Max min fairness and congestion control in the context of bit-rate oriented quality model

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Frame Relay: characteristics

- Packet switching with virtual circuit service
  - Label named DLCI: Data Link Connection Identifier
  - Virtual circuits are bi-directional
- “Connection” is associated with the virtual circuit
- No error control (DL-control is not used even at the edge)
- No flow control
- LAP-F protocol
- Packet size:
  - variable up to 4096byte
- Mainly thought for data traffic

LAPF packet

- ADDRESS field contains the DLCI (Data Link Connection Identifier) and some additional bits

FLAG
ADDR (MSB)
ADDR (LSB)
control
Information
CRC (MSB)
CRC (LSB)
FLAG

DL-CORE
DL-CONTROL

ADDRESS field

- DLCI: Data Link Connection Identifier
- FECN/BECN: forward/backward explicit congestion notification
- DE: discard eligibility
- C/R: command/response
- D/C: DLCI or DL-CORE
- EA: extension bit

Default format (2 byte)

upper DLCI			C/R	EA 0
lower DLCI	FECN	BECN	DE	EA 1

3 byte format

upper DLCI			C/R	EA 0
DLCI	FECN	BECN	DE	EA 0
lower DLCI or DL-CORE control			D/C	EA 1

4 byte format

upper DLCI			C/R	EA 0
DLCI	FECN	BECN	DE	EA 0
DLCI				EA 0
lower DLCI or DL-CORE control			D/C	EA 1

Frame Relay: user-network interface

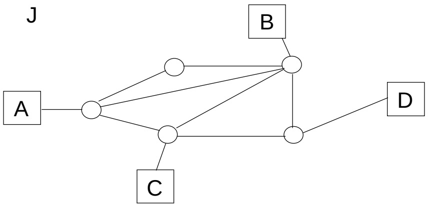
- Negotiable parameters, a-priori, on a contract basis:
  - CIR (Committed Information Rate) [bit/s]
  - CBS (Committed Burst Size) [bit]
  - EBS (Excess Burst Size) [bit]
- CIR: guaranteed bit rate (throughput)
- CBS: amount of data the network is willing to accept over a measurement period T
- EBS: amount of excess data the network may transfer over T. Packets are marked with the DE bit set to 1
- Data exceeding CBS+EBS are directly discarded at network access

Frame Relay: definition of the measurement interval T

CIR	CBS	EBS	T
> 0	> 0	> 0	CBS/CIR
> 0	> 0	= 0	CBS/CIR
= 0	= 0	> 0	EBS/Access Rate

Frame Relay: resource allocation

- $\Sigma_A CIR_{A,J} \leq ACCESS\_RATE_A$
  - where A,J refers to the VC from node A to node J



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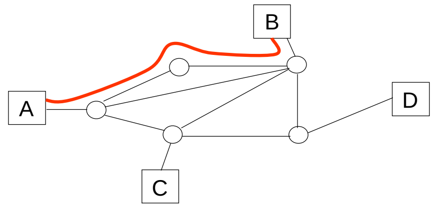

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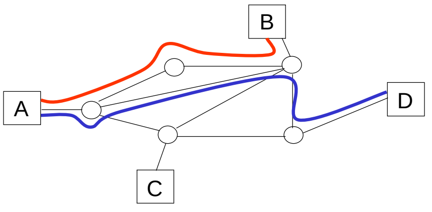

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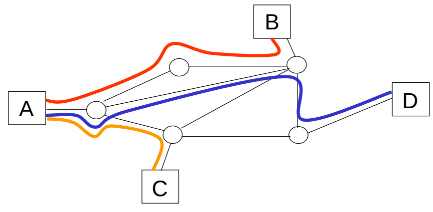

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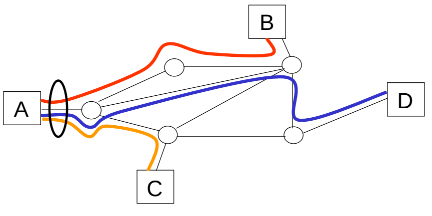
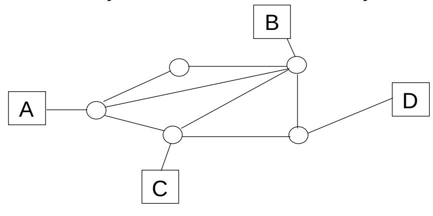


