Traffic and Congestion Control in ATM Networks

COMP5416
Chapter 13
Lesson Outline

- Issues of ATM transmission
- ATM services description
- Various traffic control functions to support the ATM services
Introduction

- Control needed to prevent ATM switch buffer overflow
- High speed and small cell size gives different problems from other networks
- Each ATM service has an exact service description
- ATM traffic control functions are used to meet the SLA (service-level agreement)
Problems with ATM Congestion Control

- Most traffic not amenable to flow control
  - Voice & video can not stop generating
- Feedback slow
  - Small cell transmission time vs propagation delay
- Wide range of applications
  - From few Kbps to hundreds of Mbps
  - Different traffic patterns, like CBR vs VBR sources
- High speed switching and transmission
  - Volatile congestion and traffic control
  - Reacting to changing conditions may produce extreme fluctuations!

Thus, two key performance issues
Key Performance Issues - Latency/Speed Effects

- E.g. data rate 150 Mbps
- Takes \( \frac{(53 \times 8 \text{ bits})}{(150 \times 10^6)} = 2.8 \, \mu s \) to insert a cell
- Transfer time depends on number of intermediate switches, switching time and propagation delay. Assuming no switching delay and speed of light propagation, RTT of \( 48 \times 10^{-3} \) sec across USA
- A dropped cell notified by return message will arrive after source has transmitted \( N \) further cells
- \( N = \frac{(48 \times 10^{-3} \text{ seconds})}{(2.8 \times 10^{-6} \text{ seconds per cell})} = 1.7 \times 10^4 \) cells = \( 7.2 \times 10^6 \) bits
  
  i.e. over 7 Mbits!
- Thus, traditional approaches breaks down for ATM WANs
Key Performance Issues - Cell Delay Variation

- For digitized voice delay across network must be small
- And rate of delivery to receiving app must be constant
- However, variations will still occur -> Jitter!
- Dealt with by Time Reassembly of CBR cells – cell delivery is delayed by V(i)
- Results in cells delivered at CBR with occasional gaps due to dropped cells
Time Reassembly of CBR Cells

\[ \delta = \text{cell insertion time} \]

\[ \begin{align*}
D(0) & \quad V(0) \\
D(1) & \quad V(1) \\
D(2) & \quad V(2) \\
D(3) & \quad V(3) \\
D(4) & \quad V(4) \\
\end{align*} \]

Slope = \( R \) cells/sec = \( 1/\delta \)

Cell arrives late; discarded

Control in ATM Networks
ATM Traffic-Related Attributes

- Six service categories
  - Constant bit rate (CBR)
  - Real time variable bit rate (rt-VBR)
  - Non-real-time variable bit rate (nrt-VBR)
  - Unspecified bit rate (UBR)
  - Available bit rate (ABR)
  - Guaranteed frame rate (GFR)

- Characterised by ATM attributes in four categories!
  - Traffic descriptors
  - QoS parameters
  - Congestion (only for ABR)
  - Other service-specific attributes
### ATM Service Category Attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>CBR</th>
<th>rt-VBR</th>
<th>nrt-VBR</th>
<th>UBR</th>
<th>ABR</th>
<th>GFR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Traffic Parameters</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>PCR, CDVT</td>
<td>Specified</td>
<td>Specified</td>
<td>Specified</td>
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<tr>
<td>SCR, MBS, CDVT</td>
<td>N/A</td>
<td>Specified</td>
<td></td>
<td>N/A</td>
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<td></td>
</tr>
<tr>
<td>MCR</td>
<td>N/A</td>
<td>N/A</td>
<td>Specified</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MCR, MBS, MFS, CDVT</td>
<td>N/A</td>
<td>N/A</td>
<td>Specified</td>
<td>N/A</td>
<td></td>
<td></td>
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<tr>
<td><strong>QoS Parameters</strong></td>
<td></td>
<td></td>
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<tr>
<td>Peak-to-peak CDV</td>
<td>Specified</td>
<td></td>
<td>Unspecified</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max CTD</td>
<td>Specified</td>
<td></td>
<td>Unspecified</td>
<td></td>
<td></td>
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<tr>
<td>CLR</td>
<td>Specified</td>
<td></td>
<td>Unspecified</td>
<td>See note 1</td>
<td>See note 6</td>
<td></td>
</tr>
<tr>
<td>Feedback</td>
<td></td>
<td>Unspecified</td>
<td>Specified</td>
<td>Unspecified</td>
<td></td>
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<tr>
<td><strong>Congestion Control</strong></td>
<td></td>
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<tr>
<td><strong>Other Attributes</strong></td>
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<td></td>
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</tr>
<tr>
<td>BCS</td>
<td>Unspecified</td>
<td></td>
<td>Optional</td>
<td></td>
<td>Unspecified</td>
<td></td>
</tr>
<tr>
<td>MDCR</td>
<td>N/A</td>
<td></td>
<td>Optional</td>
<td></td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

