TrbNet – The new trigger and readout network for HADES
Outline

- Why and how the old trigger network is replaced
  - Brief view of the network protocol
  - Features of the new network protocol
    - Performance measurements
Requirements – Why do we need a new network?

- too many different hardware types and protocols involved
- no feedback from modules
- length oriented data transfers
  - no handshake protocol, risk of buffer overflows
- bulky cables: hard to handle & introducing noise
**Requirements – What features are needed?**

- One network protocol for all connections including FEE readout
  - Easy to use & maintain

- One common network for triggers, data & slow control
  - Fast data transmission > 1 Gbit/s for data
  - Low latency < 5 µs for triggers

- Network transparent for applications
  - No application has to bother with network protocol

- Protocol adaptable to all hardware setups
  - Small boards need low hardware consumption
  - High performance network nodes

- Modular code design to easily change parts of logic
  - Network medium can be chosen for each link individually
  - Code is reusable in different configurations
Network Setup

- Optical networks and hubs connect all parts
  - Fast connections & negligible influence on detector
- Most boards are based on programmable logic (FPGAs)
  - Only a small number of different devices is used
- Processing algorithms can be applied to data during transport
  - Placement of IPU algorithms in FPGAs
Challenge: fast triggers & data on the same network

- Network is divided into channels
  - Transfers can run in „parallel“
  - Each channel uses independent resources despite network media

- Four channels will be used:
  - LVL1 trigger
  - IPU data
  - LVL2 trigger / data read-out
  - Slow control

- All data is transported as small packets with 64 bit
  - Channels can be switched very fast

<table>
<thead>
<tr>
<th>Channel / Path</th>
<th>Packet Type</th>
<th>Datawords</th>
</tr>
</thead>
<tbody>
<tr>
<td>63-56</td>
<td>55-51</td>
<td>50-48</td>
</tr>
<tr>
<td>reserved</td>
<td>Channel / Path</td>
<td>Packet Type</td>
</tr>
</tbody>
</table>
Features I: Slow Control

- All devices are connected to the same network
  - Slow control can be done from one terminal
- Every board has standardized status registers
  - Easy implementation of an overall status screen
- Multiple boards can be addressed simultaneously
  - One command to get the status of the whole electronics
- Detector specific control with additional registers
- Each board is identifiable by a network address and on-board ID
- Hubs can switch off individual ports
  - Exclude detectors with malfunctions from trigger distribution
Many responses to a transfer are a common case for the network

- All boards answer with a busy release packet after a trigger
- Front end electronics send their data after a readout request

Data from different endpoints is merged into one data stream inside hubs

- This is the first step of **event building**

Terminations (busy release) are merged into one packet

- CTS gets one packet back that shows the detector is ready to accept the next trigger
Event Data Format: Example

- All data is tagged with network address
  - No need for detector addresses in event format
- Redundant information can easily be extracted before writing data to tape
Trigger & Readout Process

- Fast trigger signal, FEE starts read-out
- Trigger code sent to FEE
- FEE finishes read-out
- Busy release received by CTS
- CTS triggers data transfer from FEE to IPU
- IPU starts algorithms
- IPU finished, data transported to MU
- Image data received by MU
- MU makes LVL2 trigger decision
- LVL2 trigger is sent / start of read-out
- All data sent to event builders
How to – Accessing the Network

- Sending / Receiving data is done by writing / reading data to / from a FIFO
- Additional ports for target address, type of transfer and error pattern
- Sending data is blocked during times where no transfer is allowed

→ applications can not harm the network with erroneously sent data
Test Setup

- TRBnet endpoints
- optical link (TRBnet)
- LVDS (TRBnet)
- Ethernet
• longest connection: CTS to MDC FEE (optical)

  ↪ CTS, 2 layers of hubs, TRB w. MDC concentrator, MDC frontend

  ↪ 2 Xilinx, 4 Lattice FPGAs

  ↪ 4 optical links, 1 LVDS connection

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Packet Sizes</td>
<td>50   ns</td>
</tr>
<tr>
<td>Hub data handling</td>
<td>100  ns</td>
</tr>
<tr>
<td>10m optical fiber</td>
<td>60   ns</td>
</tr>
<tr>
<td>Xilinx Transmit &amp; Receive</td>
<td>180 ns</td>
</tr>
<tr>
<td>Lattice Transmit &amp; Receive</td>
<td>400 ns</td>
</tr>
<tr>
<td>Sum for one transfer</td>
<td>2100 ns</td>
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</table>
**Trigger distribution and detector dead time**

- LVL1 trigger signal is distributed using high speed cable
- Trigger code is sent over TrbNet
  - Arrives up to 2 µs after the fast trigger signal
- Release signal is sent by each detector when read out is finished
  - Transport of busy release adds 2 µs to the total detector dead time
- But: busy release can be sent earlier, if
  - ... FEE can accept another trigger before having processed last one
  - ... FEE busy time ends within 2 µs
### Performance – How fast is it?

