An overview of Quality of Service in the Internet

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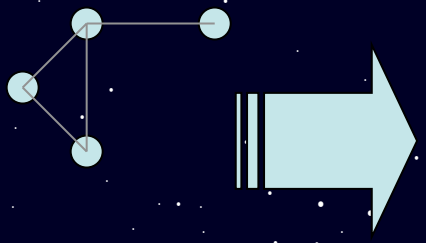
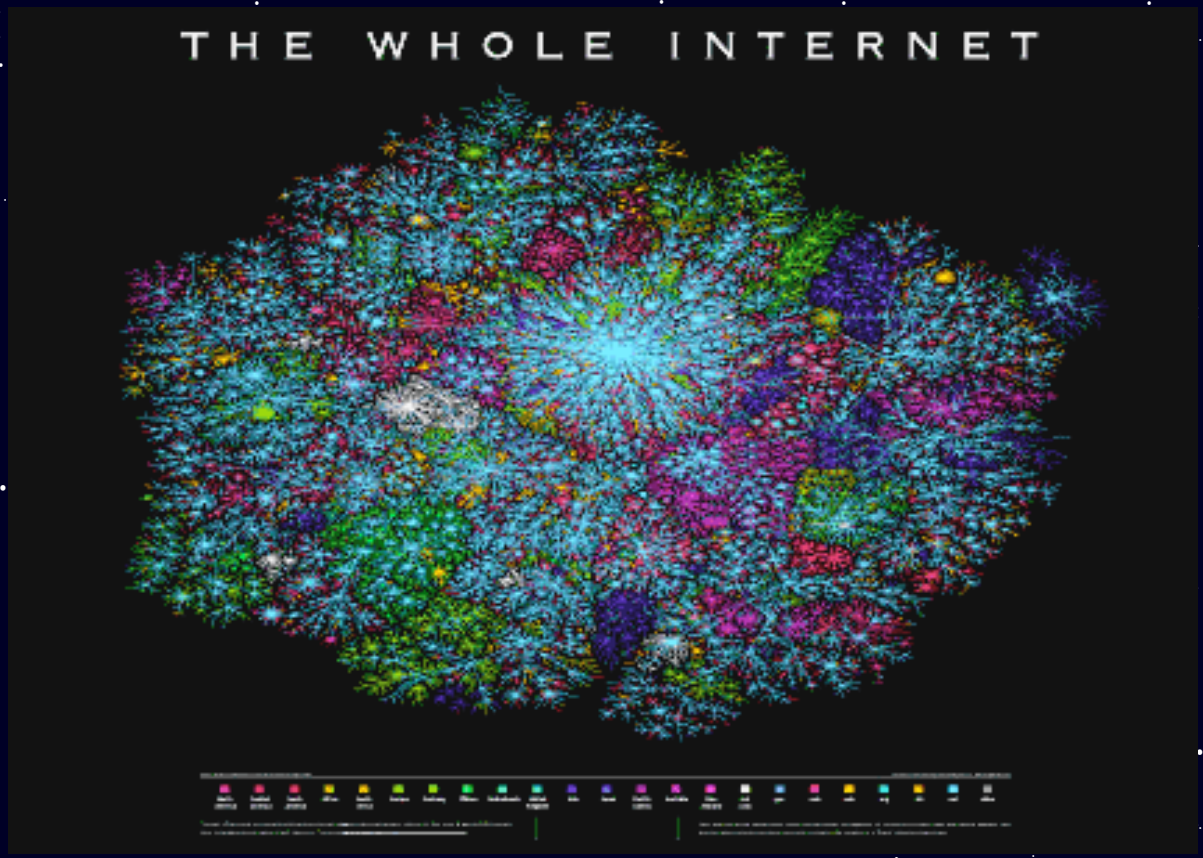
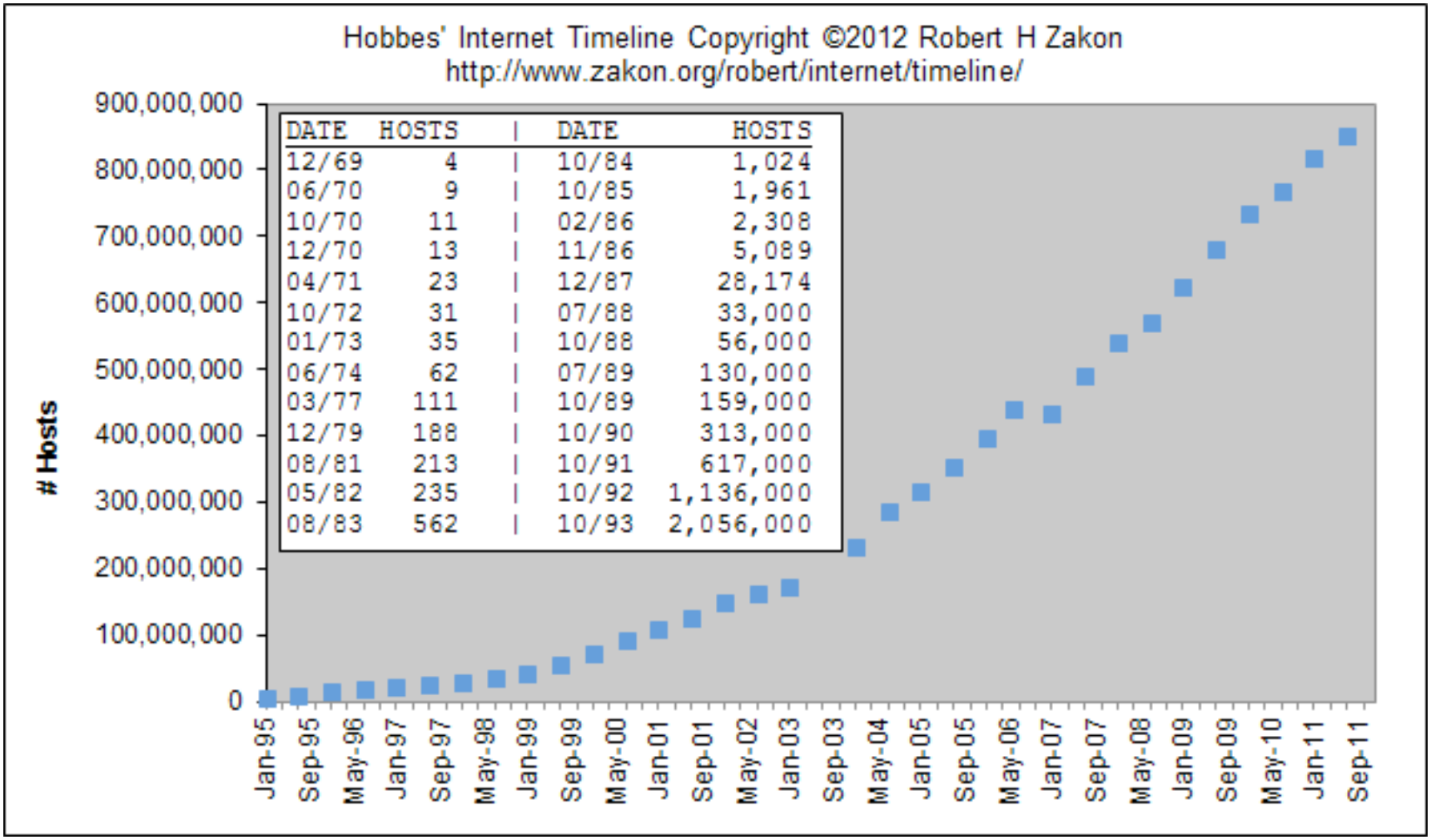
The big-bang of the Internet



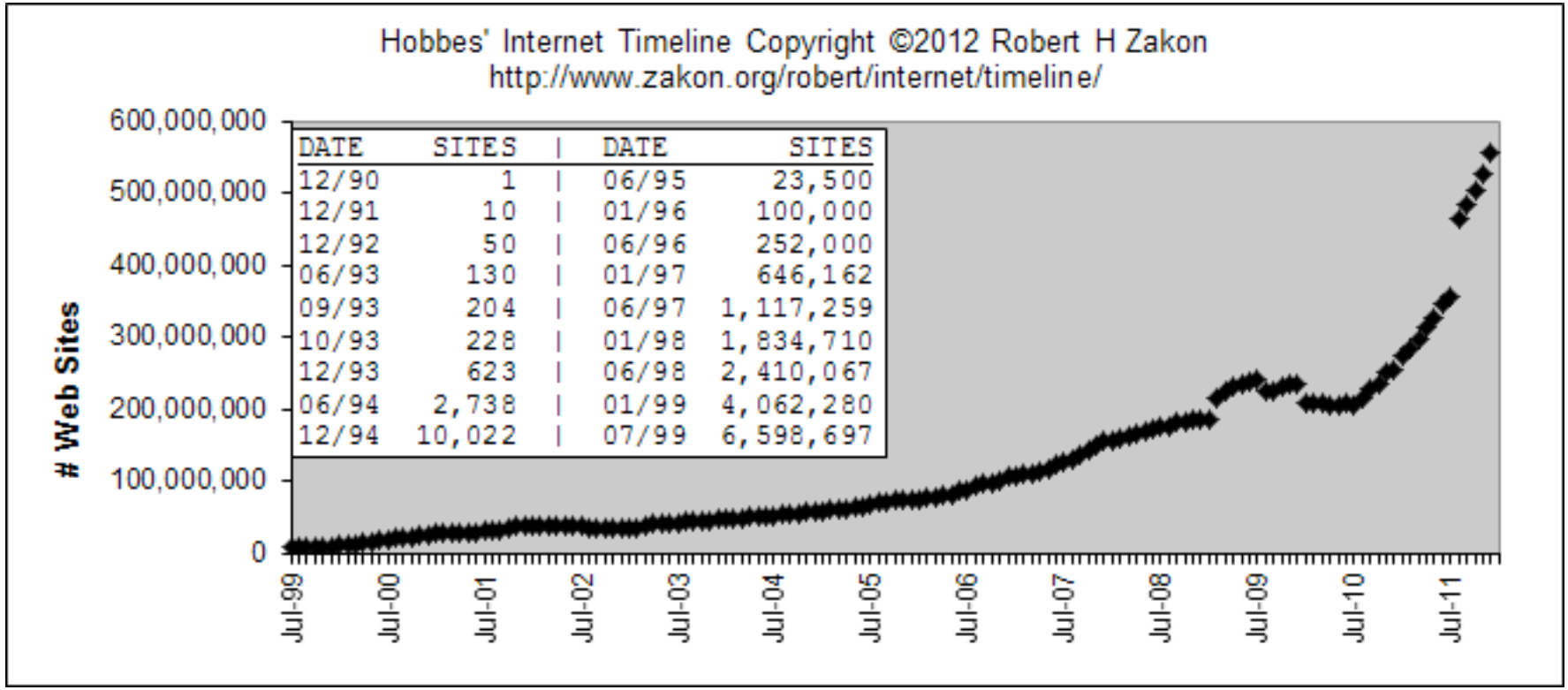


Internet host



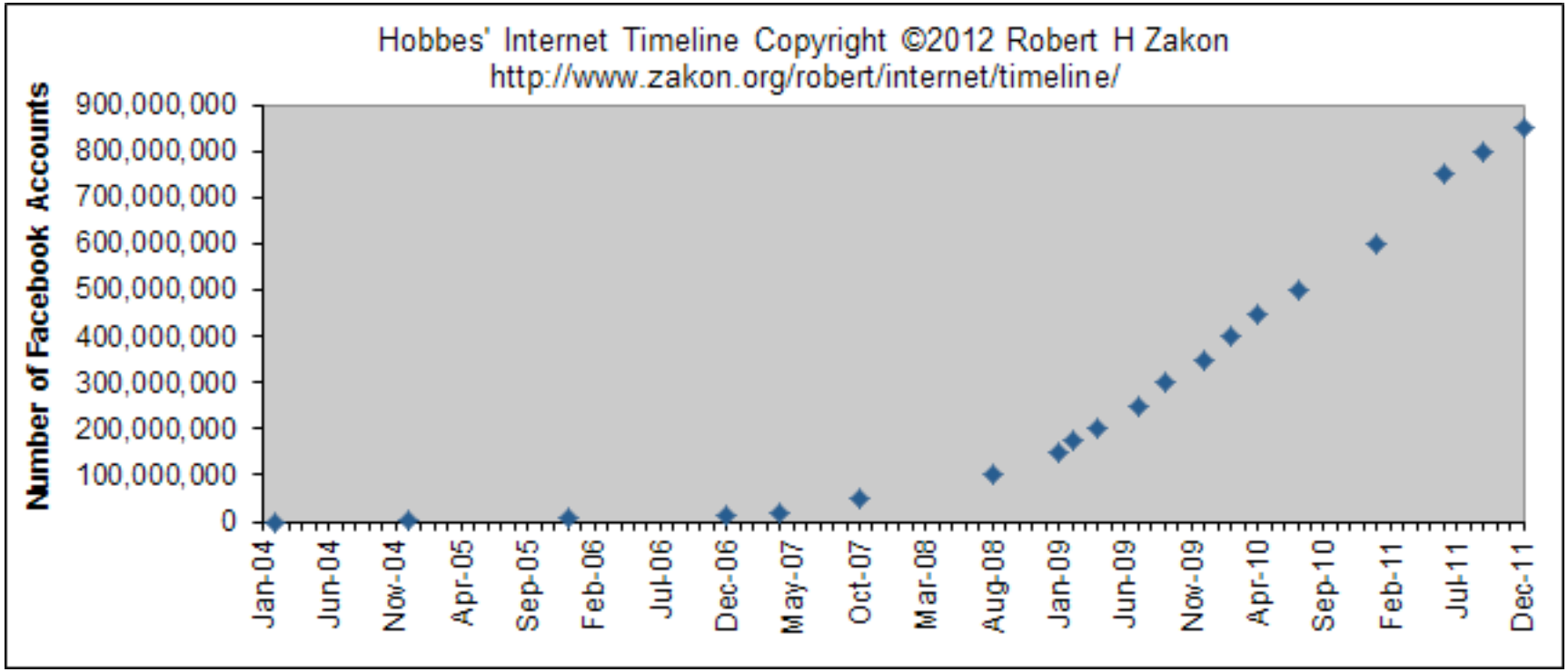
DATE	HOSTS	DATE	HOSTS
12/69	4	10/84	1,024
06/70	9	10/85	1,961
10/70	11	02/86	2,308
12/70	13	11/86	5,089
04/71	23	12/87	28,174
10/72	31	07/88	33,000
01/73	35	10/88	56,000
06/74	62	07/89	130,000
03/77	111	10/89	159,000
12/79	188	10/90	313,000
08/81	213	10/91	617,000
05/82	235	10/92	1,136,000
08/83	562	10/93	2,056,000

of www sites



DATE	SITES	DATE	SITES
12/90	1	06/95	23,500
12/91	10	01/96	100,000
12/92	50	06/96	252,000
06/93	130	01/97	646,162
09/93	204	06/97	1,117,259
10/93	228	01/98	1,834,710
12/93	623	06/98	2,410,067
06/94	2,738	01/99	4,062,280
12/94	10,022	07/99	6,598,697

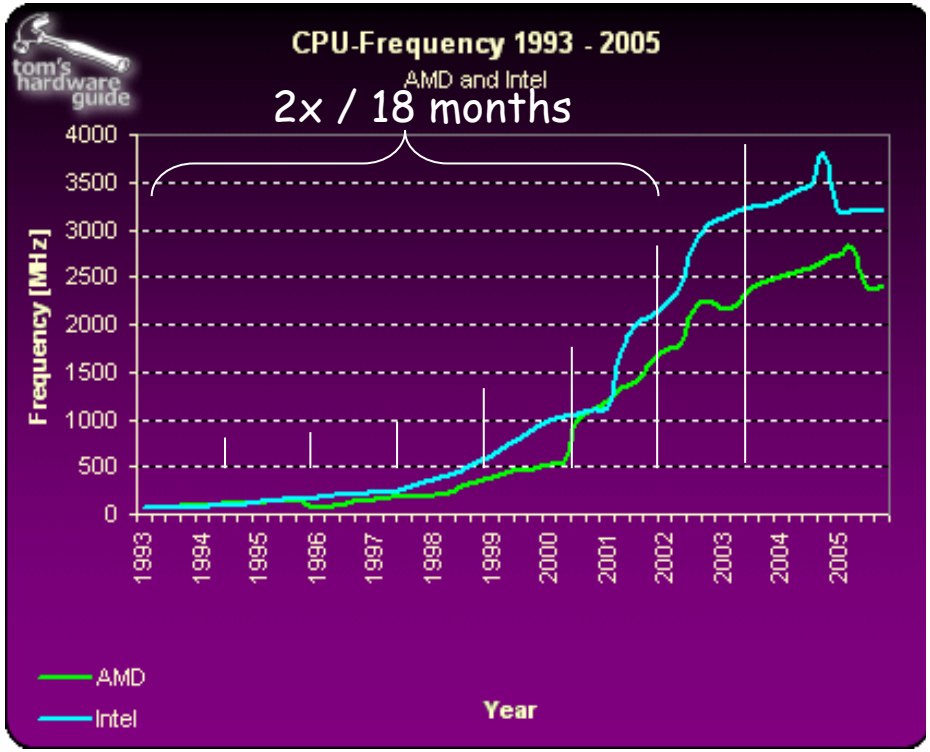
of facebook account

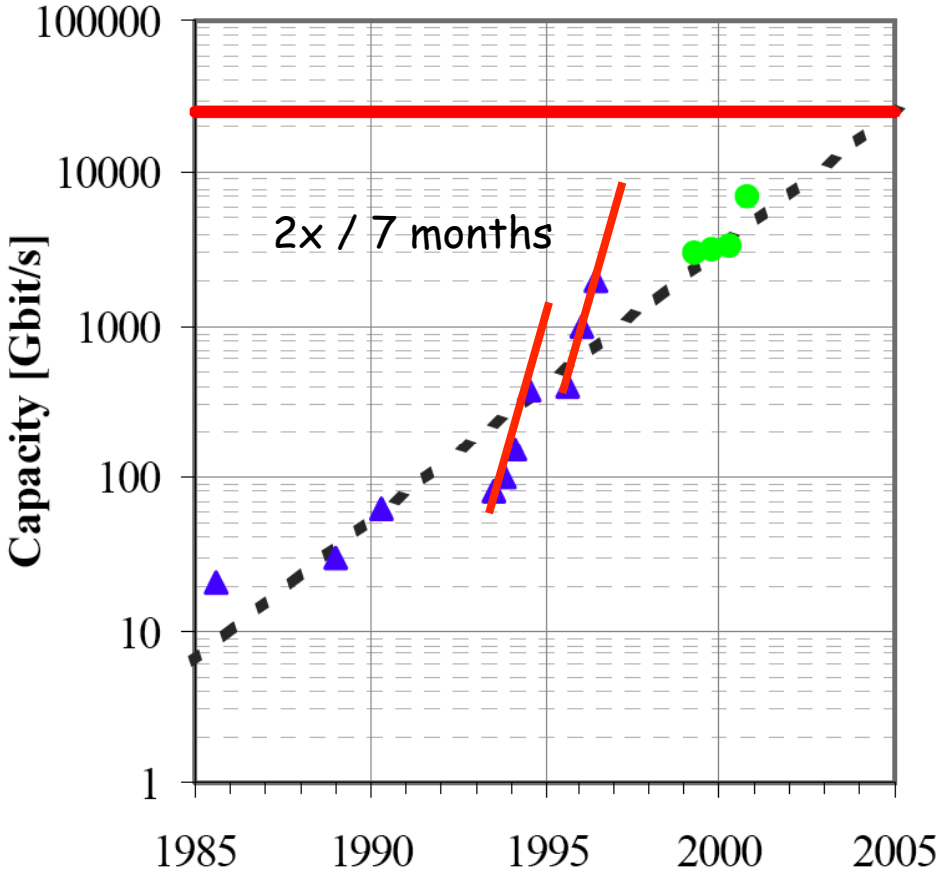


Outline

- What is Quality of Service?
- How QoS is realized in current Internet
- How it can be optimally realized
- How it can be realistically realized
- 2 leading technologies for QoS
  - DiffServ
  - MPLS

1st revolution: going optical

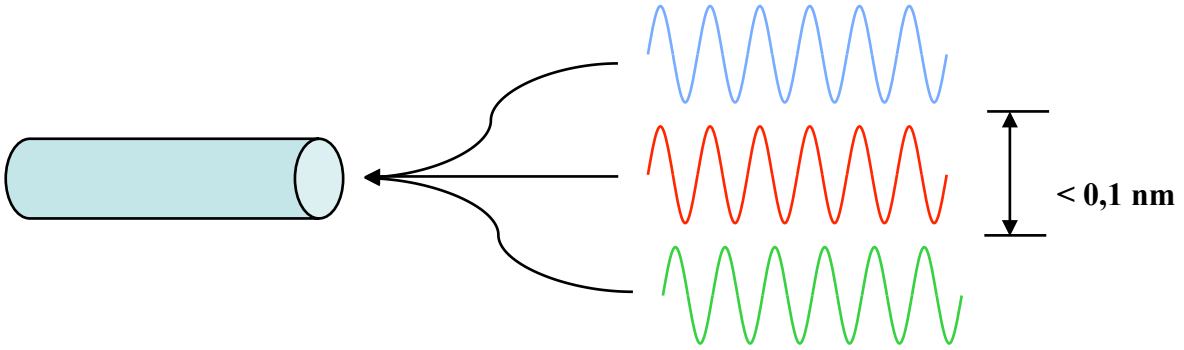


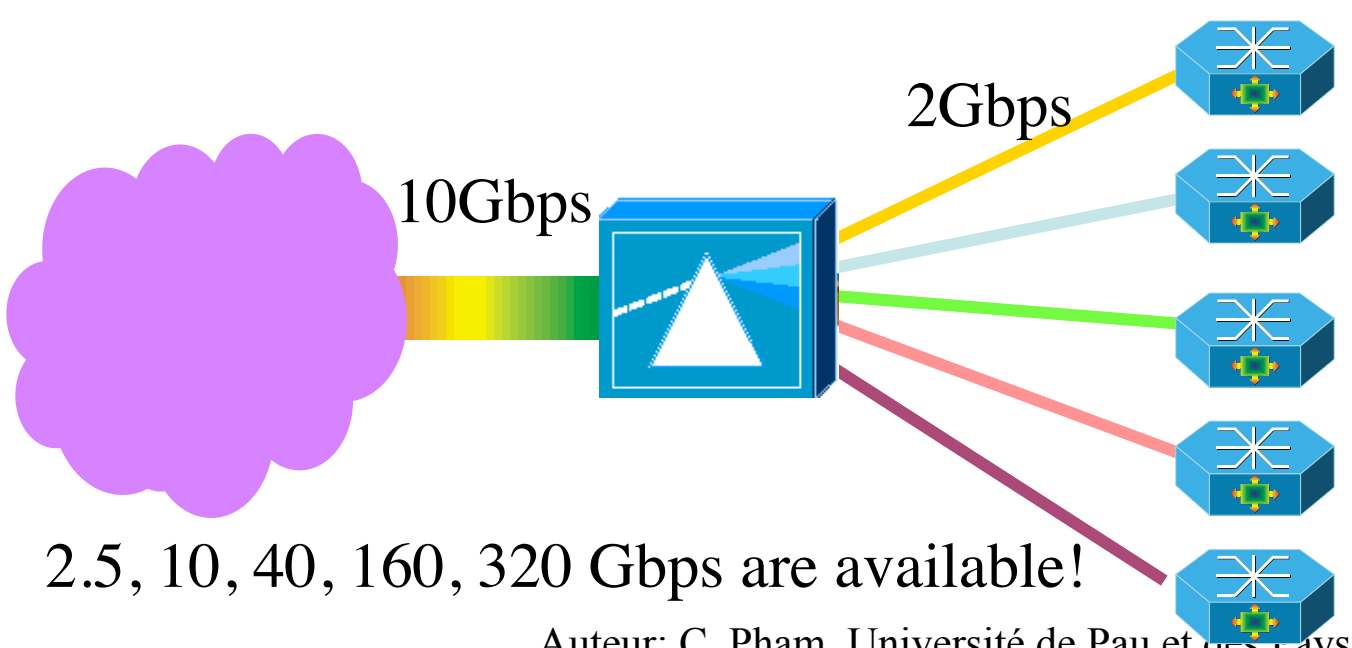


Source « Optical fibers for Ultra-Large Capacity Transmission » by J. Grochocinski

DWDM, bandwidth for free?

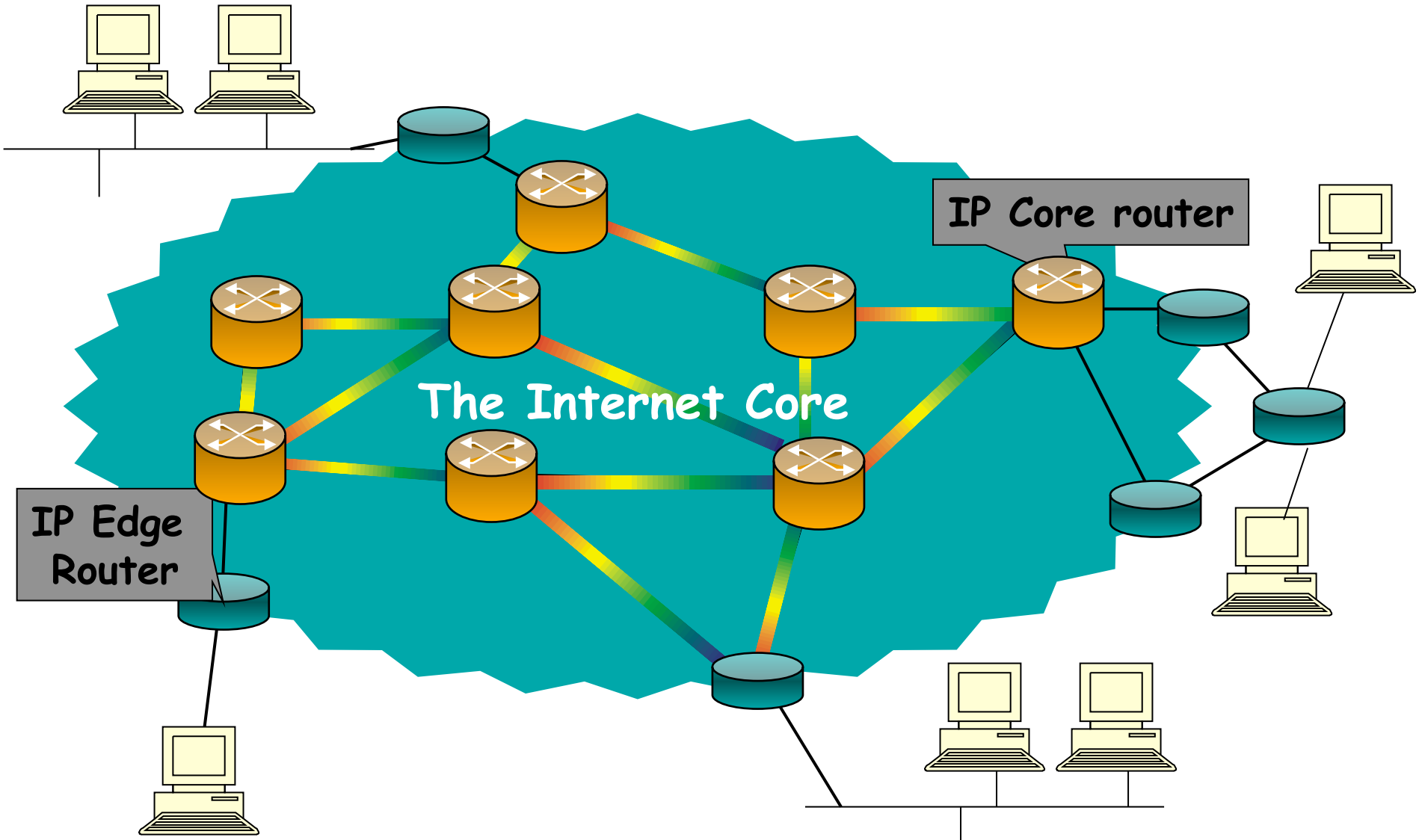
DWDM: Dense Wavelength Division Multiplexing



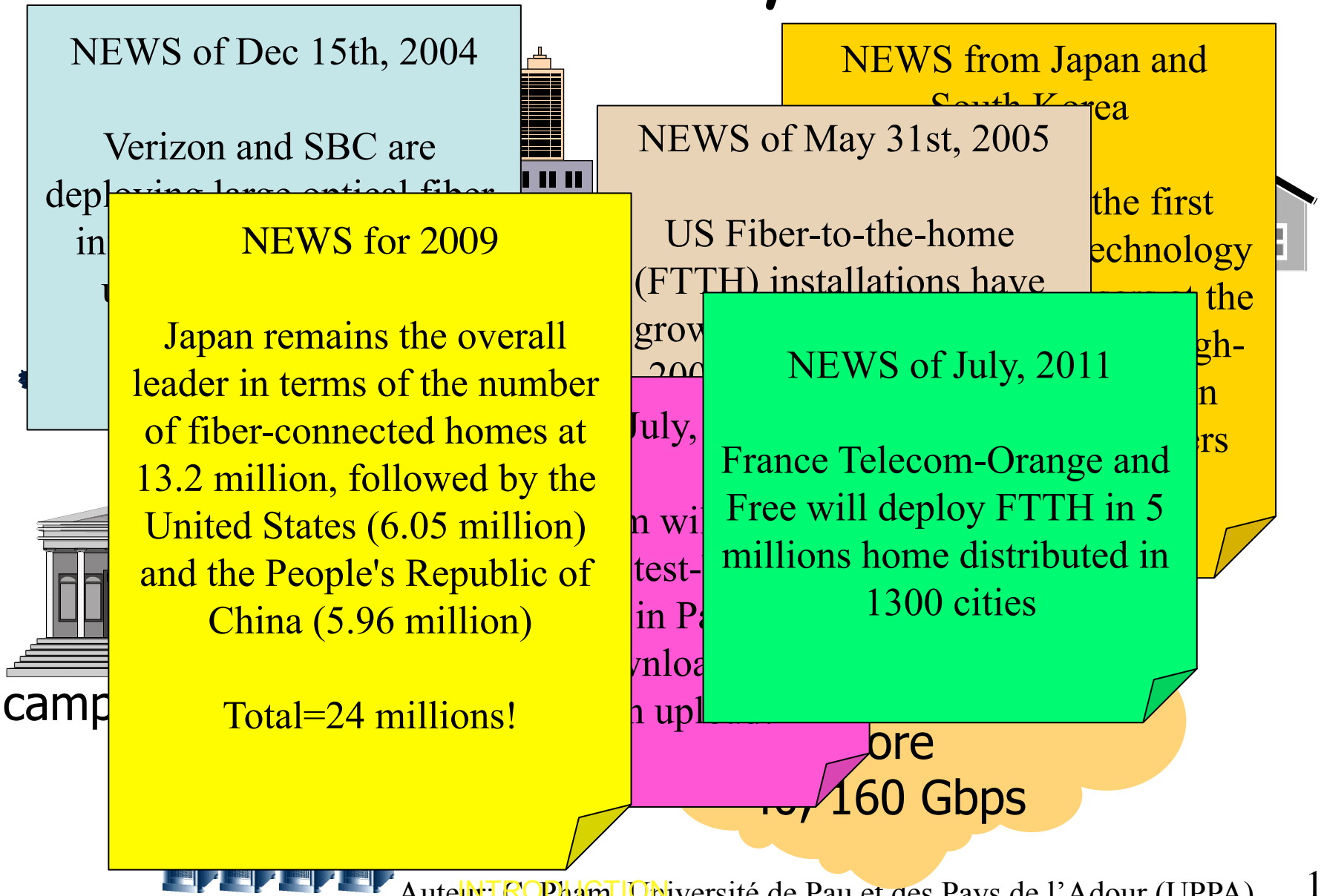


2.5, 10, 40, 160, 320 Gbps are available!

Internet core is 100% optical



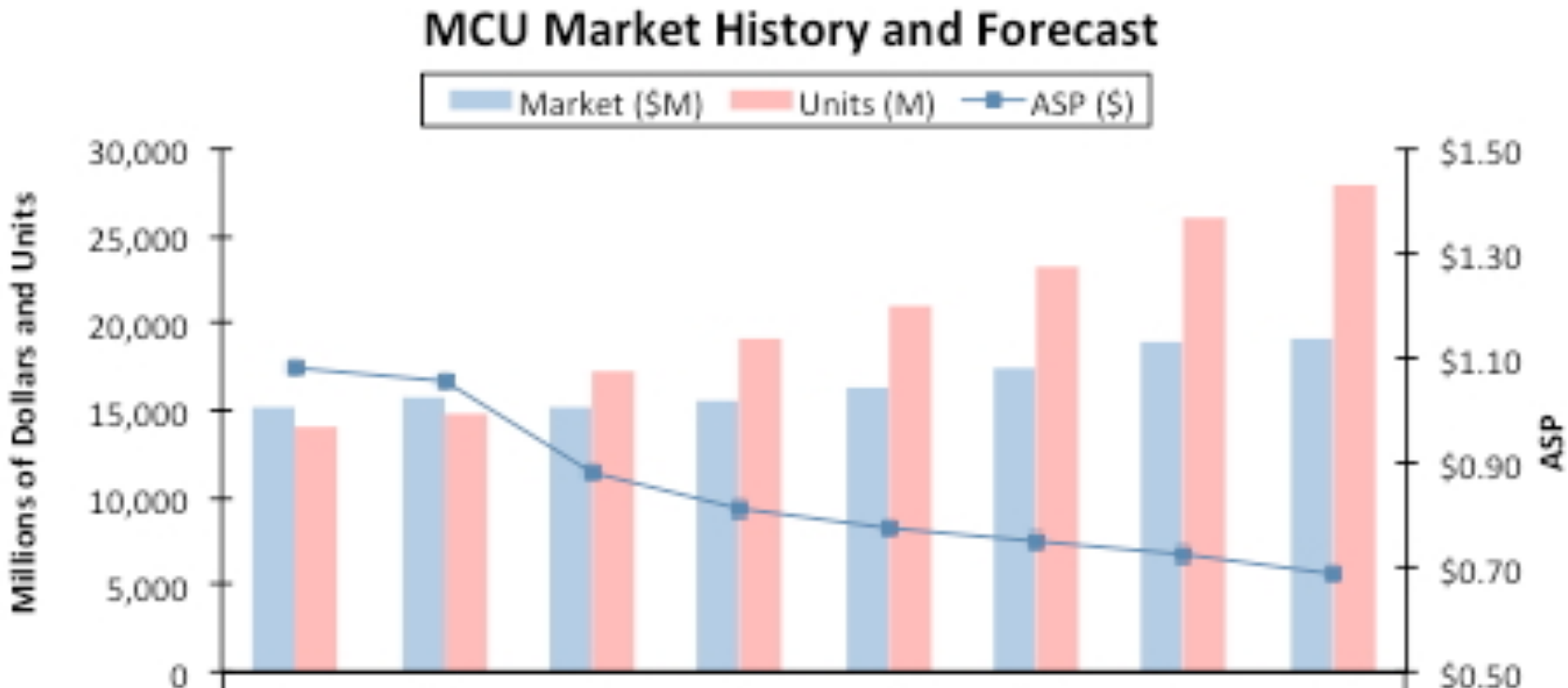
Fibers everywhere?



