Complete modelling of AVB in Network Calculus Framework

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retour sur innovation

Outline

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Audio/Video Bridging (ABV)

- AVB: Audio/Video Bridging
- Affordable network for multimedia
  - interest from automotive industry
  - aeronautical use (?)
- Ethernet-based
- IEEE 802.1 AVB task group
  - Set of standards/addendum: 802.1ba, 802.1as, 802.1at, 802.1av
- Dynamic creation of flow
- Flow throughput specification
- Multicast: mono-source/multi-sink
- Several classes ($\approx$ credit-based bounded priorities)

AVB main standards

- 802.1ba: Audio Video Bridging Systems
  - Global definition of AVB system
  - AVB elements:
    - Talker: produce stream(s)
    - Listener: consume stream(s)
    - Bridge: forward stream(s)
- 802.1as: Timing and Synchronization for Time-Sensitive Applications
  - Synchronisation protocol
  - Election of clock grandmaster
  - Computation of link delay
- 802.1qat: Stream Reservation Protocol (SRP)
  - flow specification TSpec
    - MaxFrameSize
    - MaxIntervalFrames

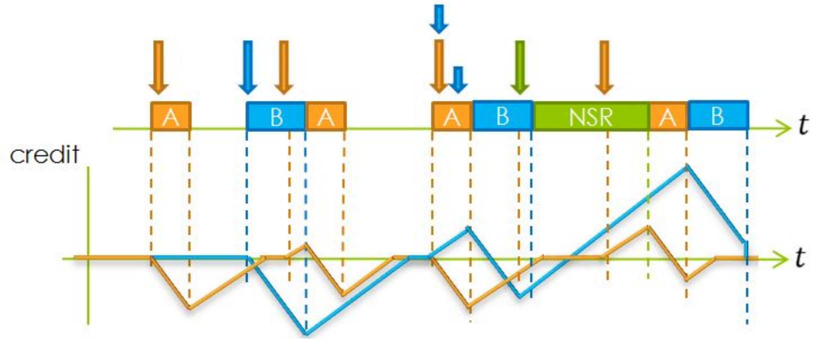
802.1Qav: credit-based shaping

- Virtual Bridged Local Area Networks Amendment 12: Forwarding and Queuing Enhancements for Time-Sensitive Streams
- 8 priority levels
- classes A & B
  - highest priority
  - credit-based shaping
- idea
  - allocate a % of bandwidth per class
  - limited priority

Details of queue credit-based shaping

- parameters
  - per node capacity/bandwidth C
  - per class *idle slope* $id_X < C$ (configuration)
  - implicit *send slope* $sd_X = id_X - C < 0$
- per class credit variable c_X
- Algorithm
  - send class X frame iff
    - $c_X \geq 0$
    - no highest priority frame can be send
    - no preemption
  - during sending, decrease c_X with slope sd_X
  - during waiting, increase c_X with slope id_X
  - during idling (no frame), increase c_X with slope id_X, up to 0

Example of queue credit-based shaping



Outline

What is network calculus ?

- a theory to compute memory and delay bounds in networks
- used to certify A380 backbone
- accurate ($\approx$ 20% on realistic configuration)
- efficient ($\approx$ 10s with 10^4 flows)
- scalable
- based on $(\min, +)$ dioid

Mathematical background

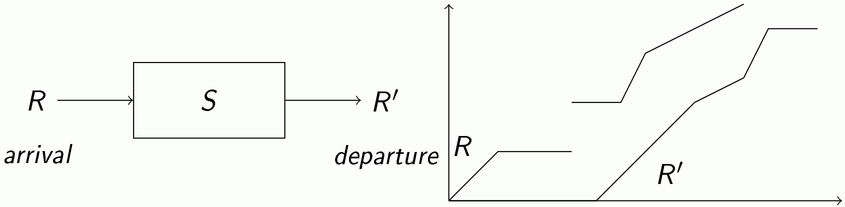
- Main objet: non decreasing function

$$\mathcal{F} = \{f : \mathbb{R}_{\geq 0} \to \mathbb{R}_{\geq 0} \mid x < y \implies f(x) \leq f(y)\}$$
$$\mathcal{F}_0 = \{f \in \mathcal{F} \mid f(0) = 0\}$$

