Protocol Analysis 201 for High-Speed Fibre Channel Fabrics

Live Webcast
April 11, 2019
10:00 AM PT
Today’s Speakers

David Rodgers
Sr. Product Marketing Manager
BoD, FCIA
Teledyne LeCroy

Yamini Shastry
Principal Engineer
Viavi Solutions

Joseph Kimpler
Global Manager, Alliances and Enablement
ATTO Technology
About the FCIA

The Fibre Channel Industry Association (FCIA) is a mutual benefit, non-profit, international organization of manufacturers, system integrators, developers, vendors, and industry professionals, and end users

– Promotes the advancement of Fibre Channel technologies and products that conform to the existing and emerging T11 standards.
– Maintains resources and supports activities to ensure multi-vendor interoperability for hardware, interconnection, and protocol solutions.
– Promotion and marketing of FC solutions, educational awareness campaigns, hosting public interoperability demonstrations, and fostering technology and standards conformance.

https://fibrechannel.org/
Agenda

FC SAN Elements
Analyzer placement
Getting most out of the capture
Post-capture analysis
Trace Formats, Trace reading, Graphing
Metric groups - Deeper analysis
Debug Examples
Benefits of purposeful error injection
Layer 2, 3, 4 Jamming examples
**Fibre Channel Layers**

**FC has functional layers:**

- **FC-0**: The interface to the physical media; transceivers, cables, etc.
- **FC-1**: Transmission protocol or data-link layer, encodes and decodes signals.
- **FC-2**: Network Layer consists of the low level Fibre Channel protocols; port to port connections.
- **FC-3**: Common services layer, a thin layer that could eventually implement functions like encryption or RAID redundancy algorithms; multiport connections.
- **FC-4**: Protocol-mapping layer, in which upper level protocols such as NVMe, SCSI, IP or FICON, are encapsulated into Information Units (IUs) for delivery to FC-2.

Device and Interop Testing

Generators/IO Tools
- Performance Testing
- Compliance Testing
- Functionality Testing
- Data Integrity Testing

Analyzer
- Capture and Analysis
- Protocol Violations/Errors
- Interop Testing

Jammer
- Error Injection
- Error Recovery
FC Switched Link Elements

Host Stack

- APPs
- VMs
- OS
- Hypervisors
- NVMe/SCSI
- FC HBA

Switch

ISL

Switch

Controller Stack

- NVMe SCSI SSDs, HDDs, Flash Drives
- Controller
- NVMe/SCSI
- FC HBA
FC Switched Link Elements
- Specific to Analyzer
SAN Issues

Fabric

- Configuration issues – Misconfigured zones
- Oversubscribed ISLs – Throughput congestion
- Dropped / discarded frames
- Slow drain devices (End points)
Troubleshooting

Problem Detection
- Physical errors
- Link resets/Aborts
- Missing Targets (LUNs) or ports
- Performance problem

Problem Monitoring
- Fabric monitoring tools
- Port logs/Device counters
- Compare: Problematic SAN configs/performance to baseline configs/

Is the problem from the host side, target side, fabric links or can’t be determined

Can the issue be recreated?

Can it be captured on analyzer????
Analyzer Placement and Setup

Placement of analyzer

- Host Link
- Target Link
- On the ISL
- Each end of the network
Getting the Most of a Capture

Setting up triggers and filters

- Link issues: Trigger on an error (Capture every word)
  - Stateless errors - simple triggers
  - Stateful errors - complex triggers
- Credit issues: Trigger(frame loss, credit loss), deep buffers, capture all Frames and R_RDYs
- Latency Issues: Visual trigger (throughput dip/threshold triggers), Filter out data frames
- Data Corruption issues: Visual trigger (app failure or bluescreen), capture frames only

Post-capture analysis

- Error Counters
- Frame to R_RDY timings, time on idle link, Out of credit situations w.r.t Frame counts
- Exchange latencies – SCSI/NVMe
- Data comparison, command overlap metrics
Trace Format Options

- **Event/Exchange Based View**
  - Group trace information based on event/exchange
  - Easily visualize and analyze transactions, make measurements

- **Important for the FW/Driver developer, SW/application engineer**
Trace Format Options

- **Chronological Based View**
  - Group trace based on events over time
  - Represents the transactions over the wire in order presented
  - Correlate information port by port

