Satellite Data Archival on Object Storage Along with Hierarchical Storage Management

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Abstract: ***The use of Indian Remote Sensing Satellite data has brought in transitions towards development in wide range of applications such as agriculture, weather monitoring and prediction, managing natural resources and disaster management, etc., catering to the needs of these applications in managing the data resources has brought in challenges. The need for storage solutions to archive such a huge data with relatively good accessible speed becomes a paramount. Software-defined Storage solutions represent a transformative shift in the data storage industry with enhanced safety, efficiency, and flexibility. It has the potential to save hundreds of peta-bytes by reducing the cost. This paper explores the design considerations and frameworks handled for the installation and deployment of object storage and explain the functional concepts and the intricate relationship between the object storage and the existing SAN storage. Moreover, it extracts the possibilities of integrating the on-premises object storage solution with a HSM based storage architecture. This new type of storage system has been introduced to deliver real-time data support for enhancing overall data product generation, application development and data dissemination. The functionality and effectiveness of this customized object storage solution has been assessed at the IMGEOS Data Center in NRSC, Hyderabad. The placement of software-defined storage system possesses connectivity capabilities enabling interaction with the environment and the applications accessing the storage, thereby reinforcing data availability and accessibility.***

Keywords: EO, IMGEOS, NLSAS, SAN, SSD, User Meta Data, Data Archival

1.Introduction

Remote Sensing and Image Interpretation, works with the principle of electromagnetic and microwave radiation interaction with the objects under the area of sensor coverage. The basics of remote sensing include regions, bands, sensors, platforms, image resolution and spectral response patterns on different objects available in nature like water bodies, vegetation and urban structures, etc. The raw remote sensing data recorded through the medium of radiation contain many systematic deformations and inaccuracies. The data have to be processed at various levels using different techniques to remove the deformations and inaccuracies. There is a remarkable difference between raw data recorded, then acquired and processed to a stage that is usable. Finally, the data is converted into various products and supplied to consumers for various applications.

Remote Sensing data always mean raster data, the other raster data products include digital pictures, digital aerial photographs, even scanned maps. In simple terms raster data means pixels organized in rows and columns to form a matrix of cells, where each cell holds value representing information, such as reflected electromagnetic radiation, temperature or height values. The data products from various satellite sensors are developed in a suitable and standard form and format with specified radiometric and geometric accuracies which can be used for themes of interest. This is mostly formulated to a photographic output for visual processing or in a digital format amenable for further digital processing.

NRSC, ISRO receives, generates and manage increasingly large volumes of Earth Observation (EO) data from satellite every day. Before reaching to users, the data undergo some processing steps to form derived data-sets and model output that is being used by various applications. The data volume archived has increased gigabyte-folds, to approximately 28 PB in 2023. The data requirements for various applications are highly random and anonymous and this demand is propelling the organization to maintain data on-disk and supply them within acceptable dissemination delays, more importantly with un-interrupted availability. EO Satellite data is largely unstructured, that this difficult to organize into a traditional database with rows and columns. An effective setup that can make up the execution of such requirements has given rise to the inception of object storage setup at IMGEOS data center.

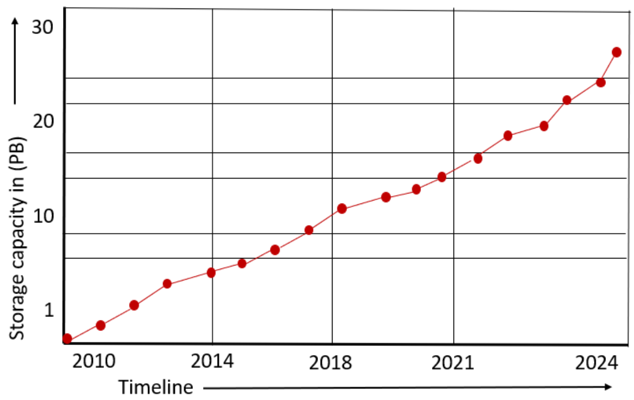

Figure 1: Historical and cumulative data archive volume in IMGEOS

Satellite Ground segment Data Center

The data center coordinates and oversees the facets of the organization that are involved particularly in the satellite data acquisition, processing and dissemination of satellite data and information including the systems, storage, networks and their configurations along with the data flow. The IMGEOS data center establishes policies and guidelines, wherever appropriate, working in close coordination with all the ground station segments that deals remote sensing mission development and operations. IMEGOS data center maintains an active data archive supporting the Indian Space Agency and Remote sensing research community. Figure 2. Shows the data center infrastructure evolution over a decade.

