EO-ALERT: NEXT GENERATION SATELLITE PROCESSING CHAIN FOR RAPID CIVIL ALERTS

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ABSTRACT

In this paper, we provide an overview of the H2020 EU project EO-ALERT. The aim of EO-ALERT is to propose the definition and development of the next-generation Earth observation (EO) data and processing chain, based on a novel flight segment architecture moving optimised key EO data processing elements from the ground segment to on-board the satellite. The objective is to address the need for increased throughput in EO data chain, delivering EO products to the end user with very low latency.

1. INTRODUCTION

Earth observation (EO) data delivered by remote sensing satellites provide a basic service to society, with great benefits to the civilian. The data is nowadays ubiquitously used throughout society for a range of diverse applications, such as environment and resource monitoring, emergency management and civilian security [1].

Over the past 50 years, the EO data chain that has been mastered involves acquisition process of sensor data on-board the satellite, its compression and storage on-board, and its transfer to ground by a variety of communication means, for later processing on ground and the generation of the downstream EO image products.

While the market is growing, the classical EO data chain generates a severe bottleneck problem, given the very large amount of EO raw data generated on-board the satellite that must be transferred to ground, slowing down the EO product availability, increasing latency, and hampering applications to grow in accordance with the increased User Demand for EO products.

This paper provides an overview of the EO-ALERT project, an H2020 European Union research activity that addresses the challenge of a "high speed data chain" and the need for increased EO data chain throughput. EO-ALERT proposes the definition and development of the next-generation EO data and processing chain, based on a novel flight segment architecture that moves optimised key EO data processing elements from the ground segment to on-board the satellite. The objective is to deliver the EO products to the end user with very low latency for increased throughput.

Achieving this goal poses great challenges on the flight system, to be addressed through a combination of innovations in the on-board elements of the data chain and the communications link. As such, this goal necessitates innovation in several critical technological areas; namely on-board reconfigurable data handling, on-board image generation, on-board image processing, high-speed on-board avionics, on-board data compression and reconfigurable high data rate communication links to ground. Such innovations will also provide capabilities for the optimisation of the classical EO data chain towards a data chain with greatly improved data throughput.

The paper presents preliminary project results on the above technological areas, with particular attention to the development of a flexible and reconfigurable data handling architecture integrating different on-board technologies for both Synthetic Aperture Radar (SAR) and optical sensor data, including image generation, image processing for rapid alerts, joint compression and encryption algorithms. The paper will also discuss possible applications of the envisioned high-speed data chain and introduce open issues regarding the implementation of the proposed architecture, from the use of dedicated hardware platforms to commercial off-the-shelf (COTS)-based implementations. The aim is to raise interest in this ambitious project from the on-board data compression and processing community, share

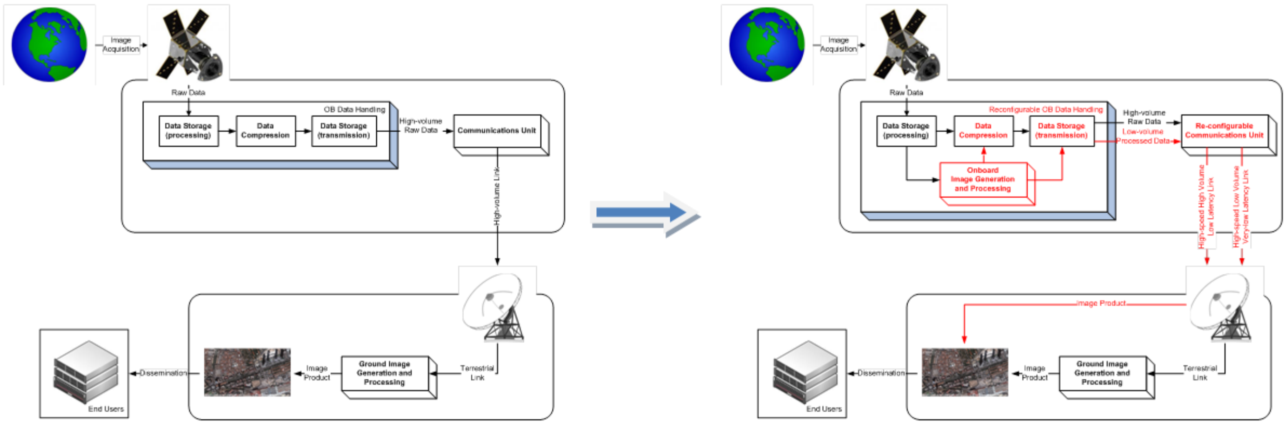

Figure 1 EO-ALERT data chain moving ground processing and data management to the flight segment for very low latency EO image products: (left) classical data chain based on raw data compression and transfer, (right) innovative data chain showing its key elements and new data flows (in red)

their views on the different technological challenges, and foster fruitful discussions towards new ideas and solutions.

