ATM Technology
ATM Service Categories

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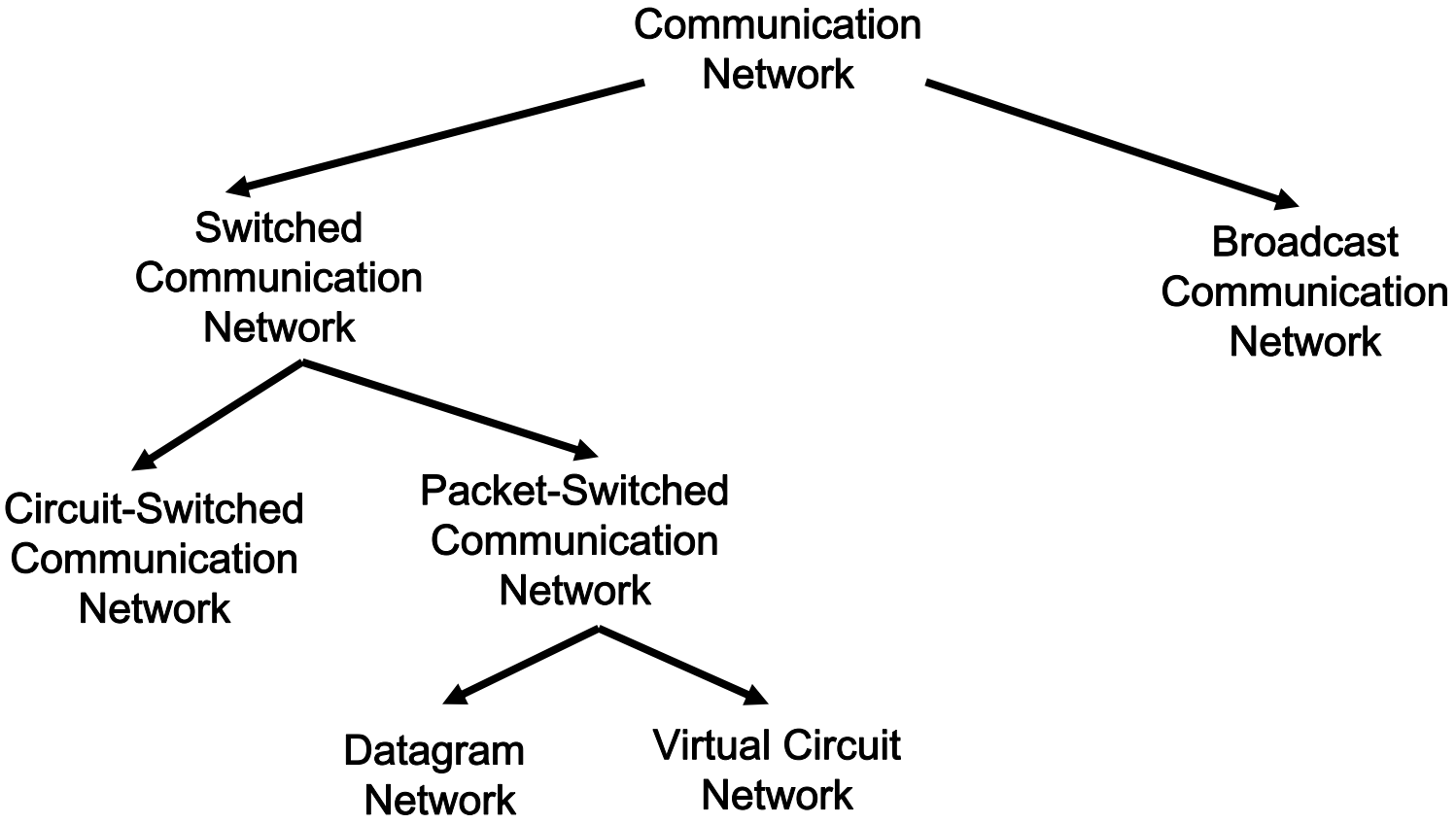
A Taxonomy of Communication Networks

- Communication networks can be classified based on the way in which the nodes exchange information:



Asynchronous Transfer Mode (ATM)

- The technology supported by the telecom operators as the solution for Broadband ISDN
- Unified solution for LAN, MAN, WAN
- Was fully standardized by the end of 90s, but …
  Internet was already very widely spread
- Now mainly serves for the provision of backbone connections

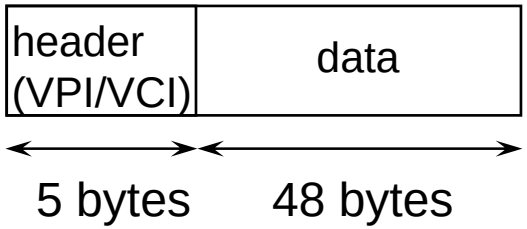
Key Features of ATM

- Asynchronous: non-periodic transfer of information between ports in switches

STM (Synchronous Transfer Mode):

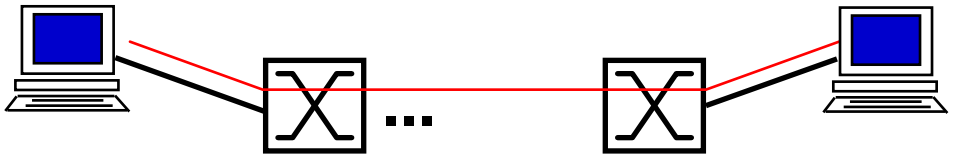
ATM:

- Short fixed size cells

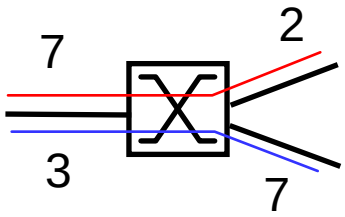


Key Features of ATM (cont.)

- Connection oriented: Virtual Channel (VC) connection is setup prior to information transfer



- Labels vs. addresses: labels have local significance
  ⇒ scalability



Switching in Packet Networks

- Datagram (e.g. Internet): packet header contains full address information
  - Address has global significance

Destination address: 147.52.16.2

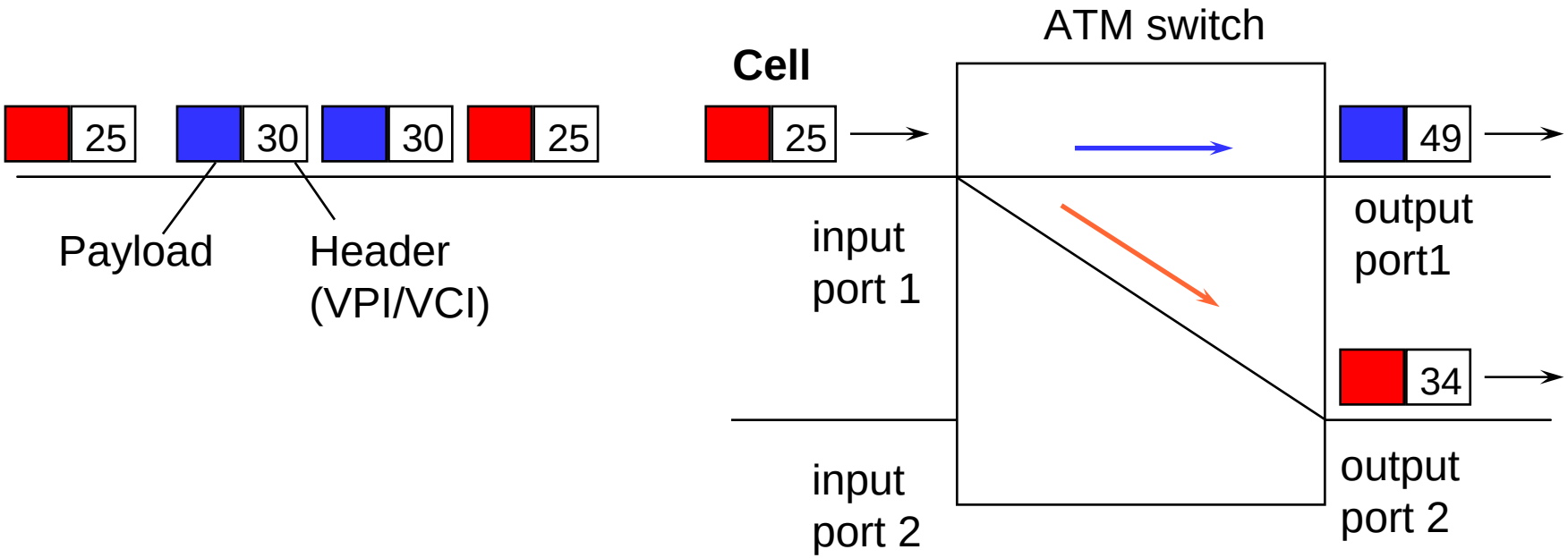
- Virtual circuit (e.g. ATM, Frame Relay): packet header contains virtual circuit identifier
  - Address has local significance

