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Satellite Acquisition System at INGV Rome headquarters

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Satellite Acquisition System at INGV Rome headquarters

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Cover Satellite dishes on the roof of the INGV headquarters | *In copertina Le parabole satellitari sul tetto della sede INGV*

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Abstract

This technical report describes the MAST satellite acquisition system (Multimission Acquisition SysTem) operating at the INGV headquarters in Rome since 2019 and part of the main instrumentation of the ADEO laboratory (Earth Observation Data Acquisition) established in May 2021 by the Remote Sensing Functional Unit of the ONT section.
The system acquires meteorological and environmental satellite data transmitted by the EUMETSAT Consortium through the EUMETCast distribution system. EUMETCast's Basic, High volume 1, High Volume 2, and Terrestrial services are currently distributing real-time or near real-time more than 120 data and products acquired by Earth Observation (EO) instruments aboard satellites in geostationary and polar orbit managed by major international space agencies.
The MAST system was designed to reliably receive this increasingly large amount of data distributed through the EUMETCast service. Therefore, it responds to the need to supply INGV with an EO satellite data acquisition system capable of providing the most accurate and timely information possible on the expected scenario in the case of major events of volcanic, environmental, and seismic activity. It also provides the necessary infrastructure to develop and deploy new monitoring and research products generated from EO space data.
This report describes both the hardware and the software structure related to the acquisition and organization of the satellite data distributed by the EUMETCast service that are the basis of the generated products. MAST was also designed with particular attention to the overall reliability of the system, achieved with the redundancy of its hardware and software components. Furthermore, easily replaceable commercial and modular hardware components and Python-based open-source acquisition software in Linux were used. These choices allow easier MAST system management without additional maintenance and licensing costs, fully controlled by INGV personnel.

Keywords Satellite data; Acquisition; Earth observation

Introduction

Over the last few decades, the launch of Earth observation (EO) satellites has allowed us to increase our scientific and technological knowledge for understanding the Earth system.
In the past, receiving data from polar satellites required expensive antennas and systems that allowed tracking the satellite once it was visible on the horizon. In recent years, the spatial resolution and the definition of the sensors mounted on board the satellites in both geostationary and polar orbits have increased considerably.
Through the EUMETCast [EUMETSAT TD 15, 2021] distribution service, the EUMETSAT consortium retransmits data from geostationary and polar satellites equipped with EO remote sensing instruments through ordinary telecommunications satellites. Compared to the past, this distribution system allows users to manage the receiving stations more easily.
Following EUMETSAT's recommendations, MAST design goals were set to obtain a system as reliable as possible through the complete hardware and software redundancy implemented with two independent acquisition chains [Stelitano et al., 2020]. In case of failure of any one of the system components, redundancy is an essential feature to achieve the overall reliability required to monitoring services in near real-time (i.e. Annex A, INGV-DPC Convention). In addition, other important design choices were the use of commercial and modular electronics, the Linux Ubuntu

server operating system, and the acquisition software created by the Pytroll [Raspaud et al., 2018] open-source project in the Python language. This made it possible to plan and implement a very economical acquisition system compared to the cost of proprietary turnkey systems, free of additional maintenance and licensing costs, flexible and expandable, and entirely under the control of INGV personnel.
The system was created to be used for satellite monitoring of volcanic events but today it lends itself to multiple uses, including environmental ones, given the variety and amount of satellite data it receives [Merucci et al., 2021].

