Challenges & Solutions for Building High Data Rate Archival Software for an Astronomy Experiment

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Abstract : Ground-based gamma-ray telescopes are built to detect Cerenkov radiation generated by the interaction of the earth's atmosphere and gamma rays coming from different astronomical sources. Major Atmospheric Cerenkov Experiment (MACE) is a 21m diameter ground-based high energy gamma-ray telescope set up by BARC at Hanle (32.7◦ N, 78.9◦ E, 4270 m asl) in the Ladakh region of North India. The telescope consists of various subsystems like camera and data acquisition system, mirror alignment, telescope control unit, sky monitoring, weather monitoring, calibration system, operator console, data archival, and analysis systems. These subsystems generate data at different rates and the archiving system has to handle this varied data rate, providing sufficient read-write speed for real-time analysis. The camera and data acquisition system generates main data at an estimated rate of 1kHz with an average throughput of ~20 MB/sec, which may increase with the increase of hit pixels. Storage of such large data and subsequent analysis has led to the requirement for developing a robust and fault-tolerant data archiving software. In this paper, we present a detailed software architecture, design, implementation, and testing of the Data Archival System (DArS) Software for MACE Telescope. We describe the challenges faced in our previous implementation and how this design has helped us solve the issues. Generic software architecture has been designed which can be adopted for systems with similar functional requirements. The design principles followed provide scalability and maintainability of the software.

CHALLENGES IN ARCHIVE SYSTEM FOR SCIENTIFIC EXPERIMENTS

- Both hardware and software challenges
- Physical transfer of data from remote location
- For array of telescopes, telescopes are geographically distributed
- Transfer of data may not be possible over the internet
- Available options for analysis : situ analysis or physical transfer of data then offline analysis
- For array of telescopes, data from all the telescopes need to be accumulated and analyzed
- Delay between data acquisition and accumulation of data in the data center delays the analysis process
- Analysis technique also varies from one experiment to the other
- Demands customized experiment-specific software

MAJOR ATMOSPHERIC CERENKOV EXPERIMENT

Figure I : MACE Telescope at Hanle

(showing different subsystems either at the Telescope or located at control room)

DATA ARCHIVAL HARDWARE DESIGN

- MACE data archival system hardware designed as a combination of Solid State Drives (SSDs), hard disk drives, and tape drives
- SSD drives are configured as RAID-6 array with 2.8 TB usable capacity.
- Hard disk-based storage is realized using general-purpose disks and comprises of Just a Bunch of Disks (JBOD), arranged in RAID-6.
- Tape storage is based on LTO-6 technology each with 2.5 TB capacity and 2.5:1 compression.

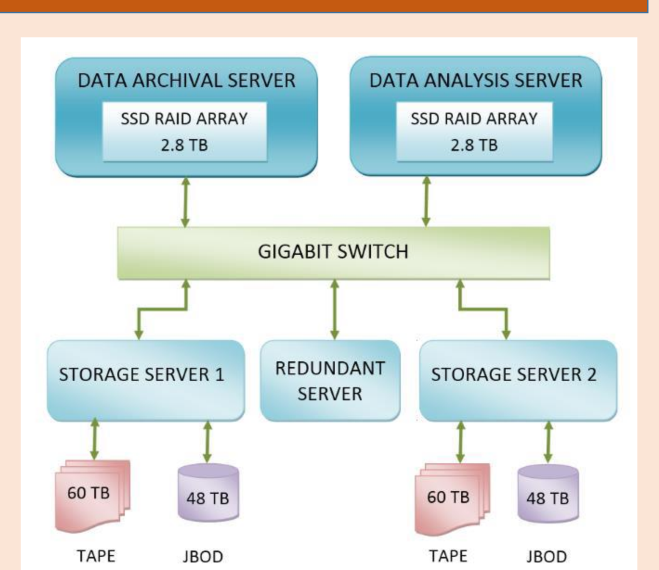

Figure II : MACE Data Archival Hardware Design

SSDs are deployed at a critical stage due to their low failure rate compared to general-purpose hard disks, at places of low atmospheric pressure. To optimize cost bulk storage is realized using hard disks and tape drives. This hardware design exploited redundancy as well as diversity for fault tolerance.

DATA ARCHIVAL SOFTWARE REQUIREMENTS

Data archival system has six functional requirements. These requirements are data handling, archiving, meta-data mapping, data staging & backup, online & offline data analysis, and remote backup.