VC: 16

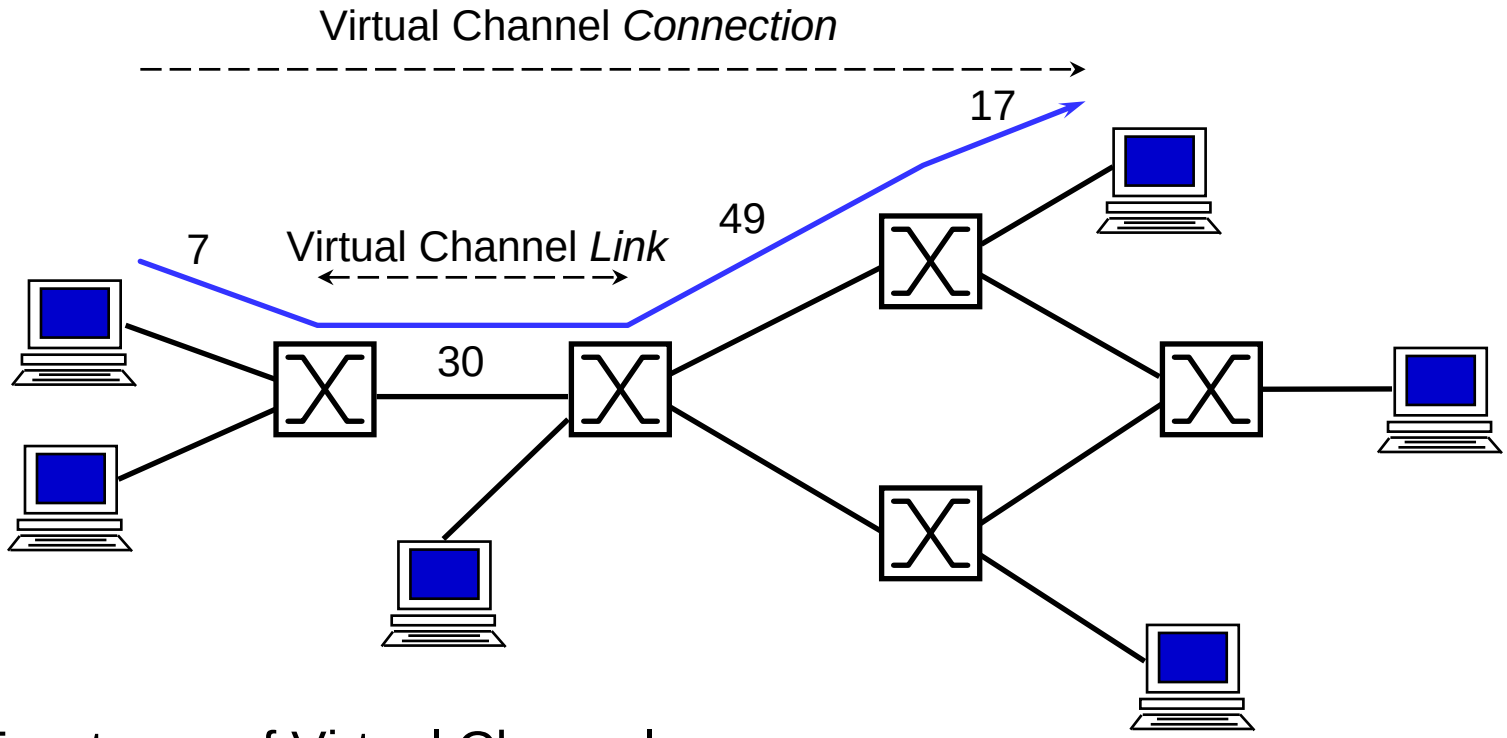
Cell Switching

Input Port	VPI/VCI	Output Port	VPI/VCI
1	25	2	34
1	30	1	49

Internal Routing Table

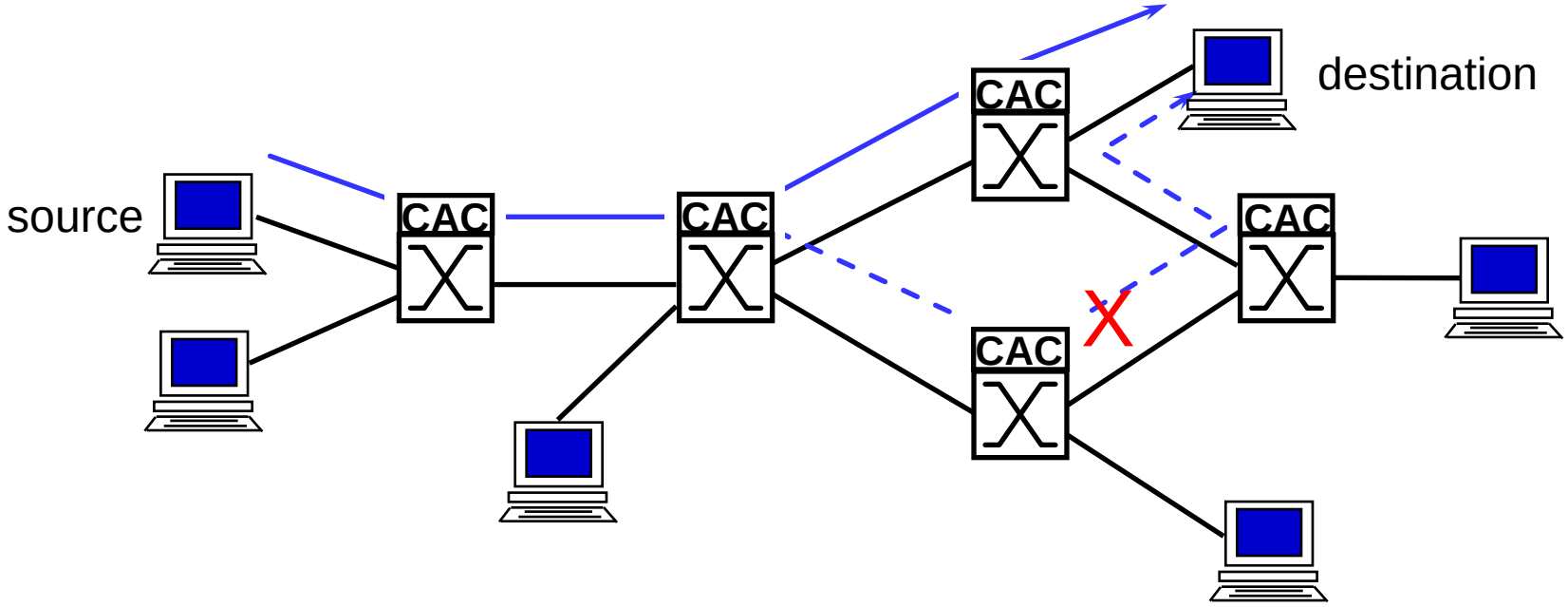


Virtual Channel Connection



- Two types of Virtual Channels:
  - Switched Virtual Channels (SVC): connection setup with signalling
  - Permanent Virtual Channels (PVC): connection setup with management

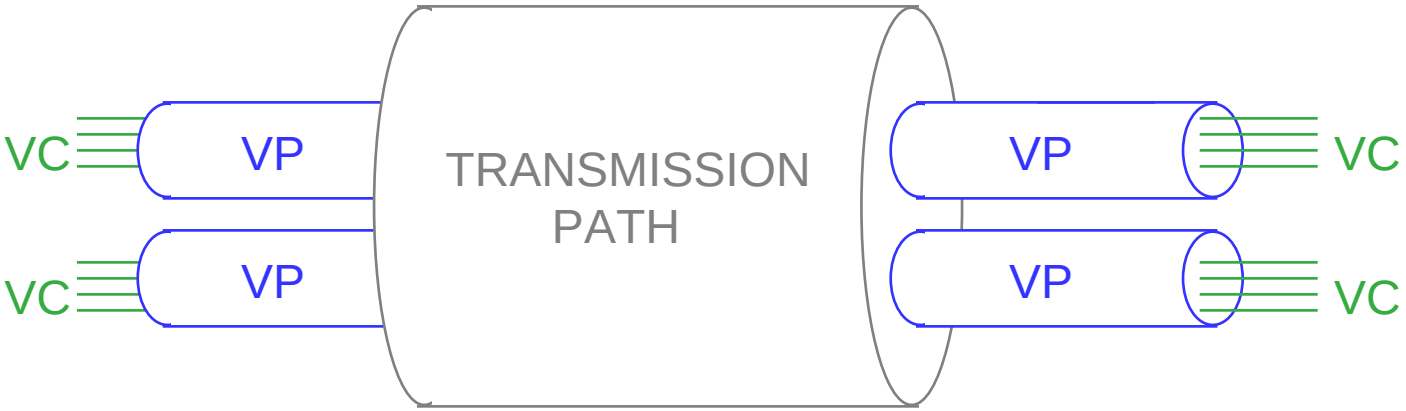
Routing and Call Admission Control (CAC)



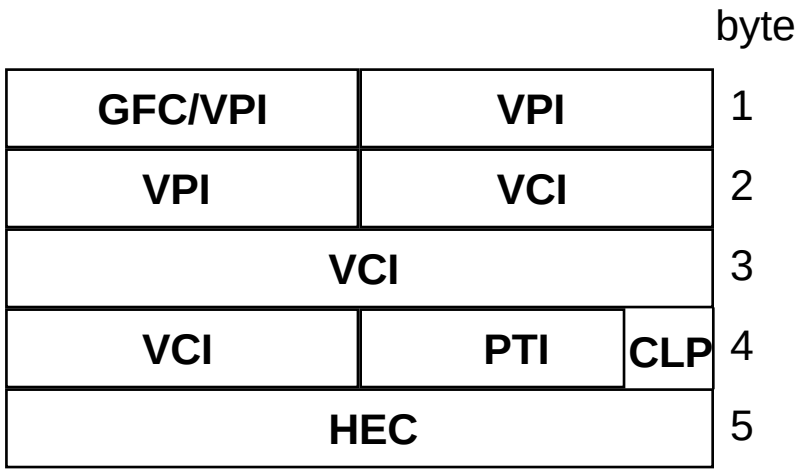
- Routing: find path from source to destination that fulfils user requirements (bandwidth, QoS)
- Call Admission Control (CAC): performed at every switch, determines whether there are enough resources to accept a call

Virtual Channels and Virtual Paths

- Cell label:
  - First 8 (12) bits: Virtual Path Identifier
  - Last 16 bits: Virtual Circuit Identifier
- Virtual Path: group of VCs treated similarly



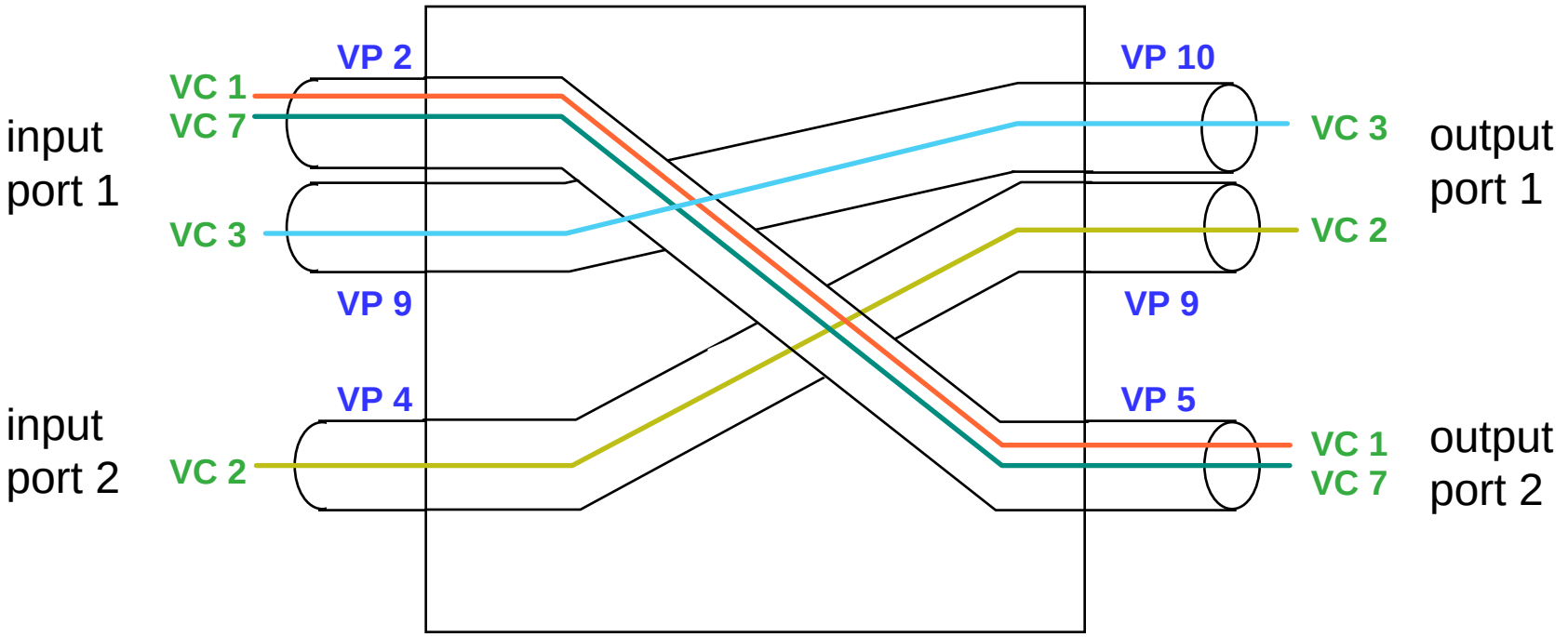
ATM Cell Header Format



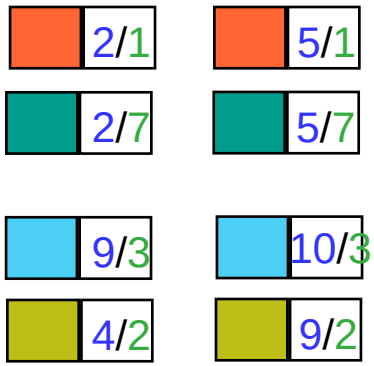
- GFC: only in UNI
- CLP=1 => cell has low priority
- PTI: identifies user cell/data cell, congestion control

GFC = Generic Flow Control
VPI = Virtual Path Identifier
VCI = Virtual Channel Identifier
PTI = Payload Type Identifier
CLP = Cell Loss Priority
HEC = Header Error Control

