High speed data networks in CMS

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on behalf of the CMS DAQ group

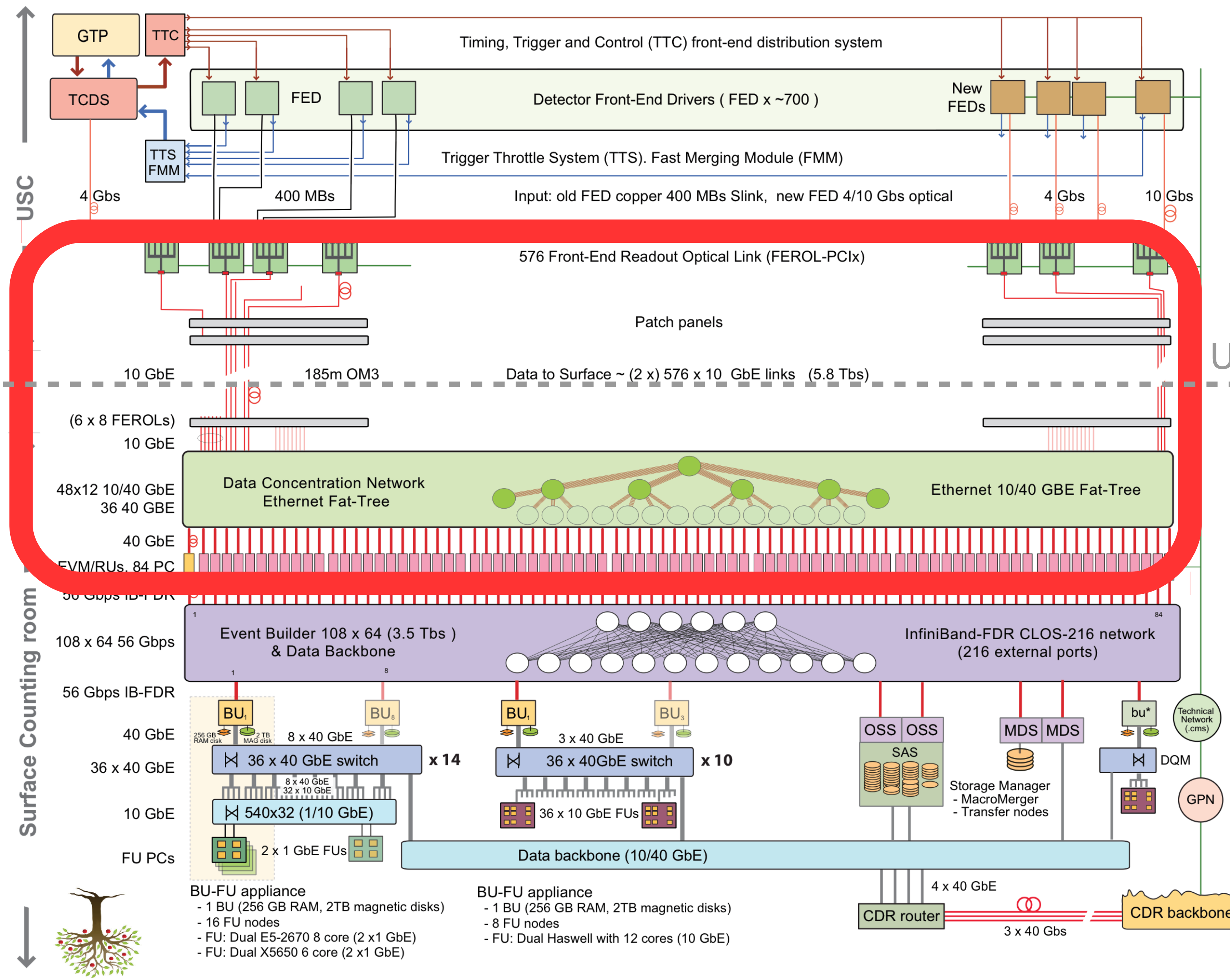
Overview

- Ethernet data concentrator network
  - Fat tree topology
  - long lasting TCP connections: importance of hash functions
- Infiniband
  - custom forwarding tables for improved performance
  - blocking counters

(Fat-Tree)

Data Concentration Ethernet Network in CMS

Data Concentration Network

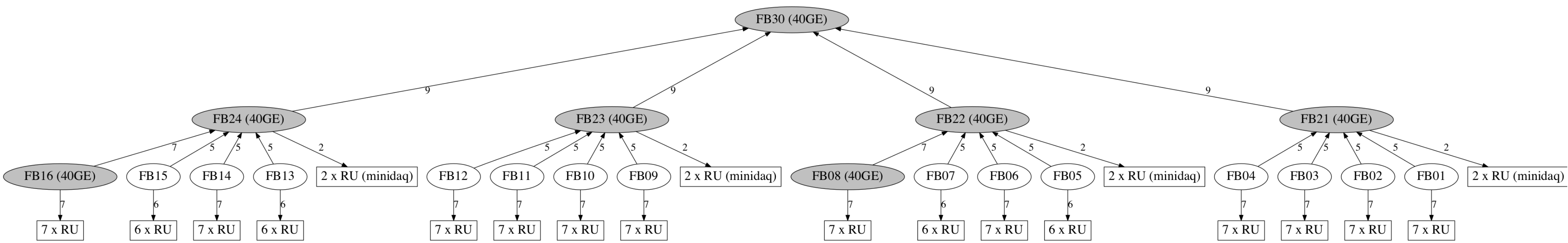


BU-FU appliance
- 1 BU (256 GB RAM, 2TB magnetic disks)
- 16 FU nodes
- FU: Dual E5-2670 8 core (2 x1 GbE)
- FU: Dual X5650 6 core (2 x1 GbE)

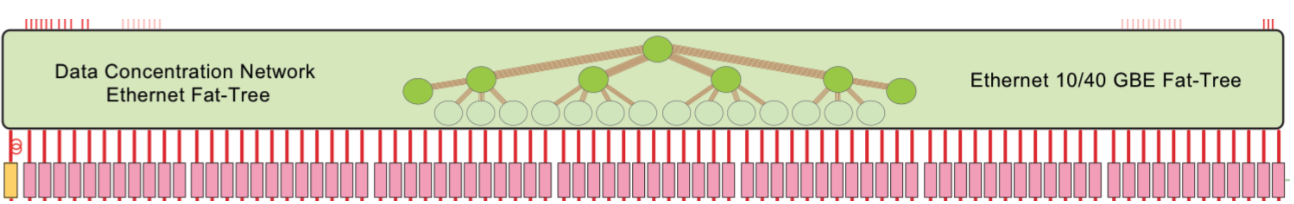
BU-FU appliance
- 1 BU (256 GB RAM, 2TB magnetic disks)
- 8 FU nodes
- FU: Dual Haswell with 12 cores (10 GbE)