1. The EUMETSAT consortium and the EUMETCast service

EUMETSAT is an intergovernmental organization based in Darmstadt, Germany, currently with 30 Member States. EUMETSAT operates the geostationary satellites Meteosat-10, and-11 over Europe and Africa, and Meteosat-9 over the Indian Ocean. It also operates two Metop polar-orbiting satellites as part of the Initial Joint Polar System (IJPS) shared with the US National Oceanic and Atmospheric Administration (NOAA) [EUMETSAT website].
EUMETCast is a multi-service dissemination system based on multicast technology. It uses commercial telecommunication geostationary satellites using DVB standards and research networks to multicast files (data and products) to a wide user community [EUMETSAT TD 15, 2021].
The EUMETCast service is divided into three sub-services: Basic, High Volume 1, and High Volume 2 Services. This is due to the continuous expansion of transmitted space data and products, which increasingly require new transponders. The data rate between Basic and High Volume service has also been increased, thanks to a new MODulation and CODing scheme.
Data from Meteosat satellites are received by ground antennas located in Fucino (Italy) and Chenia (Romania). They receive the downlink from the satellites to transmit them to the Mission Control Center (MCC) and Central Facility (CF) in Darmstadt, Germany.
The Central Facility processes the raw data and takes care of the dissemination system to end users by retransmitting the EO data in near real-time with the EUMETCast Satellite service via a commercial telecommunications satellite, such as EUTELSAT.
At the same time, the data is also retransmitted overland with the EUMETCast Terrestrial service via the GEANT network (European National Research and Education Networks (NRENs)) which brings together research institutes throughout Europe. On both Terrestrial and Satellite distribution channels, EUMETSAT also transmits data collected by satellites of other space agencies, for example, those of the EO sensors aboard the GOES (NOAA) and HIMAWARI (JMA) satellites, Figure 1.

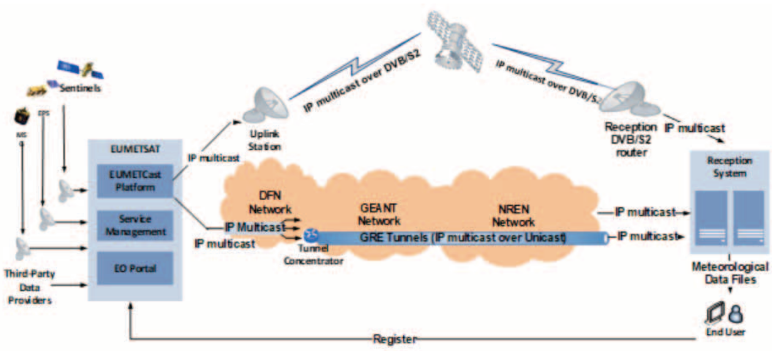

Figure 1 EUMETCast System Model.

2. MAST satellite and terrestrial design

To receive the near real-time EUMETCast Satellite data at INGV headquarters in Rome (Italy), we have implemented two twin acquisition chains: the Master Chain (MC) and Slave Chain (SC). Each of them includes:

- a satellite dish,
- three DVB receivers (Digital Video Broadcasting - Satellite 2nd generation),
- a processing server,
- a storage server.

The network infrastructure supporting this structure includes two network switches located inside the rack that houses the processing and storage servers, and on the roof of INGV headquarters, near the satellite dishes.
These switches are connected with two copper patches with 1 Gbit/s speed which are in turn configured on an LACP (Link Aggregation Control Protocol) trunk to guarantee higher speed (2 Gbit/s) and security. In case of failure of one of the two channels, the link would remain operational at half the speed.
Two Virtual Local Area Networks (VLANs) are configured on both switches. One VLAN is dedicated to the primary MC satellite acquisition chain, and one is dedicated to the secondary SC chain. In this way, the data traffic of the two acquisition chains always remains separate.
As for the acquisition of EUMETCast Terrestrial, planned but not yet implemented, it will take place via the wired network on GARR (the Italian network belonging to GEANT). Two more VLANs will be created, dedicated to the two acquisition chains, and distributed within the network infrastructure of the INGV headquarters. These VLANs will also be closed and will not be accessible from the INGV-Rome network to keep data traffic separate. They will allow the processing servers to reach the Firewalls which in turn will sort the traffic toward the Internet on the GARR network.
The infrastructure design is detailed in the graph in Appendix 4.

