Bridge-Local Guaranteed Latency with Strict Priority Scheduling

Alexej Grigorjew – March 02, 2020

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Introduction – Distributed Admission Control
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Delay ≤ ...? ⇒ Accept/Deny
Introduction – Distributed Admission Control

Transmission Selection

- SP
- CBS
- ATS
- CQF

Traffic Specification (SRP, RAP)

- MaxFrameSize
- MaxFramesPerInterval
- Interval

Delay \leq \ldots? \Rightarrow \text{Accept/Deny}
Introduction – Distributed Admission Control

Transmission Selection

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Traffic Specification (SRP, RAP)

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Delay ≤ ...? ⇒ Accept/Deny

Desired Features:

- Computationally feasible
- Do not require global information (from ●)
- Support brownfield installations ⇒ SP
Preliminaries:

- Switch delay model
- Assumptions and constraints
  - Talker characteristics
  - Switch characteristics

Contribution:

- Overview of required information from the Resource Allocation Protocol (RAP)
- Proven per-hop latency bound for Strict Priority (SP) transmission selection with only bridge-local information
- Initial evaluation of network capacity for an admission control system using this bound
Preliminaries

Switch delay models, assumptions and constraints
Switch Delay Model

Bridge-local guaranteed latency with SP

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Switch Delay Model

- Processing delay $d^{Proc}$ is device-specific and not considered
- Propagation delay $d^{Prop}$ is bounded by max cable length
- Upper bound for $d^{TQ} + d^{SF}$ desired (queuing and transmission delay)
Assumptions and Constraints – Talkers

1. Frames of stream \( i \) do not exceed their max frame size \( \hat{\ell}_i \) and min frame size \( \check{\ell}_i \).
Assumptions and Constraints – Talkers

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2. Talkers pace their traffic according to a burst size \( b_i \) and a burst interval \( \tau_i \). For any point \( t \) in time, the traffic sent by stream \( i \) in the time interval \([t, t + \tau_i]\) may not exceed \( b_i \).
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![Diagram showing talker burst and time intervals](image-url)
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Assumptions and Constraints – Bridges

3. Bridges use IEEE 802.1Q priority transmission selection, i.e., frames with a higher traffic class are always selected for transmission before frames with lower traffic classes.

(a) Within each traffic class, FIFO transmission selection is used.

(b) No shaping mechanisms are used in any considered traffic class. The earliest frame of each class is always regarded eligible for transmission.
Assumptions and Constraints – Bridges

3. Bridges use IEEE 802.1Q **priority transmission selection**, i.e., frames with a higher traffic class are always selected for transmission before frames with lower traffic classes.

(a) Within each traffic class, **FIFO** transmission selection is used.

(b) **No shaping** mechanisms are used in any considered traffic class. The earliest frame of each class is always regarded eligible for transmission.

4. Each bridge $h$ has a pre-configured maximum per-hop delay guarantee $\delta^h_p$ for each traffic class $p$.

(a) **Admission control** prevents the deployment of new streams that would cause delay violations for any deployed stream.
Latency Bound

Required information, formula and reasoning
Required Information → TSpec

TSpec should include for stream $i$:

- Traffic class $p_i$
- Min frame size $\ell_i$ (e.g., 64 B)
- Max frame size $\hat{\ell}_i$ (e.g., 1542 B)
- Committed burst size $b_i$
- Burst interval $\tau_i$

including preamble and IPG
Required Information → TSpec

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- Max frame size $\hat{\ell}_i$ (e.g., 1542 B)
- Committed burst size $b_i$
- Burst interval $\tau_i$
- Accumulated max latency $accMaxD_{h_k}^i$
- Accumulated min latency $accMinD_{h_k}^i$

\[
accMaxD_{h_k}^i = \sum_{j=1}^{k} \delta p_i^j
\]
\[
accMinD_{h_k}^i = \sum_{j=1}^{k} \frac{\ell_i}{\text{link speed}_{h_j}}
\]
Latency Bound

\[ h_k \]

- \( p_i \): traffic class
- \( \ell_i \): max frame size
- \( b_i \): burst size
- \( \delta_{hk}^{p_i} \): delay guarantee
- \( r \): link speed
- \( S \): set of all streams
- \( \text{accMax}D_i^{hk} \)
- \( \text{accMin}D_i^{hk} \)
### Latency Bound

Bridge-local guaranteed latency with SP

- \( p_i \): traffic class
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Bridge Chassis

- FIFO
- State Priority

Tx

Rx

SP

higher

lower
Latency Bound

Worst case latency of stream \( i \) at bridge \( h_k \) is bounded by:

\[
TQ,SF_i \leq \sum_{x \in S \mid p_x > p_i} y_{i,x} b_x / r + \sum_{x \in S \mid p_x = p_i} z_{x} b_x / r + \max_{x \in S \mid p_x < p_i} \hat{\ell}_x / r
\]
Latency Bound