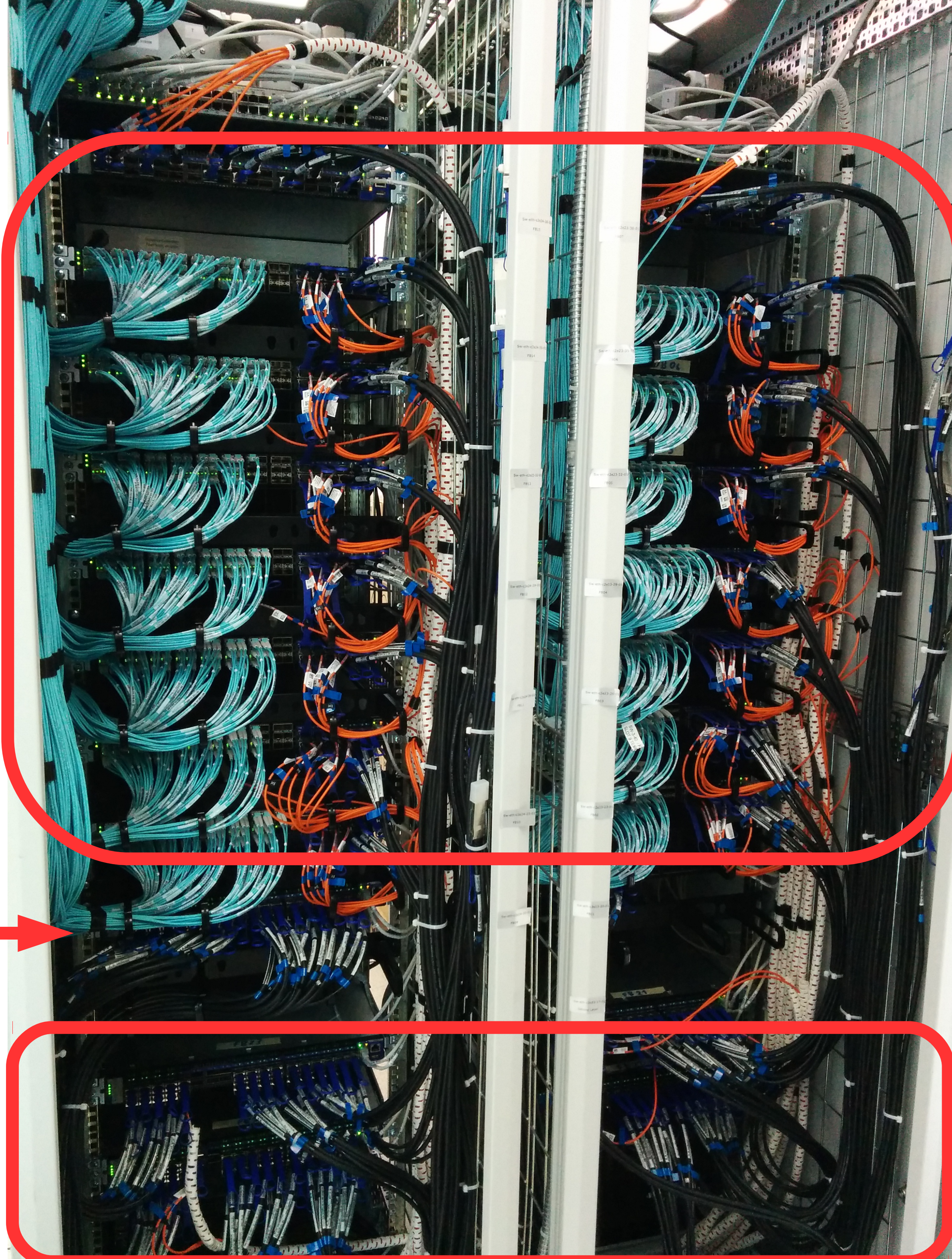
Data Concentration Network

- Plays a key part in data concentration
  - Sources 10GbE optical links from ~600 FEROLs (10 GbE TCP/IP)
  - Sinks 40GbE optical links to 108 Readout Units (RU)
  - Designed as a Fat-Tree Network with three switching layers



  - FEROLs and RUs connected to leaf switches
  - 360 Gbit/s between top and middle layer
  - 200/280 Gbit/s between leaf and middle layer





