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ÚSTAV INFORMAČNÍCH SYSTÉMŮ

MONITORING THE OPENSTACK SWIFT OBJECT STORE USING BEANSTALK EVENTS

SLEDOVÁNÍ OBJEKTOVÉHO ÚLOŽIŠTĚ OPENSTACK SWIFT POMOCÍ BEANSTALK UDÁLOSTÍ

MASTER'S THESIS

DIPLOMOVÁ PRÁCE

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Assignment:

1. Explore OpenStack Swift object storage, especially its architecture and activities. Study also MinIO object storage. Learn about the object storage OpenIO Software Defined Storage and in which way it uses Beanstalk to monitor and distribute events over the storage.
2. Design a service that will monitor activities in OpenStack Swift and, following the pattern of OpenIO, publish Swift events using the Beanstalk protocol. Consider also the ability to monitor and publish events from MinIO.
3. After consulting with the supervisor, implement the proposed service over OpenStack Swift/MinIO so that compatibility with OpenIO is guaranteed. For verification, also implement a sample client that will be able to subscribe to events using Beanstalk from both OpenIO and OpenStack Swift/MinIO.
4. Test the solution, evaluate and discuss the results. Publish the resulting software as open-source.

Recommended literature:

- Raúl GRACIA-TINEDO, Josep SAMPÉ, Gerard PARÍS, Marc SÁNCHEZ-ARTIGAS, Pedro GARCÍA-LÓPEZ and Yosef MOATTI: Software-defined object storage in multi-tenant environments. *Future Generation Computer Systems*. 99, 54-72, 2019. ISSN 0167-739X. Available at [<https://doi.org/10.1016/j.future.2019.03.020>]
- OpenStack Docs: Object Storage monitoring. The OpenStack project [online]. 2021 [seen 2021-09-29]. Available at [<https://docs.openstack.org/swift/ussuri/admin/objectstorage-monitoring.html>]
- Send notifications on PUT/POST/DELETE requests - swift-specs 0.0.1.dev82 documentation. OpenStack Foundation [online]. 2016 [seen 2021-09-29]. Available at [https://specs.openstack.org/openstack/swift-specs/specs/in_progress/notifications.html]

Requirements for the semestral defence:

- Items 1 and 2 finished and item 3 in progress.

Detailed formal requirements can be found at <https://www.fit.vut.cz/study/theses/>

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Abstract

The goal of this thesis is to create software that is able to monitor and publish event notification from Openstack Swift as well as from OpenIO Software Defined Storage (SDS) to Beanstalk queue. This thesis also proposes solution for publishing event notifications from MinIO to Beanstalk queue.

To accomplish this goal, new middleware is proposed that can be run inside pipeline of Proxy Server in OpenStack Swift and as (filter) part of asynchronous service Event-Agent inside OpenIO SDS.

Proposed middleware allows users to specify if they are interested in publishing event notifications for specific objects/containers using metadata. User can specify set of rules involving object properties, such as name (prefix, suffix, substring) and size, and only events satisfying those rules will be published.

The contribution of this thesis is unique software capable of event monitoring from both OpenIO SDS and Openstack Swift.

Abstrakt

Cílem této práce je vytvořit software, který je schopen monitorovat a publikovat notifikace o události z Openstack Swift i z OpenIO Software Defined Storage (SDS) do fronty Beanstalk. Tato práce také navrhuje řešení pro publikování notifikací o událostech z MinIO do fronty Beanstalk.

K dosažení tohoto cíle je navržen nový middleware, který lze spouštět uvnitř pipeline proxy serveru v OpenStack Swift a jako (filtr) součást asynchronní služby Event-Agent uvnitř OpenIO SDS.

Navržený middleware umožňuje uživatelům určit, zda mají zájem o publikování notifikací o události pro konkrétní objekty/kontejnery pomocí metadat. Uživatel může specifikovat sadu pravidel zahrnující vlastnosti objektu, jako je název (prefix, přípona, podřetězec) a velikost, a budou publikovány pouze události splňující tato pravidla.

Přínosem této práce je unikátní software schopný monitorování událostí z OpenIO SDS i Openstack Swift.

