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Throughput
Latency
Goals

- Frame-level only.
- Definitions applicable at AAL layer
  Extendible to higher layers.
- Applicable to switch or group of switches
Throughput

- Lossless, Peak, Full-load
- Unit = bits/sec

![Throughput Diagram](image-url)
Statistical Variations

- Repeat NRT times for TRT seconds each
  Default NRT = 30, TRT = 60 seconds
- Sample = \{T_1, T_2, T_3, ..., T_n\}
- Sample mean \(T = \frac{1}{n}\sum T_i\)
- Sample Standard Deviation \(\sigma_T = \frac{\sum (T_i - T)^2}{(n - 1)}\)
- Standard Error = Standard Deviation/ \(\sqrt{n}\)
- \(100(1-\alpha)\%\) confidence interval
  \(= (T - z_{[1-\alpha/2]} \text{Std.Err}, T - z_{[1+\alpha/2]} \text{Std.Err})\)

<table>
<thead>
<tr>
<th>Confidence</th>
<th>(\alpha)</th>
<th>(Z)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90%</td>
<td>0.1</td>
<td>1.615</td>
</tr>
<tr>
<td>99%</td>
<td>0.01</td>
<td>2.346</td>
</tr>
<tr>
<td>99.9%</td>
<td>0.001</td>
<td>3.291</td>
</tr>
</tbody>
</table>
Traffic Pattern

- n-to-n Straight: $n$ Vcs
  i to $i+1 \mod n$

- n-to-1: $n$ Vcs

- n-to-n Cross: $n^2$ Vcs

- 1-to-n Straight: 1 Vc
Background Traffic

- With and without background traffic
- To be defined
- Without background traffic until then
Frame Latency

- **MIMO** = Message in Message out latency
  \[ = \min\{LILO, FILO\text{-Normalized Frame Output Time}\} \]
- **NFOT** = Frame size/output link rate
- Applies even when: Input rate <> Output rate
  Even when frames are not contiguous
- Unit: \( \mu s \)
Statistical Variations

- Send NML cells at TTL/(NML + 1) intervals
- NML = number of marked cells for latency measurement
- TTL = Total Time for Latency measurement
- Default: NML = 30 TTL = 31 seconds
- Calculate mean and standard error
  (Same way as for throughput)
Background Traffic

- With and without background traffic
- Background traffic to be specified
- Without background traffic until then
# Reporting Results

<table>
<thead>
<tr>
<th>Traffic Pattern</th>
<th>Throughput</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Throughput</td>
<td>Peak</td>
<td>Full-load</td>
<td>Latency</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lossless Mean</td>
<td>Lossless Std Err</td>
<td>Peak Mean</td>
<td>Peak Std Err</td>
<td>Full-load Mean</td>
</tr>
<tr>
<td>n-to-n Straight</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n-to-n Cross</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n-to-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-to-n</td>
<td></td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>
### Default Parameter Values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Meaning</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>NRT</td>
<td>Number of repetitions of throughput experiments</td>
<td>30</td>
</tr>
<tr>
<td>TRT</td>
<td>Time of each repetition of throughput experiment</td>
<td>60 sec</td>
</tr>
<tr>
<td>FSA</td>
<td>Frame Size for AAL performance experiments</td>
<td>9188 Bytes</td>
</tr>
<tr>
<td>NML</td>
<td>Number of marked frames sent in latency experiments</td>
<td>30</td>
</tr>
<tr>
<td>TTL</td>
<td>Total time of latency experiments</td>
<td>31 sec</td>
</tr>
</tbody>
</table>
Throughput: Lossless, peak, full-load

Latency = Min{LILO, FILO- NFOT} = MIMO
Motion

- Include the text of 96-08011 in the baseline draft.
Latency

- For a single bit:
  Total latency = Bit in to bit out = Switch latency

- For multiple bit frames:
  - FIFO = First bit In to First bit Out
  - LILO = Last bit In to Last bit Out
  - FILO = First bit In to Last bit Out
  - LIFO = Last bit In to First bit Out
Latency: Multiple Bit Frames

