Qos in B-ISDN (ATM) networks

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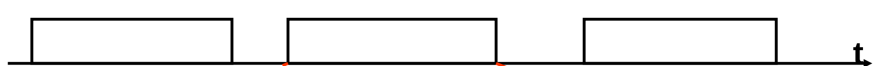
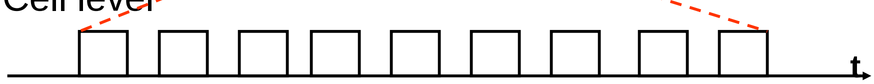
Layered model

- Used for traffic characterization and QoS definition
- Call level



- Burst level

- Cell level



Call level

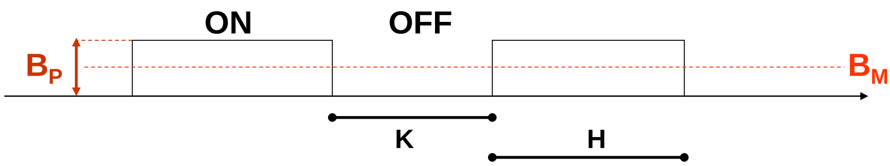
- Long-term temporal dynamics
- The traffic occupies network resources for the full call duration
- Traffic characterization
  - Call attributes
  - Call model
- Quality of service

Call level

- Call attributes
  - Type of request (on demand, permanent, semi-permanent)
  - Configuration (point-to-point, multipoint, broadcast)
  - Number of connections opened in the two directions
  - VPC / VCC
  - Traffic contract element for each connection
  - Signaling protocol used at network ingress
  - Supplementary services
- Traffic characterization
  - Call arrival process – stochastic description
  - Call duration – stochastic description
- Quality of service
  - Control plane
    - Post-selection delay
    - Answering signal delay
    - Connection closing delay
  - Point-to-point blocking probability

Burst level

- Medium-term temporal dynamics
- ON-OFF periods



- Traffic characterization:
  - OFF periods stochastic duration
  - Burst length stochastic duration
  - Bit rate during ON periods (peak rate assumed)
- Quality of service undefined

Burst level

- Burstiness: $\beta = \frac{H+K}{H}$
- Activity coefficient: $\alpha = \frac{1}{\beta}$
- Average bit rate: $B_M = \alpha B_P$
- Bit rate variance: $\sigma^2_B = B_M(B_P - B_M)$

Cell level

- Traffic characterization:
  - Inter-arrival time distribution
  - Distribution of the number of cells generated in a measurement period T
  - Often less information is accepted (also for complexity reasons)
    - Inter-arrival expected value and variance
    - From the average inter-arrival time the average bit-rate can be computed
- Quality of service:
  - reliability
    - Cell loss probability
    - Cell error probability
    - Cell mis-insertion probability (cells belonging to other VC erroneously inserted in the current VC)
  - Expected value, variance and maximum cell delay

Standard

- A traffic contract was defined
  - Traffic characterization
    - Accurate
    - Uniquely verifiable
    - Simple, to be useful for the computation of network resources that should be allocated to the connection
  - QoS guarantee
    - Parameters defined in the ITU-T I.356 reccomendation

Standard: traffic characterization

- Identification of cell flows within a connection
- Definition of traffic intrinsic parameters
  - Traffic nominal characteristics in absence of interfering traffic
- Tolerance: accepted variations with respect to nominal characteristics
  - CDVT: Cell Delay Variation Tolerance
- Conformance definition
  - GCRA algorithm (Generic Cell Rate Algorithm)

Standard: traffic characterization

- Cell flows generated by the user, excluding OAM e RM cells generated by switches (it is the set of cells whose conformance to the nominal parameter will be verified):
  - Aggregated flow
  - Data cell flow (no RM and OAM)
  - High priority data cell flow (CLP=0)
  - OAM cell flow
  - RM cell flow
  - Data + OAM cell flow
  - High priority data cell (CLP=0) + OAM flow

Standard: traffic characterization

- Definition of traffic intrinsic parameters
  - PCR (Peak Cell Rate)
    - Inverse of the minimum cell inter-arrival among two adjacent cells
  - SCR (Sustainable Cell Rate)
    - Inverse of the average inter-arrival time among two adjacent cells
  - IBT (Intrinsic Burst Tolerance)
    - Maximum ahead time for which a cell can be transmitted with respect to the nominal arrival time determined by the SCR value
  - MBS (Maximum Burst Size)
    - Maximum size of a cell burst, a group of cells that can be transmitted at PCR
    - MBS = 1 + IBT/(1/SCR-1/PCR)
    - IBT= (MBS-1)(1/SCR-1/PCR)

