

HY537: Έλεγχος Πόρων και Επίδοση σε  
Ευρυζωνικά Δίκτυα

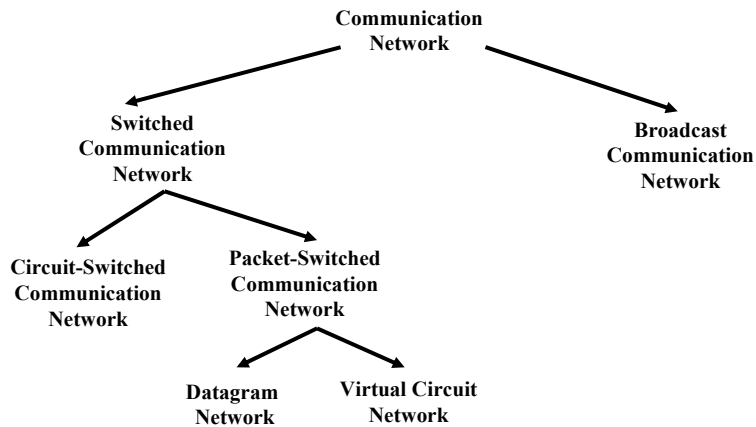
Βασίλειος Σύρης

Τμήμα Επιστήμης Υπολογιστών  
Πανεπιστήμιο Κρήτης  
Εαρινό εξάμηνο 2008

ATM Technology  
ATM Service Categories  
Frame Relay

## A Taxonomy of Communication Networks

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



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## Key Features of ATM

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

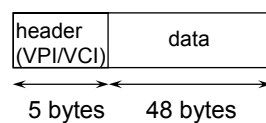
STM (Synchronous Transfer Mode):



ATM:



- **Short fixed size cells**



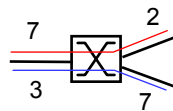
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## Key Features of ATM (cont.)

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



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



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## 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

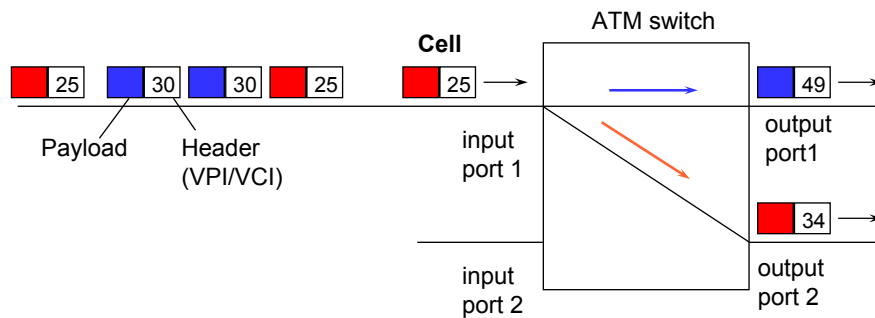
VC: 16

Network technology - 6

## Cell Switching

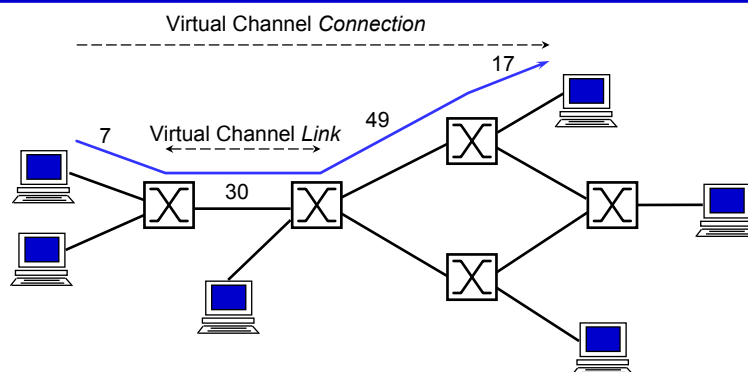
Input Port	VPI/VCI	Output Port	VPI/VCI
1	25	2	34
1	30	1	49

Internal Routing Table



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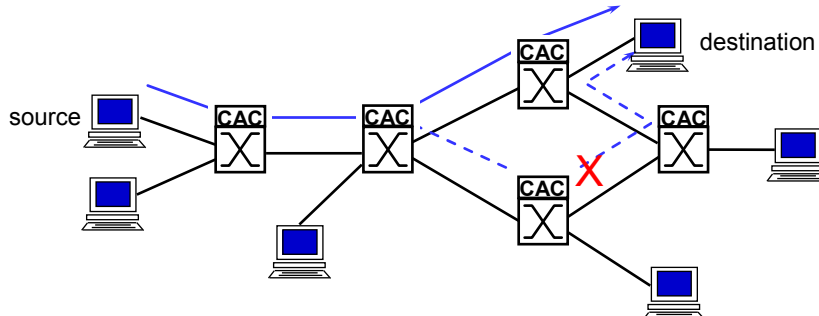
## Virtual Channel Connection



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

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## Routing and Call Admission Control (CAC)

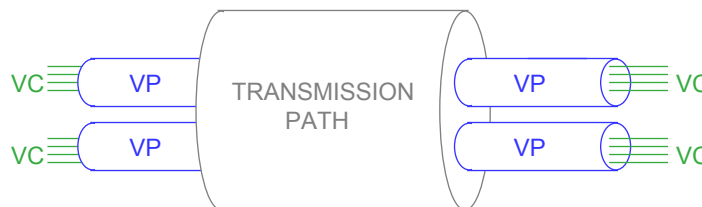


- **Routing:** find path from source to destination that fulfils user requirements (bandwidth, QoS)
- **Call Admission Control (CAC):** performed at every switch, determines whether there are enough resources to accept a call