- **Important to HW/PHY layer engineering effort**

```
<table>
<thead>
<tr>
<th>No.</th>
<th>Start Time</th>
<th>Port</th>
<th>Speed</th>
<th>Destination Addr</th>
<th>Source Addr</th>
<th>Protocol</th>
<th>OK_ID</th>
<th>FF_ID</th>
<th>Frame</th>
<th>Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>29</td>
<td>02.03.42 041 714(msec)</td>
<td>P5</td>
<td>16G</td>
<td>01:0100</td>
<td>01:0200</td>
<td>FC</td>
<td>0x0009</td>
<td>0xFFFF</td>
<td>FCP_CMD</td>
<td>FCP_DATA</td>
</tr>
<tr>
<td>30</td>
<td>03.03.45 051 535(msec)</td>
<td>P6</td>
<td>16G</td>
<td>01:0100</td>
<td>01:0200</td>
<td>FC</td>
<td>0x0009</td>
<td>0x67DB</td>
<td>FCP_RSP</td>
<td>FCP_RSP</td>
</tr>
<tr>
<td>31</td>
<td>03.03.45 062 787(msec)</td>
<td>P6</td>
<td>16G</td>
<td>01:0100</td>
<td>01:0200</td>
<td>FC</td>
<td>0x0009</td>
<td>0x67DB</td>
<td>FCP_RSP</td>
<td>FCP_RSP</td>
</tr>
<tr>
<td>32</td>
<td>03.03.45 085 790(msec)</td>
<td>P5</td>
<td>16G</td>
<td>01:0100</td>
<td>01:0200</td>
<td>FC</td>
<td>0x000B</td>
<td>0xFFFF</td>
<td>FCP_CMD</td>
<td>FCP_DATA</td>
</tr>
<tr>
<td>33</td>
<td>03.03.45 101 856(msec)</td>
<td>P6</td>
<td>16G</td>
<td>01:0100</td>
<td>01:0200</td>
<td>FC</td>
<td>0x0008</td>
<td>0x67DA</td>
<td>FCP_RSP</td>
<td>FCP_RSP</td>
</tr>
<tr>
<td>34</td>
<td>03.03.45 124 207(msec)</td>
<td>P5</td>
<td>16G</td>
<td>01:0100</td>
<td>01:0200</td>
<td>FC</td>
<td>0x0008</td>
<td>0xFFFF</td>
<td>FCP_CMD</td>
<td>FCP_DATA</td>
</tr>
<tr>
<td>35</td>
<td>03.03.45 141 707(msec)</td>
<td>P6</td>
<td>16G</td>
<td>01:0100</td>
<td>01:0200</td>
<td>FC</td>
<td>0x0000</td>
<td>0x67DC</td>
<td>FCP_RSP</td>
<td>FCP_RSP</td>
</tr>
<tr>
<td>36</td>
<td>03.03.46 152 126(msec)</td>
<td>P6</td>
<td>16G</td>
<td>01:0100</td>
<td>01:0200</td>
<td>FC</td>
<td>0x0000</td>
<td>0x67DC</td>
<td>FCP_RSP</td>
<td>FCP_RSP</td>
</tr>
<tr>
<td>37</td>
<td>03.03.45 172 176(msec)</td>
<td>P5</td>
<td>16G</td>
<td>01:0100</td>
<td>01:0200</td>
<td>FC</td>
<td>0x000F</td>
<td>0xFFFF</td>
<td>FCP_CMD</td>
<td>FCP_DATA</td>
</tr>
<tr>
<td>38</td>
<td>03.03.45 195 051(msec)</td>
<td>P6</td>
<td>16G</td>
<td>01:0100</td>
<td>01:0200</td>
<td>FC</td>
<td>0x000F</td>
<td>0x67DE</td>
<td>FCP_RSP</td>
<td>FCP_RSP</td>
</tr>
<tr>
<td>39</td>
<td>03.03.45 205 982(msec)</td>
<td>P6</td>
<td>16G</td>
<td>01:0100</td>
<td>01:0200</td>
<td>FC</td>
<td>0x000F</td>
<td>0x67DE</td>
<td>FCP_RSP</td>
<td>FCP_RSP</td>
</tr>
<tr>
<td>40</td>
<td>03.03.45 202 737(msec)</td>
<td>P5</td>
<td>16G</td>
<td>01:0100</td>
<td>01:0200</td>
<td>FC</td>
<td>0x6011</td>
<td>0xFFFF</td>
<td>FCP_CMD</td>
<td>FCP_DATA</td>
</tr>
<tr>
<td>41</td>
<td>03.03.45 209 427(msec)</td>
<td>P6</td>
<td>16G</td>
<td>01:0100</td>
<td>01:0200</td>
<td>FC</td>
<td>0x6011</td>
<td>0x67E0</td>
<td>FCP_RSP</td>
<td>FCP_RSP</td>
</tr>
<tr>
<td>42</td>
<td>03.03.45 109 446(msec)</td>
<td>P6</td>
<td>16G</td>
<td>01:0100</td>
<td>01:0200</td>
<td>FC</td>
<td>0x6011</td>
<td>0x67E0</td>
<td>FCP_RSP</td>
<td>FCP_RSP</td>
</tr>
<tr>
<td>43</td>
<td>03.03.45 103 460(msec)</td>
<td>P6</td>
<td>16G</td>
<td>01:0100</td>
<td>01:0200</td>
<td>FC</td>
<td>0x6011</td>
<td>0xFFFF</td>
<td>FCP_CMD</td>
<td>FCP_DATA</td>
</tr>
<tr>
<td>44</td>
<td>03.03.45 145 790(msec)</td>
<td>P6</td>
<td>16G</td>
<td>01:0100</td>
<td>01:0200</td>
<td>FC</td>
<td>0x6013</td>
<td>0x67E2</td>
<td>FCP_RSP</td>
<td>FCP_RSP</td>
</tr>
<tr>
<td>45</td>
<td>03.03.45 130 026(msec)</td>
<td>P6</td>
<td>16G</td>
<td>01:0100</td>
<td>01:0200</td>
<td>FC</td>
<td>0x6013</td>
<td>0x67E2</td>
<td>FCP_RSP</td>
<td>FCP_RSP</td>
</tr>
<tr>
<td>46</td>
<td>03.03.45 175 665(msec)</td>
<td>P6</td>
<td>16G</td>
<td>01:0100</td>
<td>01:0200</td>
<td>FC</td>
<td>0x6015</td>
<td>0x2425</td>
<td>FCP_RSP</td>
<td>FCP_RSP</td>
</tr>
<tr>
<td>47</td>
<td>03.03.45 209 077(msec)</td>
<td>P6</td>
<td>16G</td>
<td>01:0100</td>
<td>01:0200</td>
<td>FC</td>
<td>0x6011</td>
<td>0x2425</td>
<td>FCP_RSP</td>
<td>FCP_RSP</td>
</tr>
<tr>
<td>48</td>
<td>03.03.47 021 274(msec)</td>
<td>P5</td>
<td>16G</td>
<td>01:0300</td>
<td>01:0400</td>
<td>FC</td>
<td>0x6018</td>
<td>0xFFFF</td>
<td>FCP_CMD</td>
<td>FCP_DATA</td>
</tr>
<tr>
<td>49</td>
<td>03.03.47 178 927(msec)</td>
<td>P5</td>
<td>16G</td>
<td>01:0300</td>
<td>01:0400</td>
<td>FC</td>
<td>0x6018</td>
<td>0xFFFF</td>
<td>FCP_CMD</td>
<td>FCP_DATA</td>
</tr>
<tr>
<td>50</td>
<td>03.03.47 349 279(msec)</td>
<td>P5</td>
<td>16G</td>
<td>01:0300</td>
<td>01:0400</td>
<td>FC</td>
<td>0x6018</td>
<td>0xFFFF</td>
<td>FCP_CMD</td>
<td>FCP_DATA</td>
</tr>
<tr>
<td>51</td>
<td>03.03.019 075 956(msec)</td>
<td>P6</td>
<td>16G</td>
<td>01:0300</td>
<td>01:0400</td>
<td>FC</td>
<td>0x6247</td>
<td>0xFFFF</td>
<td>FCP_RSP</td>
<td>FCP_RSP</td>
</tr>
<tr>
<td>52</td>
<td>03.03.019 124 531(msec)</td>
<td>P5</td>
<td>16G</td>
<td>01:0300</td>
<td>01:0400</td>
<td>FC</td>
<td>0x6247</td>
<td>0xFFFF</td>
<td>FCP_RSP</td>
<td>FCP_RSP</td>
</tr>
<tr>
<td>55</td>
<td>03.03.020 533 538(msec)</td>
<td>P6</td>
<td>16G</td>
<td>01:0300</td>
<td>01:0400</td>
<td>FC</td>
<td>0x6010</td>
<td>0x2428</td>
<td>FCP_RSP</td>
<td>FCP_RSP</td>
</tr>
<tr>
<td>56</td>
<td>03.03.020 533 538(msec)</td>
<td>P5</td>
<td>16G</td>
<td>01:0300</td>
<td>01:0400</td>
<td>FC</td>
<td>0x6019</td>
<td>0xFFFF</td>
<td>FCP_RSP</td>
<td>FCP_RSP</td>
</tr>
<tr>
<td>57</td>
<td>03.03.020 533 538(msec)</td>
<td>P6</td>
<td>16G</td>
<td>01:0300</td>
<td>01:0400</td>
<td>FC</td>
<td>0x6019</td>
<td>0xFFFF</td>
<td>FCP_RSP</td>
<td>FCP_RSP</td>
</tr>
</tbody>
</table>
```
Determine Metrics