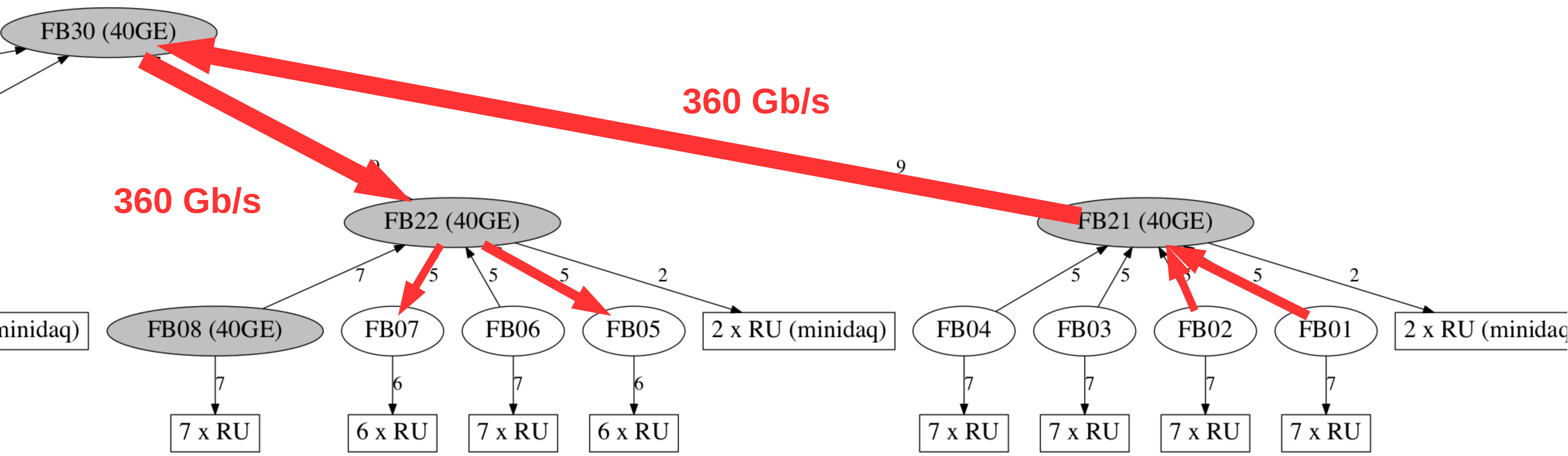
120 copper
cables deployed

Leaf switches
14x 10/40GbE
2x 40 GbE

Top layer
1x 40GbE

Middle layer
4x 40GbE SX1036

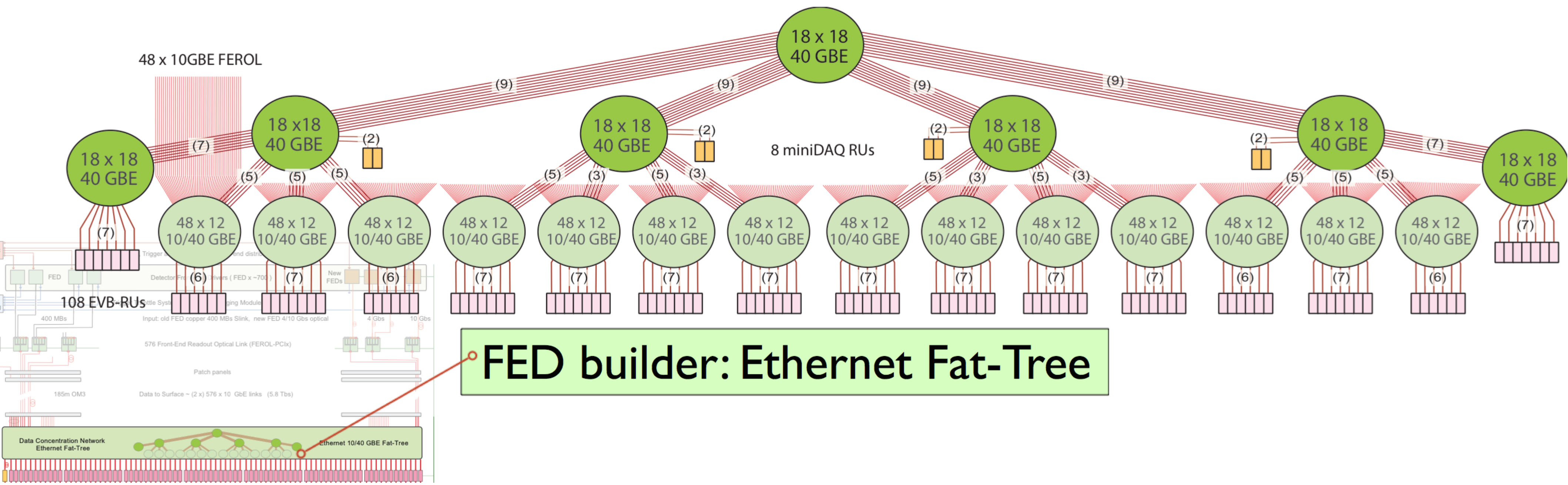
The Fattest Test




```
9x iperf running in parallel:
Connecting to host ru-c2e12-24-01.fbs0v0.cms, port 5201: [  4] 0.00-10.00  sec  39.5 Gbits/sec
Connecting to host ru-c2e12-25-01.fbs0v0.cms, port 5201: [  4] 0.00-10.00  sec  39.6 Gbits/sec
Connecting to host ru-c2e12-26-01.fbs0v0.cms, port 5201: [  4] 0.00-10.00  sec  39.6 Gbits/sec
Connecting to host ru-c2e14-24-01.fbs0v0.cms, port 5201: [  4] 0.00-10.00  sec  39.6 Gbits/sec
Connecting to host ru-c2e14-25-01.fbs0v0.cms, port 5201: [  4] 0.00-10.00  sec  39.6 Gbits/sec
Connecting to host ru-c2e12-30-01.fbs0v0.cms, port 5201: [  4] 0.00-10.00  sec  39.6 Gbits/sec
Connecting to host ru-c2e12-34-01.fbs0v0.cms, port 5201: [  4] 0.00-10.00  sec  39.6 Gbits/sec
Connecting to host ru-c2e12-35-01.fbs0v0.cms, port 5201: [  4] 0.00-10.00  sec  39.5 Gbits/sec
Connecting to host ru-c2e14-30-01.fbs0v0.cms, port 5201: [  4] 0.00-10.00  sec  39.5 Gbits/sec
```

DONE?

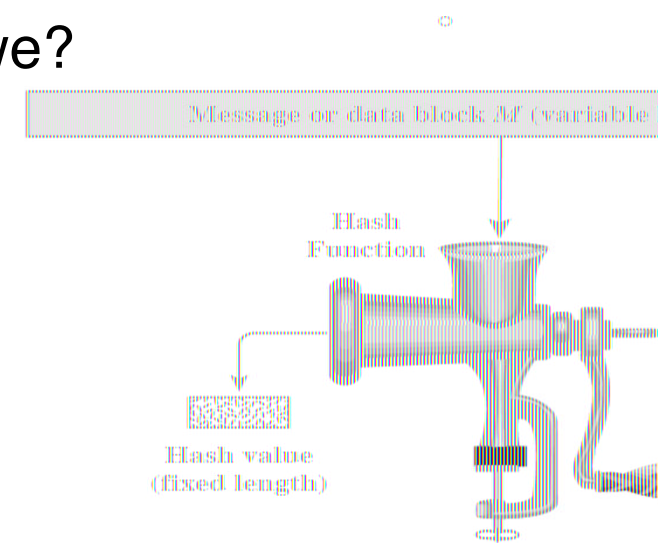
Fat-Tree and Link Aggregation



- A LAG (Link Aggregation Group) / port trunking
  - Combines a number of physical ports together to make a single high-bandwidth data path
  - Uses a load-balancing method (hash function) for packet distribution, usually a combination of
    - L2 (MAC Address)
    - L3 (IP address)
    - L4 (TCP/UDP port numbers)

Link Aggregation

- Hashing based on L2/L3/L4 is distributing network flows across the links in the LAG, hash collisions can happen!
- **Without explicit load balancing some links can be congested!**
  - Not good for long-lived data flows/streams
- **Idea: Since DAQ network is static and the actual traffic pattern is known, we can distribute the expected traffic evenly**
  - This will make use of full LAG bandwidth and eliminate any possible collisions
  - We need to know the HASH function! Can we?

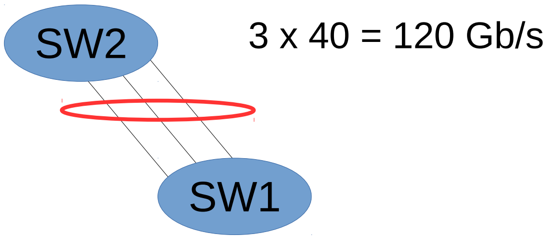


* http://www.answers.com/article/1163617/the-evolution-of-the-nist-secure-hash-algorithm-from-sha-1-to-sha-3

- Details of hash functions are usually not disclosed
- A LAG simulation software can be available
  - For a given network flow parameters (MAC, src/dst IP address and/or port number) it produces a LAG logical output port/link

- By using a parameter which can be easily changed (port numbers) a reverse hash table can be created

- Example: LAG with 3 links
  - Link 1: {1, 3, 4, 5, 6, 11, …}
  - Link 2: {7, 8, 9, 10, 18, 20, …}
  - Link 3: {2, 12, 13, 15, 16, 17, ...}



