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Grid site availability evaluation and monitoring at CMS

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Abstract. The Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider (LHC) uses distributed grid computing to store, process, and analyse the vast quantity of scientific data recorded every year. The computing resources are grouped into sites and organized in a tiered structure. Each site provides computing and storage to the CMS computing grid. Over a hundred sites worldwide contribute with resources from hundred to well over ten thousand computing cores and storage from tens of TBytes to tens of PBytes. In such a large computing setup scheduled and unscheduled outages occur continually and are not allowed to significantly impact data handling, processing, and analysis. Unscheduled capacity and performance reductions need to be detected promptly and corrected. CMS developed a sophisticated site evaluation and monitoring system for Run 1 of the LHC based on tools of the Worldwide LHC Computing Grid. For Run 2 of the LHC the site evaluation and monitoring system is being overhauled to enable faster detection/reaction to failures and a more dynamic handling of computing resources. Enhancements to better distinguish site from central service issues and to make evaluations more transparent and informative to site support staff are planned.

1. Introduction

The Compact Muon Solenoid (CMS) [1] is one of the experiments at the Large Hadron Collider (LHC) [2] of CERN. As vast quantities of scientific data are collected by the detector that need to be processed and analyzed, large quantities of computing and storage resources are required. These are provided to the experiment by the Worldwide LHC Computing Grid (WLCG), a global collaboration that agglomerates computing resources from 42 countries distributed amongst 170 computing sites to be used for the storage and analysis of the LHC experiments' data. About 125 of these sites contribute resources to CMS. Sites in the Americas are organized in the Open Science Grid (OSG) and European sites in the European Grid Infrastructure (EGI).

In Run 1 of the LHC CMS placed data in a predetermined way at sites and routed processing jobs based on data stored at each site, thus coordinating the use of computing resources centrally. In Run 2 this has evolved into a more demand-driven approach, in which data is dynamically distributed to sites and jobs are routed based on available computing resources with data read also across sites.

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CMS' resources are organized in a tiered structure. Sites are grouped into four tiers based on service level agreement, processing power, and data storage capabilities. There is one Tier-0 site, that combines resources from two datacenters of the host laboratory CERN, seven Tier-1 sites at large national/regional computing centers, 56 Tier-2 sites at large universities or institutes, and 83 Tier-3 sites at collaborating universities and research institutes. Sites of a tier have different capabilities and support level. The Tier-0 and Tier-1 sites have 24x7 support and provide tape libraries for data archival, disk storage, and compute power mainly for data processing. Tier-2 sites have only disk storage, provide computing power for data processing and analysis, and are supported during working-hours. Most Tier-3 sites are used exclusively for end-user data analysis or private Monte Carlo generation and only few are integrated in the grid.

As unscheduled and scheduled outages occur in the day-to-day operation, resources may not be continuously available to the experiment. It is imperative for the experiment to have constant monitoring that allows for the detection of outages. Failed resources need to be removed promptly from the data storage and computing infrastructure before they can impact data processing, analysis or even data quality. In order to do so, the experiment relies on a variety of test systems: SAM , Hammer Cloud and the quality reports from the PhEDEx data subscription and transfer service. In the following sections we describe how their results are used in Run 2 to guide the usage of the resources by the experiment, and the changes in strategy compared to Run 1.

2. SAM

The Service Availability Monitoring (SAM) [3] is a testing framework developed by WLCG to monitor, on-demand and at regular intervals, both compute elements (CE) and storage elements (SE) at grid sites. Tests are grouped together by services that target either SEs or CEs, and these services are grouped together to get an overview of the site's functionality in time.

The testing for storage elements is currently done through SRM by transfering a file from a test server at CERN and reading it back from the site, while also verifying that the site can translate properly from the local name-space to CMS's name-space and vice versa.

Compute elements are tested by submitting a probe to the local batch system through its grid interface. The probe must be scheduled for execution on a worker node within a set time-window. When the probe runs on one of the site's worker nodes, it asserts that the necessary operating system libraries, environment variables, and CMS software is available, that the site can successfully execute a grid job and stage output to the local storage element. The probe verifies basic functionality of the compute element and CE-SE connection.

