (3/3)

- Several paths from source to destination
- Selection based on shortest path first (SPF)

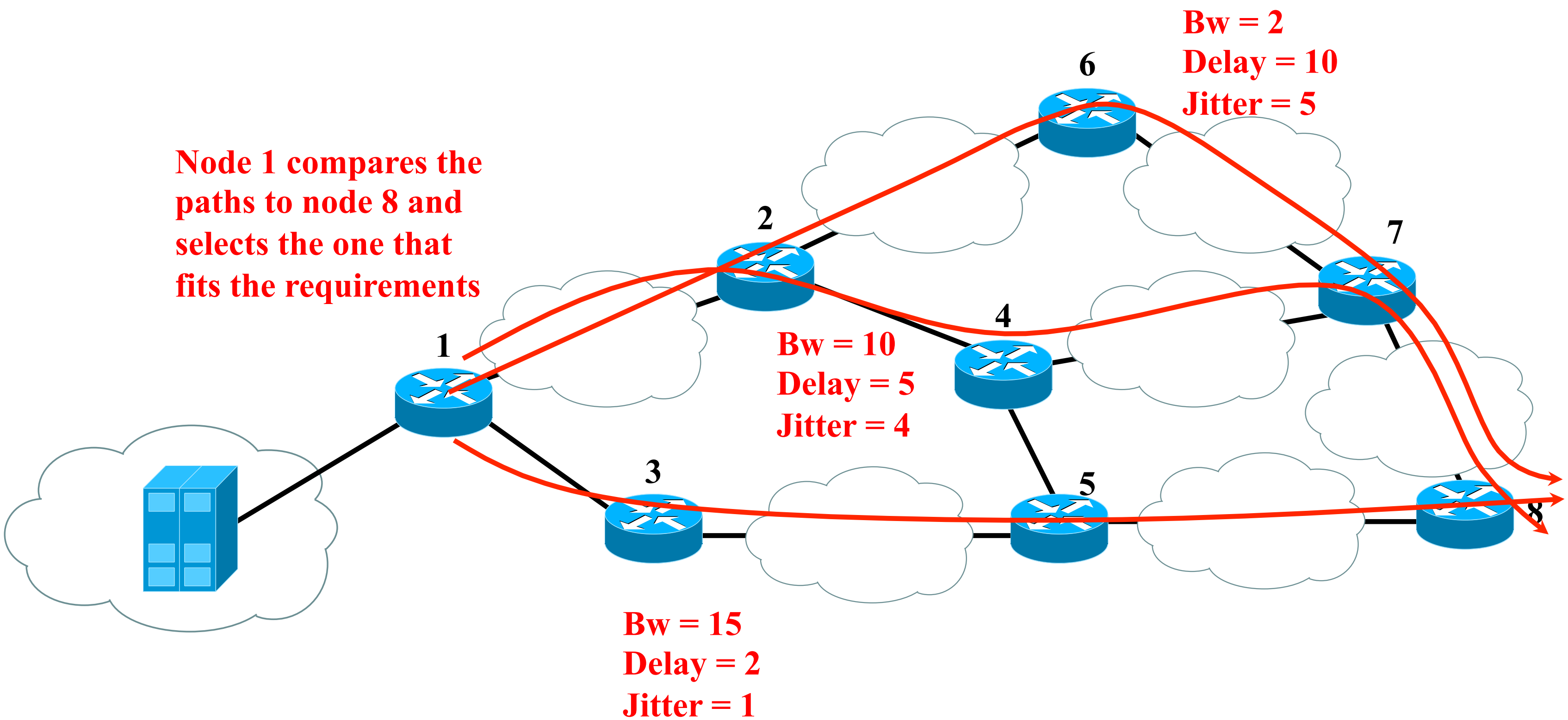


Problem formulation (1/5)

- Definition of QoS (ITU-T)
  - the collective effect of service performance which determines the degree of satisfaction of a user of the service.
- In practice
  - meet given number of requirements, e.g. delay, jitter, bandwidth (i.e. average bit-rate), etc.
- Routing is one of the actors to provide QoS
  - QoS routing enables a network operator to identify, for every new traffic flow, a path through the network that has sufficient resources to meet the flow's requirements, typically in the form of bandwidth or end-to-end delay guarantees

Problem formulation (2/5)

- Multiple paths from source to destination



Problem formulation (3/5)

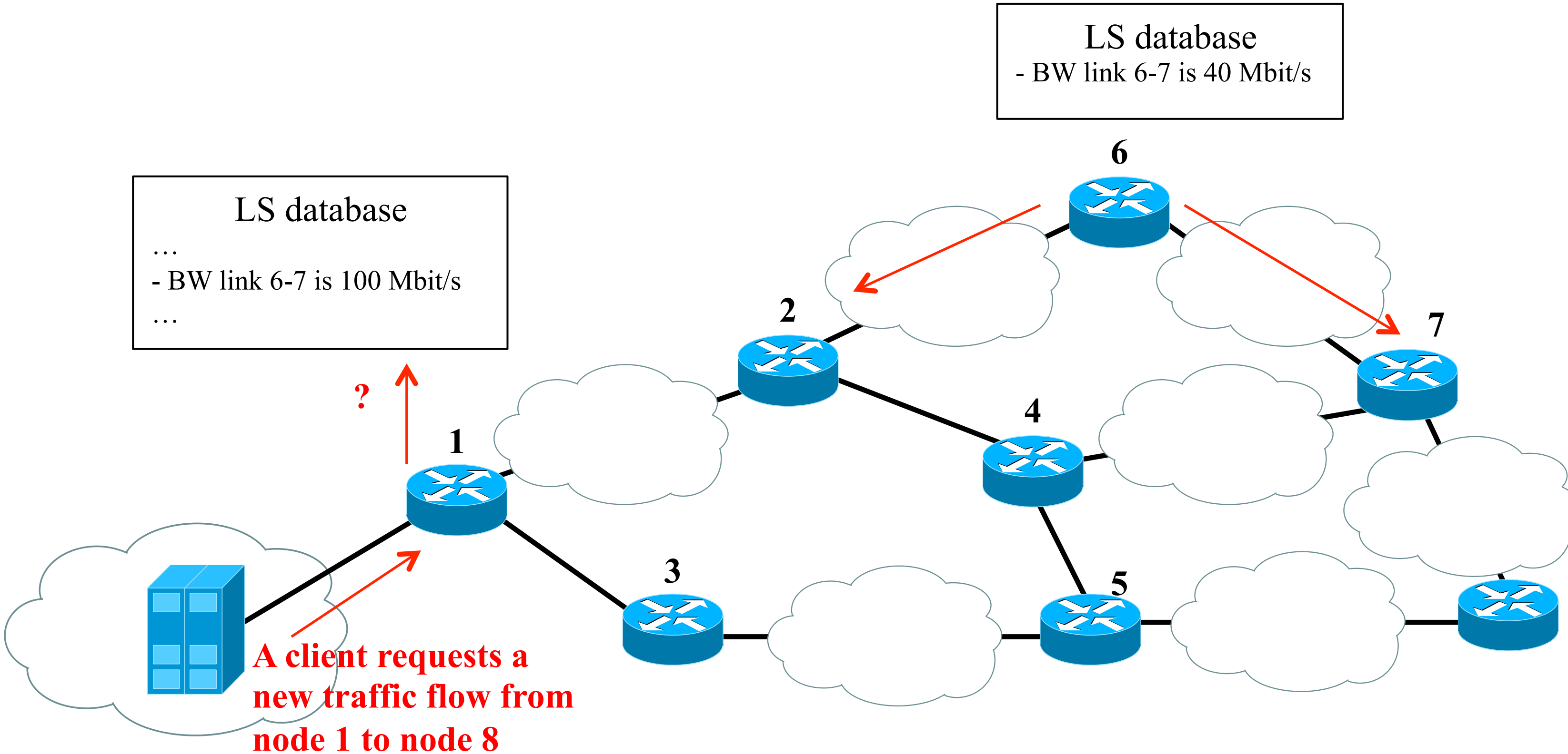
- Definition of a cost function to determine the best path, e.g.
  - Cost = α BW + β Delay + χ Jitter + … + ζ Losses
  - where α, β, χ, …, ζ are weights

Problem formulation (4/5)

- QoS routing algorithm becomes a multi-constrained routing problem
  - NP-complete, i.e. the time required to solve problem exactly cannot, *in the worst case*, be upper-bounded by a polynomial function (no fast solution to them is known).
- Definition of the OSPF-Traffic Engineering (OSPF-TE) concept to be able to disseminate arbitrary information by flooding (RFC 3630)
- Such variety of metrics
  - seriously complicates the dynamics of flooding because the flooding convergence time can be longer than the change rate of some metric (such as available bandwidth)
  - increases the signaling overhead (increase the number of control messages, i.e. OSPF LS)
  - creates <u>inaccuracy</u> of the global network status at each node

Problem formulation (5/5)

- But in dynamic networks may happen that…
- Node 1 computes the paths but its LS is inaccurate due to a change in node 7