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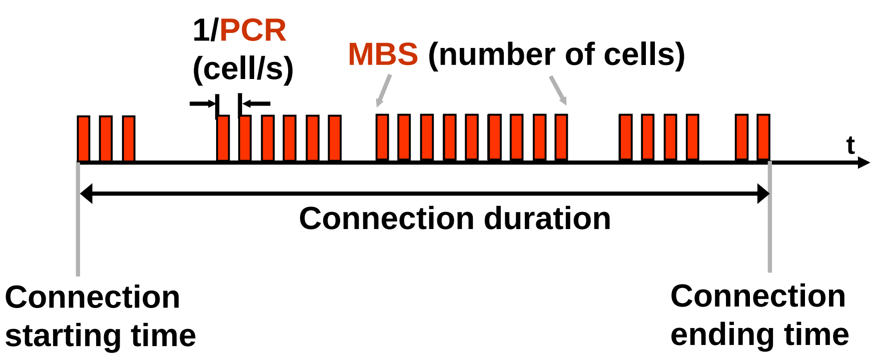
Standard: traffic characterization



SCR = number of cells/ connection duration

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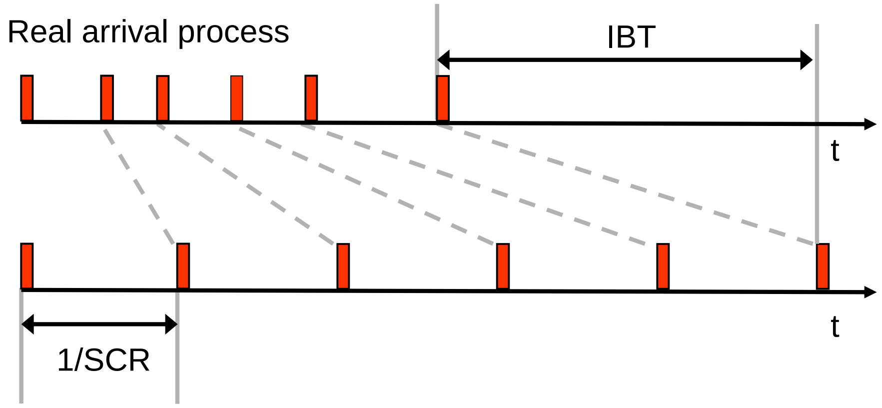
Relation between SCR and IBT

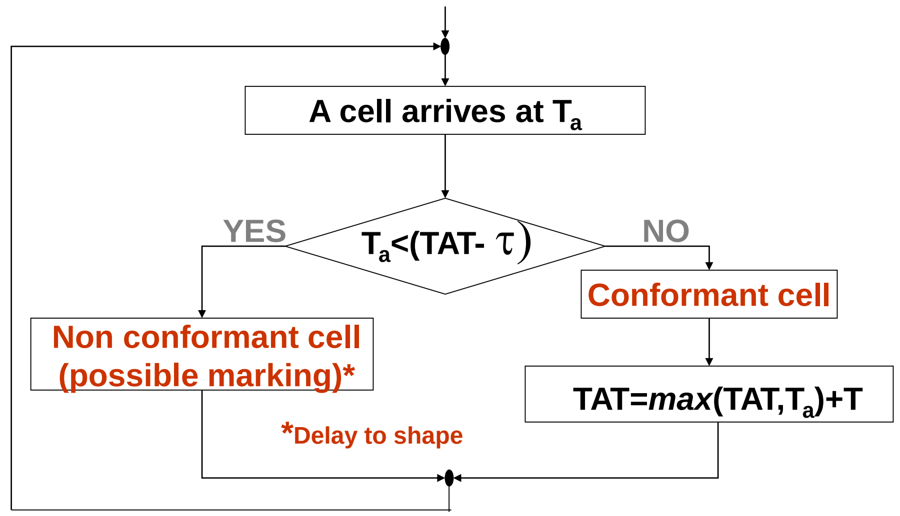


Ideal arrival process at SCR, used as a reference

GCRA: Generic Cell Rate Algorithm

- Standard algorithm for conformance verification (policing) and for traffic adaptation (shaping)
- PARAMETERS:
  - T = nominal cell inter-arrival time
  - τ = tolerance or maximum accepted variation with respect to nominal spacing
- VARIABLES:
  - T_a = real cell arrival time
  - TAT= theoretical cell arrival time