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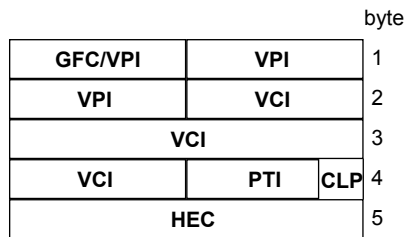
## Virtual Channels and Virtual Paths

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



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## ATM Cell Header Format

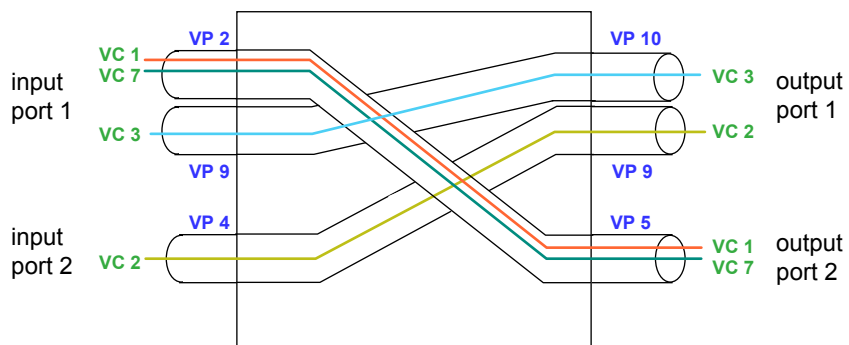


- GFC: only in UNI
- CLP=1 => cell has low priority
- PTI: identifies user cell/data cell, congestion control

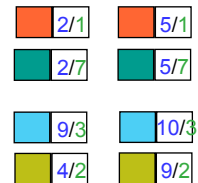
**GFC** = Generic Flow Control  
**VPI** = Virtual Path Identifier  
**VCI** = Virtual Channel Identifier  
**PTI** = Payload Type Identifier  
**CLP** = Cell Loss Priority  
**HEC** = Header Error Control

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## VP Switching

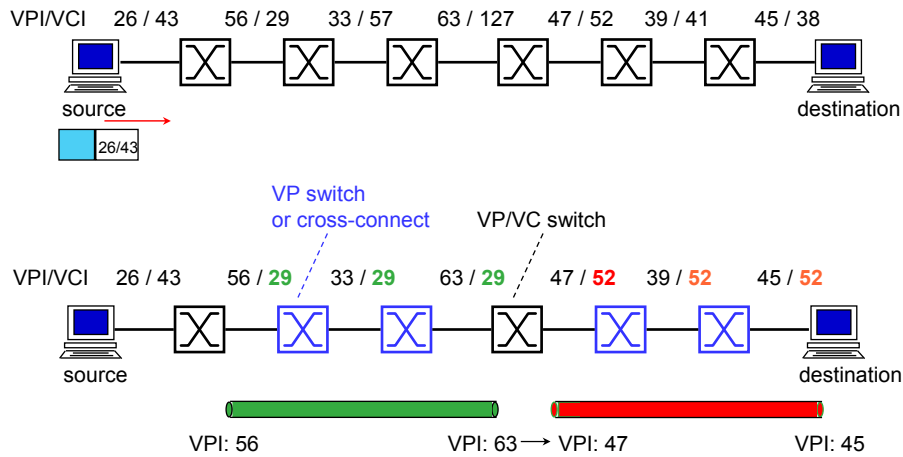


Input Port	VPI	Output Port	VPI
1	2	2	5
1	9	1	10
2	4	1	9



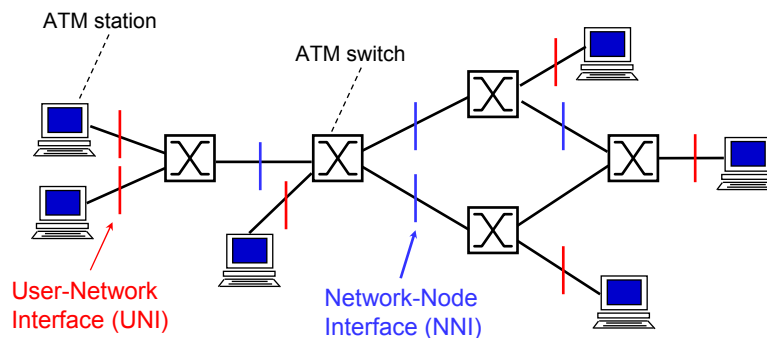
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## VP and VP/VC Switching in a Network



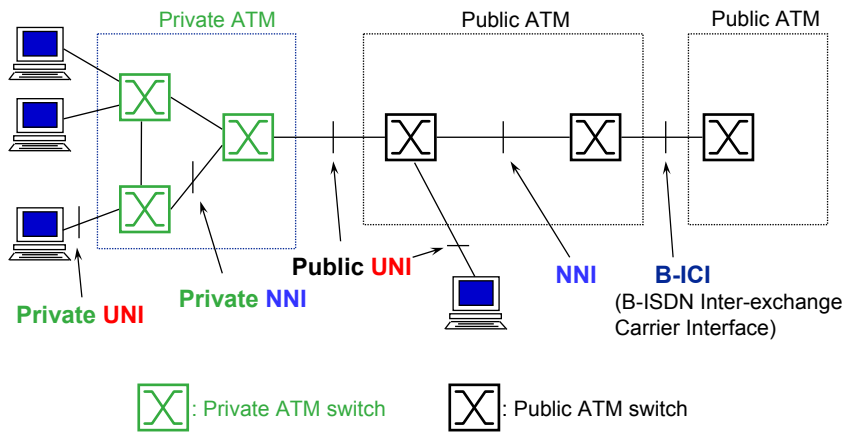
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## B-ISDN Interface Terminology