- **Common Exchange Characteristics**
  - Compare expected with Actual
    - FCCT_REQUEST to FCCT_REPLY
      - Directory Services request to the Name Server with a GS_ACCEPT followed by the ESL REQUEST for PLOGI
    - Time Stamp delta
      - Request at: 03.08.379.946.147min
      - Reply at: 03.08.399.325.845min
      - ET: 19.379.698(ms)
    - Time Stamp delta
      - Request at: 03.08.419.321.626min
      - Reply at: 03.08.420.053.156min
      - ET: 731.530(us)
### Determine Metrics

#### Exchange Characteristics Ex. 1
- FCP_CMD to FCP_RSP
- Time Stamp delta
- Data Length = **36Bytes**
  - Request at: 03.08.439.852.471min
  - Reply at: 03.08.440.069.484min
  - ET: 217.013(us)

#### Exchange Characteristics Ex. 2
- FCP_CMD to FCP_RSP
- Time Stamp delta
- Data Length = **64Bytes**
  - Request at: 03.08.440.086.418min
  - Reply at: 03.08.441.079.592min
  - ET: 993.174(us)
FC Trace Events, SCSI Performance

• Example of Summary performance for SCSI Events
  – Extracted directly from the captured transactions
  – Operations represented in S_ID/D_ID pairing
    • Is Min-Max response time within expected values?

<table>
<thead>
<tr>
<th>Port No</th>
<th>FC Source ID</th>
<th>FC Destination ID</th>
<th>Min Response Time</th>
<th>Max Response Time</th>
<th>Average Response Time</th>
<th>Total</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>P5</td>
<td>010300</td>
<td>010100</td>
<td>015.697(us)</td>
<td>001.021 110(ms)</td>
<td>394.846(us)</td>
<td>4290</td>
<td>100.00</td>
</tr>
</tbody>
</table>

**SCSI.FC-SCSI.SCSI Timing**

<table>
<thead>
<tr>
<th>Port No</th>
<th>FC Source ID</th>
<th>FC Destination ID</th>
<th>Min Response Time</th>
<th>Max Response Time</th>
<th>Average Response Time</th>
<th>Min Throughput (MB/s)</th>
<th>Max Throughput (MB/s)</th>
<th>Average Throughput (MB/s)</th>
<th>Average Min Latency Time</th>
<th>Max Latency Time</th>
<th>Average Latency Time</th>
<th>Total Byte Transferred</th>
<th>Total Duration</th>
<th>Count</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>P5</td>
<td>010300</td>
<td>010100</td>
<td>269.970(us)</td>
<td>546.845(us)</td>
<td>394.787(us)</td>
<td>0.8929</td>
<td>1.8086</td>
<td>1.2393</td>
<td>136.628(us)</td>
<td>366.020(us)</td>
<td>206.014(us)</td>
<td>2175488</td>
<td>001.724 052(ms)</td>
<td>4280</td>
<td>100.00</td>
</tr>
</tbody>
</table>