GCRA algorithm: flow diagram



Conformance verification

- Statistical multiplexing stages (switching nodes) modify the original traffic pattern due to unpredictable queuing delays
  - Cell Delay Variation Tolerance (over SCR and/or PCR)
- CDVT
  - Maximum acceptable ahead time at an interface with respect to the expected arrival time
  - Similar to IBT, but to cope with multiplexing delays, not to allow some variability in the user flow
- If GCRA is checking the PCR
  - T=1/PCR $\tau=CDVT_{PCR}$
- If GCRA is checking SCR
  - T=1/SCR $\tau=$ IBT + $CDVT_{SCR}$

Quality of service: standard ITU-T I.356

- CTD (Cell Transfer Delay)
  - Average time between the transmission of the first bit and the reception of the last bit
- 2-pt CDV (Two point Cell Delay Variation)
  - Variation of cell delivery time
  - Difference between the 10^{-8} inferior and superior quantile of CTD
- CLR (Cell Loss Ratio)
  - Cell loss probability
  - Ratio between lost cells and transmitted cells
  - CLR_0 e CLR_{0+1}

Quality of service: standard ITU-T I.356

- CER (Cell Error Rate)
  - Ratio between cells with detected errors and the total number of cells
- CMR (Cell Misinsertion Rate)
  - Ratio between erroneously received cells (cells belonging to other VCs) and the total number of received cells
- SECBR (Severely Errored Cell Block Ratio)

Quality of service classes

- Defined through some parameters:
  - CLR
  - CDV
- 4 QOS service classes standardized by ITU-T to satisfy 4 main types of user services:
  - Class 1: STRICT (CDV, CLR_{0+1})
  - Class 2: TOLERANT (CLR_{0+1})
  - Class 3: LIMITED (CLR_0)
  - Class U: BEST EFFORT (does not admit negotiation of any parameter)

Transfer modes

- ITU-T: internationally recognized standardization body
- ATM forum: de-facto standardization body
- Transfer modes defined
  - By ITU-T as ATC (ATM Transfer Capability)
  - By ATM Forum as Service Class
- Transfer mode distinguished through definition of:
  - Cell flows to which guarantees are provided
  - Parameters to characterize flows
  - Conformance verification applied to flows
  - Adopted control functions

Transfer modes

- Do not define QoS requirements
  - Each transfer mode can be associated (almost) with any negotiable QoS
- Five main transfer modes:
  - CBR/DBR: Constant/Deterministic Bit Rate
  - VBR/SBR: Variable/Statistical Bit Rate
  - UBR: Unspecified Bit Rate
  - ABR: Available Bit Rate
  - ABT: ATM Block Transfer
- ABT ed ABR use RM cells to control flow cell emission rate

Transfer modes

- Define ATM layer services and the associated QoS
- To each service, a set of admissible QoS parameters values is defined
- Network operators may add other QoS parameter values beyond the standardized ones

Transfer modes: DBR

- Characterization:
  - PCR over aggregated flow (data+OAM+RM) or
  - PCR over data+OAM flow
  - Does not use the CLP bit
- Offers static bit rate equal to the negotiated PCR (possibly more than PCR)
- Use a single instance of GCRA
- Isochronous services or fixed bit rate services
- CAC over B_P (or B_{eq})
- Associated with service class 1

Transfer modes : SBR

- Characterization (3 flavor):
  - SBR1: PCR, SCR and MBS over aggregated flow
  - SBR2: PCR over all data cells (0+1), SCR (0), MBS (0). Tagging over non conformant cells not admitted
  - SBR3: like SBR2, but tagging of non conformant cells is admitted
- Offer a variable bit rate, normally ranging between PCR e SCR to satisfy source needs, not network needs
- Always two instances of GCRA are used
- Isochronous service or data services with variable bit rate
- CAC over B_P, B_M, B_{eq} or exploiting measurements
  - Allocated bandwidth must be guaranteed through a proper scheduling algorithm
- Typically, loss rate and delays are negotiated

Transfer modes: UBR

- Standardized only by ATM Forum
  - ITU-T: UBR can be obtained as DBR with U class of service
- Characterization:
  - PCR over aggregated flow
- No conformance definition
- No bit rate allocation, no QoS guarantees on delays and loss probabilities
- Switches exploit cell discarding techniques
  - To reduce segmentation negative effects
    - More losses
    - “Useless” traffic transported
  - Loss priority in buffers