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
<th>Rate (Gbit/s)</th>
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</thead>
<tbody>
<tr>
<td>Bandwidth of optical links</td>
<td>100%</td>
<td>1.6</td>
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<tr>
<td>Addressing &amp; Locking</td>
<td>&lt; 1%</td>
<td>0</td>
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<tr>
<td>Packet Format</td>
<td>25%</td>
<td>0.4</td>
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<tr>
<td>Handshake protocol</td>
<td>1%</td>
<td>0.02</td>
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<tr>
<td>Detector data</td>
<td></td>
<td>1.18</td>
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</tbody>
</table>

- 26% of bandwidth is used for protocol, 74% are available for data

- Other media available
  - LVDS via SCSI cable: cur. 200 Mbit/s
  - LVDS via AddOn connector: 1.6 Gbit/s

- Data rate of complete detector after LVL1 trigger: 3 Gbit/s
  - 1.2 Gbit/s are sufficient due to decentralized read out
Summary & Outlook

- Network protocol, network endpoints and hubs are almost finished
- Performance meets the requirements for high trigger rates
- Easy adaption to new devices / requirements is possible
- A lot of future extensions are possible
  - Higher network speeds
  - Switches with routing functions instead of hubs
- TrbNet is a universal network protocol, not for HADES only
  - Detector test setups with data readout from multiple boards
  - Free running, triggerless detectors (with modifications)
TrbNet – The new trigger and readout network for HADES
Register Access: Example of a transfer

Channel number
Packet type

0031 f009 ffff 0018
0030 0080 0000 0000
0033 0000 0000 0018

0039 f00b f009 0018
0038 0080 fff0 05c8
0039 f00a f009 0018
0038 0080 1b20 16ce
0039 f006 f009 0018
0038 0080 0000 0000
0039 f007 f009 0018
0038 0080 0000 0000
003b 0001 0001 0010

- Warning: Temperature sensor of board F00B is not responding.
- Info: All temperatures are within normal range
Network layers

- Interface between application and network is divided into 3 layers
  - Application interface
    - ↔ adds header with addresses
    - ↔ controls access to network
  - IOBuf
    - ↔ assures data integrity (CRC)
    - ↔ avoids data loss using buffers and handshake
  - Media interface
    - ↔ prepares data for medium type
    - ↔ mostly optical links or LVDS
Application Interface / Streaming API
Network Layers

application

Data

application interface

HDR  Data  TRM

input & output buffer

HDR  Data  EOB  Data  EOB  Data  TRM

media interface

network connection

application

session layer

link layer

physical layer

application

session layer

link layer

physical layer
Table B.1: Register Definitions

<table>
<thead>
<tr>
<th>NAME</th>
<th>ADDRESS</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<th>7</th>
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<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
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<tbody>
<tr>
<td>Common Register 1</td>
<td>0000 h</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>error messages</td>
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<td></td>
<td></td>
<td></td>
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<td>trg mismatch</td>
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<td>Common Register 2</td>
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<td>trigger level 1 counter</td>
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<td>Board ROM 3</td>
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</table>

Table B.2: Packet type definitions

<table>
<thead>
<tr>
<th>NAME</th>
<th>VALUE</th>
<th>DESCRIPTION</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAT</td>
<td>0</td>
<td>Normal data word</td>
<td>Data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HDR</td>
<td>1</td>
<td>Header / Source change</td>
<td>Source Address</td>
<td>Target Address</td>
<td>sequence number / data type</td>
</tr>
<tr>
<td>EOB</td>
<td>2</td>
<td>End of Buffer</td>
<td>0</td>
<td>Data count</td>
<td>Checksum</td>
</tr>
<tr>
<td>TRM</td>
<td>3</td>
<td>Termination</td>
<td>Errorbits</td>
<td></td>
<td>sequence number / data type</td>
</tr>
<tr>
<td>EXT</td>
<td>4</td>
<td>Extended data word</td>
<td>checkum, other error detection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACK</td>
<td>5</td>
<td>Acknowledge</td>
<td>Length of Buffer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>—</td>
<td>6</td>
<td>—</td>
<td>—</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>ILL</td>
<td>7</td>
<td>Illegal word</td>
<td>—</td>
<td></td>
<td>ignore</td>
</tr>
</tbody>
</table>
Table 6.4: Logic resources needed for a full featured network endpoint with four channels and slow control capabilities. The numbers given for the individual components do not add up to the given number of the whole endpoint due to optimization processes done by the synthesis tool and differences in the configuration used on different channels.

<table>
<thead>
<tr>
<th>PART</th>
<th>NUMBER</th>
<th>SLICES</th>
<th>FF</th>
<th>LUT</th>
<th>BRAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>optical Media Interface</td>
<td>1</td>
<td>250</td>
<td>350</td>
<td>360</td>
<td>2</td>
</tr>
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<td>Multiplexer</td>
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<td>240</td>
<td>450</td>
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<td>full API</td>
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<td>280</td>
<td>300</td>
<td>510</td>
<td>2</td>
</tr>
<tr>
<td>trigger API</td>
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<td>30</td>
<td>40</td>
<td>50</td>
<td>0</td>
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<tr>
<td>Slow Control</td>
<td>1</td>
<td>360</td>
<td>320</td>
<td>620</td>
<td>0</td>
</tr>
<tr>
<td>Full Endpoint</td>
<td>1</td>
<td>2050</td>
<td>2300</td>
<td>3600</td>
<td>10</td>
</tr>
</tbody>
</table>