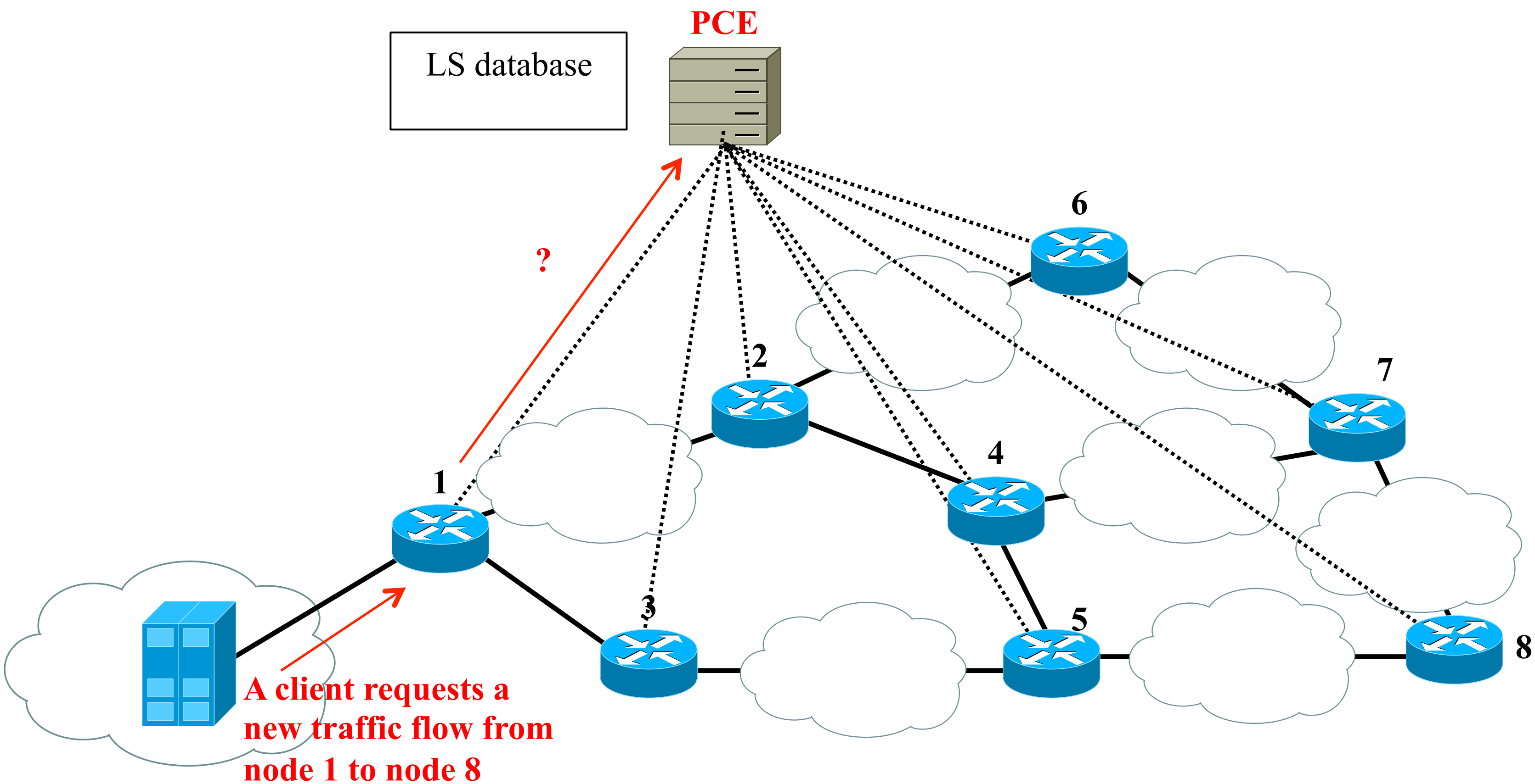


PCE solution (1/2)

- Decoupling the routing selection process from the control process
  - introduction of the Path Computation Element (PCE)

- PCE is an external entity with the unique task of computing the path from source to destination
  - centralized solution
  - it has a global database so it can compute the path without inaccuracy
  - it needs a very fast computation engine to compute exactly the path

PCE solution (2/2)



“Inaccuracy as a metric” solution

- Find a good trade-off between the protocol overhead needed to keep the state information up-to-date and the inaccuracy that arises with the limitation of the emission of updates.

- Consider the inaccuracy as a metric for the path computation
  - introduce a penalty to selected links (e.g. bandwidth close to a minimum threshold, metric too old so maybe inaccurate, etc.)

- Apply predictive or self-learning routing techniques to know the possible/probable metrics that are missing or too old
  - mechanisms that learn from the previous performance or behaviour

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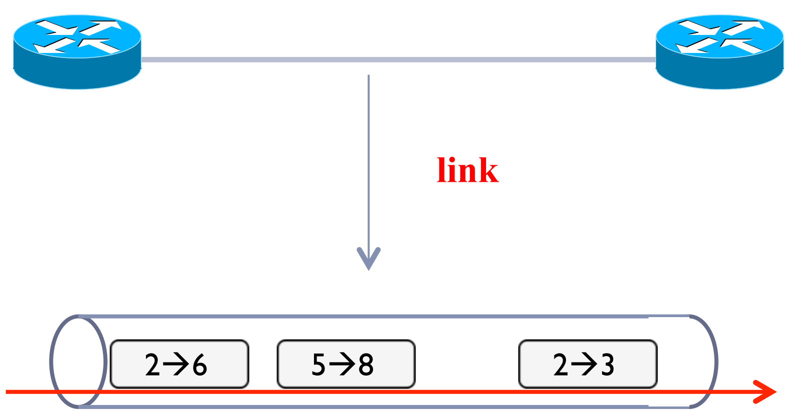
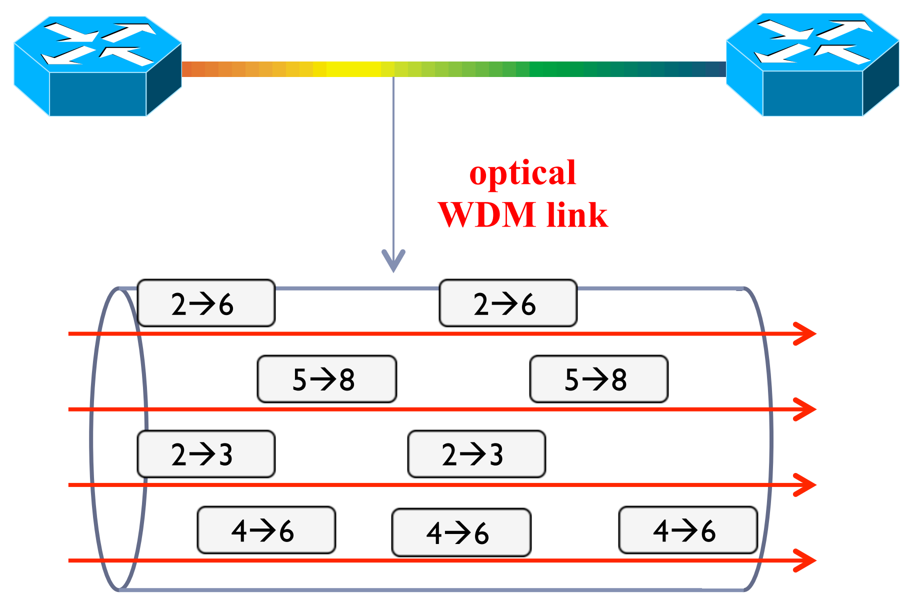
OSPF: application to optical networks

- Scenario
- Problem formulation
- Some reference solutions
- Some references

Scenario

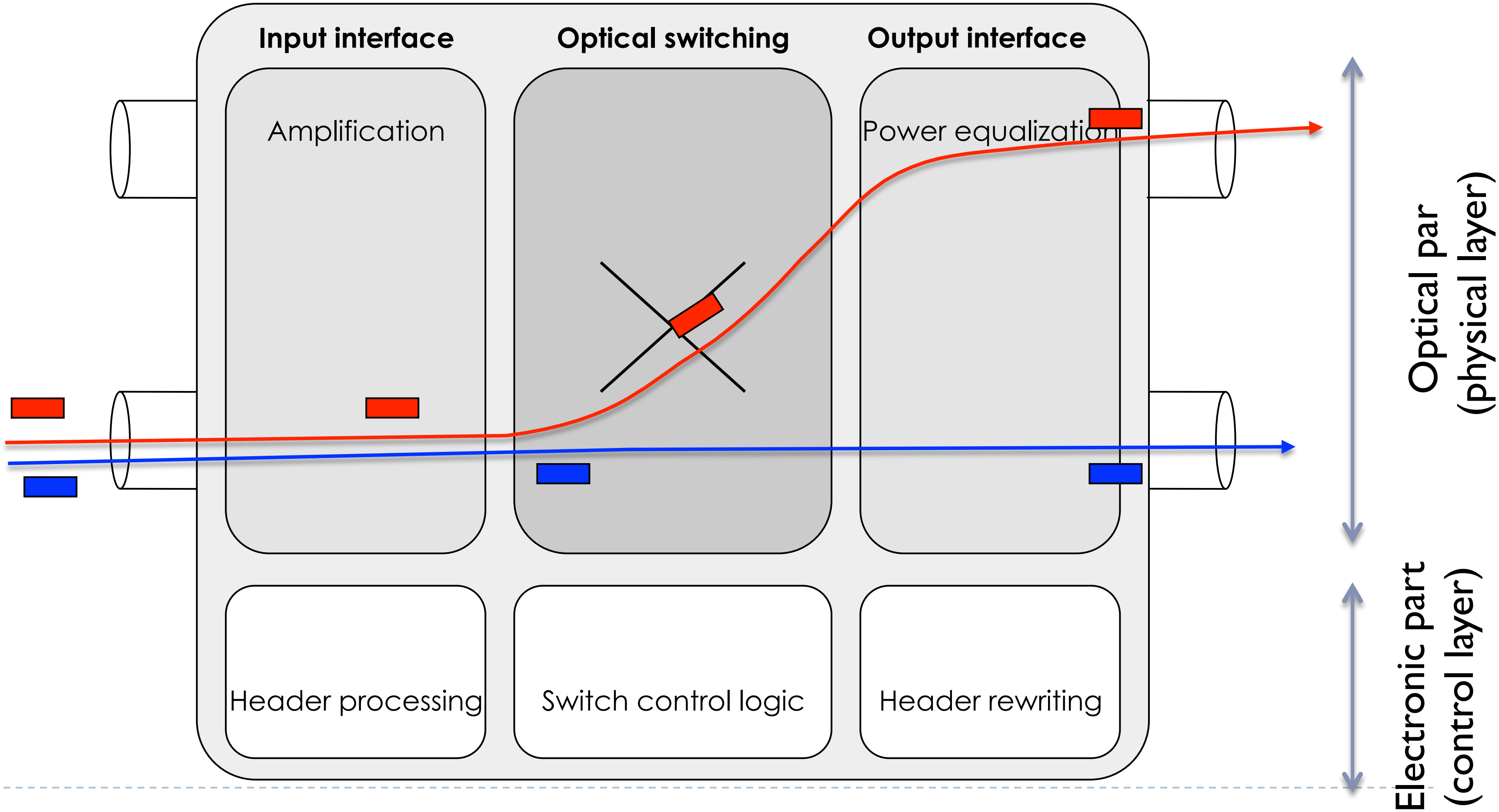
- Optical networks
  - very high capacity
  - possibility to transmit many signal at the same time at different wavelengths (80–160 wavelengths per fiber) -> Wavelength Division Multiplexing (WDM)
  - the bitrate of each wavelength can be: 2.5, 10, 40, and 100 Gbps