All SAM tests are scheduled centrally using the WLGC Experiment Testing Framework (ETF) [4], a Nagios-core based middleware for functional/availability testing of grid resources. ETF schedules tests, collects and evaluates the results. The system can also alert site administrators of failures. Tests' results are reported, and log files are viewable as they are returned from the CE or SE test server. It also allows ad hoc testing to be requested. Scheduled testing for CMS currently occurs every 15 minutes.

Results of tests are combined to determine the full functionality of a CE or SE for a given time period, and are grouped together to assess the whole site's availability and reliability. In SAM a site's availability is the fraction of time within a time interval in which the site had at least one CE and all of its SE passing all tests correctly, and reliability is a similar measure but taking into account scheduled downtimes that have been declared by the site to the grid's downtime calendar.

Although SAM tests the specific compute and storage functions at the grid level with individual tests, testing all the functionality required by CMS's production and analysis jobs is well beyond its scope. To detect rare failures in the required infrastructure CMS relies on a different tool, Hammer Cloud.

3. Hammer Cloud

Hammer Cloud (HC) [5] is an end-to-end automated site testing service with two goals: stress testing sites with a testing tool that is able to generate and deliver a large amount of quasi-real jobs to help in the commissioning of a new site, and periodic submission and monitoring of jobs for day to day monitoring of the sites' ability to run analysis-like jobs.

HC jobs use the same software and middleware that is used by user analysis jobs. This requires that the grid services are up and operational and the CMS batch scheduler is able to start jobs at the site. HC jobs check that a predetermined file at the site can be read, by running a simple analysis over the event data in the file, and producing the correct output. The data accessed by HC is part of a dataset available at all CMS sites.

Test jobs are submitted through the CMS Remote Analysis Builder (CRAB) [6], the job submission tool used for distributed analysis. CRAB takes a parameter input file in which the user defines the task to execute, divides the task into a multitude of jobs according to a splitting criterion, creates the job definitions, determines the files to be processed and submits jobs to the central CMS batch pool. As such HC is currently the test that best reveals problems in the environment beyond basic functionality as an end user would experience it. A consequence of scheduling the tests using the CMS middleware is that the jobs compete with other user jobs for processing time and thus can be delayed if users are placing a heavy load on the system. HC jobs are susceptible to central issues in the supporting services and middleware and can bring to light these issues. Such issues are recognized in case similar modes of failures appear concurrently at multiple or all sites.

Currently HC submits around 250 test jobs to each site every day. HC is also used for a second job type that uses the XRootD protocol to access data. While in the standard analysis job the data is accessed through POSIX, dcap or other SE specific protocols, this test uses the network data access protocol XrootD which CMS utilizes for data access across the wide-area network. Although this test verifies the local client at the tested site, the emphasis is on checking the server from both on- and off-site. The XRootD tests are used to determine the federation of XRootD servers the site should be part of. CMS has two such federations and XRootD data access is served from the most reliable servers first if they have the requested data.

Jobs report their success via exit status to the CMS job dashboard. From these test results a success rate is calculated for fixed time intervals. The success rate for HC jobs is defined as the ratio between successful jobs and the total number of terminated jobs that were not cancelled. (Jobs extending beyond a test interval are cancelled by HC and resubmitted.)

Currently HC tests are scheduled at 5-minute intervals, however the execution can be delayed depending on the CMS central batch system and the site's batch queue, therefore we currently sample the tests results daily to measure the average success rate per day. Work is ongoing to achieve a more constant execution and move to finer sample intervals.

4. PhEDEx quality reports

In CMS the Physics Experiment Data Export (PhEDEx) [7] is the system that manages data subscription and transfers data files to the storage elements of sites. It gathers requests for data-transfers that operators scheduled using its API, queues and performs transfers at each destination site. PhEDEx moves data in a reliable manner ensuring that the transferred data has been correctly stored at the destination. Data transfers are critical to the operation of the experiment as the recorded data need to be transferred to Tier-1 sites for processing, processed data to Tier-2 and 3 sites for analysis and Monte Carlo data sent from Tier-1 and 2 to Tier-2 and 3 sites for analysis, and to Tier-1 sites for archival. Transferring data is a continuous process not only during operation of the LHC but also during non-data taking periods when large processing activities take place. From January to October of 2016, the average data transfer rate between all the storage elements in the experiment was around 10 GB/s, with a maximum rate of about