Handle big data!

Towards small, smart devices!

MCU sales

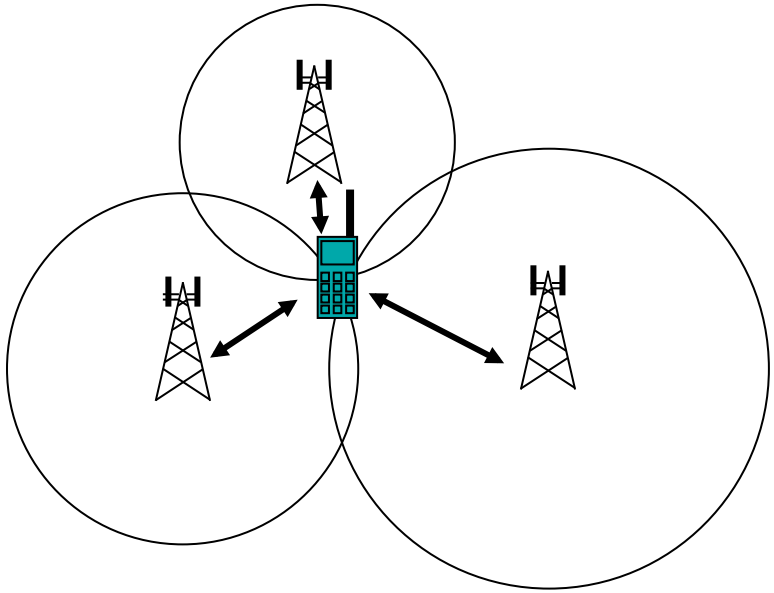


	10	11	12	13F	14F	15F	16F	17F
Market ($M)	15,166	15,716	15,168	15,518	16,281	17,451	18,970	19,208
Units (M)	14,029	14,891	17,271	19,071	21,080	23,314	26,104	27,970
ASP ($)	1.08	1.06	0.88	0.81	0.77	0.75	0.73	0.69

Source: IC Insights

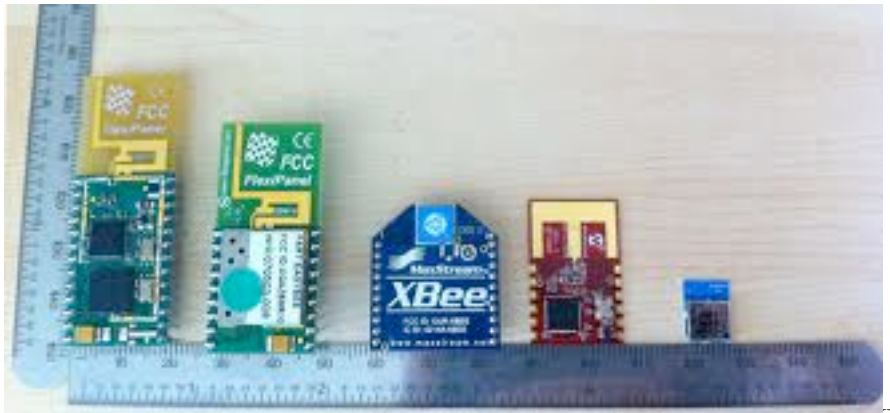
2nd revolution: Wireless Networks

- WiFi, WiMax
- BlueTooth, ZigBee, IrDA…
- GSM, GPRS, EDGE, UMTS, 3G, 4G,…



The SmartPhone revolution

Wireless communication made easy!



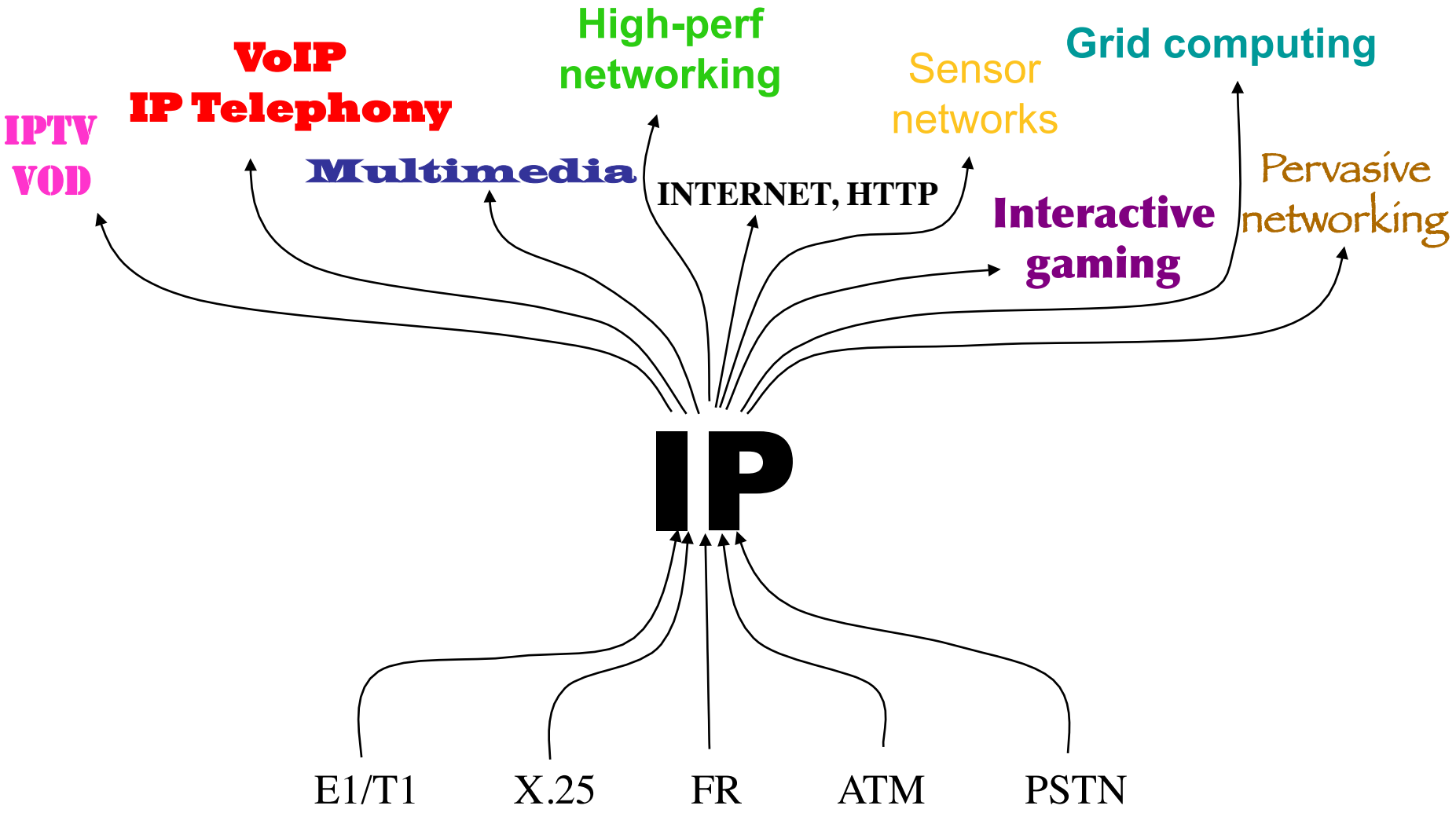
Internet of Things/ M2M

- Native communication:

- Added communication
  - Active communication

  - Passive communication

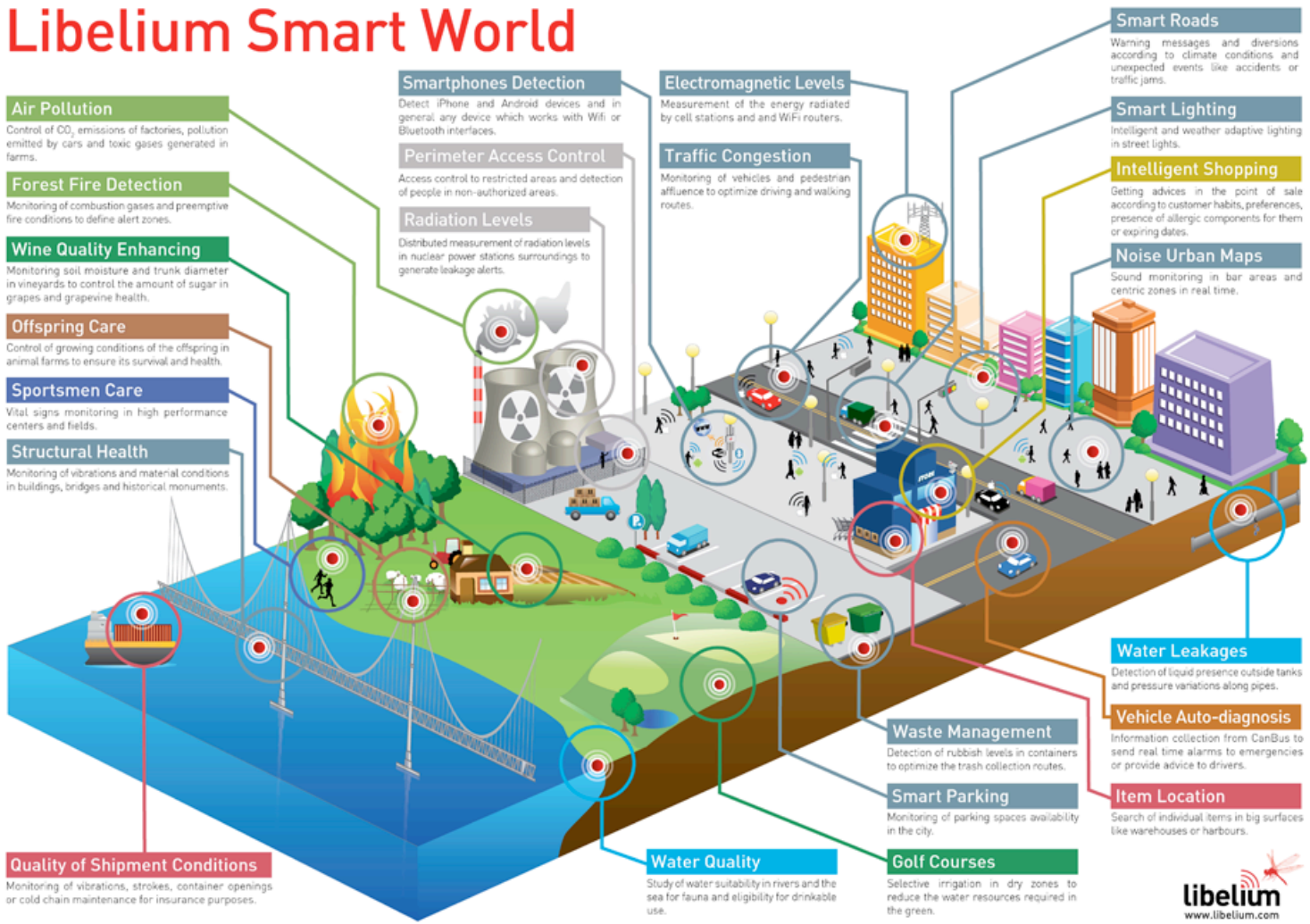
Towards all IP



Be Smart* !

- Smart…
  - City, Building, Road, Traffic
  - Agriculture
  - Farming
  - Environment: Water, Forest
  - Energy, Electricity Grid
  - Vehicule & Transportation
  - Transport & Logistic
  - Surveillance, security, safety
  - …

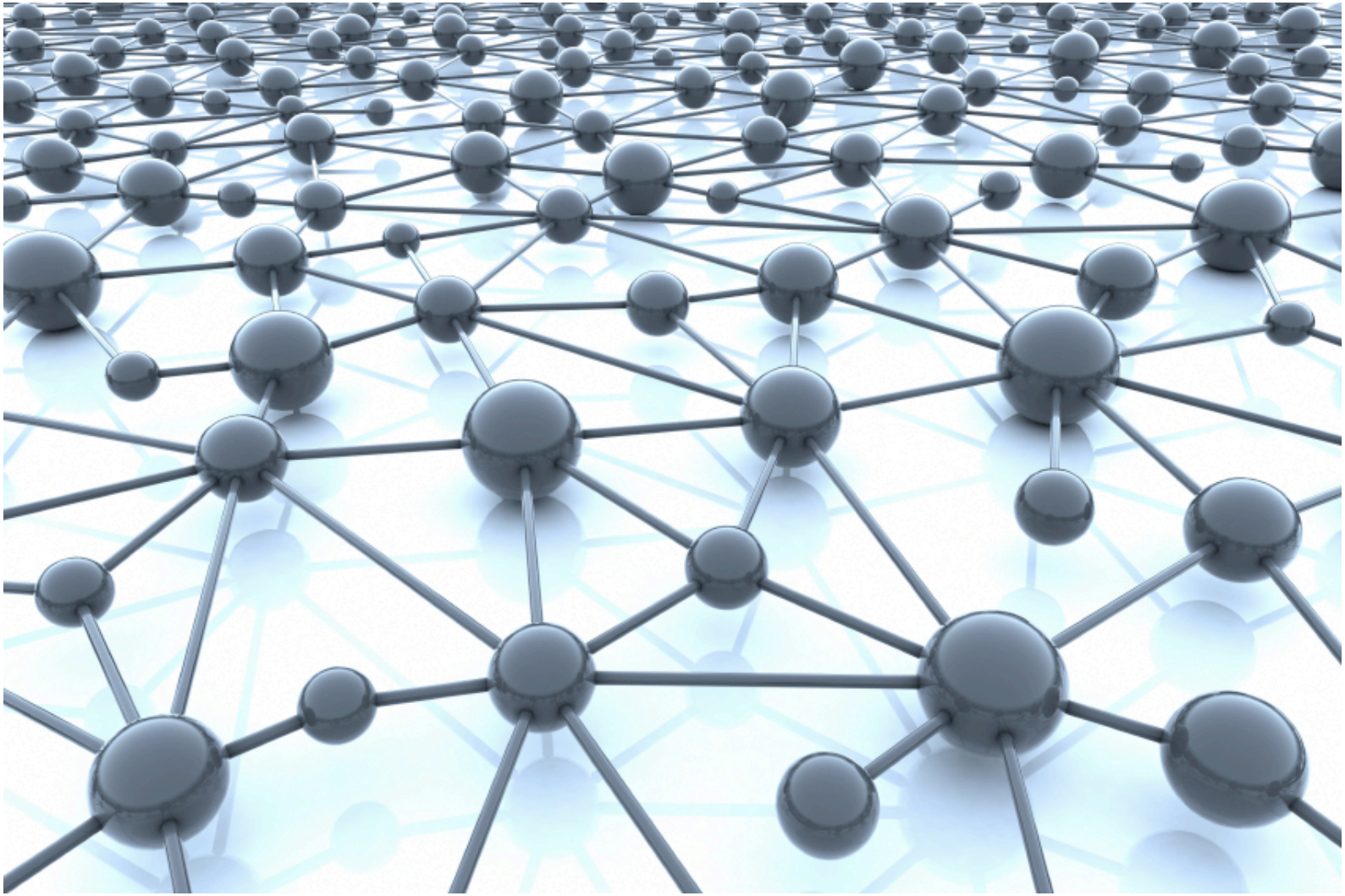
Smart Cities



HTTP://WWW.LIBELIUM.COM/TOP_50_IOT_SENSOR_APPLICATIONS_RANKING/#SHOW_INFOGRAPHIC

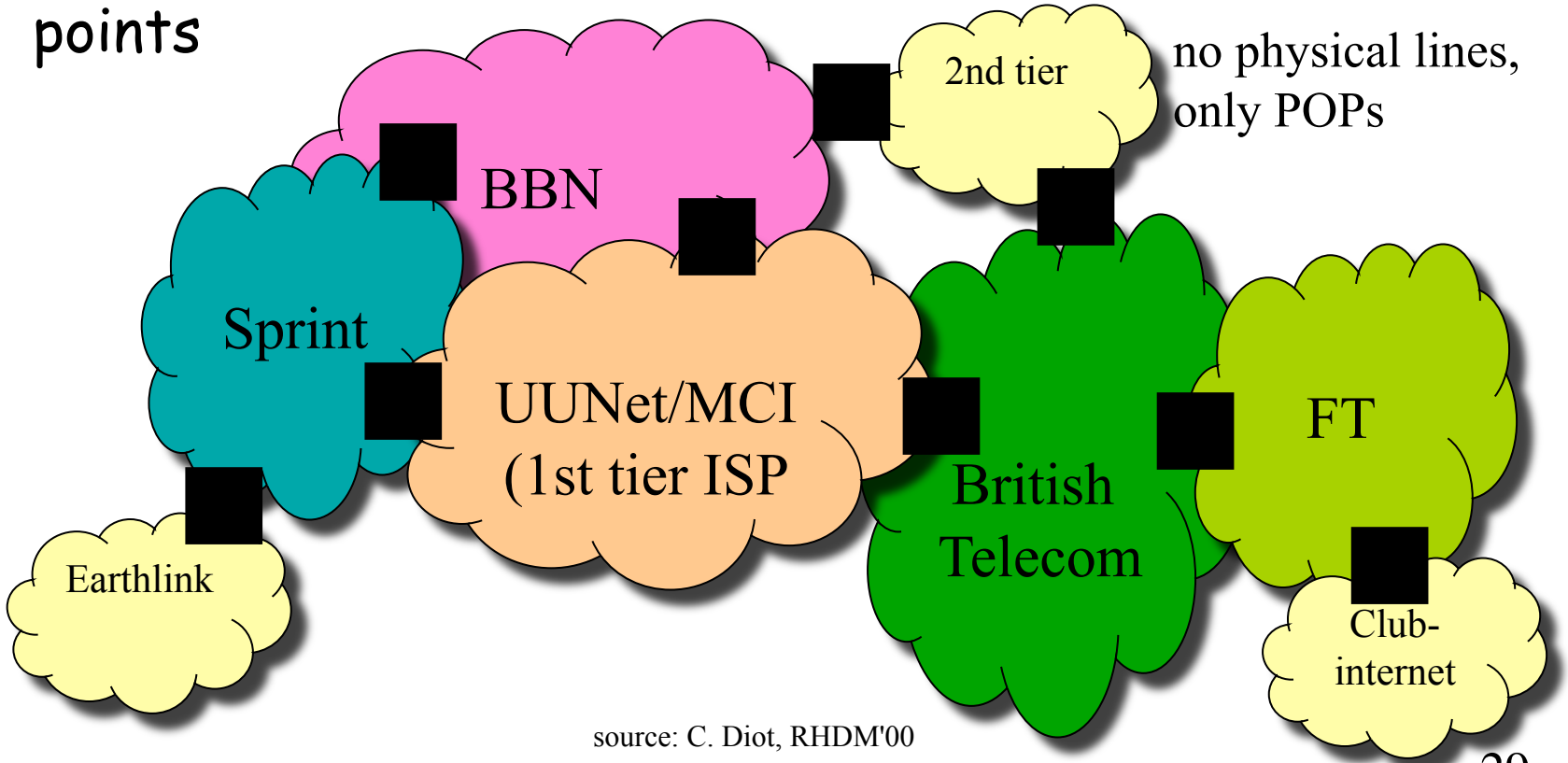
Control & Instrument

The network behind the apps



Operators and ISPs: they rule the Internet

- « 1st tier ISP » own their lines.
- Interconnections happen mostly at private peering points

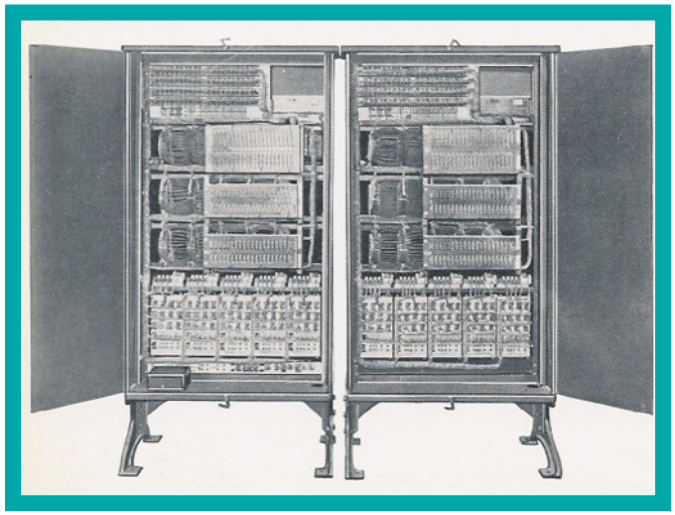


source: C. Diot, RHDM'00

Back in time:
The telephone system & network

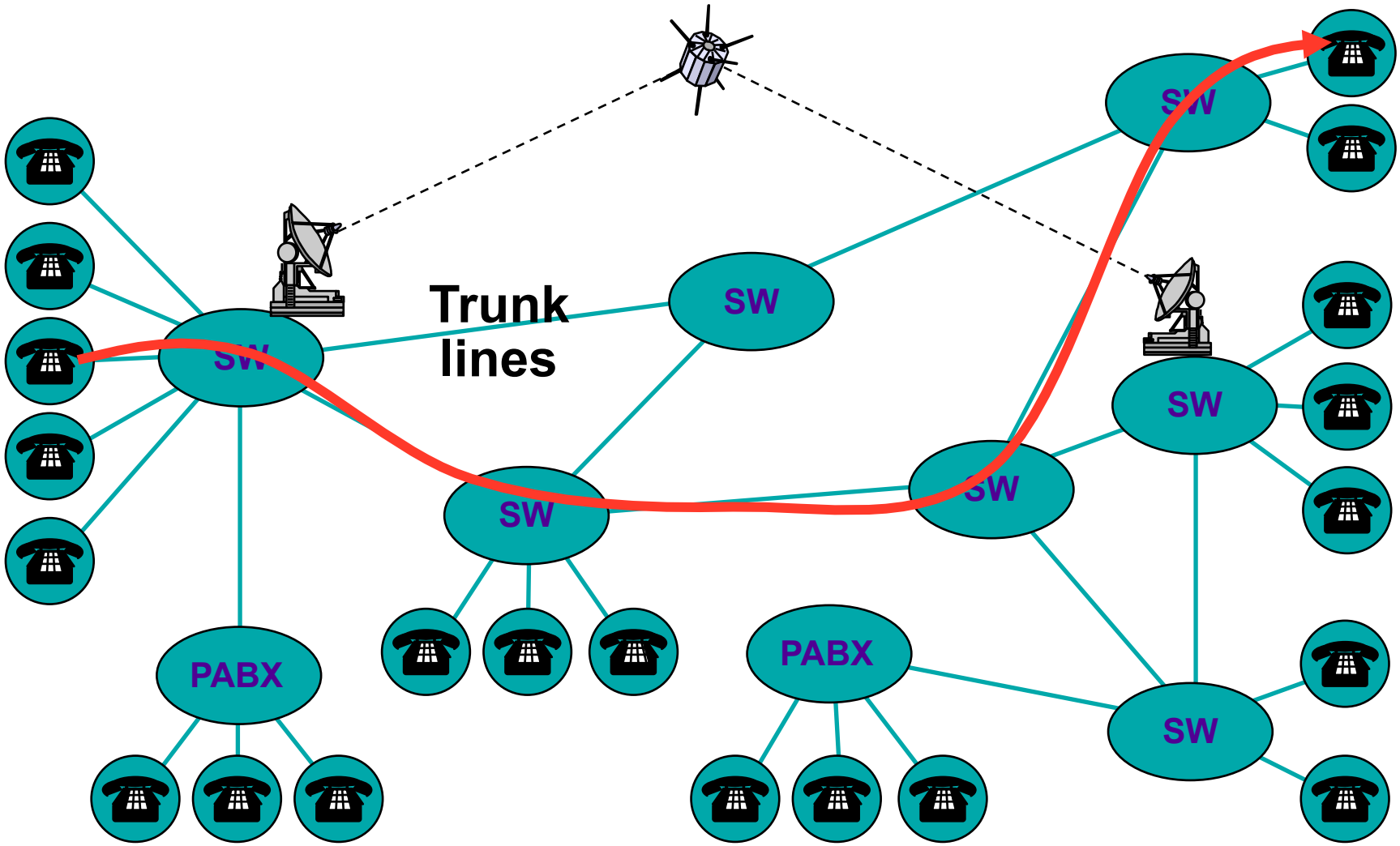
First automatic Branch Exchange Almond B. Strowger, 1891…

Signaling replaces the operator

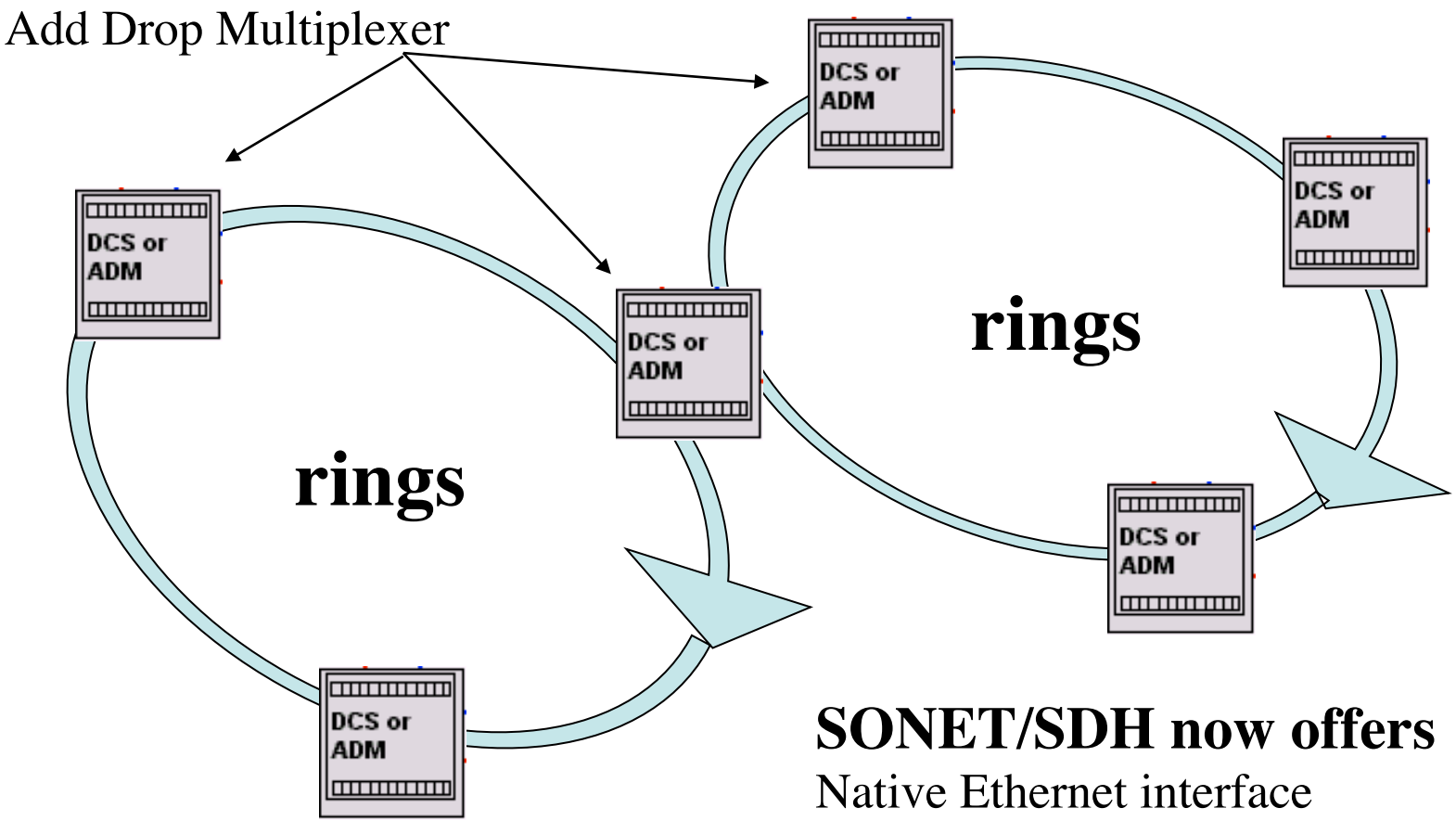


Source J. Tiberghien, VUB

The telephone circuit view



SONET/SDH transport network infrastructure



SONET/SDH now offers

Native Ethernet interface

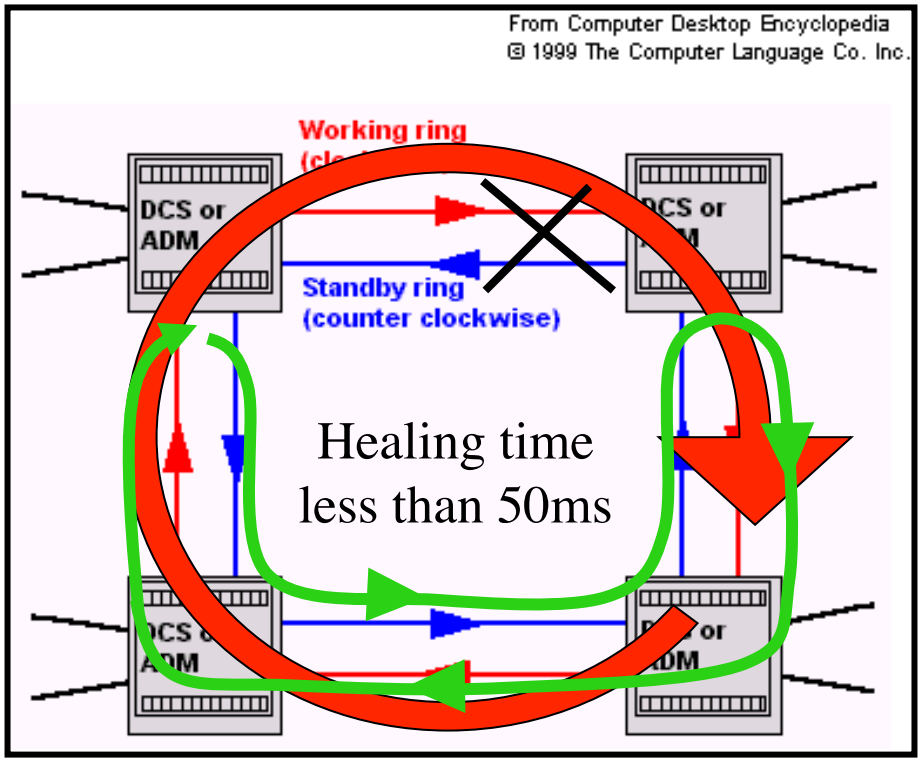
Generic Framing Procedure

Virtual Concatenation

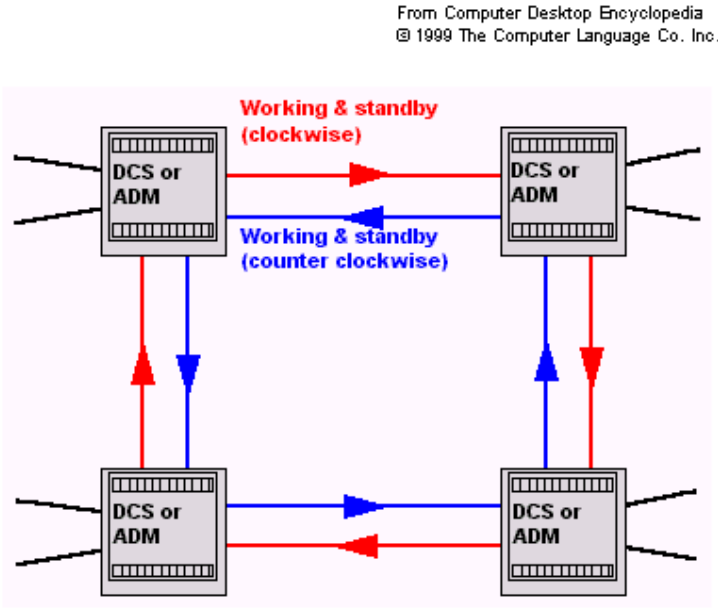
SONET/SDH and resiliency

- SONET/SDH has built-in fault-tolerant features with multiple rings
- Ex: simple case