2. EO-ALERT OVERVIEW

Data latency has become a key requirement in the EO market, since end-users require that data is available in a very short time interval. In case of polar platform satellites, what it is currently referred to as near real-time (NRT) consists of the provision of image products in the range of 1 to 3 hours; e.g. Sentinel-1 makes ocean products available within 1 hour of observation over NRT areas with a subscription [2].

Current market trends are moving beyond NRT applications, to applications with latencies in the order of 30 minutes to 15 minutes. Based on this, the latency performance concept behind EO-ALERT is to achieve latencies below 15 minutes for the EO products. To be precise, the definition of latency can be taken to be: the time from the collection of the last photons through to the time that the data is converted to a specified EO product and delivered to the user portal. Based on this performance concept, and latency definition, EO-ALERT will have a goal latency of less than one minute and require a maximum latency of less than 5 minutes, for both SAR image products and optical image products.

This will in turn flow down to requirements on the technology building blocks, which will drive the EO-ALERT solution at all technology levels.

Satellites on-board data handling has traditionally been managed in a simple fashion, where raw data is collected, compressed and scheduled for transmission to the ground segment, where data processing takes place. This entails a significant delay in the generation of knowledge that can reduce the "value" of the acquired imagery. However, the recent availability of more powerful computational systems for onboard data handling allows for a redesign of the onboard processing chain. With modern systems, it is conceivable to generate data products directly on-board, reducing the time needed to generate products, from hours to a few minutes (Figure 1). Achieving this ambitious objective requires the development of ad-hoc and novel technologies in order to 1) define a set of building blocks implementing the main processing functionalities, and 2) use these building blocks sensibly, defining an innovative reconfigurable onboard data handling architecture, that is able to achieve the desired goals, with reliable performance levels.

The proposed satellite processing chain has implications on several technological areas, including high speed avionics, Flight Segment/Ground Segment (FS/GS) communications, on-board compression and data handling and on-board image generation and processing. The project will develop both the technologies and the data handling architecture, with an approach aimed at optimizing the use of onboard resources, as well as making the most out of the available image data through direct processing on the flight segment. As far as compression is concerned, recently developed image compression concepts aimed at improving image quality for a given compression ratio, while maximizing throughput, will be adopted for the first time in space applications.

Both the technologies and the integrated technologies chain will be verified and experimentally evaluated during the project on an avionics test-bench, using first relevant EO historical sensor data. They will then be demonstrated through relevant End-to-End (E2E) tests, in which EO data acquired specifically for EO-ALERT will be injected in the system and results will be obtained, evaluated and benchmarked.

Ground truth data for evaluation will be obtained through an experimentation campaign on a real and representative test-field. Namely, EO-ALERT identified two main scenarios for testing the potential of the proposed high- speed data chain: ship detection and extreme weather monitoring, that are briefly described below.

2.1. Ship detection scenario

A deep analysis of the most common needs of maritime users has been performed in order to detect the specific needs. The most important aspects are to have a pixel size as small as possible, at least 1m and low revisit time. SAR satellites are the most suitable for ship detection, whereas very high resolution optical imagery reduce false positives and allow ship identification.

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The Key needs for the project have been defined:

- *Flexibility:* in order to mitigate risks and choose the image acquisition target date.
- *Responsiveness:* in order to make last minute changes to the image request, one hour is the target.
- *Revisit:* a constellation with less than 6 hours between satellites.

Deimos-2 and TerraSAR-X have been selected for the optical imagery and radar data respectively. Sentinel-2 and Sentinel-1 are included as backup missions.

Taking into account the user needs and in order to develop the most suitable technology, the following tests are proposed in the Mediterranean Sea:

- *Ship Monitoring*: the objective is focused on illegal fishing and cargo monitoring between 10-20 meters. TerraSAR-X will be used for ship location and detection, and Deimos-2 for ship identification to confirm the SAR detection.
- *Coastal Monitoring*: the objective is focused on maritime safety and illegal migration. TerraSAR-X will be used for ship location and detection, and Deimos-2 for ship identification to confirm the SAR detection.