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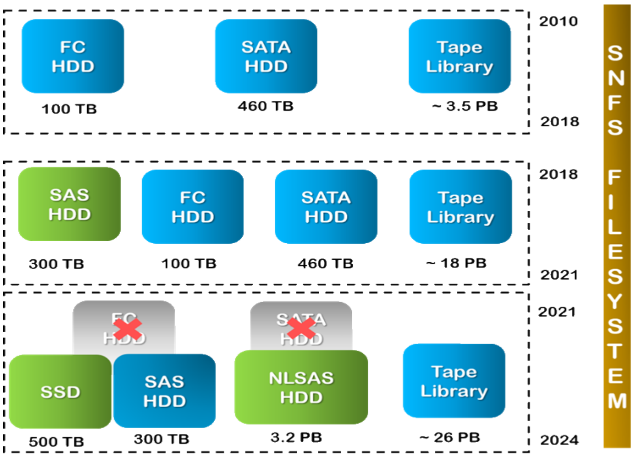

Figure 2: Storage Infrastructure acceleration over the decade

Storage Area Network (SAN)

The storage facility is fully redundant with primary and secondary / failover systems constituting a huge capacity of 36 peta bytes (PB). To serve diverse user requirements the storage is configured as SAN to provide facilities to search and access data and products. SAN is a complex network that presents block storage access to networked systems locally attached SCSI devices. The block storage takes any data, like a file or a database entry, and divides it into blocks of equal sizes and acts as a direct pipeline to the data. This also optimizes the underlying physical storage efficiently by providing efficient and reliable data access. These features made block storage as the best choice of storage for IMGEOS environment. The SAN architecture consists of three layers:

- Host layer consists of the meta-data servers as clusters that manage storage access
- Storage layer consists of physical block storage devices like solid-state drives, hard-disk drives, and magnetic tapes
- Fabric layer bridges that interconnect SAN servers and SAN storage with SAN switches, cables, and gateway devices.

Hardware

The SAN comprises of Active Storage and Archives arranged as a three-tier on-premises storage architecture. At first is a high-performance tier that typically more frequently accessed than other tiers. This tier includes enterprise-grade solid-state drives (SSD) and high performing hard disks (SAS). Then, the tier-2 storage spectrum the medium performer such as NLSAS and optical disks. The tier-2 is used for data archives where voluminous data are stored and accessed at moderate intervals. The tier-3 is a tape-based storage solution in the form of a tape library [7] that provides the majority capacity of the SAN storage. Th e data fall in between these extremes of tiers based on the requirements, supported workloads and frequency of users accessing the data, which we also call the "data temperature". Based on the access patterns the frequent or recent data is called as "Hot" data and the moderate accessed data as "Warm" and rarely accessed but still required data sets as "Cold" [3],[4]. So, each tier represents a different performance and cost pairing, as the data ages and is often less accessed, the system moves it to slower and less expensive form of storage. However, the data moved to the slower tier can be retrieved and moved back to a higher performance tier if it is needed for the workflows and product generation. Administrators set data management policies that manage data moves among the storage tiers.