1. CLR is low for sources that adjust cell flow in response to control information. Whether a quantitative value for CLR is specified is network specific.
2. May not be subject to CAC and UPC procedures.
3. Represents the maximum rate at which ABR sources may ever send. The actual rate is subject to the control information.
4. These parameters are either explicitly or implicitly specified for PVCs or SVCs.
5. CDVT is not signaled. In general CDVT need not have a unique value for a connection. Different values may apply at each interface along the path of a connection.
6. CLR is low for frames that are eligible for the service guarantee. Whether a quantitative value of CLR is specified is network specific.
7. The MDCR parameter is not considered a traffic parameter because this specification does not define a service commitment based on MDCR.
1. Traffic Parameters

Traffic pattern of flow of cells from two perspectives:

- Intrinsic nature of traffic
  - Source traffic descriptor
- Modified inside network
  - Connection traffic descriptor
Source Traffic Descriptor (1)

- Describes traffic characteristics of a source

**Peak cell rate (PCR)**
- Upper bound on traffic that can be submitted
- Defined in terms of minimum spacing between cells $T$
- $PCR = 1/T$
- Mandatory for CBR and VBR services

**Sustainable cell rate (SCR)**
- Upper bound on average rate
- Calculated over large time scale relative to $T$
- Required for VBR
- Enables efficient allocation of network resources between VBR sources
- Only useful if $SCR < PCR$
Source Traffic Descriptor (2)

- **Maximum burst size (MBS)**
  - Max number of cells that can be sent at PCR
  - If bursts are at MBS, idle gaps must be enough to keep overall rate below SCR
  - Required for VBR

- **Minimum cell rate (MCR)**
  - Min commitment requested of network
  - Can be zero
  - Used with ABR and GFR
  - ABR & GFR provide rapid access to spare network capacity up to PCR
  - PCR – MCR represents elastic component of data flow
Source Traffic Descriptor (3)

- Maximum frame size (MFS)
  - Max number of cells in frame that can be carried over GFR connection
  - Only relevant in GFR
Connection Traffic Descriptor

- Includes source traffic descriptor plus:
  - Cell delay variation tolerance (CDVT)
    - Amount of variation in cell delay
    - Represented by time variable $\tau$
  - Conformance definition
    - Specify conforming cells of connection at access switch
    - Enforced by dropping or marking cells over definition
2. Quality of Service Parameters- maxCTD

- Characterises requested performance of a VC

- Cell transfer delay (CTD)
  - Time between transmission of first bit of cell at source and reception of last bit at destination
  - Has fixed delay due to propagation etc.
  - Cell delay variation due to buffering (i.e. queuing) and scheduling
  - Maximum cell transfer delay (maxCTD) is max requested delay for connection
  - Cells exceed that threshold
    - Be discarded or delivered late
Quality of Service Parameters-
Peak-to-peak CDV & CLR

- Peak-to-peak Cell Delay Variation
  - Remaining conforming cells within QoS
  - Delay experienced by these cells is between fixed delay and maxCTD
    - This is peak-to-peak CDV
  - CDVT is an upper bound on CDV

- Cell loss ratio (CLR)
  - Ratio of cells lost to cells transmitted
Cell Transfer Delay PDF

- Fixed delay
- Peak-to-peak cell delay variation (CDV)
- Maximum cell transfer delay (CTD)
- Cells lost or delivered too late

$1 - \alpha$

Control in ATM Networks
3. Congestion Control Attributes

- Feedback is defined
  - Only for ABR (and planned for GFR)
    - Rate-based control (c.f. explicit signalling category)
  - Actions taken by network and end systems to regulate submitted traffic

- ABR flow control
  - Multiple ABR flows adaptively share available bandwidth
Traffic Control Objectives

Objectives of ATM layer traffic and congestion control

- Support QoS for all foreseeable services
- Not rely on network specific AAL protocols nor higher layer application specific protocols
- Minimise network and end system complexity while maximise network utilisation
Traffic Control Functions

To meet them, a number of control functions defined at different granularity:

- **Cell insertion time**
  - Functions that react to cells as they are transmitted

- **Round trip propagation time**
  - Network responds within a cell’s lifetime and provides feedback to source

- **Connection admission**
  - Function that determines a new connection can be accommodated (first line of defence!)

- **Long term**
  - Controls that affect more than 1 ATM connections (per VP)
## Traffic Control and Congestion Functions

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<tr>
<th>Response Time</th>
<th>Traffic Control Functions</th>
<th>Congestion Control Functions</th>
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<tr>
<td>Long Term</td>
<td>• Resource management using virtual paths</td>
<td></td>
</tr>
<tr>
<td>Connection Duration</td>
<td>• Connection admission control (CAC)</td>
<td></td>
</tr>
<tr>
<td>Round-trip Propagation Time</td>
<td>• Fast resource management</td>
<td>• Explicit forward congestion indication (EFCl)</td>
</tr>
<tr>
<td></td>
<td>• Usage parameter control (UPC)</td>
<td>• ABR flow control</td>
</tr>
<tr>
<td>Cell Insertion Time</td>
<td>• Priority control</td>
<td>• Selective cell discard</td>
</tr>
<tr>
<td></td>
<td>• Traffic shaping</td>
<td>• Frame discard</td>
</tr>
</tbody>
</table>
Traffic Control Strategies

- Determine whether new ATM connection can be accommodated

- Agree performance (QoS) parameters with subscriber
  - Traffic contract between subscriber and network (i.e. service-level agreement – SLA)

  This is **congestion avoidance**!