3. Objectives and achievement

We will now analyze in detail the main objectives set in the design of the MAST system and how they have been achieved:

- Redundancy of reception satellite dishes
- Satellite receiver redundancy
- Hardware redundancy of acquisition and processing servers
- Uniformity and redundancy of power supply in the rack at the data center
- Data acquisition and processing software

3.1 Redundancy of the reception dish

In the previous paragraph, we have seen that data dissemination by EUMETSAT takes place via commercial transmission satellites, namely EUTELSAT-10A (prime satellite) and EUTELSAT HOTBIRD-13C (backup satellite).
In 2019, the first 1.8 m Nanometrics parabolic antenna recovered from the disused satellite telemetry system of the seismic station of Posta Fibreno (Italy) belonging to the Italian seismic monitoring network was installed at the INGV-Rome headquarters.

A Low Noise Block Converter (LNB) is placed in the focus of the dish and serves to amplify the received radio frequency signal in the Ku band (10-12 GHz) and then convert it to a lower frequency. The LNB supplied with the Nanometrics dish was equipped with a single output and this only allowed it to acquire a single polarization signal. The signals sent for EUMETCast are instead both horizontally and vertically polarized. Therefore, we adapted the Nanometrics feedhorn, sized to collect all the signals from the 1.8 m dish, to a multi-output LNB.
A further limitation of this parabolic antenna consisted in not being able to receive the backup satellite (Hotbird) at the same time. To obtain this result, it would have been necessary to further modify the focus of the dish to allow it to accommodate two LNBs. We then decided to leave the Nanometrics dish with a single LNB and dedicate it to the SC slave chain.
In 2021 we purchased a second dish with a diameter of 1.8 meters to create the master chain. This second satellite dish mounts two LNBs each of which has four outputs for the different polarizations and receives signals from both the prime and backup satellites. It was installed near the first Nanometrics satellite dish (Figure 2).

Figure 2 In the foreground, the parabolic antenna of the master chain, in the background is that of the slave chain, Nanometrics. Larger in the center and oriented towards the top is the Kongsberg dish, used for acquiring data from polar satellites, which is currently not used. Behind the latter, not visible in the photo, is the cabinet inside which the DVB receivers are placed.

3.2 Redundancy of satellite receivers

The Digital Video Broadcasting (DVB) receivers are placed in a watertight cabinet located on the roof of the building between the two dishes. DVBs receive the radio frequency signal from the LNBs of the dishes and transform it into TCP/IP packets to be sent to the decryption and processing servers.
The signals transmitted via cable degrade in proportion to the cable's length, and therefore the greater the distance between the LNB and DVB, the lower the signal-to-noise ratio (SNR) on the latter. For this reason, we have decided to place the receivers as close as possible to the satellite dishes by connecting them with a coaxial cable of a maximum length of 15 m.
Among the different types of satellite receivers available on the market, LAN router, PCI Card, and USB, we have chosen to purchase LAN router type DVBs as they do not require external personal computers to be connected to, thus limiting the possible points of failure of the system. EUMETSAT has tested and uses several models of receivers, and therefore we have chosen among the models already tested and recommended for this use.
For the SC, we mounted two NOVRA S300 receivers with single RF output in 2019. Each receiver of this type can receive only one transponder of one satellite; therefore, they were well suited to the configuration of the Nanometrics antenna. We used a first receiver to receive EUMETCast Basic and High Volume Service 1 on transponder C4 at 11262.5 MHz, and a second one to receive High Volume Service 2 on transponder C10 at 11388 MHz.
The NOVRA company has developed the S300 receiver configuration software for the Windows operating system. All the computers used in the MAST system have a Linux operating system,

and we have, therefore, created a Windows virtual machine from which to connect to configure the receivers.
In 2021, when assembling the second chain, we changed the model of equipment by purchasing two AYECKA SR1s, also of the LAN router type. They have both two RF inputs and two network interfaces, one for data traffic and one for management. It is possible to receive traffic exclusively from a single satellite at a time by saving two configurations within the DVB, one for the transponder of the prime satellite, and one for that of the backup satellite.
With these configurations, if there should be a failure of the prime satellite and EUMETSAT were to transmit the data on the backup satellite, it would be sufficient to enable the appropriate configuration via software.
In this way, we have saved the purchase of three additional receivers for the backup satellite (HB13 in Figure 3), and it is easily possible to remotely configure the installed devices using the telnet protocol from any operating system.

