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The Array Data Acquisition System software architecture of the ASTRI Mini-Array Project

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ABSTRACT

The ASTRI (Astrofisica con Specchi a Tecnologia Replicante Italiana) Project was born as a collaborative international effort led by the Italian National Institute for Astrophysics (INAF) to design and realize an end-to-end prototype of the Small-Sized Telescope (SST) of the Cherenkov Telescope Array (CTA) in a dual-mirror configuration (2M). The prototype, named ASTRI-Horn, has been operational since 2014 at the INAF observing station located on Mt. Etna (Italy). The ASTRI Project is now building the ASTRI Mini-Array consisting of nine ASTRI-Horn-like telescopes to be installed and operated at the Teide Observatory (Spain). The ASTRI software is aimed at supporting the Assembly Integration and Verification (AIV), and the operations of the ASTRI Mini-Array. The Array Data Acquisition System (ADAS) includes all hardware, software and communication infrastructure required to gather the bulk data of the Cherenkov Cameras and the Intensity Interferometers installed on the telescopes, and make these data available to the Online Observation Quality System (OOQS) for the on-site quick look, and to the Data Processing System (DPS) for the off-site scientific pipeline. This contribution presents the ADAS software architecture according to the use cases and requirement specifications, with particular emphasis on the interfaces with the Back End Electronics (BEE) of the instruments, the array central control, the OOQS, and the DPS.

Keywords: ASTRI, Cherenkov, data acquisition, software

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1. INTRODUCTION

The ASTRI Mini-Array (MA) is an INAF ground-based project to construct, deploy and operate a set of nine identical dual-mirror Cherenkov gamma-ray telescopes, and several other auxiliary equipment and infrastructures [1]. The ASTRI Mini-Array scientific objective is to exploit the imaging atmospheric Cherenkov technique to measure the energy, direction and arrival time of gamma-ray photons arriving at the Earth from astrophysical sources. In the almost unexplored energy range 1-300 TeV this technique requires an array of optical telescopes (~ 4 m in diameter) at a site located at an altitude of > 2000m. The telescopes will have reflecting mirrors focusing the Cherenkov UV-optical light produced by atmospheric particle cascades (air-showers), initiated by the primary gamma-ray photons entering in the atmosphere, onto cameras with a very fast response. Most of the collected data will come from the large number of charged primary cosmic-ray initiated air-showers, which will also be recorded, then appropriate data analysis methods will be employed to reduce the level of this background and allow an efficient detection of gamma-rays coming from astrophysical sources [2]. The ASTRI Mini-Array telescopes (including the Cherenkov Camera) are an updated version of the ASTRI-Horn Cherenkov Telescope operating at Serra La Nave (Catania, Italy) on Mount Etna [3]. The nine telescopes will be installed at the Teide Astronomical Observatory, operated by the Instituto de Astrofisica de Canarias (IAC), on Mount Teide (~2400 m a.s.l.) in Tenerife (Canary Islands, Spain). The ASTRI Mini-Array System will be

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operated by INAF on the basis of a host agreement with IAC. The main scientific goal of the ASTRI Mini-Array is to perform high-energy (E > 1 TeV) observations of galactic and extragalactic sources with a sensitivity better than that reachable by the other Imaging Atmospheric Cherenkov telescopes currently in operation (HESS, MAGIC, VERITAS). Furthermore, the Mini-Array will also perform Intensity Interferometry of a selected sample of bright sources [4]. The MA must be operated remotely and no human presence is foreseen on the site during observations. The ICT systems installed on-site must be optimized to reduce costs without, however, compromising security and safety operations and the integrity of the collected data [5]. ASTRI Mini-Array will benefit from the high-speed networking connection already present at Teide to deliver all data to the Italian ASTRI Mini-Array Data Center, limiting the number of storage devices on-site to the resources needed to prevent any loss of data in case of emergency. The ASTRI telescopes will be equipped with two instruments: the Cherenkov Camera and the Stellar Intensity Interferometer Instrument (SI3). The ADAS is a sub-system of the Supervisory Control And Data Acquisition (SCADA) system which is a distributed software system operating on-site that shall manage startup, shutdown, configure, supervise and control of all site assemblies and subsystems [6]. The ADAS acquires the raw telemetry R0, packet by packet, produced by the Back End Electronics (BEE) of the Cherenkov Camera, and the raw DL0 files, file by file, produced by the Industrial PC at the back of the SI3. The ADAS streams the acquired data to the Online Observation Quality System (OOQS) [7][8] for the on-site quick-look analysis and saves the data on local storage for the transmission off-site. Also, the Cherenkov camera pre-processing is part of the ADAS and it is performed off-site as a first step of the scientific pipeline [9]. Furthermore, ADAS interfaces the central control system (CCS) and monitoring log and alarm (MLA) system [10] in order to allow the operator to monitor and control the whole on-site system from a centralized Human Machine Interface (HMI). The ADAS software architecture has been defined according to the 4+1 architectural model described in section 2. The next sections detail the use case, logical, implementation, process and physical views [11]. The last section reports conclusions and next steps.