UBR: cell discarding

- Selective Cell Discarding:
  - Drop cells belonging to a (higher layer) packet/message for which at least another cell was already dropped
  - Packet identification is easy for AAL5
  - Some “useless” traffic due to head of packets (already transmitted cells)
- Early Packet Discarding:
  - Discard full messages (entire set of cells) when the buffer occupancy exceeds a given threshold
  - Higher layer packets segmented in cells are either entirely transferred or dropped,
    - When the buffer occupancy exceeds the threshold, cells belonging to packets already partially transmitted are stored and later transmitted, cells belonging to new packets are dropped
    - Need to set up threshold value properly depending on (average?) packet size and buffer size

Other cell discarding mechanisms

- Use of the EFCI bit in the cell header PT field:
  - Used to indicate congestion to protocol layers higher than ATM
  - It is assumed that higher layer protocols react to congestion signals
- Cell discarding based on priority:
  - If buffer size occupancy becomes critical (e.g.: full buffer or buffer occupancy over threshold) low priority cells (CLP=1) are discarded
  - Divided in two categories:
    - Non protective
      - High priority may suffer losses due to low priority packets previously stored
    - Protective (full separation between high and low priority)
      - Need to control cell generation process

Transfer modes: ABR

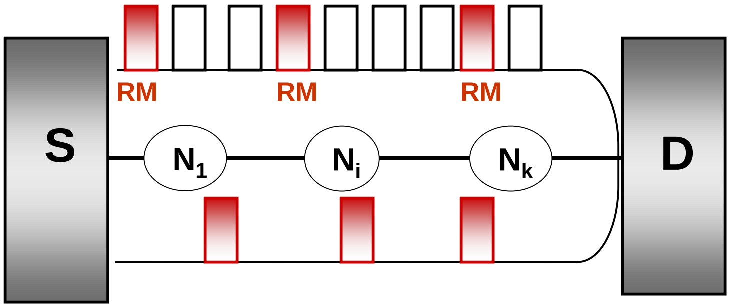
- ABR (Available Bit Rate) offers an allocated bit rate between PCR and MCR depending on network resources availability; goals
  - Full bit rate utilization
  - Fair resource partitioning
- The network explicitly signals to sources the transmission bit rate
- It provide small CLR (ideally zero CLR) if source adapt their rate to network indication

Transfer modes: ABR

- Characterization:
  - PCR over aggregate flow (data+OAM+RM)
  - MCR (Minimum Cell Rate) over aggregated flow (data+OAM+RM)
- Conformance definition based on GCRA with parameter T adapted to network signals
- Source behavior completely specified in standards
- Node algorithms, as usual, not standardized

Transfer modes: ABR

- Uses in-band RM cells (forward e backward) to obtain a continuous control of source emission bit rate (cooperating sources)



S: generates RM cells

D: retransmits received RM cells

N_i: reads and writes RM cells

ABR: source behavior

- An ABR source
  - Starts transmission at a negotiated rate (ICR)
  - Periodically inserts RM forward cells in cell flow
  - When it receives an RM backward cell it adapts the transmission rate to the minimum value contained in the cell
  - If no RM backward cells are received, the source slows down until it stops
  - If the source is silent more than a given period, it starts transmitting at the negotiated rate

ABR: node behavior

- Three possibility to control source emission rate:
  - EFCI (Explicit Forward Congestion Indication):
    - Equivalent to the congestion notification used in frame relay
    - 1 control bit to signal congestion
    - It is the simplest but less efficient mechanism
    - Destination translate EFCI bits into a CI bit in backward RM cells
  - RRM (Relative Rate Marking): nodes send on backward RM cell a ternary information through two bits (CI,NI) setting (increase rate, keep rate, decrease rate)
  - ER (Explicit Rate): nodes send on backward RM cells the rate at which a source can send cells
- Nodes overwrite info in RM cells only if constraining more source behavior

ABR: node behavior

- When adopting EFCI and RRM schemes, nodes normally control congestion by monitoring buffer occupancy
- Threshold mechanism:
  - Single FIFO, occupancy based (positional)
    - Hysteresis
  - One FIFO per VC
  - Derivative
  - Integrative
- ER: nodes control congestion measuring traffic load (background, ABR) and the number of active ABR connections

ABR: RM cell main fields

- Protocol type (ABR, ABT)
- Direction (Forward, Backward)
- NI (No-Increase), CI (Congestion Indication) bits
- ECR: Explicit Cell Rate
- CCR: Current Cell Rate
- MCR: Minimum Cell Rate
- ….