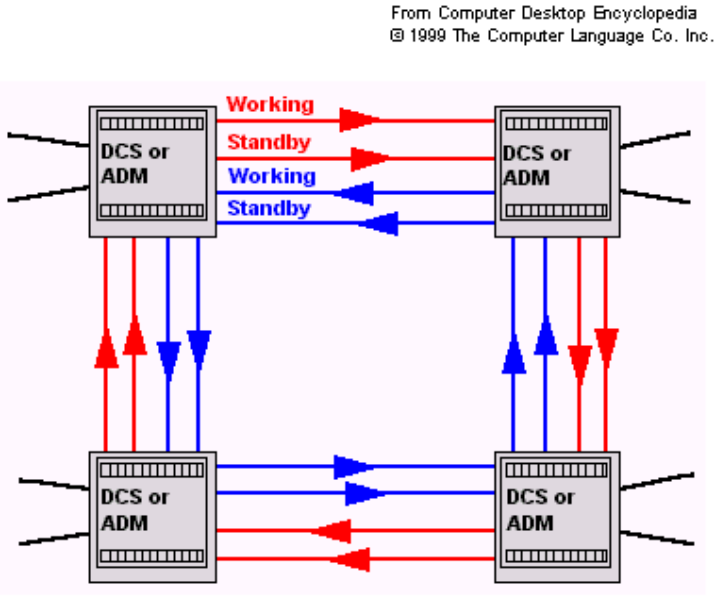
DCS
(Digital Cross-Connects)



SONET/SDH and resiliancy



bi-directional



Found in most operators

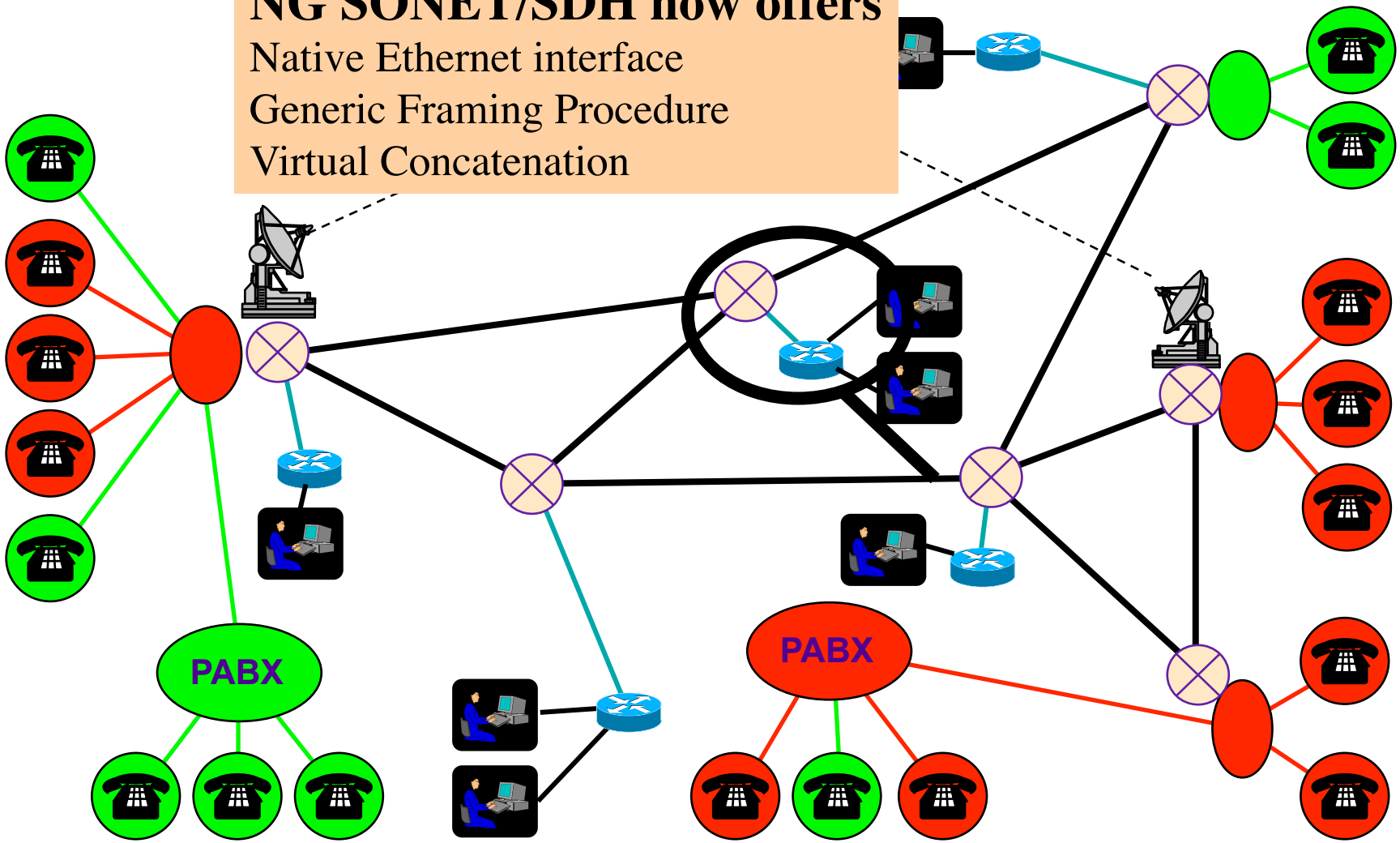
General Purpose SDH Networks

NG SONET/SDH now offers

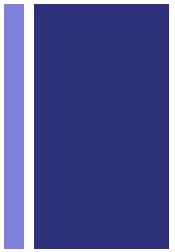
Native Ethernet interface

Generic Framing Procedure

Virtual Concatenation



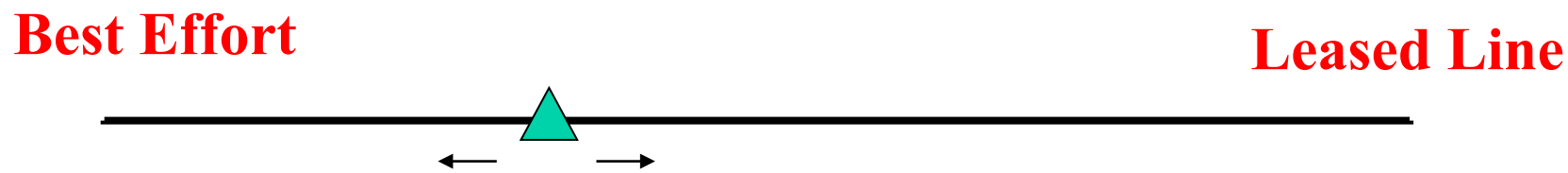
What is Quality of Service?



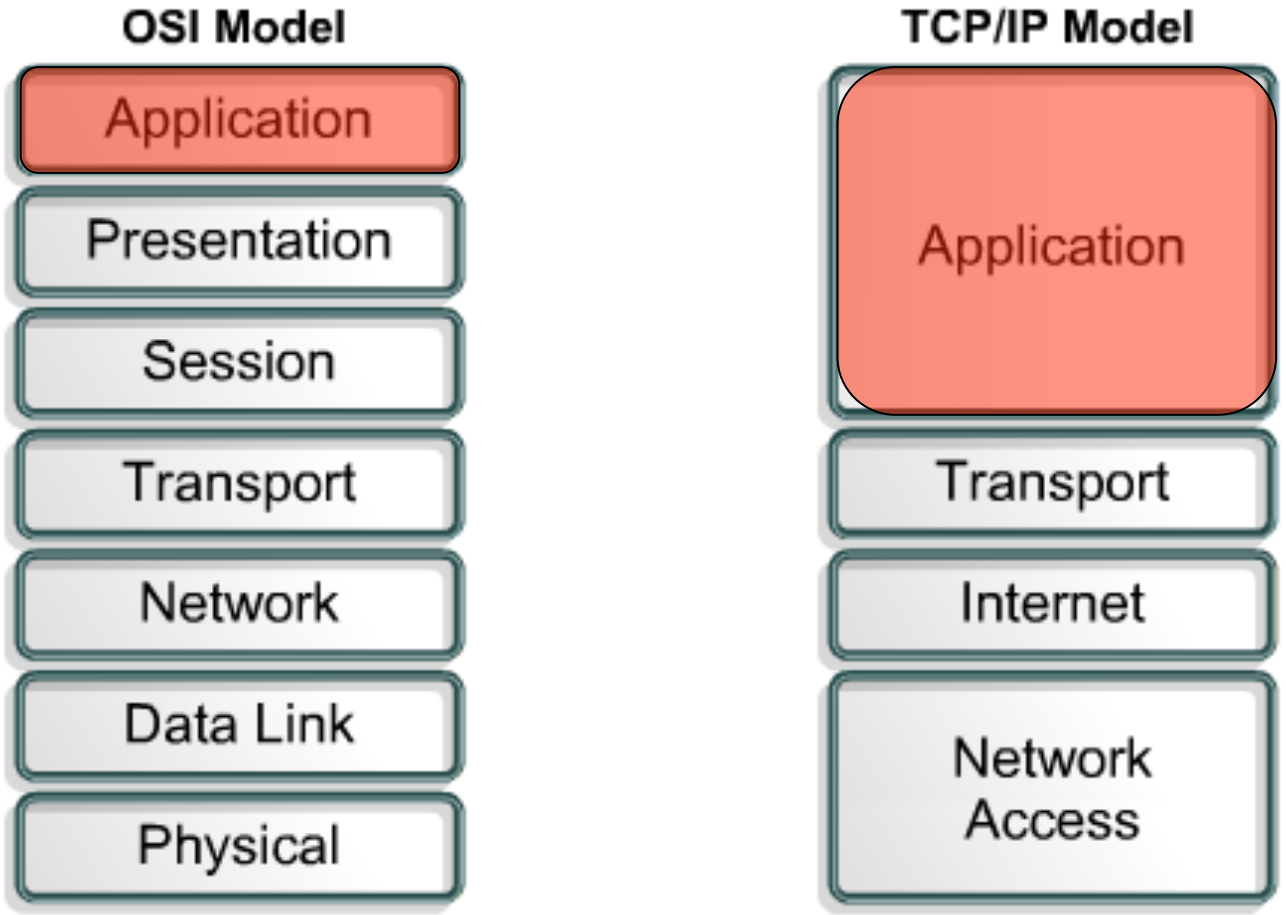
- Quality of service is the ability to provide different priority to different applications, users, or data flows, or to guarantee a certain level of performance
- QoS criteria are numerous and is highly dependant of the app.
  - Throughput, Delay, jitter, Loss rate, Availability, Uptime, ...
- ... Or driven by the end-user
  - Image resolution, sound quality, appropriate language, ...

What is QoS (contd) ?

- These parameters can be measured at several granularities:
  - "micro" flow, aggregate flow, population.
- QoS considered "better" if
  - more parameters can be specified
  - QoS can be specified at a fine-granularity.
- QoS spectrum:

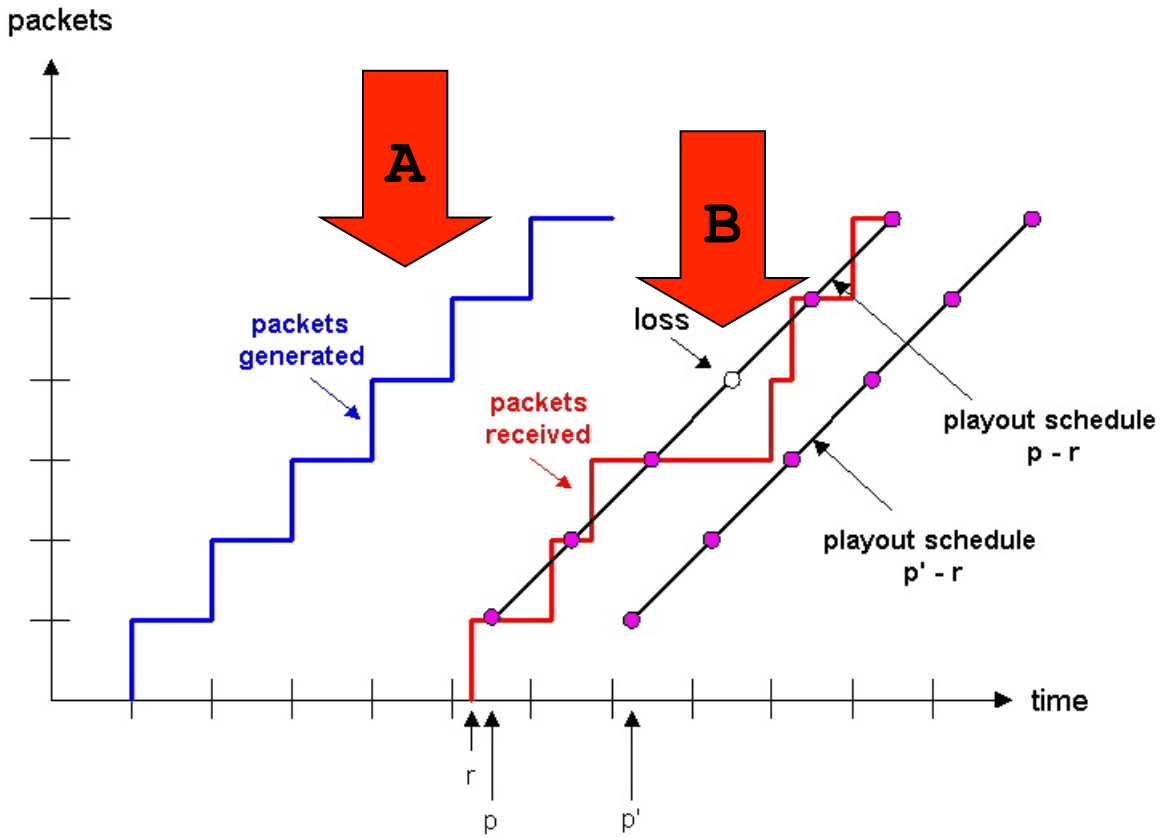


Where to put QoS?



Application layer=network as a black box

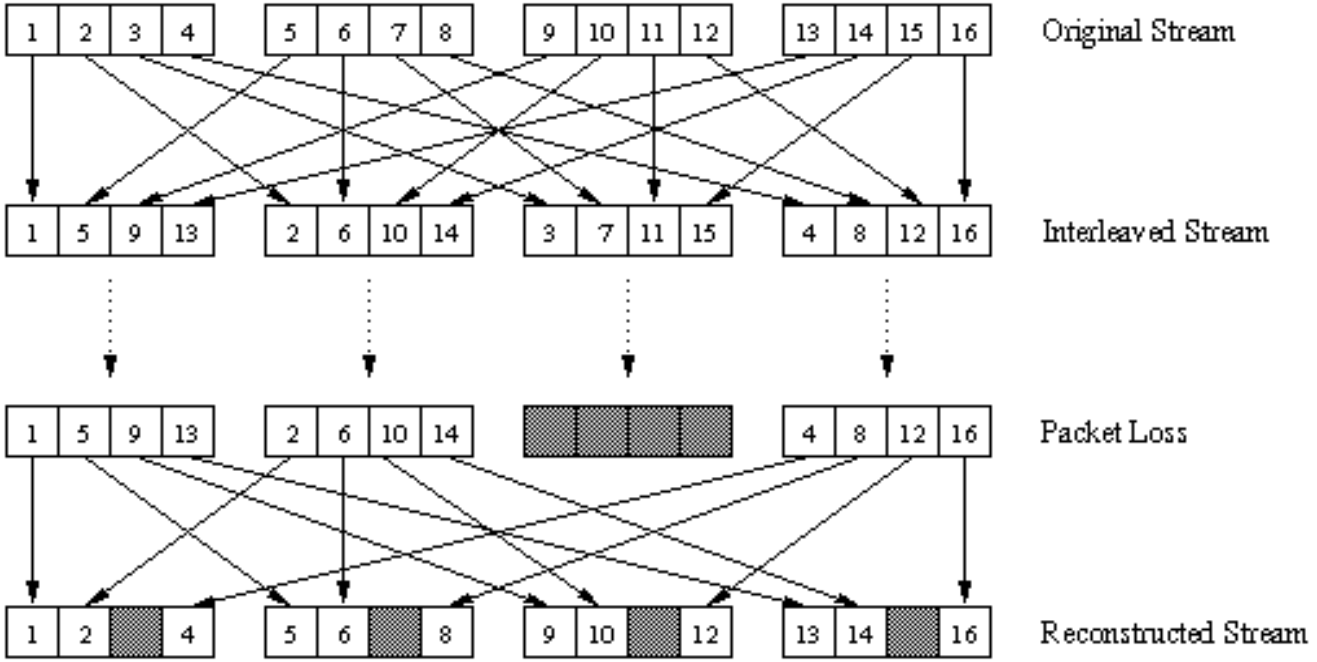
Dealing with packet jitter
Fixed playout delay



From Xavier Appé, modified by C. Pham for educational purpose only

Recovering from packet loss Interleaving

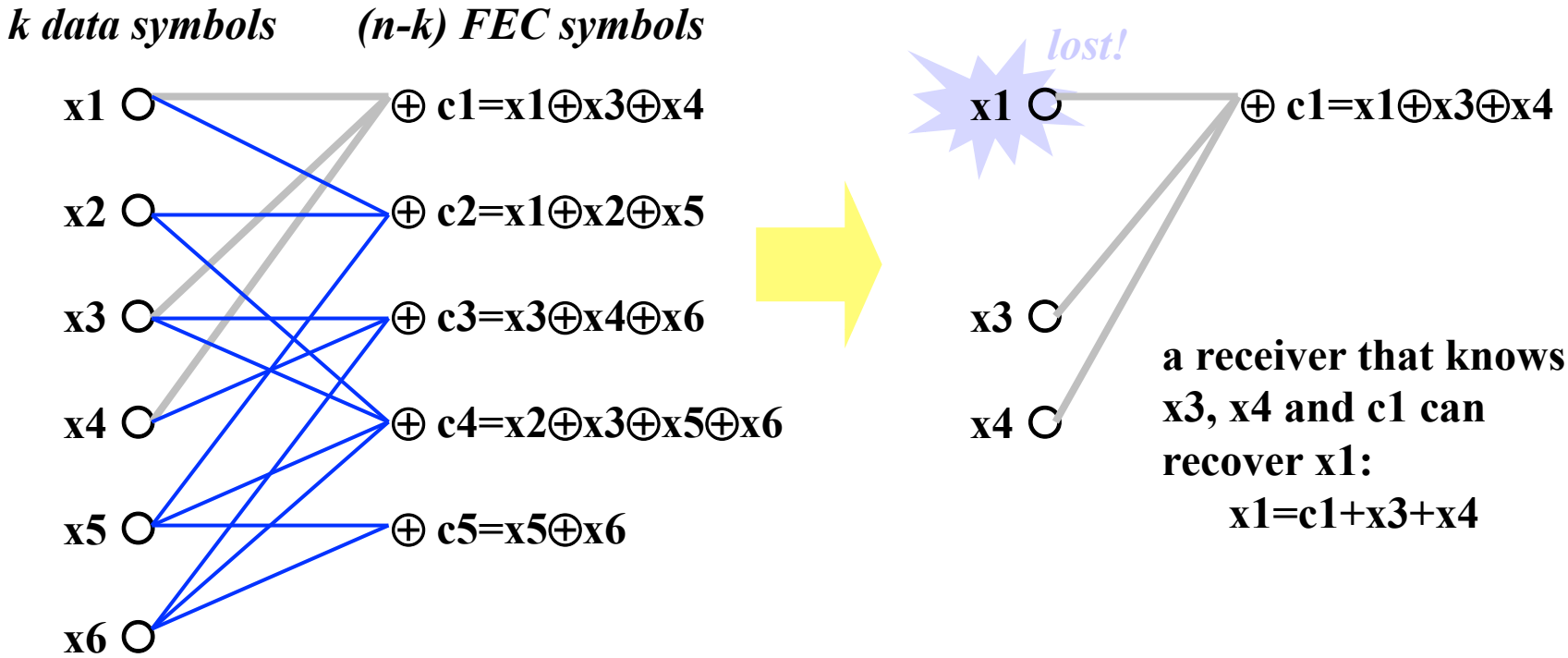
- Divide 20 msec of audio data into smaller units of 5 msec each and interleave
- Upon loss, have a set of partially filled chunks



From Xavier Appé, modified by C. Pham for educational purpose only

Large block FEC codes...

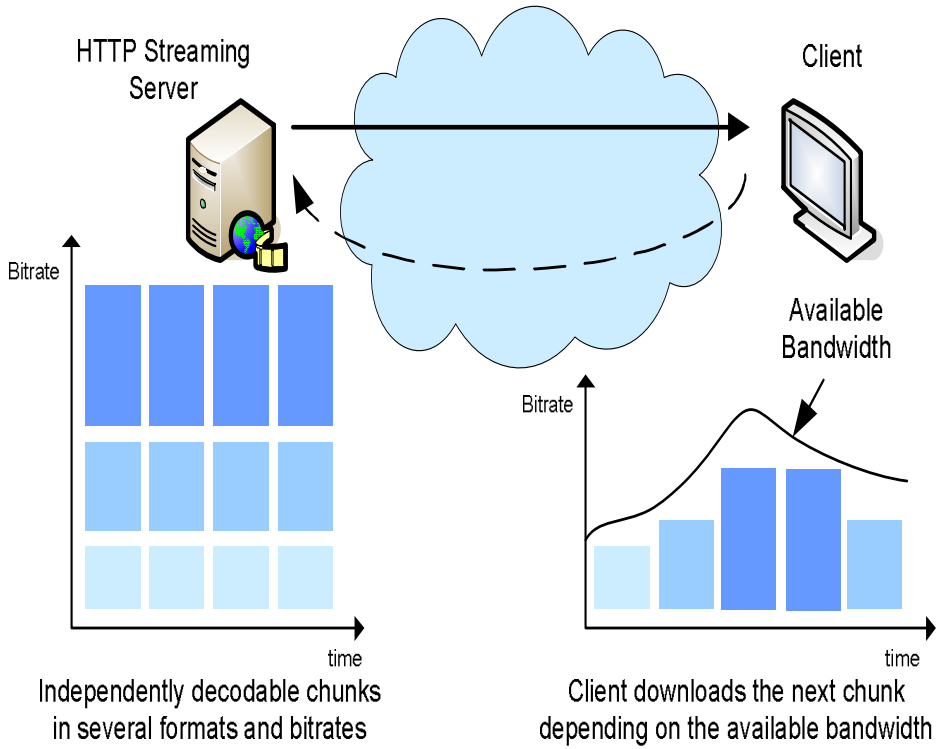
- an example: LDPC code
  - based on XOR operations (⊕)
  - uses bipartite graphs between source and FEC symbols
  - iterative decoding



From Xavier Appé, modified by C. Pham for educational purpose only

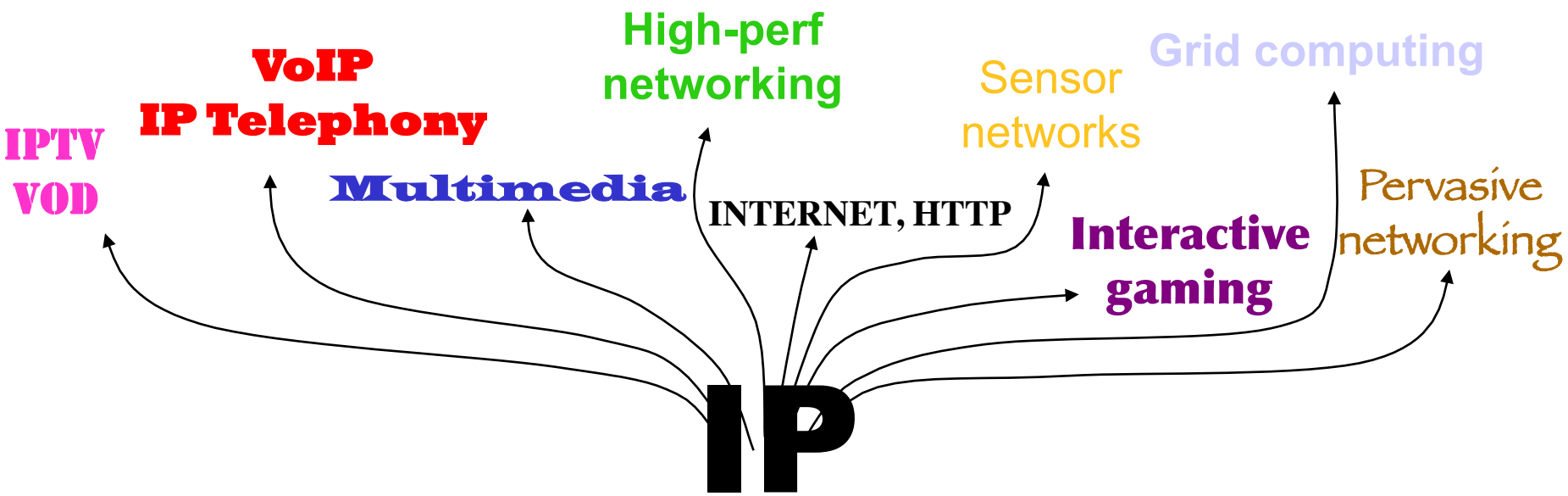
DASH: Dynamic Adaptive Streaming over HTTP

The DASH standard is a video streaming technique based on segments, available in various quality and transfered with HTTP 1.1



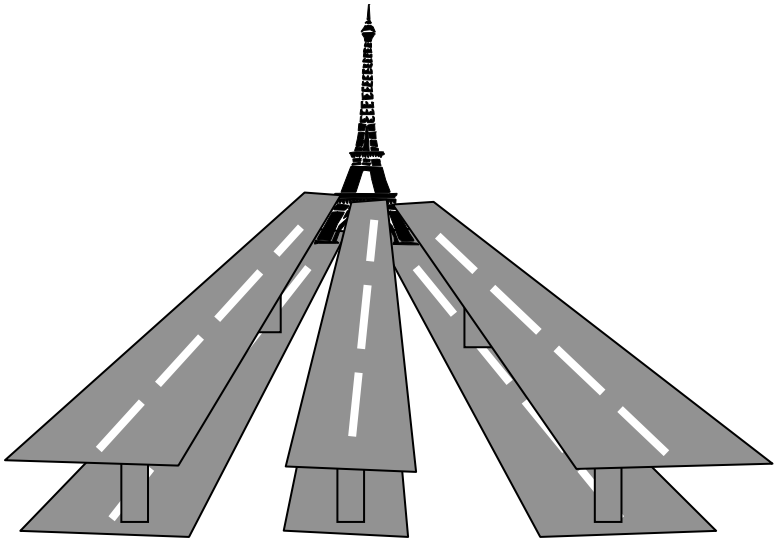
Source Yassine HADJADJAOUL

MUST maintain IP philosophy



Overprovisioning in the core

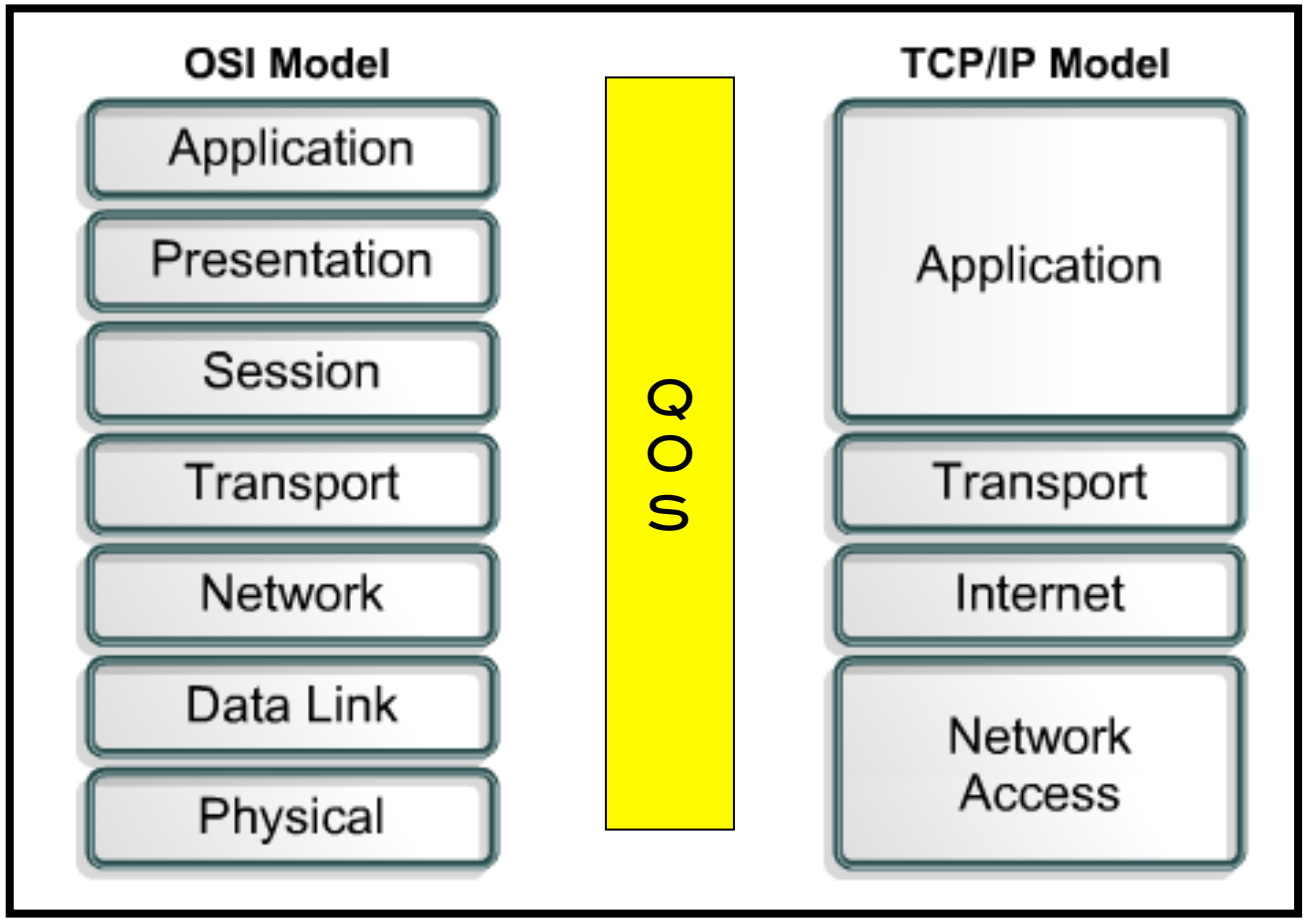
- Most operators are overprovisioning bandwidth with DWDM fibers
- 10Gbps, 40Gbps, 160 GBps, 320 Gbps, much mote to come!



IP desired service

- Isolation: my traffic is not impacted at all by yours
- Protection: my transmission path is backed up to the nth degree by failover paths
- Throughput: I get the capacity I pay for
- Delay: Whatever pattern of packets timing I send with is preserved at the far-end

30 years of INTERNET QoS…



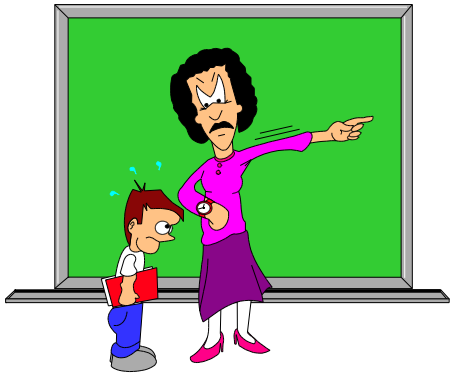
…have shown the power of selfishness!

WHY SHOULD I BOTHER WITH QOS WHEN…

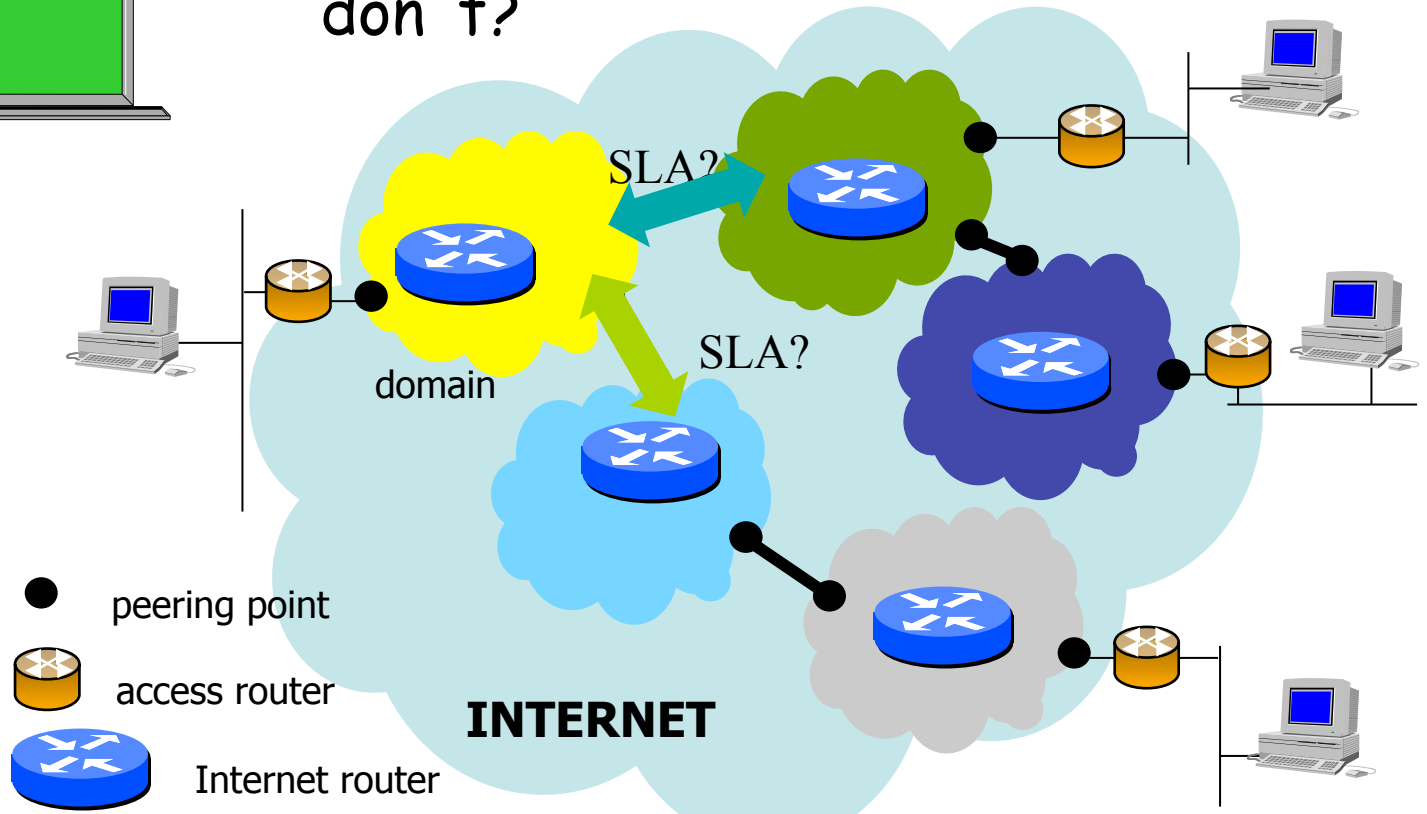
…OTHERS DON'T DO IT?