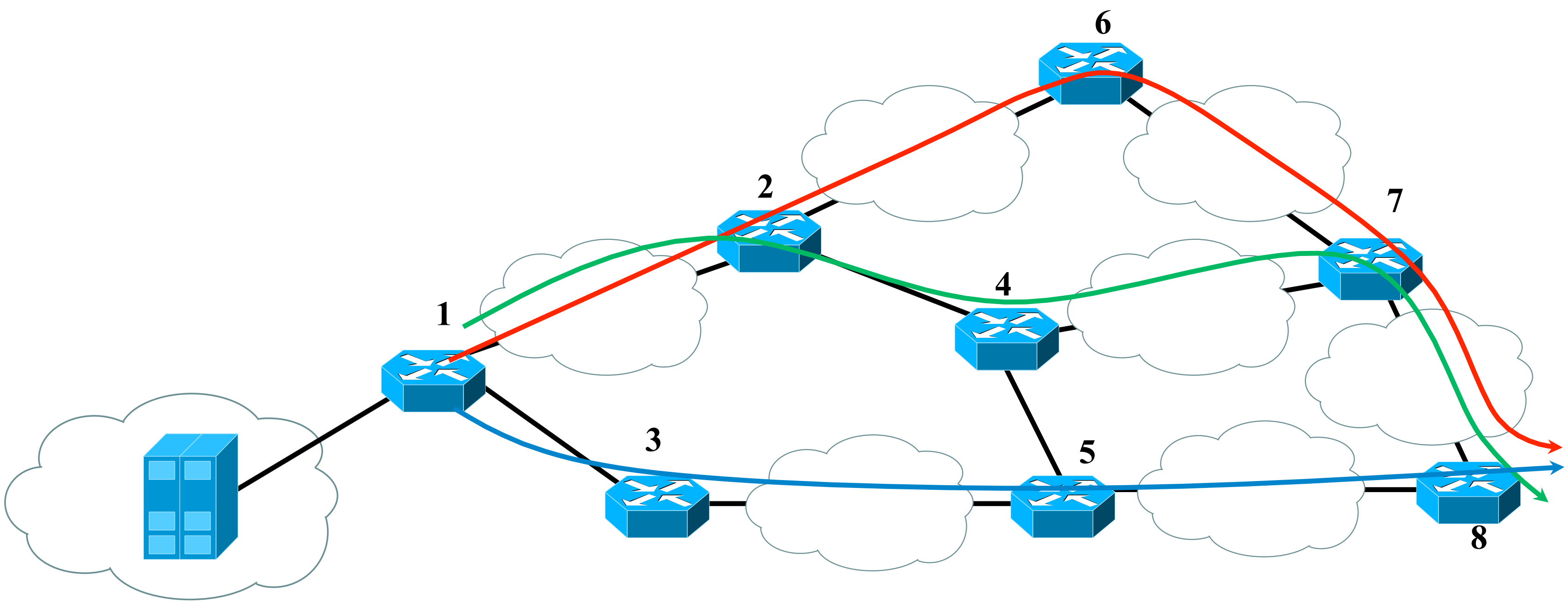
Optical router (ROADM or WXC)

- Packets flow through the nodes without any change
- The path inside the node is almost fix and determined in advance



Problem formulation (1/4)
the RWA problem

- The problem becomes a Routing and Wavelength Assignment (RWA) problem since it requires
  - selection of the path between source and destination
  - selection of the wavelength at each link from source to destination
  - the resulting path + wavelength is called **lightpath**



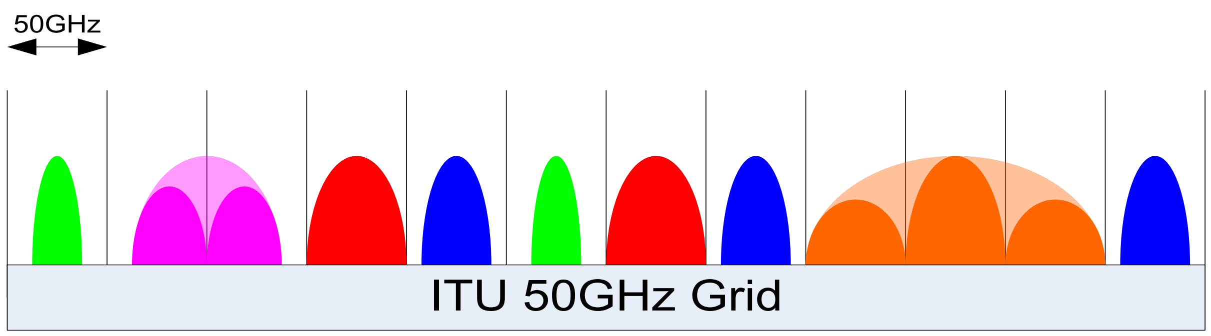
RWA solution

- RWA is NP-complete
- Apply approximate algorithms
- Decouple the routing and the wavelength assignment into two sub-problem
  - find optimal routing paths (by means e.g. of optimization technique)
  - apply simple wavelength assignment solutions like first-fit

- A PCE solution also for optical networks

WDM but

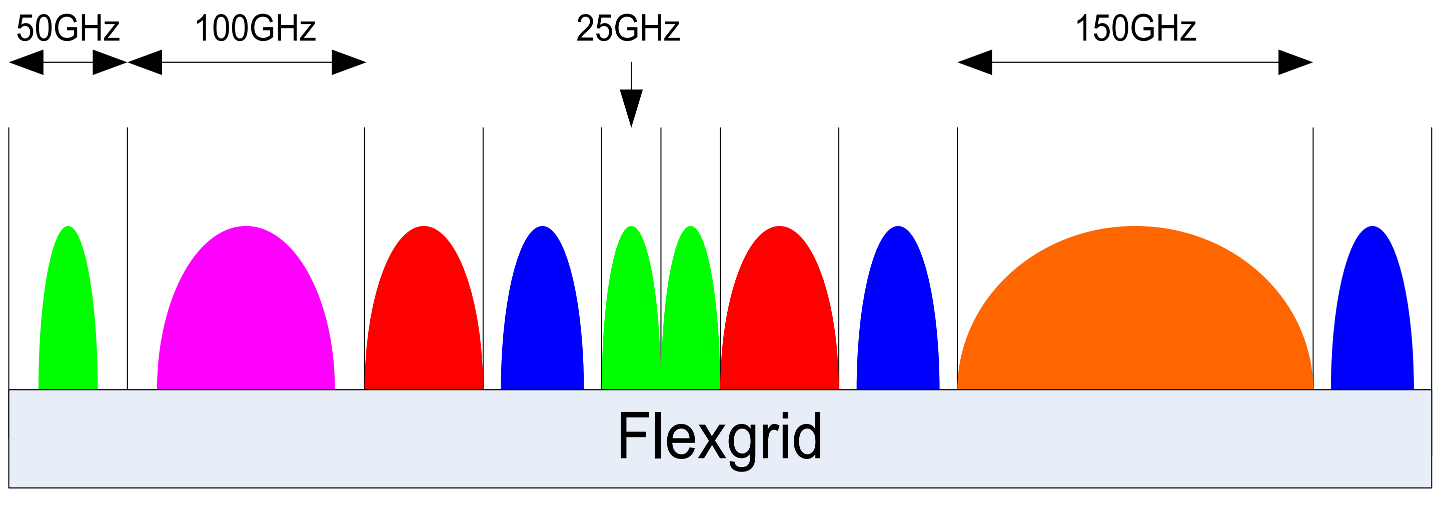
- 100 Gbps is expected to meet operator needs in the short to medium term, but traffic growth will lead to mixed line rates including 400 Gbps and 1 Tbps in the long term
- Existing DWDM systems are inflexible in two distinct ways:
  - The transponder has a fixed bit rate – for example of 10 Gbps or 40 Gbps.
  - The spectral width of each wavelength signal cannot extend beyond the fixed ITU grid width used in the system (e.g. 50 GHz)



  - Large bandwidth demands will have to be divided up so that they can be carried over the fixed grid
  - This results in a highly inefficient use of the network capacity

Flexible Optical Network

- An elastic optical transport network based on a combination of Bandwidth Variable Transponders and Flex-grid might enable a more flexible optical spectrum use
- Grid boundaries could be set in the most appropriate place

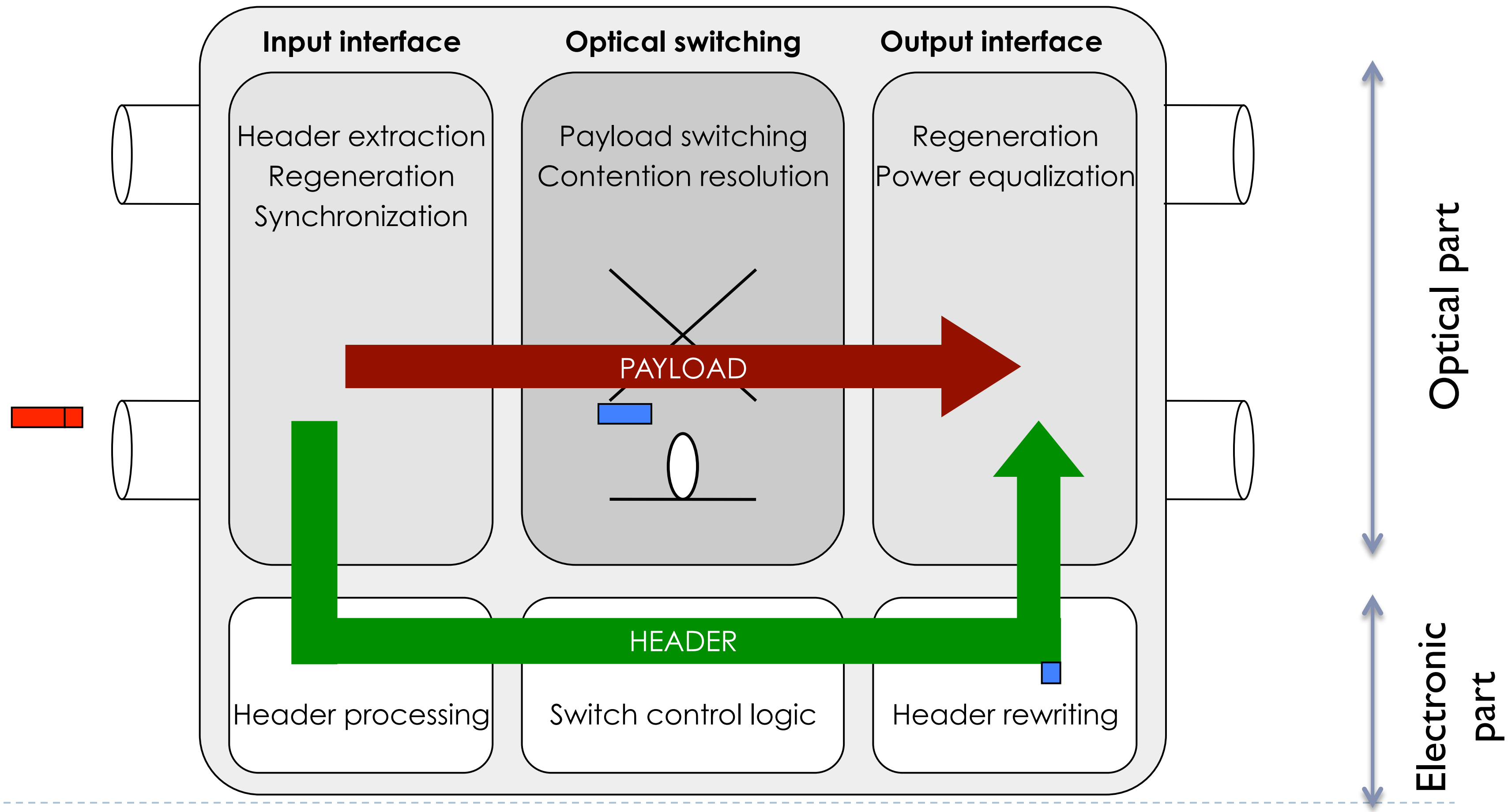


Flexible Optical Network

- The routing problem becomes a Routing and Spectrum Assignment (RSA) problem
- Determine a route and a spectrum width subject to
  - Spectrum continuity constraint (i.e., the same slots must be used in all the links of the path)
  - Spectrum contiguity constraint (i.e., the slots must be contiguous in the spectrum)
- As RWA, RSA is NP complete
  - Apply approximate algorithms
  - Decouple the routing and the spectrum assignment into two sub-problem