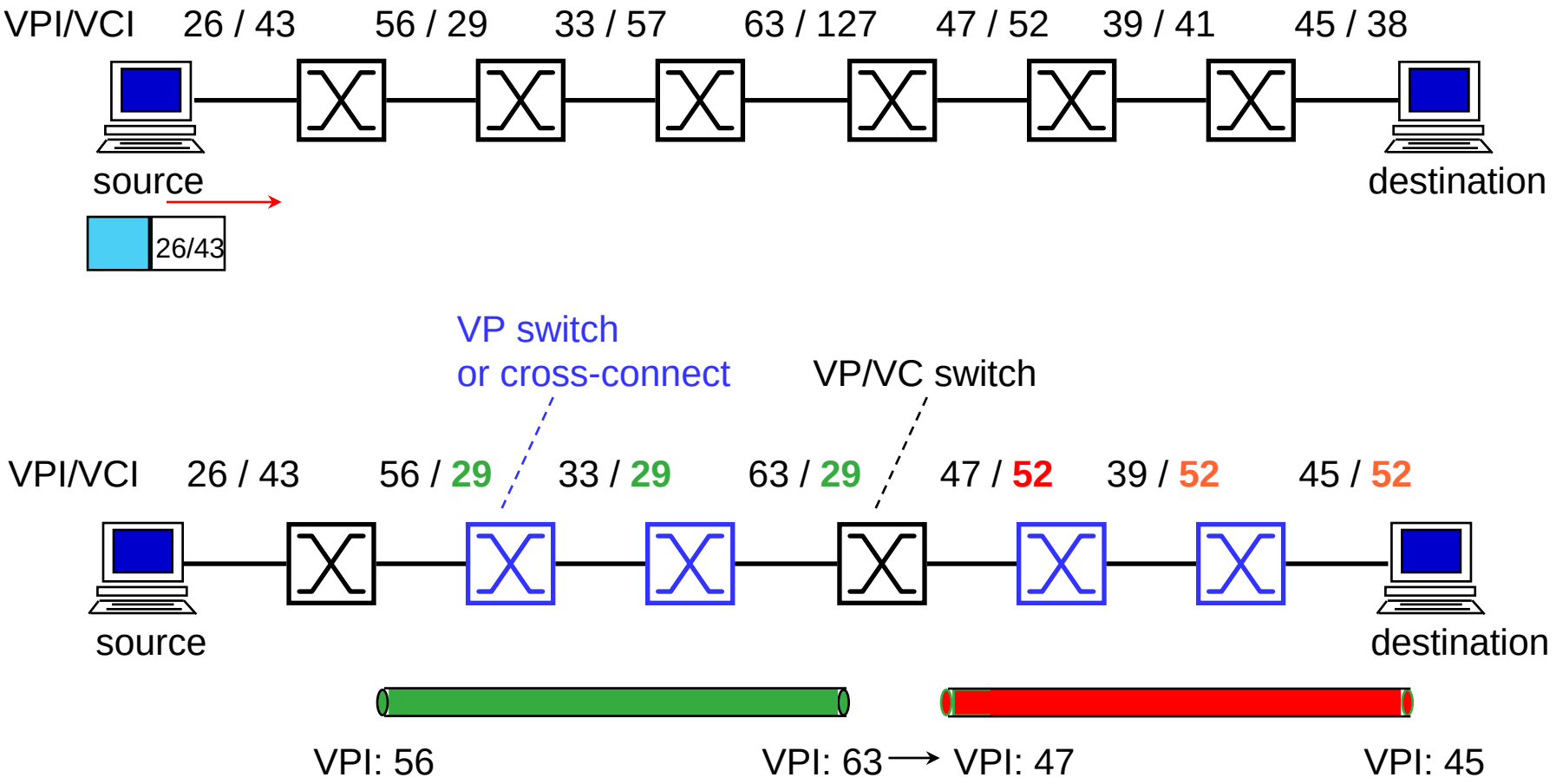
VP Switching



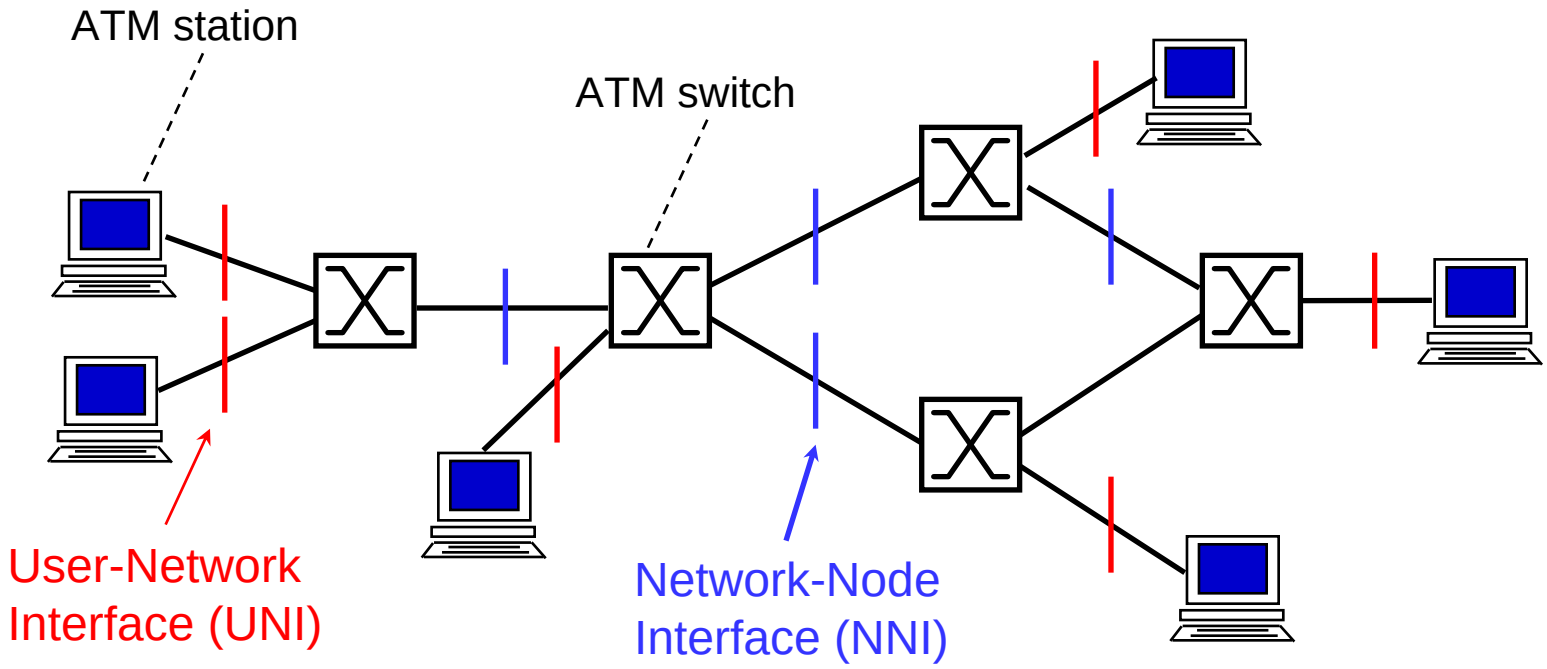
Input Port	VPI	Output Port	VPI
1	2	2	5
1	9	1	10
2	4	1	9



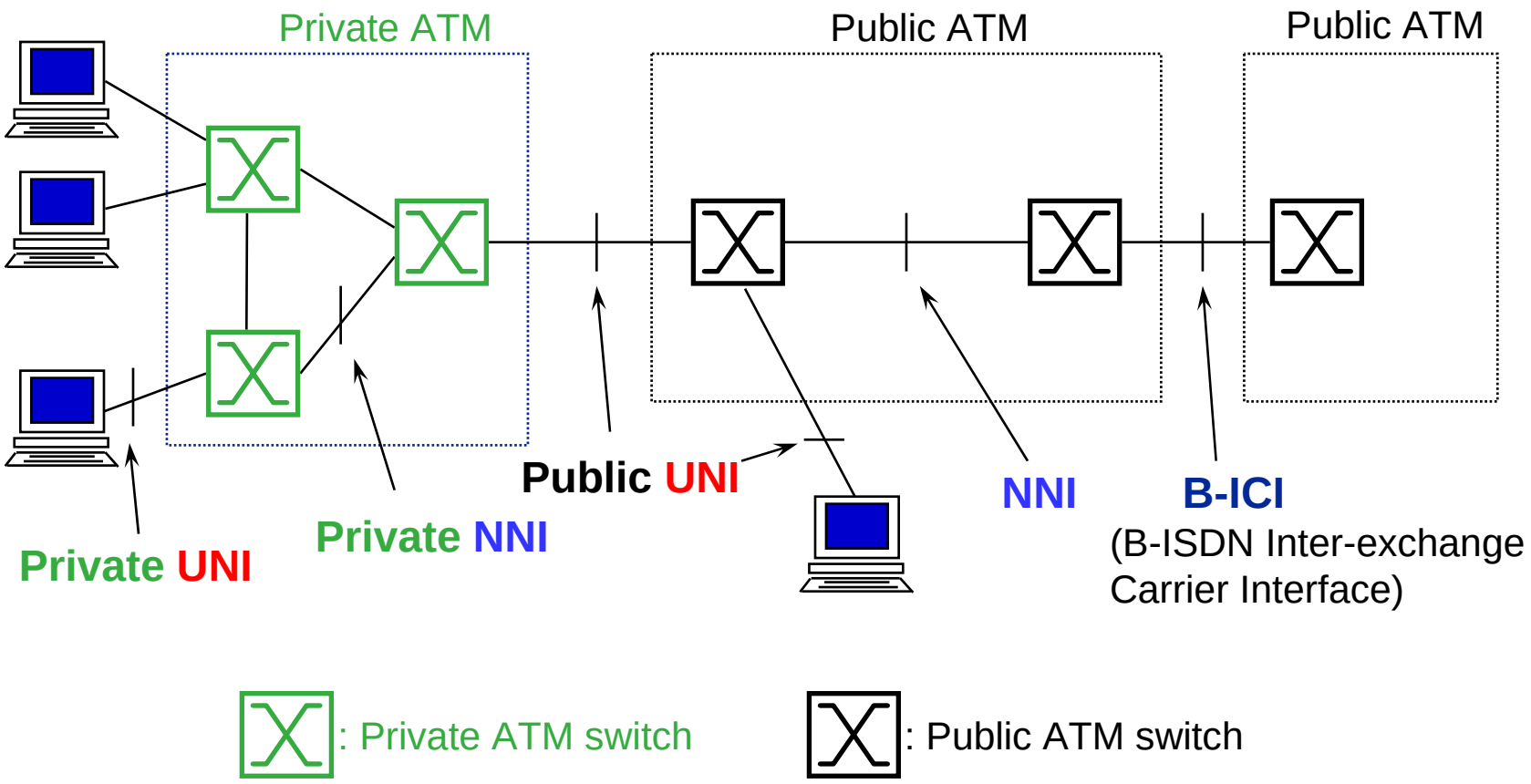
VP and VP/VC Switching in a Network



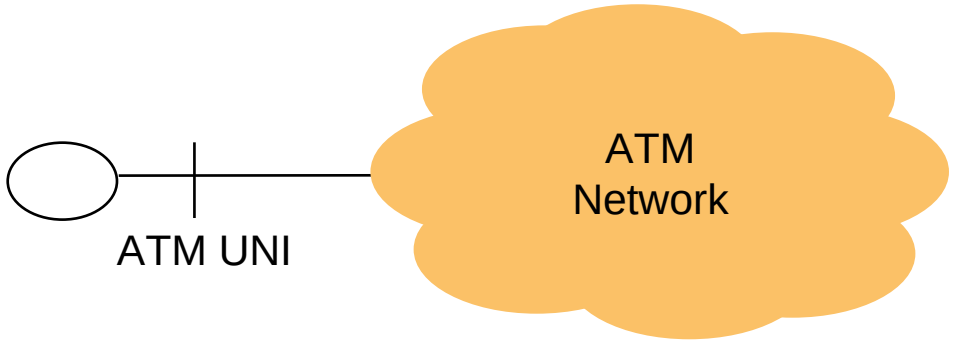
B-ISDN Interface Terminology



B-ISDN Interface Terminology (cont.)