- \( \text{FIFO} = \text{LILO} \)
- \( \text{FILO} = \text{FIFO} + \text{Frame time} \)
- \( \text{LIFO} = \text{LILO} - \text{Frame time} \)
- Nominal Frame output time \( \text{NFOT} = \text{Frame size/output speed} \)
- Total Delay = \( \text{FILO} = \text{Switch latency} + \text{Frame time} \)
- Switch Latency = \( \text{FILO} - \text{NFOT} = \text{FIFO} = \text{LILO} \)
Multiple Bit Frames (Cont)

- Switch Latency = FILO - Frame Time = FIFO = LILO
- This assumes contiguous frames ⇒ No idle cells intermingled
- Also assumes input and output lines are of same speed.
- FIFO does not reflect the degradation caused by gaps
- LILO does not reflect the degradation caused by output speed.
- FILO - NFOT is similarly incorrect if input < output speed
- MIMO = Min{FILO - NFOT, LILO} is the correct measure.
## Latency: Comparison

<table>
<thead>
<tr>
<th>No.</th>
<th>Case</th>
<th>FIFO</th>
<th>LILO</th>
<th>FILO-NFOT</th>
<th>MIMO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>Input = output, contiguous frame, zero-delay switch</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>1b</td>
<td>Input = output, contiguous frame, nonzero-delay switch</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>1c</td>
<td>Input = output, non-contiguous frame, zero-delay switch</td>
<td></td>
<td></td>
<td>This case is not possible</td>
<td></td>
</tr>
<tr>
<td>1d</td>
<td>Input = output, non-contiguous frame, nonzero-delay switch</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>2a</td>
<td>Input &gt; output, contiguous frame, zero-delay switch</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>2b</td>
<td>Input &gt; output, contiguous frame, nonzero-delay switch</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
## Latency: Comparison (Cont)

<table>
<thead>
<tr>
<th>No.</th>
<th>Case</th>
<th>FIFO</th>
<th>LILO</th>
<th>FILO-NFOT</th>
<th>MIMO</th>
</tr>
</thead>
<tbody>
<tr>
<td>2c</td>
<td>Input &gt; output, non-contiguous frame, zero-delay switch</td>
<td>×</td>
<td>×</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>2d</td>
<td>Input &gt; output, non-contiguous frame, nonzero-delay switch</td>
<td>×</td>
<td>√</td>
<td>×</td>
<td>√</td>
</tr>
<tr>
<td>3a</td>
<td>Input &lt; output, contiguous frame, zero-delay switch</td>
<td>×</td>
<td>√</td>
<td>×</td>
<td>√</td>
</tr>
<tr>
<td>3b</td>
<td>Input &lt; output, contiguous frame, nonzero-delay switch</td>
<td>×</td>
<td>√</td>
<td>×</td>
<td>√</td>
</tr>
<tr>
<td>3c</td>
<td>Input &lt; output, non-contiguous frame, zero-delay switch</td>
<td>×</td>
<td>√</td>
<td>×</td>
<td>√</td>
</tr>
<tr>
<td>3d</td>
<td>Input &lt; output, non-contiguous frame, nonzero-delay switch</td>
<td>×</td>
<td>√</td>
<td>×</td>
<td>√</td>
</tr>
</tbody>
</table>

This case is not possible
Case 1a: Input = Output Speed, Contiguous Frame, Zero-delay Switch

- Zero-delay switch = wire (or a cut-through switch)
- Switch Latency = FILO - NFOT= FIFO = LILO = MIMO = 0
- All four alternatives give correct answer
Case 1b: Input = Output Speed, Contiguous Frame, Nonzero Delay Switch

- Example: A very long wire
- Switch Latency = FILO - NFOT = FIFO = LILO = MIMO
- All four metrics give the same answer.
Case 1c: Input = Output Speed, Non-Contiguous Frame, Zero Delay Switch

- Switch = A short wire
- All bits exit as soon as they enter.
  \[ \Rightarrow \text{Non-contiguous frame is not possible.} \]
Case 1d: Input = Output Speed, Non-Contiguous Frame, Nonzero Delay Switch