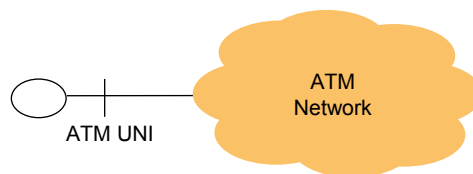
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## B-ISDN Interface Terminology (cont.)



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## ATM Layer Service Categories



- Offered at ATM UNI (User-Network Interface)

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## ATM Forum Service Categories

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	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

Network technology - 17

## ATM Forum Real-Time Service Categories

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- Constant Bit Rate (CBR):
  - real-time applications requiring a static amount of bandwidth
  - 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
  - Quality of Service (QoS) in terms of delay, delay variation, cell loss

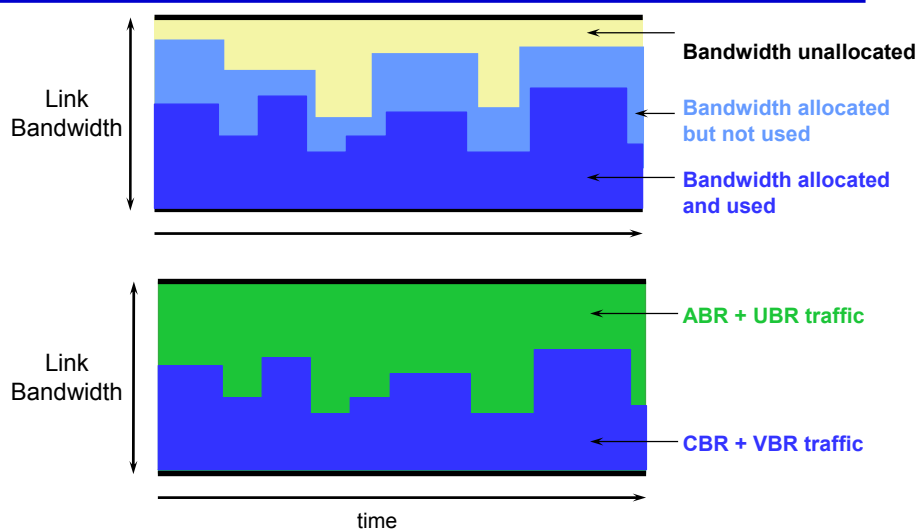
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## ATM Forum Non-Real-Time Service Categories

- Non-Real-Time Variable Bit Rate (nrt-VBR):
  - non-real-time applications with bursty traffic
  - 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

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## Bandwidth Usage



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## 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)



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## Traffic Parameters

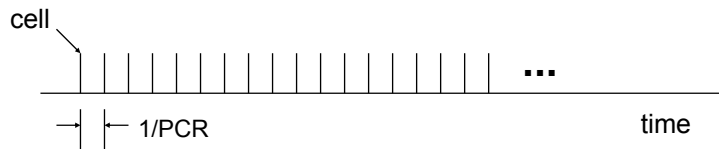
Traffic parameters describe inherent characteristics of a traffic source

- **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

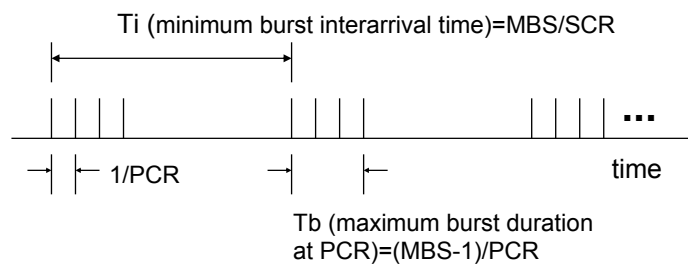
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## Traffic parameters (cont.)

Peak Cell Rate (PCR):



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



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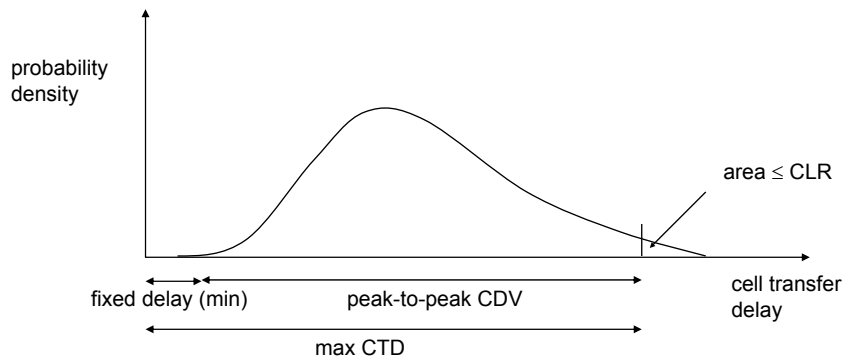
## ATM Quality of Service (QoS) Parameters

**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
- **Minimum Cell Rate (MCR):** Minimum cell rate user is allowed to always send
- The above are user negotiable
- Also, a number of additional, *non-negotiable* QoS parameters have been defined