ABR: some parameters

- Parameters negotiated when opening the VC
- PCR: Peak Cell Rate
- MCR: Minimum Cell Rate
- ICR: Initial Cell Rate
  - Source start sending at ICR. Ranges between PCR and MCR
- RIF: Rate Increase Factor
  - Negative power of 2, referring to PCR
- RDF: Rate Decrease Factor
  - Negative power of 2, referring to CCR
- TBE: Transient Buffer Exposure
  - Amount of data that can be transmitted without receiving backward RM cells

ABR: RRM

- Two control bits:
  - **CI** (Congestion Indication)
  - **NI** (Not Increase)

CI	NI	
0	0	**Increase**
0	1	**Keep**
1	-	**Decrease**

With respect to CCR (Current Cell Ratio)

- Two parameters are negotiated: RDF e RIF (Rate Decrease/Increase Factor)
- To increase rate: CCR=CCR+PCR·RIF
- To decrease rate: CCR=CCR·(1-RDF)
- Nodes cannot flip to 0 a bit set to 1 by other nodes!

ABR: example of an RRM algorithm

- Not standardized
- Measure Q_i, queue length at i, and $D(Q_i)= Q_{i-} Q_{i-1}$
- Define two thresholds: H, L, with L<H
- Positional control
  - $Q_i<L$ NI=O CI=0
  - $L<Q_i<H$ NI=1 CI=0
  - $H<Q_i$ CI=1
- Positional - Derivative control
  - $\forall Q_i$ $D(Q_i)<-\beta$ NI=O CI=0
  - $\forall Q_i$ $\beta<D(Q_i)$ CI=1
  - $Q_i<L$ $-\beta<D(Q_i)< 0$ NI=O CI=0
  - $Q_i<L$ $0 <D(Q_i)< \beta$ NI=O CI=0
  - $L<Q_i<H$ $-\beta<D(Q_i)< \beta$ NI=1 CI=0
  - $H<Q_i$ $-\beta<D(Q_i)< 0$ NI=0 CI=0
  - $H<Q_i$ $0<D(Q_i)< \beta$ CI=1

ABR: ER

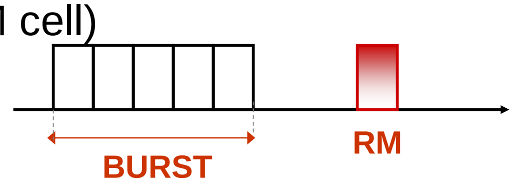
- Example of an algorithm (not standardized): ERICA
  - DATA:
    - C: link bit rate
    - Available bit rate
      - Bit rate available to ABR connections, i.e., subtract from link capacity the bit rate devoted to CBR and VBR VCs
    - Target bit rate: $R_T = 0.98 \cdot C$
      - To avoid oscillations
  - OUTPUT:
    - Fair share bit rate: B_{FSi}

ABR: ERICA

- Once the target bit rate is set, e.g. R_T=0.95 C
- Estimate
  - The number of active ABR connections (N_{ABR})
  - Background traffic (L_B),
  - ABR_i connection current load (L_{ABRi})
- Compute:
  - Available bit rate for : $B_{ABR} = R_T - L_B$
  - $B_{FS} = B_{ABR} / N_{ABR}$
  - $L_{ABR} = \Sigma L_{ABRi}$
  - $B_{VCi} = B_{ABR} \cdot L_{ABRi} / L_{ABR}$
  - ➔ $B_{FSi} = \max \{B_{FS}, B_{VCi}\}$
  - The maximum allows to target a max-min fair allocation
- B_{FSi} is written in the ER field only if smaller than the current value

Transfer modes: ABT (ATM Block Transfer)

- Standardized only by ITU-T
- Defines a block of cells as a group of cells "enclosed" by two RM cells (or preceded by one RM cell)



- Variable bit-rate service with fast resource
- Cells within a given block are transmitted at a constant bit rate

ABT: ATM Block Transfer

- Characterization:
  - BCR, sending rate for the block of cells
- Allocated bandwidth is block by block variable through RM reservation
- Nodes take independent decisions: the burst reaches the destination only if all nodes are able to accept it
- Block guarantees, not connection guaranteees

ABT

- Two flavours:
  - IT (Immediate Transmission):
    - Send a block of cells at a constant bit rate, equal to BCR
    - Each node either discards or accepts the full block
      - Rather inefficient when crossing several nodes
    - Exploits part of the available bandwidth for short periods
    - Acceptance can be done looking at bit rate only, at buffer only, or at both
  - DT (Delayed Transmission):
    - Can re-negotiate block transfer rate, but need to wait for a positive answer from the network
    - Continuous negotiation, without exploiting signalling resources

Exercise

- Discuss a possible architecture to support ATM transfer modes
  - Queuing structure
  - Schedulers
- Start by considering each transfer mode separately