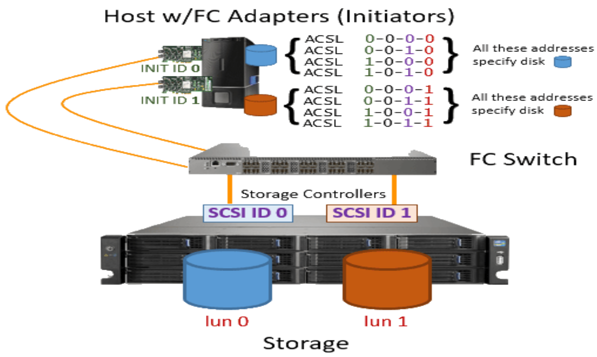

Figure 3: Logical disks or LUNs assigned to host as SCSI devices

Software: Quantum Stornext is the software platform ideally suitable to store, protect and archive satellite data like large video files, digital imagery and other formats of unstructured data under filesystem structure i.e., Stornext filesystem (SNFS) [1]. The SNFS retains the mix of storage hardware tiers under single namespace with integrated data lifecycle management. The SNFS filesystem software offers variety of services on the data such as storage allocation, metadata management, client access control and client connections. The Hierarchical Storage Management (HSM) [2], is incorporated inside the Stornext Storage Manager (SNSM) which sits on top of SNFS. SNSM uses intelligent data movers to transparently locate data on multiple tiers of storage and automatically handles data access based on policies. Regardless of where data resides in this architecture, it is always visible and accessible to clients in the namespace where it was written. Policies enable automated optimization of storage performance, cost, and protection level. The SNSM interfaces the tier-3 tape library that gains hardware information, status and operations of the tape library (SL8500), with the support of an application known as Automated Cartridge System Library System (ACSLS).

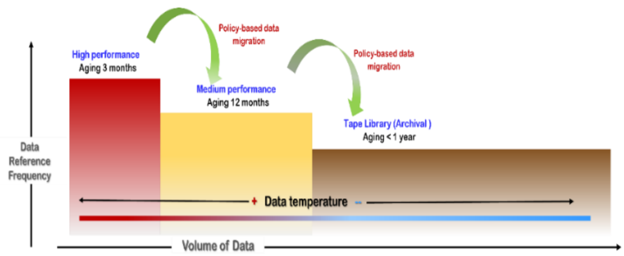

Figure 4: Policy based data movement handled by Stornext Storage Manager (SNSM)

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Enhancing availability and accessibility of Satellite Imagery as Objects

The data center has gone through the phase of creating and implementing the proper data access controls via StorNext filesystem in the form of files and directories to users in the production network. On its further move the open-data policy has brought in interest of many space start-ups, academicians and students. They are investing their research and development for bringing in better algorithms for data processing and product generation with the costless data given under ISRO open-data policy [6].

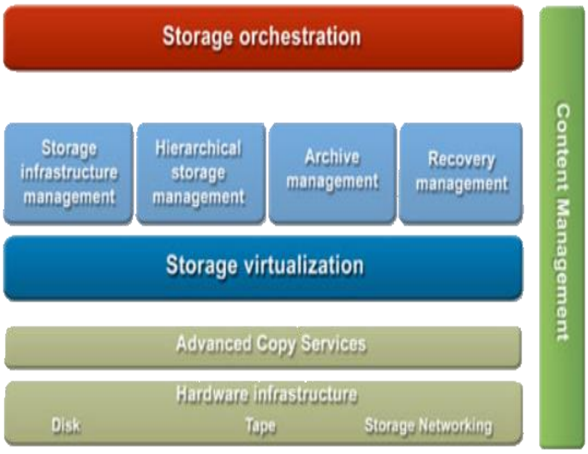


Figure 5: SAN storage consolidated architecture and controls

IT administration is tasked on this commitment in maintaining the availability of peta bytes of data stored in the SAN and make them accessible to users at anonymous time intervals. This assignment needs meticulous planning and implementation of storage technology that can support data availability and capacity at low operational maintenance with average data access latency. Hence, Object storage was opted to be used as archival storage to store warm data because object storage retrieves data instantaneously better than cold storage. Data-intensive workflows need simple solution to consolidate and manage massive amounts of data in an array of formats and access requirements. Quantum ActiveScale, the storage solution architected for both active and cold data, and provides reliable object storage platform built for high-performance access, storage efficiency and long-term durability. Object storage, also known as object-based storage, is a strategy that manages and manipulates data storage as distinct units, called **objects**. Object storage adds comprehensive metadata to the file, eliminating the tiered file structure used in file storage, and places everything into a flat address space, called a storage pool. This metadata is key to the success of object storage, together this combination is known as object identifier, these objects are put inside a structure called as **Buckets**. The object storage is accessed using an internet protocol S3 (Simple Storage Service) which light and easy to use and mingles well with all programming language. The seamless integration of object storage solution into IMGEOS HSM based storage architecture has posed some challenges and opportunities. One such challenge is modifying data access services that shall be shifted from the HSM storage on to the object storage solution. Opportunities include refactoring of the archive storage to a cloud-native architecture; upgrading the speed of data to the need of virtualized compute infrastructure that can be spun on demand; and also reorganizing data to be more analysis and access-friendly.