Network technology - 24

## ATM QoS parameters (cont.)



Network technology - 25

## 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)

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## 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

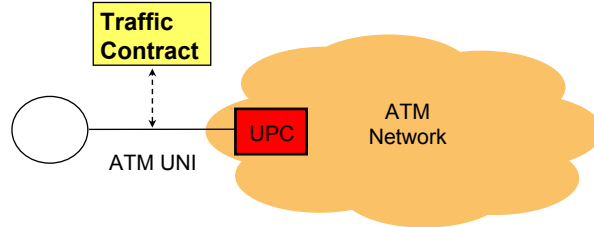
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## Traffic Control in ATM

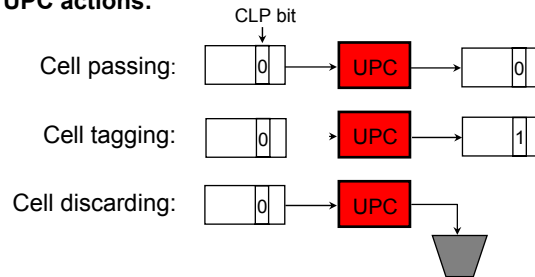
- Connection Acceptance Control (CAC)
- Routing
- Usage Parameter Control (UPC) or Source Policing
- Shaping
- Priorities, scheduling
- Feedback control
- Other (e.g. pricing)

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## Usage Parameter Control (UPC) or Source Policing

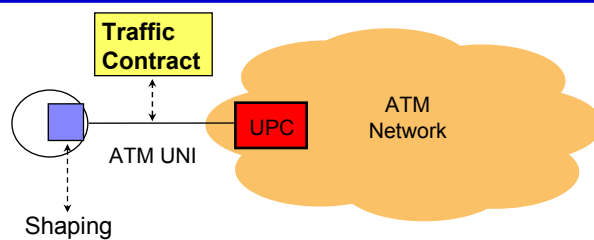


UPC actions:

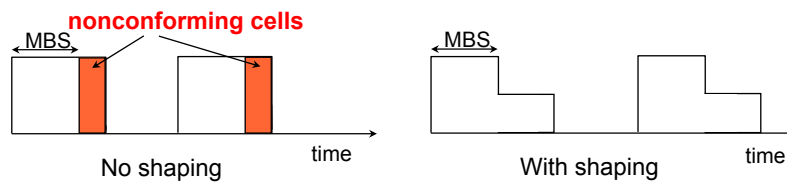


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## UPC and Traffic Shaping



- Traffic shaping at source prevents loss due to policing



MBS: maximum burst size

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## UPC (or Source Policing) Functions

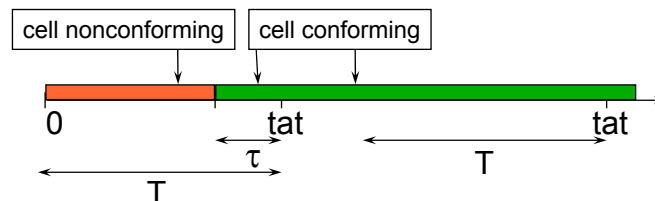
- Algorithm implemented at UNI for ensuring that user traffic adheres to traffic contract.
- Generic Cell Rate Algorithm (GCRA):
  - “Leaky bucket” type algorithm
  - Open loop algorithm

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## Generic Cell Rate Algorithm

```
GCRA( $T, \tau$ )
t: cell arrival time
tat: theoretical arrival time
if ( $t < \text{tat} - \tau$ )
  cell nonconforming
else
  cell conforming
   $\text{tat} = \max(t, \text{tat}) + T$ 
```

“Virtual Scheduling Algorithm”



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## GCRA examples

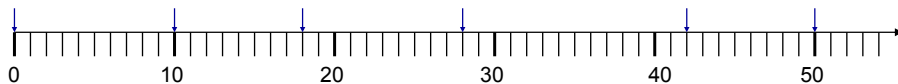
- GCRA(10,2)

- Cell arrival times: 0 10 18 28 42 50

t	0	10	18	28	42	50
tat- $\tau$	0-2	10-2	20-2	30-2	40-2	52-2
result	C	C	C	C	C	C
tat after	10	20	30	40	52	62

```

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



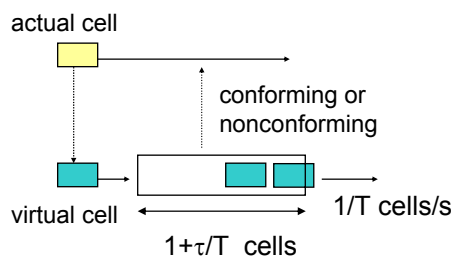
- Cell arrival times: 0 10 15 25 35

t	0	10	15	25	35
tat- $\tau$	0-2	10-2	20-2	20-2	35-2
result	C	C	NC	C	C
tat after	10	20	20	35	45

Network technology - 33

## Leaky Bucket Algorithm

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



B: bucket contents