ATM Layer Service Categories



- Offered at ATM UNI (User-Network Interface)

ATM Forum Service Categories

	Service Category	Typical Application
Real-Time :	Constant Bit Rate (CBR)	Circuit emulation, videoconferencing,
	Real-Time Variable Bit Rate (rt-VBR)	Compressed video/audio
Non-Real-Time:	Non-Real-Time Variable Bit Rate (nrt-VBR)	Critical data
	Available Bit Rate (ABR)	LAN interconnection,
	Unspecified Bit Rate (UBR)	File transfer, message transfer

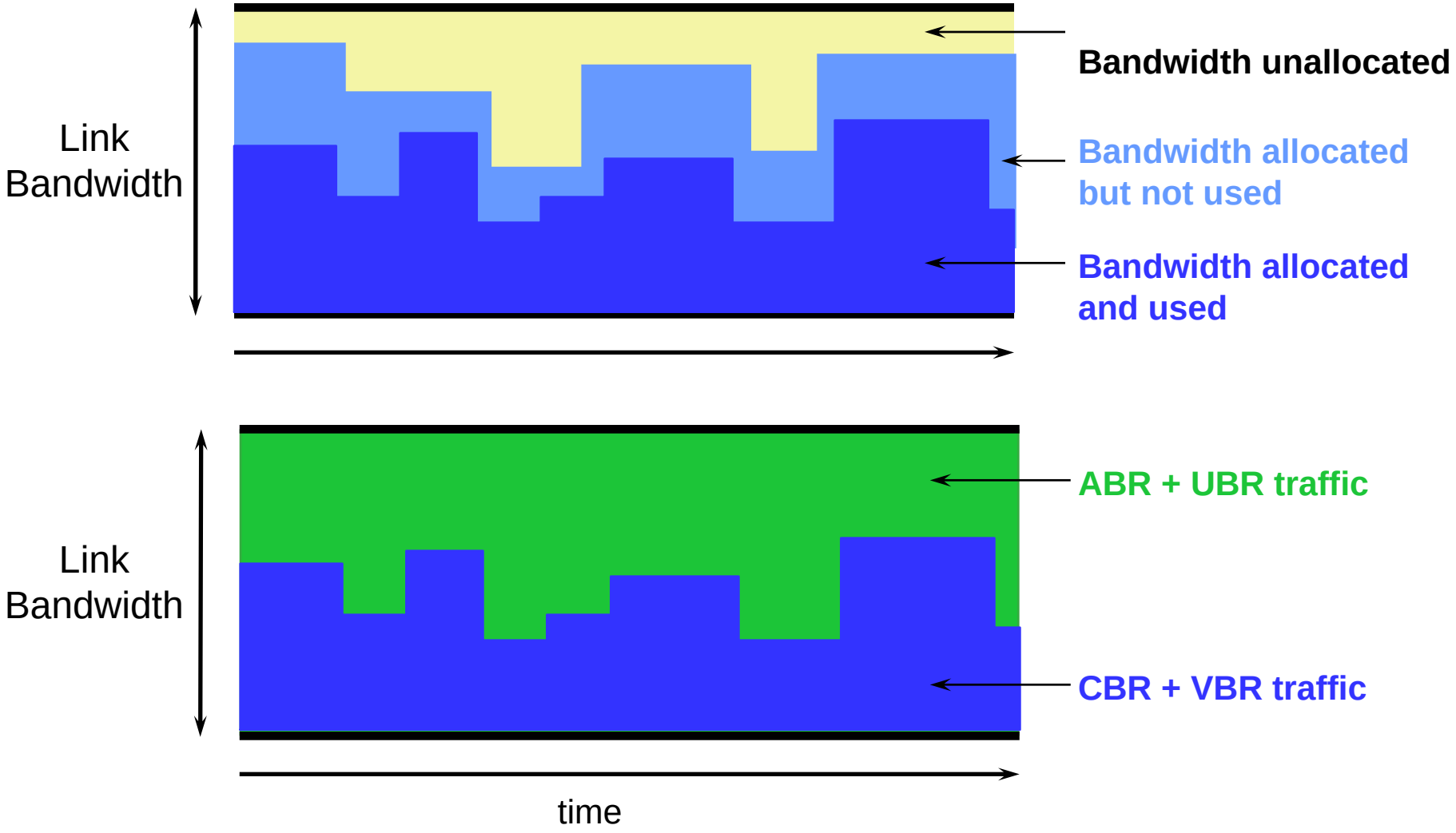
ATM Forum Real-Time Service Categories

- Constant Bit Rate (CBR):
  - real-time applications requiring a static amount of bandwidth
  - Guaranteed Quality of Service (QoS) in terms of delay, delay variation, cell loss
- Real-Time Variable Bit Rate (rt-VBR):
  - real time applications with “bursty” traffic
  - Guaranteed Quality of Service (QoS) in terms of delay, delay variation, cell loss

ATM Forum Non-Real-Time Service Categories

- Non-Real-Time Variable Bit Rate (nrt-VBR):
  - non-real-time applications with bursty traffic
  - Guaranteed cell loss bound but no delay bounds
- Available Bit Rate (ABR):
  - “elastic” applications which can adapt their traffic rate
  - closed loop flow control supported
- Unspecified Bit Rate (UBR):
  - non-real-time applications, no service guarantees

Bandwidth Usage



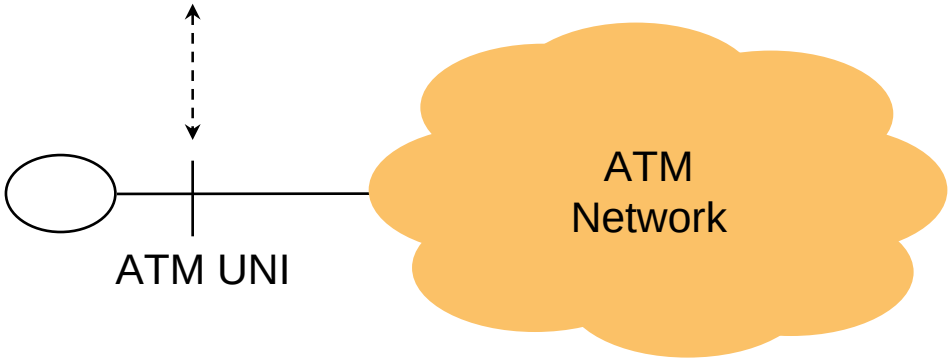
Traffic Contract Negotiation

Traffic Contract:

Traffic parameters: peak rate, sustainable cell rate, burst size, minimum cell rate

QoS parameters: cell delay, cell delay variation, cell loss ratio

Conformance definition: Generic Cell Rate Algorithm (GCRA)



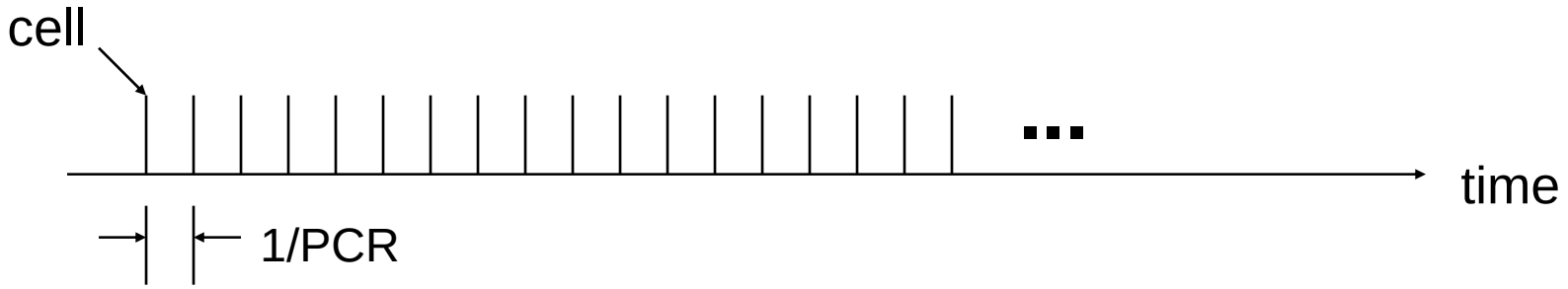
Traffic Parameters

Traffic parameters describe inherent characteristics of a traffic source

- **Peak Cell Rate (PCR):** Maximum instantaneous rate
- **Sustained Cell Rate (SCR):** Average cell rate measured over some long interval
- **Maximum Burst Size (MBS):** Maximum burst size (# of cells) that can be sent at the peak rate
- **Minimum Cell Rate (MCR):** Minimum cell rate user is guaranteed to have

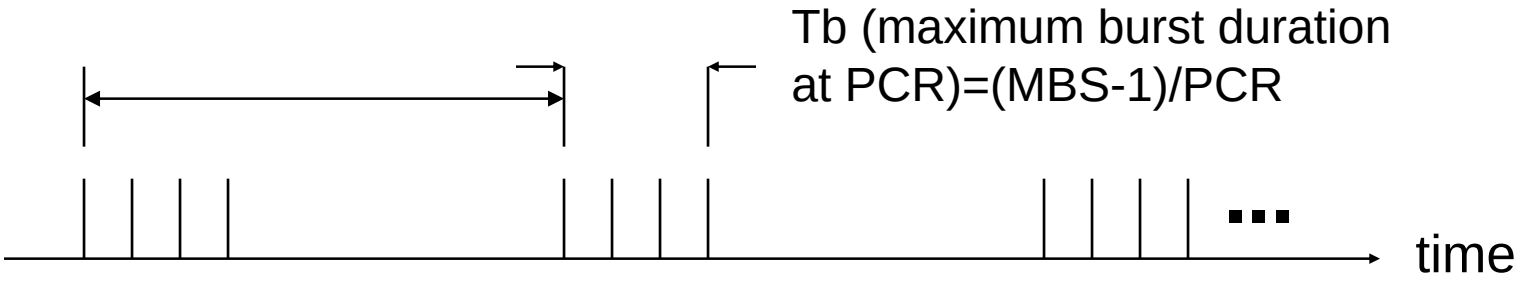
Traffic parameters (cont.)

Peak Cell Rate (PCR):

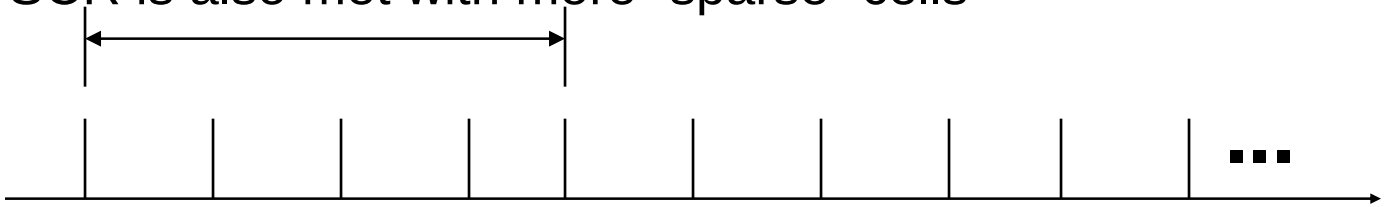


Peak Cell Rate (PCR), Sustainable Cell Rate (SCR), Maximum Burst Size (MBS)