**SCSI.FC-SCSI.SCSI Read Operation**

<table>
<thead>
<tr>
<th>Port No</th>
<th>FC Source ID</th>
<th>FC Destination ID</th>
<th>Min Response Time</th>
<th>Max Response Time</th>
<th>Average Response Time</th>
<th>Min Throughput (MB/s)</th>
<th>Max Throughput (MB/s)</th>
<th>Average Throughput (MB/s)</th>
<th>Average Min Latency Time</th>
<th>Max Latency Time</th>
<th>Average Latency Time</th>
<th>Total Byte Transferred</th>
<th>Total Duration</th>
<th>Count</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>P5</td>
<td>010300</td>
<td>010100</td>
<td>269.970(us)</td>
<td>546.845(us)</td>
<td>394.787(us)</td>
<td>0.8929</td>
<td>1.8086</td>
<td>1.2393</td>
<td>136.628(us)</td>
<td>366.020(us)</td>
<td>206.014(us)</td>
<td>2175488</td>
<td>001.724 052(ms)</td>
<td>4280</td>
<td>100.00</td>
</tr>
</tbody>
</table>
FC Metrics, ELS and FCP

**FC.ELS/AL**

<table>
<thead>
<tr>
<th>Port No</th>
<th>FC Source ID</th>
<th>FC Destination ID</th>
<th>Type</th>
<th>Count</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffff01</td>
<td>ELS_REQUEST</td>
<td>3</td>
<td>16.67</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffff01</td>
<td>ELS_REPLY</td>
<td>1</td>
<td>5.56</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffff01</td>
<td>ELS_REPLY</td>
<td>1</td>
<td>5.56</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffff01</td>
<td>ELS_REPLY</td>
<td>1</td>
<td>5.56</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffff01</td>
<td>ELS_REQUEST</td>
<td>1</td>
<td>5.56</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffff01</td>
<td>ELS_REQUEST</td>
<td>1</td>
<td>5.56</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffff01</td>
<td>ELS_REQUEST</td>
<td>1</td>
<td>5.56</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffff01</td>
<td>ELS_REQUEST</td>
<td>1</td>
<td>5.56</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffff01</td>
<td>ELS_REQUEST</td>
<td>1</td>
<td>5.56</td>
</tr>
<tr>
<td>Total: 18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FC.ELS/AL.ELS Command**

<table>
<thead>
<tr>
<th>Port No</th>
<th>FC Source ID</th>
<th>FC Destination ID</th>
<th>Command</th>
<th>Response</th>
<th>Count</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffff01</td>
<td>RPSC</td>
<td>Accept</td>
<td>1</td>
<td>11.11</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffff01</td>
<td>RSCN</td>
<td>Accept</td>
<td>1</td>
<td>11.11</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffff01</td>
<td>PLOGI</td>
<td>Accept</td>
<td>1</td>
<td>11.11</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffff01</td>
<td>PRLI</td>
<td>Accept</td>
<td>1</td>
<td>11.11</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffff01</td>
<td>LOGO</td>
<td>Accept</td>
<td>1</td>
<td>11.11</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffff01</td>
<td>PLOGI</td>
<td>Accept</td>
<td>1</td>
<td>11.11</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffff01</td>
<td>PRLI</td>
<td>Accept</td>
<td>1</td>
<td>11.11</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffff01</td>
<td>PLOGI</td>
<td>Accept</td>
<td>1</td>
<td>11.11</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffff01</td>
<td>ADISC</td>
<td>Accept</td>
<td>1</td>
<td>11.11</td>
</tr>
<tr>
<td>Total: 9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FC.FCP Frames**

<table>
<thead>
<tr>
<th>Port No</th>
<th>FC Source ID</th>
<th>FC Destination ID</th>
<th>Frame Type</th>
<th>Count</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>P6</td>
<td>010300</td>
<td>010300</td>
<td>FCP_DATA</td>
<td>4257</td>
<td>33.32</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>010300</td>
<td>FCP_CMD</td>
<td>4290</td>
<td>33.58</td>
</tr>
<tr>
<td>P6</td>
<td>010300</td>
<td>010300</td>
<td>FCP_RSP</td>
<td>4228</td>
<td>33.10</td>
</tr>
<tr>
<td>Total: 12775</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Compare and contrast events across multiple links, by OX_ID and RX_ID pairs
- Tabular view of commands, ie PLOGI, indicating “normal” link functionality
- FCP request/response ratio indicating normative operation
## Performance Metrics, Events/Utilization

### FC.GS

<table>
<thead>
<tr>
<th>Port No</th>
<th>FC Source ID</th>
<th>FC Destination ID</th>
<th>Type</th>
<th>Count</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>P6</td>
<td>fffffff</td>
<td>010300</td>
<td>FCCT_REPLY</td>
<td>5</td>
<td>22.73</td>
</tr>
<tr>
<td>P6</td>
<td>ffff0a</td>
<td>010300</td>
<td>FCCT_REPLY</td>
<td>6</td>
<td>27.27</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffff0a</td>
<td>FCCT_REQUEST</td>
<td>6</td>
<td>27.27</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffffc</td>
<td>FCCT_REQUEST</td>
<td>5</td>
<td>22.73</td>
</tr>
</tbody>
</table>