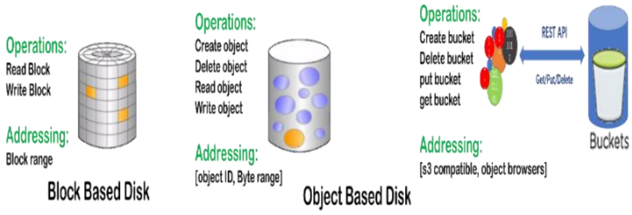


Figure 6: Block and Object storage difference and interfaces

Architectural changes in Storage services for Data Processing

In general, the observations of remote sensing satellite data, its sources and devices are quantitative. The raw data is acquired at predefined coordinates and sensor specifications. The sensors record radiance, which is processed into raw images for further analysis and interpretation. In pre-processing image co-registration and phase calibration is performed. Satellite data Processing turns the gathered data into reliable and clear images, readable by both humans and algorithms. During data processing, satellite imagery data can be integrated with previously taken and/or different scale satellite imagery, and with spatial or other data sources. Unlike, tape storage that retrieves data from the magnetic media and writes to the disk storage for user access involves mechanical movement. This kind of data services involves in the environment is acceptable by applications that can wait. On the other hand, data availability and accessibility are very crucial for real-time applications which cannot wait on such delays. Additionally, data supplied by the filesystem are in the form of files that requires meta-information which is another layer of information. Since, data objects that are not files, can be handled by object import method to map objects. By using such mapping methods, the objects can be directly mapped to the application from the object storage container (bucket) and can remain connected with the application as and when required. Hence, object storage was brought into the storage environment for faster data access to support Machine Learning (ML) algorithms provide effective tools for analyzing satellite imagery.

There are multiple steps involved in the satellite imagery data processing and it starts with the level`0` processing. The level`0` processing operation consumes the RAW and provides outputs that will be used for further level of data product generation. One of the outputs of level`0` processing is Framed Raw Extended Data (FRED) format, enabling to make better and more applicable insights for further level of data processing. FRED files are considered as warm data, after the crossing the policy retention period on-disk according to the archive policy. These files are maintained in storage tiers like object storage [4], to aid the next level of data processing at a better acceleration. Similarly, satellite data products that are developed irrespective of user order is known as off-the-shelf products (OTS). These products by definition are ready to use and now it will be maintained under ready to access environment. This modern way to migrating these types of files off to secondary tier using object storage is called as Active Archiving. By this mode of archiving, we can regularly free up precious space and defer expensive capacity expansion, optimize storage resources and supply data at the compute speed of AI / ML algorithms. Archival to object storage ensures that data is protected against outages, hardware failures, and data loss. Object storage also has built-in support for WORM and S3 object locking that enable immutability to maintain data integrity.