Ti (minimum burst interarrival time)=MBS/SCR



SCR is also met with more “sparse” cells

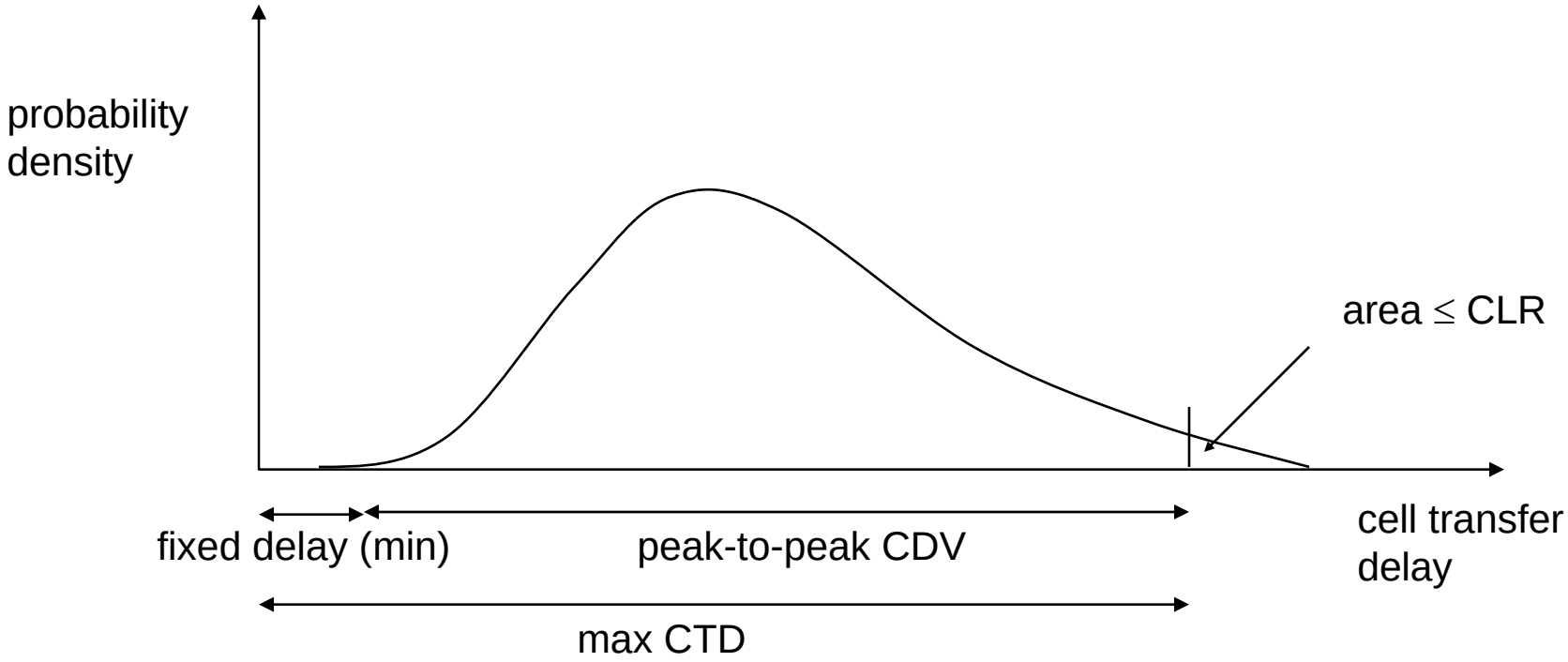


ATM Quality of Service (QoS) Parameters

ATM QoS parameters characterise performance of an ATM layer connection

- **Max Cell Transfer Delay (CTD):** Delay experienced by a cell between network entrance and exit points
- **peak-to-peak Cell Delay Variation (CDV):** max - min cell transfer delay
- **Cell Loss Ratio (CLR):** Percentage of cells that are lost
- The above are user negotiable

ATM QoS parameters (cont.)



Conformance Definition

Conformance definition defines conformity at an interface with respect to traffic contract according to one or more instances of GCRA

- GCRA: Generic Cell Rate Algorithm
- Above applies to CBR, VBR, and UBR
- ABR is a special case (includes feedback)

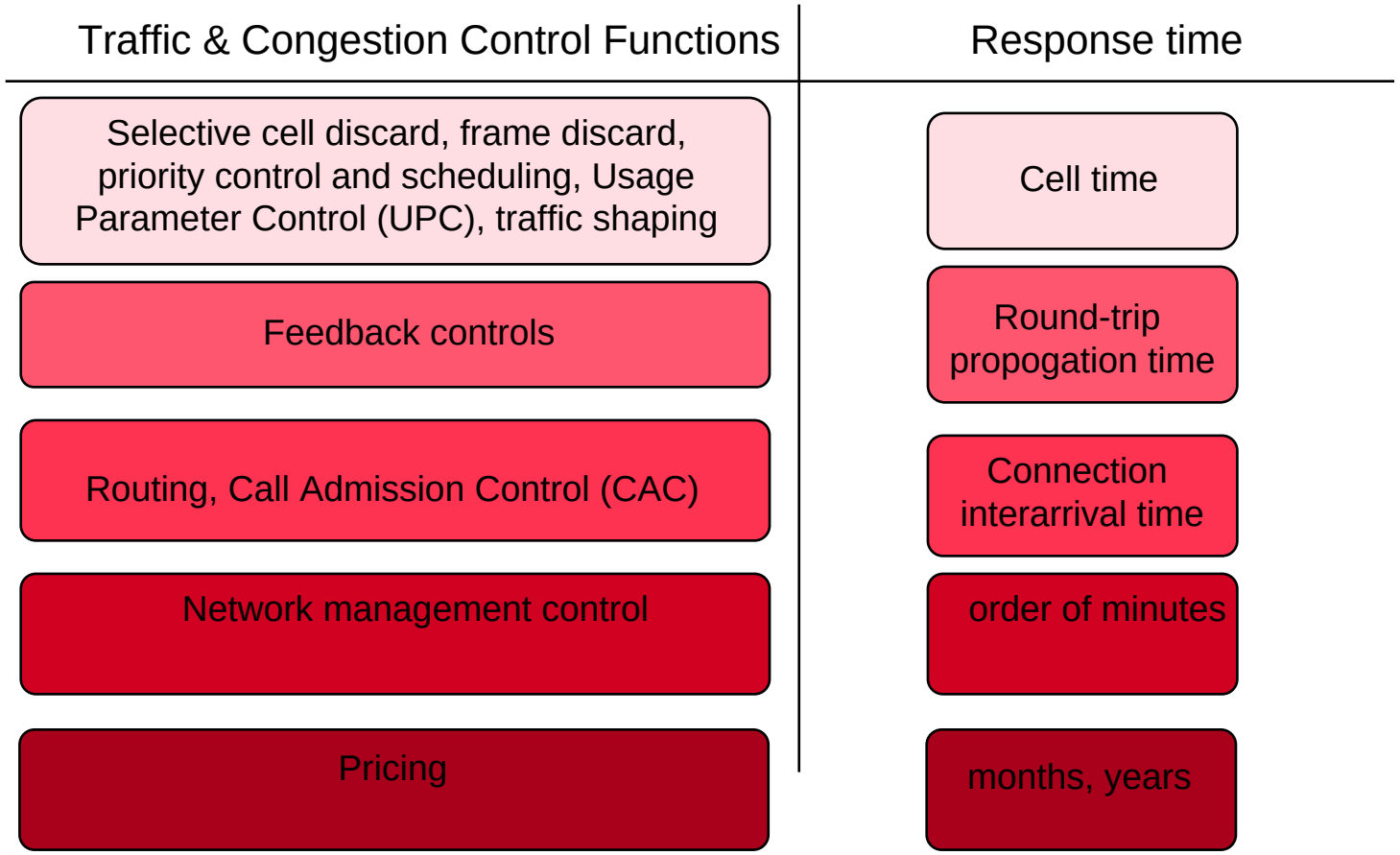
Service Category Attributes and Guarantees

Service Category	Traffic Description	Guarantees			Feedback Control
		Min Loss (CLR)	Delay/ Variance	Bandwidth	
CBR	PCR	✓	✓	✓	**NO**
rt-VBR	PCR,SCR, MBS	✓	✓	✓	**NO**
nrt-VBR	PCR,SCR, MBS	✓	**NO**	✓	**NO**
ABR	PCR,MCR+ behavior	✓	**NO**	✓	✓
UBR	(PCR)	**NO**	**NO**	**NO**	**NO**

Traffic Control in ATM

- Connection Acceptance Control (CAC)
- Routing
- Usage Parameter Control (UPC) or Source Policing
- Shaping
- Priorities, scheduling
- Feedback control
- Other (e.g. pricing)

Time scales of network control

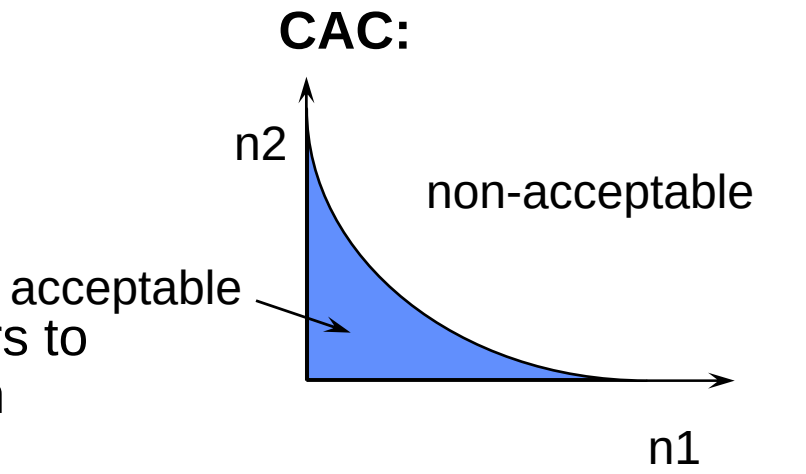


Network control and pricing

- Set of feasible services depends on network control mechanisms
- Economic incentives influence network control mechanisms
- Network control: guarantees contracts
- Pricing: influences demand in order to increase efficiency

Network Control for Congestion

- **Guaranteed services**
  - Call Acceptance Control - CAC
  - user-network contract
  - Use charging as incentive for users to provide more accurate information about traffic profile

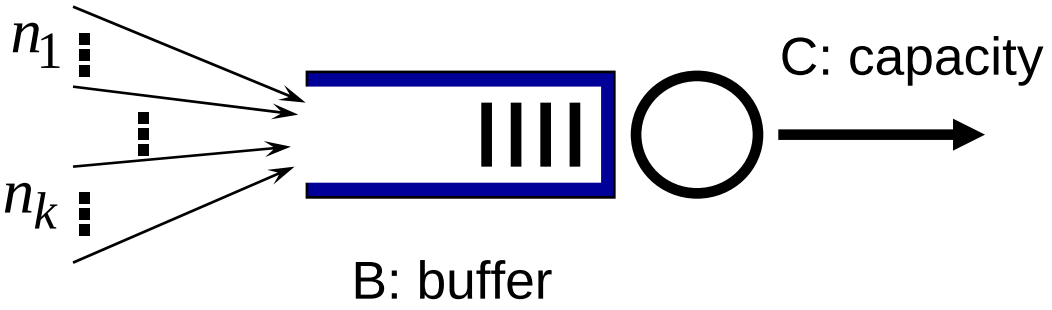


(n1,n2: number of multiplexed sources of type 1,2)

- **Best effort services (ABR):**
  - no CAC, except for MCR (Minimum Cell Rate)
  - Flow control
  - Use charging to control congestion

Prototype Problem of Call Acceptance (for Guaranteed QoS)

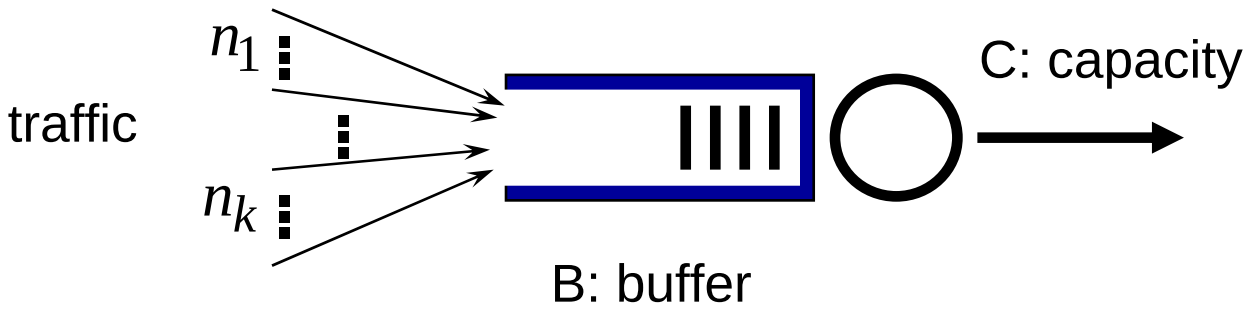
- *k* traffic classes
- class *i* contains n_i sources



Statisical QoS constraint: e.g. CLP less than p (e.g. $p=10^{-8}$)

What $(n_1,\ldots,n_k)$ do not violate QoS constraints ?

Prototype Problem of Call Acceptance (cont.)

