Performance and evolution of the ATLAS TDAQ system with pp collisions at 7 TeV

Takanori Kono (DESY)
for the ATLAS Collaboration

IEEE RealTime 2012
Berkeley, California, USA, 11-15 June, 2012

Introduction

- ATLAS Trigger & DAQ (TDAQ) system
 - System architecture
 - TDAQ operation in 2011
- Trigger performance
 - Challenges for the trigger
 - Signatures and performance
 - Improvements for 2012 data-taking
- Conclusion

ATLAS experiment

Inner Detector

- Pixel (pixel detector)
- SCT (silicon strip detector)
- TRT (transition radiation tracker)

Calorimeter

- LAr : EM calorimeter
- Tile: Fe/Scintillator tile

Muon spectrometer

- MDT, CSC : precise momentum measurement
- RPC, TGC : trigger chambers

Magnet system

- 2 T solenoid
- 0.5 T toroid

ATLAS Trigger and DAQ system

Design values

RoI = Region(s)
of interest: (η, ϕ)

- Three level trigger system
- Level-1
 - Hardware-based trigger using calorimeter and muon detectors
 - Triggers the readout from the frontend electronics
 - 40 MHz $\rightarrow$ ~65 kHz
- Level-2
 - Process data in Regions of Interest (Rois) or other subset
 - ~65 kHz $\rightarrow$ ~5.5 kHz
- Event Filter
 - Runs after the full event building
 - ~5.5 kHz $\rightarrow$ ~400 Hz
- Events are written out into “streams” based on the trigger

High Level Trigger (HLT, =L2+EF)

- Step-wise execution of several algorithms
 - Algorithms calculate physical quantities from event data (Object reconstruction)
 - Separate algorithms apply selection criteria
 - If the object fails, stop the proceeding steps
- Most trigger selections run in the RoI-based mode at both L2 and EF
- Example: (execution steps in the electron trigger)
 - **Step 1** : Requests **data from the calorimeters** and checks the quality of the EM cluster
 - **Step 2** : Requests **data from Inner Trackers** and checks the quality of the electron candidate
 - If the selection fails at step1, step 2 is not executed **which reduces the execution time and data access rates**

Data-taking in 2011/2012

- 2011 data-taking
 - $\sqrt{s}=7$ TeV, 50 ns bunch spacing
 - $\mathcal{L} \sim 3.7 \cdot 10^{33} \text{ cm}^{-2}\text{s}^{-1}$, $\int \mathcal{L} dt \sim 5 \text{ fb}^{-1}$
 - Continuous increase of the instantaneous luminosity ($2 \cdot 10^{32} \rightarrow 3.7 \cdot 10^{33} \text{ cm}^{-2}\text{s}^{-1}$) required improvements in the trigger selection to keep rates under control
 - Overall TDAQ efficiency: 94.9%
 - 2.7 PB of data recorded (4.7 M files)
- 2012 data-taking
 - $\sqrt{s}=8$ TeV, 50 ns bunch spacing
 - $\mathcal{L} \sim 6.6 \cdot 10^{33} \text{ cm}^{-2}\text{s}^{-1}$, $\int \mathcal{L} dt \sim 4 \text{ fb}^{-1}$ so far
 - Increased beam intensity
 - $\rightarrow$ Higher pile-up condition (additional pp interaction per bunch crossing)

TDAQ operation in 2011 (1)

L1, L2, EF rates in pp collision

- High L1 trigger rate
- System was **stressed in terms of bandwidth and data flow**
- Operate at the margin to get the most out of the system

Trigger rates in heavy ion collision

- Low L1 trigger rate (<10 kHz)
- Large event size and complex processing at the HLT
- System was **stressed in terms of computing power**

Successful data-taking in both types of runs

TDAQ operation in 2011 (2)

- Evolution of the trigger selections
- DAQ system capability
 - Requirement on DAQ resources depends on the trigger menu
 - HLT farm increased by ~50% (16 new racks) in 2011
 - L2/EF sharing of XPU racks is configurable run by run

Type	Racks	Nodes	Model	Cores	Memory
EF	14	448	E5540@2.53GHz	8	16 GB
XPU	11	341	E5420@2.50GHz	8	16 GB
XPU	25	904	X5650@2.67GHz	12	24 GB

(12 new racks replaced 16 old ones in 2012)

Readout System (ROS)

- Serves detector data fragments to L2 algorithms and Event Builder
- Performance can be limited by access rate, load or bandwidth
 - L2 algorithms must be aware of the limits
- Rolling replacement of old ROS PCs (75/153)