```

If B+1 > 1 +  $\tau/T$ 
  cell nonconforming
else
  cell conforming
  B = B+1
    
```

## Equivalence of virtual scheduling algor. $(T, \tau)$ & Leaky Bucket $(r, b) = (1/T, 1 + \tau/T)$

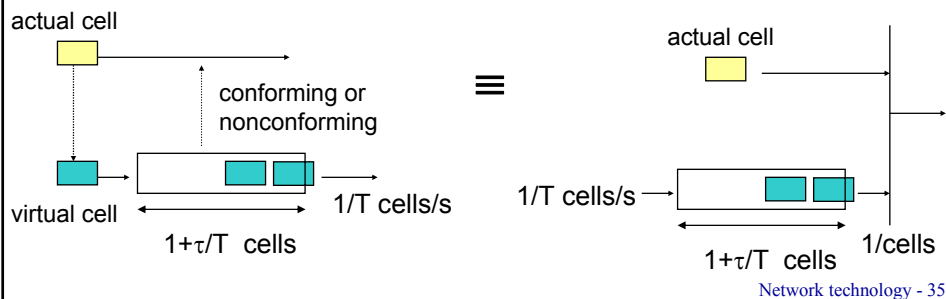
- Virtual scheduling algorithm

III

- Leaky Bucket

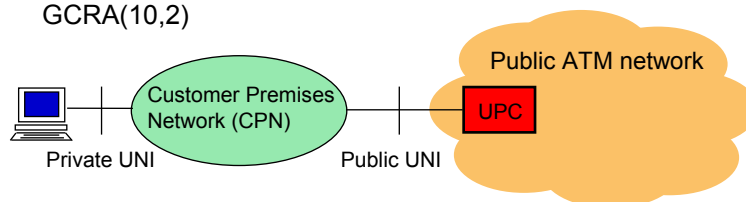
```