- Some associated operators: convolution $*$, deconvolution $\oslash$, non-negative $[\cdot]^+$

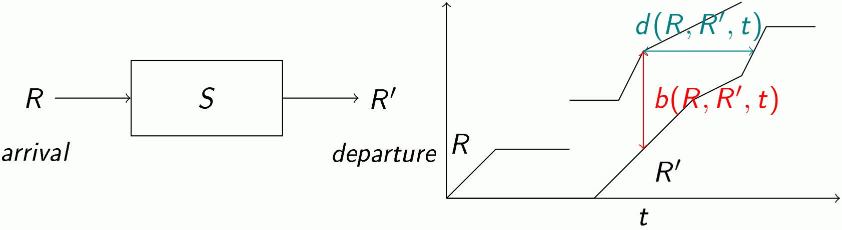
$$(f * g)(t) = \inf_{0 \leq s \leq t} f(t-s) + g(s)$$
$$(f \oslash g)(t) = \sup_{0 \leq s} f(t+s) - g(s)$$
$$[x]^+ = \max(x, 0)$$

Reality modelling



- Flow : Cumulative curve R
  - $R(t)$: amount of data sent up to time t
- Serveur : simple input/output relation: $S \subset \mathcal{F}_0 \times \mathcal{F}_0$
  - Property: departure/output produced after arrival/input: $R \xrightarrow{S} R' \implies R \geq R'$

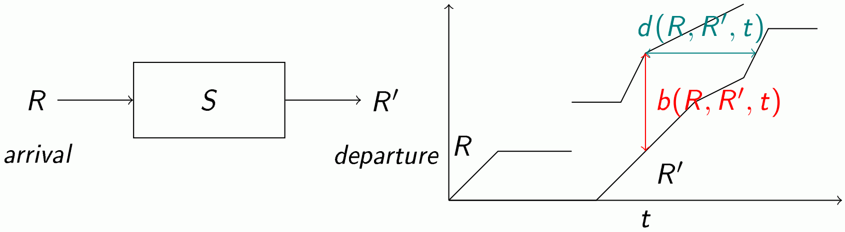
Reality modelling



- buffer use and delay

$$b(R, R', t) = R(t) - R'(t) \quad d(R, R', t) = \underbrace{d \text{ tq } R'(t+d) = R(t)}_{\text{continuous}}$$

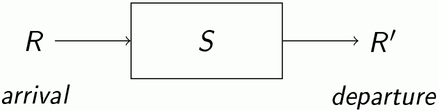
Reality modelling

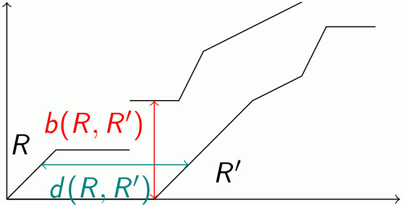


- buffer use and delay

$$b(R,R',t) = R(t) - R'(t) \quad d(R,R',t) = \underbrace{\inf\left\{d \mid R'(t+d) \geq R(t)\right\}}_{\text{general}}$$

Reality modelling





- buffer use and delay

$$b(R, R', t) = R(t) - R'(t) \quad d(R, R', t) = \inf \{ d \mid R'(t + d) \leq R(t) \}$$

- worst delay and buffer use

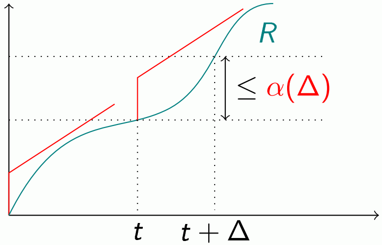
$$b(R, S) = \max_t b(R, R', t) \qquad d(R, R') = \max_t d(R, R', t)$$

$$b(R, S) = \max_{R \xrightarrow{S} R'} b(R, R') \qquad d(R, R') = \max_{R \xrightarrow{S} R'} d(R, R')$$

Arrival curve

A flow R has arrival curve α iff

$$\forall t, \Delta \geq 0 : R(t+\Delta) - R(t) \leq \alpha(\Delta) \quad (1)$$



- real behaviour approximation
- no unique arrival curve
    - accuracy of the model