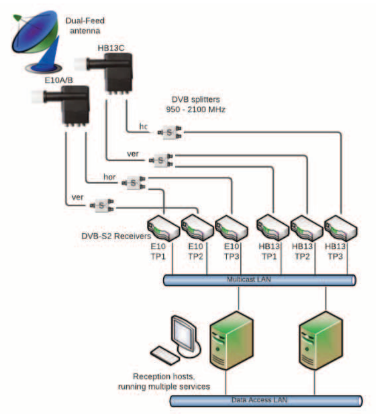

Figure 3 Single chain reception system using passive splitters recommended by EUMETSAT [Eumetsat wiki space].

The data transmission of the EUMETCast service is evolving, and several changes are still ongoing as of the end of 2022 (Figure 4) [Eumetsat transponder migration].
The transmission satellite was changed from Eutelsat-10A to Eutelsat-10B by first changing the transponder from C10 to C3 (later renamed WK10 and WK9). In the coming months, an additional transponder (WK4) will also be activated to create a new data channel: the High Volume Service 3.
By December 2023, the MAST system will also receive data transmitted by the geostationary satellite Meteosat Third Generation (MTG). For these reasons, at the time of writing this report, additional Novra S400 model receivers are being purchased.
The S400 model overcomes the limitations of the previous model by mounting a double RF input and a double network card and allowing control via the telnet protocol.

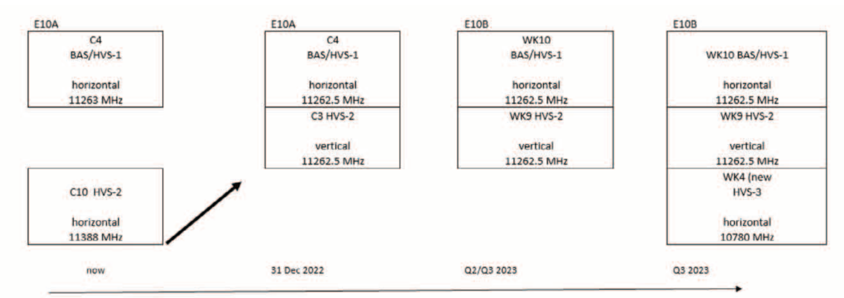

Figure 4 Transponder evolution on the prime EUMETCast Europe satellite at 10° East.

3.3 Hardware redundancy of acquisition, processing, and storage servers

Twin HP Proliant 580 Gen 10 model servers were purchased in early 2019. Each server is equipped with 256 Gb of Ram, 2 processors for a total of 36 cores, two 300 GB hard drives, a 960 GB solid state hard drive, and 5 mechanical hard drives of 1.8 TB each.
The Ubuntu Server Linux operating system is installed in a RAID configuration on the 300 GB hard drives. The SSD hard disk has a high writing speed compatible with real-time data acquisition and processing and has therefore been dedicated to receiving data streams from DVB receivers on a circular buffer. The 1.8 TB hard drives, also in RAID configuration, are used for data storage and subsequent processing for which there is no need for low latencies and real-time response.
One advantage of SSD disks is their faster read and write speeds compared to traditional hard disks (HDDs). This means that data can be accessed and processed much faster, which is essential when dealing with large volumes of data. In addition, SSDs have no moving parts, making them more reliable and less prone to failure even under intensive work. Another advantage of the new servers is the dual power supply. Each server is already set up to accept another 8 hard disks, SSD or mechanical depending on the need, and is dedicated only to one of the two acquisition chains.
In 2021, two DELL POWEREDGE R7425 model servers were purchased to play the role of second-level storage. Each server is dedicated to a single acquisition chain and has 50 TB of disk space.