2. ARCHITECTURAL APPROACH

The main objectives of the architecture are to present the organization of the software system, describe its structural elements and their behavior, and compose these structures into larger subsystems. The architecture describes the components, their responsibilities and interfaces, and their primary relationships and interactions. The Architecture is defined by looking at the system from different viewpoints and is then illustrated through different views (see Figure 1). The logical view is a functional decomposition of the system with the description of the global information flow (based on the analysis of use cases and the data models). The process view deals with the dynamic aspect of the system. The implementation view represents the detailed design of the implemented system. The physical view depicts the topology of software components on the physical layer as well as the physical connections between these components. The use case view concerns a list of actions or event steps typically defining the interactions between an actor and the system to achieve a goal. The actor can be a human or another system.

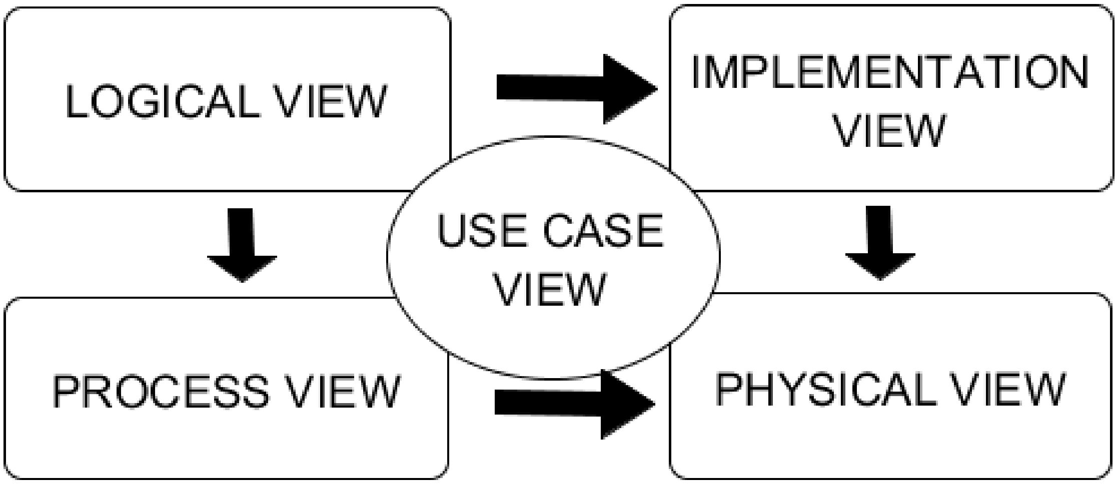

Figure 1. Illustration of 4+1 architectural view model.

3. USE CASE VIEW

We used the use cases technique to define the functional requirements and to detail the scenarios concerning the ADAS execution. The human actors are the engineers needed during the development, test and maintenance activities. The system actors are the SCADA subsystems which interface the ADAS (OOQS, CCS, MLA), the Cherenkov Cameras and the SI3 instruments, the bulk archive and the Data Processing System (DPS).