Optical packet switching

- Implementation of conventional Internet packet switching techniques in the optical domain
- The path of the packets through the node is determined packet by packet



Optical packet switching

- Problems
  - There is no optical RAM for buffering the optical packets
    - Slow light
    - Fiber Delay Lines
    - No buffering at all
  - Optical switching at the ns scale
  - Wavelength converters to change the wavelength of the optical packets

- Now some interest for data center interconnection networks
  - Low latency
  - High throughput
  - High flexibility
  - High bandwidth dynamics

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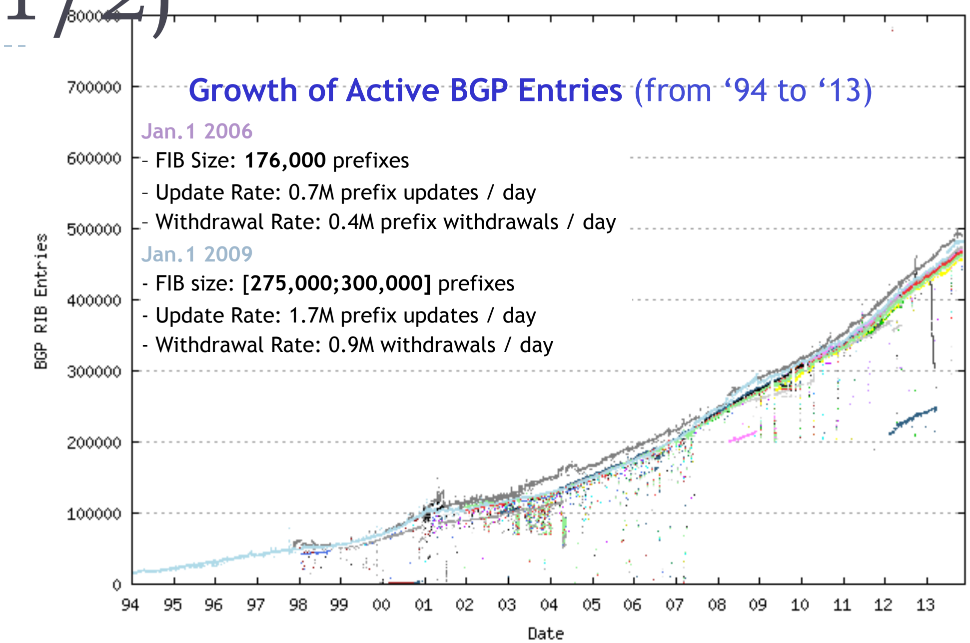
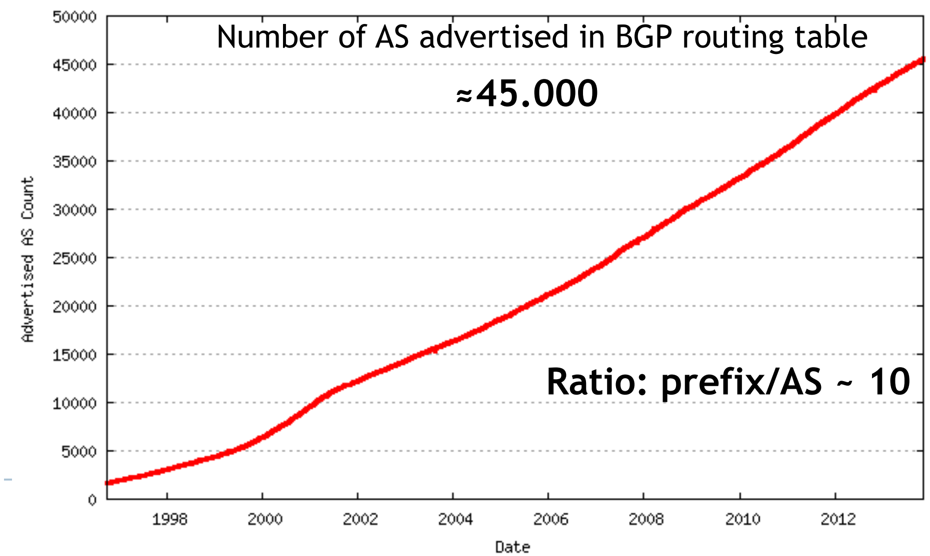
Some recent researches

- OSPF
  - Quality of Service (QoS) routing and global knowledge of the network status
  - Application to optical networks
- BGP
  - Identification of the problems
  - Short-term improvements
    - Geographical routing
    - LISP protocol
  - Revolutionary approaches
    - Compact routing
    - Greedy routing
- New Internet model
  - Energy-oriented model
  - RINA architecture

Current situation (1/2)

- Traffic
  - Traffic volume (per month): Exabytes
  - Traffic growth rate: 50% (+/- 5%) per year
- Routing tables size
  - Growth rate: 15%-25% per year
  - Number of active RT entries: 500k (2013)
- Autonomous Systems (AS)
  - Growth rate: 10% per year
  - Number of advertised AS: 45k (2013)
- Average AS-path length: steady ~3.4

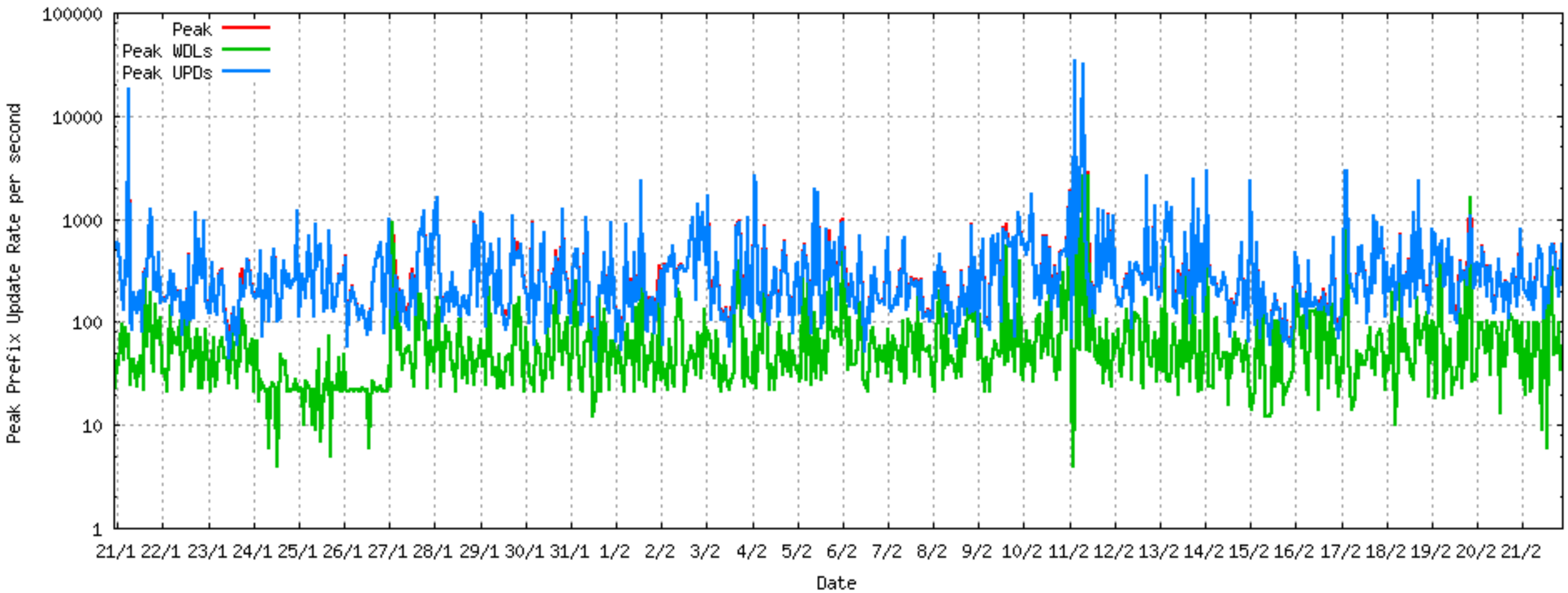




Source: BGP Routing Table Analysis Reports - http://bgp.potaroo.net

Current situation (2/2)

- Dynamics BGP updates (routing convergence)
  - Between Jan.2006 and Jan.2009: prefix update and withdrawal rates per day increased by a factor of about 2.5
  - Average: 2-3 per sec. – Peak: O(1000) per sec.



Fundamental trade-off in BGP

- **Scalability**: memory space consumption by local RT
  - Routing table size scaling better than (n log n) [preferably (log n)], where n is the number of nodes/ASes
- **Stretch**: ratio between cost/length of routing path produced by the routing scheme and minimum cost/length path
  - Bound stretch of routing paths as produced by routing scheme to small constant factor that does not grow with network size
- **Communication cost**
  - **Messaging**: number of routing updates per topology/policy change
  - **Processing:** store routing update → process (compute and possibly add/remove, or replace RT entry) → distribute routing update

Solutions

- Current trend in BGP routing system based on short-term incremental patches to attenuate symptoms instead of addressing root causes

- This approach works until
  - System engineering can 'absorb' protocol deficiencies
    - Planning and design issues to find trade-off between stability, routing table size and optimality
  - Network engineering can 'absorb' executions problems
    - Operational workarounds to resolve policy, monitoring, etc.