It's not my fault!

« environmental problems often have impacts beyond borders »



- What's the point of deploying QoS if others don't?



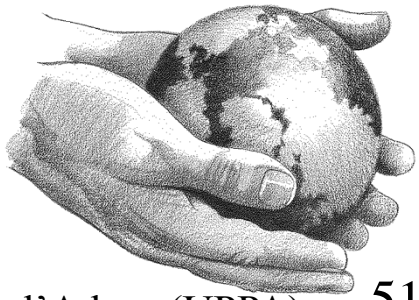
Current Internet's QoS

So why change?

Sustainable development

- "meets the needs of the present without compromising the ability of future generations to meet their own needs" [Brundtland Report, 1987]
- Trade-off between performance and needs: « why are we producing? »
- Use the right ressource, at the right place, at the right time

a new dimension of global responsibility—
not only to planetary resources but also to planetary fairness



Is overprovisioning harmful?

- NO: overprovisioning is not very costly. Adding new wavelengths is quick. Customers are happy and quick return on investment!

- YES: while overprovisioning, alternative solutions are not deployed. High risk that relying too much on old technologies makes upgrades impossible (c.f. IPv6, TCP,…)

Lessons learned from sustainable development

- Limit globalization
- Limit the pursuit of continued economic prosperity
- Redistribute labour, wages,…
- Promote the use of local resources
- Change mentality

Community networks?

CONNECTED COMMUNITIES

CONFINE

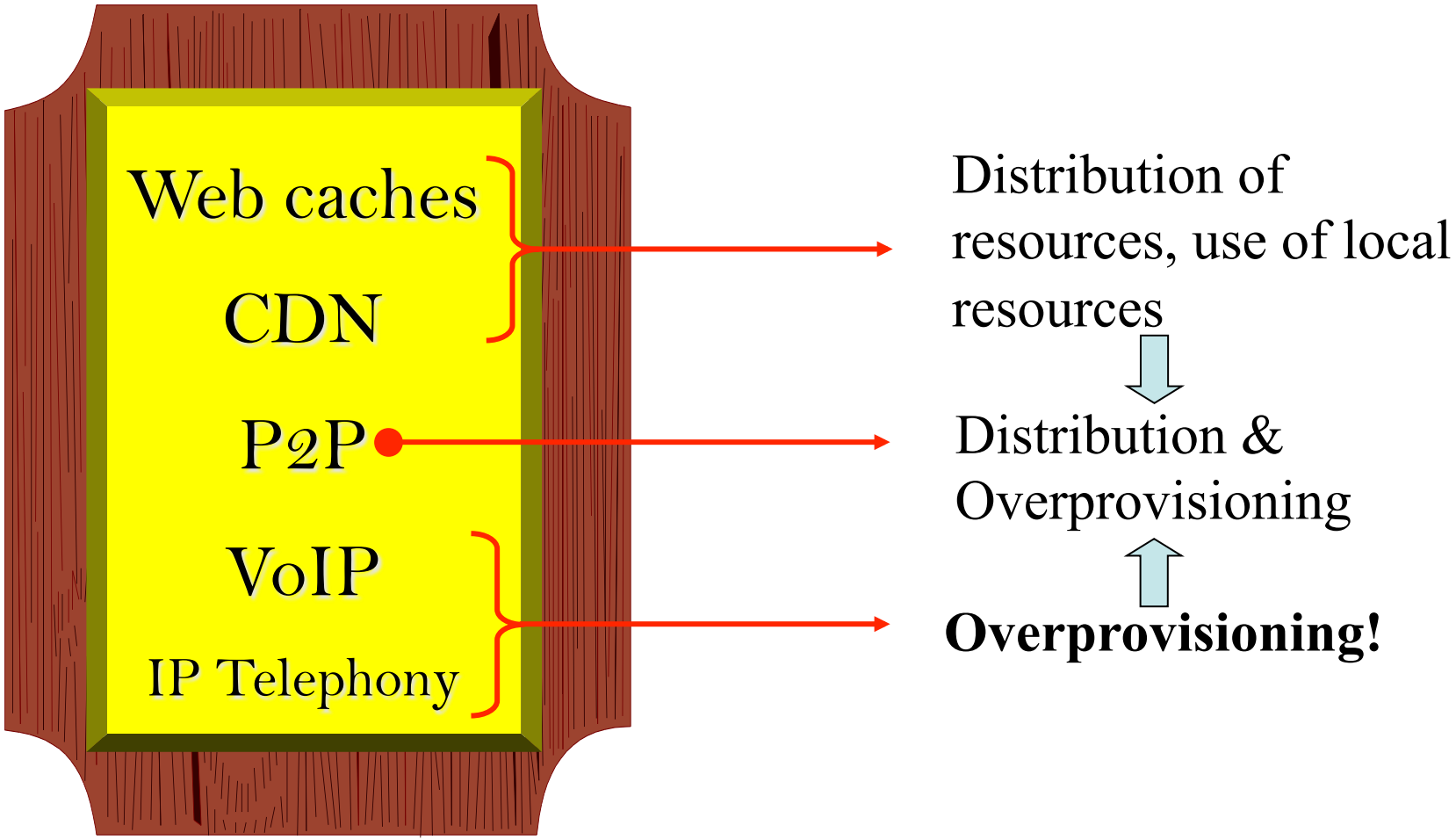
Limitations of the current Internet

- Bandwidth
  - Raw bandwidth is not a problem: DWDM
  - Provisioning bandwidth on demand is more problematic
- Latency
  - Mean latencies on Internet is about 80-160ms
  - Bounding latencies or ensuring lower latencies is a problem
- Loss rate
  - Loss rate in backbone is very low
  - End-to-End loss rates, at the edge of access networks are much higher
- Communication models
  - Only unicast communications are well-defined: UDP, TCP
  - Multi-parties communication models are slow to be deployed

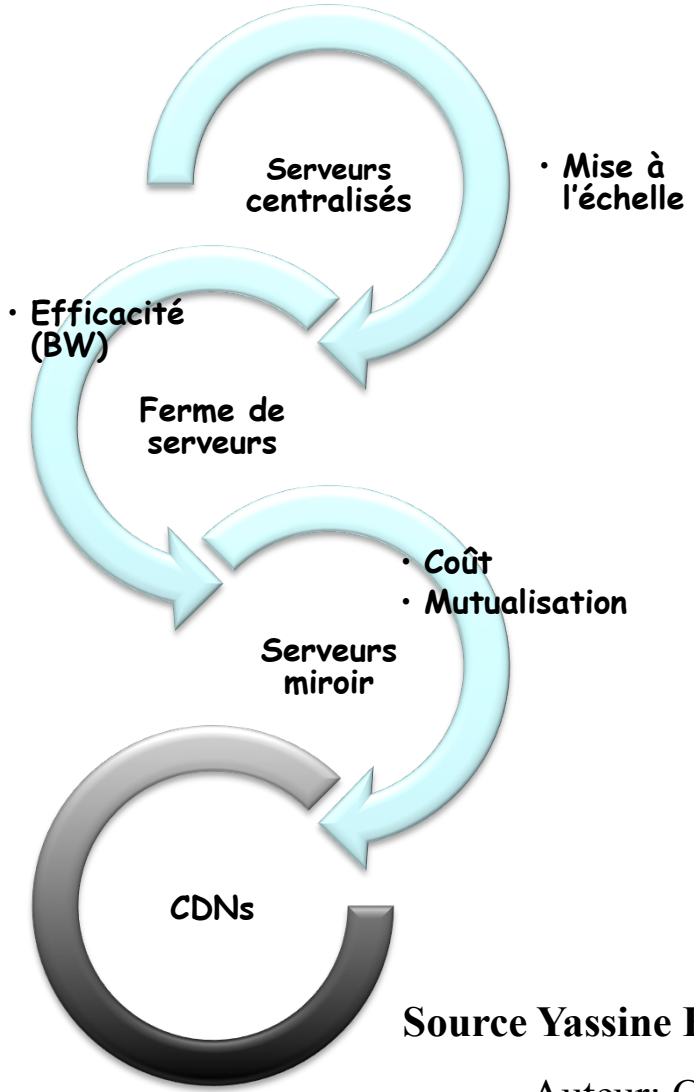
Net Neutrality or Not?

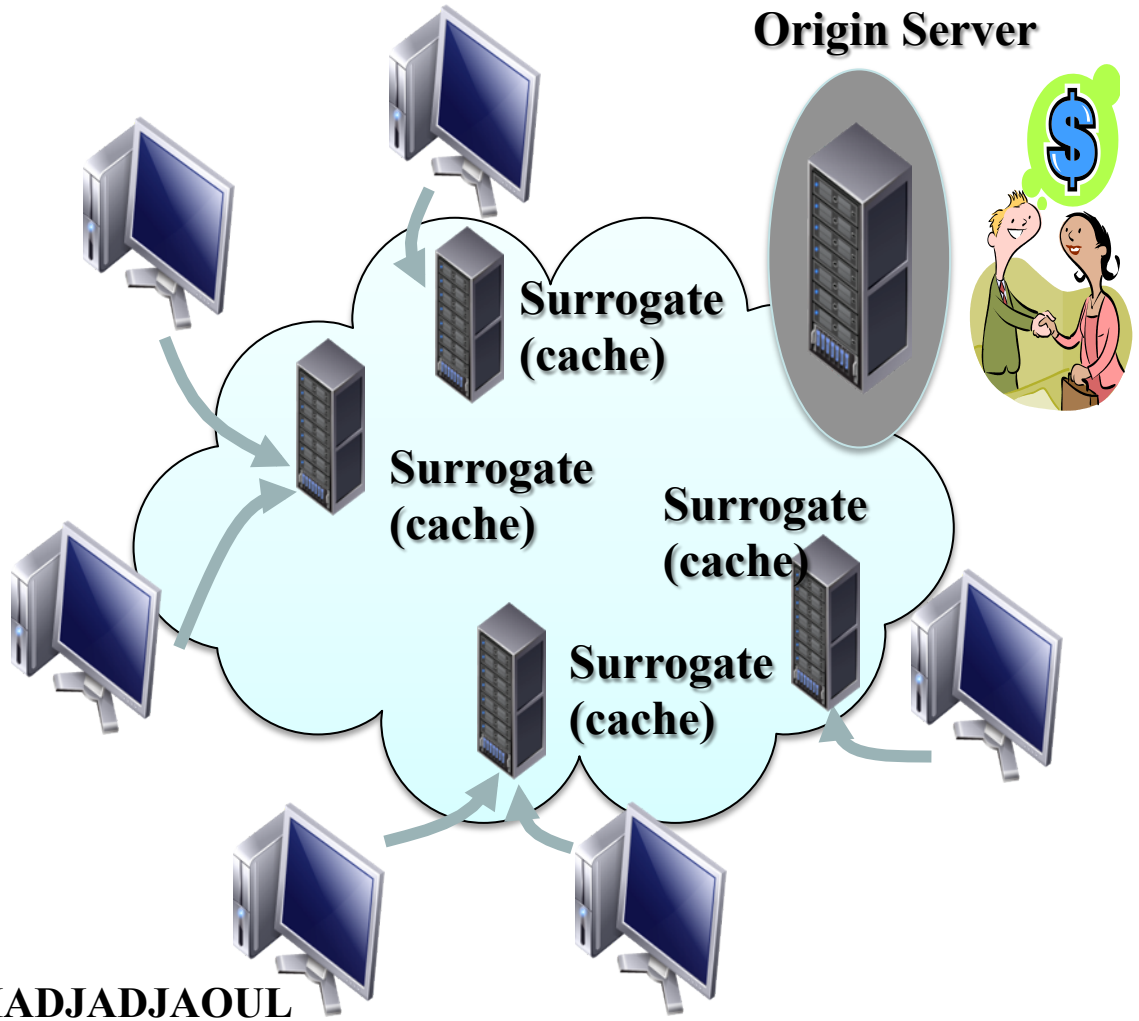
- NN or NNN? That's the question!
- NN = dumb network!
- Internet's success is in a large part debtful to what's called Net Neutrality (IP neutrality)

Some NN success stories



CDN





Source Yassine HADJADJAOUL

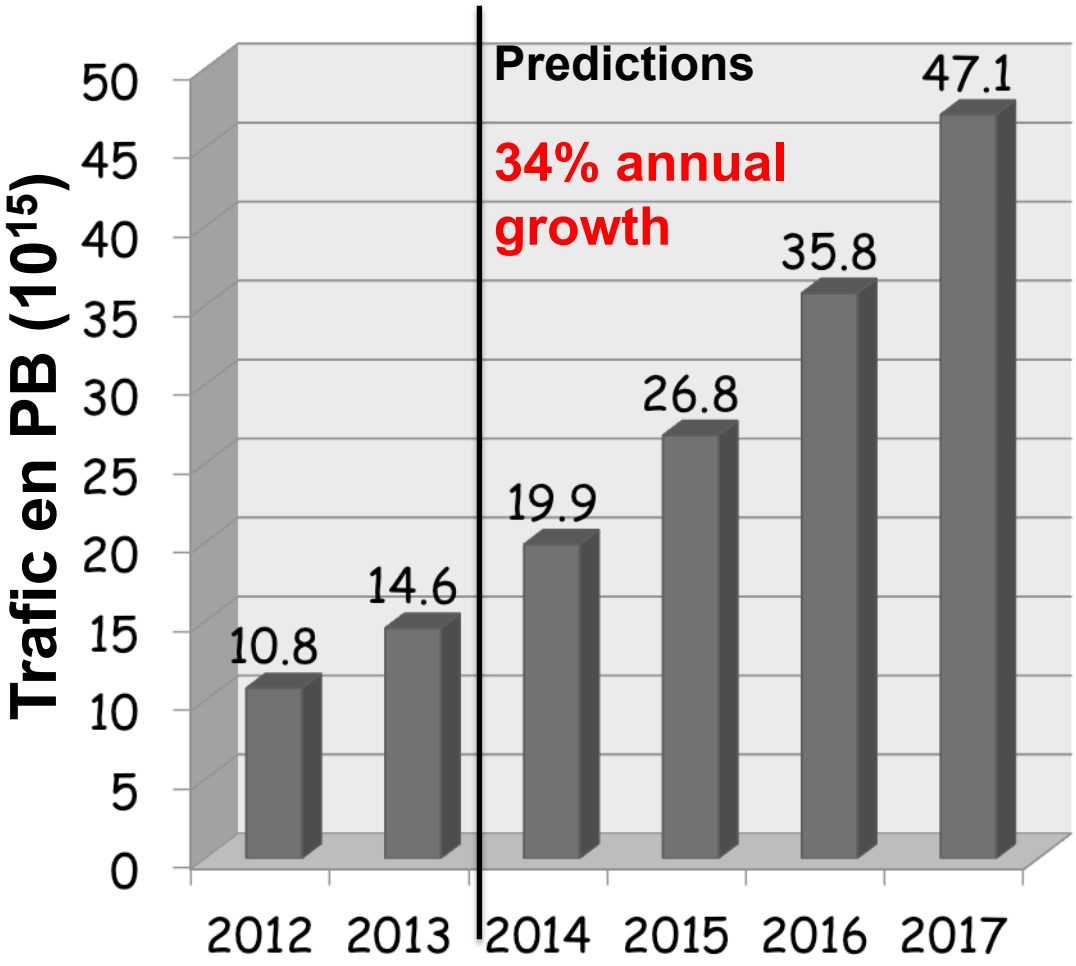
The Akamai EdgePlatform:

85,000+ Servers	1700+ POPs	950+ Networks	660+ Cities	72+ Countries

Resulting in traffic of:
5.4 petabytes / day
790+ billion hits / day
436+ million unique clients
IPs / day

Source Yassine HADJADJAOUL

CDNs traffic evolution

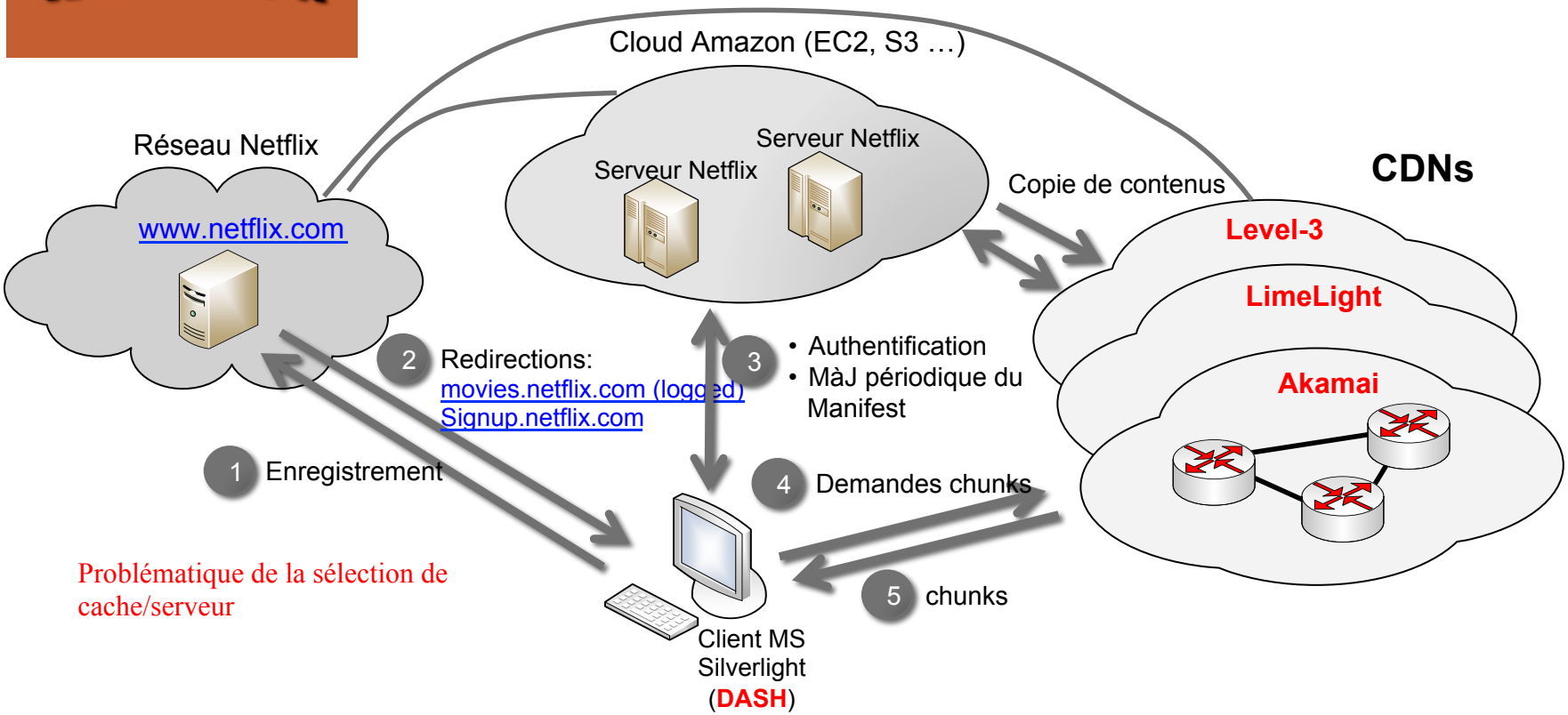


Source Yassine HADJADJAOUL

- **Dominating method for streaming.**
  - **51% of Internet traffic will go through CDNs in 2017 (34% in 2012).**
  - **65% of video traffic on Internet will go through CDNs in 2017 (53% in 2012)**

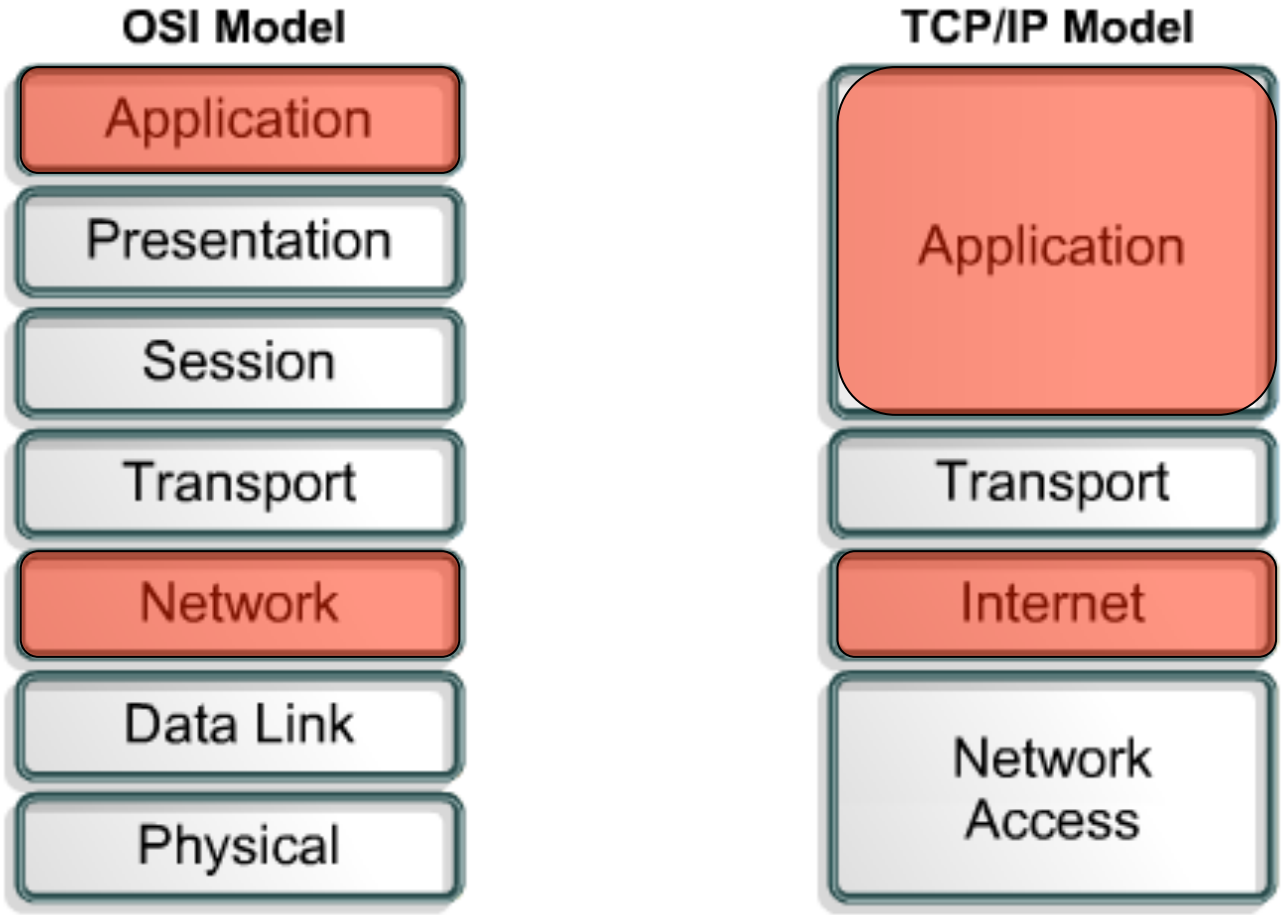
Typical architecture

Source Yassine HADJADJAOUL



V. K. Adhikari, Y. Guo, F. Hao, M. Varvello, V. Hilt, M. Steiner, and Z.-L. Zhang. INFOCOM, page 1620-1628. IEEE, (2012)

Where to put QoS?



Internet Routers

©Juniper

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©Nortel Networks

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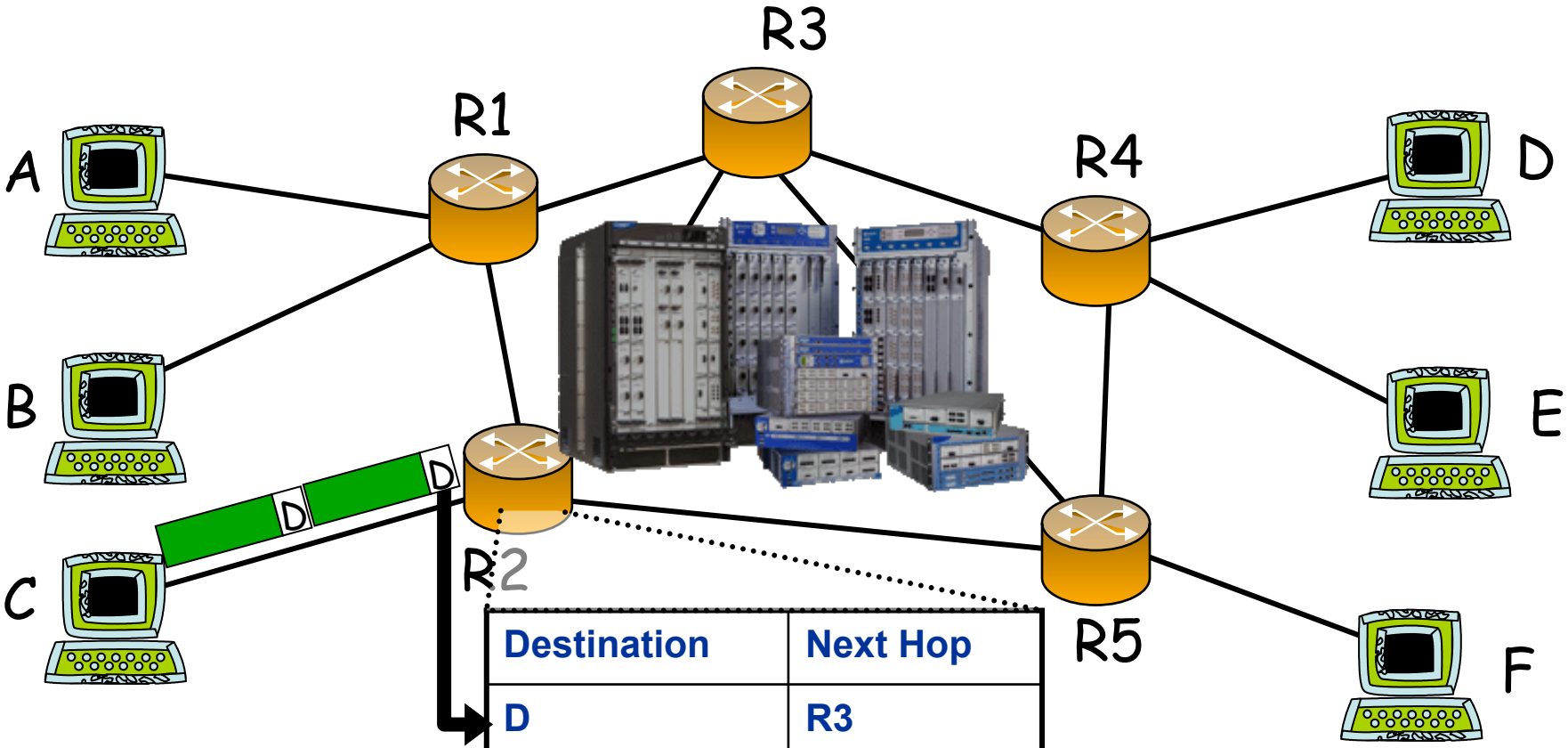
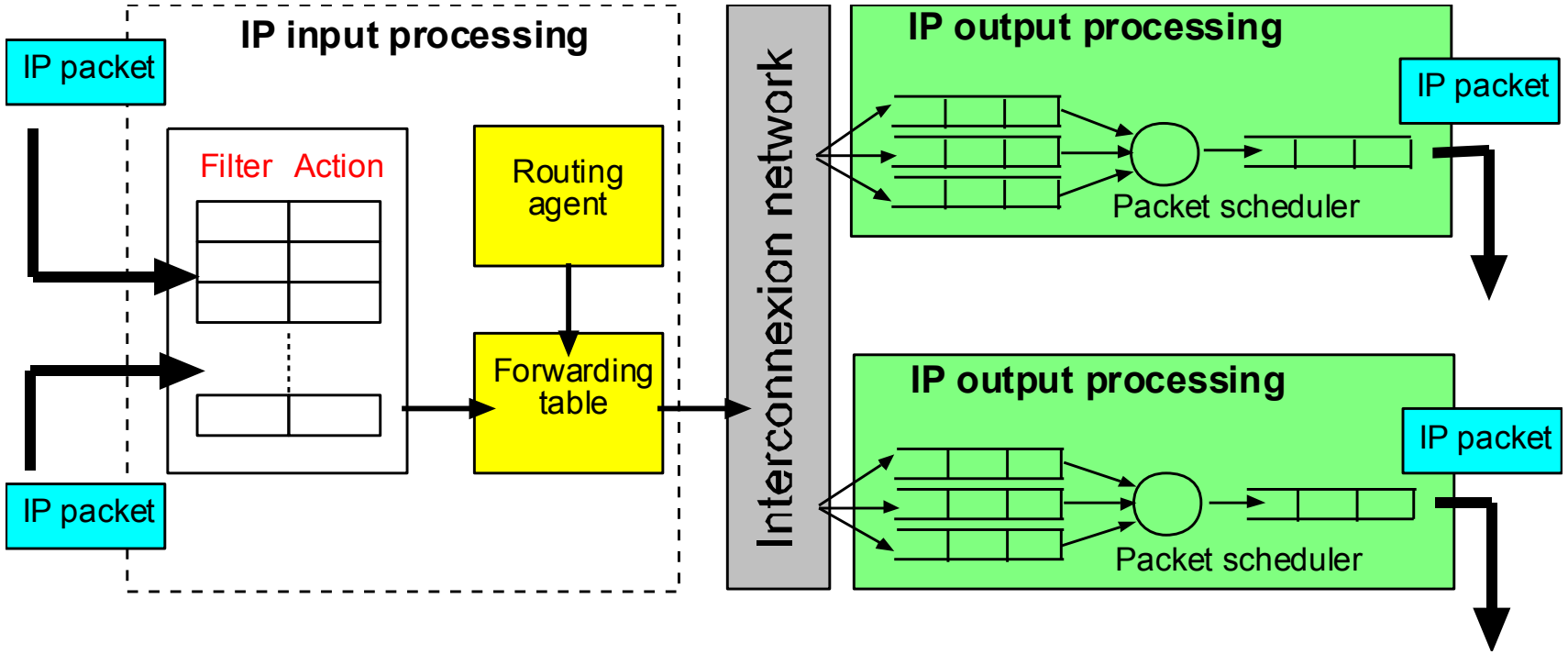
and more…

If no NN then give more power to routers!



Destination	Next Hop
D	R3
E	R3
F	R5

General architecture of an IP router



- receives input packets,
- sends packets to output buffers,
- transmits packets.

In 2000, I had a dream: active networking!