Worst case latency of stream $i$ at bridge $h_k$ is bounded by:

$$d_{TQ,SF}^i \leq \sum_{\{x \in S | p_x > p_i\}} y_{i,x} b_x / r + \sum_{\{x \in S | p_x = p_i\}} z_x b_x / r + \max_{\{x \in S | p_x < p_i\}} \hat{\ell}_x / r$$

number of bursts from interfering streams

$$y_{i,x} \geq \frac{\text{accMax}D_{x}^{h_k} - \text{accMin}D_{x}^{h_k-1} + \delta_{p_i}^{h_k}}{\tau_x}$$

$$z_x \geq \frac{\text{accMax}D_{x}^{h_k} - \text{accMin}D_{x}^{h_k-1}}{\tau_x}$$
Reasoning – Residence Times of Frames in TQ

\[ p_i \quad \text{traffic class} \]
\[ \ell_i \quad \text{min frame size} \]
\[ \delta_{h_k}^{p_i} \quad \text{delay guarantee} \]
\[ \tau_i \quad \text{burst interval} \]
\[ \text{accMax}D_{i}^{h_k} \]
\[ \text{accMin}D_{i}^{h_k} \]
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Reasoning – Residence Times of Frames in TQ

\[ \delta_{h_3}^{p_i} \]

\[ \text{link speed}_{h_2} \]

\[ \tilde{\ell}_i \]

\[ \text{traffic class} \]

\[ \ell_i \]

\[ \text{min frame size} \]

\[ \delta_{p_i}^{h_k} \]

\[ \text{delay guarantee} \]

\[ \tau_i \]

\[ \text{burst interval} \]

\[ \text{accMaxD}_{i}^{h_k} \]

\[ \text{accMinD}_{i}^{h_k} \]
Reasoning – Residence Times of Frames in TQ

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Reasoning – Residence Times of Frames in TQ

hop

\[ a_{ccMinD_i}^{h_6} \]

\[ a_{ccMaxD_i}^{h_7} \]

time

\[ p_i \] traffic class
\[ \ell_i \] min frame size
\[ \delta_{p_i}^{h_k} \] delay guarantee
\[ \tau_i \] burst interval
\[ a_{ccMaxD_i}^{h_k} \]
\[ a_{ccMinD_i}^{h_k} \]
Reasoning – Residence Times of Frames in TQ

Diagram showing latency times for different hops and traffic classes.

Key:
- $p_i$: traffic class
- $\ell_i$: min frame size
- $\delta_{h_k}^{p_i}$: delay guarantee
- $\tau_i$: burst interval
- $accMaxD_{h_k}^{p_i}$: maximum delay
- $accMinD_{h_k}^{p_i}$: minimum delay

Bridge-local guaranteed latency with SP
Reasoning – Same-Class Bursts $z_x$

How many bursts from stream $x$ can be in the queue of $h_n$ at the same time?

$z \geq \left\lceil \frac{\text{accMax}D_{x}^{h_n} - \text{accMin}D_{x}^{h_n-1}}{\tau_x} \right\rceil$
Reasoning – Same-Class Bursts $z_x$

How many bursts from stream $x$ can be in the queue of $h_n$ at the same time?

$$z \geq \left\lceil \frac{\text{accMax}D^h_{x} - \text{accMin}D^{h_{n-1}}_{x}}{\tau_x} \right\rceil$$
Reasoning – Same-Class Bursts $z_x$

- How many bursts from stream $x$ can be in the queue of $h_n$ at the same time?
- Project time $t_{obs}$ to interval $[t_\ell, t_r]$ at the talker $h_1$

$$z \geq \left\lceil \frac{accMaxD_x^{h_n} - accMinD_x^{h_n-1}}{\tau_x} \right\rceil$$
Reasoning – Higher-Class Bursts $y_{i,x}$

$h_n$

$h_1$

$\tau_x$
Reasoning – Higher-Class Bursts $y_{i,x}$

Higher class frames that arrive later can still interfere ⇒ observe duration $\Delta t_{obs}$ instead of a single moment
Reasoning – Higher-Class Bursts $y_{i,x}$

Higher class frames that arrive later can still interfere
⇒ observe duration $\Delta t_{obs}$ instead of a single moment

How long can these frames interfere?
→ as long as is in the queue: $d_{i}^{TQ}$
⇒ recursive relationship: $d_{i}^{TQ} \leq \ldots d_{i}^{TQ} \ldots$
Reasoning – Higher-Class Bursts $y_{i,x}$

- Higher class frames that arrive later can still interfere
  ⇒ observe duration $\Delta t_{obs}$ instead of a single moment

- How long can these frames interfere?
  → as long as is in the queue: $d_{i,TQ}^T$
  ⇒ recursive relationship: $d_{i,TQ}^T \leq \ldots d_{i,TQ}^T \ldots$

\[
\text{higher class frames that arrive later can still interfere} \\
\Rightarrow \text{observe duration } \Delta t_{obs} \text{ instead of a single moment} \\
\Rightarrow \text{recursive relationship: } d_{i,TQ}^T \leq \ldots d_{i,TQ}^T \ldots
\]
Evaluation

Inaccuracies and comparison to ATS
Worst Case Scenario Construction

- A single bridge is observed
Worst Case Scenario Construction

- A single bridge is observed
- Assuming periodic traffic (w.l.o.g.)
Worst Case Scenario Construction