- ... but is subject to "unknown but **limited scalability**"

Solutions space: evolutionary vs. revolutionary

Short-term solutions

- Geographical routing
- Overlay routing such as **LISP**

Compact Routing

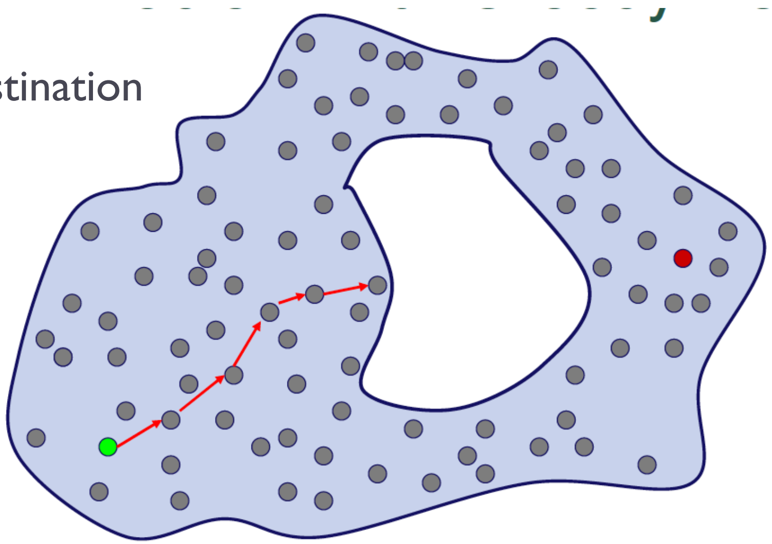
- **Name dependent schemes**: e.g. TZ scheme, BC scheme, etc.
- **Name independent schemes**: e.g. Abraham scheme

Greedy Geometric Routing

- **Updatefull**: Internet topology graph embedding into hyperbolic plane (requires full view topology graph)
- **Updateless**: graph constructed from hidden hyperbolic space yielding to scale-free topologies

Geometric routing

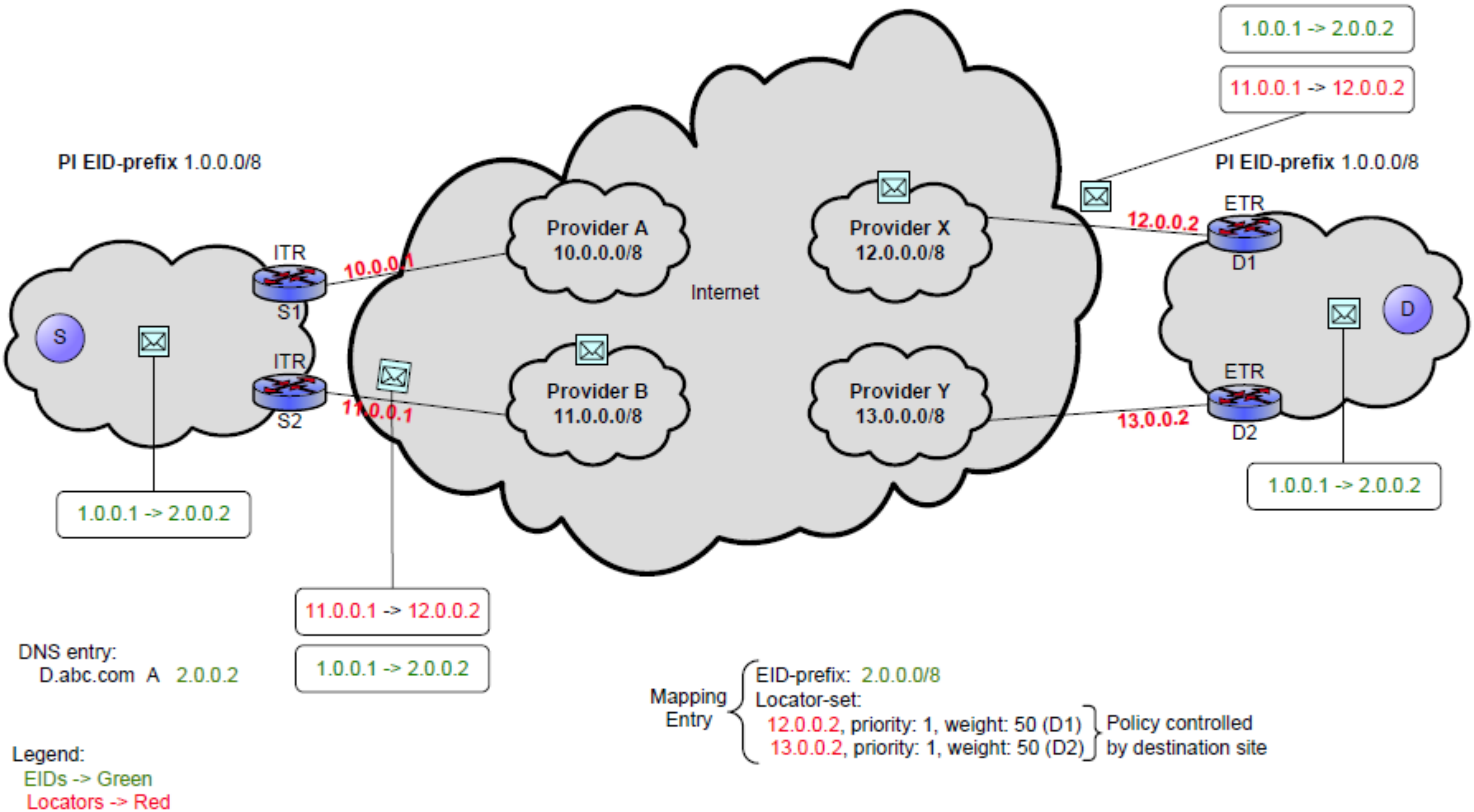
- Principle
  - relies on geographic position information
  - source sends a message to the geographic location of the destination instead of using the network address
- Requirements
  - each node determines its own location
  - source is aware of the location of the destination
  - with this information a message can be routed to the destination without knowledge of the network topology or a prior route discovery
- Routing decision
  - forward to the neighbor that is nearest to the destination
- Problem
  - can get stuck at a local minimum (i.e. it is not able to find a global optimal solution taking only local decision in a conventional plane)



LISP

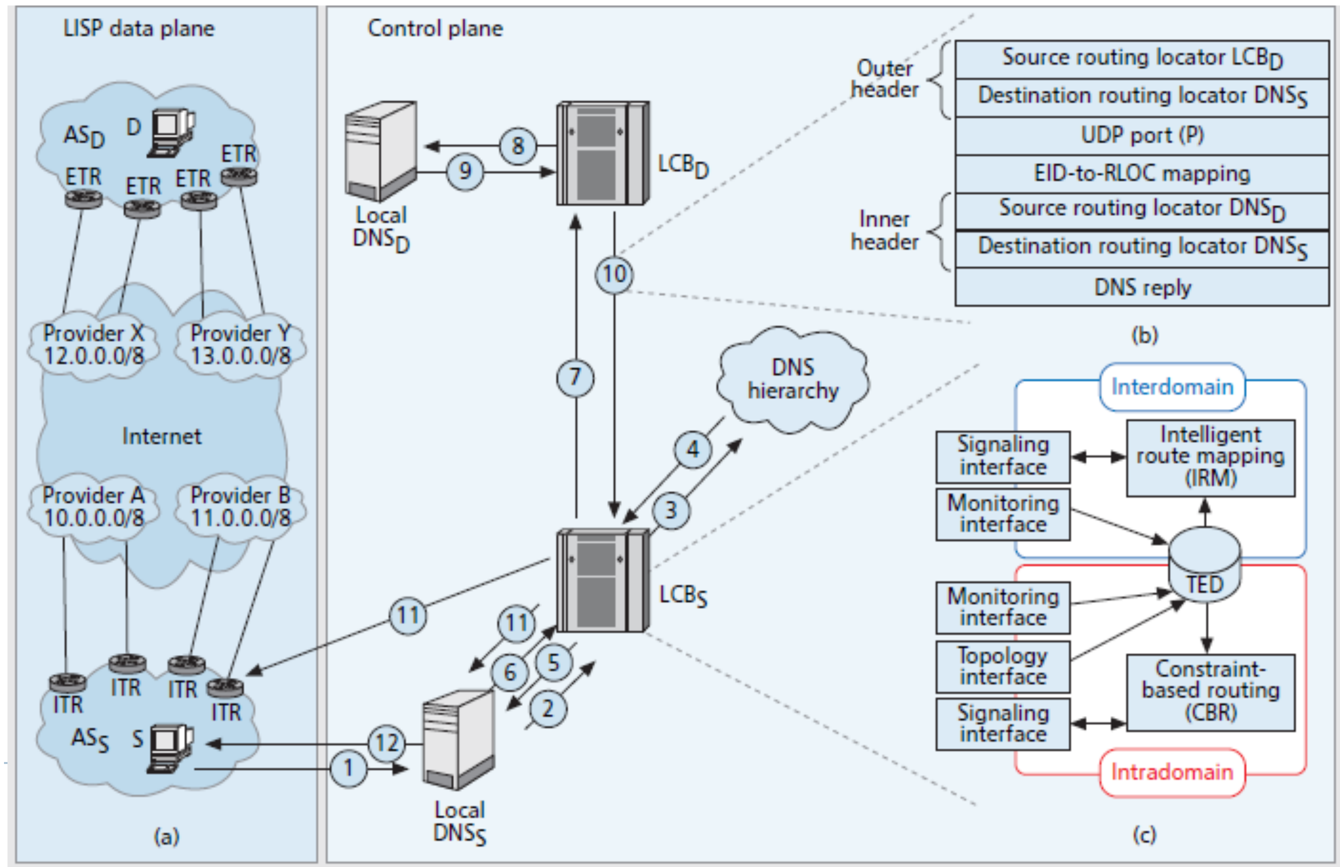
- The IP addresses currently used by endhosts play two complementary roles
  - **Identifier role**: the IP address identifies (with port) the endpoint of transport flows
  - **Locator role**: the IP address indicates the paths used to reach the endhost. These paths are updated by routing protocols after each topology change
- LISP: Locator/Identifier Separation Protocol
- IETF proposal
- Define a router-based solution where current IP addresses are separated in two different spaces:
  - Endpoint Identifier (EID): identify end-host, non-globally routable
  - Routing Locator (RLOC): Internet core address space, globally routable

LISP


PI EID-prefix 1.0.0.0/8
PI EID-prefix 1.0.0.0/8
1.0.0.1 -> 2.0.0.2
11.0.0.1 -> 12.0.0.2
ITR
S1
ITR
S2
S
10.0.0.1
11.0.0.1
Provider A
10.0.0.0/8
Provider B
11.0.0.0/8
Internet
Provider X
12.0.0.0/8
Provider Y
13.0.0.0/8
12.0.0.2
13.0.0.2
ETR
D1
ETR
D2
D
1.0.0.1 -> 2.0.0.2
1.0.0.1 -> 2.0.0.2
11.0.0.1 -> 12.0.0.2
1.0.0.1 -> 2.0.0.2
DNS entry:
D.abc.com A 2.0.0.2
Mapping Entry
EID-prefix: 2.0.0.0/8
Locator-set:
12.0.0.2, priority: 1, weight: 50 (D1)
13.0.0.2, priority: 1, weight: 50 (D2)
Policy controlled by destination site
Legend:
EIDs -> Green
Locators -> Red

LISP

- Requires an additional distributed database of EID-RLOC mappings
- Proposal
  - Obtaining and configuring the corresponding mapping during the DNS resolution process for the destination EID



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Compact routing

- Compact routing algorithms make RT sizes compact by omitting "some" network topology details such that resulting path length increase stays small

- Principle
  - given coherent full view of the network topology build routing algorithm that balances efficiently trade-off between stretch and size of RT

- Compact routing scheme
  - stretch bound by constant: does not grow with the network size
  - RT sizes scale sub-linearly: at most of the order of n bits of routing information stored per RT (per node)
  - may increase the communication cost (i.e. increase the number of control messages)

Greedy routing

- Principle of greedy
  - follow the **problem solving heuristic** of making the locally optimal choice at each stage with the hope of finding a global optimum
  - only information necessary for greedy routing to operate: coordinates of local node, its neighbors, and message destination