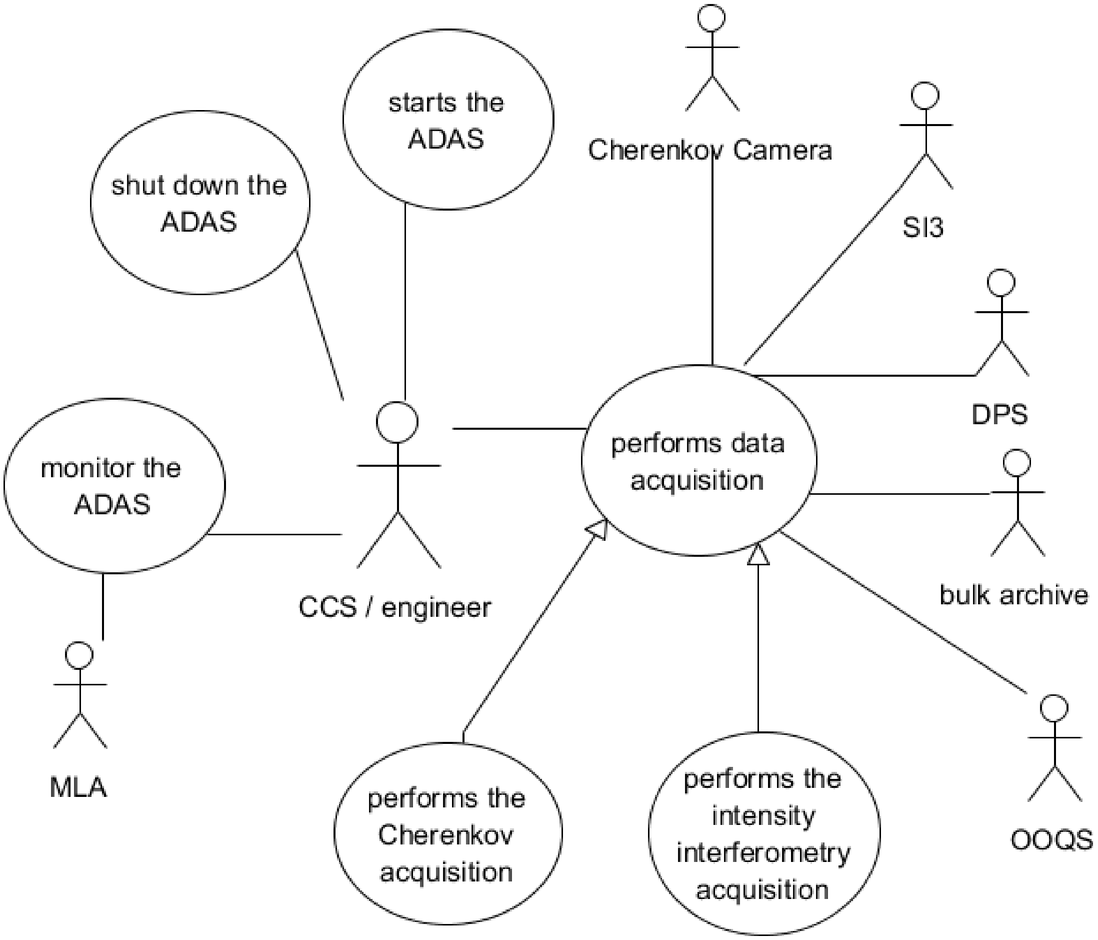

Figure 2. UML use case diagram of the ADAS.

The CCS execute the ADAS start-up, shut down and monitor the ADAS during the operations. The engineers execute the ADAS during development, test and maintenance activities. The ADAS engineer provides support either during the Cherenkov observing night or the Intensity Interferometry observing night. Furthermore, ADAS provides support during the development, verification and maintenance of the instruments. Concerning the Cherenkov observations, the ADAS acquires the R0 (raw) data, as a bit stream packet by packet from the Cherenkov camera BEE [12][13] via TCP/IP and generates the DL0 files in telemetry format, one per telescope and for each Run, which are saved in a Local Bulk Repository. The software saves the data within the same run in a binary file and checks the packet integrity through packet length and Cyclic Redundancy Check (CRC). Concerning the Intensity Interferometry observations, the ADAS acquires the DL0 files (raw) data from the SI3 Back End Electronics via FTP for each telescope and for each Run. DL0 files have a max size of 150 GB and are acquired at a maximum rate of 4 Gbit/s. Data is then copied into a Local Bulk Repository at a lower data transfer rate (1 Gbit/s). Either for Cherenkov or Intensity interferometry observations, the ADAS shall stream the DL0 to the OOQS. The ADAS shall provide to the MLA all information concerning its status and any potential alarm which may raise human intervention. The DL0 shall be transferred from the local bulk repository to the off-site bulk archive. The ADAS is also in charge of converting the Cherenkov DL0 data files (telemetry format), saved in the bulk archive, in DL0 FITS data format. The files will be grouped by telescope and Run, data sub-type (events, calibrations, housekeeping, variance) [14]. The DL0 FITS shall contain data translated from binary to alphanumeric data, ready for the stereo event builder and further processing.