Information supplied by the product should be a text file including the following parameters with a very short latency as a first step:

- Position Information.
- Movement Information.
- Ship details

And in a second step, with a short latency:

- Ship identification
- Clipping ship

2.2. Extreme weather scenario

A field where EO-ALERT technology can be very helpful and beneficial is meteorology. Very early alerts for some meteorological phenomena that are hard to forecast in space and time, like convective storms, are very useful for the forecaster's nowcasting tasks. This kind of information can reduce the negative impact of these kind of hazardous phenomena. On the other hand, NRT information on surface winds can be very profitable for offshore wind farms.

Two meteorological phenomena are going to be detected in this scenario: convective storms and surface winds overseas and oceans.

In case of convective storms, four stages of convection should be detected: preconvective environments, convection initiation, and mature and dissipation stages of the storms. Special attention will be given to storm detection and monitoring, providing specific information on individual storm location, trajectory and characteristics. Information on overshooting tops detection will also be provided. Convective storm detection will be mainly based on Geosynchronous Equatorial Orbit (GEO) platforms data.

SAR data will be used for surface wind speed estimations overseas and oceans.

OPERA [3] weather radar network products have been chosen as the ground truth for convective storm detection over continental areas. Weather radar on-board a ship will be used for storm detection overseas and oceans. Wind speed detection buoys with anemometers and/or anemometers on-board ships will be used as the ground truth for surface winds alerts.

3. EO-ALERT ARCHITECTURE

In this section, we will describe the EO-ALERT envisioned architecture for providing high-speed data acquisition, processing, and generation of rapid alerts. The aim of the project is to propose a flexible data-handling architecture, managing both optical and SAR data, so as to streamline the use of on-board resources.

The proposed architecture is illustrated in Figure 2. The design of the architecture has been performed keeping into account the following three key drivers:

- *Modular*: the architecture is based on well-defined functions, with clear interconnections among them, in such a way that modifications to one function will have minimal or no impact on the other functions.
- *Scalable*: the architecture can adapt to different data types, e.g. optical/SAR, and to different sensor types for each kind of data (e.g., images from different sensors and having different sizes), within the maximum memory and computational capabilities provided by the avionics.
- *Reconfigurable*: the architecture will allow reconfiguration of the available computing resources for the optical processing and SAR processing functionalities. This can be provided via on-the-fly download of new software from the CPU to the relevant board in order to change its functionality. Reconfigurability can also help provide fault detection, isolation and recovery (FDIR), by offloading to a new board the tasks previously carried out by a board that has had a failure. This approach is very innovative and convenient with respect to conventional approaches employing redundant boards.

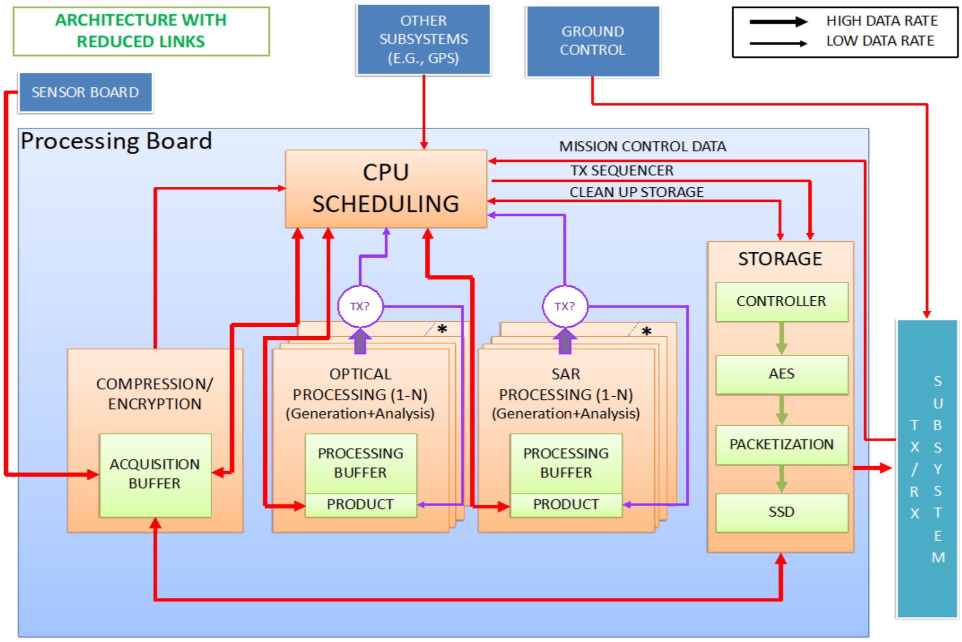

Figure 2 EO-ALERT architecture

Based on the remarks above, the architecture was designed using three main blocks: The Sensor Board, the processing Board and the Transmitter/Receiver (TX/RX) subsystem.