20 GB/s during production campaigns before major physics conferences.

PhEDEx is composed of site agents installed and running at each storage element. The agents perform data uploads, downloads and other local file operations while central agents coordinate with the sites agents. A central database holds the file metadata and file inventory information of the storage elements at each site. In order to transfer data between sites, PhEDEx storage elements need to be linked, i.e. links commissioned. Links are tested for performance, a minimal transfer bandwidth and success rate. The number of links and bandwidth requirements vary between tiers. For each connection two links are setup, one to transfer the experiment data and a second one to transfer test data at regular intervals to verify continuous connectivity and performance. Test data are transferred continuously on the second set of links at a low rate per link. PhEDEx aggregates information about the success rate of transfers in each link over a time interval and calculates a quality parameter, between 0% and 100%, that summarizes the link performance. More information about PhEDEx monitoring and link quality can be found in [8]. This per link performance metric is aggregated into a metric that measures all the sites outgoing and incoming links and for each site, grouped by destination site tier. During Run 1 data was not directly transferred between Tier-2s, i.e. Tier-2-to-Tier-2 links not utilized. In Run 2, dynamic data management has enabled the usage of Tier-2 sites for additional activities previously limited to Tier-1 sites. Data placement and the processing schema are more dynamic; therefore, we are currently investigating whether measuring the transfer quality between Tier-2 sites is necessary.

5. Site Readiness

For a properly functioning site all three tests should be successful. To determine the functional state of a site for the day a set of requirements for each of the above metrics is used. Transient errors at the site and central infrastructure issues can affect the tests results. Site issues can be caused by individual worker nodes misbehaving, site-wide configuration issues, overloading of the site due to pressure from production and user-analysis jobs, to name the most common categories of problems. When problems occur the site administrator must be notified, the issues investigated and resolved. Different teams of people participate in the remediation of problems: developers and operators of the CMS middleware, site administrators at the affected site and also other administrators who have experienced a similar issue before. The requirements for alerting the site administrator and temporarily removing the site from being used by CMS must allow for temporary problems to be solved without permanent repercussions to the site but must be firm enough to be an indicator of the sites availability to be used for the execution of jobs and storage of data. Each site's daily test performance is summarized by a flag that we call this Site Readiness, which we use as an indicator to predict future performance. Site Readiness has been used by the experiment during Run 1, as presented in [9], [10]. However, significant changes to the definition of this metric have been made between Run 1 and Run 2 to have faster evaluation and to make the metrics more accurate. Currently, site performance is evaluated using the following criteria: A Tier-1 site must have SAM availability and HC success rate above 90%, half of its links to other sites must have at least 50% transfer success and links to four different Tier-1 sites and to twenty Tier-2 sites must be commissioned. For Tier-2 sites, as their support level is lower and their function in the experiment not as critical as Tier-1 sites, it is sufficient to have over 80% SAM availability and HC success rate, commissioned and functioning links to at least four Tier-1 with over 50% transfer success. Passing all the criteria gives a site an 'Ok' status. In case any metric falls below the thresholds the site will be marked as in 'Error' state unless the site is on a scheduled downtime. To qualify as a scheduled downtime the site must declare it at least 24 hours in advance to the downtime calendars used in the experiment.

6. Site Statuses

The Site Readiness metric allows us to assess past performance of a site. What is of interest to CMS, however, is the chance of a job executing successfully now or in the near future. Computing resources that do not function correctly or are expected to not function correctly or completely (for instance, because the storage element at a site is unavailable) need to be removed promptly from the CMS resource pool. On the other side is the desire to utilize repaired and fully functioning resources again quickly. For the forward-looking aspect we use three status metrics. Each of the status metrics is per site, evaluated each morning and the status assigned for the following day. The use of three status metrics, compared to only one, is to account for special data processing and user analysis needs.