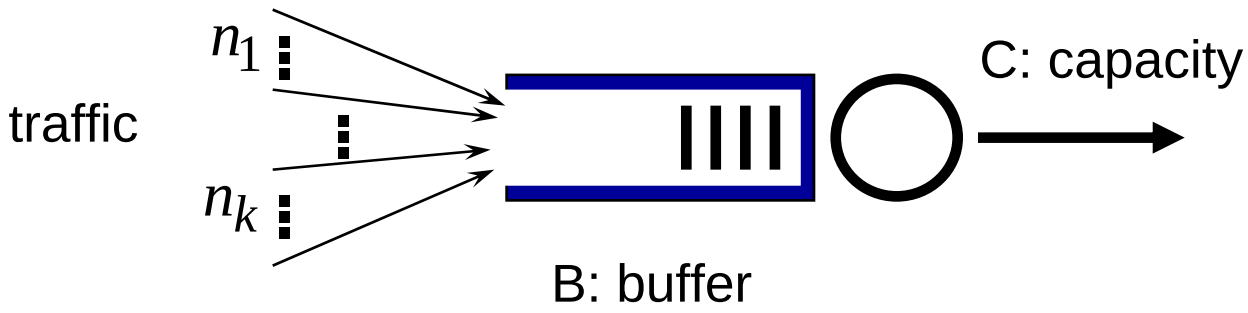


Peak rate allocation: sufficient condition

acceptance region: $n_1 \cdot h_1 + \ldots n_k \cdot h_k < C$

- accomplishes zero cell loss
- simple acceptance criterion (linear in n_i)
- dedicated capacity per source (reminds circuit switching)
- conservative: assumes worst-case demand arises simultaneously
- no multiplexing gain → less revenue, more expensive to customers

Prototype Problem of Acceptance Control (cont.)



Mean rate allocation: only necessary condition

acceptance region: $n_1 \cdot m_1 + \ldots n_k \cdot m_k < C$

- ultimate multiplexing gain
- simple (linear in n_i)
- no performance guarantees (only CLP<1 !)

Effective Bandwidth and Many Sources Asymptotic

- If $n_i = N\rho_i$, $C=Nc$ and $B=Nb$, then

$$\lim_{N\to\infty}\frac{1}{N}\log \Pr[\text{overflow}] = -I = \sup_t \inf_s \left\{ st\sum_1^k \rho_j a_j(s,t) - s(ct+b) \right\}$$

and thus $\Pr[\text{overflow}] \approx e^{-NI} = e^{-\gamma}$

- $a_j(s,t)$ is the *effective bandwidth* of sources of type *j*,

$$a_j(s,t) = \frac{1}{st}\log Ee^{sX_j[0,t]}$$

  - $X_j[0,t]$ = number of cells in $[0,t]$
  - s = space scale parameter
  - t = time scale parameter

Simplifying the Problem of Acceptance Control

Use Effective Bandwidths $n_1 \cdot eb_1 + \ldots n_k \cdot eb_k < \hat{C}$

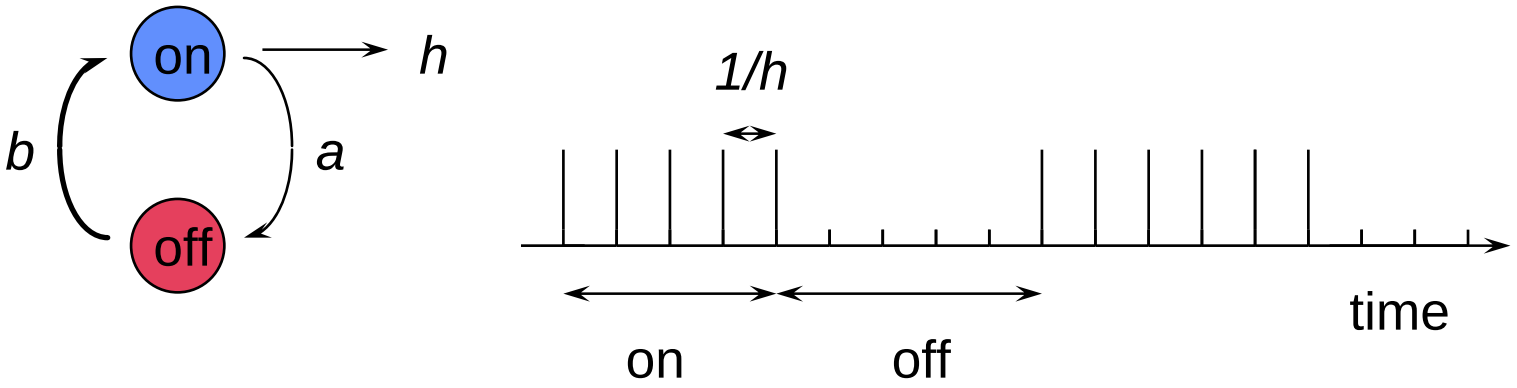
acceptance region:

- eb_i depends only on source type, traffic mix, capacity, buffer and QoS requirements,
- summarises each source's effect on QoS
- immediate guarantee of QoS
- linearizes a very complex problem of QoS
- still allows easy estimation of available capacity

$$m_i \leq eb_i \leq h_i$$

ON/OFF Source Model

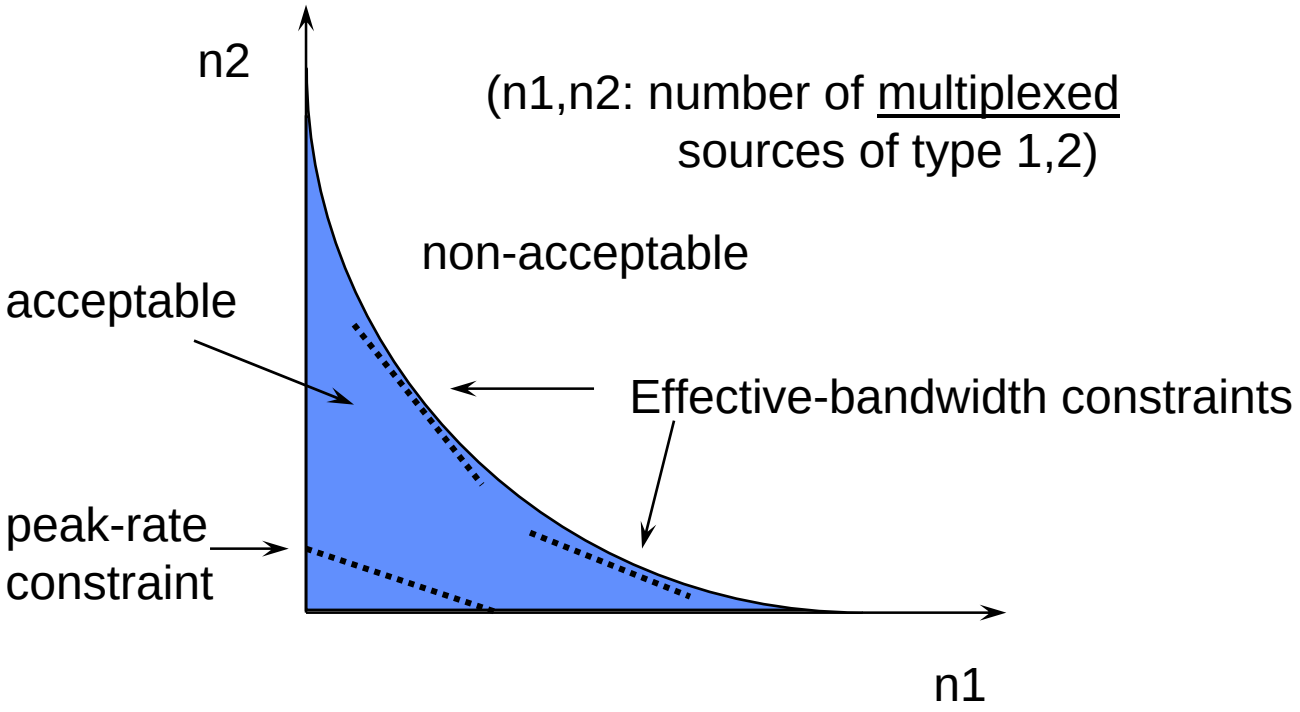
ON/OFF source: ON & OFF periods are exponentially distributed
mean ON period = *1/a*, mean OFF period = *1/b*



mean rate $m = b*h/(a+b)$

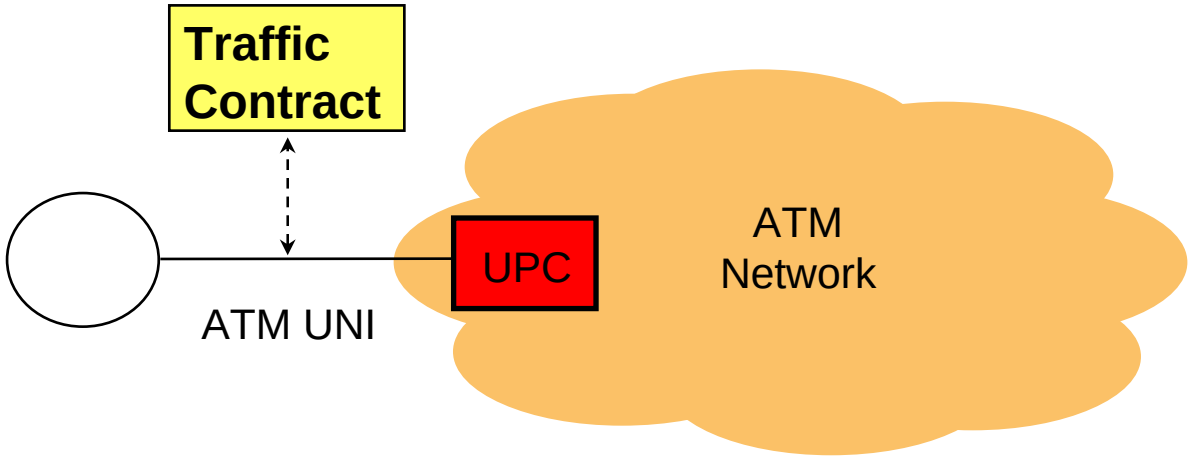
effective bandwidth $$eb_i = \frac{1}{s}\log\left[1+\frac{m}{h}\left(e^{sh}-1\right)\right]$$

CAC: Peak Rate vs. Effective Bandwidth

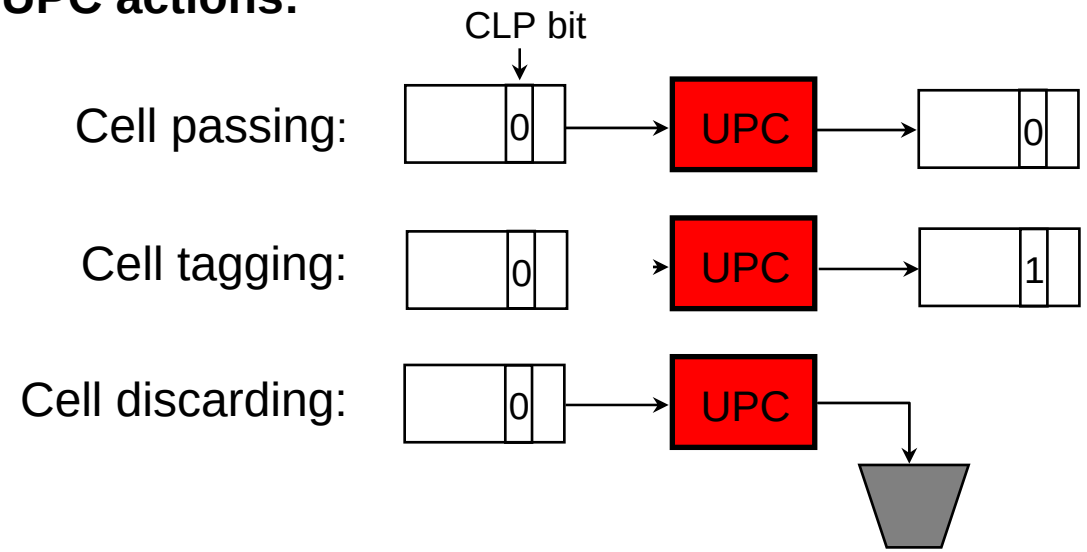


- **Effective Bandwidth CAC constraints correspond to tangents of the acceptance region boundary curve**
  - The right selection of a tangent depends on the operating point