The Sensor Board acquires the optical/SAR raw data and it transfers it to the acquisition buffer.

The Processing Board consists of a Central Processing Unit (CPU) board and some Field-Programmable Gate Array (FPGA) boards, each one with its own Random Access Memory (RAM) storage unit. The FPGA boards are dedicated to the following tasks: 1) compression/encryption; 2) optical processing; 3) SAR processing, 4) Storage. Any additional boards may be used to increase the computational resources for Optical Processing and SAR Processing. In this case, two or more boards dedicated to the same task will be interconnected via the CPU in order to enable data transfer among them. Optionally, the storage board can be the same as the compression/encryption board, thereby reducing the number of boards employed, or freeing up boards for the more computationally demanding tasks.

The connections between the Sensor Board, the Processing Board, the TX/RX subsystem and all the internal connections in the Processing Board are represented in the diagram by the arrows. The star point of the links is the CPU. Ideally, one could have point-to-point links and avoid the use of shared buses to prevent possible congestions during the data transfer and to guarantee a low latency; however, the CPU used in the avionics should guarantee high enough bandwidth using the CPU as star point. The links can be either high data rate or low data rate.

In the following sections, we will describe in more detail the tasks to be implemented in the boards composing the Processing Boards and the TX/RX subsystem.

3.1. Optical image processing

The Optical Processing Board receives the optical raw data from the compression/encryption board (via the CPU) and stores them into the Processing buffer. Firstly, it applies a process to generate the image. This process will typically work on sub-images or sets of lines of the image, possibly with sensor-specific image size that can be adjusted dynamically. Subsequently, the image is analysed, and a final product is generated and stored. Based on the results of image analysis, this board can trigger a transmission request to the CPU; in this case, both the raw data and the product are scheduled for transmission by the CPU.

In order to comply with the characteristic of modularity and scalability, the two main steps identified as Image Generation and Image Processing will be developed independently of each other.

The Image Generation module is responsible for the conversion of raw data from the sensor into an image containing the restored and calibrated spectral radiance values for the scenes observed at the top of the atmosphere.

The implementation of the Image Generation will depend on the optical sensor and will include the following steps:

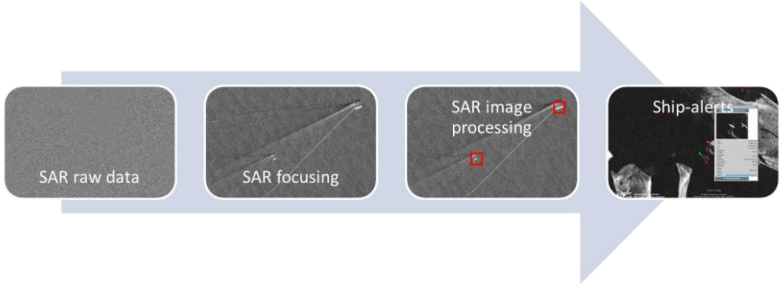

Figure 3 Illustration of the processes to be computed by the dedicated FPGA board named SAR processing

- Calibration; this removes the effect of electrical crosstalk, compensates the difference in pixel response, and converts the pixel values to radiance values making use of calibration information generated during calibration campaigns.
- Denoising; this removes high-frequency noise making use of the edge-preserving LLSURE operator [4] that automatically adapts to the noise variance in the image.
- Deconvolution; this compensates the low pass filtering or blurring that the optical system introduces in the image.

The Image Processing module is responsible for the analysis of an image to detect events of interest and generate an alarm that will be sent with very low latency to the ground. Different algorithms will be implemented for the two operation scenarios, as described in the following.

3.1.1. Ship Detection

The ship detection process will be composed of two sequential steps: coarse detection and discrimination. The coarse detection avoids the search of ships over the whole image by providing a reduced set of ship candidates to the next stage, and at the same time it mitigates the possible effects caused by the presence of land in the image. The set of ship candidates is analysed in the discrimination stage, which distinguishes between ships and false positives to provide the final detection.
The coarse detection step will be implemented using a threshold-based technique that exploits the fact that water presents a low reflectivity compared with land, clouds, and ships allowing for fast water non-water segmentation. In particular, it will be based on Otsu's method that automatically finds the optimum threshold separating two classes, so that their combined intra-class variance is minimal [5].
The discrimination stage analyzes the output from the coarse detection to discern if the candidate is a ship or a false positive. Each ship candidate, tagged with a unique label, will be analyzed based on a set of features designed to encode the gradient distribution of the object, by analyzing the direction of the edges inside a pixel neighborhood. The use of Histogram of Oriented Gradients (HOG) descriptor [5] provides robustness against different illumination conditions; the decision boundary will be computed by using a Support Vector Machine with a radial basis function kernel [7].