6.1. LifeStatus

The most basic of the status metrics is called LifeStatus. It is derived directly from the Site Readiness values of the previous days. LifeStatus is set automatically for only Tier-2 sites. Tier-1 sites, with 24x7 support are expected to resolve performance issues and failures promptly. Tier-3 sites are generally not integrated into the grid and in such a case only used for selected data processing and user analysis, i.e. don't warrant automatic evaluation/handling. LifeStatus can take three values for a site: 'Enabled' in case a site is expected to function well during the day; 'Waiting Room' when a site is expected to not function correctly during the day and better be disabled for both data processing and user analysis activities. A site is usually in this state if problem investigation and correction take extra time. The expectation is that sites enter the state for a short period of time, a few days only. In case a site stays dysfunctional for an extended period, most often due to support issues at the site, its state is changed to 'Morgue'. The site is then no longer checked for new issues, repair progress followed at lower priority and when all known issues are resolved the site is effectively re-commissioned.

A Tier-2 site is temporarily disabled, 'Waiting Room' when it receives the fifth Site Readiness error state in two weeks (not counting weekends). The site administrators are explicitly notified about the reasons that led to the disabling. The site support team tries to understand the repeated, continuous or new issue and assist the site in becoming fully functional again. While a site is temporarily disabled it will not receive new production or analysis jobs, but those already scheduled will run and stage out their output. The site will be available to transfer data to other sites if the SE is functional. A site that is temporarily disabled will be re-enabled automatically on the third Site Readiness ok state in a row but can be returned to service before by either site support team or site admins (see below).

If a site has been in the 'Waiting Room' for a long period, currently 30 days, it will be flagged in 'Morgue' status. Any data unique to the site will be copied to another site and PhEDEx links disabled to prevent additional data from being placed at the site. Before a site is removed from the state it has to be stable for an extended period of time, currently five days. Services at the site will be checked and recommissioned and the site kept in 'Waiting Room' state during this period.

The state of LifeStatus can be manually overridden by both site support team members and site admins. This is used to both remove a dysfunctional site quicker from service and also to return sites with well understood and resolved issues fast back into service. The feature was introduced for Run 2 to regain computing resources faster after repair. Manual overrides are particularly useful when a site had an issue that has been fixed but took longer to resolve; we do not want the site to be disabled if a temporary glitch causes a bad Site Readiness status, so we override the site to be kept enabled in this case so that the issue that has already been fixed doesn't impact the site's status.

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6.2. *ProdStatus*
The ProdStatus metric determines if sites should be used for data processing. These jobs typically require, prior to processing, input data to be transferred by PhEDEx to the execution site's local storage system, data is then processed locally and written to temporary storage at the site and transferred to other sites for analysis and archival. The CMS Workload management system, WMAgent [11], manages the life cycle of a workflow, which can be as simple as a single job or a more complex interdependent group of jobs.

Two main workflow types are distinguished: generation and simulation of MC events and reconstruction and digitization of both MC generated events and collision data.

Generation and simulation require little input, but significant CPU time. In addition to CPU time, reconstruction and digitization jobs require data transfers from and to the site. Batch slots have time limits and a faster job execution is achieved by having multiple jobs operate on an input file concurrently. Both types of workflow produce small output files that are not optimal for tape storage. Later jobs in the workflow merge the output files into appropriately sized files. This merging needs to be done on the same site so only the resulting files are transferred out for archival and less data is moved over the wide area network (WAN). Production jobs, therefore, require very stable sites that can successfully run longer jobs and transfer their output for archival.

ProdStatus has three states: (i) 'enabled', in which resources are used by production jobs (ii) 'drain', jobs executing and queuing at the site can complete but new jobs will not be submitted, and (iii) 'disabled', in which the site is excluded for production activities. Sites that are not enabled in LifeStatus are not considered for production. In case of an approaching downtime or two days with Site Readiness error state within three days the site state is changed to 'drain'. If a site reaches the 'Morgue' its state will be set to 'disabled'. A site is re enabled after the downtime or after two consecutive Site Readiness 'OK'. ProdStatus can also be manually overridden, similar to LifeStatus.

6.3. *CrabStatus*
A site being used for user-analysis jobs is controlled via the CrabStatus metric. On average user-analysis jobs are shorter than production jobs, do not require PhEDEx for data transfers and are independent single-step jobs. Therefore, for these jobs HC is a better fitting metric than Site Readiness, which includes tests in SAM that probe parts of the site not directly required by user-analysis jobs, and the PhEDEx test results. Even though Site Readiness is indirectly used in the metric by requiring an 'enabled' LifeStatus, HC evaluations are used for quicker removal and reintegration of sites when temporary issues arise.