4. THE LOGICAL VIEW

The component diagram in Figure 3 shows the ADAS components and the relations with the external systems in terms of transmission protocols. ADAS interfaces the CCS through two ACS (Alma Common Software)[15] components: the ADAS master and the ADAS Manager. The first is in charge of starting and monitoring the ADAS ACS components, the latter is responsible for the acquisition process management. The design decision of using the ACS framework has been taken at the project level and it is intended as a constraint for the ADAS. We decided to implement the Cherenkov camera data acquisition as a TCP/IP server. TCP/IP is an industry-standard model which implements a client server architecture which guarantees data delivery. We decided to implement the dispatchers from the ADAS to the OOQS with Apache Kafka[16] and AVRO[17]. Kafka is a framework to share data with high performances. AVRO supports data serialization and de-serialization. From the experience with the ASTRI-Horn prototype we learned that the Cherenkov Camera pre-processing (that is, the RAW-to-FITS data conversion) is not suitable for on-line purposes. For this reason, we decided to deploy this software off-site in the bulk archive as a preliminary step of the scientific pipeline [14]. The DPS commands the camera pre-processing for each raw file. The data transmission from the on-site storage to the off-line bulk archive is in charge of the ASTRI Archive system[18].

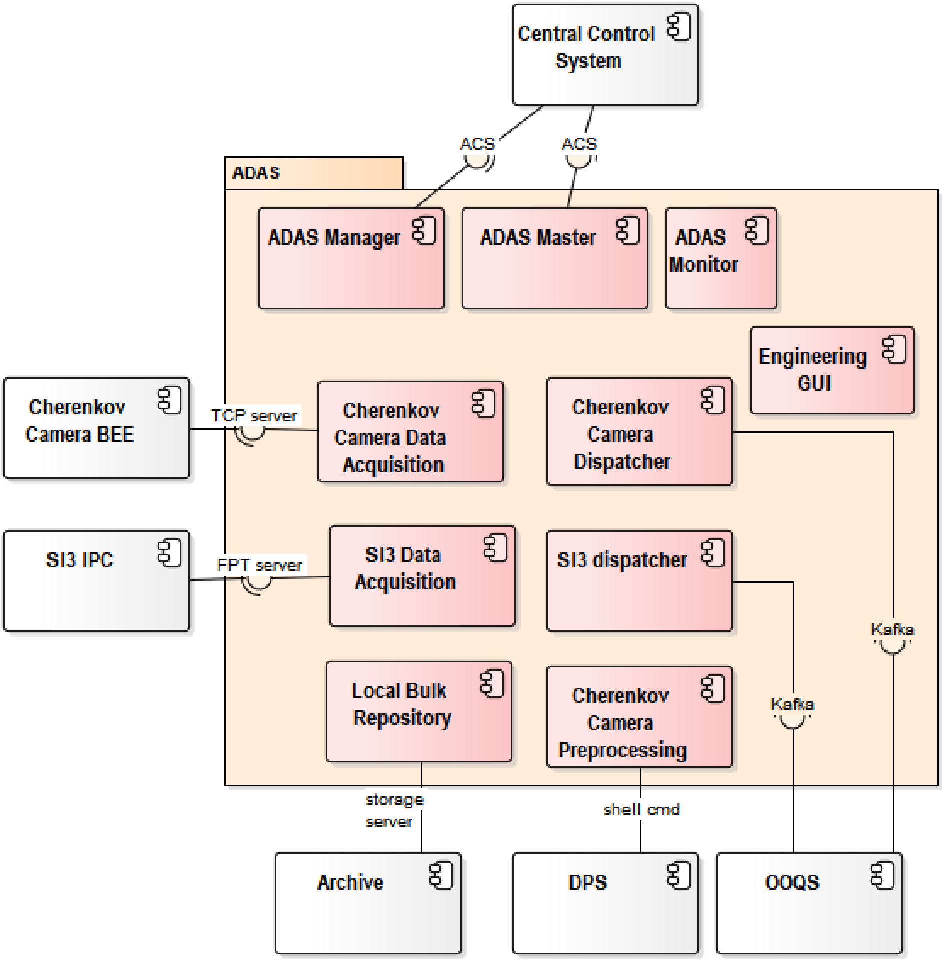

Figure 3. UML component diagram of the ADAS showing the interfaces with the external systems.

5. THE IMPLEMENTATION VIEW