- FIFO does not reflect the degradation caused by gaps. FIFO is not a correct measure of switch latency.
- Switch Latency = total delay - frame time
- FILO - NFOT = LILO = MIMO
- Other three metrics give the same answer and are correct.
Case 2a: Input > Output Speed
Contiguous Frame, Zero-Delay Switch

- Zero delay switch = Two port memory
- Total Delay = FILO
  = Switch Latency + Nominal Frame Output Time
- Switch Latency = FILO - NFOT = FIFO = 0
- In this case, LILO will give wrong answer.
- LILO > FILO - NFOT \Rightarrow MIMO = FILO - NFOT = 0
- MIMO is also correct
Case 2b: Input > Output Speed
Contiguous Frame, Nonzero-Delay Switch

- Total Delay = FILO = Switch Latency + Frame Time
- Switch Latency = FILO - NFOT = FIFO
- In this case, LILO is affected by the output speed and gives wrong answer.
- LILO > FILO - NFOT ⇒ MIMO = FILO - NFOT
- MIMO is also correct
Case 2c: Input > Output Speed
Non-contiguous Frame, Zero-delay Switch

- Zero-delay switch = Two port memory
- A zero-delay switch will not introduce any gaps
  ⇒ This case is not possible.
Case 2d: Input > Output Speed, Non-contiguous Frame, Nonzero delay Switch

- Switch Latency = total delay - frame time = FILO - NFOT
- FIFO does not reflect gaps ⇒ FIFO is wrong
- LILO is affected by output speed and is wrong.
- LILO > FILO - NFOT
  ⇒ MIMO = \( \min\{LILO, FILO - NFOT\} = FILO - NFOT \)
  ⇒ MIMO is also correct.
Case 3a: Input < Output Speed, Contiguous Frame, Zero-delay Switch

- Zero-delay Switch = 2-port memory
- Contiguous frames are possible only if the transmission of the first bit is timed based on frame size.
- FIFO is non-zero $\Rightarrow$ Not a correct measure of switch latency
- FILO - NFOT = FIFO = non-zero. Also incorrect.
- LILO is zero. So it is correct.
- MIMO = Min{LILO, FILO - NFOT} is zero. It is also correct.
Case 3b: Input < Output Speed, Contiguous Frame, Nonzero-delay Switch

- To maintain frame contiguity, the departure of first bit has to be scheduled depending upon the output speed.
- FIFO can be made arbitrarily large by increasing the output link speed (and not changing the switch at all). FIFO - NFOT is similarly incorrect.
- LILO is the only metric that can be argued to be correct.
- LILO < FILO - NFOT
  \[ \text{MIMO} = \min\{\text{LILO}, \text{FILO} - \text{NFOT}\} = \text{LILO} \]
- MIMO is also a correct measure.
Case 3c: Input < Output Speed, Non-Contiguous Frame, Zero-delay Switch

- Zero-delay switch = two port memory
- To obtain contiguous cell, the first bit of the cell is sent such that the last bit can be sent immediately upon arrival.
- FIFO is non-zero. So it is incorrect.
- FILO - NFOT is non-zero. So it is incorrect.
- Gaps are caused by speed difference. Not attributable to switch.
- LILO is zero. So it is correct
- MIMO = Min{LILO, FILO - NFOT} is zero. So it is also correct.
Case 3d: Input < Output Speed, Non-Contiguous Frame, Nonzero-delay Switch

- To maintain cell contiguity, first bit transmission time depends upon the output speed. FIFO can be made arbitrarily large by increasing the output link speed (and not changing the switch).
- FIFO can also be made small by sending the first cell fast but introducing idle cells later $\Rightarrow$ FIFO is not correct.
- FILO - NFOT > FIFO is similarly incorrect.
- LILO is the only metric that can be argued to be correct.
- $\text{LILO} < \text{FILO} - \text{NFOT} \Rightarrow \text{MIMO} = \text{LILO}$