- Application to greedy routing
  - find the shortest paths between nodes
  - routing is performed in the dark (i.e., no routing update messages are exchanged, no knowledge of the network's global topology)
  - use the particular geometric properties of the topology to facilitate the packet routing process while keep its efficiency robust even under dynamic network conditions

- Requirement
  - require the embedding (mapping) of the network topology into an Hyperbolic plane
  - in an Euclidean (classical) plane an optimal solution cannot be found using greedy routing

Greedy routing

- Approach
  1. Build an hyperbolic space underlying the Internet topology
  2. Specify node distribution and inter-connection as a function of the hyperbolic distance between nodes
  3. Perform greedy routing in such setting

- Challenges
  - Develop technique to compute the AS/routers coordinates in the underlying hyperbolic space
    - Embedding of newly added nodes not always possible without changing coordinates of all network nodes
    - Each node shall be able to autonomously compute its hidden hyperbolic coordinates based solely on information locally accessible
  - Determine dependency of greedy routing algorithms on topologies properties

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Some recent researches

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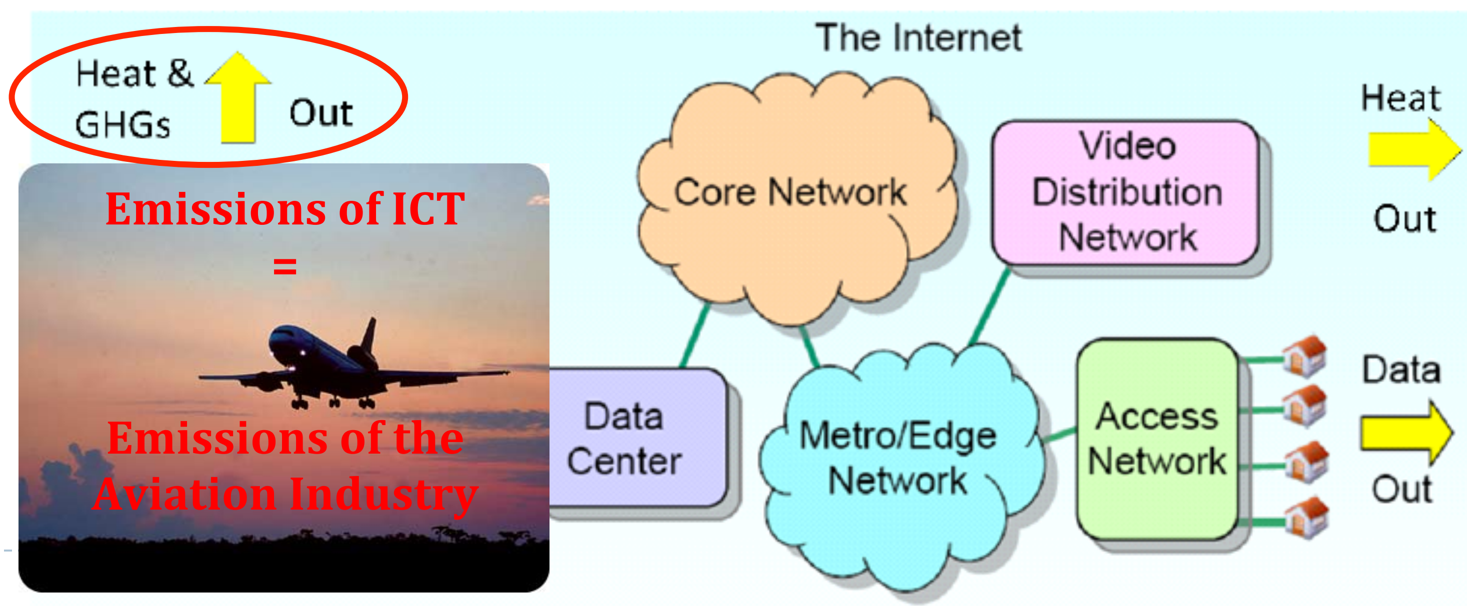
Sustainable Internet architecture

- Situation
- Problem formulation
- Some reference solutions
- Some references

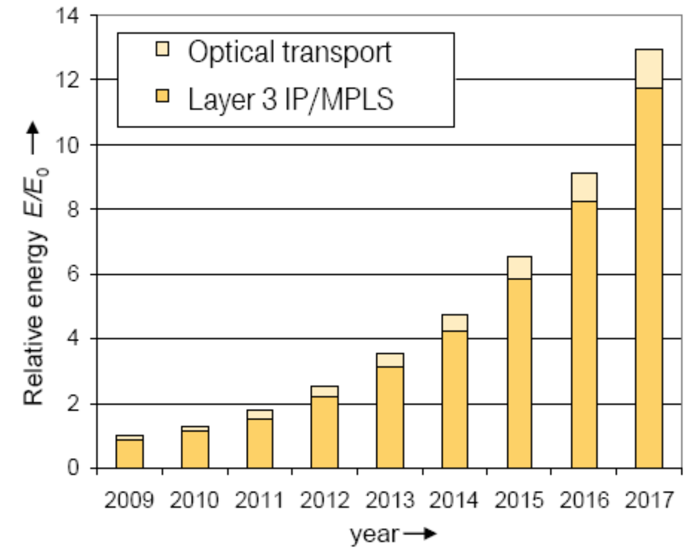
Scenario (1/2)

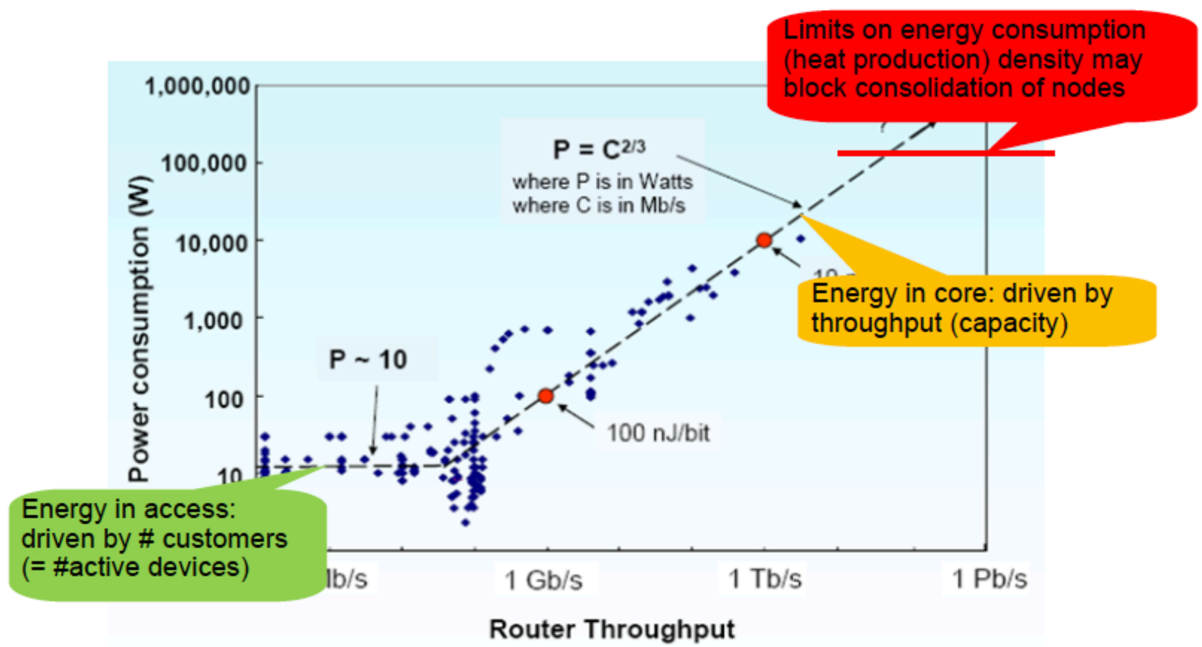
- ICT consumes two times energy
  - Powering devices
  - UPS + Cooling (HVAC, Heating Ventilation and Air Conditioning)
- Energy consumption means GreenHouse Gases (GHG) emissions
  - Climate changes, global warming & dimming, pollution
  - Major contributors to the GH effect:
    - water vapor, carbon dioxide CO_2, methane, ozone, nitrous oxide, chlorofluorocarbons



Scenario (2/2)

- Current situation and trend
- Access networks
  - major contributor to the energy consumption
  - replacement of current copper technologies with mobile and optical infrastructure reduces considerably the energy consumption
- Core networks
  - the energy consumption for IP routers is becoming a bottleneck
  - in Japan it is expected that by 2015, IP routers will consume 9% of the nation's electricity.





Problem formulation (1/3)

- Define protocols, algorithms, architecture, devices, etc. able to reduce the overall energy consumption
- BUT pay attention to the rebound effect
  - i.e. do we really reduce GHG emissions increasing the energy efficiency?

Rebound effect

increased energy efficiency

⇓

overall reduced costs

⇓

increased demand

⇓

energy consumption increases

⇓

GHG emissions overtake the offset gained by energy efficiency

Problem formulation (2/3)

- Energy-efficiency
  - refers to a technology designed to reduce the equipment energy consumption without affecting the performance, according to the do more for less paradigm. It takes into account the environmental impact of the used resources and constraints the computations to be executed taking into account the ecological and potentially the economic impact of the used resources. Such solutions are usually referred to as eco-friendly solutions.
- Energy-awareness
  - refers to an intelligent technology that adapts its behavior or performance based on the current working load and on the quantity and quality of energy that the equipment is expending (energy-feedback information). It implies knowledge of the (dirty or green) sources of energy that supply the equipment thus differentiating how it is currently being powered. Energy-aware solutions are usually referred to as eco-aware solutions.
- Energy-oriented Infrastructures
  - Energy-Efficiency + Energy-Awareness