- Programmable nodes/routers
- Customized computations on packets
- Standardized execution environment and programming interface
- No killer applications, only a different way to offer high-value services, in an elegant manner
- However, adds extra processing cost

Motivations behind Active Networking

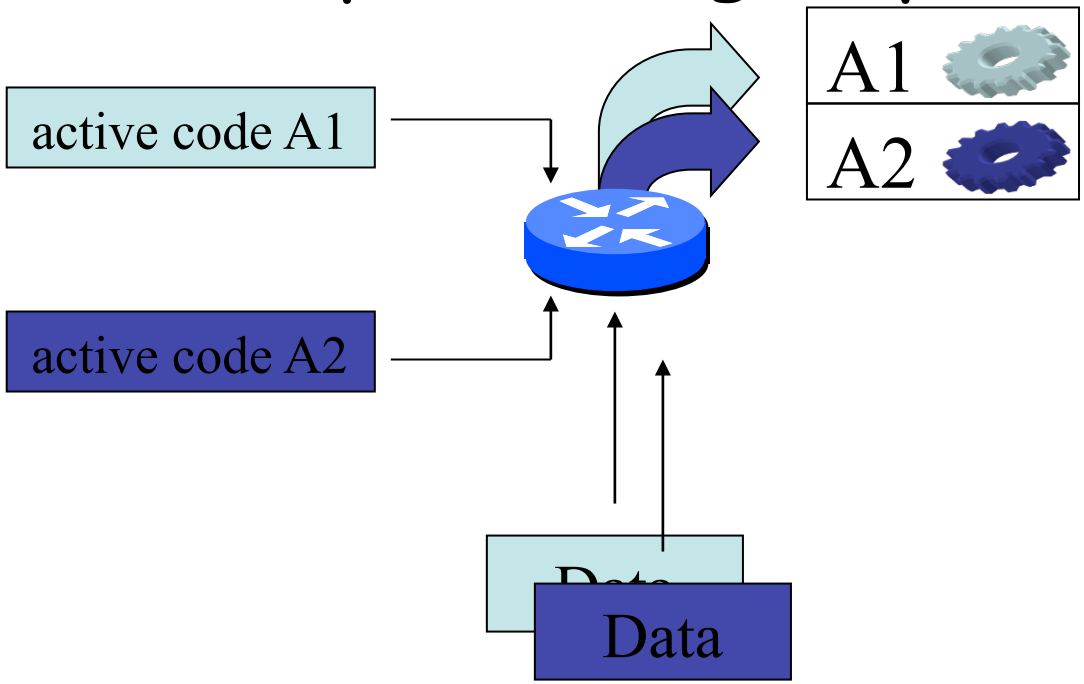
- From the user perspective
  - applications can specify, implement, and deploy (on-the-fly) customized services and protocols
- From the operator perspective
  - reduce the latency/cost for new services deployment/management
- From the network perspective
  - globally better performances by reducing the amount of traffic

Active networks implementations

- Discrete approach (operator's approach)
  - Adds dynamic deployment features in nodes/ routers
  - New services can be downloaded into router's kernel
- Integrated approach
  - Adds executable code to data packets
  - Capsule = data + code
  - Granularity set to the packets

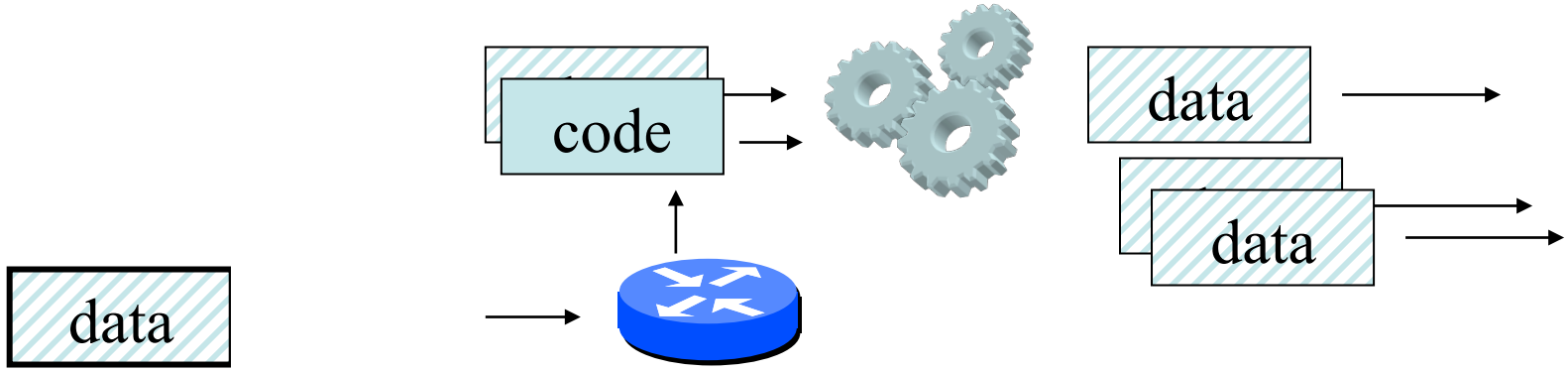
The discrete approach

- Separates the injection of programs from the processing of packets



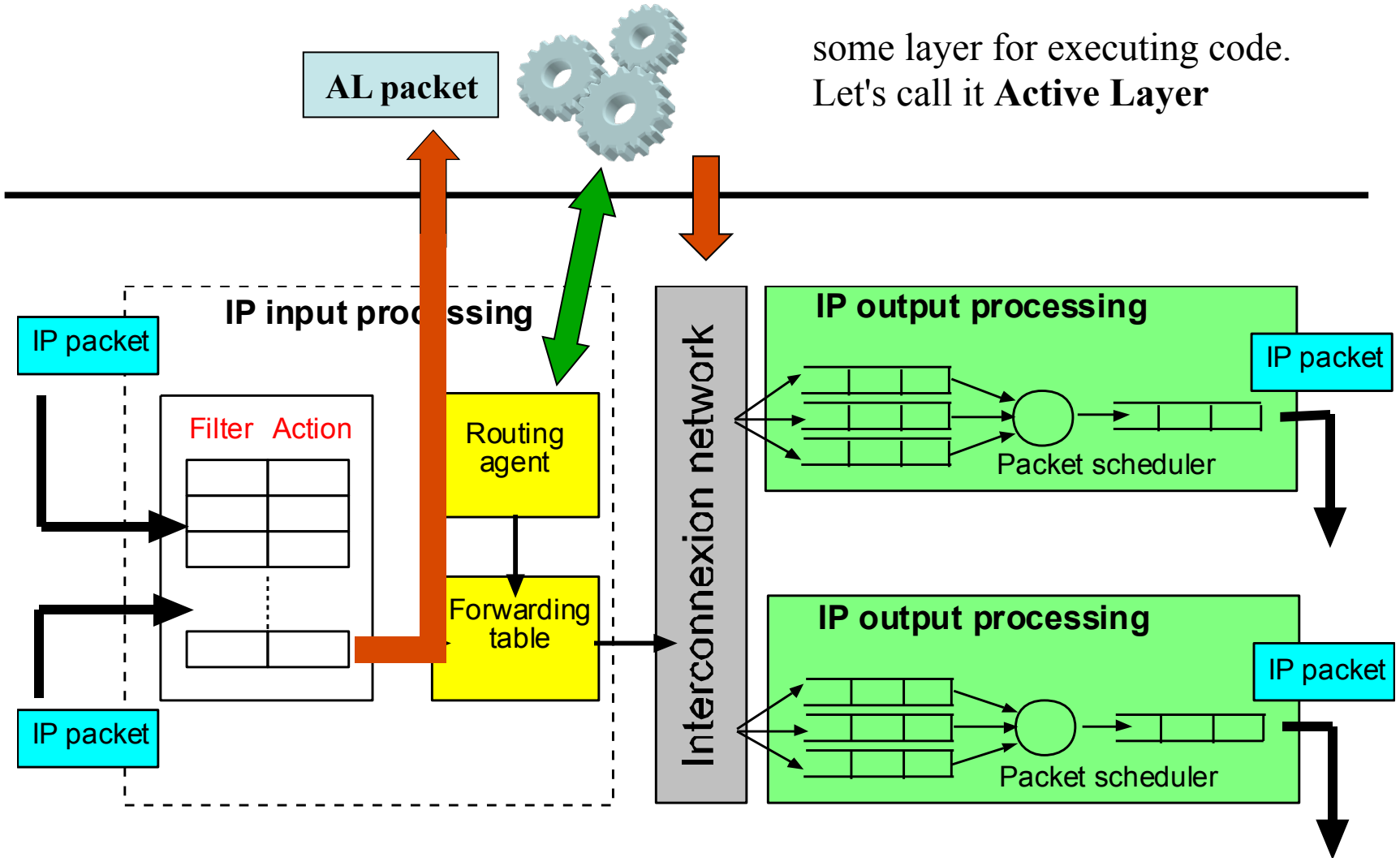
The integrated approach

- User packets carry code to be applied on the data part of the packet

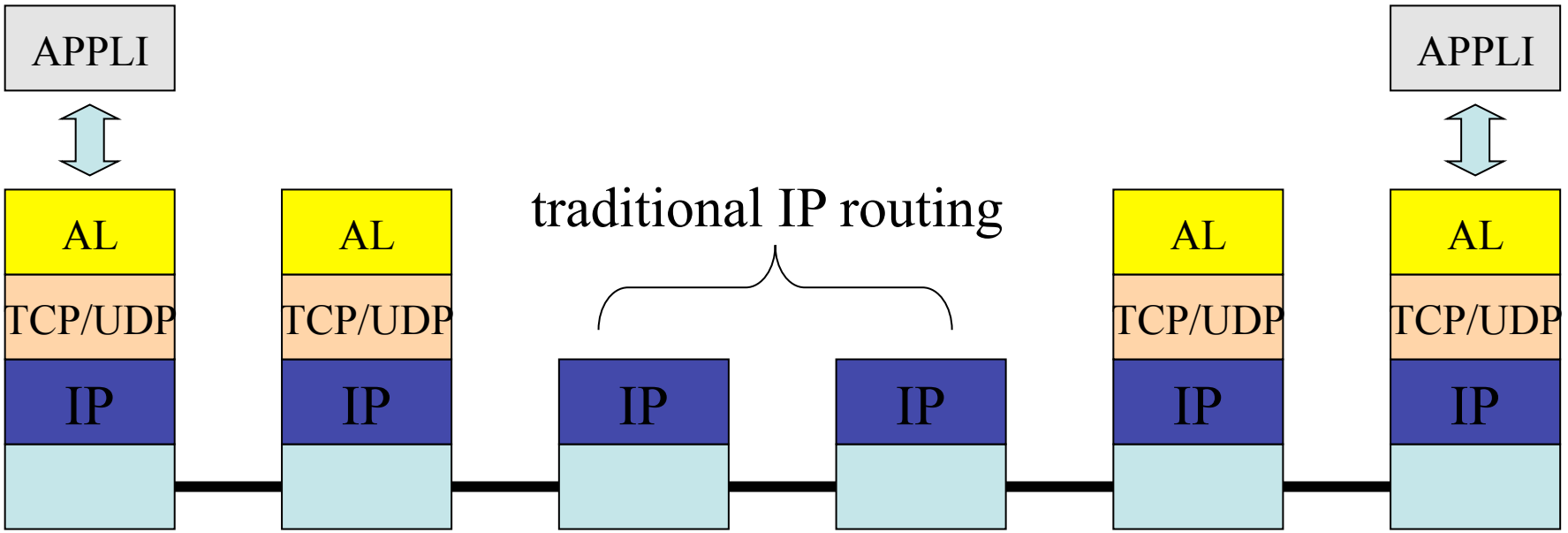


- High flexibility to define new services

An active router



Interoperability with legacy routers



Active network revisited

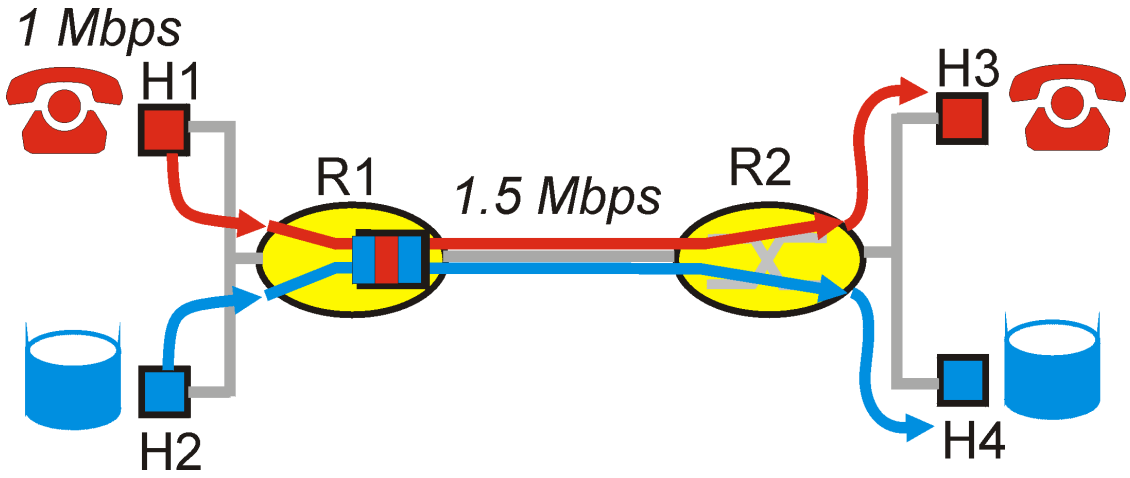
- Software Defined Networking (SDN) wants to decouple the control plane from the data plane
- Somehow similar to discrete active/ programmable network concepts
- Better perception from the user because controlled by operators and hardware vendors

How to upgrade the Internet for QoS?

- Approach: de-couple end-system evolution from network evolution
- End-to-end protocols: TCP, RTP, H.323, etc to spur the growth of adaptive multimedia applications
  - Assume best-effort or better-than-best-effort clouds
- Network protocols: IntServ, DiffServ, RSVP, MPLS, COPS …
  - To support better-than-best-effort capabilities at the network (IP) level

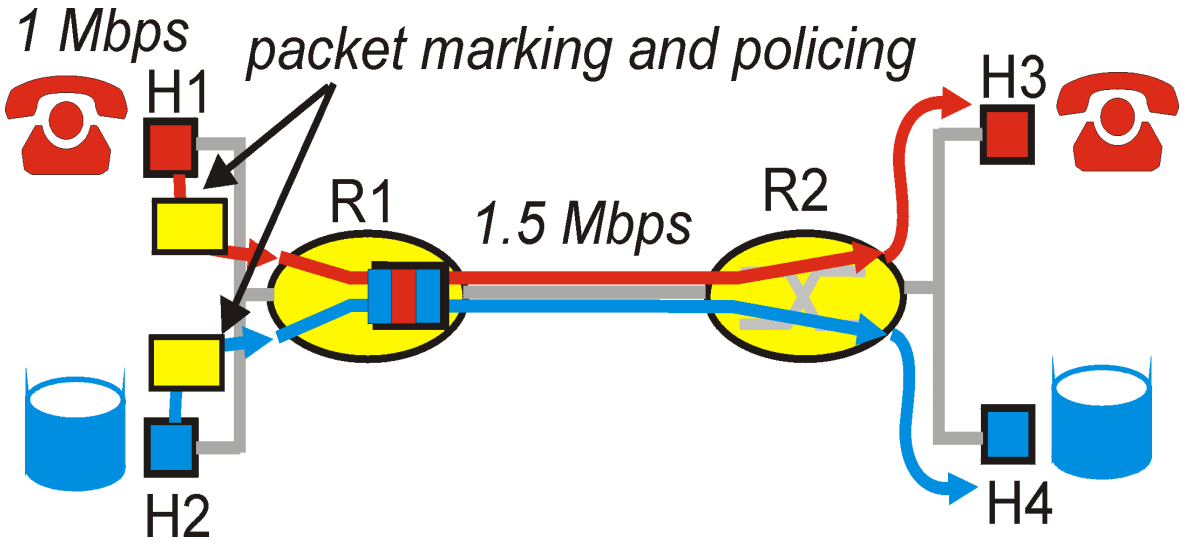
Principles for QOS Guarantees

- Consider a phone application at 1Mbps and an FTP application sharing a 1.5 Mbps link.
  - bursts of FTP can congest the router and cause audio packets to be dropped.
  - want to give priority to audio over FTP
- **PRINCIPLE 1: Marking of packets is needed for router to distinguish between different classes; and new router policy to treat packets accordingly**



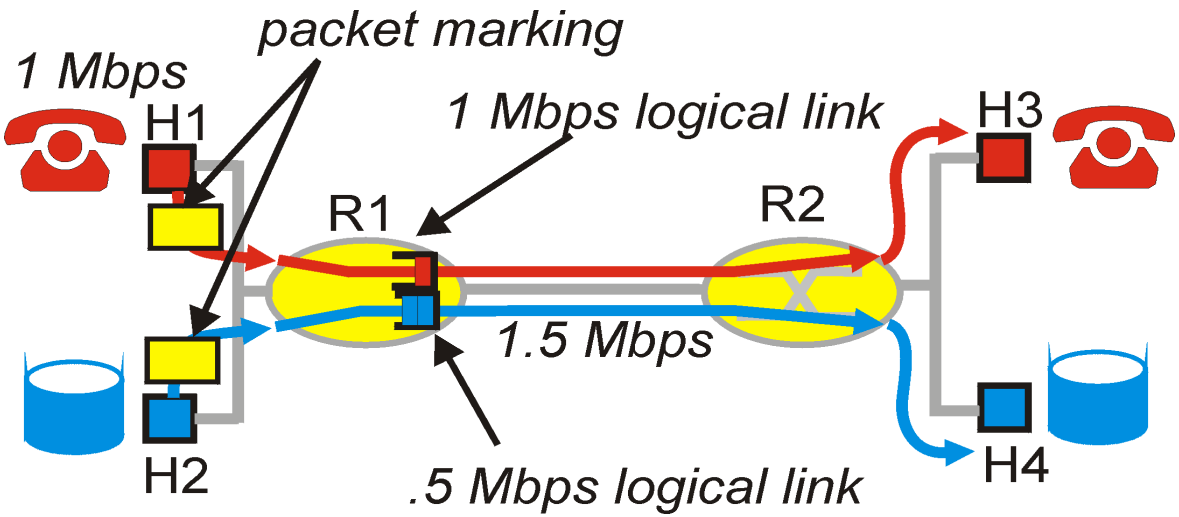
Principles for QOS Guarantees (more)

- Applications misbehave (audio sends packets at a rate higher than 1Mbps assumed above);
- **PRINCIPLE 2: provide protection (isolation) for one class from other classes**
- Require Policing Mechanisms to ensure sources adhere to bandwidth requirements; Marking and Policing need to be done at the edges:



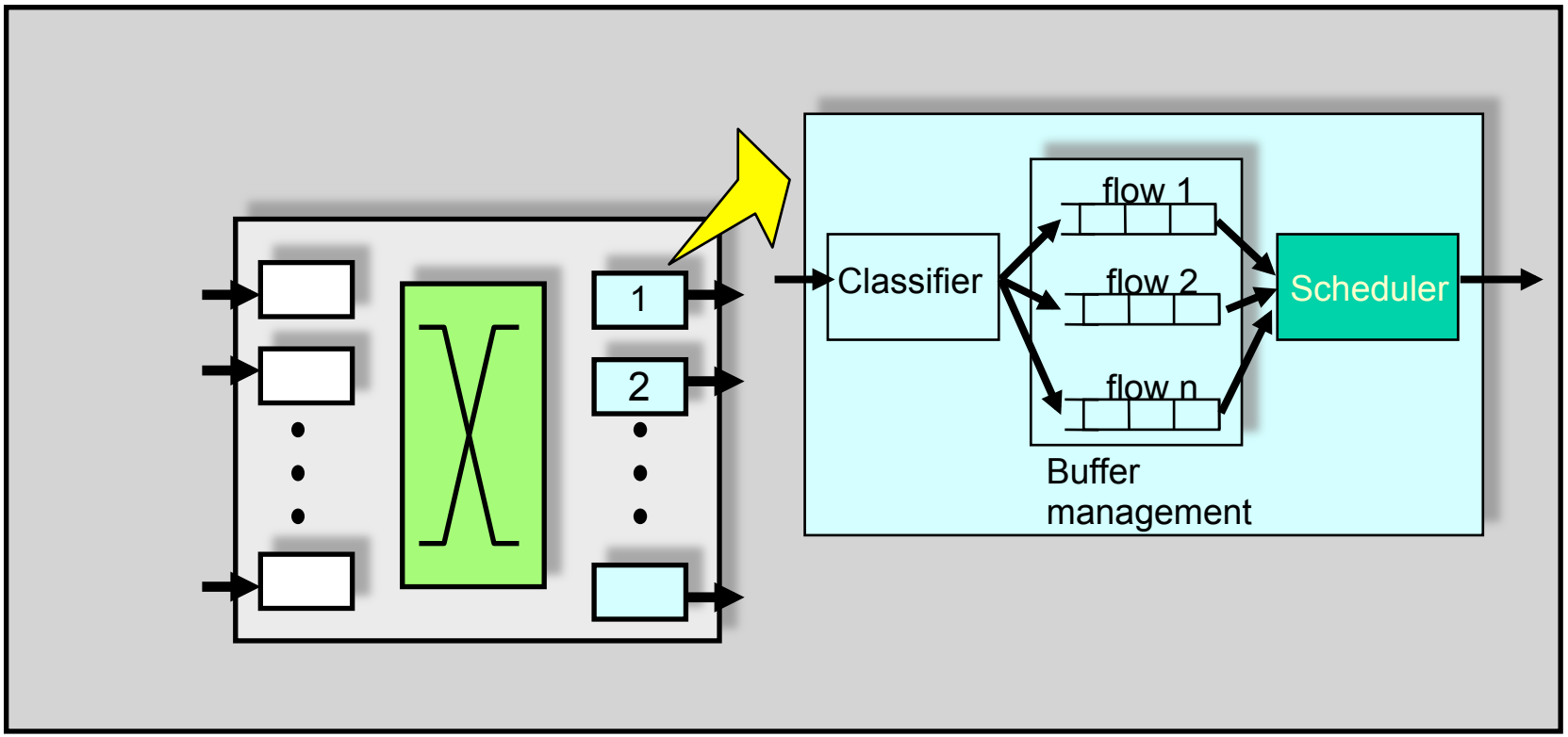
Principles for QOS Guarantees (more)

- Alternative to Marking and Policing: allocate a set portion of bandwidth to each application flow; can lead to inefficient use of bandwidth if one of the flows does not use its allocation
- **PRINCIPLE 3: While providing isolation, it is desirable to use resources as efficiently as possible**

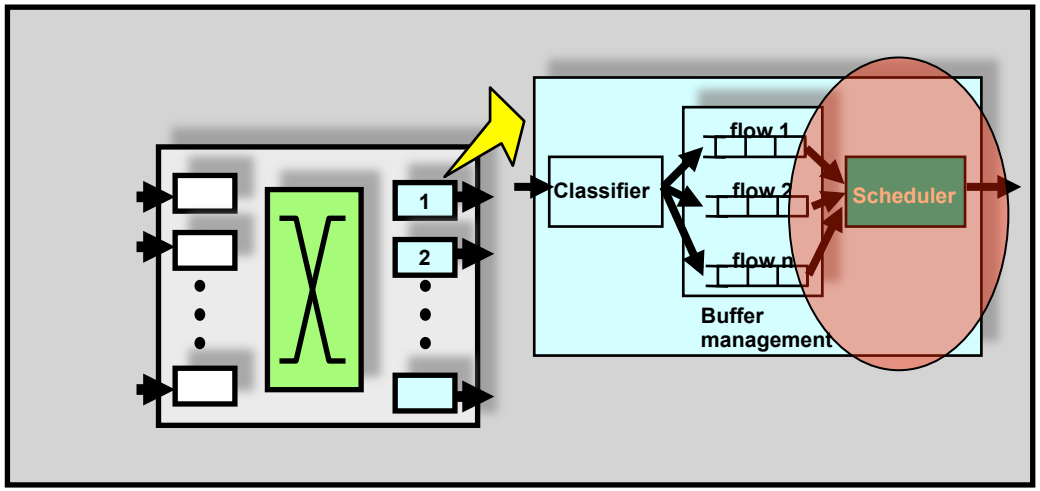


Generic Router

- Route packet and store in output buffer
- Decide when and what packet to send on output link

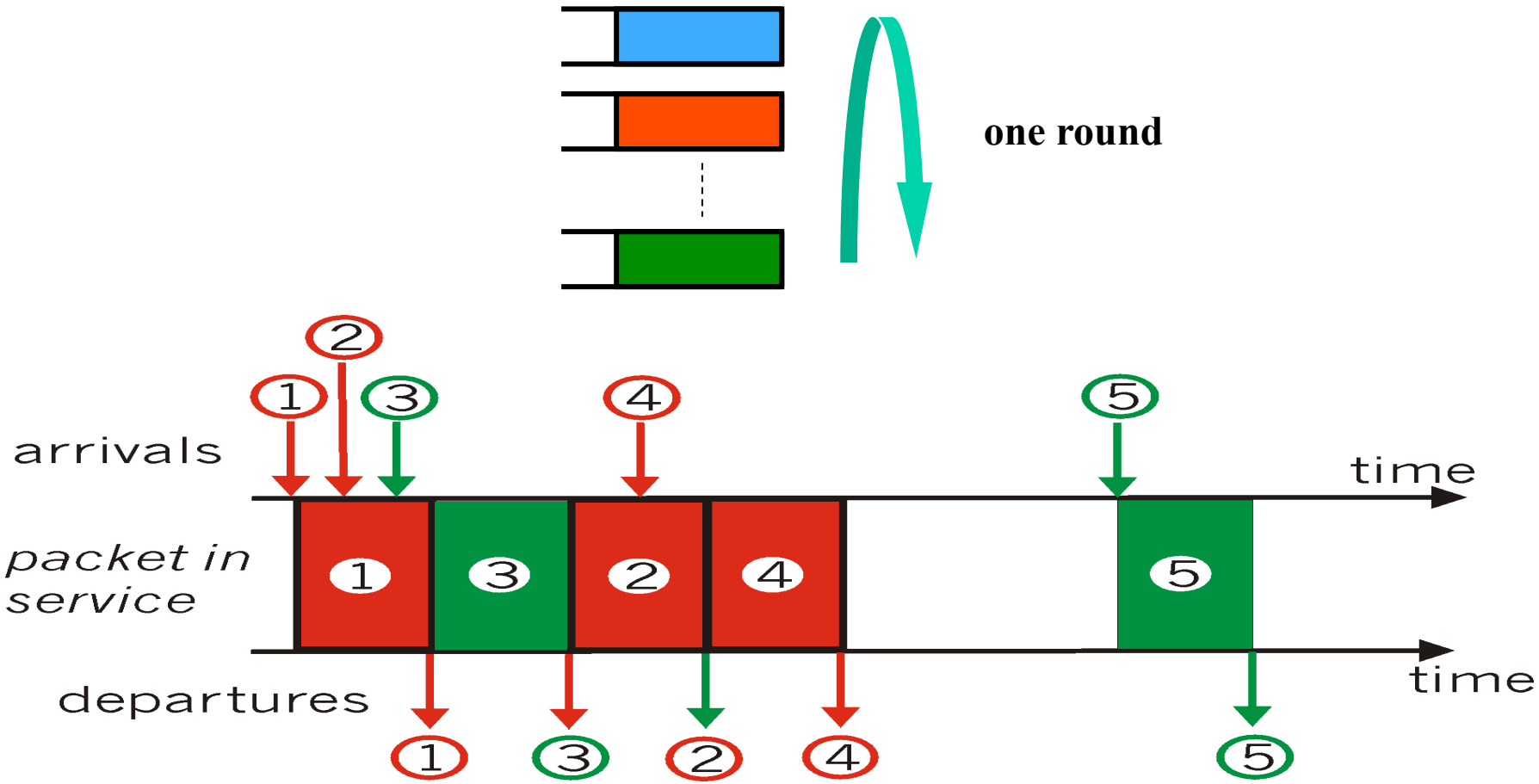


SCHEDULING

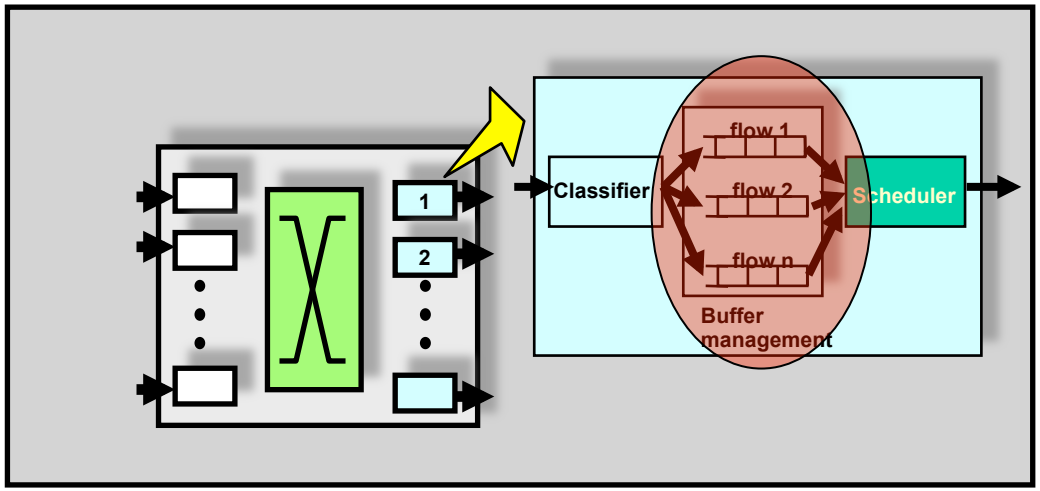

1
2
Classifier
flow 1
flow 2
flow n
Scheduler
Buffer
management

Round Robin (RR)

- Round Robin: scan class queues serving one from each class that has a non-empty queue

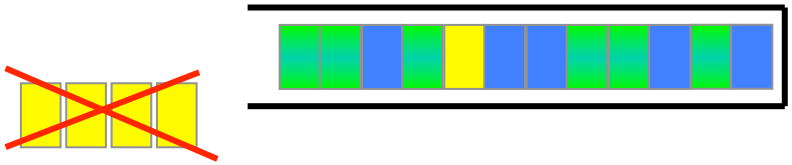


BUFFER MANAGEMENT

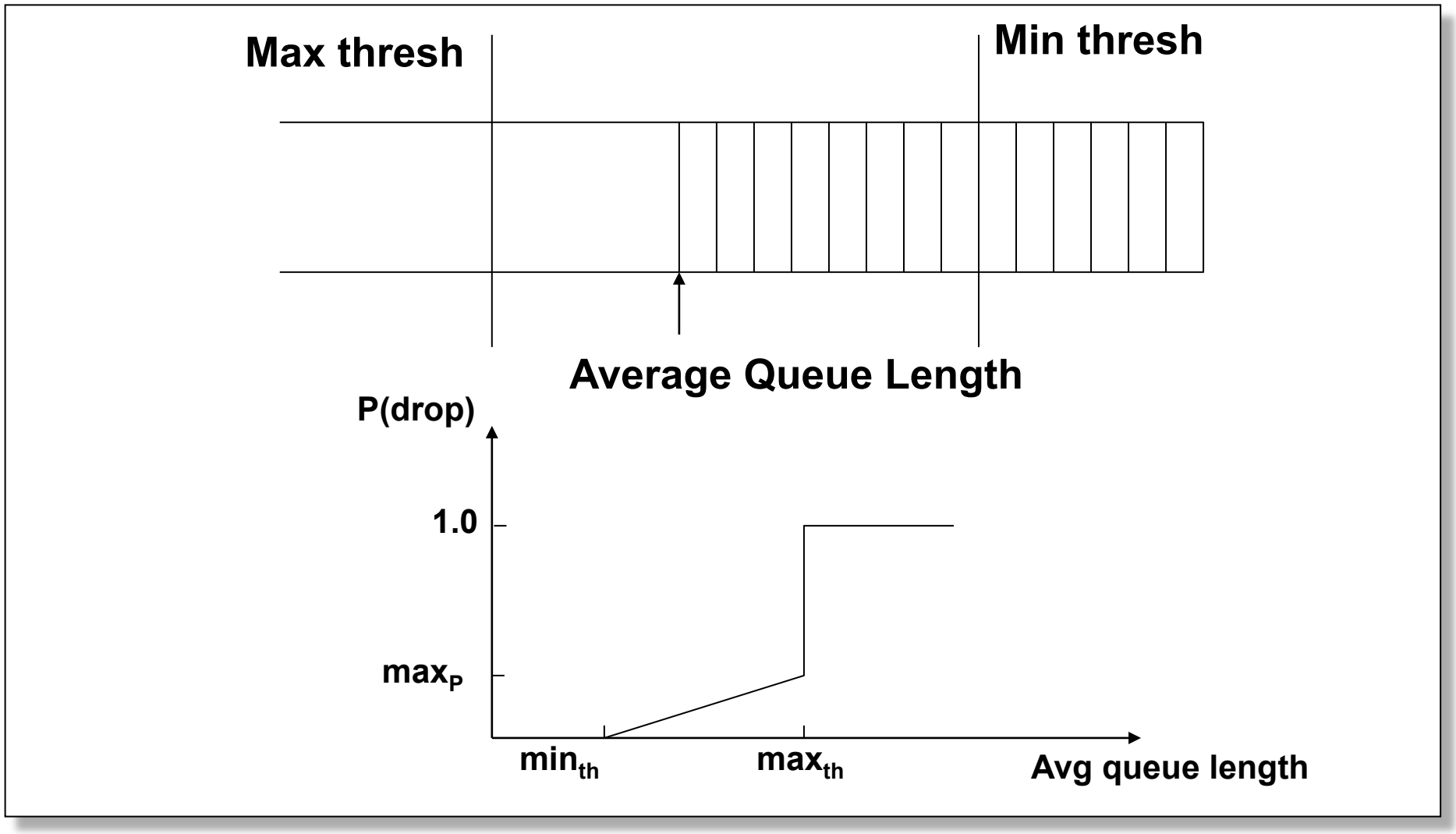


Typical Internet Queuing

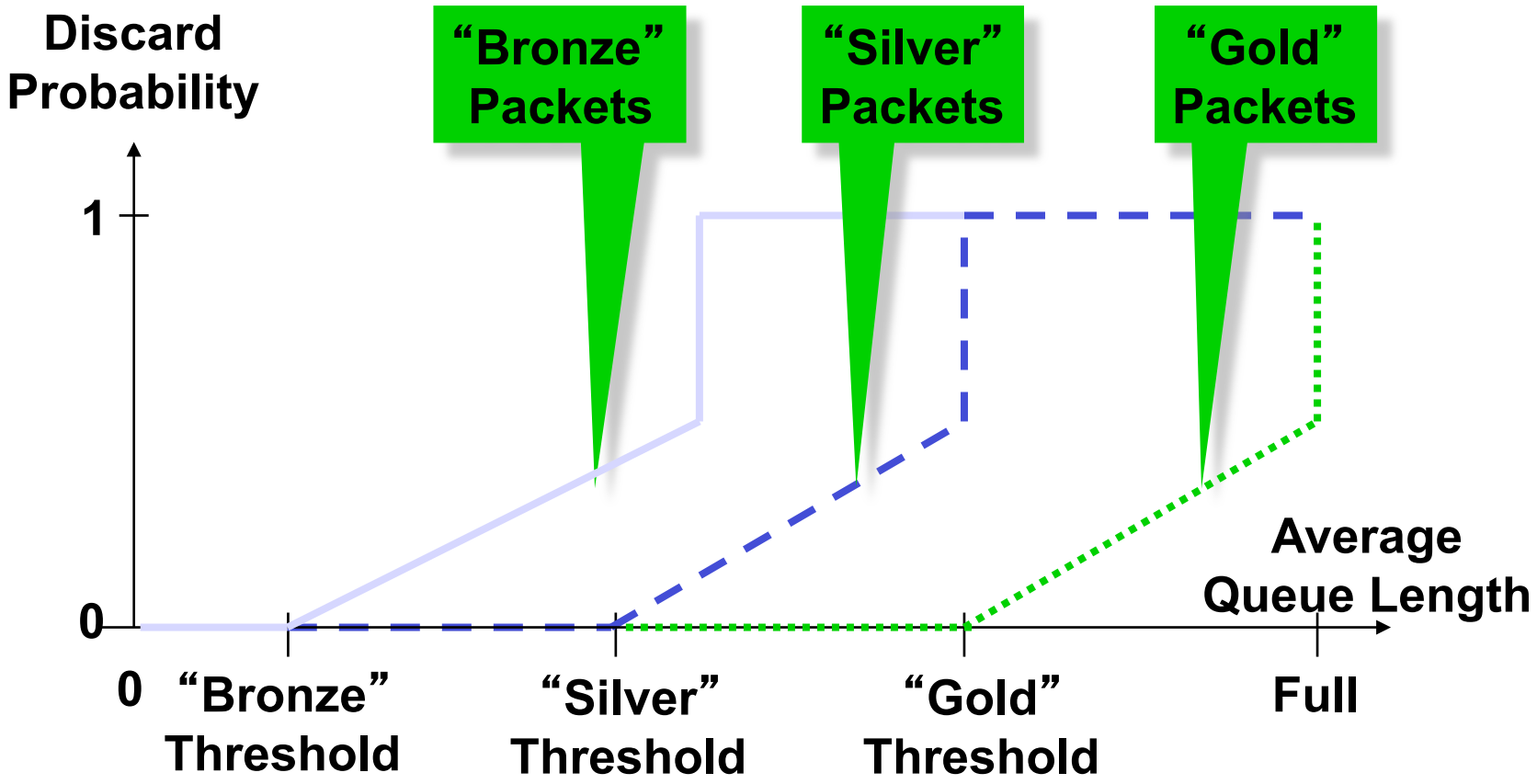
- FIFO + drop-tail
  - Simplest choice
  - Used widely in the Internet
- FIFO (first-in-first-out)
  - Implies single class of traffic
- Drop-tail
  - Arriving packets get dropped when queue is full regardless of flow or importance
- FIFO Issues:
  - No isolation between flows: full burden on e2e control
  - No policing: send more packets → get more service
- Drop-tail issues:
  - Synchronization: end hosts react to same events because packets tend to be lost in bursts (see TCP!!)