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- Worst case construction and simulation
Worst Case Scenario Construction

- A single bridge is observed
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Worst Case Comparison – Higher Class Streams

![Graph showing latency comparison between SP worst case construction and high class streams.]

\[ \delta_{h_k}^{P_i} \]

\[ \text{Type} \]

- SP worst case construction

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Worst Case Comparison – Higher Class Streams

Bridge-local guaranteed latency with SP

\[ \delta_{i,k}^{p_i} \]

Number of high class streams

Taker Delay [\mu s]

Type

- SP worst case construction

\[ \delta_{h,k}^{p_i} \]

IN1
IN2
IN3
IN4
IN5
IN6
IN7
IN8
OUT2

365\mu s 373\mu s 381\mu s 389\mu s 397\mu s
Worst Case Comparison – Higher Class Streams

Steep increase of worst case delay when close to $\tau_i$
Worst Case Comparison – Higher Class Streams

- Steep increase of worst case delay when close to $T_i$
- Delay explodes near full bandwidth utilization

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Worst Case Comparison – Higher Class Streams

- Worst case construction
  - Steep increase of worst case delay when close to $\tau_i$
  - Delay explodes near full bandwidth utilization
- SP bound moves linearly towards the full-utilization point
  - $\sim 280$ streams can be deployed (instead of $\sim 350$)
Worst Case Comparison – Higher Class Streams

- **Worst case construction**
  - Steep increase of worst case delay when close to $\tau_i$
  - Delay explodes near full bandwidth utilization

- **SP bound moves linearly towards the full-utilization point**
  - $\sim 280$ streams can be deployed (instead of $\sim 350$)

- **Comparison to Asynchronous Traffic Shaping (Qcr)**
  - ATS bound starts lower, but reaches $\delta_{\alpha_h,k}$ at the same point
Worst Case Comparison – Frame Locality

- Influence of network topology
  - Frames arriving from a single port vs. many in-ports
Worst Case Comparison – Frame Locality

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  → Frames arriving from a single port vs. many in-ports
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- SP latency bound reached when all frames arrive from different ports
Worst Case Comparison – Frame Locality

- Influence of network topology
  → Frames arriving from a single port vs. many in-ports
- Frames show less interference if they arrive from the same in-port
- SP latency bound reached when all frames arrive from different ports
- This is not solved by a simple subtraction!
  → The time interval, during which higher class frames can interfere, would become larger than the per-hop delay. $\Delta t_{obs} \nless \delta^{hk}_{pi}$
Comparison of Network Capacities – Setup

- Deployment of random* streams in a small network
- Admission control: check whether \( d_{iTQ, SF}^i \leq \delta_{hk}^i \) for every hop
## Comparison of Network Capacities – Setup

- Deployment of random* streams in a small network
- Admission control: check whether $d_{i}^{TQ, SF} \leq \delta_{p_{i}}^{h_{k}}$ for every hop

*Random streams...

- Random talker
- Random listener
- Random configuration from table →
- 20 instances of each parameter set
- Mean capacity with 99.5% confidence intervals reported

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- Admission control: check whether $d_{i}^{TQ, SF} \leq \delta_{h_{k}}^{p_{i}}$ for every hop

*Random streams...
- Random talker
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Parameters
- Number of deployed streams: 100 – 2000
- Per-hop delay guarantees for both traffic classes $(\delta_{3}, \delta_{2})$: 100 µs – 8000 µs

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Comparison of Network Capacities – SP vs ATS

![Comparison of Network Capacities – SP vs ATS](image)
Comparison of Network Capacities – SP vs ATS

- No significant difference with small per-hop delay guarantees $\delta_{pi}$
  - Per-hop reshaping shows little effect if only one burst of each stream is in the network at the same time (cf. residence times)
  - SP is a viable alternative if burst intervals are large in comparison to $\delta_{pi}$
No significant difference with small per-hop delay guarantees $\delta_{p_i}$

- Per-hop reshaping shows little effect if only one burst of each stream is in the network at the same time (cf. residence times)
- SP is a viable alternative if burst intervals are large in comparison to $\delta_{p_i}$

ATS shows better network utilization than SP for large guarantees $\delta_{p_i}$

- Multiple bursts of the same stream in the network if $\tau_i \geq$ end-to-end delay
- Per-hop beneficial for less impairment
- SP may still be a viable: remaining bandwidth can be used by best effort traffic
Conclusion

- Bridge-local bounded latency with SP is feasible
  - Proven delay guarantee with low complexity for distributed systems
  - Bound only applicable in admission control scenarios
  - Streams whose latency exceeds their guarantee must be denied

- SP shows good network utilization in many situations
  - Capacity comparable to ATS for “large” transmission intervals
  - Still viable with “small” intervals → remaining bandwidth can be used by BE

- Requirements are similar to other mechanisms
  - Most information is already contained in current TSpec fields of Qcc
  - Accuracy can be improved by accMinLatency and minFrameSize

- Can be adapted depending on the scenario
  - Improving inaccuracies due to frame locality
  - Adaptation for other mechanisms (e.g. distributed admission control with TAS)