Total: 22

### FC.GS.Command

<table>
<thead>
<tr>
<th>Port No</th>
<th>FC Source ID</th>
<th>FC Destination ID</th>
<th>Type</th>
<th>Sub Type</th>
<th>Command</th>
<th>Response</th>
<th>Count</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffffc</td>
<td>Directory Service</td>
<td>Name Server</td>
<td>GID_PN</td>
<td>Accept</td>
<td>1</td>
<td>9.09</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffff0a</td>
<td>Management Service</td>
<td>Name Server</td>
<td>RPA</td>
<td>Accept</td>
<td>1</td>
<td>9.09</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffffc</td>
<td>Directory Service</td>
<td>Name Server</td>
<td>RSPN_ID</td>
<td>Accept</td>
<td>1</td>
<td>9.09</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffffc</td>
<td>Directory Service</td>
<td>Name Server</td>
<td>GID_FF</td>
<td>Accept</td>
<td>1</td>
<td>9.09</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffffc</td>
<td>Directory Service</td>
<td>Name Server</td>
<td>RFF_ID</td>
<td>Accept</td>
<td>1</td>
<td>9.09</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffffc</td>
<td>Management Service</td>
<td>Fabric Configuration Server</td>
<td>GFN</td>
<td>Accept</td>
<td>1</td>
<td>9.09</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffffc</td>
<td>Management Service</td>
<td>Fabric Configuration Server</td>
<td>GMAL</td>
<td>Reject</td>
<td>3</td>
<td>27.27</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffffc</td>
<td>Directory Service</td>
<td>Name Server</td>
<td>RFT_ID</td>
<td>Accept</td>
<td>1</td>
<td>9.09</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffffc</td>
<td>Management Service</td>
<td>Fabric Device Management Interface</td>
<td>RHBA</td>
<td>Accept</td>
<td>1</td>
<td>9.09</td>
</tr>
</tbody>
</table>

Total: 11

### FC

<table>
<thead>
<tr>
<th>Port No</th>
<th>FC Source ID</th>
<th>FC Destination ID</th>
<th>Type</th>
<th>Count</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffffc</td>
<td>ELS Frame</td>
<td>1</td>
<td>0.01</td>
</tr>
<tr>
<td>P6</td>
<td>010300</td>
<td>ffffc</td>
<td>ELS Frame</td>
<td>4</td>
<td>0.03</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffffc</td>
<td>GS Frame</td>
<td>6</td>
<td>0.05</td>
</tr>
<tr>
<td>P6</td>
<td>010300</td>
<td>ffffc</td>
<td>GS Frame</td>
<td>5</td>
<td>0.04</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffffc</td>
<td>ELS Frame</td>
<td>3</td>
<td>0.02</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffffc</td>
<td>ELS Frame</td>
<td>4</td>
<td>0.03</td>
</tr>
<tr>
<td>P6</td>
<td>010300</td>
<td>ffffc</td>
<td>ELS Frame</td>
<td>1</td>
<td>0.01</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffffc</td>
<td>ELS Frame</td>
<td>1</td>
<td>0.01</td>
</tr>
<tr>
<td>P6</td>
<td>010300</td>
<td>ffffc</td>
<td>GS Frame</td>
<td>5</td>
<td>0.04</td>
</tr>
<tr>
<td>P6</td>
<td>010300</td>
<td>ffffc</td>
<td>ELS Frame</td>
<td>3</td>
<td>0.02</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffffc</td>
<td>FCP Frame</td>
<td>8485</td>
<td>66.21</td>
</tr>
<tr>
<td>P5</td>
<td>010300</td>
<td>ffffc</td>
<td>FCP Frame</td>
<td>4290</td>
<td>33.48</td>
</tr>
</tbody>
</table>

Total: 12815
Metric Groups (for deeper analysis)

- Error Counts
- Bandwidth vs Throughput
- Protocol overheads, Time on Link, IFG
  - Host/target/network/idle time
- Queue Depth vs Pending IOs
  - Issued IOs
  - Completed IOs
- MB/Sec, Command Latencies
  - Command to Command Time
  - First response time
  - Data Time
  - Data to Status Time

**Credit analysis and command latencies are discussed in detail in Protocol Analysis for High-Speed Fibre Channel Fabrics**

https://www.brighttalk.com/webcast/14967/333863
Debug Example 1 - Analyzer Placement
Debug Example 1 – Host Delay

- Pending IOs graph dips with MB/Sec graph
- Indicates a host side delay.
Debug Example 1 – Host Delay cont'd.

Plot FC/NVMe exchange completion time to confirm.

Various metric groups can bring us to the same conclusion
Ex: Completed IOs vs Issued IOs
Delta time is 14871.9895 us. Host stalls before issuing commands.
Debug Example 2 - Analyzer Placement
Debug Example 2 - Controller Bug

- Pending IOs increase when MB/Sec dips
- May indicate a controller side delay.
### Debug Example 2- Controller Bug contd.

In the trace, incomplete exchanges are shown. The table below illustrates an example of such incomplete exchanges:

<table>
<thead>
<tr>
<th>Bo...</th>
<th>Side A</th>
<th>Side B</th>
<th>Age(us)</th>
<th>Pendi...</th>
<th>LBA</th>
<th>Tag</th>
<th>Source</th>
<th>Destination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Write</td>
<td>Write(10)</td>
<td>Good</td>
<td>10642.188_5</td>
<td>1</td>
<td>3800</td>
<td>5C2</td>
<td>020100</td>
<td>010100</td>
</tr>
<tr>
<td></td>
<td>Read(10)</td>
<td>Pending</td>
<td>13791.615_2</td>
<td>1</td>
<td>1000</td>
<td>239</td>
<td>020000</td>
<td>010000</td>
</tr>
<tr>
<td></td>
<td>Read(10)</td>
<td>Pending</td>
<td>13766.591_8</td>
<td>2</td>
<td>1408</td>
<td>207</td>
<td>020000</td>
<td>010000</td>
</tr>
<tr>
<td></td>
<td>Read(10)</td>
<td>Pending</td>
<td>13382.434_6</td>
<td>3</td>
<td>800</td>
<td>25E</td>
<td>020000</td>
<td>010000</td>
</tr>
<tr>
<td></td>
<td>Read(10)</td>
<td>Pending</td>
<td>13344.095_7</td>
<td>4</td>
<td>C08</td>
<td>208</td>
<td>020000</td>
<td>010000</td>
</tr>
<tr>
<td></td>
<td>Write(10)</td>
<td>Pending</td>
<td>13305.773_4</td>
<td>5</td>
<td>4000</td>
<td>24C</td>
<td>020000</td>
<td>010000</td>
</tr>
<tr>
<td></td>
<td>Write(10)</td>
<td>Pending</td>
<td>13267.437_5</td>
<td>6</td>
<td>4408</td>
<td>22B</td>
<td>020000</td>
<td>010000</td>
</tr>
<tr>
<td></td>
<td>Read(10)</td>
<td>Pending</td>
<td>83.322_4</td>
<td>7</td>
<td>1800</td>
<td>1F0</td>
<td>020000</td>
<td>010000</td>
</tr>
<tr>
<td></td>
<td>Read(10)</td>
<td>Pending</td>
<td>10723.172_9</td>
<td>3</td>
<td>1000</td>
<td>630</td>
<td>020100</td>
<td>010100</td>
</tr>
<tr>
<td></td>
<td>Read(10)</td>
<td>Pending</td>
<td>10703.137_7</td>
<td>4</td>
<td>1408</td>
<td>597</td>
<td>020100</td>
<td>010100</td>
</tr>
<tr>
<td></td>
<td>Read(10)</td>
<td>Pending</td>
<td>10347.069_3</td>
<td>5</td>
<td>800</td>
<td>57E</td>
<td>020100</td>
<td>010100</td>
</tr>
<tr>
<td></td>
<td>Read(10)</td>
<td>Pending</td>
<td>10327.037_1</td>
<td>6</td>
<td>C08</td>
<td>5E6</td>
<td>020100</td>
<td>010100</td>
</tr>
<tr>
<td></td>
<td>Read(10)</td>
<td>Pending</td>
<td>9620.183_6</td>
<td>7</td>
<td>4000</td>
<td>5E3</td>
<td>020100</td>
<td>010100</td>
</tr>
<tr>
<td></td>
<td>Read(10)</td>
<td>Pending</td>
<td>9600.152_6</td>
<td>8</td>
<td>4408</td>
<td>58A</td>
<td>020100</td>
<td>010100</td>
</tr>
<tr>
<td></td>
<td>Write(10)</td>
<td>Pending</td>
<td>7609.912_6</td>
<td>9</td>
<td>2000</td>
<td>551</td>
<td>020100</td>
<td>010100</td>
</tr>
<tr>
<td></td>
<td>Write(10)</td>
<td>Pending</td>
<td>7521.600_6</td>
<td>10</td>
<td>2408</td>
<td>593</td>
<td>020100</td>
<td>010100</td>
</tr>
<tr>
<td></td>
<td>Write(10)</td>
<td>Pending</td>
<td>6164.569_8</td>
<td>11</td>
<td>2800</td>
<td>572</td>
<td>020100</td>
<td>010100</td>
</tr>
<tr>
<td></td>
<td>Write(10)</td>
<td>Pending</td>
<td>6107.956_5</td>
<td>12</td>
<td>C08</td>
<td>595</td>
<td>020100</td>
<td>010100</td>
</tr>
<tr>
<td></td>
<td>Write(10)</td>
<td>Pending</td>
<td>4852.116_2</td>
<td>13</td>
<td>3000</td>
<td>5C7</td>
<td>020100</td>
<td>010100</td>
</tr>
<tr>
<td></td>
<td>Write(10)</td>
<td>Pending</td>
<td>4813.795_4</td>
<td>14</td>
<td>3408</td>
<td>5E4</td>
<td>020100</td>
<td>010100</td>
</tr>
</tbody>
</table>
Debug Example 3 – Analyzer Placement

Place analyzers and capture on both ends of the fabric.
Debug Example 3 - Dropped Frames

Out of Order Frame by Src/Dst

<table>
<thead>
<tr>
<th>Description</th>
<th>Timestamp</th>
<th>Source</th>
<th>Destination</th>
<th>Port Name</th>
<th>Type</th>
<th>Total Count</th>
<th>Value1</th>
<th>Value2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Out of Order Frame by Src/Dst</td>
<td>122001789.613_5</td>
<td>FC Port(1,1,3)</td>
<td>FC Port(1,1,2)</td>
<td>1,1,1 / 1,1,2</td>
<td>CrossPort</td>
<td>3</td>
<td>Time Detected 122001800.506_3</td>
<td>Delta Time 10.8927 (us)</td>
</tr>
</tbody>
</table>
### Debug Example 3 - Frame Tracing