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
    
```



## 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
- Connection must conform to GCRA(R/PCR, CDVT), where R is ATM layer rate
  - PCR=15 Mbps, CDVT=2, ATM Layer Rate=150 Mbps => GCRA(10,2)



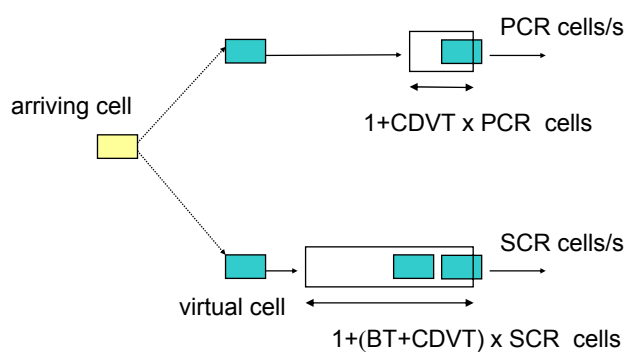
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## Traffic Contract for VBR

- 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)

Network technology - 37

## Leaky buckets for SCR and PCR policing



Network technology - 38

## Multiplexing leaky bucket streams

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

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

- 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

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

Must also have

$$Nr \leq C$$

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

$$Na \leq C$$

Network technology - 39

## Comparison of Packet Services

	Packet type	Connection type	Speed	OSI layer
X.25	variable	connection oriented	< 64 Kbps	3
Frame Relay	variable	connection oriented	- 1.5/2 Mbps	2/3
SMDS	fixed (53 byte cell)	connectionless	- 34/45 Mbps	1/2
ATM	fixed (53 byte cell)	connection oriented	- 10 Gbps, higher ?	1/2

SMDS: Switched Multi-Megabit Data Service

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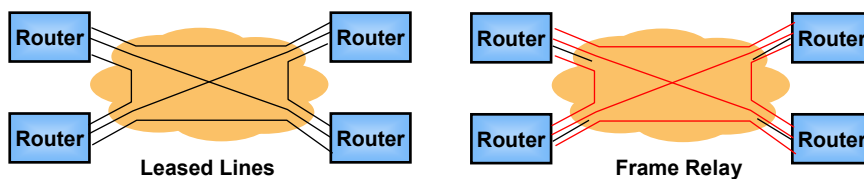
## Frame Relay vs. X.25

- Designed to eliminate much of the overhead in X.25
- Call control signaling on separate logical connection from user data
- Multiplexing/switching of logical connections at layer 2 (not layer 3)
- No hop-by-hop flow control and error control
- Throughput an order of magnitude higher than X.25

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## Frame Relay networks

- Leased lines: multiple connections => multiple lines
- Frame relay: single physical connection, but multiple logical connections

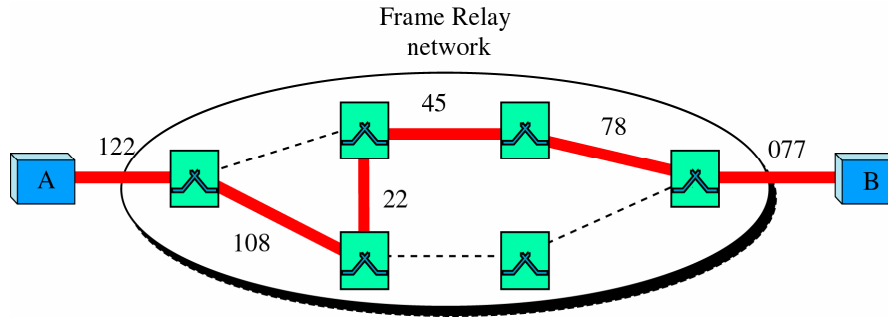


— : physical connection  
— : virtual circuit

- Features:
  - X.25 simplified - No flow/error control
  - Variable packets
  - Virtual Circuits: Data Link Connection Identifiers (DLCI)
  - Single bit congestion indication

Network technology - 42

## Frame Relay DLCI switching

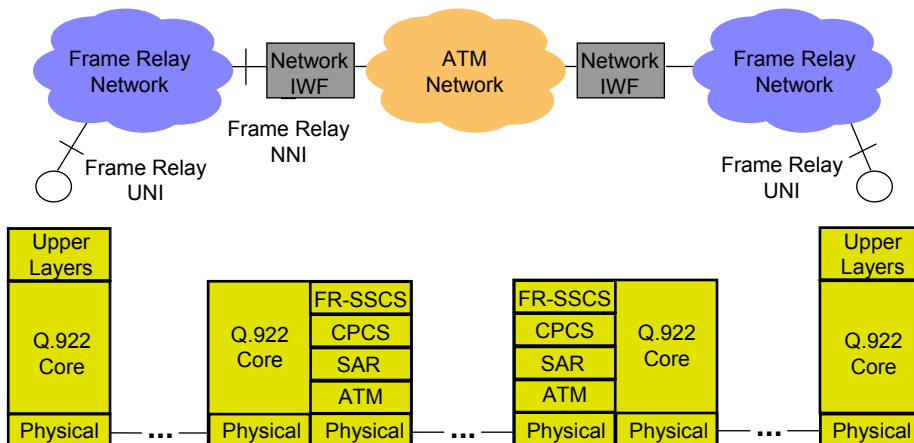


Network technology - 43

## Frame Relay/ATM Network Interworking

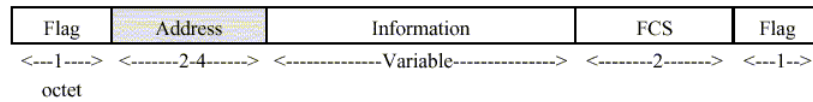
FR/ATM Network Interworking Scenario 1

IWF: Interworking Function



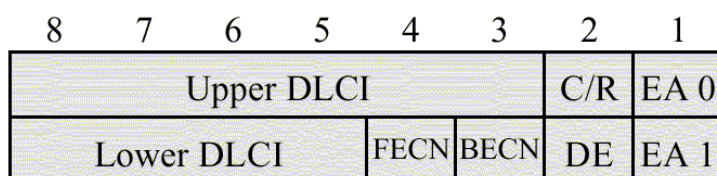
Network technology - 44

## Frame Relay frame



Network technology - 45

## Frame Relay header



- EA     Address field extension bit
- C/R    Command/response bit
- FECN   Forward explicit congestion notification
- BECN   Backward explicit congestion notification
- DLCI   Data link connection identifier
- D/C    DLCI or DL-CORE control indicator