3.1.2. Extreme weather detection

For extreme weather detection infrared (IR) images will be used together with optical images in order to retrieve the information on the cloud top temperature.
Detection and tracking of convective storms will be performed by modelling the spatio-temporal evolution of storm areas by means of visual features and the use of a Support Vector Machine (SVM) classifier, as proposed in [8].
The first step of the process is represented by the detection of cold cells in satellite imagery, in particular making use of the 10.8 μm IR channel; all the areas colder than a threshold temperature will be marked as possible storms.
Once a cell is identified as a possible storm, its evolution will be tracked over time by analysing visual features extracted from the optical images and the temperature profile extracted from IR images. A dynamic threshold will be implemented for cloud cells detection, while a combination of HOGs and optical flow features will be used as visual descriptors for cell tracking.
The temporal evolution of the detected cells will feed a SVM classifier previously trained using a dataset of optical and IR images, together with weather radar imagery to be used as ground-truth for the generation of labels.

3.2. SAR processing

As already mentioned at the beginning of this section and illustrated in Figure 2, the Processing Board includes a dedicated FPGA board for SAR processing. In details, the tasks to be computed are the SAR image generation (alternatively known as SAR focusing) and SAR image processing. These two steps are consecutive processes necessary to generate image products (e.g. ship alerts) from the raw data collected by the Sensor Board. Such workflow is depicted in Figure 3. Although

the final EO-ALERT architecture foresees additional FPGA boards to increase the computational resources, the actual implementation of such parallelization is not discussed here as at this stage no optimization of the different possible strategies has been conducted.
The generation of a precise high resolution SAR image from satellite raw data is in general a complex and computational expensive task, which is tackled with dedicated powerful computer at ground receiving station. Therefore, taking into consideration TerraSAR-X as space segment, a full adaptation of the existing focusing processor, which uses the Chirp Scaling algorithm [9], is not foreseen.
SAR image formation algorithms employed for space-borne system with resolution capabilities less than 3 meters are the Range-Doppler algorithm (RDA), the Chirp Scaling algorithm (CSA), and the wavenumber-domain Omega-K (ωKA). After a careful review and considering the objectives posed in EO-ALERT, the last is the algorithm of choice. In particular, the approximate version, named monochromatic ωKA, seems to fit well with the resolution class and scene size aimed at in the context of EO-ALERT.
A preliminary evaluation of the computational efforts needed by the monochromatic ωKA is contrasted with the resources available on the Xilinx Zynq UltraScale+ MPSoC ZCU106 board:

- Lookup Tables (LUTs): 92k (40% of 230k)
- Digital Signal Processing (DSP) slices: 1112 (65% of 1728)
- Block RAM (BRAM): 276 (88% of 312)
- Ultra RAM (URAM): 96 (100% of 96)
- Flip-flops (FF): 70k (15% of 460k)

The selection of the SAR image processing algorithms to be implemented is strictly related to the identified scenarios described in 2.1 and 2.2.
The detection of ship in SAR images involves the implementation of the following 3 image processing steps:
1) Pre-screening via adaptive thresholding;
2) Clustering and discrimination;
3) Object parameters extraction.
The optimal setting for each step needs to be found in conjunction with the outcome of the SAR image formation, e.g. trade-off between resolution and computational time, as well as with user needs, e.g. ship size.
For the extreme weather scenario, SAR image can be used to detect the ocean surface wind speed. The image processing steps involved are basically the following:
1) Image tiling;
2) Normalized Radar Cross Section estimation;
3) Geophysical Model Function inversion.
The project will employ the Geophysical Model Function previously tuned on TerraSAR-X archived images.

3.3. Compression and encryption

The Compression/Encryption Board receives the raw data from the sensor board into the Acquisition Buffer (a RAM used to store the raw data from the sensor, as well as results of intermediate calculations of the compression/encryption process); it performs the following tasks:
- notify the CPU about the received raw data;
- prepare the data for processing (e.g., tiling);
- execute the compression/encryption process;
- send compressed data to the storage board;
- optionally, compress/encrypt the products generated by the optical processing board and the SAR processing board and forward them to the storage board.