<table>
<thead>
<tr>
<th>Frame</th>
<th>Analyzer 1</th>
<th>Analyzer 2</th>
<th>FC4SD</th>
<th>Data</th>
<th>Time</th>
<th>Channel</th>
<th>MAC</th>
<th>EID</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>122001787 915</td>
<td>Analyzer 1</td>
<td>FC4SD</td>
<td>Data</td>
<td>00005000</td>
<td>010D00</td>
<td>C80001</td>
<td>B711A419</td>
</tr>
<tr>
<td>2</td>
<td>122001787 943</td>
<td>Analyzer 2</td>
<td>FC4SD</td>
<td>Data</td>
<td>00008800</td>
<td>010D00</td>
<td>C80001</td>
<td>D7682A1E</td>
</tr>
<tr>
<td>3</td>
<td>122001788 563</td>
<td>Analyzer 2</td>
<td>FC4SD</td>
<td>Data</td>
<td>00009000</td>
<td>010D00</td>
<td>C80001</td>
<td>B17A710F</td>
</tr>
<tr>
<td>4</td>
<td>122001788 887</td>
<td>Analyzer 2</td>
<td>FC4SD</td>
<td>Data</td>
<td>00005800</td>
<td>010D00</td>
<td>C80001</td>
<td>B994FF95</td>
</tr>
<tr>
<td>5</td>
<td>122001790 235</td>
<td>Analyzer 2</td>
<td>FC4SD</td>
<td>Data</td>
<td>00009800</td>
<td>010D00</td>
<td>C80001</td>
<td>91E39D02</td>
</tr>
<tr>
<td>6</td>
<td>122001791 377</td>
<td>Analyzer 2</td>
<td>FC4SD</td>
<td>Data</td>
<td>0000A000</td>
<td>010D00</td>
<td>C80001</td>
<td>56C8A9F1</td>
</tr>
<tr>
<td>7</td>
<td>122001791 883</td>
<td>Analyzer 2</td>
<td>FC4SD</td>
<td>Data</td>
<td>0000E800</td>
<td>010D00</td>
<td>C80001</td>
<td>50A37CE7</td>
</tr>
<tr>
<td>8</td>
<td>122001791 939</td>
<td>Analyzer 2</td>
<td>FC4SD</td>
<td>Data</td>
<td>0000A000</td>
<td>010D00</td>
<td>C80001</td>
<td>730927B0</td>
</tr>
<tr>
<td>9</td>
<td>122001792 501</td>
<td>Analyzer 2</td>
<td>FC4SD</td>
<td>Data</td>
<td>0000A000</td>
<td>010D00</td>
<td>C80001</td>
<td>5B7E4527</td>
</tr>
<tr>
<td>10</td>
<td>122001792 860</td>
<td>Analyzer 2</td>
<td>FC4SD</td>
<td>Data</td>
<td>0000B000</td>
<td>010D00</td>
<td>C80001</td>
<td>0F1478BF</td>
</tr>
<tr>
<td>11</td>
<td>122001793 480</td>
<td>Analyzer 2</td>
<td>FC4SD</td>
<td>Data</td>
<td>0000B000</td>
<td>010D00</td>
<td>C80001</td>
<td>1D5F23B</td>
</tr>
<tr>
<td>12</td>
<td>122001794 025</td>
<td>Analyzer 2</td>
<td>FC4SD</td>
<td>Data</td>
<td>00007000</td>
<td>010D00</td>
<td>C80001</td>
<td>097FADA9</td>
</tr>
<tr>
<td>13</td>
<td>122001794 535</td>
<td>Analyzer 2</td>
<td>FC4SD</td>
<td>Data</td>
<td>0000C000</td>
<td>010D00</td>
<td>C80001</td>
<td>3D1616EC</td>
</tr>
<tr>
<td>14</td>
<td>122001795 157</td>
<td>Analyzer 2</td>
<td>FC4SD</td>
<td>Data</td>
<td>0000C800</td>
<td>010D00</td>
<td>C80001</td>
<td>CF45F48C</td>
</tr>
<tr>
<td>15</td>
<td>122001796 249</td>
<td>Analyzer 2</td>
<td>FC4SD</td>
<td>Data</td>
<td>0000D000</td>
<td>010D00</td>
<td>C80001</td>
<td>8CA112B4</td>
</tr>
<tr>
<td>16</td>
<td>122001796 329</td>
<td>Analyzer 2</td>
<td>FC4SD</td>
<td>Data</td>
<td>0000B800</td>
<td>010D00</td>
<td>C80001</td>
<td>EECD7557</td>
</tr>
<tr>
<td>17</td>
<td>122001797 947</td>
<td>Analyzer 1</td>
<td>FC4SD</td>
<td>Data</td>
<td>00008800</td>
<td>010D00</td>
<td>C80001</td>
<td>D7682A1E</td>
</tr>
<tr>
<td>18</td>
<td>122001797 923</td>
<td>Analyzer 2</td>
<td>FC4SD</td>
<td>Data</td>
<td>0000E000</td>
<td>010D00</td>
<td>C80001</td>
<td>6D781F5C</td>
</tr>
<tr>
<td>19</td>
<td>122001798 545</td>
<td>Analyzer 2</td>
<td>FC4SD</td>
<td>Data</td>
<td>0000E800</td>
<td>010D00</td>
<td>C80001</td>
<td>4359B55</td>
</tr>
<tr>
<td>20</td>
<td>122001799 598</td>
<td>Analyzer 2</td>
<td>FC4SD</td>
<td>Data</td>
<td>0000F000</td>
<td>010D00</td>
<td>C80001</td>
<td>32CF1B04</td>
</tr>
<tr>
<td>21</td>
<td>122001800 220</td>
<td>Analyzer 2</td>
<td>FC4SD</td>
<td>Data</td>
<td>0000F800</td>
<td>010D00</td>
<td>C80001</td>
<td>8C121770</td>
</tr>
<tr>
<td>22</td>
<td>122001800 506</td>
<td>Analyzer 1</td>
<td>FC4SD</td>
<td>Data</td>
<td>0000A800</td>
<td>010D00</td>
<td>C80001</td>
<td>5B7E4527</td>
</tr>
<tr>
<td>23</td>
<td>122001802 501</td>
<td>Analyzer 1</td>
<td>FC4SD</td>
<td>Data</td>
<td>0000B000</td>
<td>010D00</td>
<td>C80001</td>
<td>0F1478BF</td>
</tr>
</tbody>
</table>

Frame 1 seen on Analyzer 2 and then on Analyzer 1.
Debug Example 3 - Frame Tracing

Frames 3, 4, 5 are dropped enroute and cannot be seen on Analyzer 1.

