WHAT IS CONGESTION?

- congestion occurs when the number of packets being transmitted through the network approaches the packet handling capacity of the network
- congestion control aims to keep number of packets below a level at which performance falls off dramatically
- a data network is a network of queues
- generally 80% utilization is critical
- finite queues mean data may be lost
Queues at a Node

Interaction of Queues
IDEAL NETWORK UTILIZATION

EFFECTS OF CONGESTION - NO CONTROL
MECHANISMS FOR CONGESTION CONTROL

BACKPRESSURE
- if node becomes congested it can slow down or halt flow of packets from other nodes
  - cf. backpressure in blocked fluid pipe
  - may mean that other nodes have to apply control on incoming packet rates
  - propagates back to source
- can restrict to high traffic logical connections
- used in connection oriented nets that allow hop by hop congestion control (eg. X.25)
- not used in ATM nor frame relay
- only recently developed for IP
**CHOKE PACKET**

- a control packet
  - generated at congested node
  - sent to source node
  - eg. ICMP source quench
    - from router or destination
    - source cuts back until no more source quench message
    - sent for every discarded packet, or anticipated

- is a rather crude mechanism

**IMPLICIT CONGESTION SIGNALING**

- transmission delay increases with congestion
- hence a packet may be discarded
- source detects this implicit congestion indication
- useful on connectionless (datagram) networks
  - eg. IP based
    - TCP includes congestion and flow control - see chapter 17
- used in frame relay LAPF
**EXPLICIT CONGESTION SIGNALING**

- Network alerts end systems of increasing congestion
- End systems take steps to reduce offered load
- **Backwards**
  - Congestion avoidance notification in opposite direction to packet required
- **Forwards**
  - Congestion avoidance notification in same direction as packet required

**EXPLICIT SIGNALING CATEGORIES**

<table>
<thead>
<tr>
<th>Binary</th>
<th>Credit based</th>
<th>Rate based</th>
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<tbody>
<tr>
<td>a bit set in a packet indicates congestion</td>
<td>indicates how many packets source may send</td>
<td>supply explicit data rate limit</td>
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<tr>
<td></td>
<td>common for end-to-end flow control</td>
<td>nodes along path may request rate reduction</td>
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Traffic Management

**fairness**
- provide equal treatment of various flows

**quality of service**
- different treatment for different connections

**reservations**
- traffic contract between user and network
- excess traffic discarded or handled on a best-effort basis

Congestion Control in Packet Switched Networks

- send control packet to some or all source nodes
  - requires additional traffic during congestion
- rely on routing information
  - may react too quickly
- end to end probe packets
  - adds to overhead
- add congestion info to packets in transit
  - either backwards or forwards
ATM Traffic Management

- high speed, small cell size, limited overhead bits
- still evolving

- majority of traffic not amenable to flow control
- feedback is slow due to reduced transmission time compared with propagation delay
- wide range of application demands
- different traffic patterns
- different network services
- high speed switching and transmission increases volatility

Latency/Speed Effects

- consider ATM at 150Mbps
- takes $\sim 2.8 \times 10^{-6}$ seconds to insert a single cell
- time to traverse network depends on propagation delay and switching delay
- given implicit congestion control, by the time dropped cell notification has reached source, 7.2x10^6 bits have been transmitted
- if source and destination on opposite sides of USA, propagation time $\sim 48 \times 10^{-3}$ seconds
- assume propagation at two-thirds speed of light
CELL DELAY VARIATION

- for ATM voice/video, data is a stream of cells
- delay across network must be short
- rate of delivery must be constant
- there will always be some variation in transit
- delay cell delivery to application so that constant bit rate can be maintained to application

TIMING OF CBR CELLS

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

- \[ D(i) \] for \( i = 0, 1, 2, 3, 4 \)
- \[ V(i) \] for \( i = 0, 1, 2, 3, 4 \)
- Cell arrives late, discarded
- Slope = \( R \) cell/sec = 1/\( \delta \)
NETWORK CONTRIBUTION TO
CELL DELAY VARIATION

- in packet switched networks is due to queuing
delays and routing decision time
- in Frame relay networks is similar
- in ATM networks
  - less than frame relay
  - ATM protocol designed to minimize processing overheads at
    switches
  - ATM switches have very high throughput
  - only noticeable delay is from congestion
  - must not accept load that causes congestion

CELL DELAY VARIATION
AT THE UNI

- application produces data at fixed rate
- 3 layers of ATM processing causes delay
  - interleaving cells from different connections
  - operation and maintenance cell interleaving
  - if using synchronous digital hierarchy frames, these are
    inserted at physical layer
- cannot predict these delays
ORIGINS OF CELL DELAY VARIATION

ATM layer traffic and congestion control should support QoS classes for all foreseeable network services.

should not rely on AAL protocols that are network specific, nor higher level application specific protocols.

should minimize network and end to end system complexity.

TRAFFIC AND CONGESTION CONTROL FRAMEWORK
TRAFFIC MANAGEMENT AND CONGESTION CONTROL TECHNIQUES

ATM traffic techniques:
- resource management using virtual paths
- connection admission control
- usage parameter control
- selective cell discard
- traffic shaping

RESOURCE MANAGEMENT USING VIRTUAL PATHS

○ QoS parameters concerned with are:
  - cell loss ratio
  - cell transfer delay
  - cell delay variation
TIMINGS CONSIDERED

- timing intervals considered:
  - cell insertion time
  - round trip propagation time
  - connection duration
  - long term

- traffic control strategy then must:
  - determine whether a given new connection can be accommodated
  - agree performance parameters with subscriber

- now review various control techniques

RESOURCE MANAGEMENT USING VIRTUAL PATHS

- separate traffic flow according to service characteristics on a virtual path
  - user to user application
  - user to network application
  - network to network application