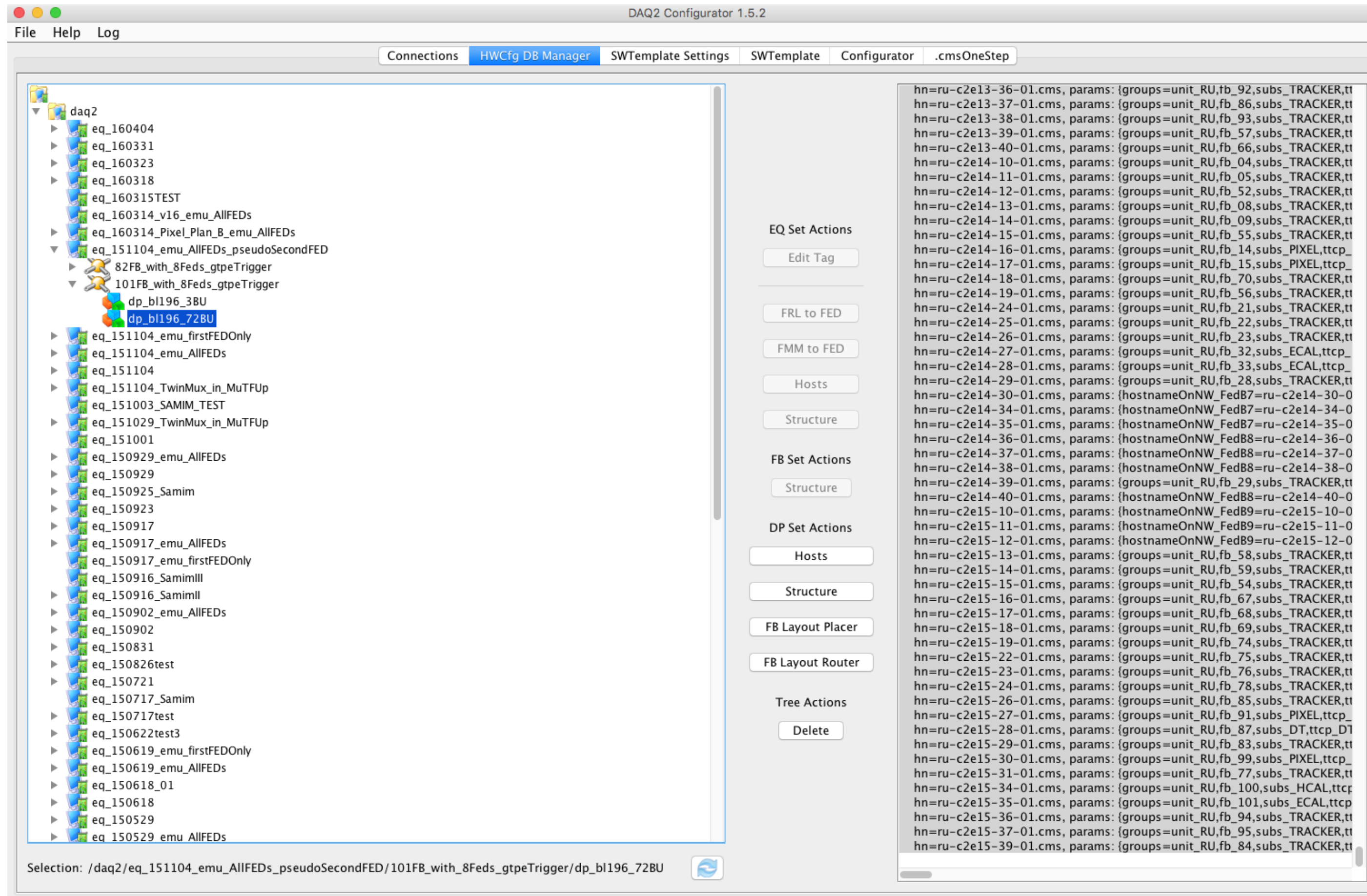
- We can force/bind a TCP/IP stream to a particular LAG port with some clever algorithm

Algorithm

- Problem is two fold (Place and Route)
  - Place part
    - Find a good destination (RU) for a given set of FEROL sources (FEDBuilder)
    - Minimize switch crossing
    - Do not exceed capacity of any physical link
  - Route part
    - Find a good source port assignments such as the hash function doesn't have collisions / network traffic don't overlap between LAG links
- Combinatorial problem with factorial time complexity
  - Greedy heuristics
    - for each destination (RU) a rank is calculated based on the network throughput it receives, number of FEROLs and number of hops
    - RU with the lowest rank is selected (placed)

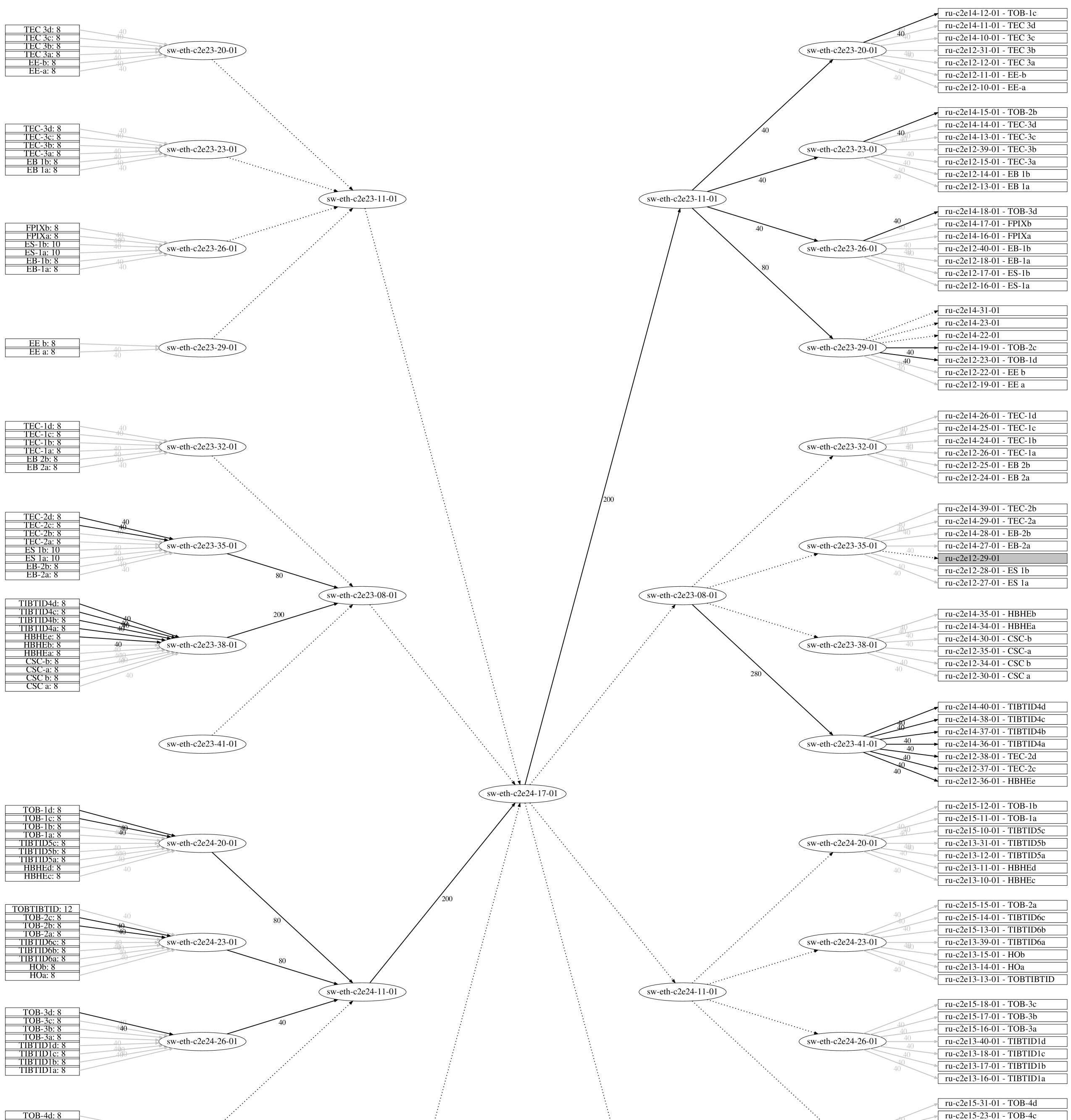
Implementation: DAQ Configurator

- Algorithms implemented in Java, part of DAQ Configurator tool:

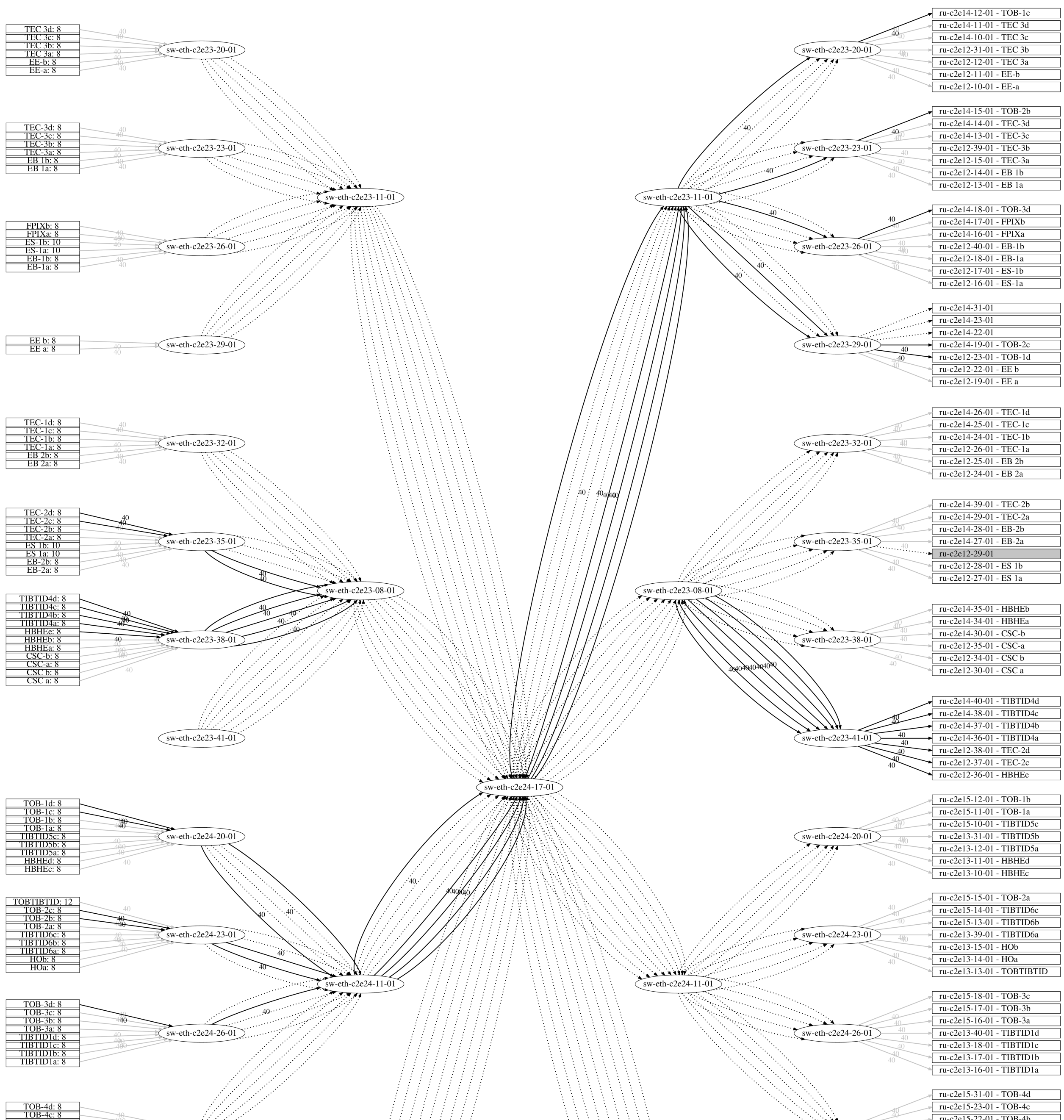



```
Switch to switch link occupancy:
sw-eth-c2e23-08-01 -> sw-eth-c2e23-41-01:  Sending 280 Gb/s over a 280 Gb/s link, i.e. 100% of the link bandwidth
sw-eth-c2e24-17-01 -> sw-eth-c2e23-11-01:  Sending 200 Gb/s over a 360 Gb/s link, i.e.  56% of the link bandwidth
sw-eth-c2e24-08-01 -> sw-eth-c2e24-41-01:  Sending 200 Gb/s over a 280 Gb/s link, i.e.  71% of the link bandwidth
sw-eth-c2e24-11-01 -> sw-eth-c2e24-17-01:  Sending 200 Gb/s over a 360 Gb/s link, i.e.  56% of the link bandwidth
sw-eth-c2e23-38-01 -> sw-eth-c2e23-08-01:  Sending 200 Gb/s over a 200 Gb/s link, i.e. 100% of the link bandwidth
sw-eth-c2e24-38-01 -> sw-eth-c2e24-08-01:  Sending 160 Gb/s over a 200 Gb/s link, i.e.  80% of the link bandwidth
sw-eth-c2e23-11-01 -> sw-eth-c2e23-29-01:  Sending 80 Gb/s over a 200 Gb/s link, i.e.  40% of the link bandwidth
...
```