Figure 4 depicts the ADAS decomposition. The engineering GUI realizes the functionality provided by the ADAS manager and the ADAS monitor. This GUI shall be used only during the development and test phases of the instruments, either Cherenkov Camera or SI3. The ADAS master is the ACS component which is in charge of starting and monitoring the ACS components ADAS Manager and ADAS Monitor. The ADAS manager provides a needed interface to the Central Control System to start/stop the acquisition software and to configure the acquisition runs. Also, the ADAS Manager controls the acquisition processes (Cherenkov Camera Data Acquisition, SI3 Data Acquisition, Cherenkov Camera Dispatcher and SI3 Dispatcher). Finally the ADAS Manager controls the delivery of files from the local bulk repository to the on-site bulk archive. The ADAS Monitor gets status of the acquisition process to be passed to the ADAS Manager, and then also to the CCS and MLA systems. The Cherenkov Camera Dispatcher decodes the binary data stream produced by the Cherenkov Camera and sends this data to the OOQS. The SI3 dispatcher sends the data produced from the SI3 to the OOQS. The SI3 data acquisition implements an FTP server that allows the SI3 industrial PC to send data to the ADAS. The FTP server is also part of the local bulk repository. The Cherenkov Camera Data Acquisition acquires data, packet by packet, from the Cherenkov Camera and provides a file containing all packets generated during an observation Run by the single Cherenkov telescope. The Cherenkov Camera Preprocessing performs the offline/offsite RAW-to-FITS data conversion. This software runs as a process controlled by the DPS [18].