Frame Relay: resource allocation

- $\Sigma_{LINK} CIR_{i,j} \leq LINK\_SPEED \quad \forall$ links
  - where i,j refers to the VC from i to j



Frame Relay: resource allocation

- $\sum_{LINK} CIR_{i,j} \le LINK\_SPEED \quad \forall$ links
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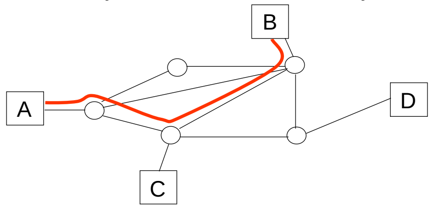

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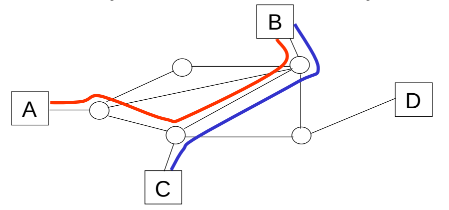

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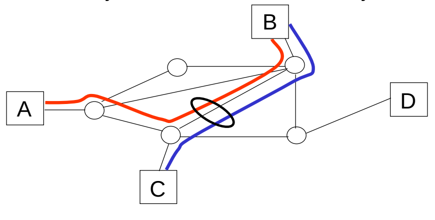


Frame Relay: algorithms

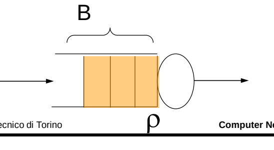
- Policing, or conformance verification
  - Leaky Bucket
  - Token Bucket
- Congestion control
  - backward
  - forward

Conformance verification

- Basic idea
  - If a packet reaches the network access and it is conformant to the CBS constraint over T, it is transmitted at high priority with DE=0
  - If a packet reaches the network access and it is not conformant to CBS over T but it is conformant to CBS+EBS over T, it is transmitted at low priority with DE=1
  - If a packet reaches the network access and it is not conformant to CBS+EBS over T, it is discarded
- Same algorithms can be used to do shaping
  - Traffic adaptation to make it conformant
  - Delay instead of marking/dropping

Leaky Bucket

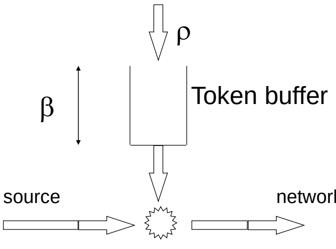
- As a traffic regulator
  - User traffic entering the buffer is transmitted at a maximum CBR rate equal to ρ
  - User traffic exceeding the buffer size B is dropped
  - Any source becomes a CBR source at rate ρ
    - If packet size is fixed
- When using to do conformance verification, if a packet arrives earlier than it should, with respect to ρ, drop it



Leaky Bucket

- Buffer size B is not a critical parameter
  - we can assume infinite buffer size
- Amount of data sent over a period T is $\leq T\rho$
- Dimensioning of parameter ρ for VBR traffic with peak B_P and average B_M
  - $\rho \cong B_M$: too much traffic could be discarded
  - $\rho \cong B_P$: waste of link bit rate, largely underutilized
- Traffic regulator which does not admit any burstiness

Token Bucket*

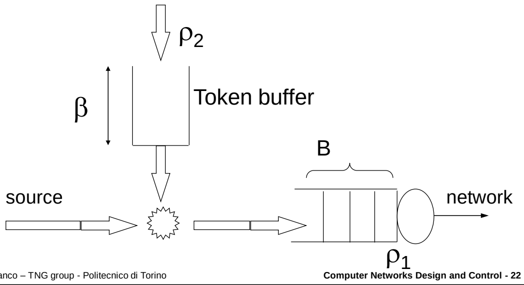


Token Bucket

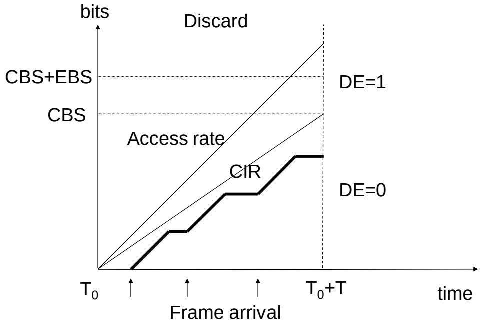
- Tokens are generated at a fixed rate ρ
- A maximum number of β tokens can be stored in the token buffer
  - Permits some burstiness
- User data are sent over the network only if there is a token available in the token buffer
- Maximum amount of data send over a period T is $\leq T\rho + \beta$
- The source becomes a VBR source with
  - $B_M \approx \rho$
  - B_P = access rate
  - Burst duration $\approx \beta$
- Access to the network can be further regulated with a cascading leaky bucket to limit B_P