3.4 Redundancy of the power supply of the devices placed in the acquisition rack

The devices described in 3.3 are placed in a rack dedicated to the acquisition of satellite data located in the CED (Data Center) and were previously placed under an unmaintained UPS, in cascade to the INGV power supply network.
The INGV power supply network is equipped with generators that allow continuity in the event of failure of the main power supply system. The old unmaintained UPS was eliminated and the rack was equipped with two independent power supply systems, a master power line and a slave, whose UPS devices are properly maintained by the INGV-Rome IT and technical departments.
All devices, including capture and storage servers, are therefore now dual-powered because they are connected to both power networks improving system reliability and uptime. Devices equipped with a single power supply, such as the switch inside the rack, are currently connected to the master power line.
Overall, the combination of higher-performance servers with SSD disks and dual power supplies has significantly improved the processing capabilities for handling multiple signals from different satellites. Data can be now processed faster and more efficiently, with increased reliability and reduced downtime due to power supply problems.

3.5 The data acquisition and processing software

The data streams received from the DVBs are transmitted to the acquisition servers with TCP/IP protocol and acquired through the Tellicast® program supplied by EUMETSAT which decrypts and collects the data in various folders on the SSD hard drives.

An example of the Tellicast monitoring graphical interface is shown in Figure 5. The different interfaces are available on different ports depending on the service received (Basic, High Volume 1, and High Volume 2 services).

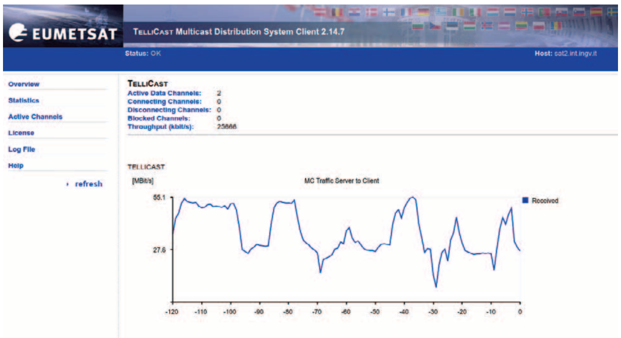

Figure 5 Tellicast program monitoring interface.

Files originally downloaded from EUMETCast are deleted from the SSD area after 12 hours (Figure 6, dot 1).

The first-level data (L1) is automatically transferred to circular buffer areas of different capacities according to the priority of the specific data.

The first buffer is in the SSD disk itself, and the data present in this area are used for automatic processing in real-time. Some of them are in compressed format, and during the transfer from the Tellicast folders to the SSD buffer, they are decompressed on the fly and are deleted after 24 hours (Figure 6, dot 2).

At the same time, the L1 data is saved in assigned quotas on the mechanical hard disks of the 1.8 TB processing server and kept there for one year (Figure 6, dot 3).

Currently, the decompressed data is temporarily saved for 2 years in a NAS made available within a specific project (Figure 6, dot 4).

The last save of the compressed data is indefinite (LTS, Long Term Storage) on the storage servers. They will be saved for longer-term archiving and staged processing requests following relevant geophysical events (Figure 6, dot 5). The filing structure is “sensor/type/year/month_day”.

For the automatic transfer of data into the different buffer areas, the Trollmoves library written in Python was used. This library is one of the components of the open-source satellite data processing suite PyTroll [Raspaud, et al, 2018]. Trollmoves is a server/client-based file transfer program implemented in Python.

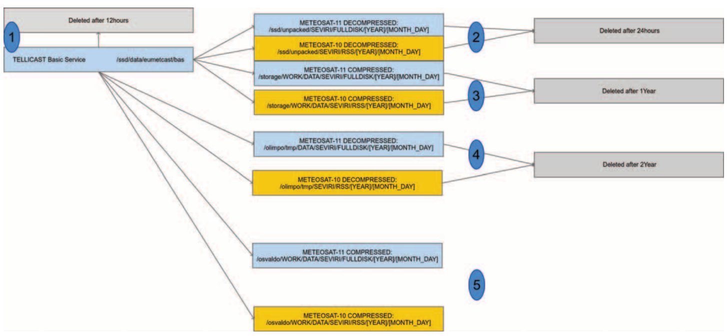

Figure 6 Data distribution and storage scheme.