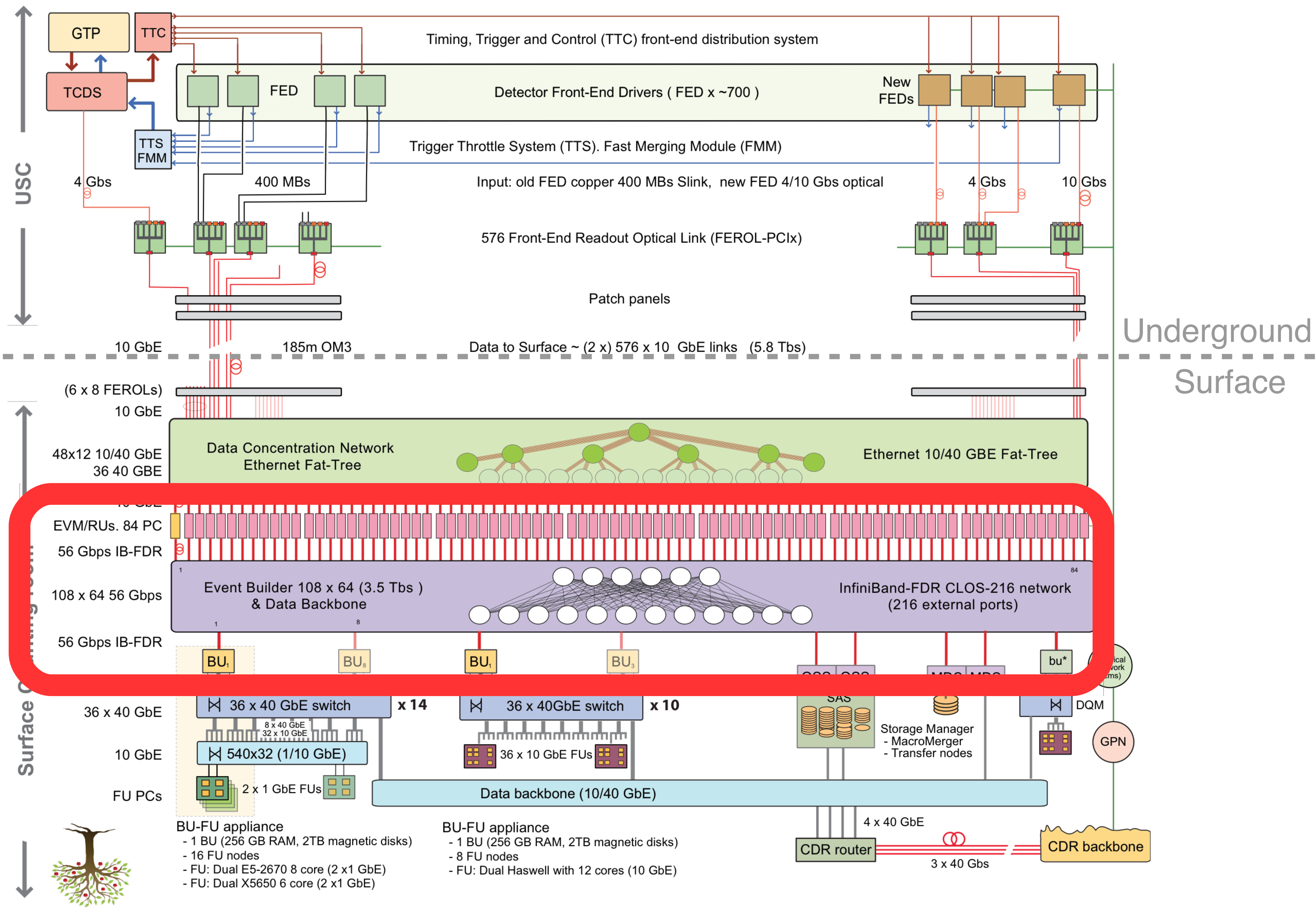
DAQ Configurator: RU Placing



DAQ Configurator: Stream Routing



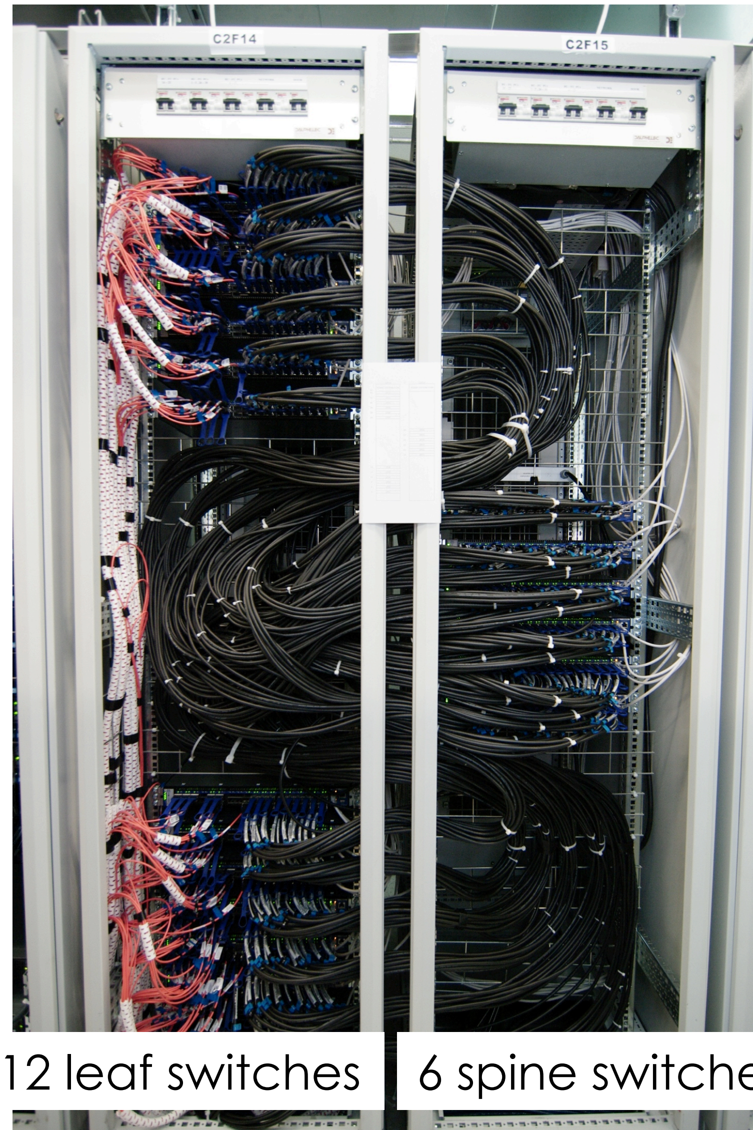
Infiniband Event Building Network



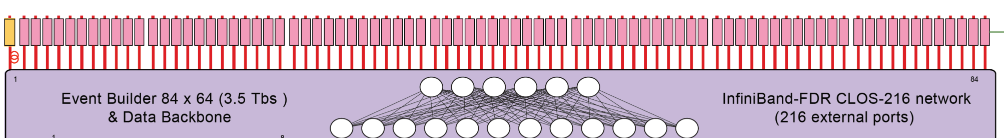
CMS Infiniband EVB network

- central part of event builder
  - assembles full events
  - all destinations need to receive from all sources
    - full NxM connectivity needed

- 12 leaf, 6 spine switches
- 36 FDR (56 GBit/s) ports per switch
- 3 links between each leaf/spine pair
- 18 x 12 = 216 external ports
  - **~ 6 Tbit/s** bandwidth



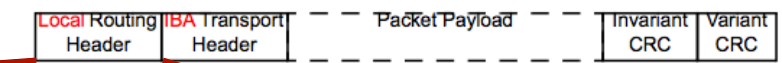
12 leaf switches | 6 spine switches



Infiniband forwarding

- Infiniband uses **Local Identifiers (LIDs)** for addressing
  - 16 bits
  - assigned **by subnet manager (SM)** when nodes or SM comes up
  - used in the Local Route Header:

Local (within a subnet) Packets



bits / bytes	31-24		23-16			15-8	7-0
0-3	VL	LVer	SL	Rsv2	LNH	Destination Local Identifier	
4-7	Reserve 5	Packet Length (11 bits)				Source Local Identifier	

- differences to other protocols:
  - does **not** allow strict source routing like Myrinet
    - all packets for a given destination LID go out on the same port on a given switch
      - no hash functions for trunks like for Ethernet
      - but **can have multiple LIDs per network card**
  - 16 bit LID can be seen as having the **same function as the 64 bit Ethernet MAC address**
    - instead of using a content addressable memory like in Ethernet switches, the **linear forwarding table (LFT)** is an array of 12 kBytes
      - address is destination LID
      - content is **output port**