Token Bucket+ Leaky Bucket

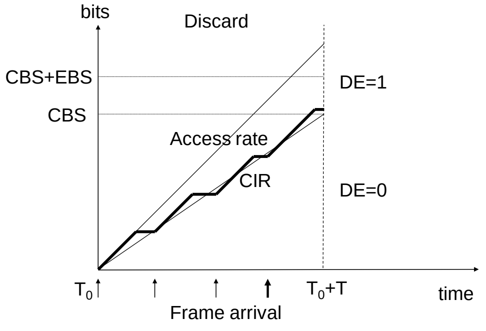
- Regulates average rate ρ_2, peak rate ρ_1, burst duration β



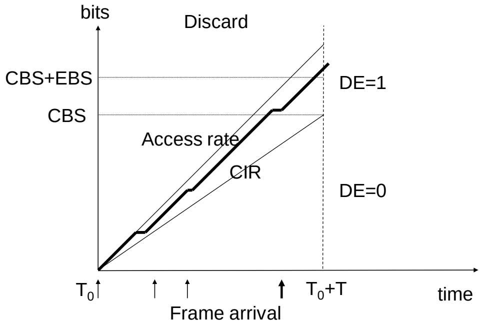
All packets conformant to CBS



One packet at low priority

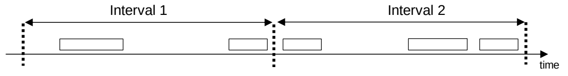


One packet discarded



Measurement problems

- Measuring a rate of an asynchronous packet flow may be complex
- Simple solution:
  - Measure over fixed length intervals



  - When does the interval starts? Border effect between adjacent intervals?

Measurements problems

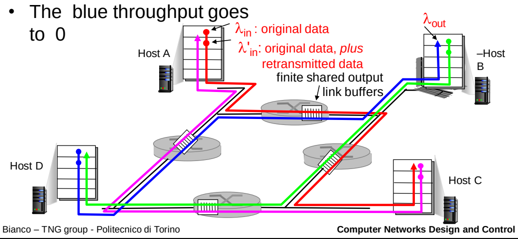
- Better solution is a temporal sliding window of T seconds
  - When a packet arrives, the rate is measured accounting for the amount of byte received during the last T seconds
  - Difficult to implement (necessary to remember packet arrival times)
- It is possible to exploit a fluid approximation
  - New rate R estimate at each packet arrival
  - At packet arrival, we assume that the flow has transmitted R*T byte in the last T seconds and the estimate of R is updated

Congestion*

- Informally
  - too many sources sending too much data, too fast for network to handle
- More formally
  - Average input rate larger than average output rate
- Congestion signal
  - long delays (queueing in router buffers)
  - lost packets (buffer overflow at routers)
- Effect
  - Retransmissions (sometimes un-needed)
  - Reduced throughput

Effect of congestion

- Multihop paths
- As red traffic increases, all arriving blue pkts at upper queue are dropped
- The blue throughput goes to 0
- When packet dropped, any "upstream transmission capacity used for that packet was wasted!



Solutions?*

- Increase the buffer size
  - Buffers helps in solving
    - Contentions
    - Short term congestion only
  - For permanent overload, the excess traffic is lost, regardless of the buffer size
- Increase the link speed
  - We may even create worse congestion
- Increase processing speed
  - We will transfer more packets, possibly exacerbating the congestion
- Congestion is created by an excess of traffic
  - To solve it, we need to reduce the input traffic

Approaches to congestion control*

- Drop based
  - Network nodes only drop packets when needed
  - Relies on end-to-end (transport) protocols to solve the congestion
- Credit based
  - Network nodes provide credits to upstream nodes
    - Backpressure
- Signalling based (to users)
  - Network nodes detect congestion and signal to users
    - Via a single or few bit (forward/backward)
    - Via explicit rate computation
- In all cases, rely on cooperation