Frame 1, 2 and 6 seen on Analyzer 2 and then on Analyzer 1.
Benefits of Purposeful Error Injection and Packet Modification in FC0

- Create specific “errors” to test fabrics and their capacity to recover from failure scenarios, examples:
  - Emulate Cable Pull testing (force disconnect/reconnect)
  - Alter Speed-Negotiation advertisement, add Transmitter Training Errors
  - Alter Primitives
    - Ex. change SoF1 to EOF
    - Introduce latency
- Stress Test Fabric-Link Participants
- Replicate Customer environments/issues
- Optimize Error recovery algorithms
Benefits of Purposeful Error Injection in Transmitter Training Routines

• Test fabrics participants and their capacity to recover from failure scenarios, examples;
  – Alter Speed-Negotiation advertisement, add Transmitter Training Errors
  – Introduce latency in the linkup exchange

• Modify Transmitter Training Control and Status Field exchanges to examine link interoperation
  – TT sequence has a greater impact with the increase of fabric speeds
    • Modify Control Field values
      – Change EXTENDED MARKER value
      – Turn “Off” FECReq
      – Turn “On” Parallel Lane Support
    • Modify Status Field values
      – Change FECCap value
      – Spoof Coefficient status
  – Modify values to unexpected or “bad” values

• Establish worse case limitations
• Emulate link partner characteristics
Benefits of Purposeful Error Injection and FEC Effects

• Testing FEC Limitations
  – FEC is mandatory in PAM4 fabrics
  – How do the link participants respond to Correctable Errors
  – How do the link participants respond to Uncorrectable Errors

• Insertion of FEC decay conditions errors

• Characterize the capabilities of the fabric under examination!
FC-1, Link Layer

• Supports the Specifics for Link Control including:
  – Ordered Sets
    • Frame Delimiters
      – SOF, EOF
    • Primitive Signaling
      – Idles, R_RDY, ARB
  – Primitive Sequences
    – LR, LRR, NOS, OLS
  – Encoding/Decoding
  – Transmitter Training

• Characterize the transactions
  – Timing, Control Messaging, Verification
Benefits of Purposeful Error Injection and Packet Modification in FC1

- Create specific TX/RX conditions to test link recovery
  - Alter Primitives
    - Change SOF to EOF
    - Force ABTS
  - Force Link Resets
    - Force link failure to test link failover
    - Change R_RDY to IDLE
    - Change LRR to IDLE
- Test/Optimize Error recovery algorithms
Errors in FC2 Framing Protocol

• Create specific Framing/Exchange errors to test framing
  – Alter Class of Service parameters
  – Change OX_ID or RX_ID information
  – Modify SEQ_ID count
  – Change Frame/Data/Link control values
  – Introduce ABTS
  – Obfuscate Buffer to Buffer Credits

• May be required of FW and Driver Engineering teams
Example #1, BBC Jamming

- Emulating Credit Starvation by modifying BBC response, turn R_RDY into IDLE or OLS – Continuous, One Time, Variable
  - Test the effects of maximum Link budget and latency characteristics
Extended Link Services

• Common ELS Commands and Response
  - PLOGI
  - FLOGI
  - PRLI
  - PRLO
  - LS_ACC
  - LS_RJT
Example #2, ELS Jamming

- Port Login on **S_ID 010300**
- Modify ELS Request to reduce initially reported Buffer to Buffer Credits – Continuous jam
Example #3, ELS Jamming

- Port Login on S_ID FFFFFA
- Modify ELS Reply to Reject PLOGI – One time or Continuous jam
FC-NVMe Jamming Example #4

FC-NVMe Host

NVMe Command
Jam the Queue ID (Connection ID)

No response from Target as the QID is not recognized.

Host Aborts the command

Target completes the abort

Host Retries the command

Target completes the command successfully

FC-NVMe Target
1) NVMe Connection ID Jammed from 0xF03 -> 0xFF2.
   • Host sent a command to a valid queue ID 0x03
   • Target receives a command to unknown queue 0xF2
   • Target ignores the command and doesn’t send a response.
2) Host times out after about ~21 seconds and issues an NVMe Abort to Abort the jammed command
3) Target completes the abort
4) Host sends a ABTS (FC layer)
5) Host retries the command with the correct Connection ID 0xFF2
6) Target Completes the command successfully.
Our Next FCIA Webcast:

Fibre Channel Zoning Basics

June 27, 2019
10:00 am PT/1:00 pm ET

Register at:
https://www.brighttalk.com/webcast/14967/355259
After this Webcast

• Please rate this event – we value your feedback
• We will post a Q&A blog at http://fibrechannel.org/ with answers to all the questions we received today
• Follow us on Twitter @FCIAnews for updates on future FCIA webcasts
• Visit our library of FCIA on-demand webcasts at http://fibrechannel.org/webcasts/ to learn about:
  – Fibre Channel Fundamentals
  – FC-NVMe
  – Long Distance Fibre Channel
  – Fibre Channel Speedmap
  – FCIP (Extension): Data Protection and Business Continuity
  – Fibre Channel Performance
  – FICON
  – Fibre Channel Cabling
  – 64GFC
Thank You