In general, the Compression/Encryption Board will provide compression functionality for the data types available onboard that have to be transmitted to the ground station. This includes the acquired optical and SAR raw data, the optical and SAR images generated onboard, and possibly the data products generated onboard.
Compression of optical images will be based on the upcoming Issue 2 of the CCSDS-123 lossless compression standard [10], which extends it to near-lossless and lossy compression, enabling very flexible quality control policies. This standard is based on a Differential Pulse Code Modulation (DPCM) prediction loop centered around a spatial/spectral predictor that aims at obtaining an estimate of the value of the current pixel to be encoded, as a function of a few already encoded (past) neighboring pixels in the same spectral channel and in a few previous spectral channels. The prediction mechanism is adaptive, in that these neighboring coefficients are combined linearly to obtain this estimate, and the coefficients of the linear combination are changed for every new pixel in order to obtain the most accurate estimation, and hence the minimum possible energy of the residual, i.e. the difference between the true pixel value and its estimate.
The prediction residuals are then quantized and entropy-coded.
The project will employ a subset of the options available in the standard, so as to optimize compression efficiency for the data types relevant to the application scenarios, as well as minimize latency. It is foreseen that the sample-based Golomb coder [11] will be used, along with a subset of the prediction and quantization modes.
For SAR raw data and images, the compression algorithms still have to be decided between a suitably extended version of [10], or other more conventional techniques.
For encryption, two options are considered. In the first option, the compression algorithm has some built-in encryption capability. It is foreseen that low complexity

joint compression and encryption techniques will be used for this task, like scrambling/sign randomization of prediction residuals and randomization of the entropy encoder [12]. In the second option, which will not be implemented in the test bench, encryption employs Advanced Encryption Standard (AES) and is performed just before packetization (in this case, the Compression/Encryption board only performs compression).

3.4. Storage

The Storage Board is used to store the data to be forwarded to the TX/RX subsystem, i.e. data processed and received by the Compression/Encryption board, implementing an efficient data-handling policy. Every acquired image is compressed and immediately sent to the Storage board, but only images “of interest” are going to be forwarded to the TX/RX subsystem. To this end, the Storage board implements a Controller that manages the data handling. The Controller receives information from the CPU regarding the order in which the data must be queued for transmission and which data must be purged from the storage because it does not have to be transmitted. The queuing order is based on two priorities (“normal” and “high”) typically associated to image data and product data respectively. High priority data may be transmitted first and may require the interruption of transmission of normal priority data in order to reduce latency.

3.5. TX/RX subsystem

The TX/RX subsystem has been designed to support the reconfigurable on-board data handling and to satisfy the overall achievement of very low data latency and high data throughput.

The communication system aims at the dual objective of providing simultaneously very high data rates with high availability and low latency. This is achieved by a system design combining two independent channels with specific characteristics. The low-latency, low volume data products will adopt predominantly conventional microwave links in X-, Ka- and Q-band. For the high-volume products (optical and SAR raw data) both microwave and optical links are envisaged.

For microwave links, the fade mitigation techniques (adaptive data rates, adaptive modulation and coding for the RF links) offer the possibilities to reduce dependency of weather effects, thus providing high availability without huge link margins and large antennas, easing the accommodation in the ground segment of the increase in data rates required. Advanced signal processing optimized synchronization algorithms in the demodulators are applied to ensure reliable links to mitigate channel impairments. Higher-order modulation schemes in combination with powerful forward-error correction can offer the transmission by microwave links up to 2.5 Gbit/s.

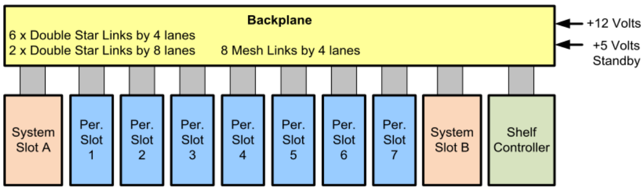

Figure 4 CPCI Serial Space Architecture

For reliable optical links, site diversity is inevitable to cover the need for reliable optical and RF links with very low latency. Distributed optical ground stations, fulfilling local constraints, can guarantee high availability. To correct burst errors on the optical channel and to improve the link quality and reliability pulse-position modulation, signal processing and forward-error correction coding techniques are used.

To support very low latency transfer for the EO alerts, an optimal combination of traditional ground stations and mobile platforms will be assessed.

4. HIGH-SPEED AVIONICS

From a design point of view, in order to achieve the functionalities foreseen in the described architecture, three different approaches have been investigated with regard to reliability: full COTS solution, full space-grade solution and hybrid solution [13][14]. On one side, the use of full COTS solutions ensures mass and power reduction, higher performance, miniaturization, availability of state of the art technology, cost and development time reduction. The performances are at the state of the art but the risk for the mission is very high due to the radiation environment the board has to sustain.