Random Early Detection (RED)

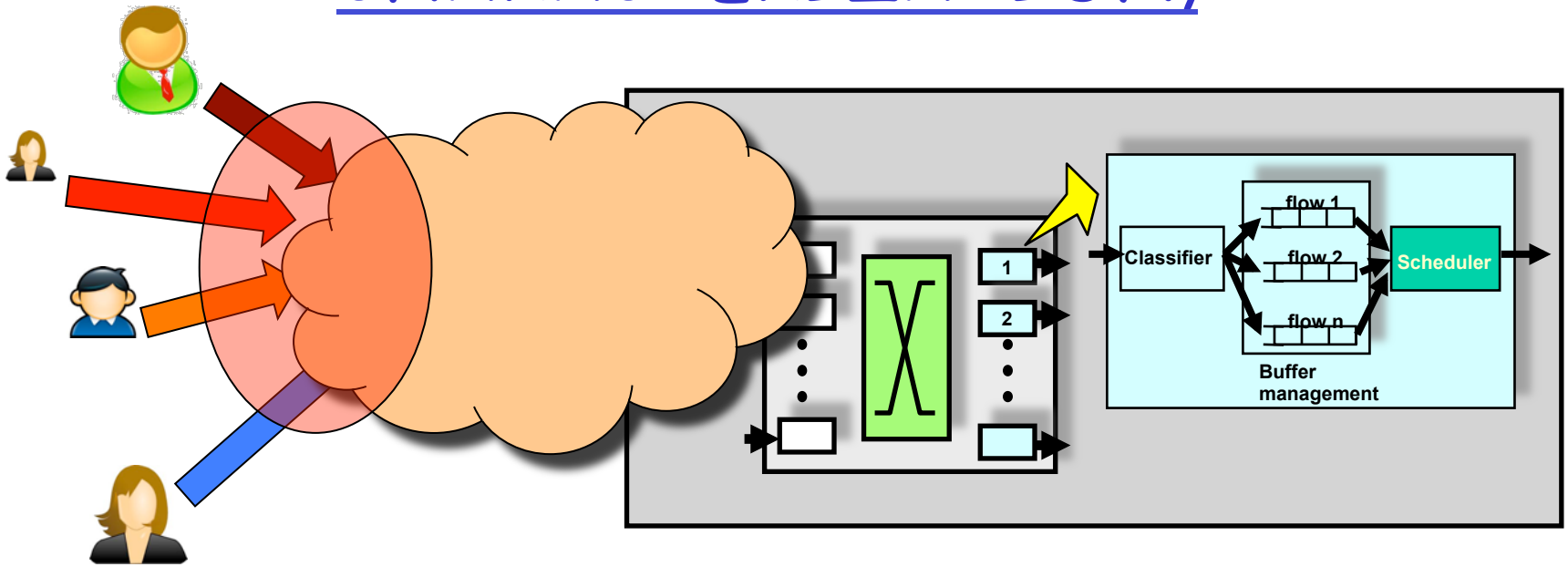


RED with Multiple Thresholds



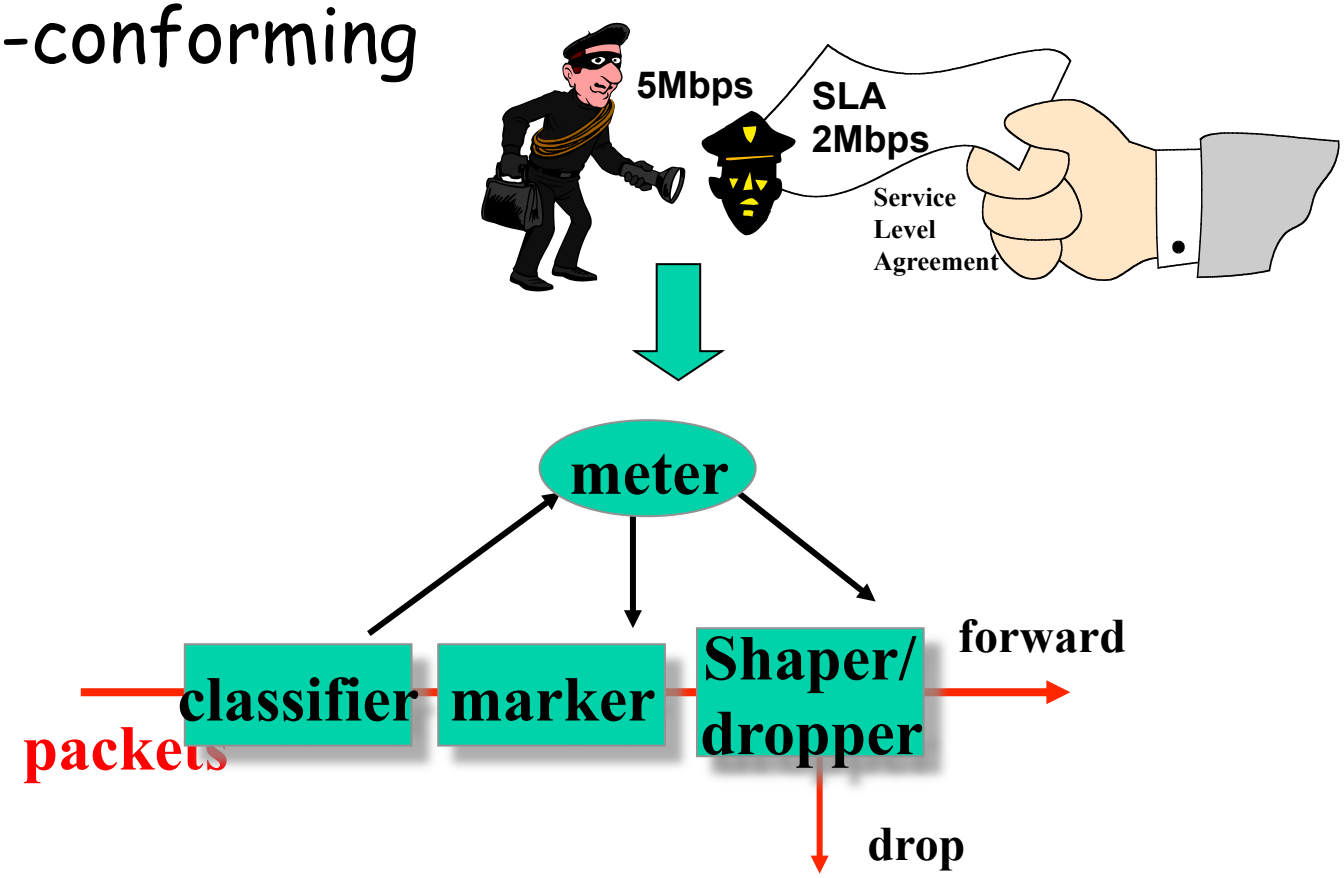
source Juha Heinänen

TRAFFIC, SERVICE CHARACTERIZATION,



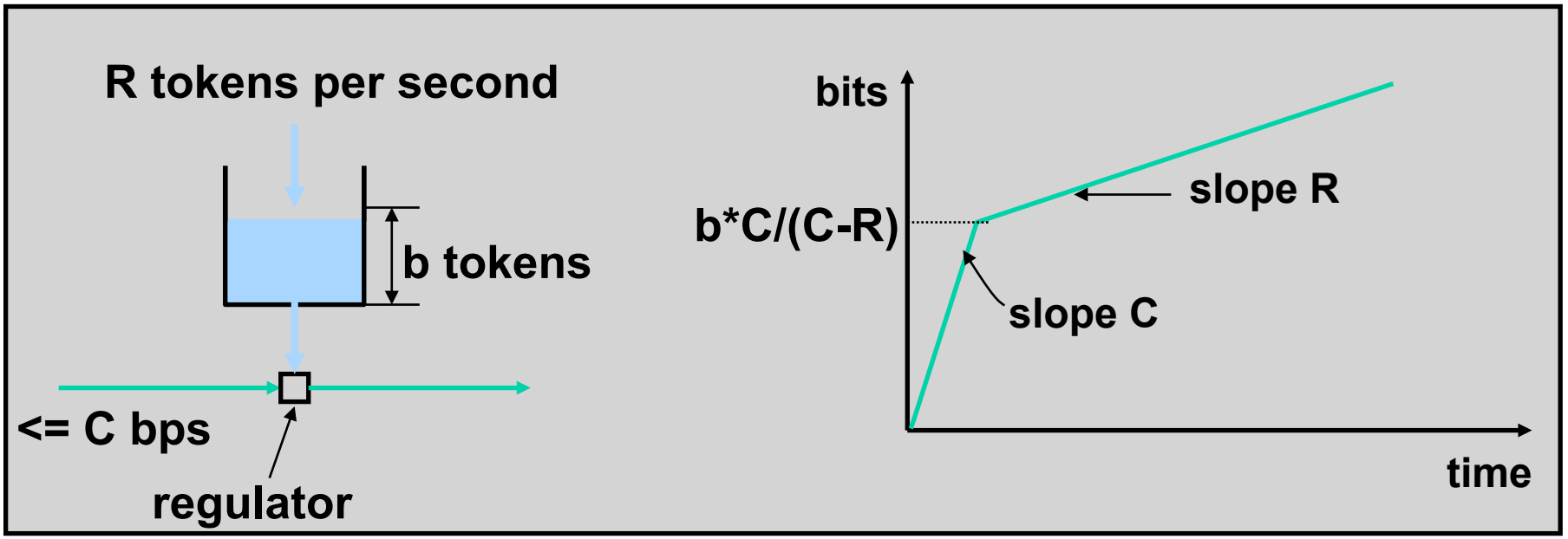
Traffic Conditioning

- User declares traffic profile (eg, rate and burst size); traffic is metered and shaped if non-conforming



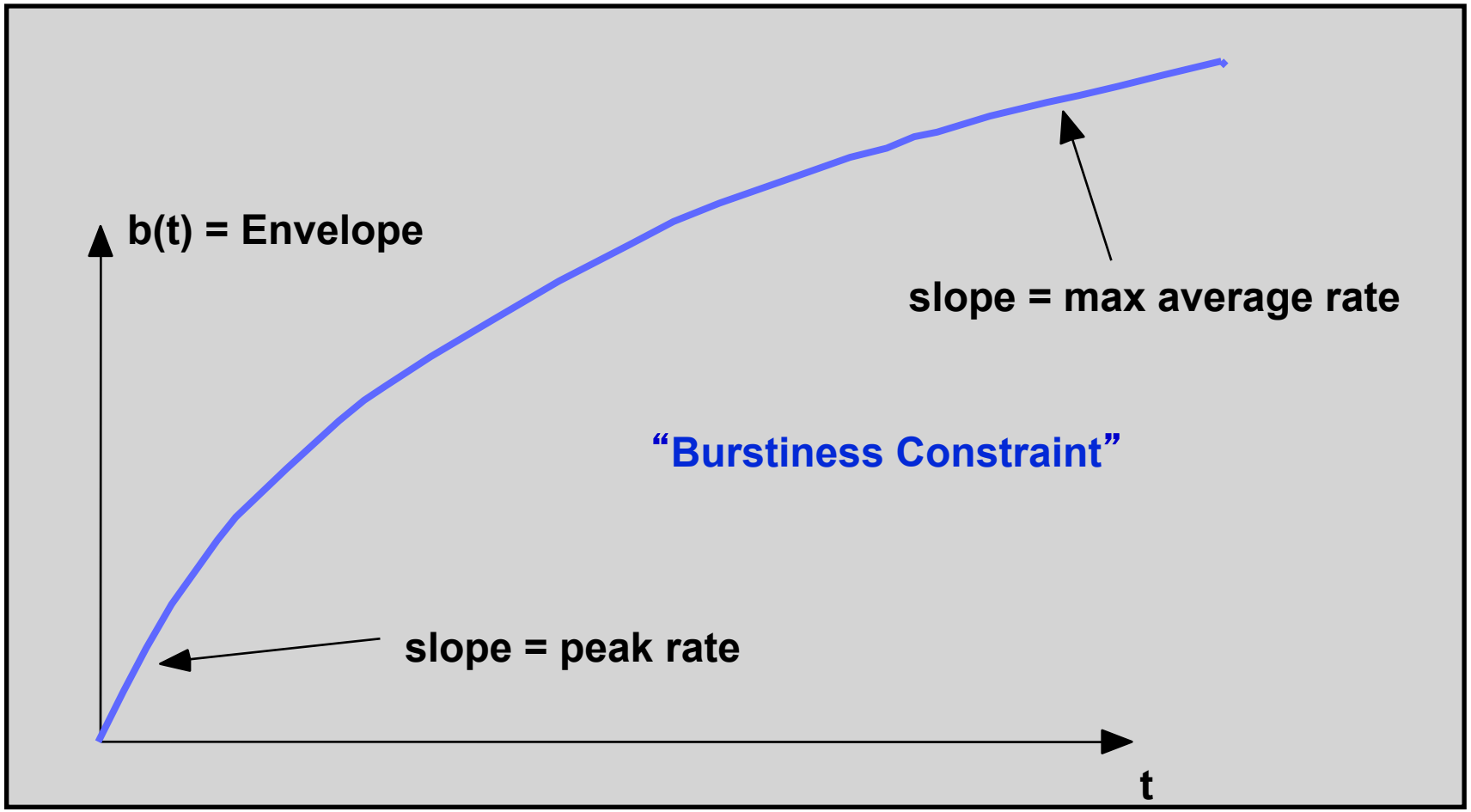
Ex: Token Bucket

- Characterized by three parameters (b, R, C)
  - b – token depth
  - R – average arrival rate
  - C – maximum arrival rate (e.g., link capacity)
- A bit is transmitted only when there is an available token
  - When a bit is transmitted exactly one token is consumed



Traffic Envelope (Arrival Curve)

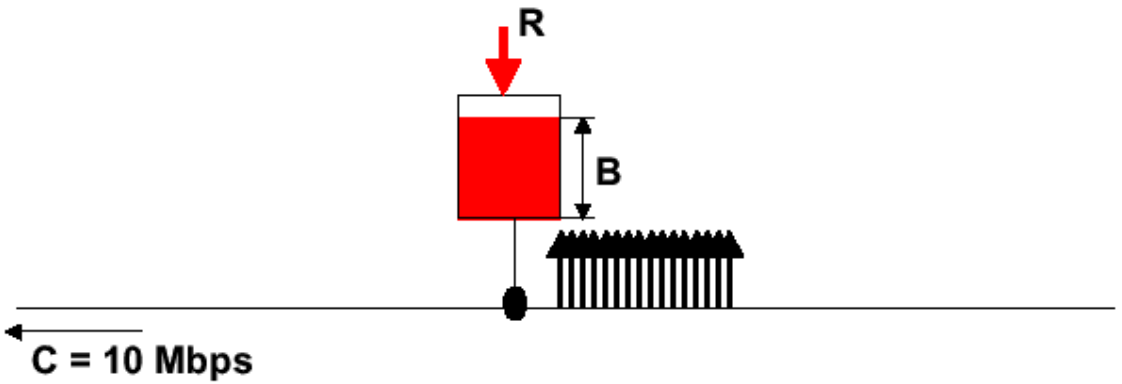
- Maximum amount of service that a flow can send during an interval of time t



Token Bucket

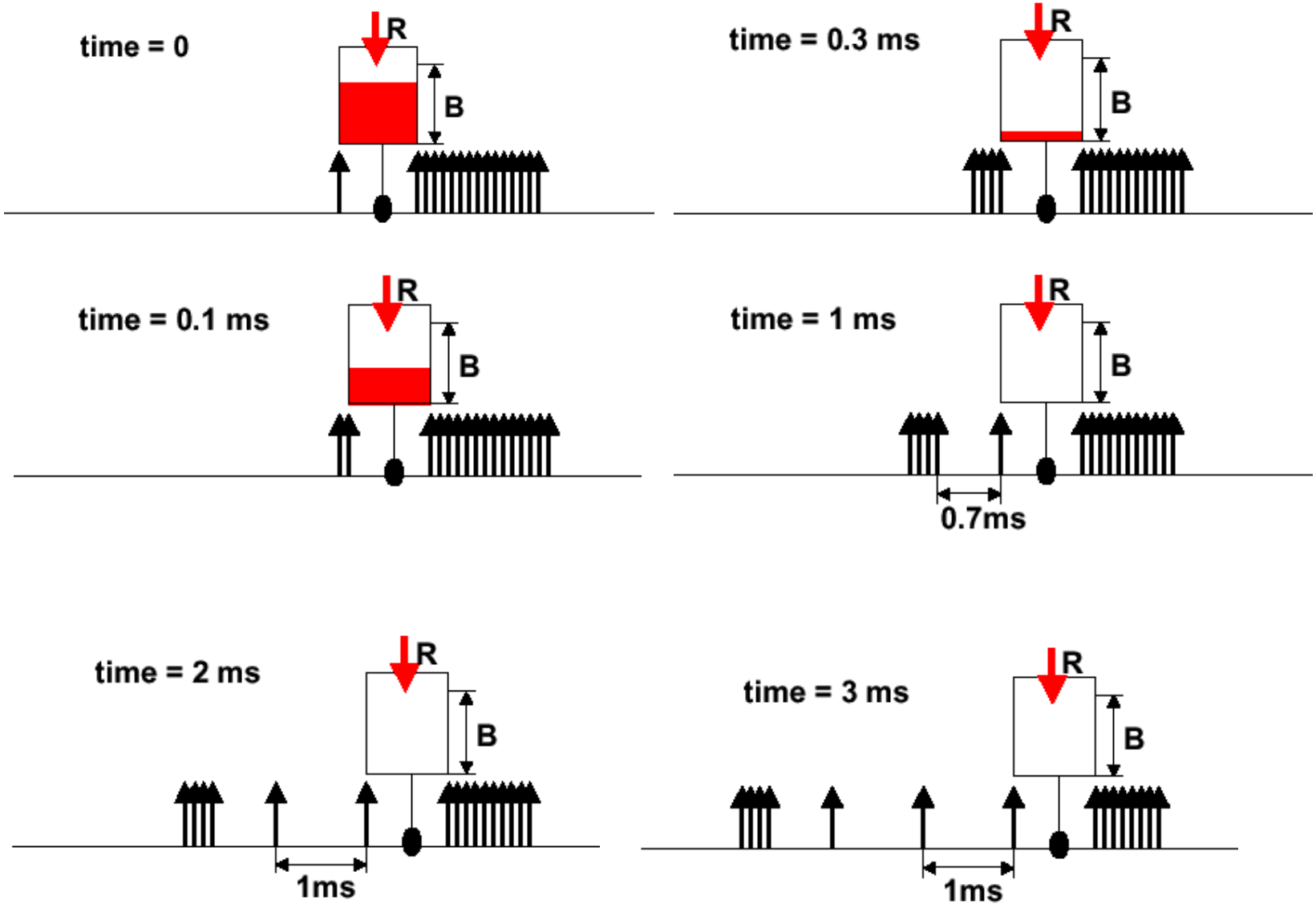
Example

- B = 4000 bits, R = 1 Mbps, C = 10 Mbps
- Packet length = 1000 bits
- Assume the bucket is initially full and a "large" burst of packets arrives



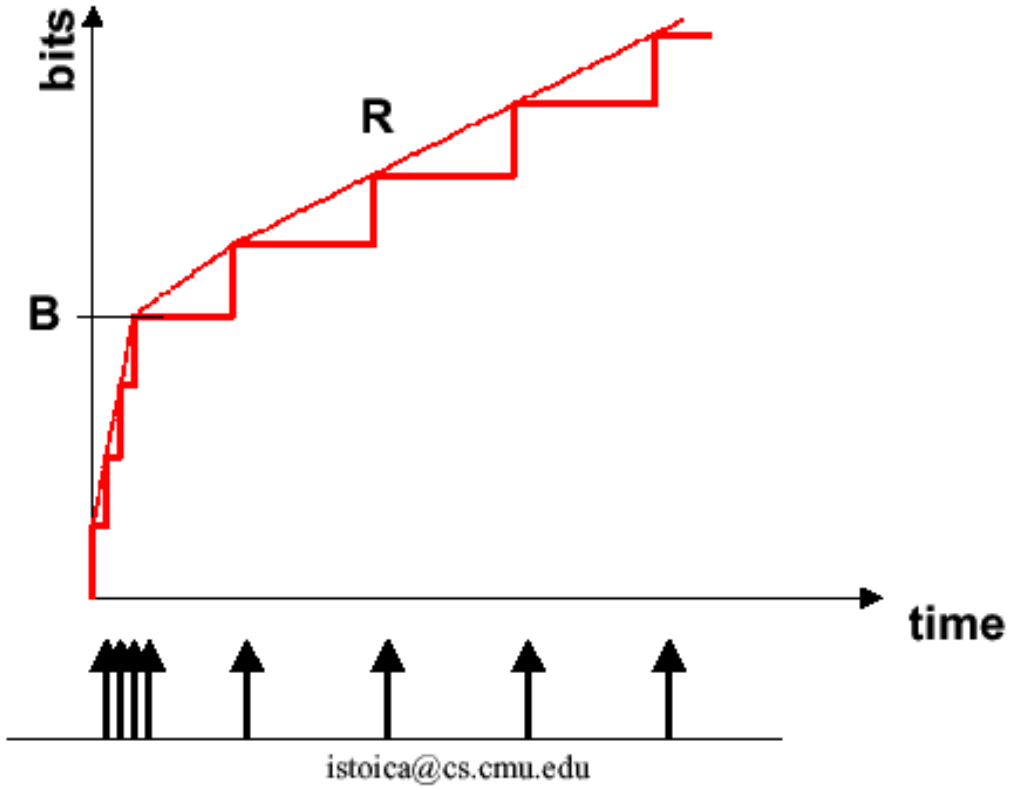
istoica@cs.cmu.edu

Token Bucket



Arrival curve

A(t) – number of bits received up to time t



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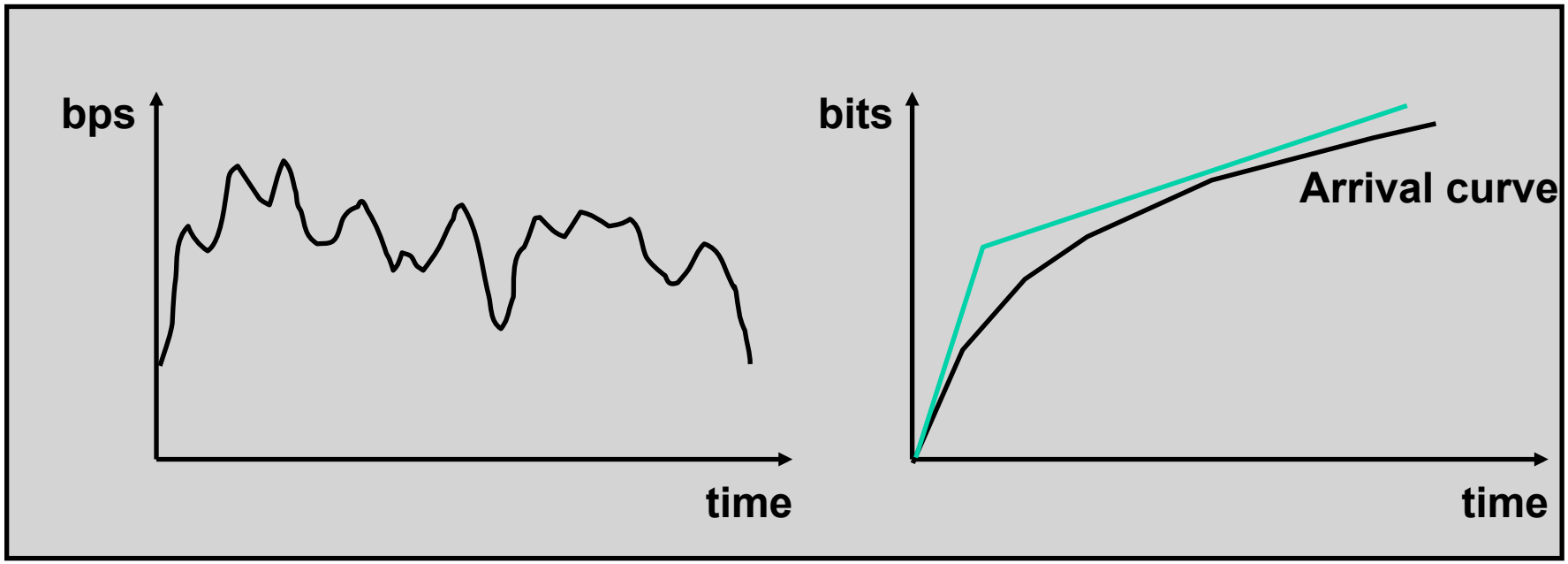
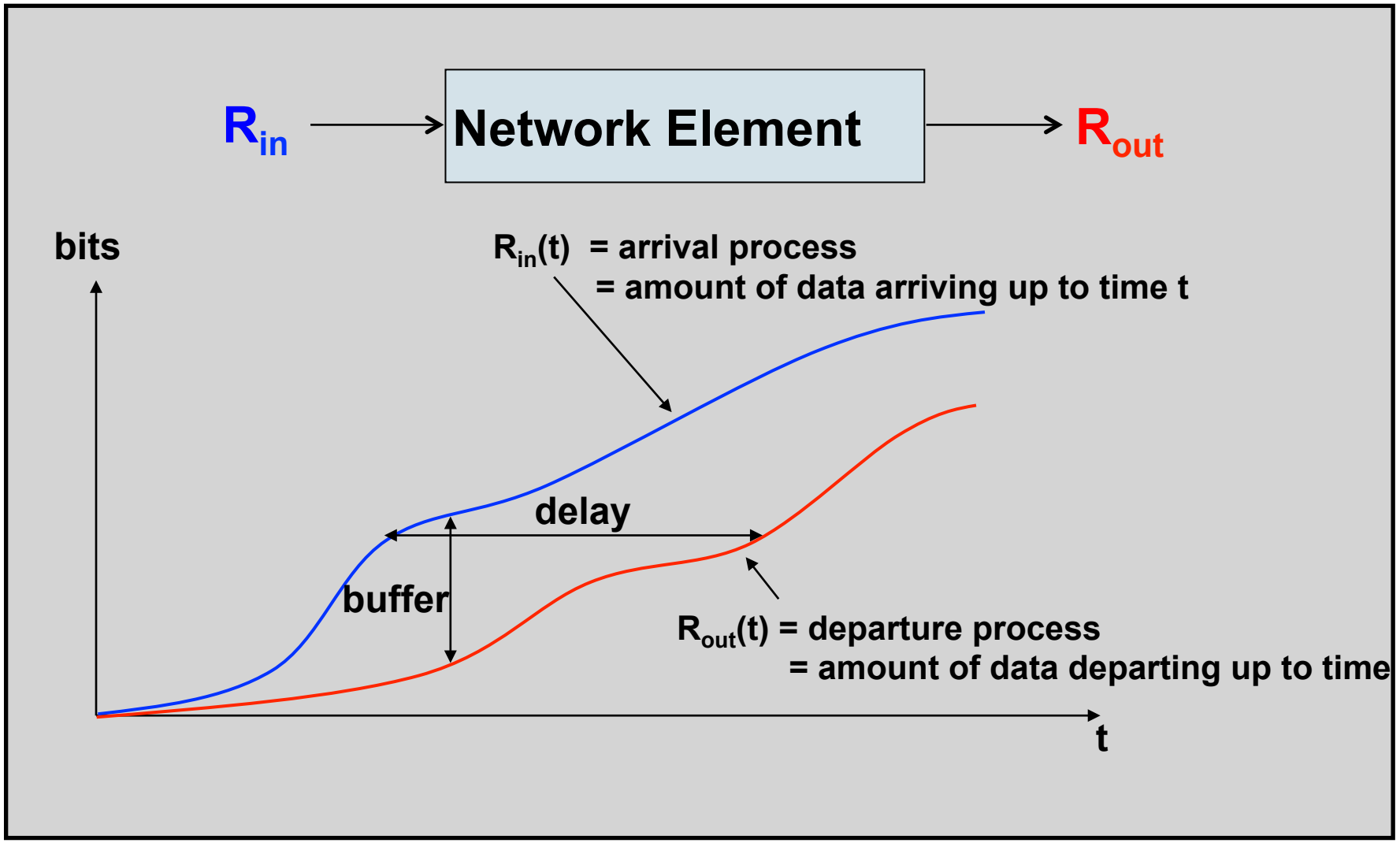
Characterizing a Source by Token Bucket

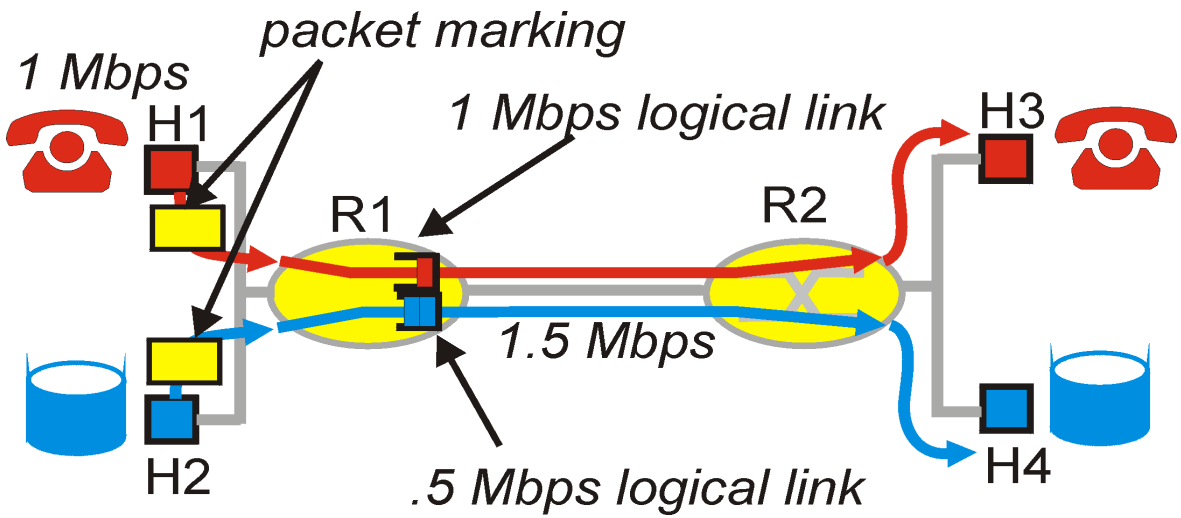
- Arrival curve – maximum amount of bits transmitted by time t
- Use token bucket to bound the arrival curve