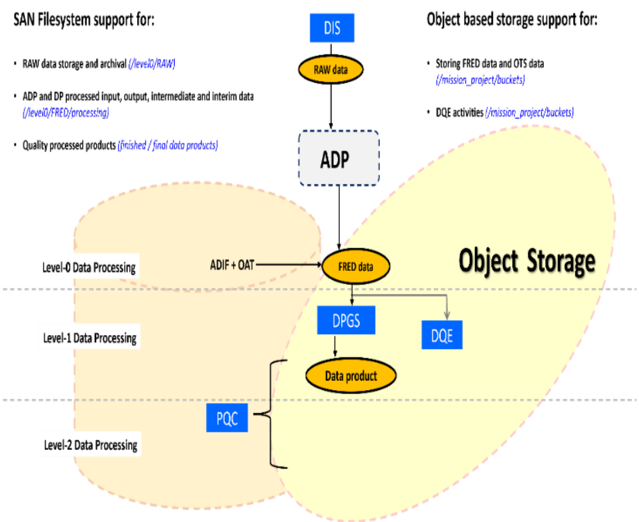


Figure 7: Integration of Object storage into HSM SAN storage

On-Premises Object Storage Solution

NRSC data center has implemented an on-premises object solution that can support multi-track users simultaneously. The installed Object storage solution is configured with 12 nodes to distribute the information across "nodes" to enhance data durability with a technology called "Erasure Coding". Usable capacity of 16.7 PB with a throughput of 29 GB/s, data protection up to two nodes and 4 hard disks failure [11]. IAM – Identity Access Management is configured and integrated with the solution for object access and various controls on the actions on objects, buckets and users. The Kafka server is configured to capture the usability metrices and to monitor the availability, accessibility and capacity of the object storage components including the buckets. Load balancer is configured among the 12 nodes in round-robin scheduling to ensure the availability of object storage end-point to the clients. Automated System alerts / Email notification on incidents on system health is configured in the solution and a web-based software-defined storage platform is configured to support NFS/CIFS clients. This object storage solution is integrated to the operational HSM SAN solution.

The object storage operations are managed by control plane that is used for account, bucket and user creations and also deletion. Pop-up alerts are there for monitoring and the same is send as emails by enabling the mail options in the configuration settings. This sends automated mails when there are any noticeable events in the object storage setup. This solution is designed with an approach to bring in a storage array for warm data archival with better and data transfer throughputs with simple upload and download of large files using S3 protocol. The user accounts for operating the object storage are created based on the role in the data processing (DP) chain. Since, the solution is targeted to archive level '0' and OTS data primarily, two user accounts one for level`0` and one for data processing operations were created. Policies for these user accounts are set using policy documents which are created as .json file, it describes actions, resources and condition keys. The actions on objects like GET/PUT (cp), LIST (ls), REMOVE (rm), MAKE BUCKET (mb) etc., along with the bucket are specified in the policy document. Prefixes are created inside the bucket and the objects are pushed under prefix based on the satellite mission. The policy will take effect and determine access to resources, authentication after applying the policy document to the indented user [12], [13].

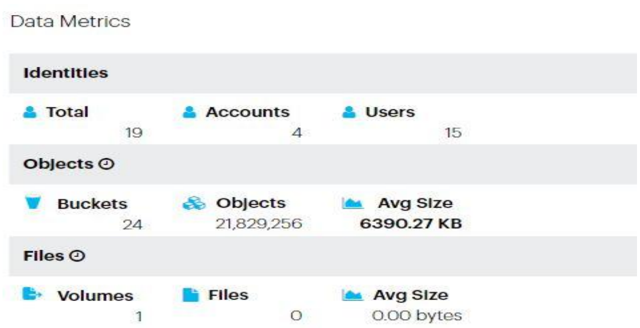
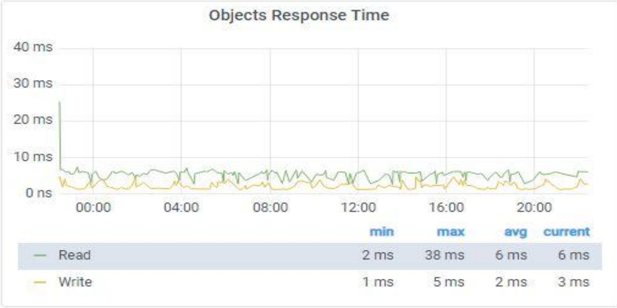


Figure 8: Data metrics captured from Object storage solution

The object storage user accounts are configured to fit multi-mission activities, on-par with the traditional environment. The level`0` and data processing user accounts are configured to operate on multi-mission satellite operations by applying multiple policy-documents created for each satellite mission, many (policies) to one (user) configuration. While creation of bucket it is intended to be used by multiple instances to ensure availability and sufficient storage capacity to manage the operations. The data center administrator monitors the availability and compute capacity for the Satellite management plane and automatically scales the master instances if necessary. The user accounts, buckets, policy document, policies are applied and implemented using IAM [14]. The clients are enabled to operate the S3 bucket by using the endpoint which is configured with load-balancer configuration. The interfaces to actively archive files on to object storage and access them back when it is required by the applications can be done by the Browser based interface and Command Line Interface (CLI) without the need for programming. Also REST API provides the most functionality, and requires programming expertise, Buckets mounted as NFS share at client systems.