- DE     Discard eligibility

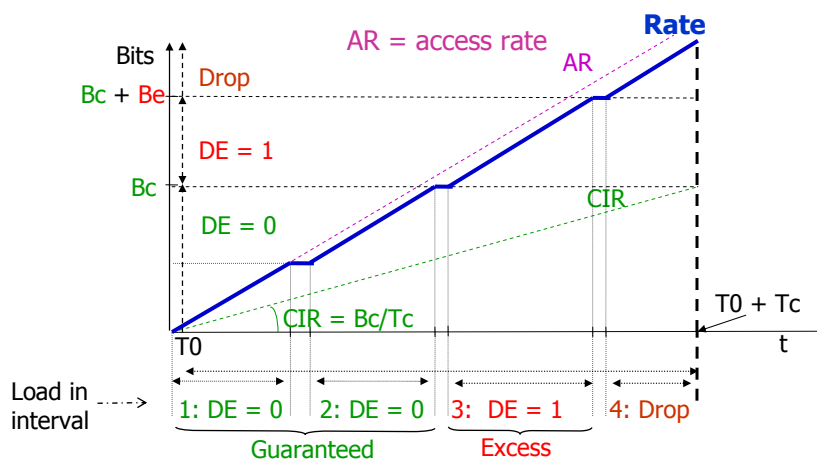
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## Frame Relay Traffic Parameters

- Committed Information Rate (CIR)
- Committed Burst Size (Bc)
  - Measurement interval  $T=Bc/CIR$
- Excess Burst Size (Be)
  - Excess Information Rate (EIR):  $EIR=Be/T$
- If bits in interval T
  - between Bc and Bc+Be => Mark Discard Eligible (DE) bit in frame
  - over Bc+Be => Discard frame

Network technology - 47

## Frame Relay conformance checking



Network technology - 48

## Frame Relay/ATM Traffic Parameter Conversion

- Different methods using 2 or 3 GCRA's
- Method 1: 3 GCRA's to characterize
  - peak (= frame relay access line rate)
  - CIR, Bc
  - CIR+EIR, Bc+Be
- Method 2: 2 GCRA's to characterize
  - first GCRA: peak (= frame relay access line rate)
  - second GCRA: CIR, Bc
- or
  - first GCRA: CIR+EIR, Bc+Be
  - second GCRA: CIR, Bc
- Need to take into account the cell overhead (tax)

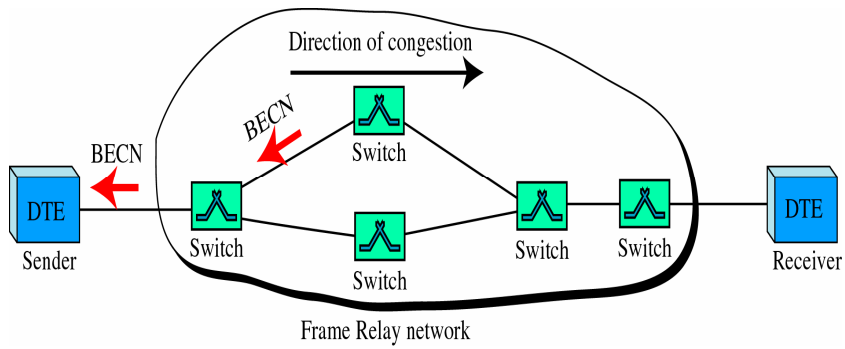
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## Frame Relay congestion control

- Congestion notification
  - Two bits in the frame are used
  - BECN(Backward Explicit Congestion Notification)
  - FECN(Forward Explicit Congestion Notification)
- Frame Relay itself does not implement rate control
  - This is left for higher layers
- Frame discard: using DE (Discard Eligible) bit

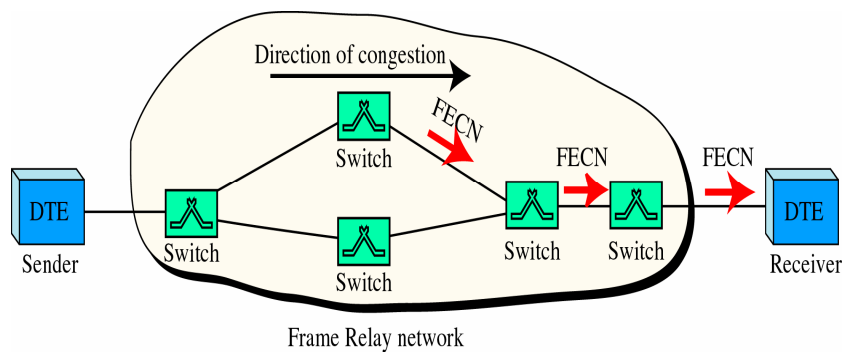
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## Frame Relay BECN



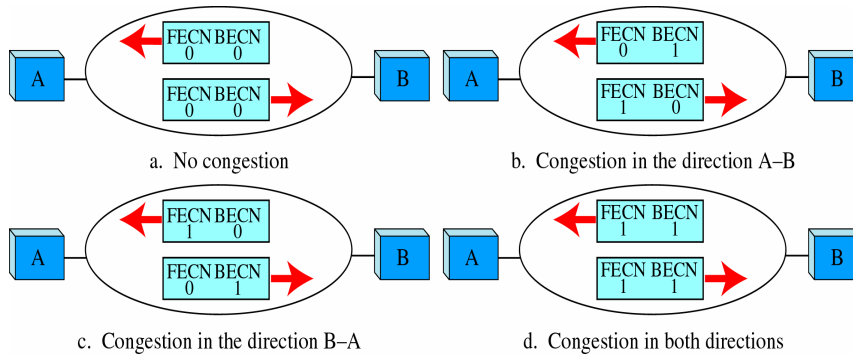
Network technology - 51

## Frame Relay FECN



Network technology - 52

## Four cases of congestion control



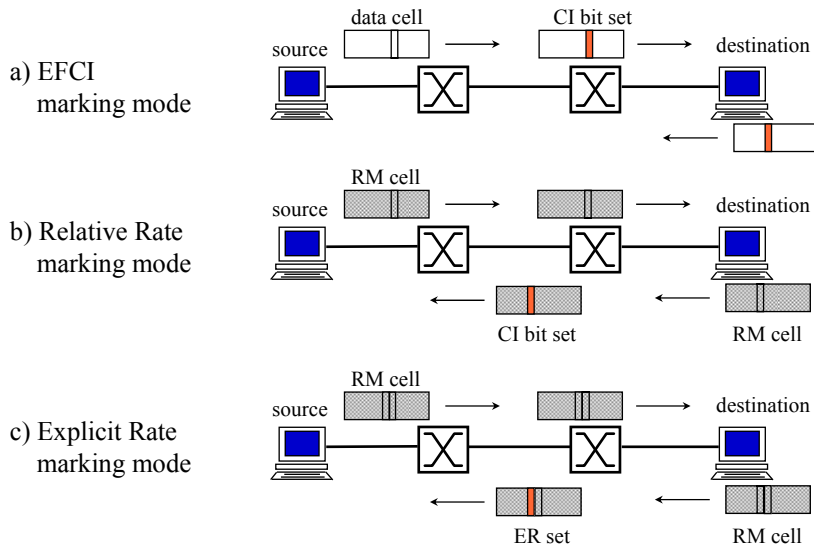
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## Available Bit Rate (ABR) Services

- 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 flow control
  - binary feedback (Explicit Forward Congestion Indication - EFCI)
  - rate-based (Explicit Rate - ER), Resource Management cell

Network technology - 54

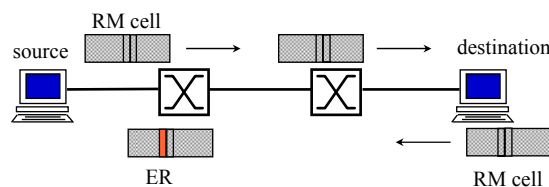
## ABR Flow Control



Network technology - 55

## Switch Operation with ABR Flow 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



$$ER = \min(ER_{cell}, ER_{computed})$$

Network technology - 56

## ABR Flow Control: Source Behavior

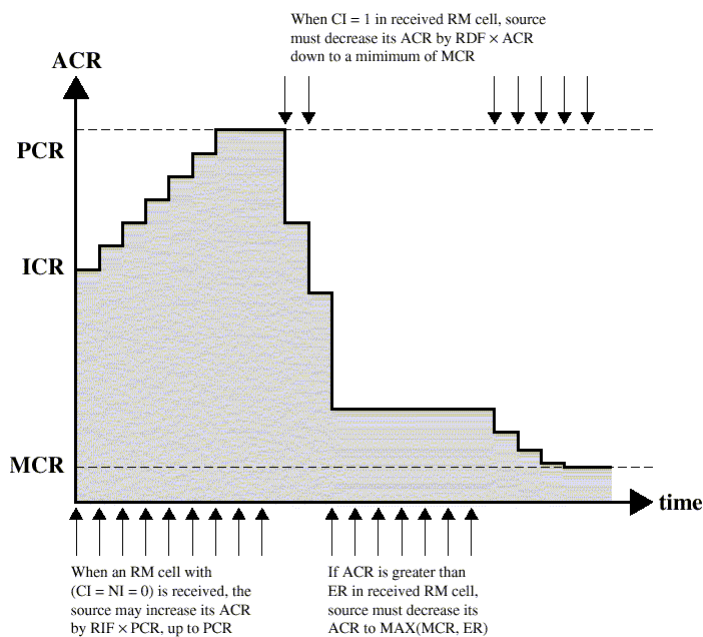
- Same algorithm for any network (internal) modes
- If no congestion  $\Rightarrow$  can increase sending rate (additive)
- If congestion  $\Rightarrow$  decrease sending rate (multiplicative)
- At all times, sending rate  $\leq$  Explicit Rate (ER)

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 CR
- Else if NI=0
  - Increase ACR by amount proportional to PCR but not more than PCR
- If  $ACR > ER$  set  $ACR = \max\{ER, MCR\}$

Network technology - 57