- QoS parameters concerned with are:
  - cell loss ratio
  - cell transfer delay
  - cell delay variation
CONFIGURATION OF VCCs AND VPCs

- All VCCs within VPC should experience similar network performance
- Options for allocation:
  - Aggregate peak demand:
    - Set VPC capacity to total of all peak VCC rates
    - Will meet peak demands, but often underutilized
  - Statistical multiplexing:
    - Set VPC capacity to more than average VCC rates
    - Will see greater variation but better utilization
CONNECTION ADMISSION CONTROL

- first line of defense
- user specifies traffic characteristics for new connection (VCC or VPC) by selecting a QoS
- network accepts connection only if it can meet the demand and maintain QoS

**traffic contract parameters**
- peak cell rate (PCR)
- cell delay variation (CDV)
- sustainable cell rate (SCR)
- burst tolerance

TRAFFIC RATE MANAGEMENT

- must discard frames to cope with congestion
  - arbitrarily, no regard for source
  - no reward for restraint so end systems transmit as fast as possible
  - committed information rate (CIR)
    - data in excess of this liable to discard
    - not guaranteed in extreme congestion situations
    - aggregate CIR should not exceed physical data rate
- committed burst size
- excess burst size
USAGE PARAMETER CONTROL (UPC)

- UPC function monitors a connection to ensure traffic obeys contract
- purpose is to protect network resources from overload by one connection
- done on VCC and VPC
- peak cell rate and cell delay variation
- sustainable cell rate and burst tolerance
- UPC discards cells outside traffic contract

CELL RATE ALGORITHM

- traffic flow is compliant if the peak rate of cell transmission does not exceed the agreed peak cell rate
- cell rate algorithm:

  | known as the *leaky bucket algorithm* | compliant cells are passed on |
  | defines traffic compliance            | noncompliant cells are discarded |
SELECTIVE CALL DISCARD

- when network at point beyond UPC discards (CLP=1) cells
- aim to discard lower-priority cells when congested to protect higher-priority cells
  - note. can’t distinguish between cells originally labeled lower priority, versus those tagged by UPC function

TRAFFIC SHAPING

- UPC provides a form of traffic policing
- can be desirable to also shape traffic
- smoothing out traffic flow
- reducing cell clumping
- token bucket
TOKEN BUCKET FOR TRAFFIC SHAPING

GUARANTEED FRAME RATE (GFR) AS SIMPLE AS UBR FROM END SYSTEM VIEWPOINT
- Places modest requirements on ATM network
- End system does no policing or shaping of traffic
- May transmit at line rate of ATM adaptor
- No guarantee of delivery
  - So higher layer (e.g., TCP) must do congestion control
- User can reserve capacity for each VC
  - Ensures application can send at min rate with no loss
  - If no congestion, higher rates maybe used

GFR TRAFFIC MANAGEMENT

Diagram showing token bucket flow with rate \( \rho \) and capacity \( \beta \), and frame rate \( K \) for arriving and departing cells.
FRAME RECOGNITION

- GFR recognizes frames as well as cells
- When congested, network discards whole frame rather than individual cells
- All cells of a frame have same CLP bit setting
- CLP=1 AAL5 frames lower priority (best effort)
- CLP=0 frames minimum guaranteed capacity

GFR CONTRACT PARAMETERS

- Peak cell rate (PCR)
- Minimum cell rate (MCR)
- Maximum burst size (MBS)
- Maximum frame size (MFS)
- Cell delay variation tolerance (CDVT)
COMPONENTS OF GFR SYSTEM SUPPORTING RATE GUARANTEES

TAGGING AND POLICING

- discriminates between frames that conform to contract and those that don’t
- set CLP=1 on all cells in frame if not
  - gives lower priority
- maybe done by network or source
- network may discard CLP=1 cells
  - policing
BUFFER MANAGEMENT

- deals with treatment of buffered cells
- congestion indicated by high buffer occupancy
- will discard tagged cells in preference to untagged cells
  - including ones already in buffer to make room
- may do per VC buffering for fairness
- cell discard based on queue-specific thresholds

SCHEDULING

- preferential treatment to untagged cells
- separate queues for each VC
- make per-VC scheduling decisions
- enables control of outgoing rate of VCs
- VCs get fair capacity allocation
- still meet contract
GFC CONFORMANCE DEFINITION

- UPC function monitors each active VC to ensure traffic conforms to contract and tags or discards nonconforming cells.
- Frame conforms if all cells conform.

GFR VC FRAME CATEGORIES

- Nonconforming frame:
  - Cells of this frame will be tagged or discarded.
- Conforming but ineligible frames:
  - Cells will receive a best-effort service.
- Conforming and eligible frames:
  - Cells will receive a guarantee of delivery.
QoS Eligibility Test

- Two stage filtering process
  - A frame is tested for conformance to contract
    - If not, may discard or tag
    - Set upper bound & penalize cells above upper bound
    - Do expect attempt to deliver tagged cells
  - Determine frames eligible for QoS guarantees
    - Under GFR contract for VC
    - Set lower bound on traffic
    - Frames in traffic flow below threshold are eligible

GFR VC Frame Categories

- Nonconforming frame
  - Cells of this frame will be tagged or discarded
- Conforming but ineligible frames
  - Cells will receive a best-effort service
- Conforming and eligible frames
  - Cells will receive a guarantee of delivery

- Form of cell rate algorithm is used
SUMMARY

➢ congestion effects
  • ideal and practical performance

➢ congestion control
  • backpressure, choke packet, implicit/explicit

➢ traffic management
  • fairness, QoS, reservations

➢ ATM traffic management

➢ ATM-GFR traffic management
  • tagging, policing, buffer, scheduling

➢ QoS eligibility testing