Services

- approximation of the server behaviour
- several flavors of service
- minimal simple service β

$$R' \geq R * \beta$$

- minimal strict service β

$$\forall (s, s+\Delta], \forall x \in (s,t] : R(x) > R'(x) \implies R'(s+\Delta) - R'(s) \geq \beta(\Delta)$$

- maximal simple service β^M

$$R' \leq R * \beta^M$$

- shaping σ

$$\forall t, \Delta \geq 0 : R'(t+\Delta) - R'(t) \leq \sigma(\Delta)$$

- service hierarchy

min. strict $\implies$ min. simple   shaping $\implies$ max. simple

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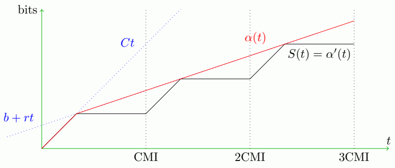
Why different flavors of service?

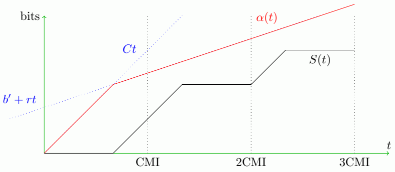
- simple minimal service: delay computation
- strict minimal service: hierarchical scheduling (SP/FIFO, WRR/FIFO...)
- maximal and shaping: limits output burst $\Longrightarrow$ reduce *next* delay

Outline

A standard ambiguity

- Flow specification
  - per class interval length (class measurement interval – CMI)
  - maxFrameSize: clear
  - maxIntervalFrames: "*the maximum number of frames that the Talker may transmit in one class measurement interval*"
  - long term throughput $r = \frac{\text{maxIntervalFrames} \times \text{maxFrameSize}}{\text{CMI}}$
  - burst value b
  - periodic or periodic + jitter





Two fundamental lemmas

Credit bound

$$sd_A \frac{l^A_{\max}}{C} \leq credit_A \leq id_A \frac{l^n_{\max}}{C} \qquad (2)$$

$l^A_{\max}$: max. frame size of flow A, $l^n_{\max}$: max. frame size of other flows

Credit variation

$$c_X(t+\Delta) - c_X(t) = id_X \Delta + \frac{sd_X - id_X}{C}\left(X'(t+\Delta) - X'(t)\right) \qquad (3)$$

Contribution

After some rewriting...

- four kinds of service for class A servers

$$\beta^A_{\text{strict}}(t) = id_A \left[t - \frac{l^n_{max}}{C} - l^A_{max} \frac{C - id_A}{id_A C} \right]^+$$

$$\beta^A_{\text{min}}(t) = \frac{id_A C}{id_A - sd_A} \left[t - \frac{l^n_{max}}{C} \right]^+$$

$$\sigma^A(t) = \frac{id_A C}{id_A - sd_A} \left[t + \frac{l^n_{max}}{C} - l^A_{max} \frac{sd_A}{id_A C} \right]$$

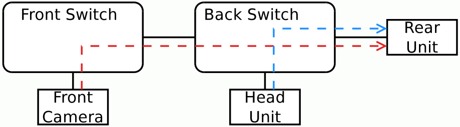
$$\beta^A_{\text{max}}(t) = \frac{id_A C}{id_A - sd_A} \left[t - l^A_{max} \frac{sd_A}{id_A C} \right]$$

- the same work for the class B

Outline

Experiment

- no real case study
  - lack of space, time and user
- considering a simple example inspired from automotive [?]



- load 10%
- different modelling (with/without jitter, with/without shaping, concave/staircase arrival curves)

	$\alpha_{\text{per}}^{\text{conc}}$	$\alpha_{\text{per}}^{\text{st}}$	$\alpha_{\text{jit}}^{\text{conc}}$	$\alpha_{\text{jit}}^{\text{st}}$
No shaping	1.030ms	0.975ms	1.925ms	1.828ms
Shaping	0.877ms	0.837ms	1.509ms	1.429ms

Outline

Conclusion

- a formal model for AVB worst-case performances
- on-line computation (admission control)
  - closed formula for concave arrival model
  - propagation problem
- off-line computation (embedded system, static conf.)
- AVB future ?
  - automotive: from AVB to TSN, or ad-hoc AVB extension
  - other