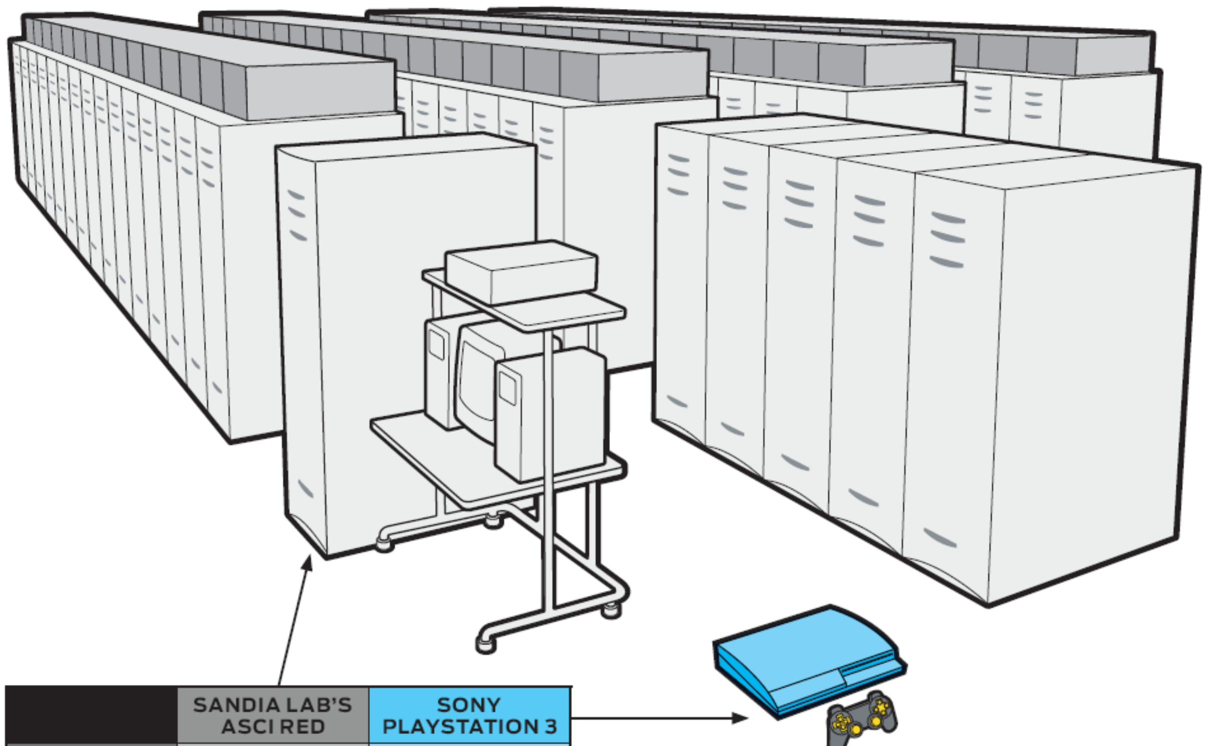
Problem formulation (3/3)

- Targets
  - Consider Energy as an additional constraint
  - Consider Type of Energy (dirty or renewable) as an additional input
    - Solar (thermal + photovoltaic), Aeolian, Hydropower & Tidal, Geothermic, Biomass (CO_2 emissions)

Examples: energy-efficiency

- Doing more with less

SUPERCOMPUTER VS. GAME CONSOLE

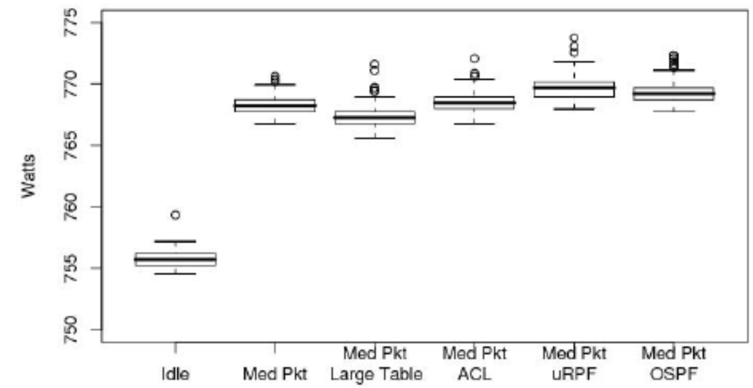


	SANDIA LAB'S ASCI RED	SONY PLAYSTATION 3
DATE OF ORIGIN	1997	2006
PEAK PERFORMANCE	1.8 teraflops	1.8 teraflops*
PHYSICAL SIZE	150 square meters	0.08 square meter
POWER CONSUMPTION	800 000 watts	<200 watts

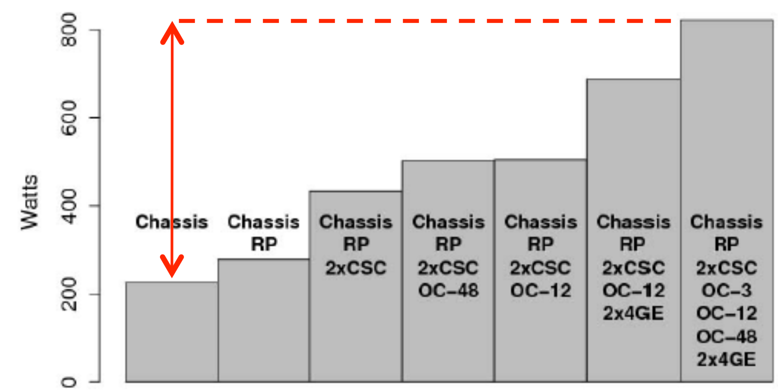
* For GPU; CPU adds another 0.2 teraflops

Examples: energy-awareness (1/3)

- Current router architectures are not energy-aware
  - The difference between idle and heavily loaded router vary only of 3% (25 W on 750 W)
  - Energy consumption is a function of capacity and not use



- But power consumption of base system is less than 50% of full configuration
  - Focus on energy-aware architectures that can adapt their behavior, and so, their energy consumption, to the actual traffic loads



Power consumption for different installed line cards configurations of the GSR Cisco Router

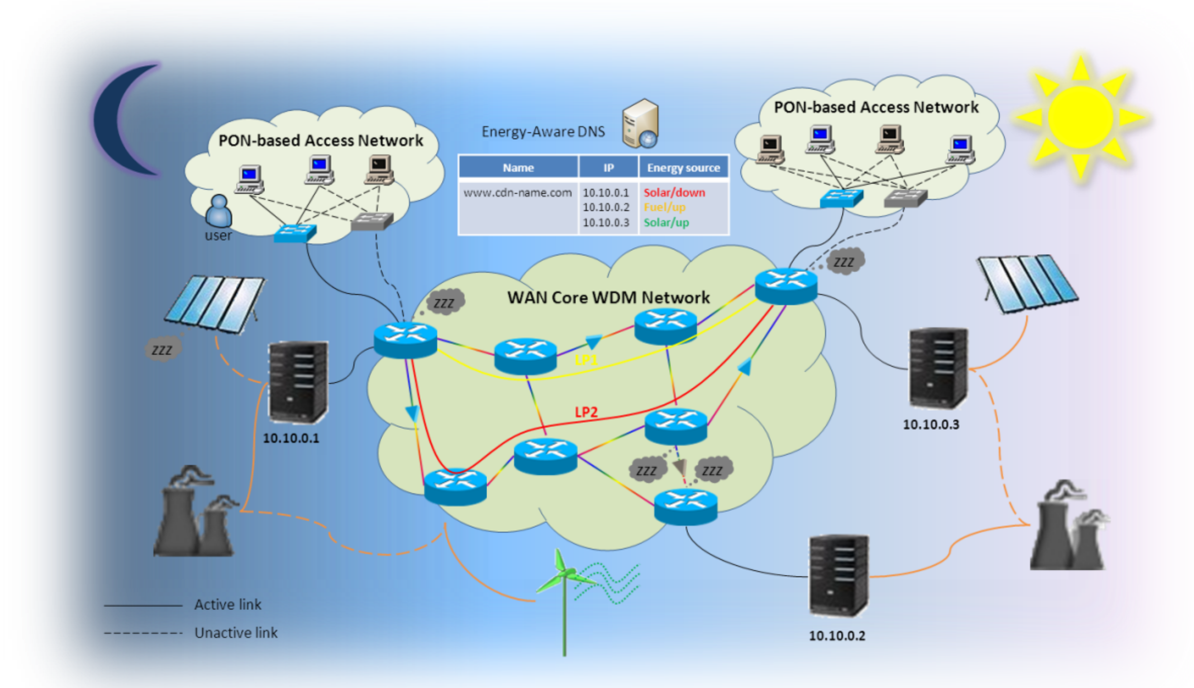
Examples: energy-awareness (2/3)

- Sleep-mode
  - switch-off or downclocking interfaces or devices when not used

- Two initial proposals for Ethernet line cards
- Adaptive Link Rate (ALR)
  - dynamically modify the link rate according to the real traffic needs
- Low Power Idle (LPI)
  - transmission on single interface is stopped when there is no data to send and quickly resumed when new packets arrive

Examples: energy-awareness (3/3)

- Consider the type of energy in network decisions



- Energy-aware OSPF-TE extension
  - disseminate information on the type and amount of energy used in each router
- Use such information in routing algorithm decisions

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New Internet architecture

- Situation
- RINA architecture in brief
- Some references

TCP/IP model

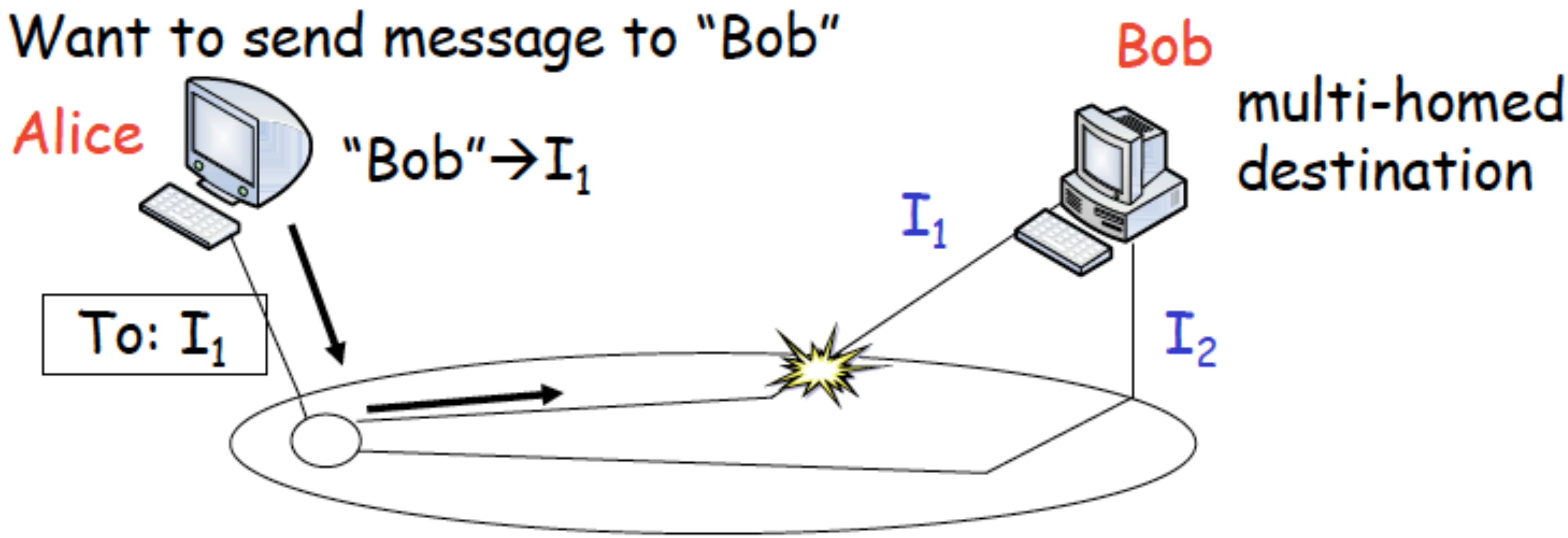
Transport (L4)
Network (L3)
Data Link (L2)
Physical (L1)