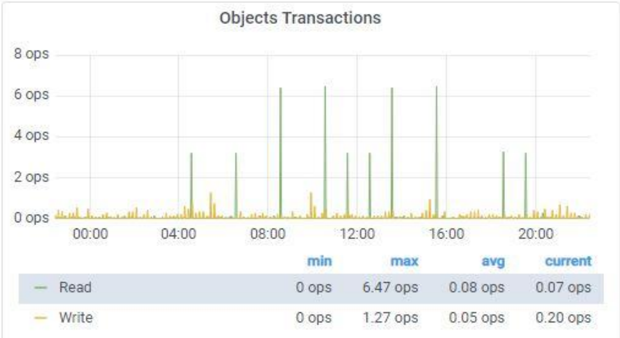


Figure 9, 10: Object response time and transactions in a day

To make a data processing (DP) host machine eligible to access object storage, it can be configured using client package. This package is installable and configurable on hosts including physical hardware and virtual machine. The other requirement is configuring the DNS which can resolve and redirect the request to the object storage end-point [17]. Finally, the host configuration is completed by applying the inputs like access and secret key, geo-location and data format. Now, the client can reach the object storage end-point using any one of the methods mentioned above. The simplest method being the command line interface which demands the user to know few S3 command sets. Apart, from data archival the object storage is also tasked with server configuration backups that are critical aspect of maintaining IT resilience and disaster recovery readiness.

Figure 11: Custom policy for data durability

Operations of object storage with IRS EOS-08 satellite, data retrieval mission is mentioned below. Three use cases with average data size corresponding to 10 files of 25GB is retrieved from tape library which is functioning as TIER-III under SAN. The data is retrieved from LTO7 media which delivers 300 MB/s; however, retrieval time depends upon the workload condition of the tape library. It took around 2 hour and 15 mins for all 10 files to reach the requestor. The object storage system has a through put of around 29 GB/stook 30 minutes to download the same set of files from its end-point. Thus, the performance of object storage in the above use case is around 4-5x faster than tape library. These performance rating is subjected to the work load conditions of the tape library. They delay may further increase with the increase in the file size.

Table: Access time comparison Tape (LTO7) vs. Object Storage

Satellite Mission	Size (GB)	Access time (Minutes)	
Storage Class:		Tape	Object
CartoSat-3S	420.64	23.17	12.33
EOS-08	6.9	4.37	0.54
EOS-04	11.1	4.31	1.03
EOS-06Mosaic	36	6	2.32

Figure 12: List of objects stored under e08fred bucket with DM sensor as prefix

Object storage stands out from traditional file or block storage due to its architectural benefits. We have designed the storage nomenclature and policy taking into consideration the challenges faced with tape library storage. The FRED data and OTS data products are archived under one flat structure known as the Bucket. Each object inside a bucket has unique object IDs denoting the prime relevance to the data. This method of archiving data accelerates data transfer speed by eliminating the need for managing directory hierarchies for different satellites and data products. Since, data is stored in bucket tagging objects with complete descriptions such as mission name, sensor, orbit no., station, etc., will be helpful in searches makes it easier to access. The policies for archiving FRED and OTS in Object storage systems are catered to ensure data is protected with replication using erasure coding (rebuilding lost data from fragments).

2.Conclusion

The necessity of the organization is met with the mix of on-premises object storage and three-tier HSM based storage. This hybrid models enable seamless synchronization, ensuring data availability across both platforms. The Object storage is a fully managed service that allows you to transfer data from a variety of sources. The data access from users hits the data source the SAN at anonymous time intervals, level of concurrency without requiring significant upfront planning or configuration. This has been provided as the popular option for storing and protecting data within their data center and under their own IT security and data governance policies. Object storage is a turnkey storage appliance and with we have built a customizable and scalable object storage cluster configured with software-defined storage with S3/HTTP access. Resiliency and durability are built into the architecture by integrating object storage with HSM based SAN storage are the other benefits. This also ensures the data stored and archived under this infrastructure can manage and orchestrate data-driven workflows efficiently. It is also designed to be scalable, reliable, and secure, and it provides a range of features and tools for managing and scheduling transfers, such as transfer acceleration, scheduling, monitor its progress and error handling.

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