Trollmoves Server is a process that follows a directory for new files and publishes a message when a matching file appears. If a Client makes a request for a file, the file is transferred using one of the built-in movers based on the destination given in the request. Trollmoves Client is configured to subscribe to a specific topic and to make requests for matching files published by a Server. The destination of the file is given in the request message. The Server handles the actual transfer [Trollmoves repository].
The management and launch of Trollmoves instances are included in the Python Conda environment [Anon, 2020] in which all the necessary libraries are installed. The start, stop, and monitoring of the instances is managed graphically through the Supervisor program [Supervisor website].

4. Conclusions

This technical report describes the state of the art related to the MAST satellite acquisition system operating at the INGV headquarters since 2019. MAST was created to provide real-time or near real-time data and satellite products of interest for volcanic and environmental monitoring. In the case of major events it is important to have real-time data to define the scenario as timely and accurately as possible. For this reason, the MAST system was developed and fully deployed at the INGV headquarters in Rome, from reception equipment to processing and storage.
This report describes both the hardware and the software structure related to the acquisition and organization of the satellite data distributed by the EUMETCast service which are the basis of the generated products. MAST has been designed with particular attention to the overall reliability of the system, achieved with the redundancy of its hardware and software components.
Two parallel master and slave acquisition chains have been implemented which allow the data to be acquired independently and redundantly to mutually compensate for problems that may occur to one of the two. Furthermore, commercial and modular hardware components, easily replaceable, and open-source acquisition software based on the Python language under the Linux operating system were used. These choices allow system management without additional maintenance and licensing costs, and under the complete control of INGV personnel.
The system currently acquires spatial data from the three EUMETCast services Basic, High Volume 1, and High Volume 2 services.
Future works foresee a database under development to record the various acquired files and integrate those possibly missing due to reception problems of one chain or another. Furthermore, a graphical interface is being developed for easier and more accurate remote monitoring of the MAST infrastructure.
In the second half of 2023, the system will be expanded to receive data from a new transponder. In particular from next December 2023 EUMETSAT will make available the data acquired by the Third Generation Meteosat satellite, currently in the commissioning phase.

Acknowledgements

The satellite data acquisition system for the Earth Observation MAST was financed with funds from the DPC-INGV All. A convention, and funds from the INGV Pianeta Dinamico project.

List of abbreviations

ADEO	Acquisizione Dati di Earth Observation
BAS	BAsic Service
CED	Centro Elaborazione Dati
CF	Central Facility
DPC	Dipartimento Protezione Civile
DVB	Digital Video Broadcasting
EO	Earth Observation
GB	GygaByte
HDD	Hard Disk Drive
HVS	High Volume Service
IJPS	Initial Joint Polar System
INGV	Istituto Nazionale di Geofisica e Vulcanologia
JMA	Japan Meteorological Agency
LACP	Link Aggregation Control Protocol
LAN	Local Area Network
LNB	Low Noise Block Converter
LTS	Long Term Storage
MAST	Multimission Acquisition SySTem
MC	Master Chain
MCC	Mission Control Centre
MODCOD	MODulation and CODing
MTG	Meteosat Third Generation
NAS	Network Attached Storage
NRENs	National research and education networks
NOAA	National Oceanic and Atmospheric Administration
ONT	Osservatorio Nazionale Terremoti
PCI	Peripheral Component Interconnect
RAID	Redundant Array of Independent Disks
RF	Radio Frequency
SC	Slave Chain
SNR	Signal-Noise Ratio
SSD	Solid State Drive
TB	TeraByte
TCP/IP	Transmission Control Protocol / Internet Protocol
USB	Universal Serial Bus
UPS	Uninterruptible Power Supply
VLAN	Virtual Local Area Network

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Supervisor website: http://supervisord.org/

Trollmoves repository: https://github.com/pytroll/trollmoves#trollmoves-server

APPENDIX 1

Data and products transmitted by EUMETCast Basic Service and currently acquired by MAST.