Keywords

OpenIO Software Defined Storage, Openstack Swift, MinIO, Beanstalk queue, Event monitoring, Event notification, Amazon S3 event notification, Object storage

Klíčová slova

OpenIO Softwarově definované úložiště, Openstack Swift, MinIO, Beanstalk fronta, Monitorování událostí, Oznámení o událostech, Amazon S3 oznámení o události, Objektové úložiště

Reference

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Monitoring the OpenStack Swift Object Store Using Beanstalk Events

Declaration

Prohlašuji, že jsem tuto bakalářskou práci vypracoval samostatně pod vedením pana X... Další informace mi poskytli... Uvedl jsem všechny literární prameny, publikace a další zdroje, ze kterých jsem čerpal.

.....

Nemanja Vasiljević

January 3, 2022

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Chapter 1

Introduction

In the current world, cloud computing became the most popular way of delivering different types of services through Internet. One of the most popular cloud service is cloud storage, which allows users to store data in remote locations maintained by third party. Based on how cloud storage manages data, cloud storage can be divided into 3 types: Block storage, File storage and Object storage. Object storage manages data as objects, each object typically includes data itself and some additional informations stored in objects metadata. Since data are stored in remote locations, to which users don't have direct and complete access, some users or external services might want to receive informations about certain events (for example change of content) in storages where their data are located.

Importance of this thesis is to provide event informations to users in OpenIO SDS and OpenStack Swift, which will allow user to react on those events and possibly prevent/detect unwanted actions. Providing event notifications will allow users to have better picture on what is going on in their storage and improve monitoring in these object storages.

There was two attempts[17][19] to solve this issue within OpenStack Swift which were not officially accepted and their solution is outdated. Currently there is no official solution for publishing event notification in OpenStack Swift nor OpenIO Software-Defined Storage (hereinafter SDS).

My interest in this topic stems from its possible impact to extensive amount of users that OpenStack Swift and OpenIO have. Contributing to open source projects is something that I always wanted to be part of. Possibility to improve user experience in OpenStack Swift and OpenIO SDS and allow those storages to be even more competitive against commercial storages (Amazon, Google, ...) is another reason why I choose this topic.

The goal of this thesis is to create program/middleware which will publish event notification to user specified destination. One of supported destination will be Beanstalk queue, but program will allow to easily add other types of destinations (for example Kafka) using predefined interface. Proposed program will allow user to specify, using objects metadata (such as name prefix/suffix and object size) and type of event, which event notification should be published. Program will be able to run within OpenStack Swift as well as OpenIO SDS. This thesis will strive to find such solution that could be officially accepted as part of OpenStack Swift and OpenIO SDS.

Structure of thesis - TODO - there will be probably change in chapters structure

Chapter 2

Background

This chapter introduces Object storage, its core concepts, and the underlying technologies. After introducing the Object storage, for sufficient understanding of this master thesis topic, it is essential to explain how Software-defined storage manages data, and what types of events can occur inside. The last part of this chapter describes the concept of event notifications, why they are essential, and current interfaces for publishing them to users.

2.1 Object storage

Object storage, also known as *object-based storage (OBS)*, handles data as objects instead of hierarchical methods used in file systems[35]. The object storage is designed to handle data as whole objects, making it an ideal solution for any unchanging data. Data in object stores are changed by replacing objects or files, and therefore object stores are the preferred mechanism for storing such files[36].

2.1.1 Key concepts

Key concepts of object storage are[28]:

- Objects - An object typically consist of user data and metadata uploaded to object storage.
- Containers/Buckets - represents logical abstraction used to provide a data container in object storage. An object with the same name in two different containers represents two different objects. This concept segregates data using bucket ownership and a combination of public and secret keys bound to object storage accounts, allowing users and applications to manipulate with authorized data for specific types of manipulation (read/write/update).
- Metadata - Additional information about data, such as date of creation and last modification, size, hash.
- Access Control Lists(ACLs) - used as primary security construct in object storage, stored in account or bucket level and allows owners to grant permissions for certain operations based on UUID, email, ...
- Object Data protection - two primary data protection schemes in object storage are Replication and Erasure Coding.

Replication is a method used to ensure data resilience. Data are copied into multiple locations/disks/partitions. In case of failure, data are used from a secondary copy to recreate the original copy or as a primary copy.

Erasur coding is a process through which the data is separated into fragments. Then fragments are expanded and encoded with redundant pieces and stored across different storage devices. Erasure coding adds redundancy and allows object storage to tolerate failures.