Routing engines

- Subnet manager generates forwarding tables
  - Mellanox Infiniband switches have an embedded OpenSM
  - OpenSM can also be run on any server connected to Infiniband network
    - allows for more flexibility
  - each subnet manager is assigned a priority
    - highest priority manages the network
    - lower priority SM are in standby
- Available routing engines in OpenSM:
  - minhop (default)
  - updn
  - dnup
  - ftree
  - file
  - lash
  - dor
  - torus-2QOS
  - dfsssp
  - sssp

our default for folded Clos network

our gateway to our own static routing tables

Routing algorithm

- The default fat tree routing algorithm does **not assume anything about the actual traffic pattern**
  - should not matter in theory as long as one does send more than $\frac{\text{linespeed}}{\max(N,M)}$ from any of the N sources to any of the M destinations
  - in practice however:
    - our links are **temporarily oversubscribed ('bursty traffic')**
    - we must **wait for the slowest source**
    - **head of line blocking** is most likely an issue
- Idea: since we **know the actual traffic pattern**, we can **distribute the expected traffic evenly**
  - this should **eliminate bottlenecks**
  - make use of links which otherwise would have low utilization

Algorithm

- Problem formulation:
  - **minimize spread** of
    - number of communications over the **spine switches** or
    - number of communications over **the links between leaf and spine switches**
    - etc.
  - subject to:
    - do not exceed **capacity** of any link
    - communications to the same destination on a switch must continue over the same links

- Looks like a **combinatorial problem** with factorial time complexity
  - use a **heuristic**:
    - go through all (source → destination) pairs
      - assign route over leaf switch with least occupancy so far
        - if not already constrained by previous routing table entries

Implementation

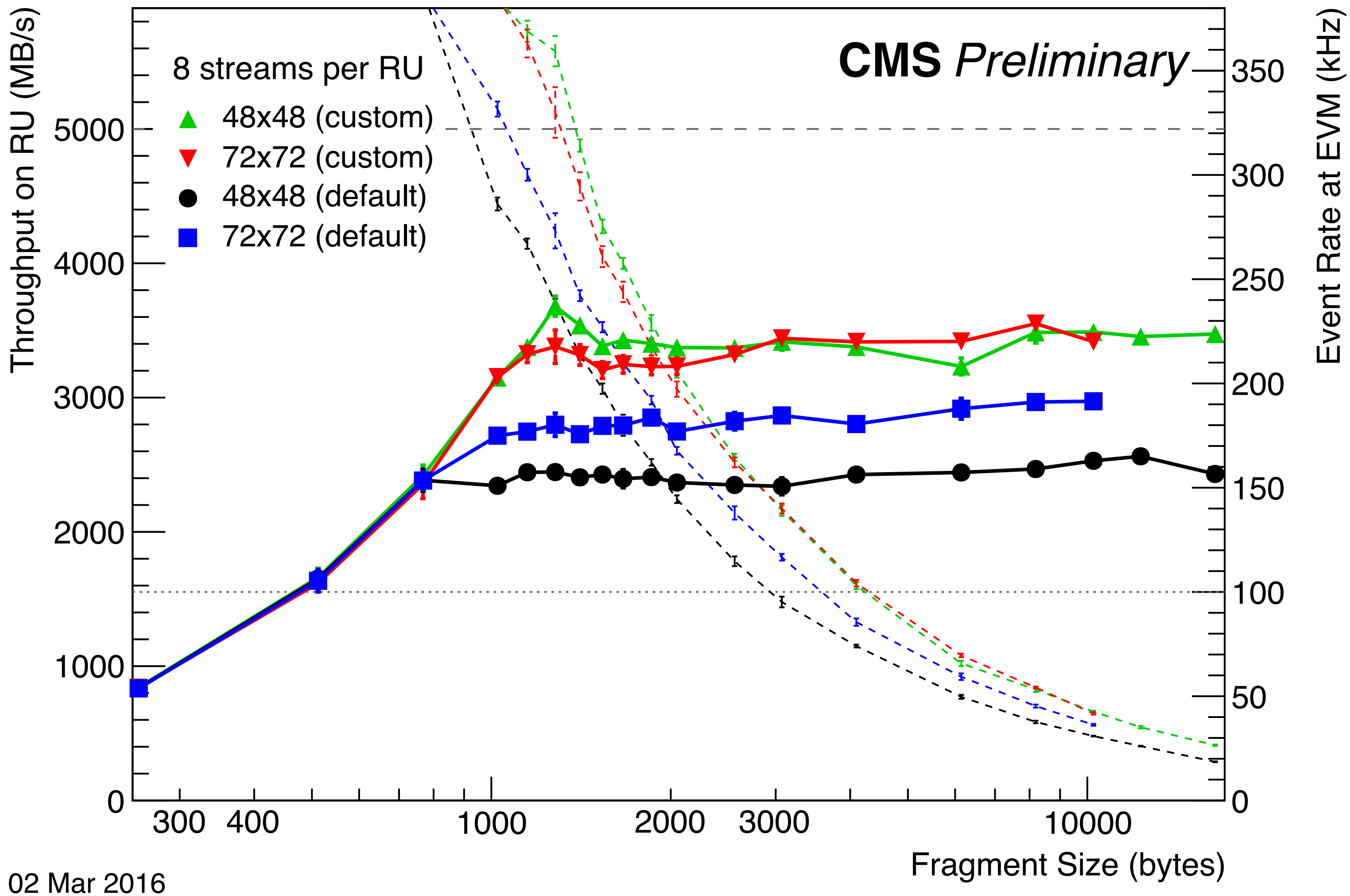
- Algorithm is implemented in python
  - ⊕ **fast turnaround** to try out new algorithms
  - ⊕ algorithm core separated from 'framework' code
  - ⊕ independent of OpenSM
  - ⊖ **only static** forwarding tables possible

    no adaptation to **actual throughput** as luminosity decreases with time

- Here be dragons:
  - during early stages of development, managed to bring down **the entire Infiniband network**, power cycle needed
  - need to assign **all** forwarding table entries, including those to LIDs of switches
    - diagnostics such as ibqueryerrors will not work otherwise