CHANNEL NAME	MAX MULTICAST DATA RATE (KBPS)	REMARKS
E1B-GEO-1	2000	SEVIRI IODC High Rate
E1B-GEO-2	1000	SEVIRI IODC Meteorological Products
E1B-TPG-1	8000	Third Party GEO Europe, Fengyun-2
E1B-TPL-1	12000	Third Party LEO Europe, VIIRS Fire, NPP GDS VIIRS EDR
E1B-RDS-1	11600	EUMETSAT Advanced Retransmission Service (EARS)
E1B-GEO-3	2000	SEVIRI Fulldisk 0° High Rate
E1B-GEO-4	7100	SEVIRI Fulldisk 0° Meteorological Products
E1B-GEO-5	1619	SEVIRI Rapid Scan Service High Rate
E1B-GEO-6	387	SEVIRI Rapid Scan Service Meteorological Products
E1B-TPC-6	500	Ocean MODIS, Multi-service and Third Party Data for Africa
E1B-EPS-1	740	Metop Multi Sensor
E1B-EPS-2	24	Metop AMSU-A
E1B-EPS-3	1100	Metop ASCAT
E1B-EPS-5	13140	Metop GOME
E1B-EPS-6	5700	Metop GRAS
E1B-EPS-8	154	Metop MHS
E1B-EPS-10	13140	Metop AVHRR
E1B-EPS-11	13140	Metop IASI
E1B-EPS-N-13	18	NOAA AMSU-A
E1B-EPS-N-15	686	NOAA AVHRR
E1B-EPS-N-16	34	NOAA HIRS
E1B-EPS-N-17	49	NOAA MHS
E1B-EPS-N-14	60	EPS Global data (NOAA ATOV L2)
E1B-RDS-2	13675	JPSS Regional data
E1B-SAF-1	2750	OSI SAF Data
E1B-SAF-2	2000	LSA SAF Data
E1B-SAF-3	1250	AC SAF Data
E1B-SAF-4	150	CM SAF Data
E1B-SAF-5	1500	H SAF Data
E1B-SAF-6	150	ROM SAF Data
E1B-TPC-3	300	Copernicus Global Land
E1B-TPC-5	500	Copernicus Global Land

APPENDIX 2

Data and products transmitted by EUMETCast High Volume Service 1 and currently acquired by MAST.