2.1.2 Object data

With object storage techniques, each object contains[28]:

- **Data** - user-specified data that needs to be stored in persistent storage. Such data can be binary data, text file, image, etc.
- **Metadata** - additional data that describe objects data. Metadata can be divided into two types: Device-managed metadata is additional information maintained by a storage device and used as part of object management in physical storage[35]. The second type is Custom metadata, to which users can store any additional information in key and value pairs. In object storage, metadata is stored together with the object.
- **A universally unique identifier (UUID)** - This ID, created using a hashing process based on object name and other additional information, is assigned to each object in object storage. Using ID object storage systems can tell apart objects from one another. ID is also used to extract data in a system without knowing their physical location/drive and offset.

2.1.3 Access to object storage

Object storage services provide a RESTful interface [38] over HTTP protocol to store and access objects. This approach allows users to create, read, delete, update, or even query objects anytime and anywhere simply by referencing UUID (or using specific attributes for querying), usually with a proper authentication process. The most popular interfaces for communicating with object storages are Amazon S3 (Simple Storage Service) API and OpenStack Swift API.

2.1.4 Pros and cons of object storage

Pros:

- Capable of handling a large amount of unstructured data
- Reduced TCO and cheap COTS - Object storage is designed to utilize cheap COTS(Commercial off-the-shelf) components. As a result Total Cost of Ownership(TCO) is lower than owning homemade Network-Attached Storage(NAS)[36].
- Unlimited scalability - Since object storages are built on distributed systems, they scale very well compared to traditional storages, where they often have an upper limit[27].
- Wide-open metadata - allows users to store custom metadata and the possibility of creating metadata-driven policies, such as compression and tiering.

Cons:

- No in-place update - object must be manipulated as a whole unit.
- No locking mechanism - object storage does not manage object-level locking, and it is up to applications to solve concurrent PUT/GET.
- Slower - this makes object storages a poor choice for applications that need rapid and frequent access to data.

2.2 Software-Defined storage

Software-Defined Storage(SDS) is a storage architecture that separates software storage from hardware allowing greater scalability, flexibility, and control over the data storage infrastructure. With the growth of Software-Defined Networks(SDN) and the need for Software-Defined Infrastructure(SDI), which aims to virtualize network resources and separate control plane from the data plane, this principle was needed to be applied on Object storage as well[31].

To overcome limitations of traditional storage infrastructures, the Software-Defined Storage (SDS) is imposed as a proper solution to simplify data and configuration management while improving the end-to-end control functionality of conventional storage systems[34]. Furthermore, while traditional storages like storage area networks (SAN) and network-attached storage (NAS) provides scalability and reliability, SDS provides it with much lower cost by utilizing industry-standard or x86 system and therefore removing dependency on expensive hardware[23].

2.2.1 Principles

There is no clear definition on criteria for defining software-defined storage, although several fundamental principles can be deducted[30]:

- **Scale-out** - SDS should enable low-cost horizontal scaling (by adding new commodity hardware to existing infrastructure) compared to vertical scaling with more powerful (and expensive) hardware.
- **Customizable** - SDS should offer system storage customization to meet specific storage QoS requirements. This will allow users to choose storage solution based on their requirements/performance and avoid unnecessary overpaying.
- **Automation** - once QoS is defined process of deployment and monitoring on object storage should be automated and done without the need for human resources.
- **Masking** - SDS can mask underlying storage system and distributed system as long as they provide common storage API and meet required QoS. SDS can offer block or File API even though data are saved in object storage (like Ceph does).
- **Police Management** - SDS Software must manage storage according to specified policies and QoS requirements despite being in multi-tenant space. SDS must be capable of handling failures and autoscale in case of change in workloads.

2.2.2 Architecture

As previously described, the main characteristic of SDS is to separate storage functions into control plane and data plane.

Control plane - the control plane represents an abstraction layer with main goal to virtualize storage resources. It offers high-level functions that are needed by the customer to run the business workload and enable optimized, flexible, scalable, and rapid provisioning storage infrastructure capacity. These capabilities span functions like policy automation, analytics and optimization, backup and copy management, security, and integration with the API services, including other cloud provider services[33].