The second solution uses only space-qualified components. The risk is hence lower, since components are specifically designed to sustain radiation effects but the performance are not always adequate for the scope of the application, especially when it comes to low latency on-board elaboration.

The third solution is a hybrid solution, i.e. a solution that uses COTS and space qualified components. COTS are used in conjunction with mitigation techniques to increase robustness of the design against radiation effects, whereas space qualified component are used for the critical functions.

The last solution seems to be the most promising solution for the EO-ALERT requirements representing a good trade-off between cost, development time, performance and risks and is therefore selected as baseline.

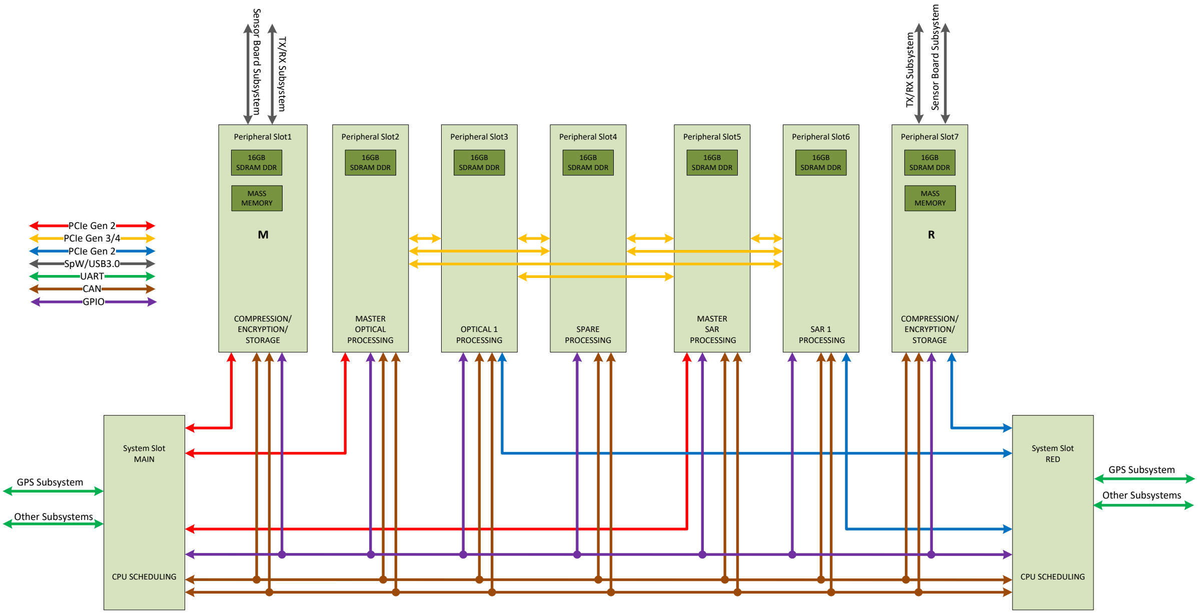

Figure 5 FM Avionics Architecture

This baseline relies on a Compact Peripheral Component Interconnect (CPCI) Serial Space architecture because it is a modular computer system, and it consists of a backplane, two system slots, seven peripheral boards, power supply and a shelf controller.
The CPCI Serial Space architecture addresses the needs of the space applications providing a flexible and robust system [15][16].
The generic architecture is reported in Figure 4.
The backplane provides slots for two system boards and up to seven peripheral boards. The double star connection allows each system slot to be connected to each peripheral board with a point-to-point high-speed link. This improves the reliability and flexibility of the system providing an intrinsic level of redundancy. Moreover, the mesh connection allows each slot to be connected with all the remaining slots thus providing the capability of direct communication between peripheral slots. The shelf controller can control the power supply of all boards separately; it can also check the status of the boards and can reset the boards individually.
The Flight Model avionics implements the needs of the compression and data handling architecture depicted in Figure 2. Moreover, such architecture provides a level of redundancy in order to allow the correct functionalities (full or at least reduced) in case of failure of one board. The proposed architecture is shown in Figure 5.
The Avionics subsystem is composed of the following boards:

- two system boards, one main and one redundant, dedicated to the CPU scheduling, and centers of the star connection with the peripheral boards;
- two boards, one main and one redundant, dedicated to compression/encryption/storage;
- five boards dedicated to the processing of the SAR and/or optical images. The boards can be reconfigured as needed, in order to increase computational capabilities of SAR/optical processing. The nominal considered configuration is three boards dedicated to optical processing and two boards dedicated to SAR processing or vice-versa. Nevertheless, the possibility of allocating up to four boards to the processing algorithm of SAR or optical images is provided.