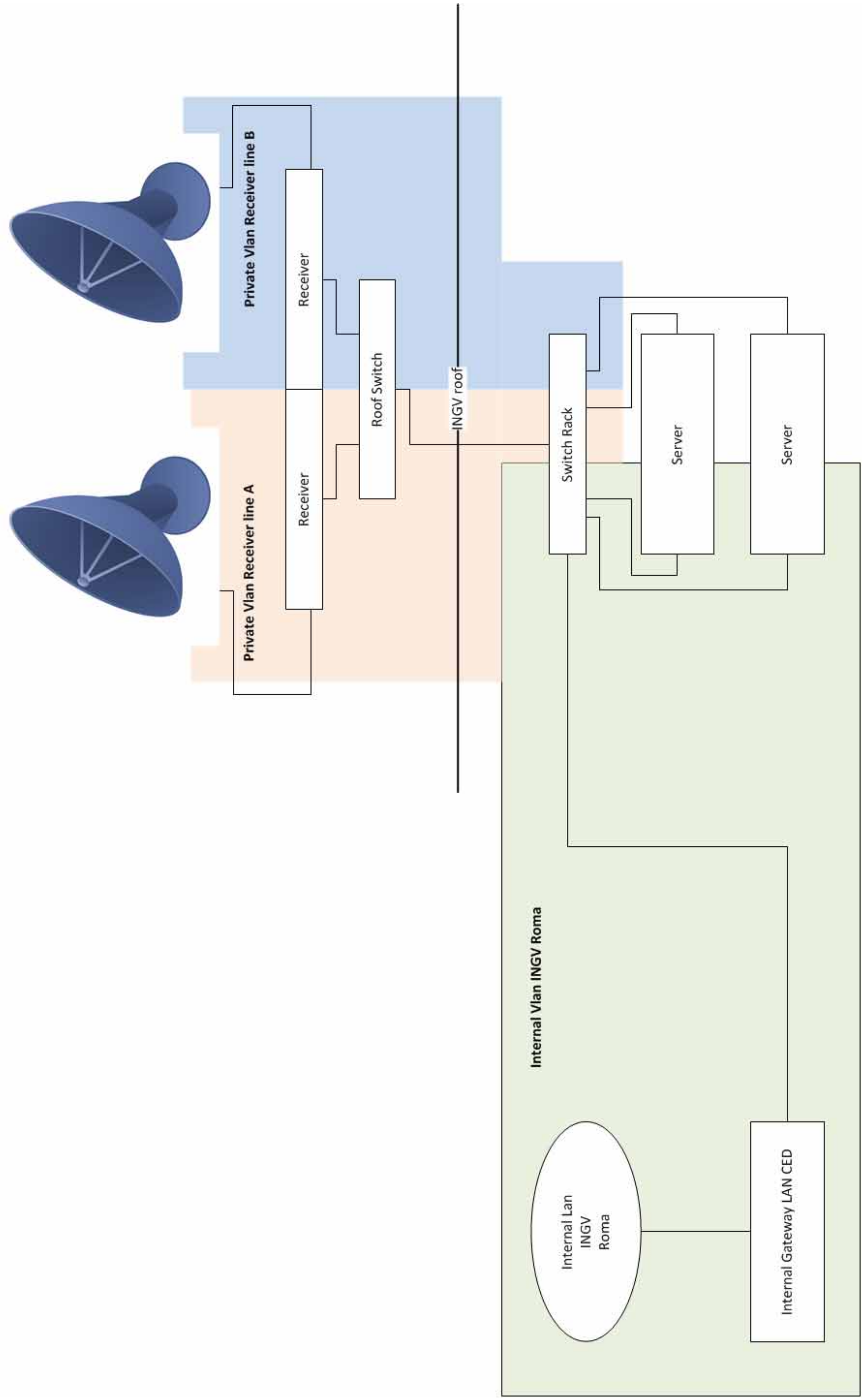
CHANNEL NAME	MAX MULTICAST DATA RATE (KBPS)	REMARKS
E1H-TPG-1	15700	GOES-16
E1H-TPG-2	15700	Himawari-9
E1H-TPG-4	15700	GOES-18
E1H-TPG-5	2000	GOES-16 space weather
E1H-TPL-1	13000	Suomi-NPP, NOAA-20, Fengyun-3C/D global
E1H-RDS-1	12500	Regional data: Suomi-NPP, NOAA-20
E1H-RDS-2	12500	Regional data: Fengyun-3

APPENDIX 3

Data and products transmitted by EUMETCast High Volume Service 2 and currently acquired by MAST.

CHANNEL NAME	MAX MULTICAST DATA RATE (KBPS)	REMARK
E2H-S3A-02	27000	Sentinel - 3A OLCI L1 Reduced Res.
E2H-S3A-03	27000	Sentinel - 3A OLCI L2 Reduced Res.
E2H-S3A-04	27000	Sentinel - 3A SLSTR L2 WST
E2H-S3A-09	27000	Sentinel - 3A SLSTR L2 FRP, AOD
E2H-S3B-02	27000	Sentinel - 3B OLCI L1 Reduced Res.
E2H-S3B-03	27000	Sentinel - 3B OLCI L2 Reduced Res.
E2H-S3B-04	27000	Sentinel - 3B SLSTR L2 WST
E2H-S3B-09	27000	Sentinel - 3B SLSTR L2 FRP, AOD
E2H-S5P-01	7000	Sentinel - 5P Aerosol
E2H-S5P-02	4000	Sentinel - 5P Cloud
E2H-S5P-03	4000	Sentinel - 5P CO
E2H-S5P-04	7500	Sentinel - 5P HCHO
E2H-S5P-05	6000	Sentinel - 5P NO2
E2H-S5P-06	10000	Sentinel - 5P O2
E2H-S5P-07	10000	Sentinel - 5P SO2
E2H-CTP-1	4000	Copernicus Third Party
E2H-CTP-2	2279	JPSS/SNPP for Cop project

APPENDIX 4


Private Vlan Receiver line B
Private Vlan Receiver line A
Receiver
Receiver
Roof Switch
INGV roof
Switch Rack
Server
Server
Internal Vlan INGV Roma
Internal Lan
INGV
Roma
Internal Gateway LAN CED

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