Features of the approaches*

- Drop
  - Easy
  - No need to be flow aware
- Credit
  - Very complex
  - Need to be flow aware to avoid blocking a link
- Signalling
  - Can trade complexity vs effectiveness
  - Can be either flow unaware or flow aware

Frame Relay: congestion

- Summation of CIR over all virtual circuits on each link may exceed the available bit rate over a link (overbooking)
  - Creates congestion, potentially a long-term congestion
- Traffic burstiness may create congestion (typically short term congestion)
- Need to control congestion?
  - X.25 (ISDN) may exploit link-by-link (hop-by-hop) flow control (and internal switch backpressure) to control (un-fairly) congestion
  - In Internet the congestion control is delegated to hosts running TCP, the network simply drops packets
  - Frame relay, which does not implement flow control, uses explicit signaling from network nodes to signal congestion to users through FECN and BECN bits

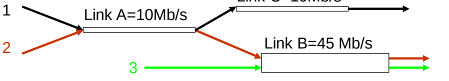
Congestion control in Frame Relay

- Flow control is not supported in Frame Relay
- The network is unprotected against congestion
  - Only protection mechanism is packet discarding
- Congestion should not occur if sources are sending at CIR!
- When a switch (network node) establishes that congestion has occurred, to signal congestion it sets one among two bits:
  - FECN (Forward technique)
  - BECN (Backward technique)

Congestion control: goals

- Avoid packet loss
- Constraints?
  - Maximum network utilization
  - Fairness
  - Often in contrast
- Simple case: all flows are alike
  - Fairness means to provide the same set of resources to all flows
  - Over a single bottleneck the problem is trivial
  - Network wide problem

Congestion control: an example



- Maximize the bit rate received by each flow
  - Flow 1: 5 Mb/s
  - Flow 2: 5 Mb/s
  - Flow 3: 40 Mb/s
- Maximize the overall network utilization
  - Flow 1: 10 Mb/s
  - Flow 2: 0 Mb/s
  - Flow 3: 45 Mb/s

Max-min fairness*

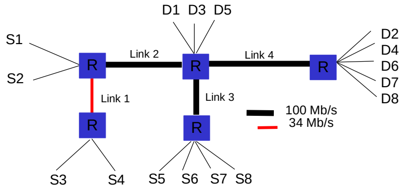
- One possible definition of fairness
- A bit rate allocation is defined as max-min if
  - It maximizes the bit rate allocation to flows who receive the minimum allocation
- Property:
  - A max-min allocation is such that, to increase the bit rate allocated to a flow, it is necessary to decrease the bit rate allocated to another flow which is already a smaller or equal bit rate
  - In other words, no bit rate increase can be obtained without penalizing flows already receiving a smaller allocation
- A max-min allocation cannot be obtained with local assignments
  - A global network view is needed

Max-min fairness: algorithm*

- Given: topology, link capacity, flows and flow routing
- 1) The algorithm starts with a 0 allocation to all flows, each flow is marked as unsatisfied
- 2) The allocation of all unsatisfied flows is increased by the same, small, quantity, until a bottleneck link is saturated
- 3) All bottlenecked flows are saturated, thus, cannot receive a larger allocation
  - Bottlenecked flows are marked as satisfied
- 4) Goto 2, until all flows are bottlenecked and satisfied
- Must re-run for any topology or flow modification

Max-min fairness: example

- Problem: find a fair bandwidth allocation to flows (Fi: Si->Di), according to the max-min paradigm



Max-min fairness: example

- Order in which links are saturated
  - L1, L4, L3, L2
- Solution: fair max-min allocation
  - F1: 45.25 Mbps
  - F2 : 20.75 Mbps
  - F3 : 17 Mbps
  - F4 : 17 Mbps
  - F5 : 37.75 Mbps
  - F6 : 20.75 Mbps
  - F7 : 20.75 Mbps
  - F8 : 20.75 Mbps

Forward congestion

- When a switch detects congestion, it sets the FECN bit to 1 on all arriving packets sharing the congested buffer
  - Congestion signaled to all congested VCs
- When the congestion indication reaches the receiver, it is redirected to the transmitter on a data flow traveling in the opposite direction
- The transmitter reduces the transmission speed according to a standardized algorithm
- Properties:
  - Relatively slow
  - Simple to implement
  - No additional traffic is created, if there is a data flow from receiver to transmitter (normally at least ACKs are sent)
  - «Automatically» signaling only to active DLCIs