- If it fails congestion may occur
  - Invoke **congestion control**!
Traffic and Congestion Control Functions

- Resource management (RM) using virtual paths
- Connection admission control (CAC)
- Usage parameter control (UPC)
- Selective cell discard
- Traffic shaping
- Explicit forward congestion indication
1. Resource Management Using Virtual Paths

- The only function defined deals with use of virtual paths.
- Virtual paths (VP) are groupings of similar virtual channels (VC).
- Need to allocate resources so that traffic is separated according to service characteristics.
Resource Management Concerns

- QoS parameters are of primary concerns to RM:
  - Cell loss ratio
  - Max CTD
  - Peak to peak CDV

- All these are affected by aggregate resources devoted to VPs

- Set VP capacity as aggregate of PCR VCs
  - Con: May be underutilised

- Set VP capacity as aggregate of SCR VCs
  - Con: Lower QoS => CDV↑, CTD↑
2. Connection Admission Control

CAC algorithm is first line of defence
User must specify service required in both directions
- Which service category (CBR, rt-VBR, nrt-VBR etc)
- Connection traffic descriptor
  - Source traffic descriptor (PCR, SCR, MBS, MCR)
  - CDVT
- Requested conformance definition (how to drop/mark cells)
- QoS requested and acceptable value for peak-to-peak CDV, maxCTD, CLR

Network accepts connection only if it can commit resources to support requests
3. Usage Parameter Control (UPC)

- A network function that monitors connection for conformity to traffic contract i.e. traffic policing/metering
- Protect network resources from overload/abuse by one connection
- Done at VP or VC level
- VPC level more important because
  - Network resources allocated at this level
  - VP capacity then is shared among VCs
Location of UPC Function

Case A

Case B

Case C

NT = Network termination
VP-Sw = Virtual path switching function
VC-Sw = Virtual channel switching function

To another user or to another network provider
UPC Algorithm for PCR

- How UPC determines whether a user is complying with contract (i.e. policing)

- Control based on PCR and CDVT:
  - A VC complies if peak does not exceed agreed peak
  - Subject to CDV within agreed bounds

- Two types of generic cell rate algorithm (GCRA) available:
  - Virtual scheduling algorithm
  - Leaky bucket algorithm

- Compliant cell passes through, non-compliant cells may be tagged or discarded
Virtual Scheduling Algorithm GCRA(I,L)

\[ I = \text{Increment} \left( \frac{1}{R} \right), \]
where \( R \equiv \text{PCR} \)

\[ L = \text{Limit} \text{ (requested CDVT)} \]

TAT = Theoretical arrival time

\( t_a(k) = \text{Time of arrival of a cell} \)
Cell Arrival at UNI (T=4.5δ)

- If $\tau$ increases (> T - $\delta$), conforming cells can drift further from TAT causing cell-clumping.

- Chances of stressing network resources are greater!!

- The same GCRA can be used to monitor SCR and the associated MBS
  - with $\tau_s = (MBS-1)(T_s-T)$
4. Selective Cell Discard

- Two priority levels may be requested by user
  - Priority for individual cell indicated by CLP bit in ATM cell header
  - If two levels are used, traffic parameters for both flows specified
    - High priority CLP = 0
    - All traffic CLP = 0 or 1
  - May improve network resource allocation such as in MPEG streaming (I, P, B frames)
Discard Strategy

- Non-conforming cells from UPC test fed to this function
- Starts when network faces congestion, discards CLP=1 cells first
- Discard low priority cells to protect high priority cells
5. Traffic Shaping (TS)

- Recall: GCRA is a form of **traffic policing**
  - Flow of cells regulated
  - Cells exceeding performance level tagged or discarded
- **Traffic shaping** used to smooth traffic flow
  - Reduce cell clumping
  - Fairer allocation of resources
  - Reduced average delay
Token Bucket Algorithm for TS

Max # cells departing =
R = ρT + β
6. Explicit Forward Congestion Indication

- Essentially same as frame relay’s FECN and BECN binary schemes
- If node experiencing congestion, network sets forward congestion indication in cell headers (Payload Type field)
  - Tells end-users that congestion avoidance should be initiated in this direction
  - User may take action at higher level
Summary

- A VC declares its characteristics using traffic descriptors and request for certain QoS.
- When a VC passes CAC, the network monitors its behaviour using UPC, performs shaping (TB) and discards non-conforming cells (SCD).
- ATM uses an array of algorithms to provide reliable QoS performance:
  - It's complex and expensive.
- Next: IP QoS frameworks.