The simple model

TCP(L4)
IP(L3)
IEEE 802.3 (L2)
VXLAN(L2)
UDP (L4)
IP (L3)
IP (L3)
IEEE 802.3 (L2)
MPLS (L2.5)
IEEE 802.1q (L2)
IEEE 802.1ah (L2)
10GBASE-ER (L1)

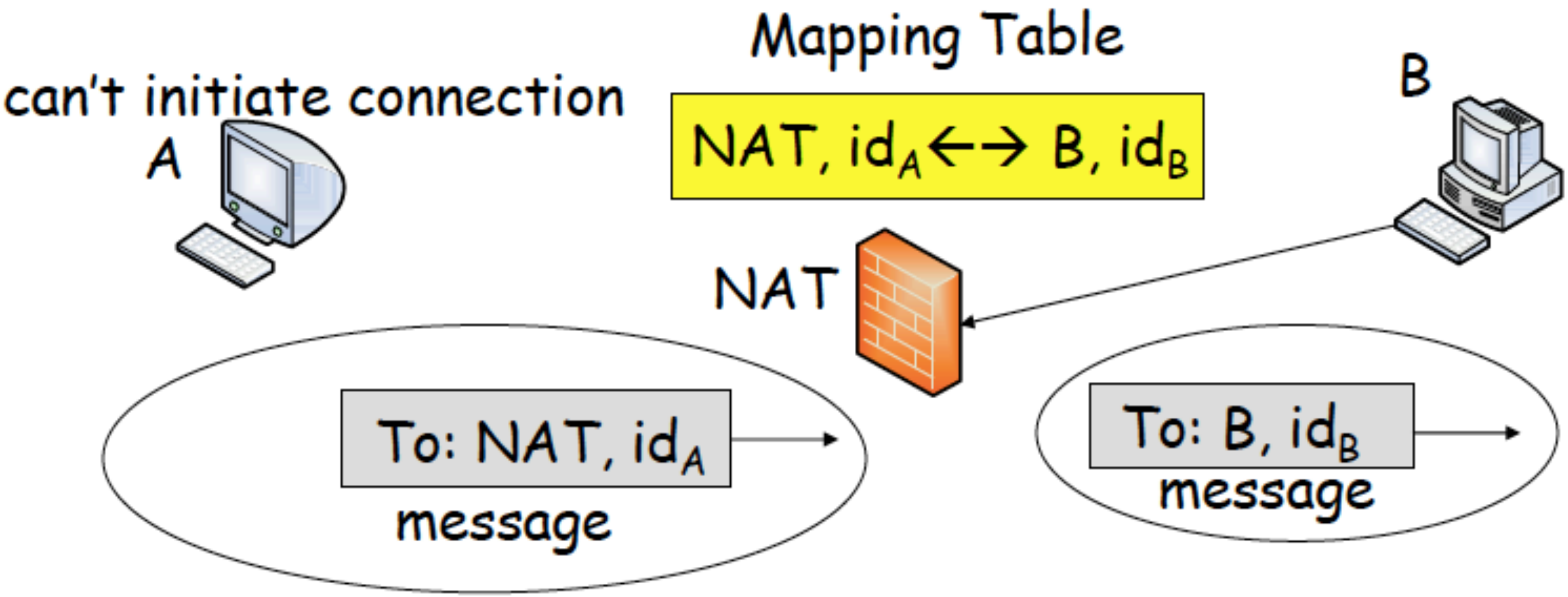
The complex reality (just an example)

Example 1 – bad addressing and routing



- Naming "interfaces" - i.e., binding objects to their attributes (Point-of-Attachment addresses) - makes it hard to deal with multihoming and mobility
- Destination application process identified by a well-known (static) port number

Example 2 – ad-hoc scalability & security



- Network Address Translator aggregates private addresses
- NAT acts as firewall
  - preventing attacks on private addresses & ports
- But, hard to coordinate communication across domains when we want to

RINA architecture

- Recursive InterNetwork Architecture
  - Based on InterProcess Communication (IPC), like in a OS between process
  - Programmable funtionalities

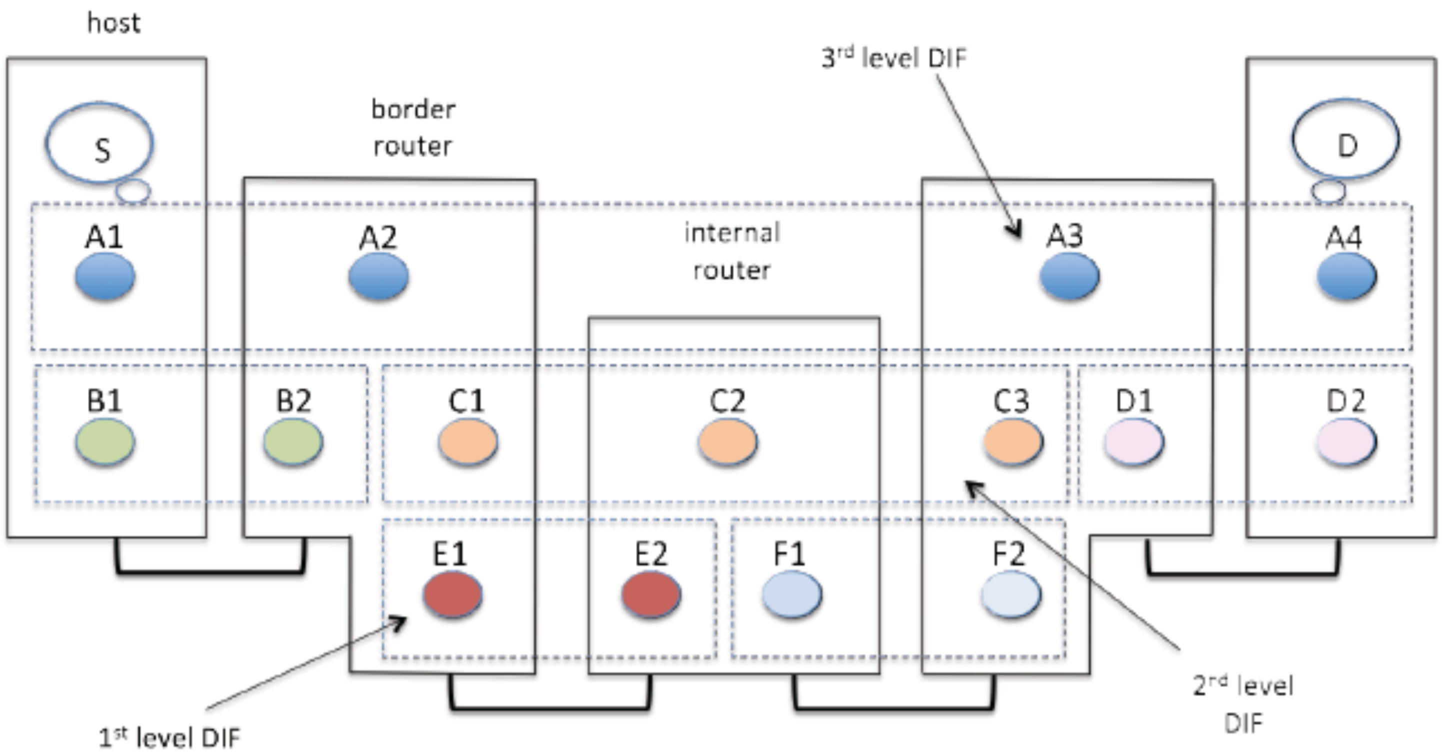
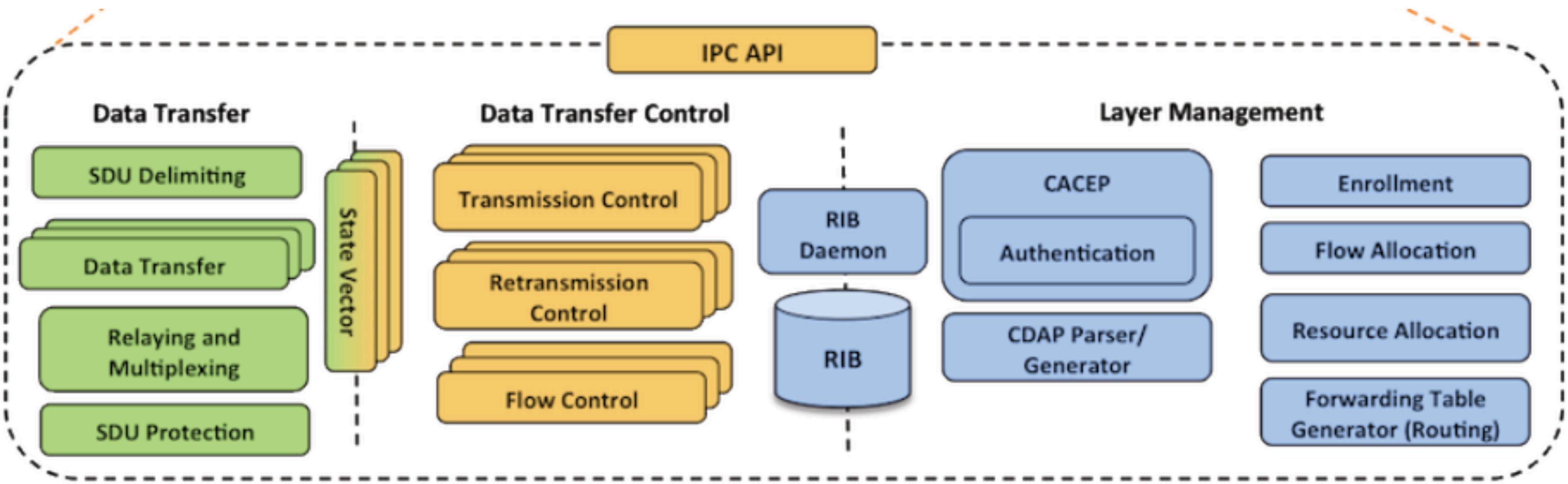


Figure 2 An example of the RINA architecture. Vertical rectangles represent systems (machines), black solid lines physical interconnections, horizontal rectangles represent DIFs and circles represent processes. Solid represent IPC processes, each color is associated to the membership of different DIFs.

RINA architecture

- Recursive InterNetwork Architecture
  - Based on InterProcess Communication (IPC)
  - Distributed IPC Facility (DIF)



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Presentation: suggested topics

- Intra-domain
  - Routing inaccuracy problem
  - RWA in optical networks
  - RSA in optical networks
- Inter-domain
  - LISP mechanism
  - Compact routing
  - Greedy routing
- New Internet models
  - Sustainability in Internet networks
  - Energy-awareness in networks
  - RINA architecture
- Others
  - SDN/OpenFlow architecture
  - Content Distribution Networks (CDN)

Presentation: recommended structure

- Outline
  - Index of the presentation
- Scenario
  - Define the context
- Problem definition/formulation
  - Define the problem/s
- Solution/s
  - Describe the details of the solution or solutions
- Summary and conclusions
  - Include personal opinion