Backward congestion

- When a switch detects congestion, it sets the BECN bit to 1 on all packets belonging to congested VCs
  - These packets are not stored in the congested buffer!
  - Ad-hoc signaling packets may be generated by the switch if no data traffic is flowing in the opposite direction
- The transmitter reduces the transmission speed according to a standardized algorithm when it detects packets with BECN=1
- Properties:
  - Relatively fast
  - Complex: need to store a list of congested (active?) DLCI on the forward path and to wait (or to create after a timeout) packets with the proper DLCI on the backward path

Source behaviour: FECN

- The FECN technique is based on the idea that congestion phenomena are relatively slow
- Transmitter
  - Start transmitting at a speed equal to CIR
  - Computes the percentage of LAP-F frames received with a FECN bit set to 1 ($FECN_1$) over a pre-determined time interval
    - If $FECN_1$ is >50%, the emission rate is reduced
    - If $FECN_1$ is <50%, the emission rate is incremented

Source behaviour: FECN

- Measuring interval δ=2RTT
- Rate based transmitter:
  - $R_{INITIAL} = CIR$
  - if $FECN_1 > FECN_0$
    - $R_{New}=0.875R_{Old}$
  - if $FECN_1 < FECN_0$
    - $R_{New}=1.0625R_{Old}$
  - If not transmitting for T, restart from $R_{INITIAL}$
- Window based transmitter:
  - $W_{INITIAL} = 1$
  - if $FECN_1 > FECN_0$
    - $W_{New}=0.875W_{Old}$
  - if $FECN_1 < FECN_O$
    - $W_{New} = W_{Old}+1$

Source behaviour: BECN

- The BECN technique is based on the idea that congestion phenomena are fast
  - Instantaneous reaction (not based on δ=2RTT)
- $R_{INITIAL} = CIR$
- If a single frame with BECN=1 is received:
  - $R_N=1/8R_O$
- If a single frame with BECN=0 is received:
  - Increase rate

Congestion control: issues*

- Fairness among flows
  - More active flows receive more congestion signals
    - May be ok, since are creating more congestion, but is it max-min fair?
  - Temporarily inactive flows?
- Signaling frequency
  - Any reaction to congestion signals is constrained by the flow RTT
  - It would make sense to adapt the (congestion) signaling frequency to flow RTT
    - Practically impossible to know flow RTT in network nodes (may be done at the tx/rx side)
  - Connections with shorter RTTs react faster
    - Both when increasing and decreasing rate
- When congestion is detected (set up congestion bit in the header)
  - Operate on packet reaching the buffer or leaving the buffer?

Congestion control: issues*

- How to detect congestion?
  - Measure ingress flow speed in each buffer
    - Over which time interval?
    - Worth complexity given the binary feedback available?
      - Always balance complexity, performance, signaling capability
    - Operates on a flow basis or on traffic aggregate?
  - Threshold on buffer occupancy
    - Instantaneous buffer occupancy
      - Fast, but unstable
      - Typically exploits some hysteresis to avoid switching between congested/non-congested state
    - Average occupancy over a time-sliding measurement window
      - How the window size should be determined?
      - More stable, but slower in reaction
    - Occupancy derivative
      - More precise than occupancy alone
        - » Buffer occupancy of 100 packets should be treated differently if the "previous" buffer occupancy was 150 or 50 packets
      - Need to define time interval over which evaluate the derivative
    - Threshold value?
      - Close to zero occupancy to exploit most of the buffer size
      - Enough space below threshold to allow for synchronous arrivals and avoid unneeded congestion signals

Congestion control: issues*

- Buffer sizing?
  - Buffer above threshold should increase proportionally to
    - Number of connections involved in congestion
    - Connection RTTs
    - Need to buffer in-flight packets
    - Connection rate
- Always pay attention to
  - The scenario in which algorithms are compared
    - Network topology (often single bottleneck node examined)
    - Number of flows
    - Flow behavior
  - Difficulty in properly setting parameters
    - If choosing wrong values what happens?
    - How difficult is to set up proper values?
    - Algorithm robustness to parameter setting
  - Algorithm complexity w.r.t. performance gain
- All parameters (threshold, measurement window, buffer size) could be set off-line or modified at run time
  - Run time modification is worth the effort?