Performance

from Remi Mommsen's talk



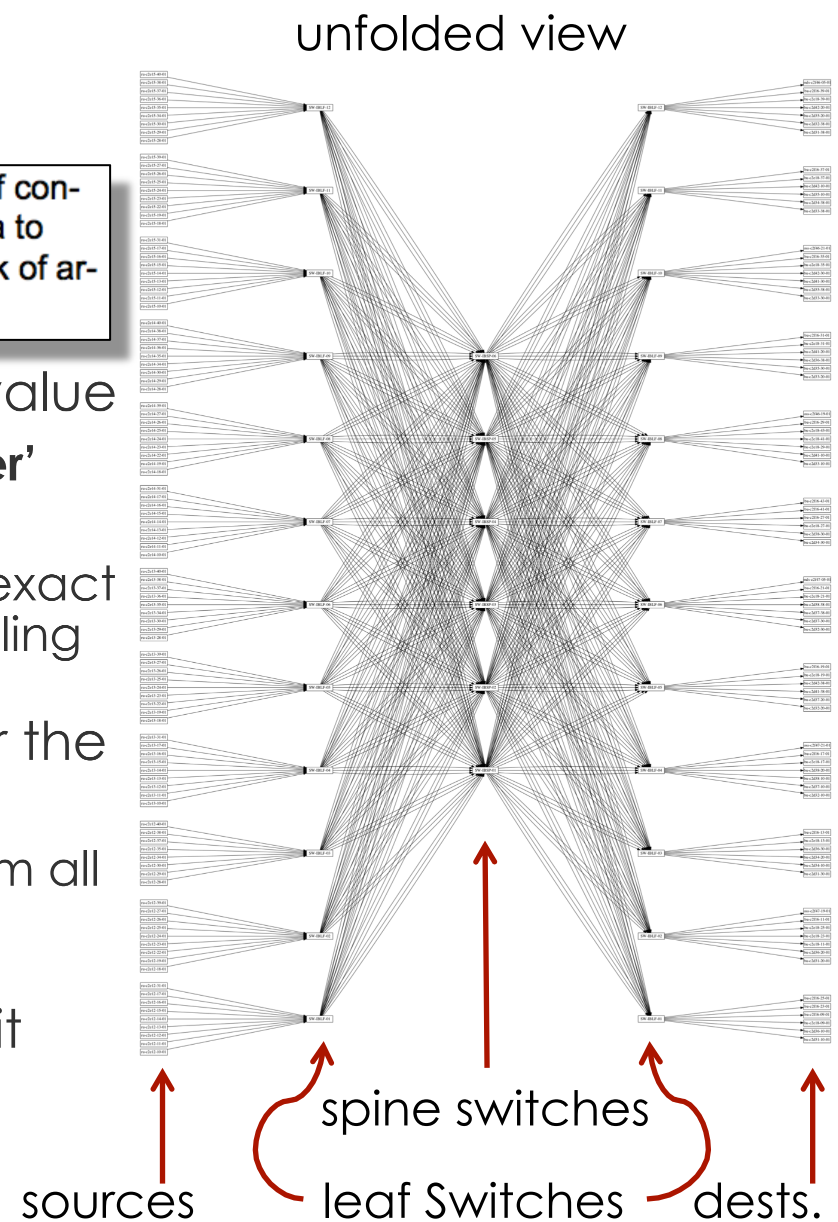
16 (40) % improvement for 72x72 (48x48) system
less sensitive to actual list of sources and destinations

Finding bottlenecks in the IB network

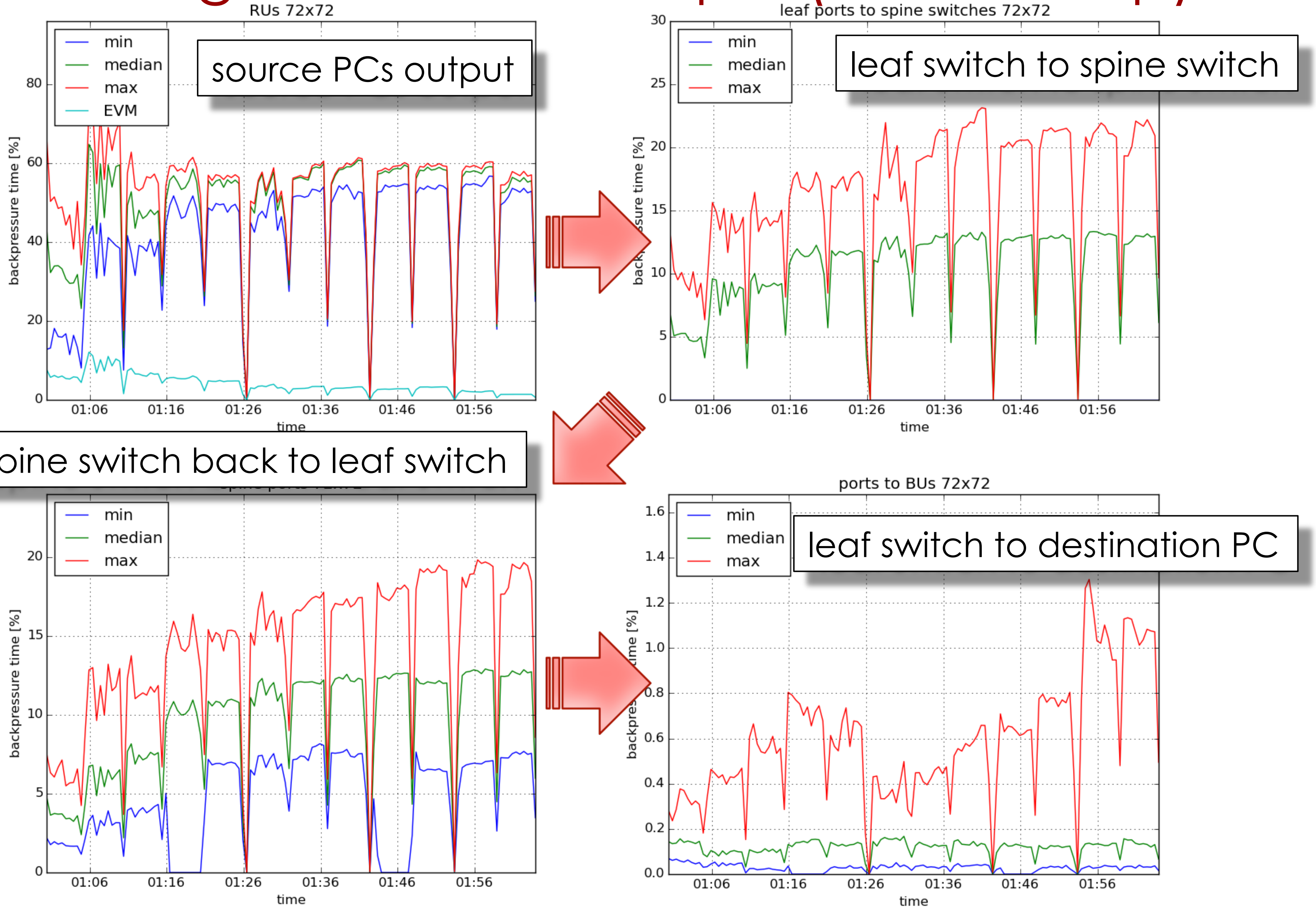
- Infiniband supports many diagnostic counters

> • PortXmitWait. This provides information on a potential victim of congestion. It is the number of ticks during which the port had data to transmit but was unable to because of a lack of credits or a lack of arbitration.

- Some confusion how to interpret the value
  - initially did not know about the '**multiplier' register** (factor 32…)
  - checked with manufacturer about the exact length of a 'tick' (depends on the signalling speed)
- These counters can be accessed over the network
  - **ibqueryerrors** allows to retrieve them from all ports in the network in one go
- we now periodically store PortXmitWait counter values in a database



blocking counters example (72x72 setup)



Summary / Outlook

- Ethernet:
  - installed a **fat tree** topology for **data aggregation**
    - gives us **additional flexibility** in case of PC failure
  - implemented a **configuration dependent routing**
    - knowledge of LAG hash functions vital

- Infiniband:
  - custom routing gives us **better use of the available capacity**
  - **diagnostic counters** are a useful tool to **identify bottlenecks** in the network
  - routing can potentially be improved by taking into account **actual fragment sizes**
  - use of **multiple virtual lanes** may reduce head of line blocking