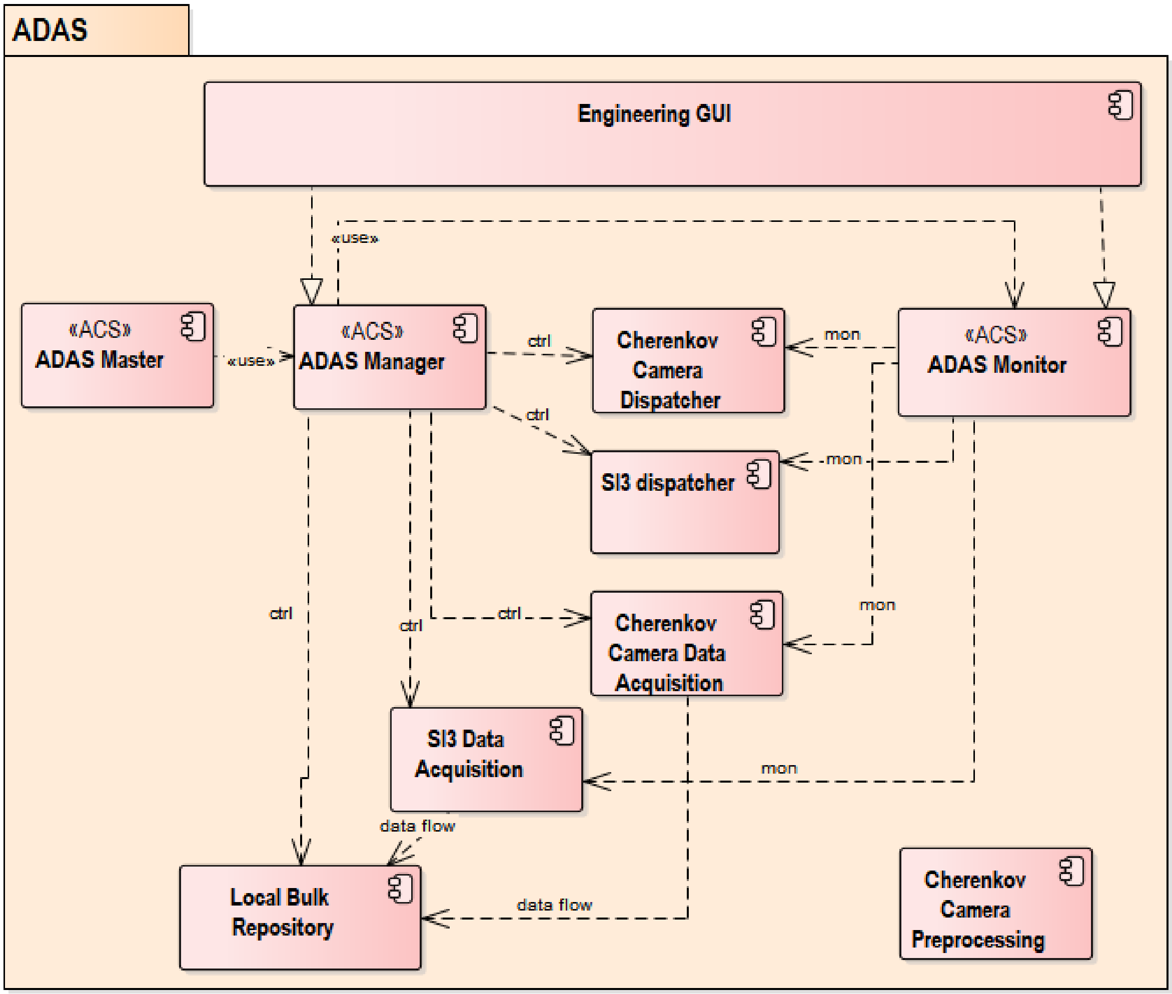

Figure 4. UML component diagram of the ADAS showing the relation between the internal components of the system.

6. THE PROCESS VIEW

Figure 5 shows the ADAS activities. The red line points the flow to start-up: the CCS sends the “start” command to the ADAS Master component which in parallel starts the ADAS Manager and the ADAS Monitor. The ADAS Manager starts the Cherenkov Camera or SI3 data acquisition according to the observing night schedule. The ADAS Monitor collects monitoring data. After the start-up, the CCS sends to the ADAS Manager, which propagates the command to the Cherenkov Camera / SI3 data acquisition, the configuration for the next run (blue line). The green line depicts the processes which manage the acquiring data. The Cherenkov Camera / SI3 data acquisition acquires and queues data for the dispatcher which is in charge of pushing the data to the OOQS. In parallel, the Cherenkov Camera / SI3 data acquisition stores the raw data in files on the local bulk repository. The archive system sends the files from the on-site storage to the off-site bulk archive. Once a file arrives off-site, the DPS performs the preprocessing as a preliminary step of the Cherenkov data reduction and analysis.