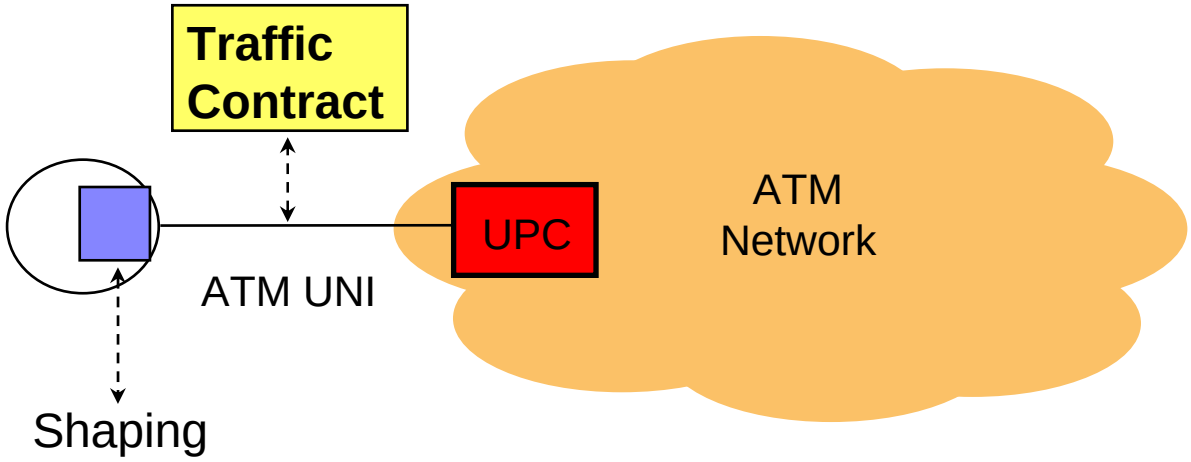
Usage Parameter Control (UPC) or Source Policing



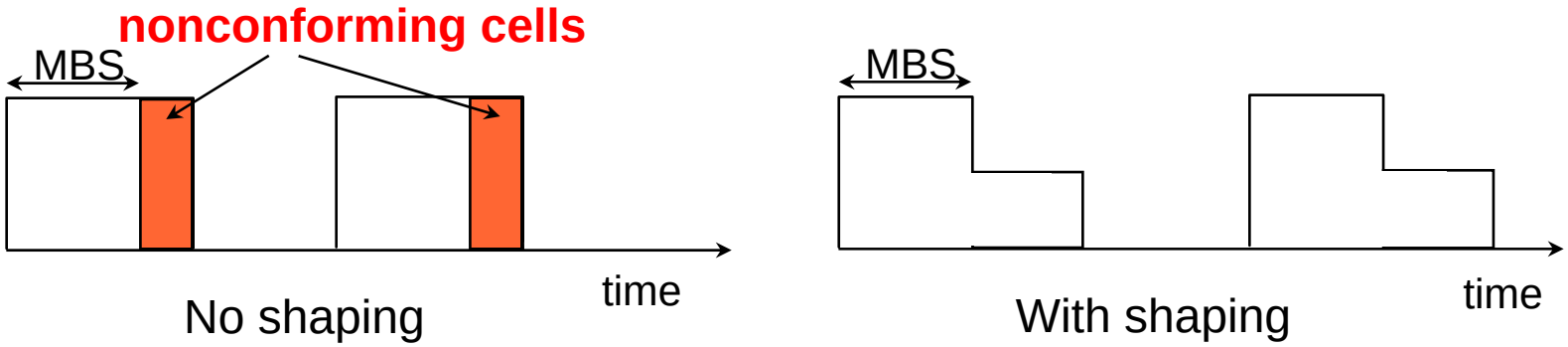
UPC actions:



UPC and Traffic Shaping



- Traffic shaping at source prevents loss due to policing



MBS: maximum burst size

UPC (or Source Policing) Functions

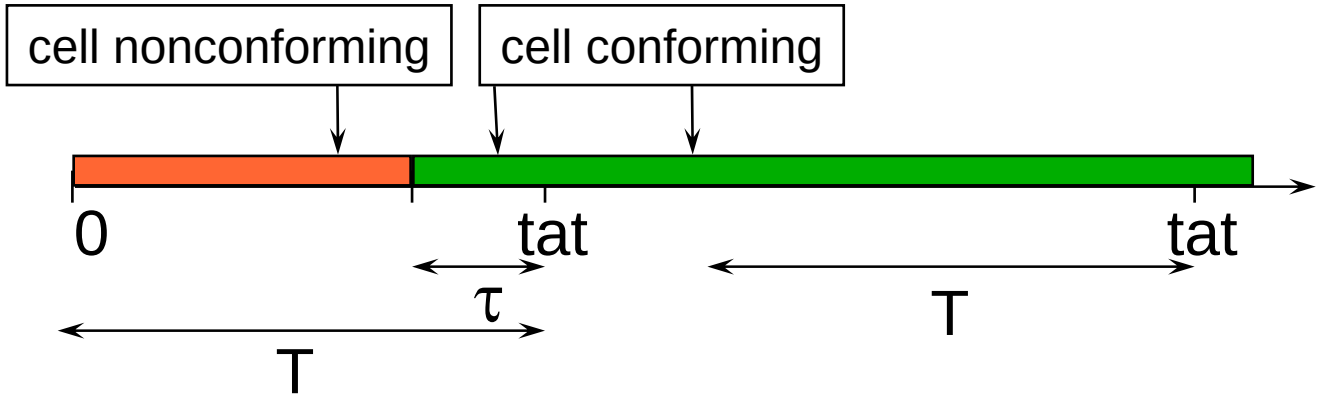
- Algorithm implemented at UNI for ensuring that user traffic adheres to traffic contract.
- Generic Cell Rate Algorithm (GCRA):
  - “Leaky bucket” type algorithm
  - Open loop algorithm
  - Specified by ATM Forum

Generic Cell Rate Algorithm

GCRA(T, τ)
t: cell arrival time
tat: theoretical arrival time

if (t<tat- τ)
    cell nonconforming
else
    cell conforming
    tat=max(t,tat)+T

"Virtual Scheduling Algorithm"

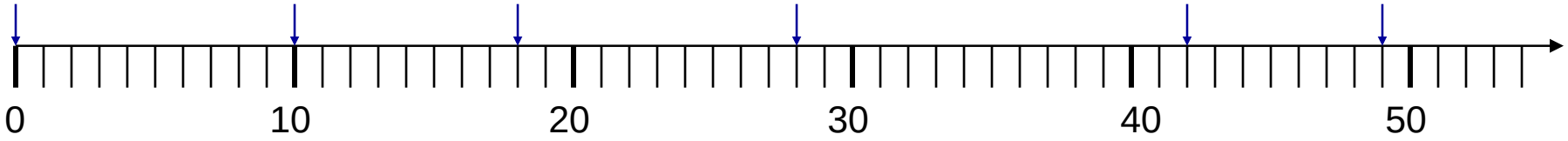


GCRA examples

- GCRA(10,2)
  - Cell arrival times: 0 10 18 28 42 49

t	0	10	18	28	42	49
tat-τ	0-2	10-2	20-2	30-2	40-2	52-2
result	C	C	C	C	C	NC
tat after	10	20	30	40	52	52

```
if (t<tat- τ)
   cell nonconforming
else
   cell conforming
   tat=max(t,tat)+T
```

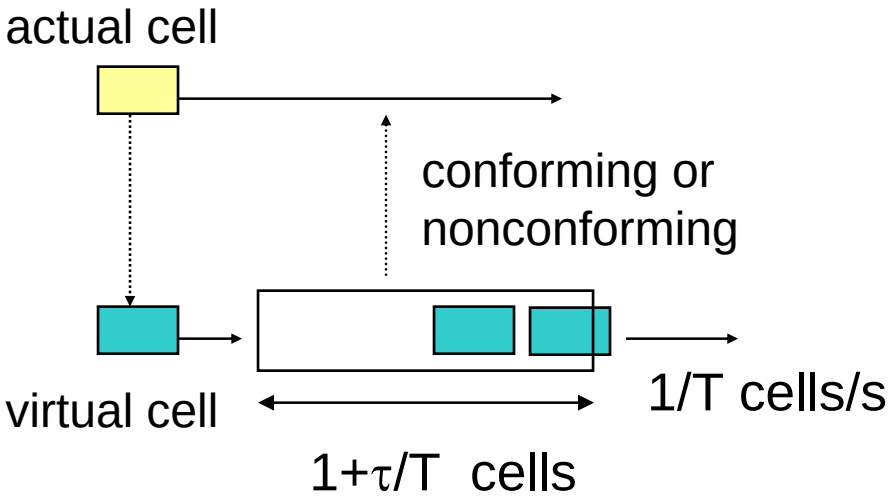


  - Cell arrival times: 0 10 15 25 35

t	0	10	15	25	35
tat-τ	0-2	10-2	20-2	20-2	35-2
result	C	C	NC	C	C
tat after	10	20	20	35	45

Leaky Bucket Algorithm

- Bucket size=1+τ/T
- Leak rate=1/T cells/s
- Bucket contents increased by 1 for each conforming cell