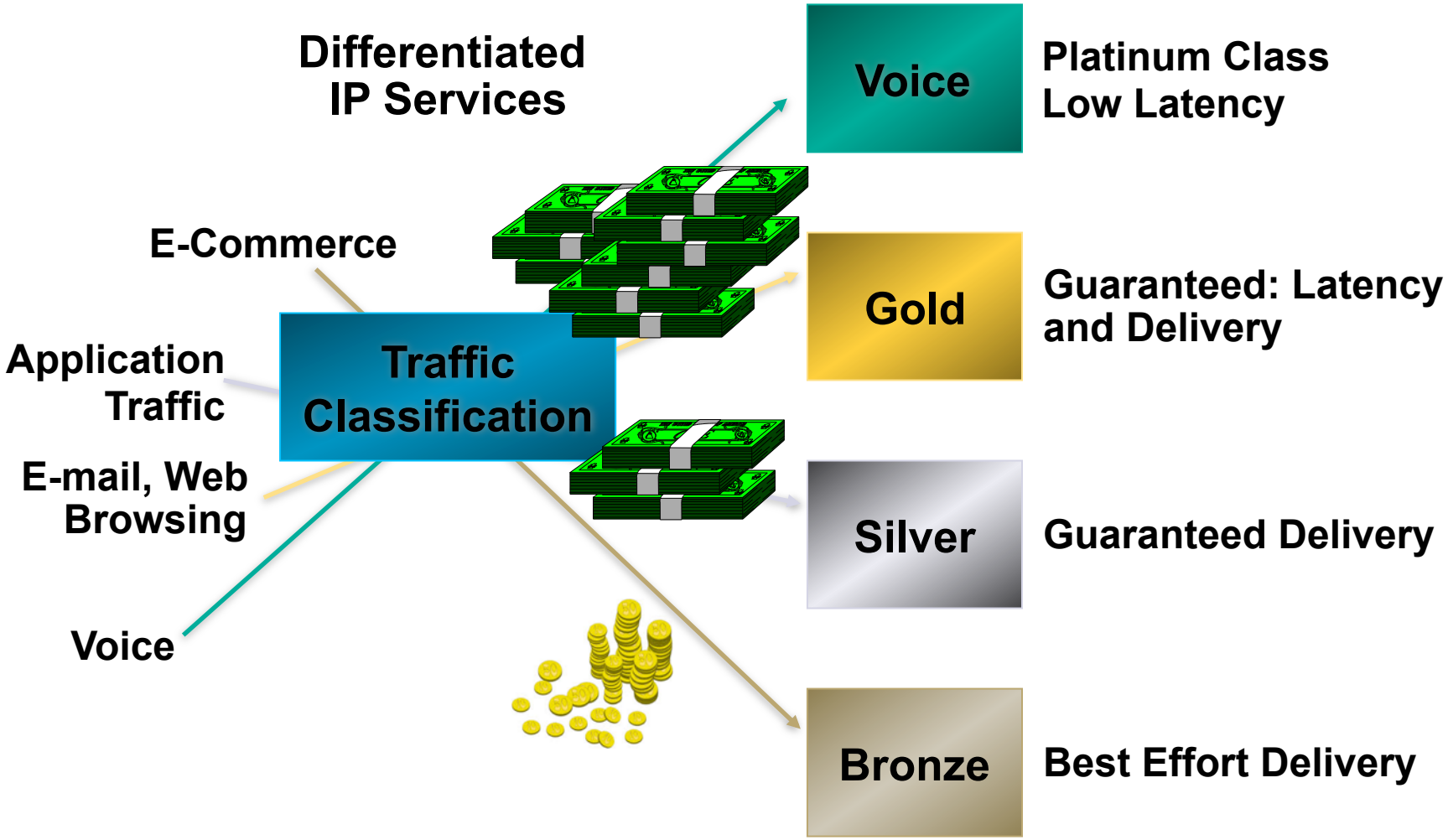
Arrival and Departure Process



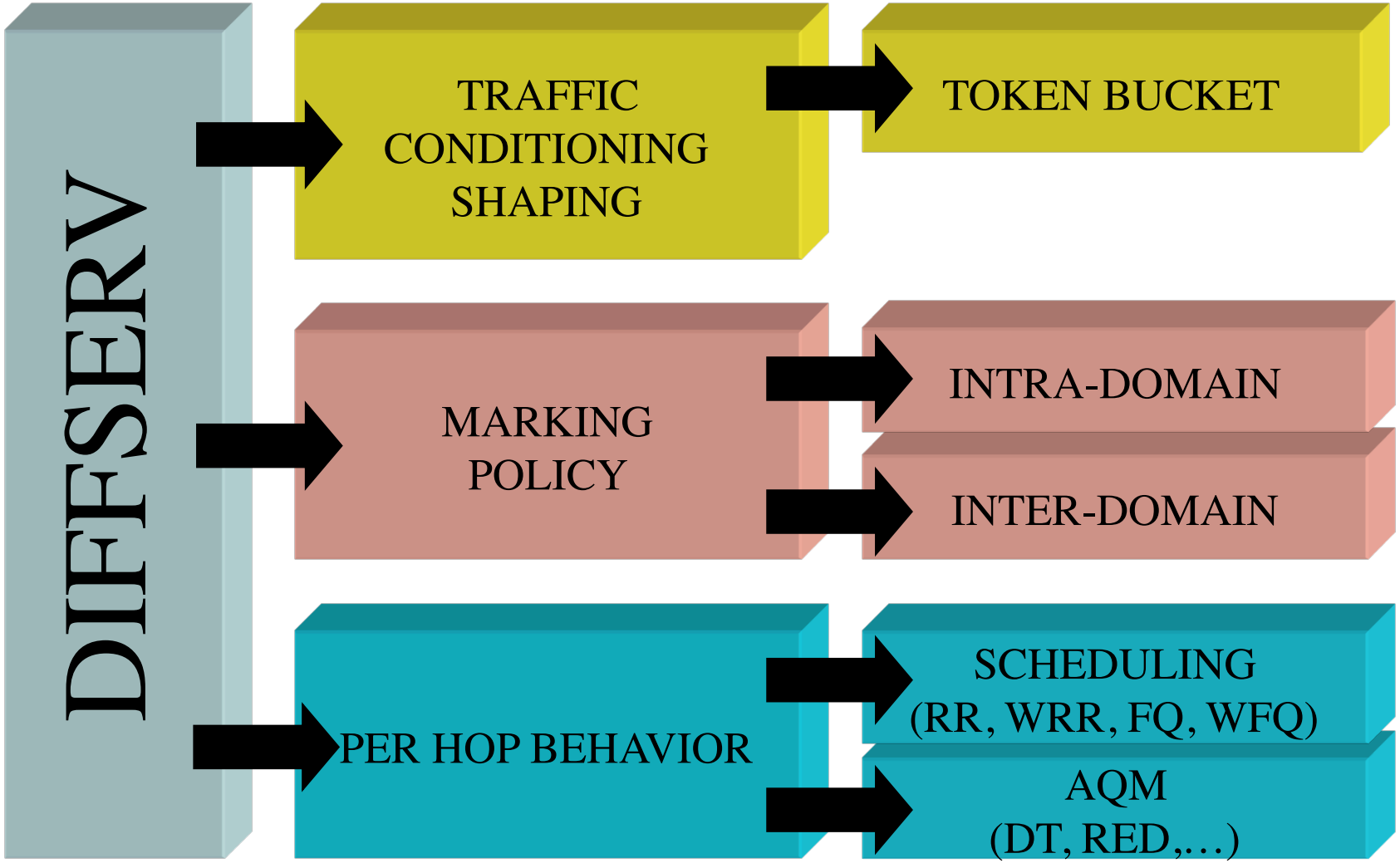
PUTTING IT TOGETHER



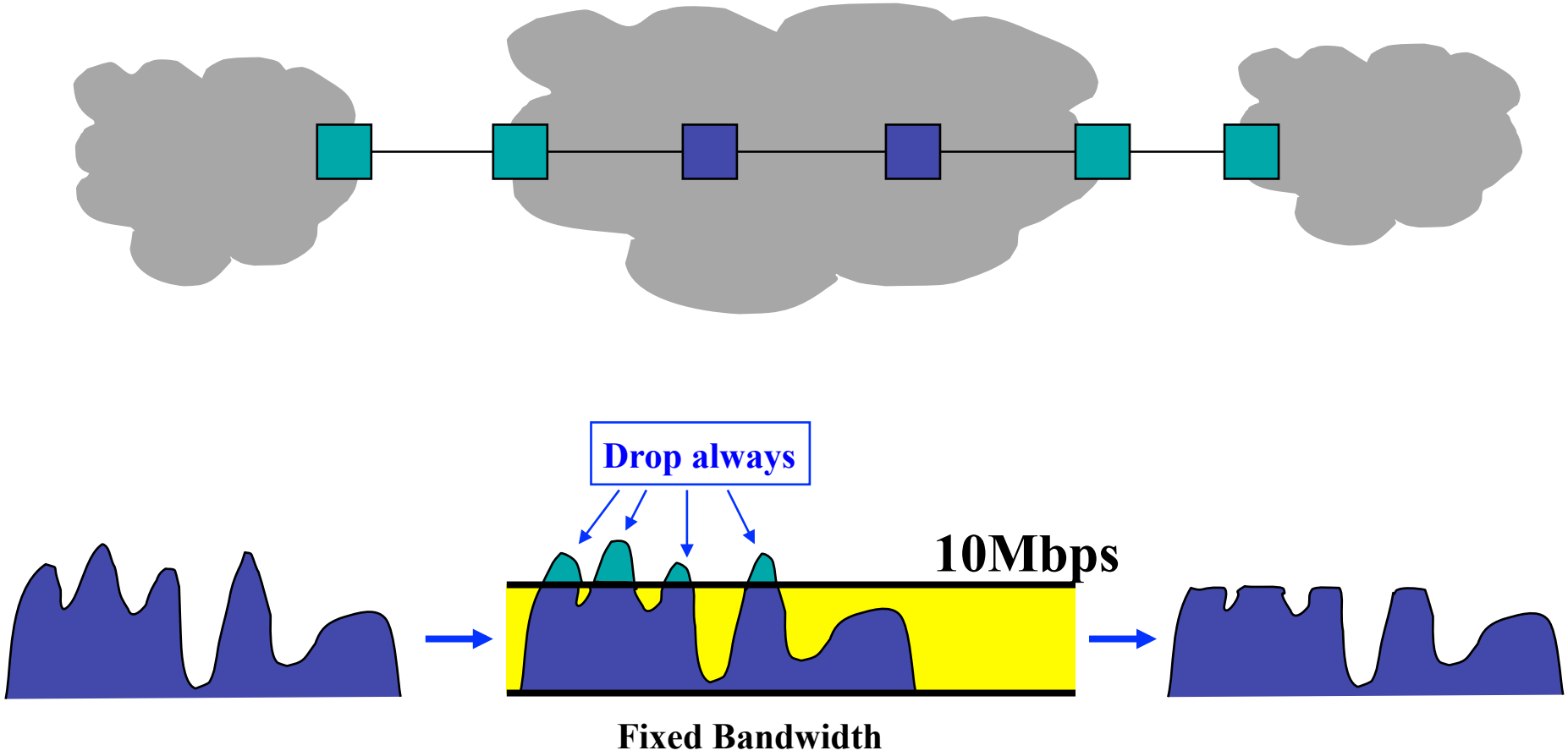
Divide traffic into classes



DiffServ building blocks

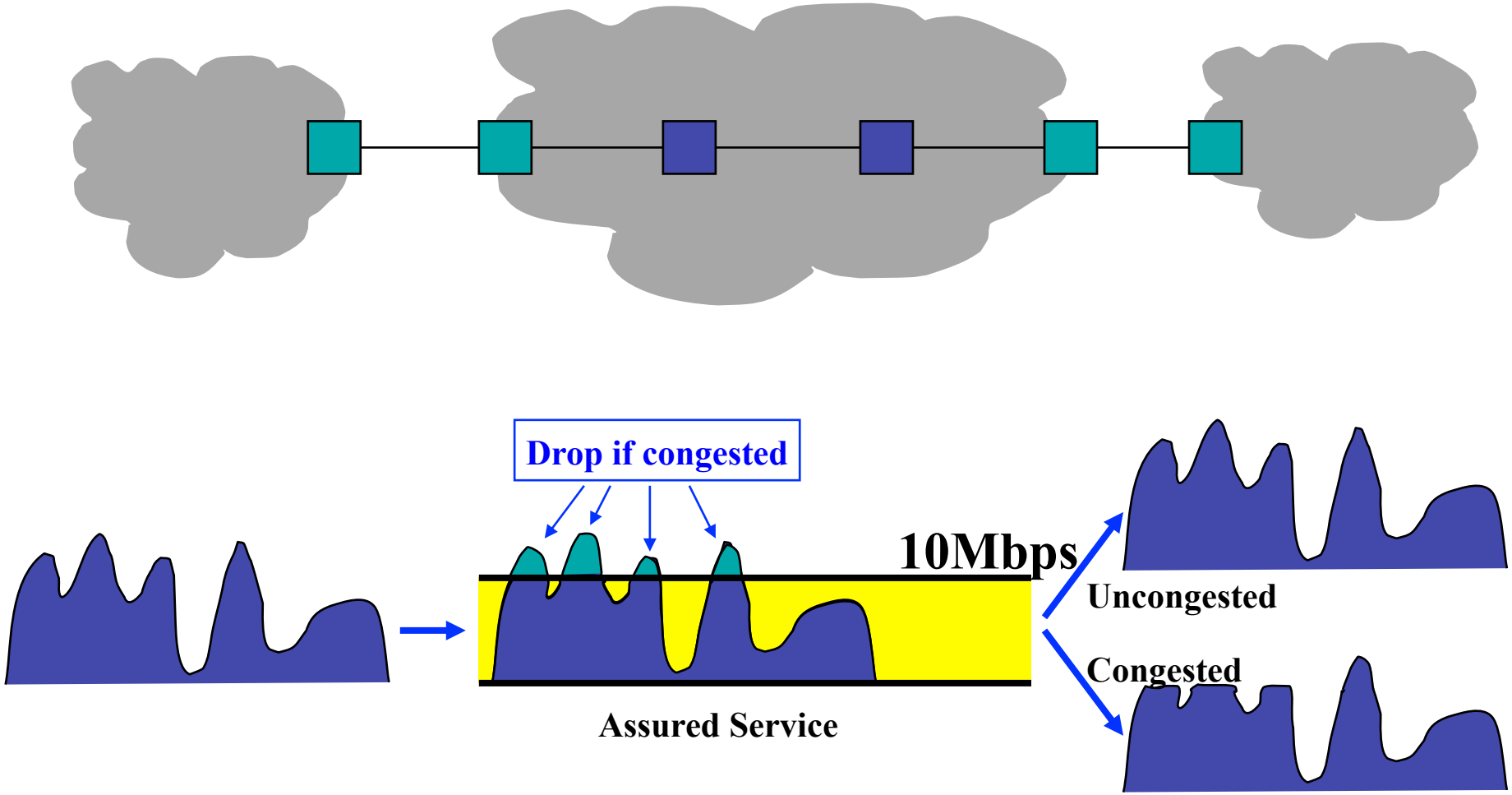


Premium Service Example



source Gordon Schaffee

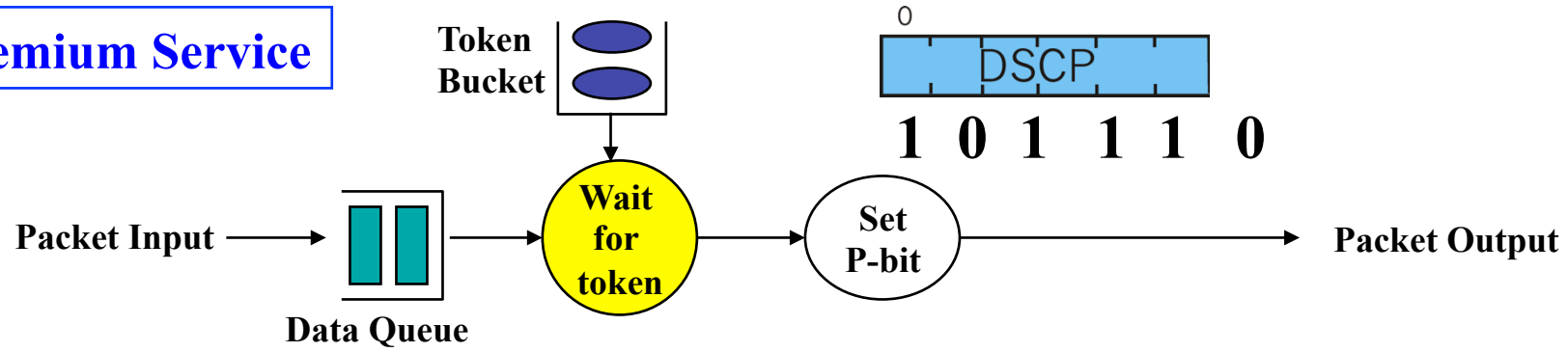
Assured Service Example



source Gordon Schaffee

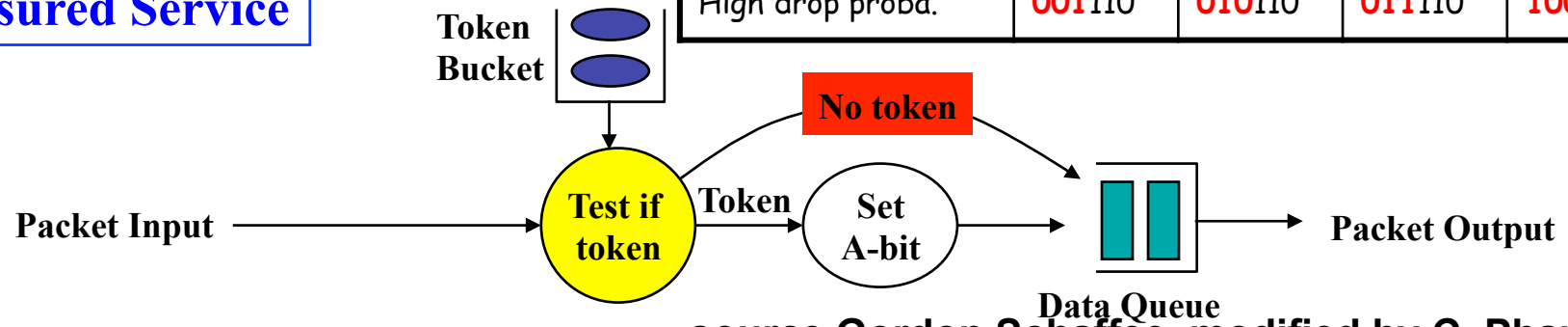
Border Router Functionality

Premium Service



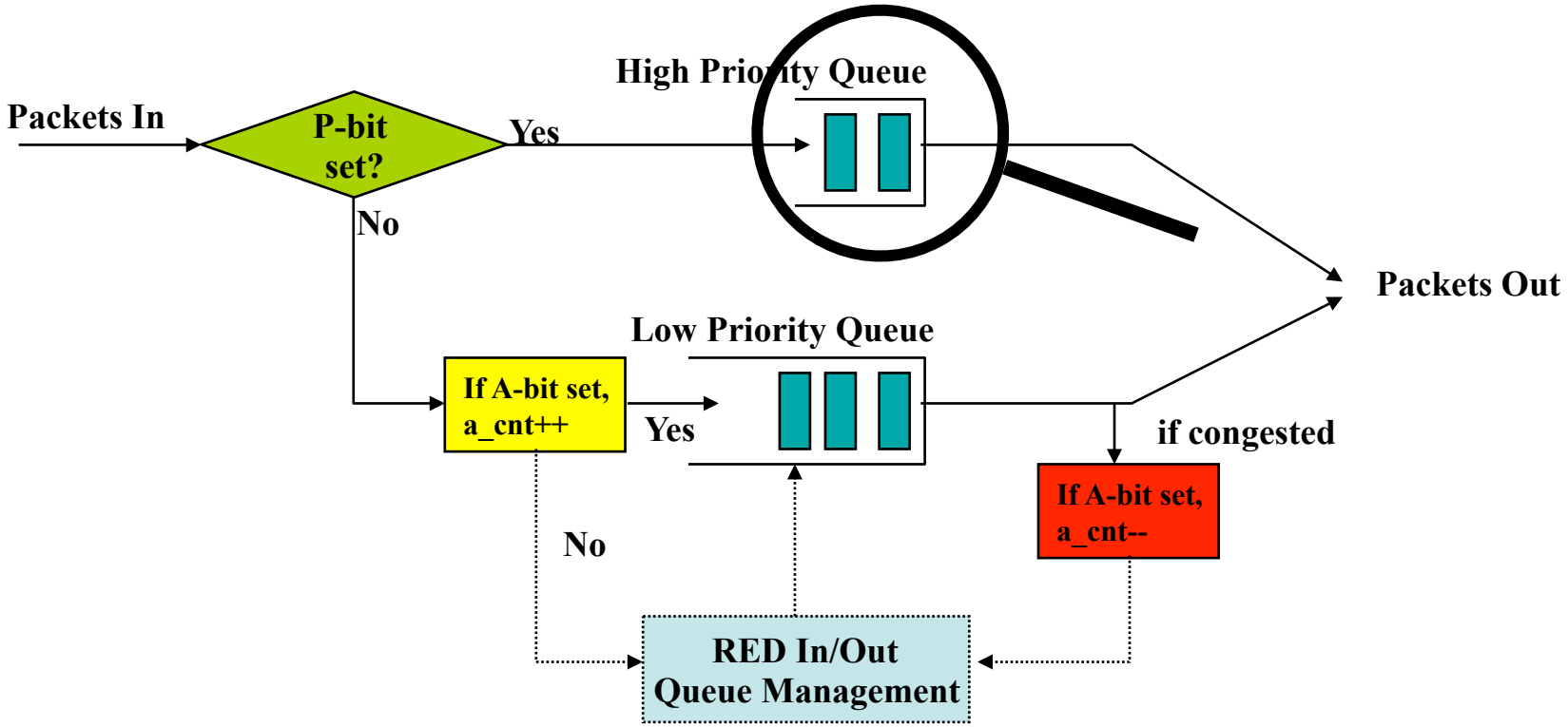
Assured Service

0 DSCP	Class 1	Class 2	Class 3	Class 4
Low drop probability	001010	010010	011010	100010
Medium drop proba.	001100	010100	011100	100100
High drop proba.	001110	010110	011110	100110



source Gordon Schaffee, modified by C. Pham

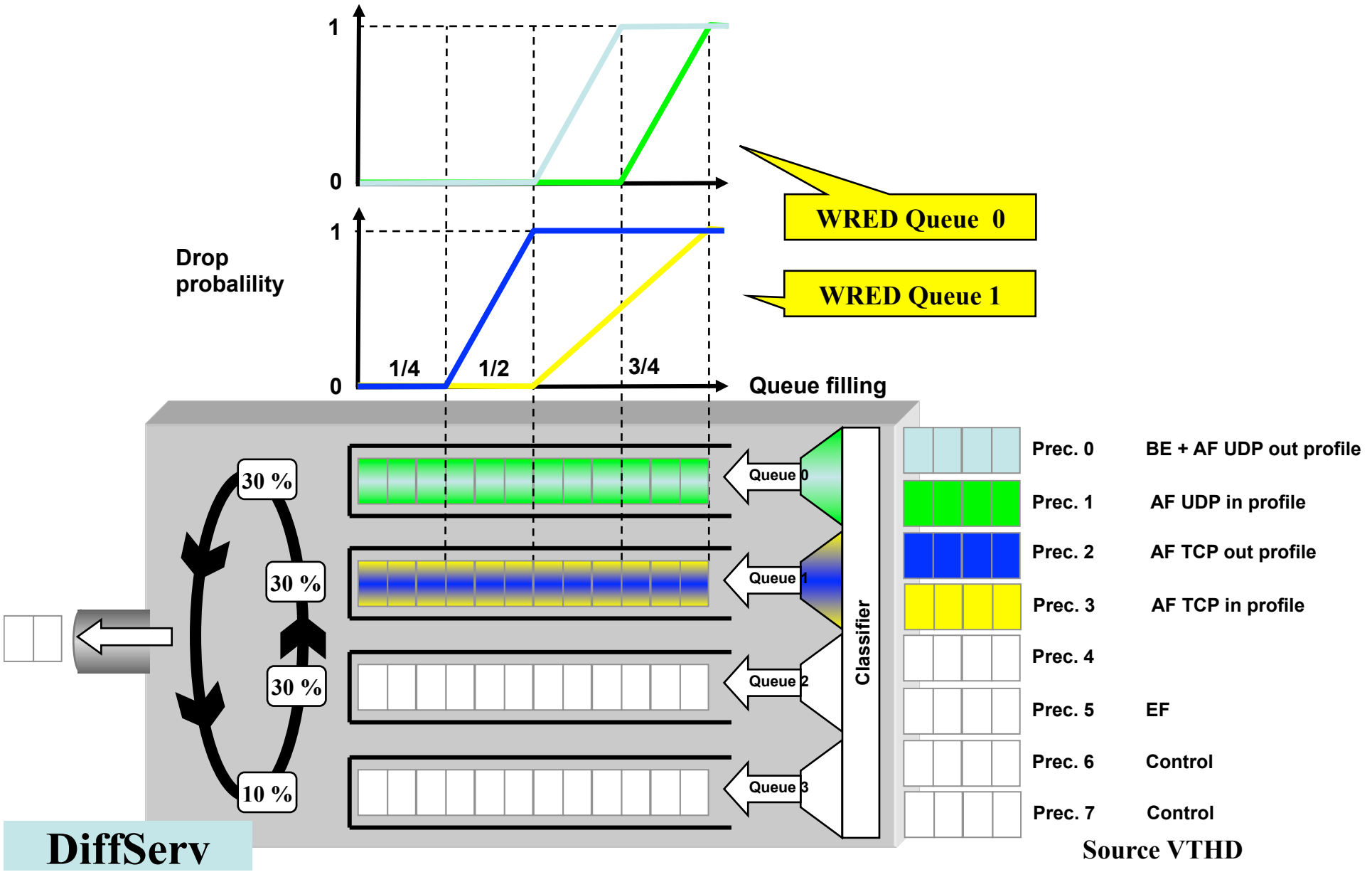
Internal Router Functionality



A DSCP codes aggregates, not individual flows
No state in the core
Should scale to millions of flows

source Gordon Schaffee, modified by C. Pham

Router configuration

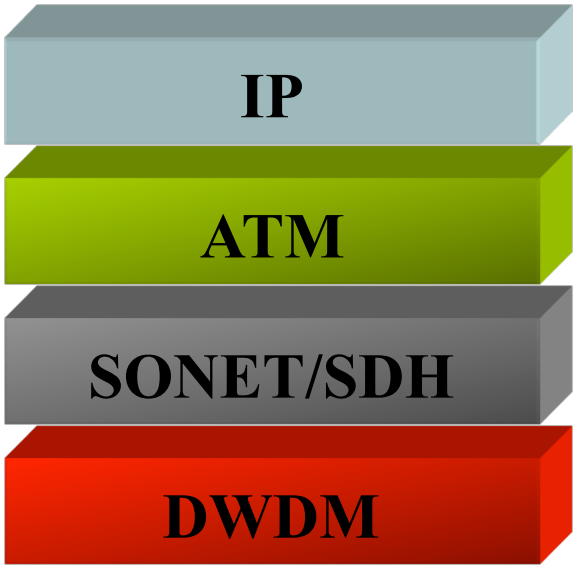


DiffServ

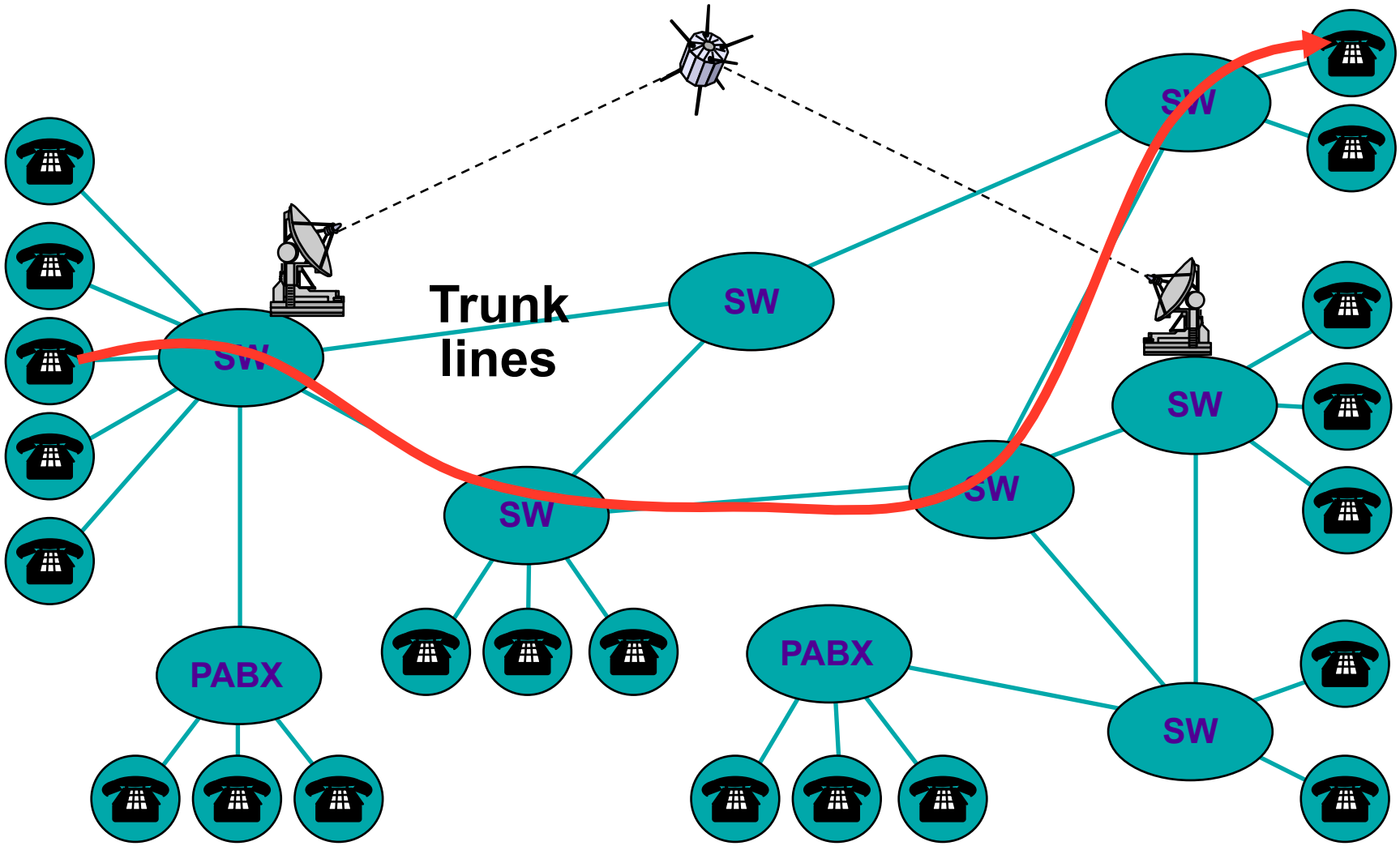
Source VTHD

Bandwidth provisioning: towards Traffic Engineering

- DWDM-based optical fibers have made bandwidth very cheap in the backbone
- On the other hand, dynamic provisioning is difficult because of the complexity of the network control plane:
  - Distinct technologies
  - Many protocols layers
  - Many control software



The telephone circuit view



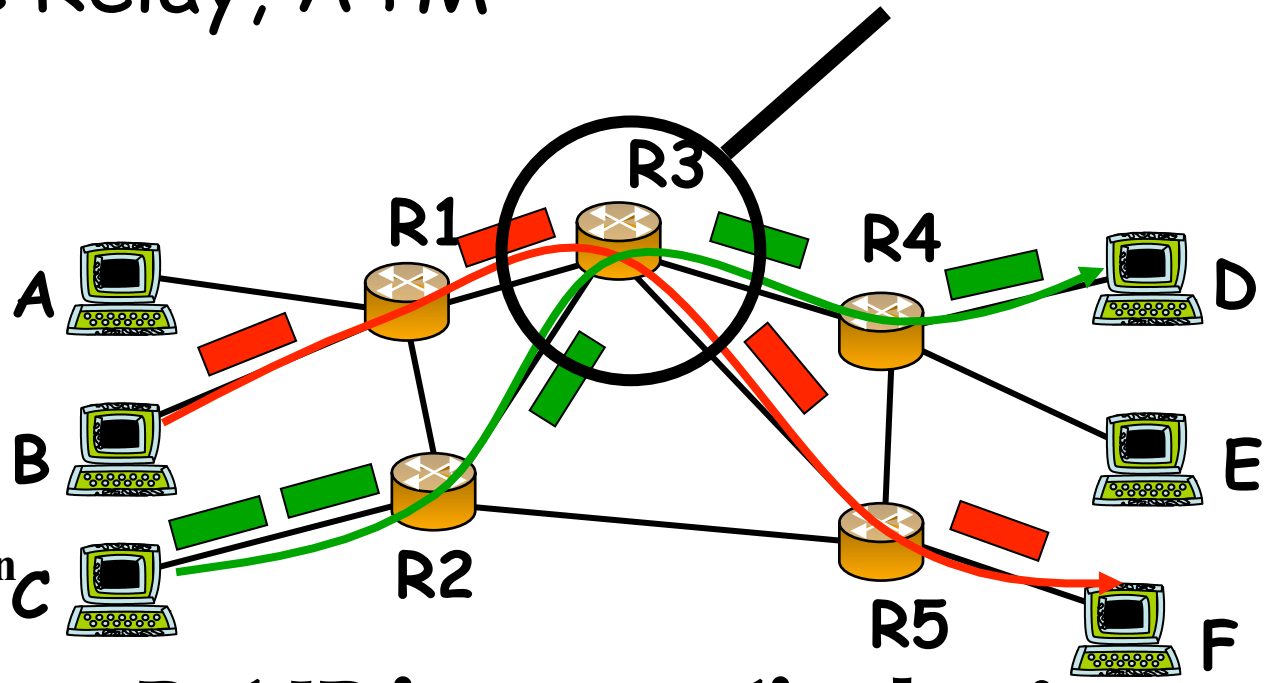
Advantages of circuits

- Provides the same path for information of the same connection: less out-of-order delivery
- Easier provisioning/reservation of network's resources: planning and management features

From telco circuits to IP virtual circuits

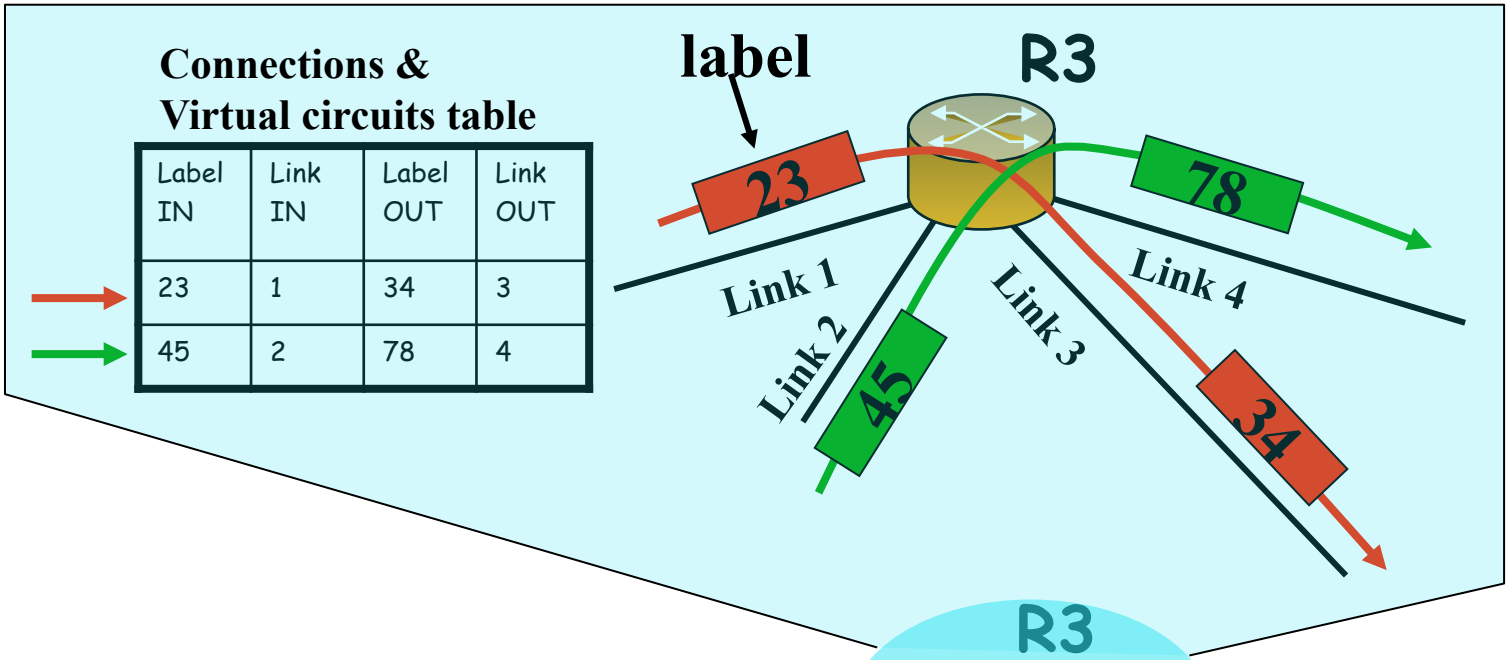
- Virtual circuit refers to a connection oriented network/link layer: e.g. X.25, Frame Relay, ATM

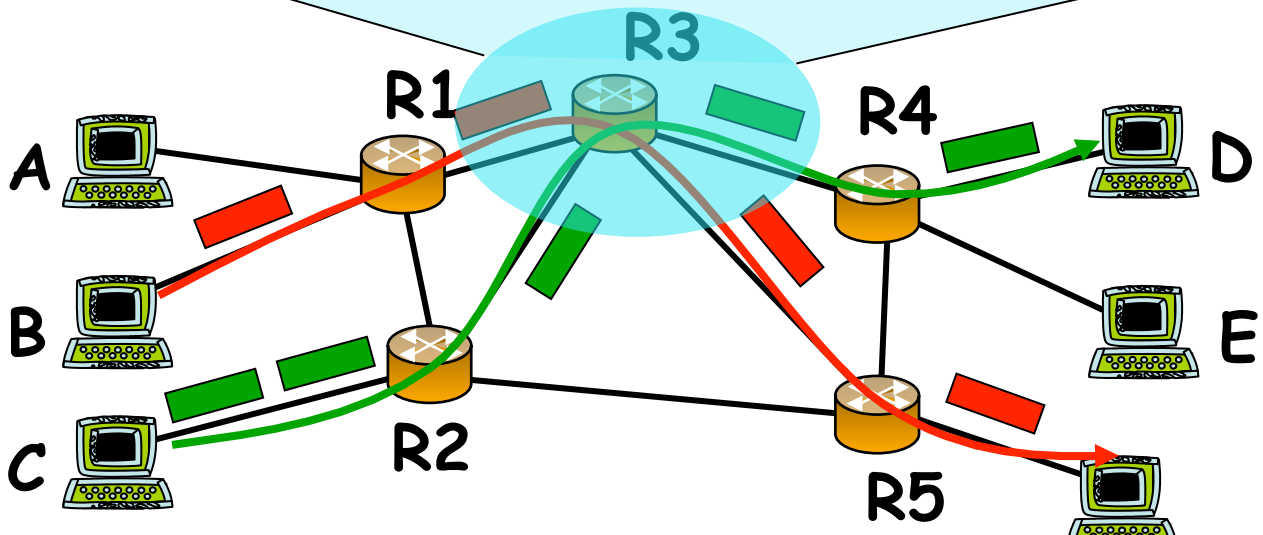
Virtual Circuit Switching: a path is defined for each connection



But IP is connectionless!