Sites that are enabled in LifeStatus and that have at least one successful HC evaluation during the previous three days will be enabled for analysis.

7. Planned improvements
In Run 2 CMS has incorporated new resources into its processing: resources from private and public clouds [12], and opportunistic sites that allow CMS to use their computing resources when the main user is not fully utilizing them. In Run 1 the CMS site topology was described by several information sources, however, their development did not keep up with changes to the sites' resources and their topology. WLCG has started work on a new system, the Computing Resources Information Catalogue (CRIC) [13], to describe site topology and service configuration. In addition to core CRIC, experiment specific CRIC systems are foreseen. CMS is looking forward to using this system to consolidate information from all the current site and services information systems.

CMS is moving to a more dynamic data processing approach, instead of centrally managing data transfers and execution of jobs the collaboration is also scheduling jobs where processing power is currently available and reading data over the XRootD data access protocol. Also, the delimitation of activities for each tier is blurring, e.g. in Run 1 the first pass of reconstruction of physics objects was exclusive to the Tier-0, currently, tests are being conducted to include Tier-1 sites. Similarly, in Run 1 data processing was exclusive to Tier-1 sites, whereas it is currently being done in both Tier-1 and Tier-2 sites.

All of the above developments have prompted us to rethink the strategies for site evaluation. Run 1 policies were adjusted from a weekly evaluation of the site's states to a daily one, and new metrics are being introduced for a more accurate model of the likeliness of a site to run a job successfully: (i) A new Pilot Startup Site Test (PSST), which will evaluate basic functionality at each worker node before a job is executed, (ii) metrics with much finer-granularity for even quicker removal and reactivation of sites. (iii) a Job Results metric, that will evaluate the exit codes for both production and analysis jobs to better assess site problems.

7.1. Pilot Startup Site Test

The experiment's batch system submits data processing and user analysis jobs to the batch system of sites in the CMS computing grid through a pilot system [14]. Before a CMS job starts in a batch slot, a brief functionality check of the worker node is performed. The pilot based CMS batch system, SAM and HC have each such brief tests currently. We are unifying and enhancing these tests, reporting results to a dashboard and preventing CMS jobs from starting in case a problem is detected. This gives us consistent error reports and increases the coverage of SAM and HC. SAM and HC submit test jobs to the site and they are assigned an available slot by the CMS batch system. In larger sites a malfunction in a worker node won't be evidenced until a test job lands in that slot, which can result in production and user-analysis jobs failing while the site passes the tests.

7.2. Finer Granularity metrics

Currently, site evaluations are stored daily in the experiment dashboard and site statuses are evaluated from these results. Error states are only evidenced after evaluation i.e. the following day. The sites used in the experiment are distributed across time zones so there is potentially a significant delay in response after problems are visible. In addition to this, transient problems e.g. interruptions in networking may not be visible as they already passed after a day. In order to have speedier removal and reintegration of resources and to minimize communication delays we have started work to reduce test evaluation periods to 15-minute intervals. This reduction has required changes in both SAM and HC and has brought to light some limitations about their scheduling, time to execution after job submission and aggregation of individual tests into site-level metrics. Addressing these issues is ongoing. For PhEDEx link evaluation, finer granularity evaluation of test data transfers requires changes in the scheduling for injecting test data into each link, the PhEDEx operations team is currently examining on how to do so without increasing the bandwidth used by these test transfers.

Once these issues have been addressed and we are able to use finer granularity test results into our metrics we will change the Site Readiness and the derived site statuses presented above to control use of the resources in a quicker way and to present information to site administrators that is closer to the current status.

7.3. Job Results metric

After the execution every job in CMS reports their exit status to the experiments' dashboard. We have found that recurring job error codes are often correlated to site problems. We are currently designing a new metric, Job Results, to identify such correlations. However, all errors are not directly attributable to sites. Errors caused by not well-behaved jobs or by problems reading data across the WAN must be excluded from the evaluation before the site's condition is assessed. Currently, we are working on finding the most indicative set of errors that are caused by actual site problems, on how to extrapolate error codes across sites to indicate health of the central services and on the best of thresholds for these metrics to minimize false positives. Once we have found evaluation criteria that allow us to identify site related problems with an acceptable false positive rate, this new metric will be added to those currently used to determine site status.

