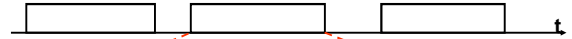


Qos in B-ISDN (ATM) networks

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Layered model

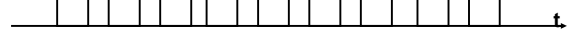
- Used for traffic characterization and QoS definition
- Call level



- 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: $\sigma_B^2 = B_M(B_P - B_M)$

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 recommendation

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)

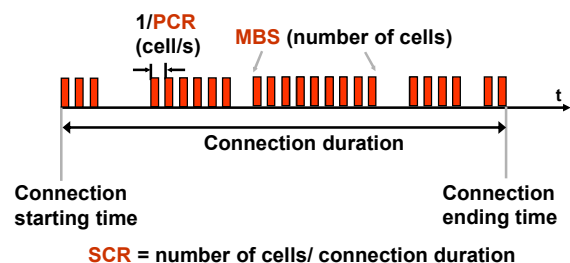
Standard: traffic characterization

- 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

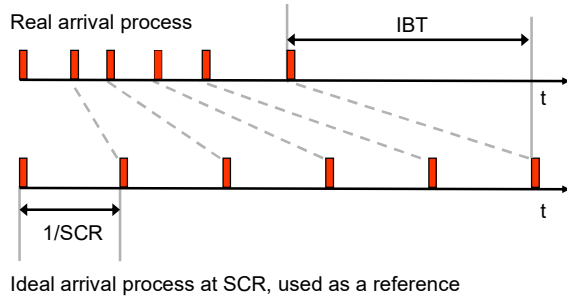
Standard: traffic characterization

- 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
 - $MBS = 1 + IBT / (1/SCR - 1/PCR)$
 - $IBT = (MBS - 1) / (1/SCR - 1/PCR)$

Standard: traffic characterization



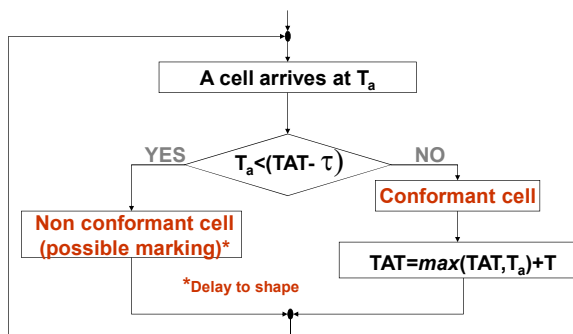
Relation between SCR and IBT



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^{-9} 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

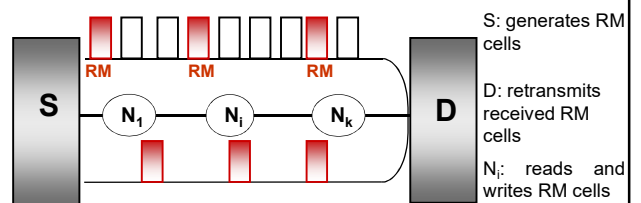
- ABR (Available Bit Rate) offers an allocated bit rate between PCR and MCR depending on network resources availability; goals
 - Full bit rate utilization
 - Fair resource partitioning
- The network explicitly signals to sources the transmission bit rate
- It provide small CLR (ideally zero CLR) if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



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: $CCR = CCR + PCR \cdot RIF$
 - To decrease rate: $CCR = CCR \cdot (1 - RDF)$
 - 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
 - $Q_i < L$ $NI=0$ $CI=0$
 - $L < Q_i < H$ $NI=1$ $CI=0$
 - $H < Q_i$ $CI=1$
- Positional - Derivative control
 - $\forall Q_i$ $D(Q_i) < -\beta$ $NI=0$ $CI=0$
 - $\forall Q_i$ $\beta < D(Q_i)$ $CI=1$
 - $Q_i < L$ $-\beta < D(Q_i) < 0$ $NI=0$ $CI=0$
 - $Q_i < L$ $0 < D(Q_i) < \beta$ $NI=0$ $CI=0$
 - $L < Q_i < H$ $-\beta < D(Q_i) < \beta$ $NI=1$ $CI=0$
 - $H < Q_i$ $-\beta < D(Q_i) < 0$ $NI=0$ $CI=0$
 - $H < Q_i$ $0 < D(Q_i) < \beta$ $CI=1$

ABR: ER

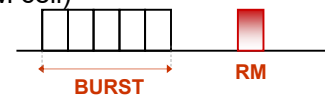
- Example of an algorithm (not standardized): ERICA
 - DATA:
 - C : link bit rate
 - Available bit rate
 - Bit rate available to ABR connections, i.e., subtract from link capacity the bit rate devoted to CBR and VBR VCs
 - Target bit rate: $R_T = 0.98 \cdot C$
 - To avoid oscillations
 - OUTPUT:
 - Fair 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 connection current load (L_{ABRi})
- Compute:
 - Available bit rate for: $B_{ABR} = R_T - L_B$
 - $B_{FS} = B_{ABR} / N_{ABR}$
 - $L_{ABR} = \sum L_{ABRi}$
 - $B_{VCI} = B_{ABR} - L_{ABR} / L_{ABR}$
 - $\rightarrow B_{FSi} = \max\{B_{FS}, B_{VCI}\}$
 - 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 guarantees

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