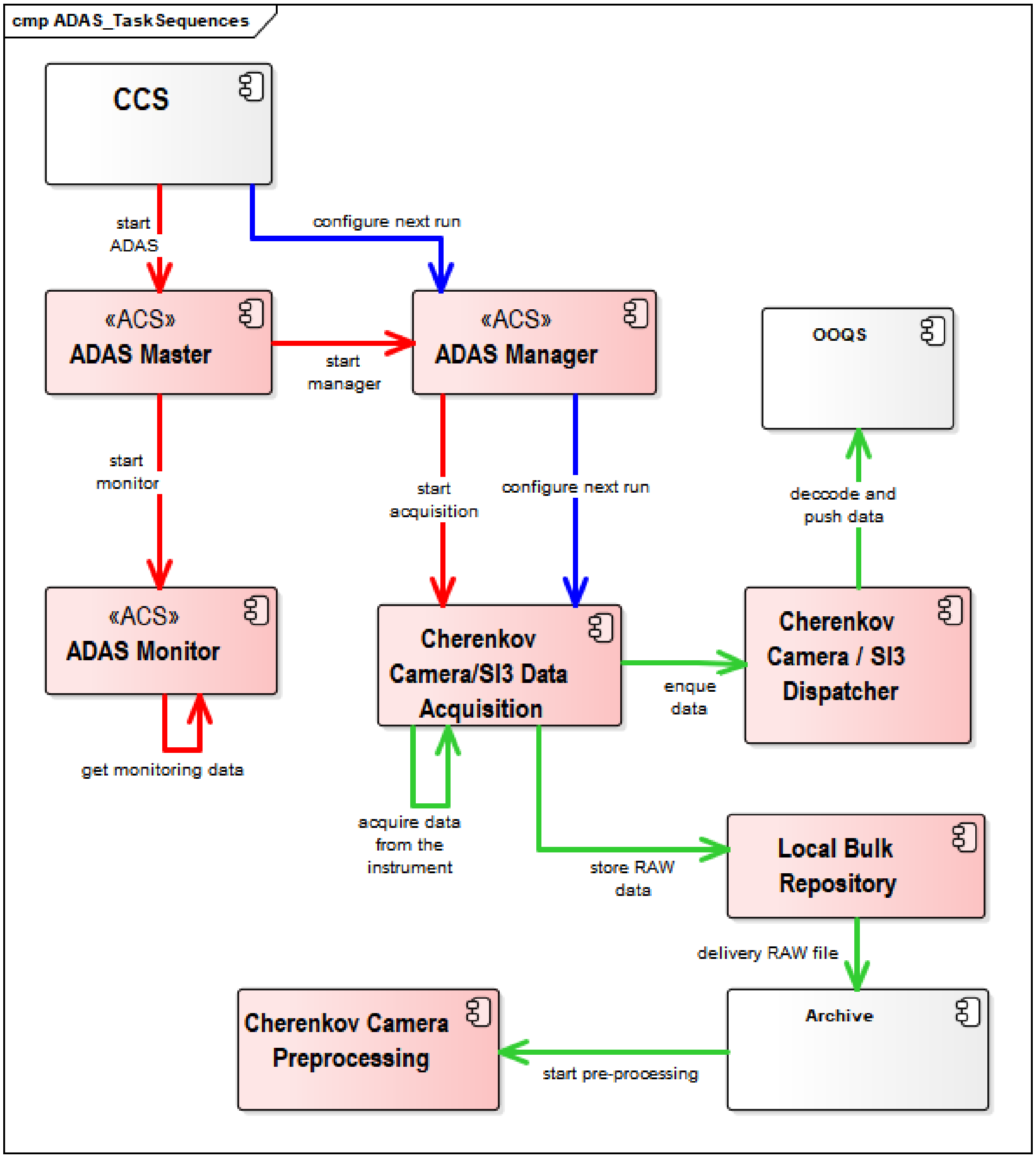

Figure 5. ADAS process view.

7. THE PHYSICAL VIEW

The ADAS is deployed in the Instrument workstation during the development and testing phases of the instruments (Cherenkov Camera and SI3) in the factory. In operations the ADAS is deployed in 9 camera servers, one per each telescope of the array (see Figure 6). Each camera server connects the SI3 and the Cherenkov Camera BEE through a dedicated point-to-point optical fiber connection of 1 GBps. The camera servers, through a switch, also connect the servers which host the OOQS and CCS, and the on-site storage server.