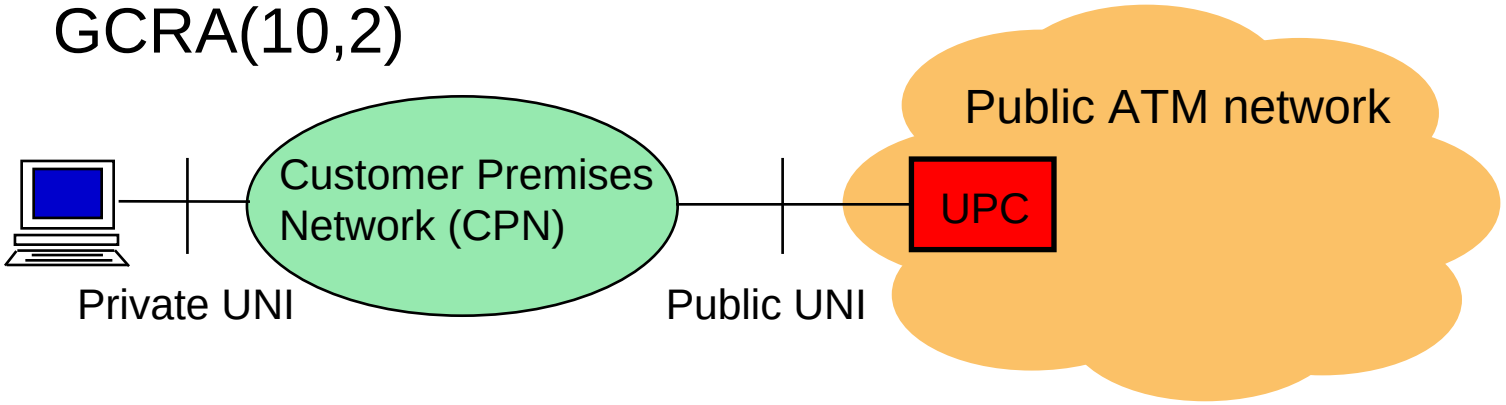
- Is provably equivalent to GCRA

B: bucket contents

If B+1> 1+τ/T
  cell nonconforming
else
  cell conforming
  B=B+1

Traffic Contract for CBR

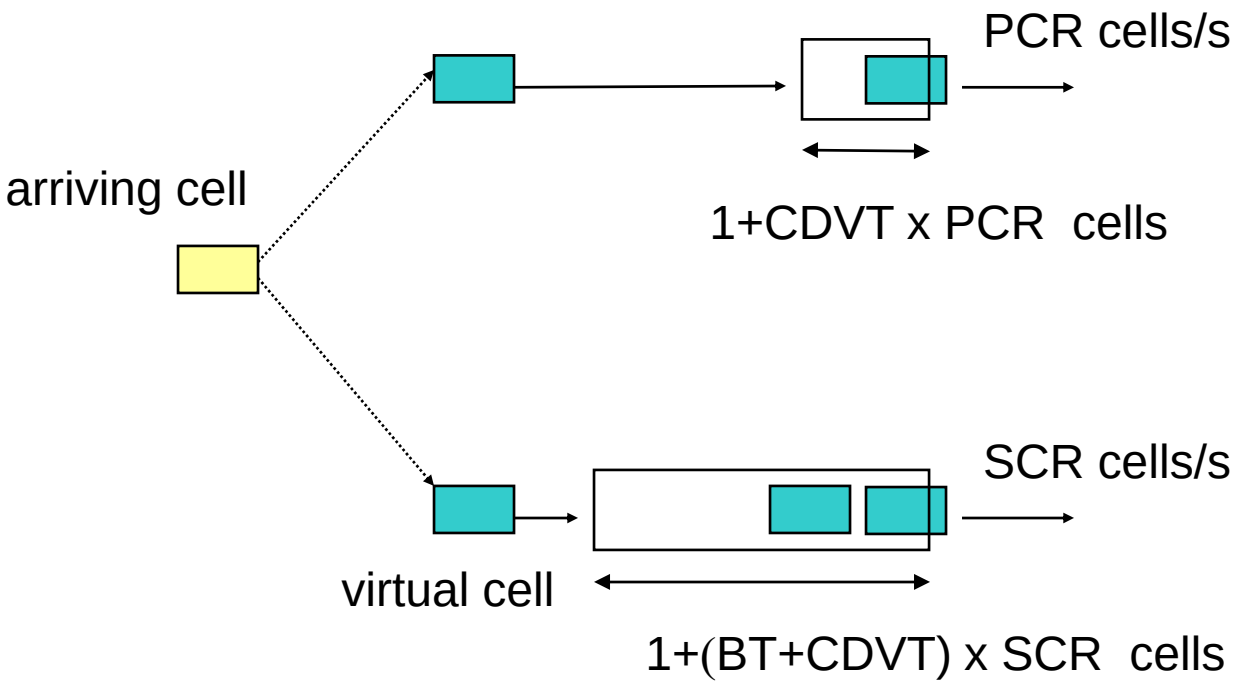
- For each CBR connection:
  - PCR (Peak Cell Rate)
  - CDVT (Cell Delay Variation Tolerance): takes care of slotted nature of ATM, physical overhead, ATM layer function overhead
    - E.g. only with CDVT we can have PCR=2/3*R, where R is ATM layer rate
- Connection must conform to GCRA(R/PCR,CDVT), PCR=15 Mbps, CDVT=2, ATM Layer Rate=150 Mbps =>
  GCRA(10,2)



Traffic Contract for VBR

- For each VBR connection:
  - PCR, CDVT
  - SCR, MBS, CDVT
  - BT=(MBS-1)(R/SCR-R/PCR), where R: ATM Layer Rate
- Connection must conform to
  - GCRA(R/PCR,CDVT) AND
  - GCRA(R/SCR, BT+CDVT)
- Equivalent description: Dual leaky bucket

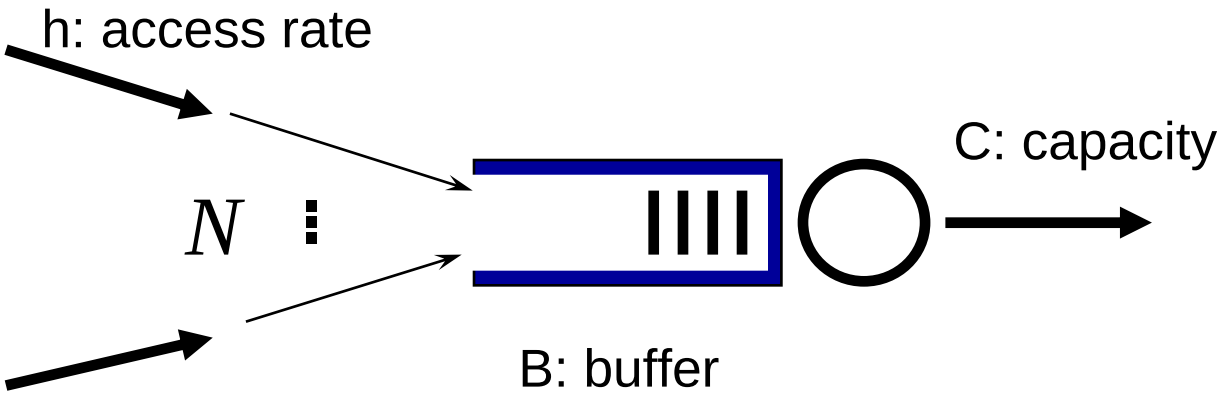
Leaky buckets for SCR and PCR policing



Deterministic multiplexing of leaky bucket streams

- Assume leaky bucket (r,b) and access rate h
- Maximum time t user can transmit at rate h

$$ht \leq rt + b \Rightarrow t = \frac{b}{h - r}$$



- Deterministic QoS constraints: no losses, delay < D for all cells

Multiplexing leaky bucket streams (cont.)

- Maximum backlog Q if N users (r,b) multiplexed on link with capacity C

$$Q = Nht - Ct = (Nh - C)\frac{b}{h - r}$$

- Delay constraint D

$$\frac{Q}{C} \le D \Rightarrow (Nh - C)\frac{b}{h - r} \le DC \Rightarrow N\left(h\frac{b}{b + (h - r)D}\right) \le C$$

- Must also have: $Nr \le C$

- Finally: CAC criterion $Na \le C$, where a is the *effective bandwidth*

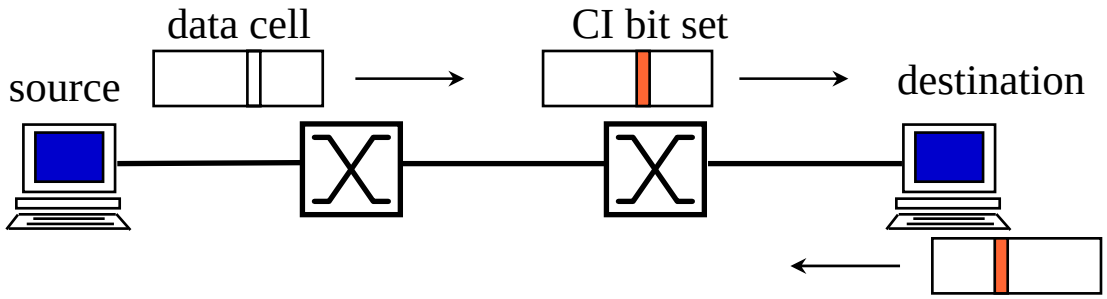
$$a = \max\left\{h\frac{b}{b + (h - r)D}, r\right\}$$

Available Bit Rate (ABR) Services within ATM

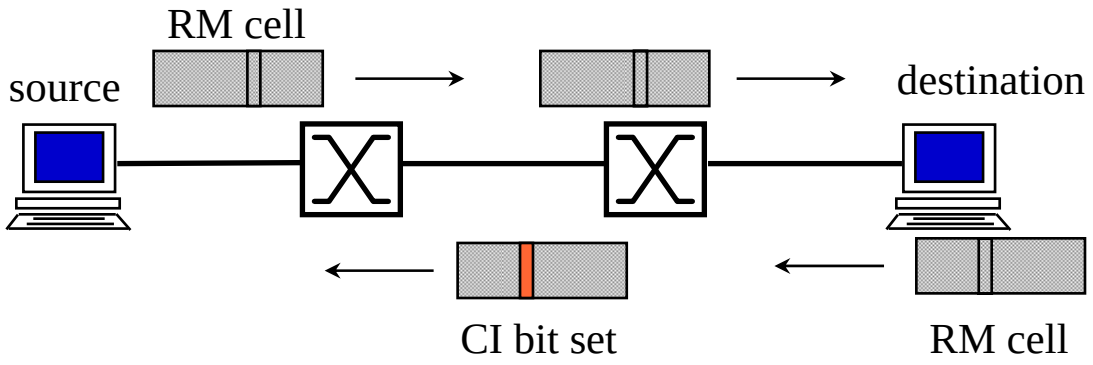
- Intended for elastic sources (i.e., sources which can increase/decrease their traffic rate)
- For each ABR connection:
  - PCR (Peak Cell Rate)
  - MCR (Minimum Cell Rate)
- No specific QoS parameters
  - CLR (Cell Loss Ratio) is expected to be low for compliant sources
  - fair share of available bandwidth
- Rate-based closed loop congestion control
  - binary feedback (Explicit Forward Congestion Indication - EFCI)
  - rate-based (Explicit Rate - ER), Resource Management cell

ABR Congestion Control

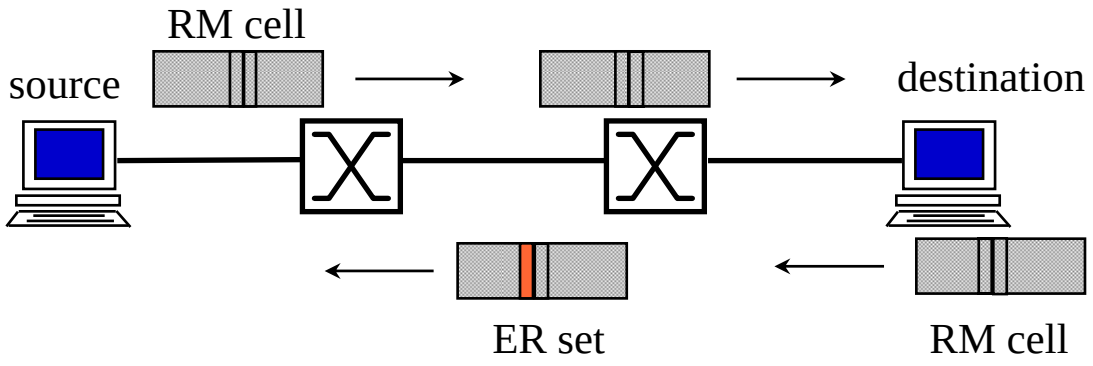
a) EFCI marking mode



b) Relative Rate marking mode

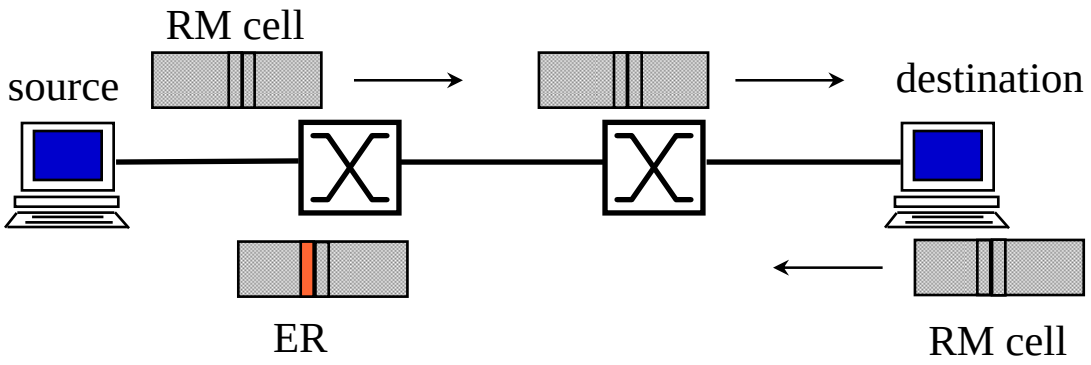


c) Explicit Rate marking mode



Switch Operation with ABR Congestion Control

- Each switch computes Explicit Rate (ER)
  - e.g., ER=C/N, where C is link capacity and N number of ABR connections
- Sets minimum of value in ER field (in RM cell) and computed ER



ER=min(ER_cell, ER_computed)

ABR Congestion Control: Source Behavior

- Same algorithm for any network (internal) modes
- If no congestion $\Rightarrow$ can increase sending rate (additive)
- If congestion $\Rightarrow$ decrease sending rate (multiplicative)
- At all times: Sending Rate $\leq$ Explicit Rate (ER)

Actually a bit more complicated (NI: No Increase, ACR: Allowed Cell Rate)

- If CI=1
  - Reduce ACR by amount proportional to current ACR but not less than MCR
- Else if NI=0
  - Increase ACR by amount proportional to PCR but not more than PCR
- If ACR>ER set ACR=max{ER,MCR}

ABR versus TCP

- ABR feedback controls rate of transmission
  - Rate control
- TCP feedback controls window size
  - Window control
- ABR feedback explicit from switches or destination
  - ECN (Explicit Congestion Notification)
- TCP feedback implicit (losses)
- ATM switch must perform:
  - Congestion control: Monitor queue length
  - Fair capacity allocation: Throttle back connections using more than fair share
- Active Queue Management schemes similar to above
  - RED (Random Early Detection)