The **CPU scheduling** (MAIN and REDundant) board is used mainly for the data transfer management. The CPU is the center of the star and is the bridge for the communication between the boards. The image data are received from the compression/encryption/storage board and forwarded to the optical processing board and/or to the SAR processing board. These communication links (red lines in the picture) are of Peripheral Component Interconnect Express Generation 2 (PCIe Gen2) type.
The CPU scheduling also receives ground control data, parameters, configurations, and, generally, any information needed to execute properly a given mission. These communication links (green line in the figure) are of universal asynchronous receiver-transmitter (UART) type.
The CPU scheduling retrieves also ancillary data from the relevant subsystems (e.g., Global Positioning System). These communication links (green line in the figure) are of UART type.
The CPU scheduling is connected to all the boards of the subsystem via a redundant Controller Area Network 2.0 (CAN2.0) link (brown line in Figure 5) for

configuration, monitoring, telemetry/commands and low data rate link purposes.

In addition, a set of general-purpose input/output (GPIO) (purple line in the figure) are exchanged between the boards for generic purpose.

The **Compression/Encryption/Storage** (M and R) board receives the raw data from the sensor board, forward the data to the CPU Scheduling board, receives product data from the processing boards, executes the compression/encryption process and stores compressed data in the mass storage. The data are exchanged through a communication link of PCIe Gen2 type (red lines in the figure). Moreover, the relevant data are forwarded to the TX/RX subsystem in order to be transmitted on ground.

The communication links with the sensor board and with the TX/RX subsystem could be of spacewire type or Universal Serial Bus 3.0 (USB3.0) type. The spacewire link is widely used in space application but the maximum speed is 200 Mbit/s. The USB3.0 interface is mainly used for consumer applications but the speed can reach up to 5 Gbit/s.

The **Master Optical Processing** board receives the image data from the CPU scheduling MAIN board via the PCIe Gen2 link (red line in the figure) and performs the dedicated algorithm for optical image processing. In addition, the image data can be forwarded to additional processing boards in order to parallelize the calculations. The product data are received back by the additional processing boards for forwarding to the Compression/Encryption/Storage board. The link for the exchange of image/product data between processing boards is of PCIe Generation 3/4 (Gen3/4) type (yellow line in the figure).

The **Optical 1 Processing** board is an additional board dedicated to the processing of the optical images. In nominal condition (i.e. no failure), the board receives the image data from Master Optical Processing board for parallelization of the algorithm and sends back product data.

If a failure is detected the subsystem is switched to the redundant part and the board can be reconfigured as the Master Optical Processing board, thus receiving the image data from the CPU scheduling RED board via the PCIe Gen2 link (blue line in the figure) and forwarding data to additional processing boards in order to parallelize the calculations via the PCIe Gen3/4 type (yellow line in the figure).

The **Spare Processing** board is a board that can be configured as optical processing board or SAR processing board depending on the need of the application. This board is able to communicate with the other processing boards via a PCIe Gen3/4 link (yellow line in the figure).

The **Master SAR Processing** and the **SAR 1 Processing** boards behaves exactly as their optical counterparts (namely, the Master Optical Processing board and the Optical 1 Processing board) for radar data.

5. DISCUSSION AND CONCLUSIONS

In this paper, we have presented an overview of the EO-ALERT project, its objectives, structure and expected innovations, and a description of the status of the current activities. The main outcomes of the project to date, with the project now approaching the end of its first year of activity, is the selection and conceptual definition of the candidate technology solutions and the definition of a preliminary on-board avionics architecture for on-board image generation, processing, compression, including both optical and SAR data, and the high data rate and very low latency communication to ground. The architecture is targeted to the generation of alerts in two example scenarios, ship detection and extreme weather monitoring, however it remains quite general and can be easily adapted to alternative scenarios. A preliminary study of its requirements demonstrates that the proposed architecture can be efficiently implemented relying on a hybrid solution combining space qualified components and high performance COTS components. Next activities will include the implementation of the different building blocks of the envisioned data chain, namely optical processing, SAR processing, compression/encryption, and TX/RX subsystem, and their individual verification against their respective requirements. These building blocks will then be integrated into a high-speed avionics test bench for a testing campaign using real EO data from the chosen scenarios, allowing the evaluation of their performance in a representative environment.

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