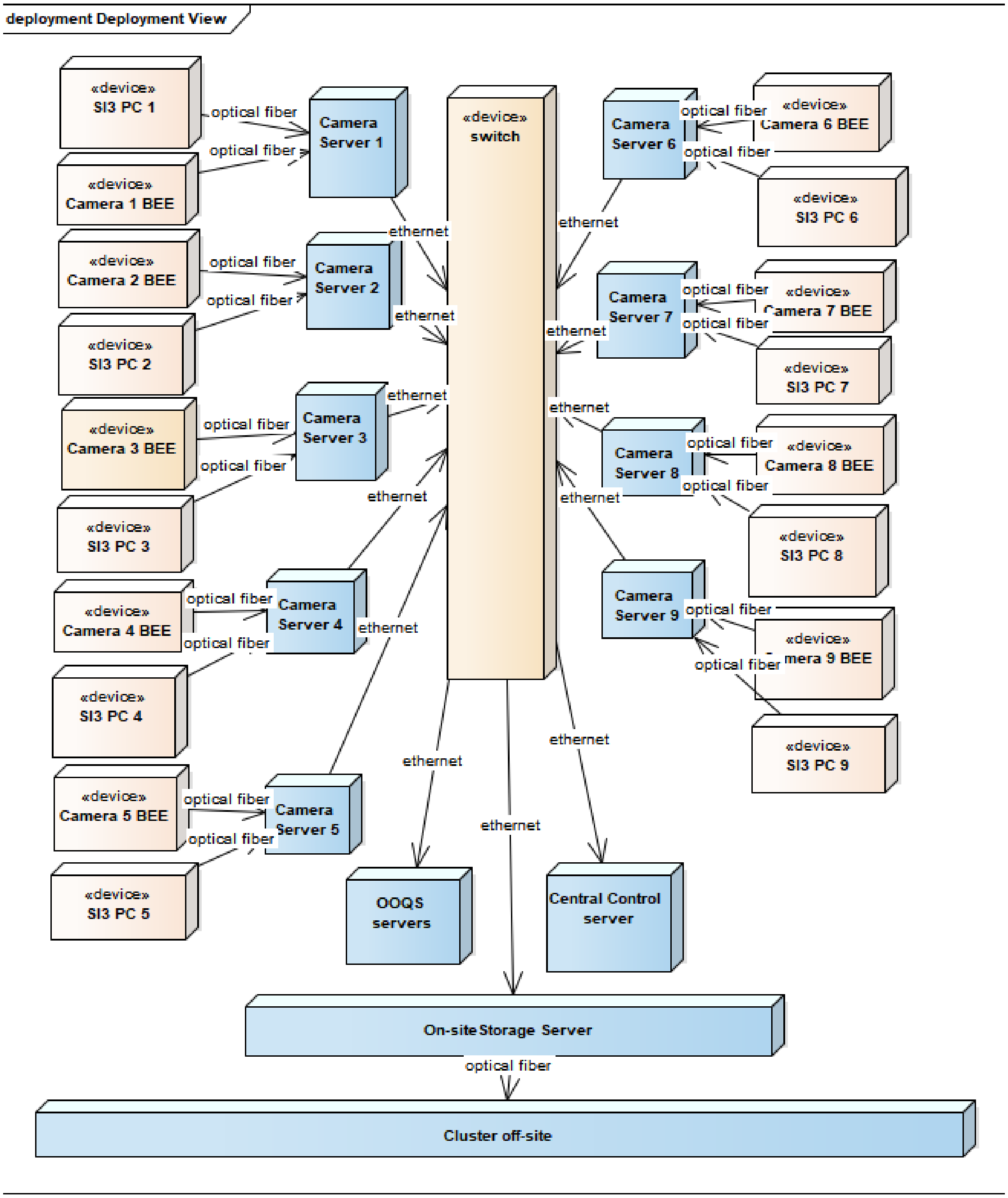

Figure 6. UML deployment diagram of the ADAS.

8. CONCLUSIONS

This paper presents the ADAS software architecture for the ASTRI Mini-Array project according to the use case view detailed in section 3. This architecture has been defined keeping in mind the lessons learned from the ASTRI-Horn experience [19][20][21]. The conversion RAW-to-FITS has been moved off-line and off-site, and we selected AVRO-Kafka technologies to push data to the OOQS for a quick quick online analysis of the status of the ongoing observation. In addition, the ADAS architecture for the Mini-Array includes the SI3 instruments and provides support for 9 telescopes which observe in parallel. We have prepared a first version of detailed design and we are in the development phase. Because we adopted a development model iterative-incremental [22] we plan to make an assessment of the system at the end of the first iteration of the software integration, verification and validation, in order to confirm or make any change to the proposed architecture.

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