- **Data Handling:** The incoming data from different subsystems of the telescope are received over TCP/IP protocol at different data rates and handled by customized self-defined applications.
- **Archiving:** Raw data received needs to be archived in separate files maintaining a well-defined directory structure to facilitate data retrieval.
- **Meta-data Mapping:** Users will retrieve these data files based on meta-data parameters like source name, date of observation, file type, and observation number. These parameters will be mapped to the observation data files for data retrieval.
- **Data Staging & Backup:** Data from the SSD are to be copied to the tape drives as well as hard disk drives. The older data needs to be deleted to create space for the new incoming data.
- **Online & Offline Analysis:** The online analysis of the telemetry data packets gives an overall system health performance measure. A quasi online approach is to be followed in case of event data online analysis using simplistic algorithms with less stringent parameter cuts.
- **Remote Backup:** A similar file structure architecture is to be maintained for remote backup and further data analysis at BARC Mumbai. MACE Telescope site Hanle and BARC Mumbai are connected through 256 kbps shared satellite link.

SOFTWARE ARCHITECTURE

The DArS software has been designed following a Layered Architecture. It consists of five layers, which are the Data layer, the Data access layer, the Communication layer, the Service layer, and the Presentation layer

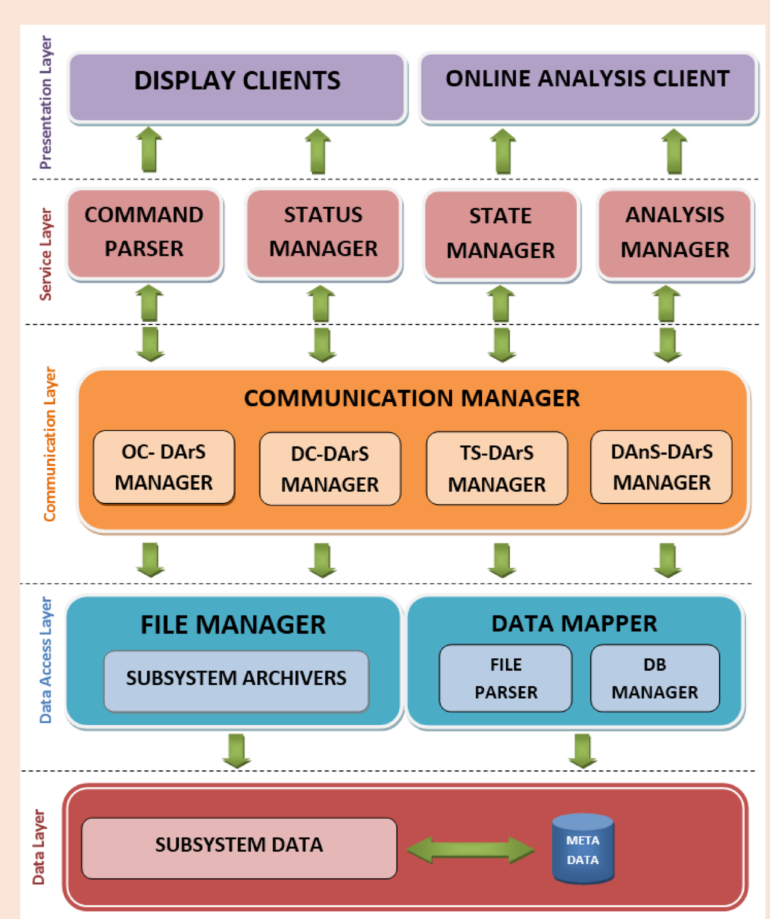

Fig III: Layered Architecture

Data Layer: The data layer consists of the data from different subsystems along with the meta-data stored in files and databases

Data Access layer: Responsible for handling the data from the Communication Layer. File Manager and Data Mapper components are responsible for performing the tasks in this layer.

Communication Layer: This layer is the core of DArS software with the primary responsibility of receiving data and command from subsystems. On receiving data the communication manager notifies the upper layer components for specific actions.

Service layer: It consists of four components and these are Command Parser, Status Manager, State Manager, and Analysis Manager.

Presentation layer: This is the topmost layer of the five-layered architecture. It consists of Display Client and Online Analysis Client.

The five-layered architecture has been designed with an object-oriented paradigm. Each component module from the architecture is segregated into one or multiple classes. In Figure IV, we have presented the classes and their relationships.