8. Conclusion

The Run 1 monitoring system of CMS grid sites was refined for Run 2 to achieve a faster turnaround disabling and re enabling computing resources when issues arise. The frequency with which site statuses are determined has been increased from weekly to daily, and work toward finer granularity is ongoing. Adjustments in the policy and algorithm to determine LifeStatus resulted in a 30% better prediction of site usability, i.e. a site being disabled during Site Readiness error states and enabled during ok states.

Changes in the organization of resources have caused the need for a new information system, currently being developed by WLCG. New tests and metrics are being introduced to supplement the Run 1 era tests. With the new tests we expect to better understand failures and in certain cases prevent them altogether. Current and future improvements in the evaluation of site statuses, together with a new, more detailed information system allow for better use of grid resources and the incorporation of new types of grid sites into the computing setup of the experiment.

References

[1] Chatrchyan S *et al.* (CMS) 2008 *JINST* **3** S08004
[2] Evans L and Bryant P 2008 *Journal of Instrumentation* **3** S08001 URL `http://stacks.iop.org/1748-0221/3/i=08/a=S08001`
[3] Andrade P, Babik M, Bhatt K, Chand P, Collados D, Duggal V, Fuente P, Imamagic E, Joshi P, Kalmady R, Karnani U, Kumar V, Tarragon J, Lapka W and Triantafyllidis C 2012 *Journal of Physics: Conference Series* **396** 032008 URL `http://stacks.iop.org/1742-6596/396/i=3/a=032008`
[4] WLCG 2016 Documentation page for ETF Online URL `http://etf.cern.ch/docs/latest/user/overview.html`
[5] van der Ster D C, Elmsheuser J, beda Garca M and Paladin M 2011 *Journal of Physics: Conference Series* **331** 072036 URL `http://stacks.iop.org/1742-6596/331/i=7/a=072036`
[6] Spiga D, Lacaprara S, Bacchi W, Cinquilli M, Codispoti G, Corvo M, Dorigo A, Fanfani A, Fanzago F, Farina F, Gutsche O, Kavka C, Merlo M and Servoli L 2008 *Nuclear Physics B - Proceedings Supplements* **177178** 267 – 268 ISSN 0920-5632 proceedings of the Hadron Collider Physics Symposium 2007Proceedings of the Hadron Collider Physics Symposium 2007 URL `http://www.sciencedirect.com/science/article/pii/S092056320700953X`
[7] Rehn J, Barrass T, Bonacorsi D, Hernandez J, Semeniouk I, Tuura L and Wu Y 2006 *Computing in High Energy and Nuclear Physics (CHEP) 2006*
[8] Bagliesi G *et al.* 2010 *Journal of Physics: Conference Series* vol 219 (IOP Publishing) p 062055
[9] Bagliesi G, Bloom K, Brew C, Flix J, Kreuzer P and Sciabà A 2012 *Journal of Physics: Conference Series* vol 396 (IOP Publishing) p 032041
[10] Flix J, Hernández J and Sciabà A 2011 *Journal of Physics: Conference Series* vol 331 (IOP Publishing) p 072020
[11] Cinquilli M, Evans D, Foulkes S, Hufnagel D, Mascheroni M, Norman M, Maxa Z, Melo A, Metson S, Riahi H, Ryu S, Spiga D, Vaandering E, Wakefield S and Wilkinson R 2012 *Journal of Physics: Conference Series* **396** 032113 URL `http://stacks.iop.org/1742-6596/396/i=3/a=032113`
[12] Garzoglio G 2016 *Computing in High Energy and Nuclear Physics (CHEP) 2016*
[13] Di Girolamo A 2016 *Computing in High Energy and Nuclear Physics (CHEP) 2016*
[14] Sfiligoi I, Bradley D C, Holzman B, Mhashilkar P, Padhi S and Wurthwein F 2009 *2009 WRI World Congress on Computer Science and Information Engineering* vol 2 pp 428–432