Virtual circuit principles





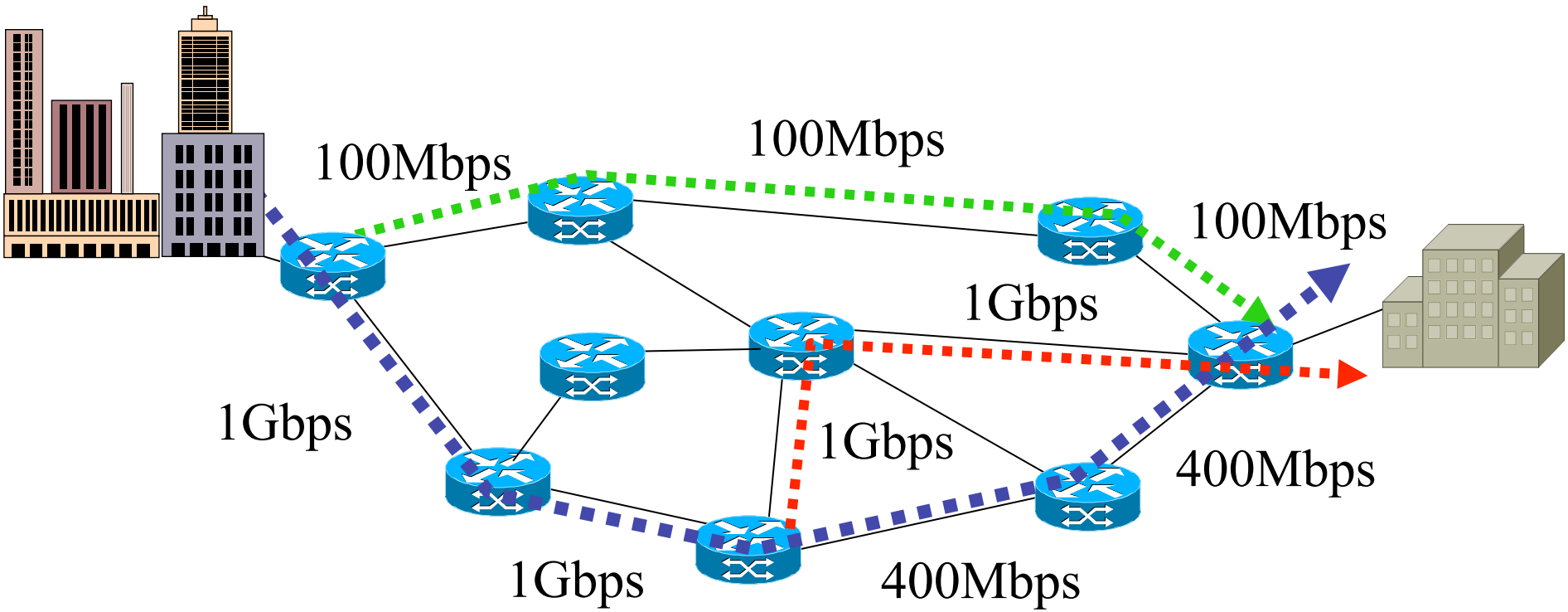
Virtual Circuit Switching

Why virtual circuit?

- Initially to speed up router's forwarding tasks: X.25, Frame Relay, ATM.

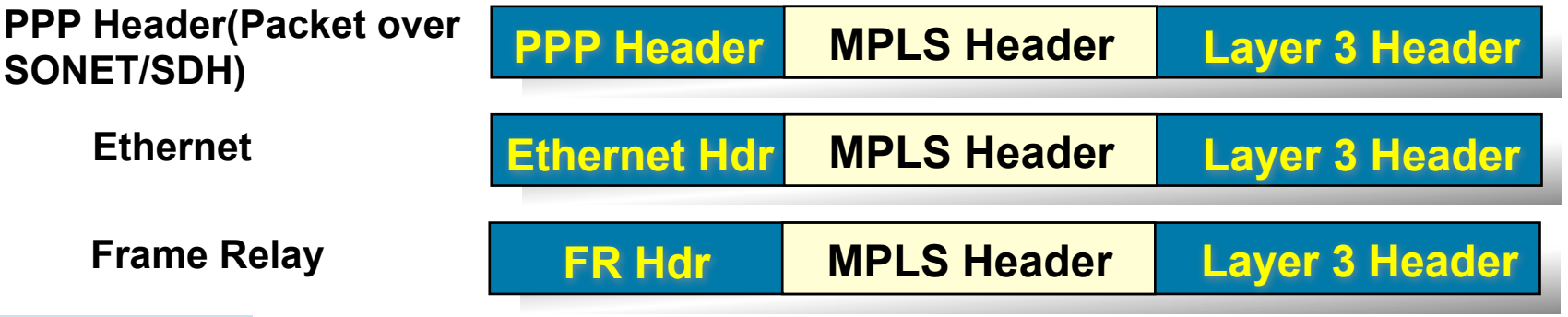
Now: Virtual circuits for traffic engineering!

Traffic Engineering vs traditional IP routing

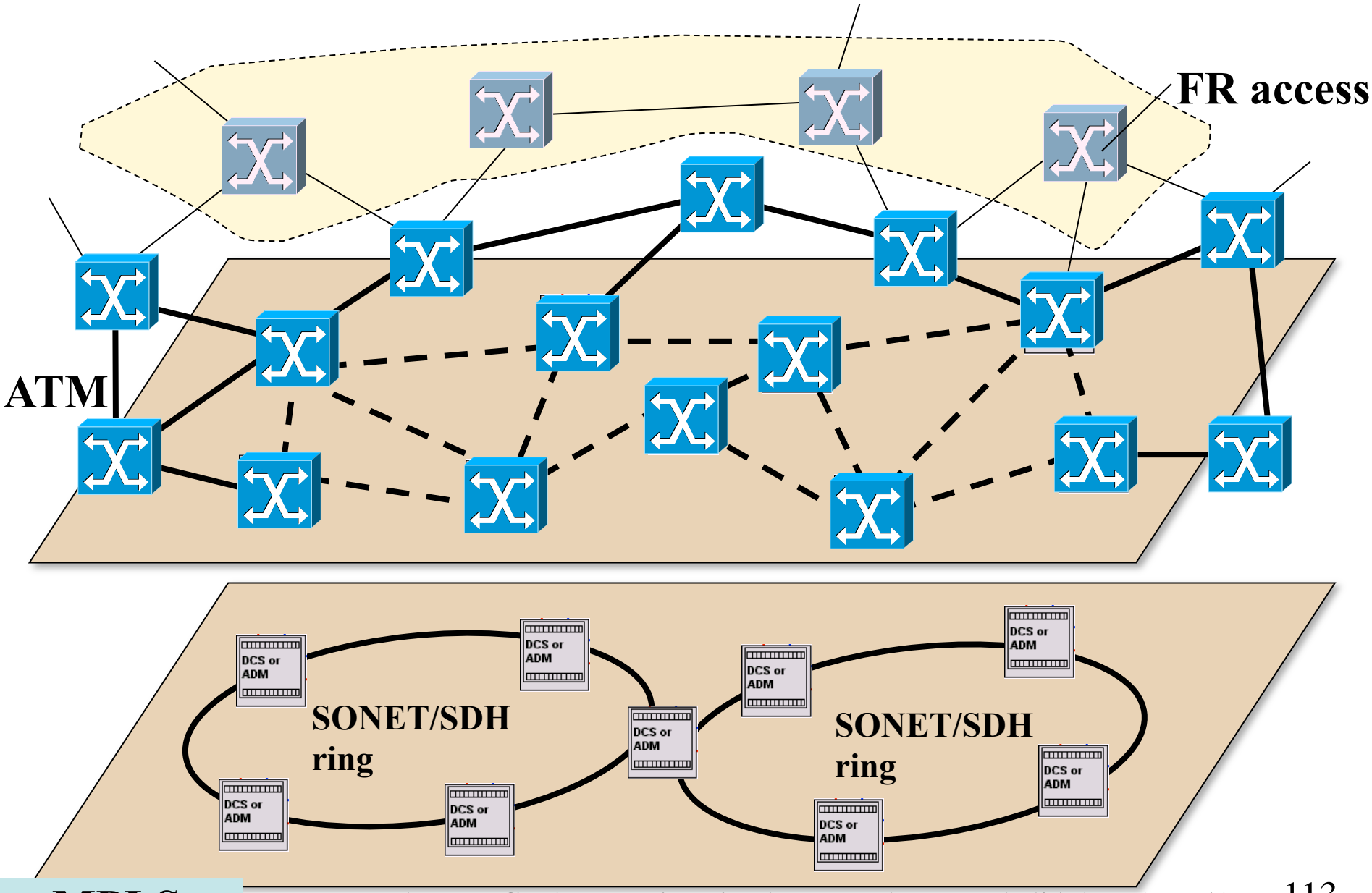


Virtual circuits in IP networks

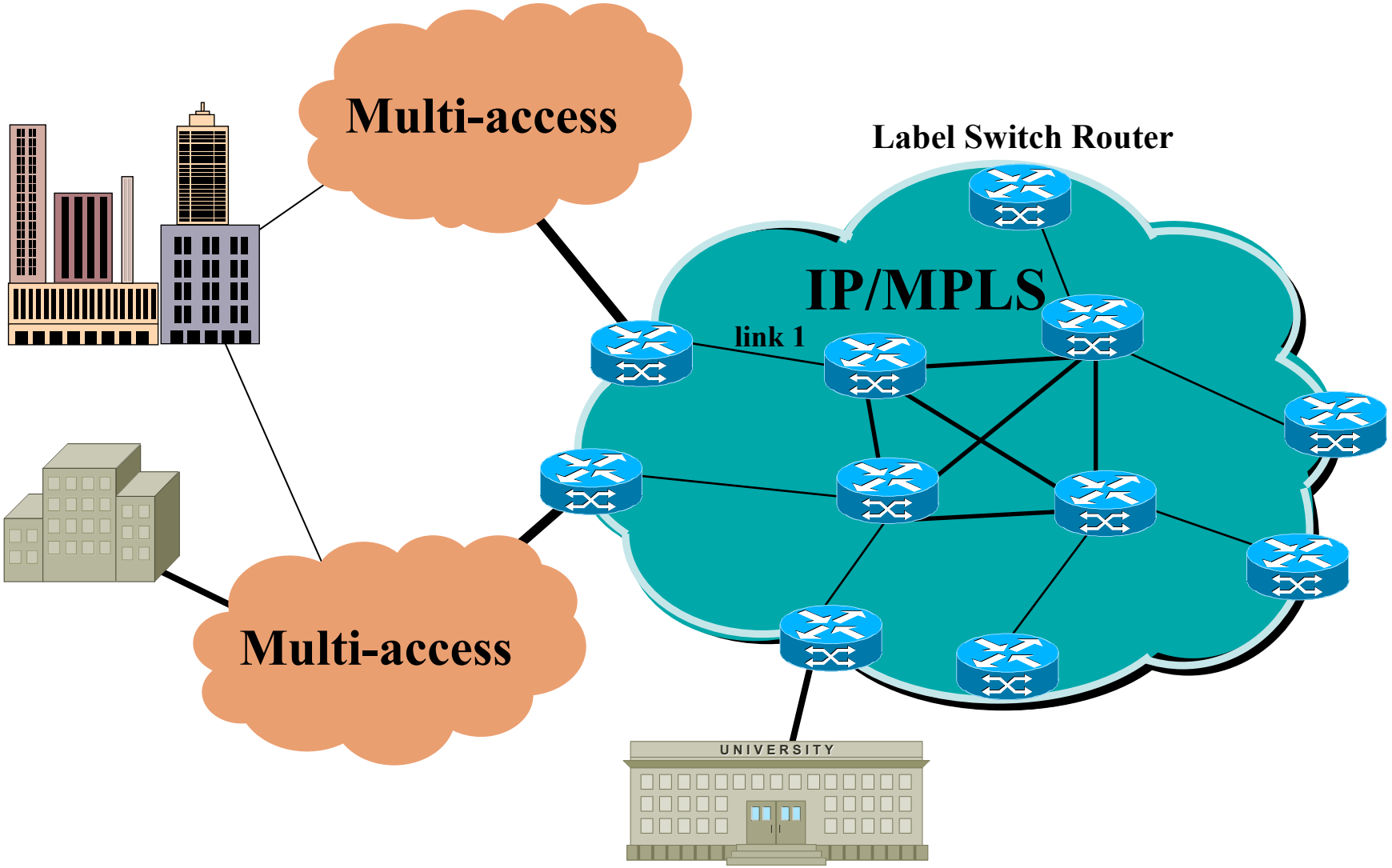
- Multi-Protocol Label Switching
  - Fast: use label switching➔ LSR
  - Multi-Protocol: above link layer, below network layer
  - Facilitate traffic engineering



From multilayer networks…



…to IP/MPLS networks



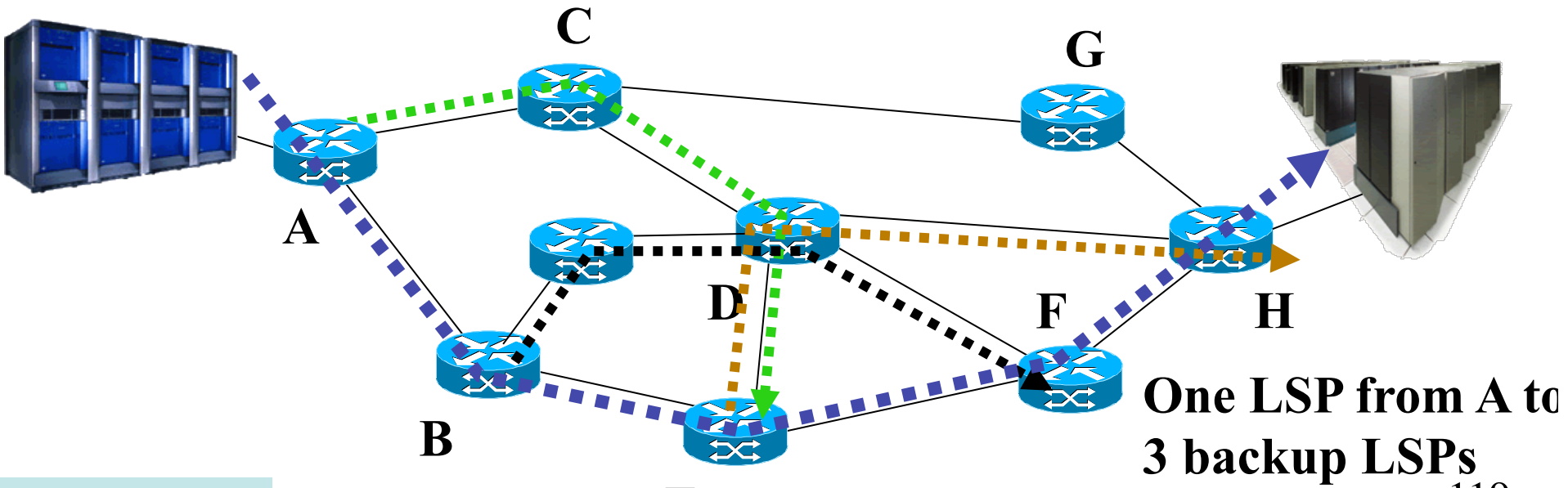
MPLS for resiliency
MPLS FastReroute

- Intended to provide healing capabilities
- Selects an alternate route in tenth of ms, provides path protection
- Traditional routing protocols need minutes to converge!
- FastReroute is performed by maintaining backup LSPs

MPLS for resiliency, con't

Backup LSPs

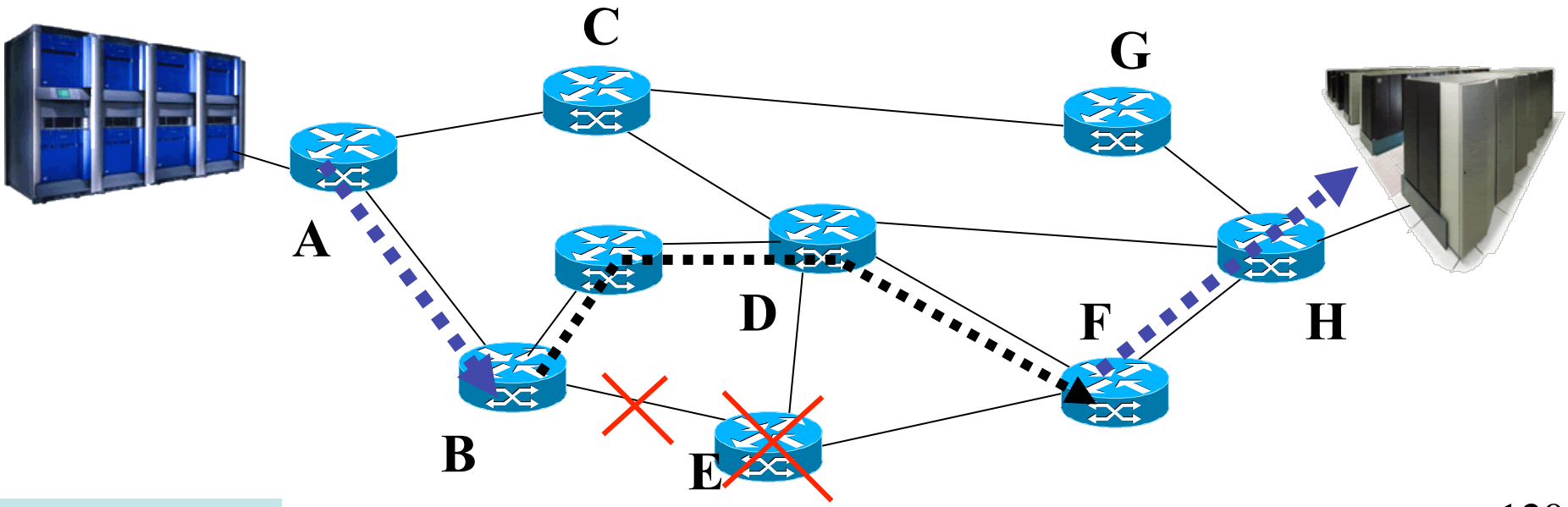
- One-to-one
- Many-to-one: more efficient but needs more configurations



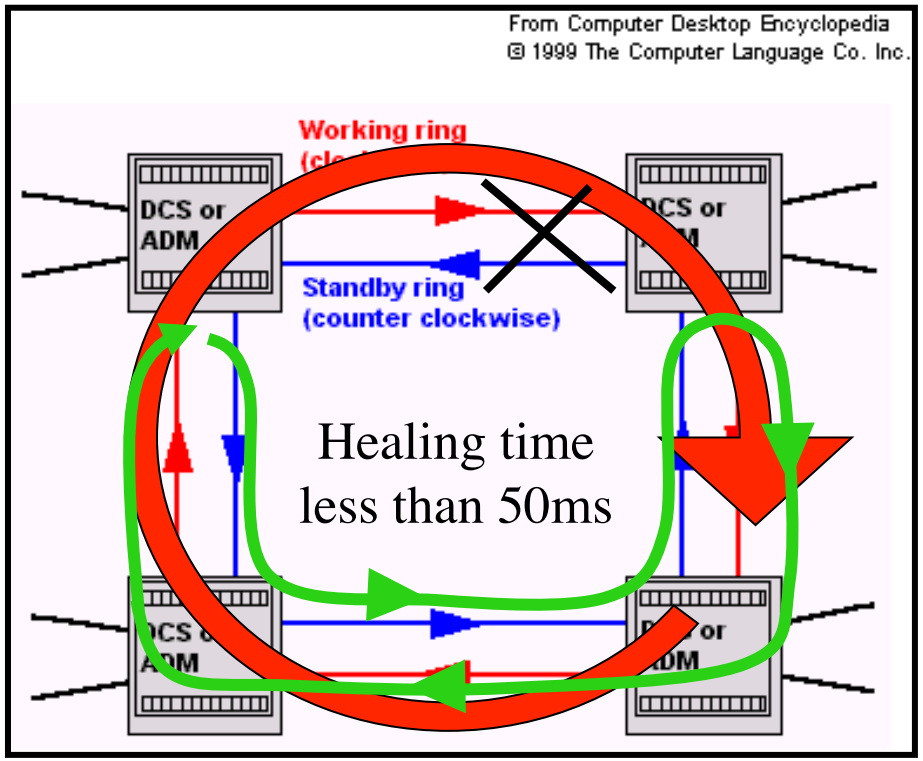
MPLS for resiliency, con't

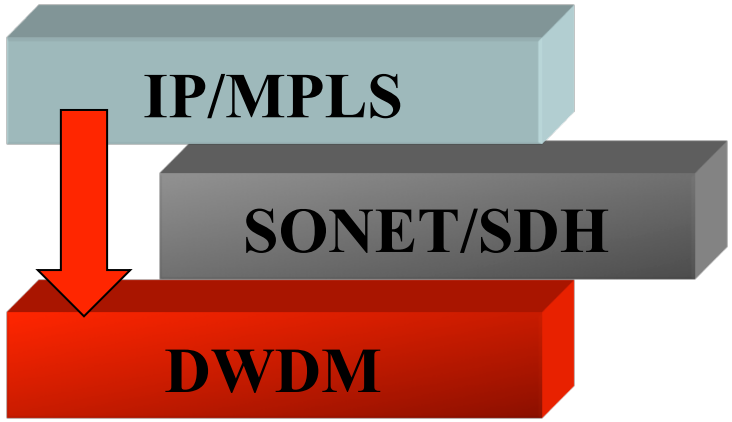
Recovery on failures

- Suppose E or link B-E is down…
- B uses detour around E with backup LSP



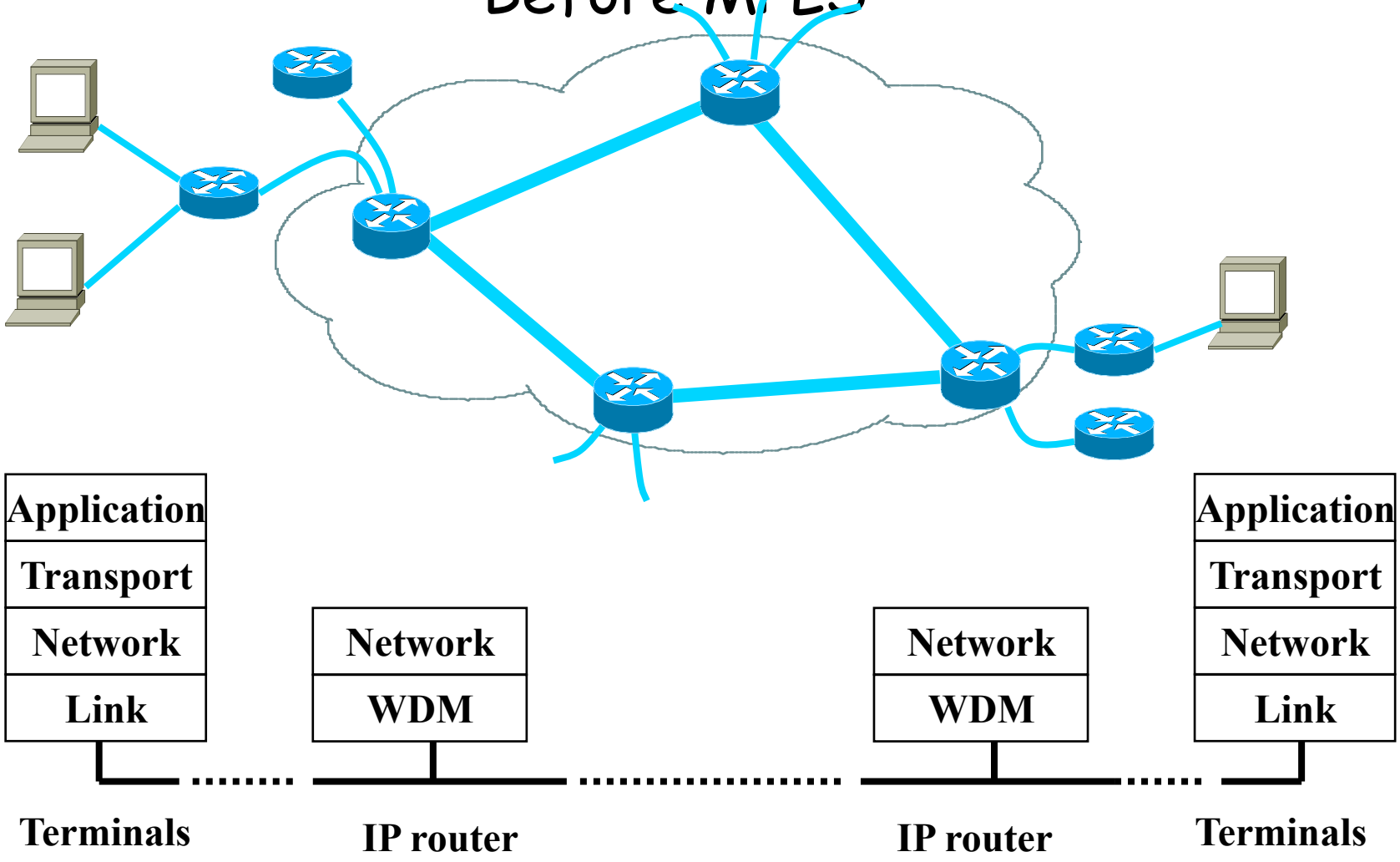
Why do we need SDH anymore?





MPLS for optical networks

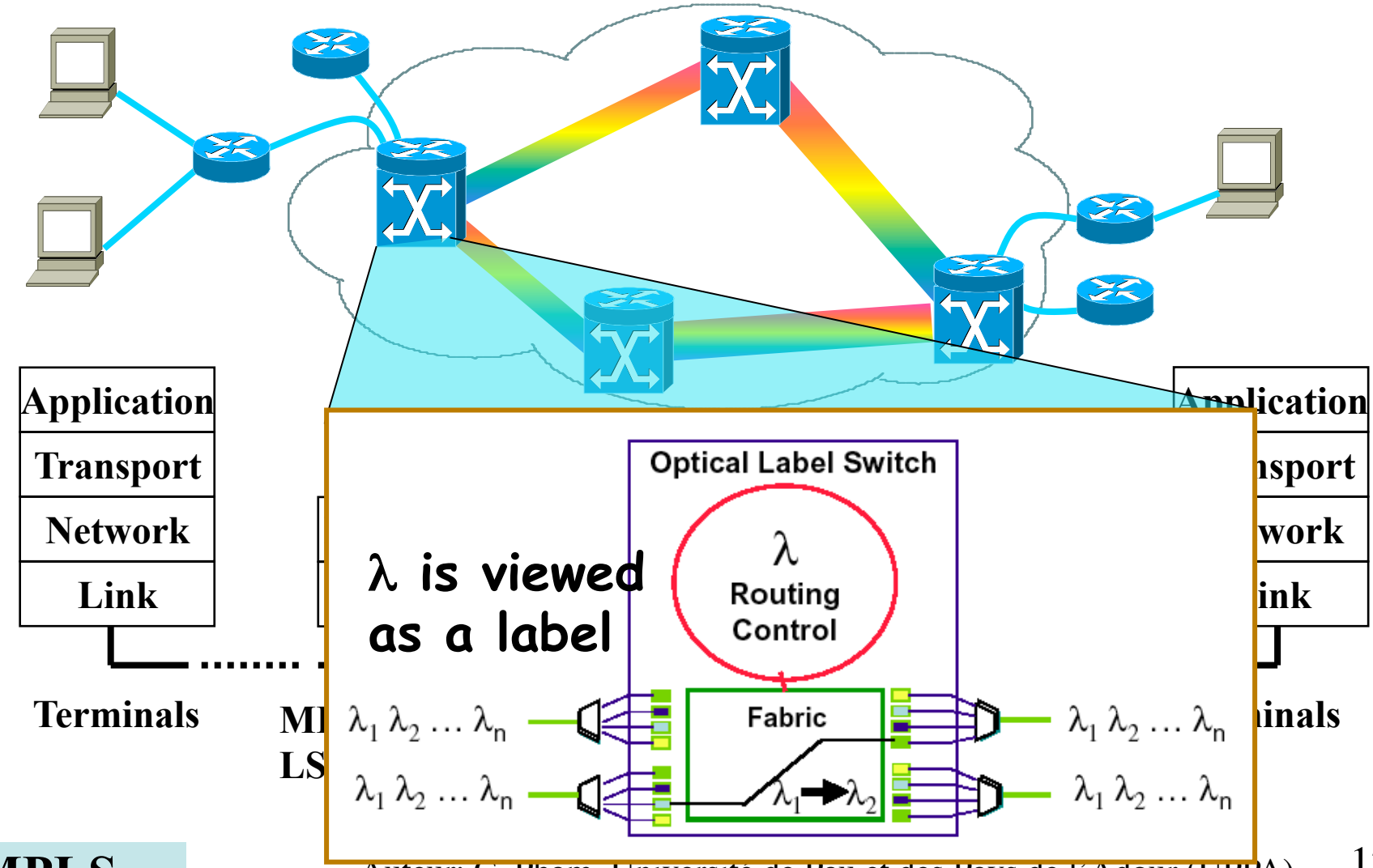
Before MPLS



Source J. Wang, B. Mukherjee, B. Yoo

MPLS for ON, con't

MPλS=MPLS+λ lightpath



Summary

Towards IP/(G)MPLS/DWDM

From cisco