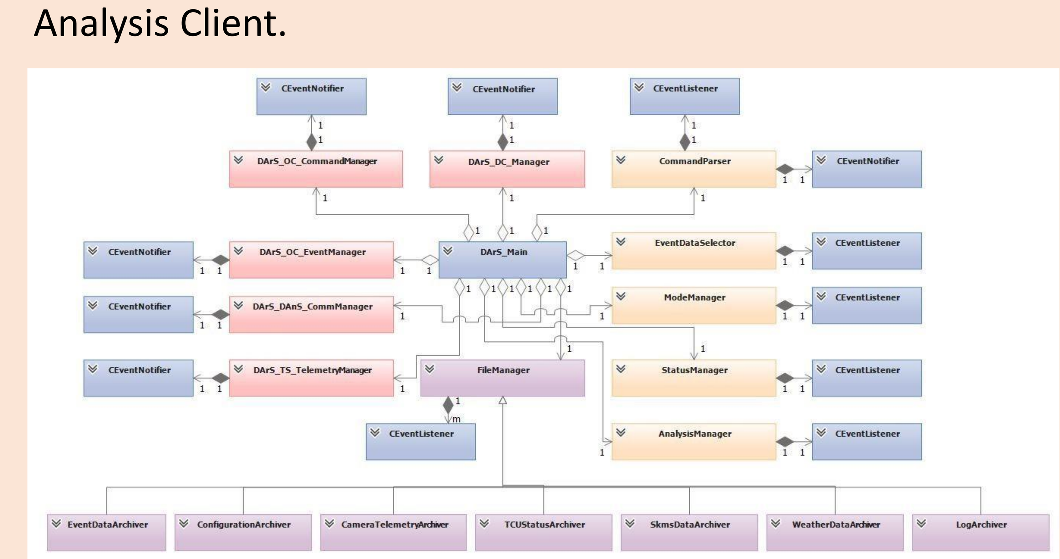

Fig IV: Class Diagram

IMPLEMENTATION & TESTING

Implementation:

DArS software has been implemented following an iterative and incremental life cycle model. The software is deployed on the Linux operating system, using C++ as the programming language and following POSIX standards. The sequence of events and interaction between the classes for implementing the functionality is represented in Fig V.

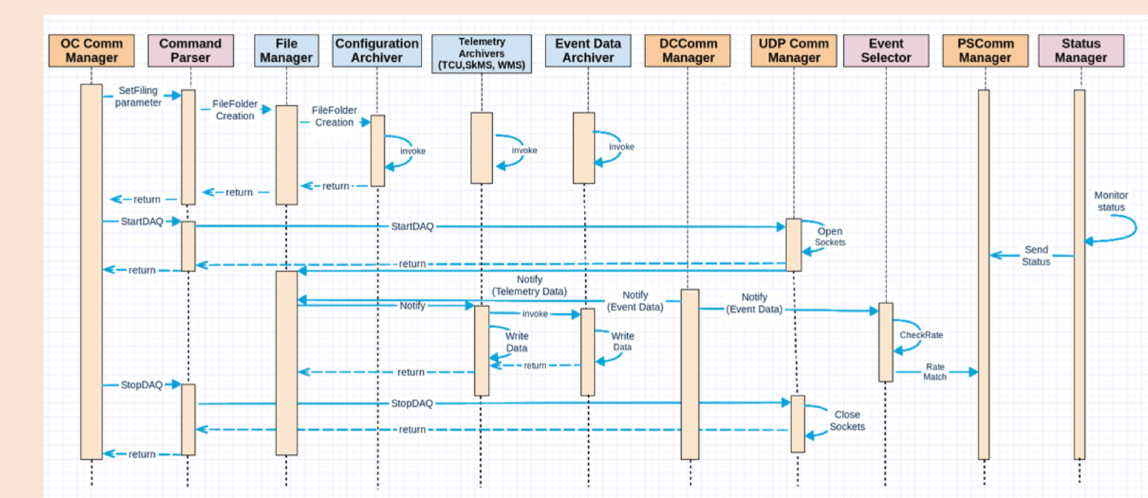

Fig V: Sequence Of Operations

Testing:

Three-level functional testing was carried out. Testing consisted of unit testing of individual classes followed by integration testing of the packages developed, system testing, and performance testing. Users have done system validation.

CONCLUSION

DArS software could successfully handle the required rate of 1 kHz. The software response was tested successfully by increasing the data rate from 10Hz to 1 kHz. Calibration limits fixed from 10Hz to 1 kHz. ~840GB of data were collected from 2018 to 2019 during the testing phase with 4 CIM Set up at the lab. We have also tested the software with 68CIMs at telescope site Hanle from October 2018 till February 2019. ~ 1TB [Fig VI] of Level 0 data were generated from the test runs at telescope site Hanle during the installation phase of the telescope from 2017 to 2021. Observational test runs were carried out in 2021, with all the telescope subsystems installed completely. With full CIM load and maximum data rates, the DArS software performed as expected without any deviation from the test runs carried out at the lab, with just 5% CIM modules. A stable version of the software was released at the site for use.

ACKNOWLEDGEMENT

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REFERNCE

Please refer to the paper : D Sarkar., et al. “A Generic High Data Rate Archiving Software Solution: In Context of an Astronomy Experiment". Acta Scientific Computer Sciences 3.7 (2021): 72-82. for more details. https://actascientific.com/ASCS/pdf/ASCS-03-0144.pdf