## Variations of ACR (Allowed Cell Rate)



## ABR versus TCP

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- ABR feedback controls rate of transmission
  - Rate control
- TCP feedback controls window size
  - Window control
- ABR feedback explicit from switches or destination
- TCP feedback implicit (losses)
  - ECN (Explicit Congestion Notification)
- 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)

Network technology - 59

## GFR: Guaranteed Frame Rate

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- Provides guaranteed minimum capacity, in terms of frame rate
- User may use any additional available capacity
- No guarantee of frame delivery
- Requires network to recognize frames
  - All cells of frame have same CLP bit
  - When congestion occurs, drop all cells of a frame
- Simple as UBR from end system view
  - End system does no policing or traffic shaping
  - May transmit at line rate of ATM adaptor
- Modest requirements on ATM network
- Higher layer (e.g. TCP) react to congestion signal (dropped frames)

Network technology - 60

## GFR contract

- GFR contract:
  - PCR
  - MCR
  - MBS
  - MFS (Maximum Frame Size)
  - CDVT
- ABR contract:
  - PCR
  - MCR

Network technology - 61

## GFR and other service categories

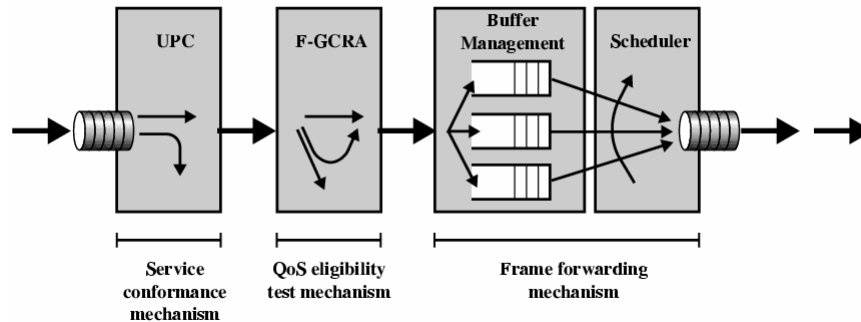
Table 13.1 ATM Service Category Attributes

Attribute	ATM Layer Service Category					
	CBR	rt-VBR	nrt-VBR	UBR	ABR	GFR
<b>Traffic Parameters<sup>4</sup></b>						
PCR, CDVT <sup>5</sup>	Specified			Specified <sup>2</sup>	Specified <sup>3</sup>	Specified
SCR, MBS, CDVT <sup>5</sup>	N/A	Specified		N/A		
MCR	N/A				Specified	N/A
MCR, MBS, MFS, CDVT <sup>5</sup>	N/A				Specified	
<b>QoS Parameters</b>						
Peak-to-peak CDV	Specified			Unspecified		
Max CTD	Specified			Unspecified		
CLR	Specified			Unspecified	See note 1	See note 6
<b>Congestion Control</b>						
Feedback	Unspecified				Specified	Unspecified

Network technology - 62

## Mechanisms for supporting rate guarantees

- Tagging and policing
- Buffer management
- Scheduling



Network technology - 63

## GFR conformance testing

- UPC function
  - UPC monitors VC for traffic conformance
  - Tag or discard non-conforming cells
- Frame conforms if all cells in frame conform
  - Rate of cells within contract: GCRA(1/PCR,CDVT)
  - All cells have same CLP
  - Within maximum frame size (MFS)

Network technology - 64

## QoS eligibility test

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- Test for contract conformance
  - Discard or tag non-conforming cells
    - Exceeding upper bound: GCRA(1/PCR,CDVT)
  - Determine frames eligible for QoS guarantee
    - Below lower bound for traffic: GCRA(1/MCR,BT+CDVT)
    - Where  $BT \geq MFS/MCR$
- Frames are one of:
  - Nonconforming: cells tagged or discarded
  - Conforming & ineligible: best effort delivery
  - Conforming & eligible: guaranteed delivery