Challenges for trigger selections

- Luminosity increase
 - $L=2 \cdot 10^{32} \rightarrow 3.7 \cdot 10^{33} \text{ cm}^{-2}\text{s}^{-1}$ in 2011 ($6.5 \cdot 10^{33} \text{ cm}^{-2}\text{s}^{-1}$ in 2012)
- Pile-up condition
 - Average number of pile-up events $\langle \mu \rangle$: $8 \rightarrow 12$ (~ 30 in 2012)
 - Need to understand the impact of pile-up on each trigger
- Physics requirements
 - Despite harsher operational conditions, a lot of pressure to increase the acceptance of the analysis

- Rate reduction at all three trigger levels
- Developments in the TDAQ system to overcome technical implementations
- Efficiency vs. rate with tighter selection criteria

Trigger signatures

Calorimeter-based triggers

- Electron/Photon
- Tau (Hadronic tau decay)
- Jet / b-jet
- Missing transverse energy
- Transverse energy sum
- Missing E_T significance

Muon-based triggers

- Muon
- B-physics triggers

Combined triggers

- Require more than one signature in the event (e.g. lepton+ E_T^{miss})
- Topological cuts on combination of objects (angular correlation, invariant mass cut, etc.)

L1 trigger rate dependence on the luminosity

Impact of pile-up on TDAQ resources

- CPU usage and event size increases with higher pile-up
 - Linear dependence is observed so far
 - Expect up to 1.65 MB/event at peak luminosity (at $\langle\mu\rangle=35$)
 - Additional bandwidth to the storage system to meet the peak demand

Event sizes in different streams

L2 processing time

EF processing time

Electron and photon triggers

- Electron triggers evolved in order to keep rates under control
 - L1 threshold tuning: 14 $\rightarrow$ 16 GeV and apply η -dependent thresholds
 - Hadronic leakage cut at L1
 - Tighter selection at the HLT
- Photon triggers stable for most of the year
- Re-optimized identification cuts for 2012
 - Robustness against pile-up

Tau triggers

- Selects hadronically decaying tau lepton
 - Di-tau, tau+electron, tau+muon
 - tau+ E_T^{miss}
- Improvements for 2012 data-taking
 - Re-optimized selection cuts in order to be robust against pile-up
 - Multi-variate techniques (Boosted Decision Tree, Log likelihood) as used in offline identification

Jet

L2

EF

- Rol-based algorithm on cells or **full scan** using L1 trigger towers (L1.5 jet)
- Anti- k_T (FastJet) jets or cone jets
- Full scan using offline algorithms. Topological cluster as the input

B-jet

- B-tagging using secondary vertex and the lifetime information
- Improvements in 2012
 - Better primary vertex reconstruction
 - Make use of new features in the HLT jet trigger

Missing E_T

- Most sensitive trigger to pile-up events
 - Measurement is done in a large area (full detector coverage)
- New developments done for 2012
 - TDAQ upgrade to calculate E_T^{miss} at L2 (Update in the ROS software and calorimeter data format to readout calorimeter summary info)
 - 50% improvement in resolution, a factor ~ 5 rejection at L2
 - Possible to use topological cluster at the EF $\rightarrow$ better resolution

E_T^{miss} significance: $E_T^{\text{miss}}/\sigma(E_T^{\text{miss}})$

Muon trigger

- L1 muon trigger
 - 2-station coincidence at 75 ns ($p_T > 10$ GeV)
 - 3-station coincidence at 50 ns ($p_T > 11$ GeV)
- Two types of algorithms at the HLT
 - Outside-in tracking
 - Inside-out tracking

Low p_T muon and B-physics triggers

- Di-muon triggers with invariant mass cuts
 - $p_T > 4 \text{ GeV}$
 - $B \rightarrow J/\Psi(\rightarrow \mu\mu) + X$
 - $B \rightarrow \mu\mu$

Changes in 2012

- New L1 di-muon trigger requiring at least one or both muons in the barrel region (effort to keep 4 GeV threshold)

Conclusion

- ATLAS TDAQ system operating successfully in 2011 and 2012 data-taking
 - LHC condition: $L=6.6 \text{ cm}^{-2}\text{s}^{-1}$, 30 pile-up events per crossing
- DAQ operation
 - Good performance for both pp and heavy ion collisions
 - Linear increase of CPU usage and data size against pile-up
- Trigger performance
 - Fully exploiting the system capability at all three levels
 - Selections were tightened in all signatures
 - Improvements for robustness against higher pile-up conditions for 2012 data-taking

Backup slides

L2 algorithm and the Readout System (ROS)

Readout Systems (ROS)

- Readout buffers hosted on PCs
Respond to RoI data requests from L2 algorithms
- Also serve data to the Event Builder
- Performance can be limited by access rate, bandwidth and load