Data plane - the data plane encompasses the infrastructure where data is processed. It consists of all basic storage management functions, such as virtualization, RAID protection, tiering, copy services (remote, local, synchronous, asynchronous, and point-in-time), encryption, compression, and data deduplication that can be requested by the control plane. The data plane is the interface to the hardware infrastructure where the data is stored. It provides a complete range of data access possibilities and spans traditional access methods, such as block I/O (for example, iSCSI), File I/O (NFS, SMB, or Hadoop Distributed File System (HDFS)), and object-storage[33].

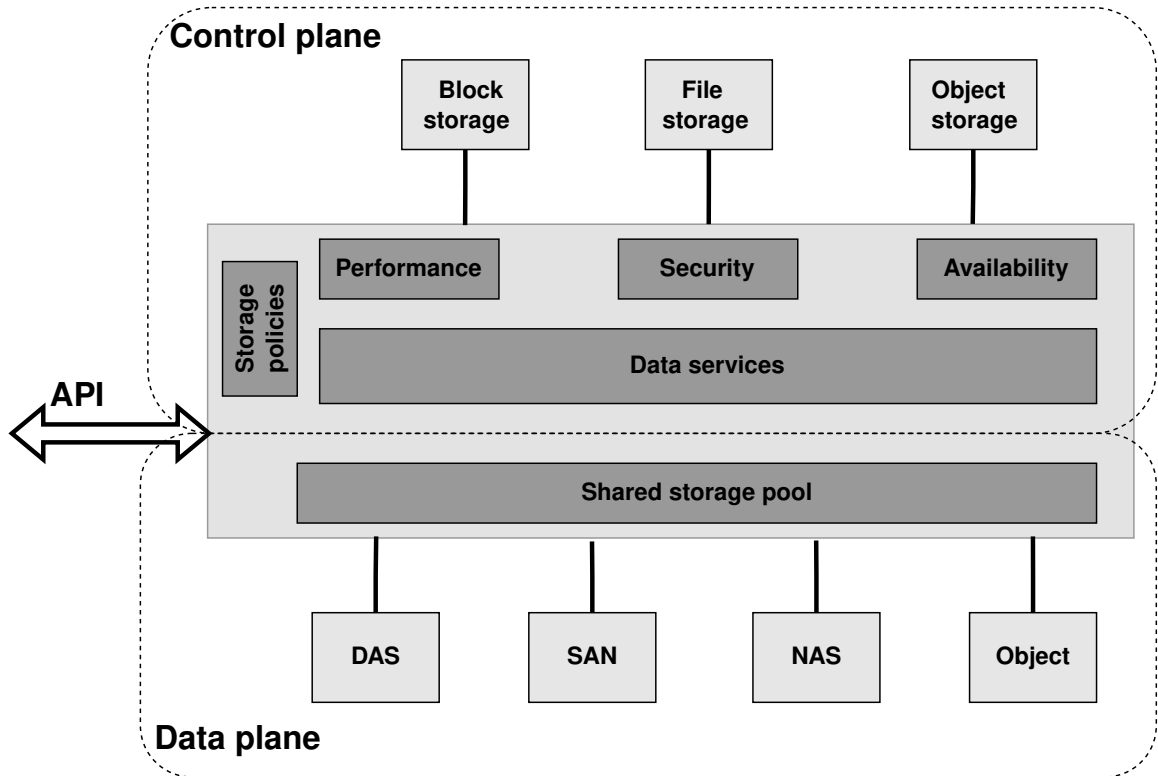


Figure 2.1: SDS data and control plane.[20], remade

2.3 Beanstalk queue

Beanstalk queue or shorter beanstalkd is a fast, simple and lightweight working queue[3]. The primary use case is to manage workflow between different parts of workers of application through working queues and messages. Beanstalkd was developed for the need of Facebook application in order to reduce average response time[3]. Provided by simple protocol design, heavily inspired by Memcached, implemented in programming language C, Beanstalkd offers lean architecture, which allows it to be installed and used very simply, making it perfect for many use cases[16].

2.3.1 Beanstalkd elements

Beanstalkd is a priority queue with server-client architecture. The server represents queues where jobs are saved based on priority. Beanstalkd architecture is composed of several components:

- Jobs - tasks stored by the client
- Tubes - used for storing tasks, each tube contains a ready queue and a delay queue.
- Producer - creates and sends jobs to beanstalkd using command „put“.
- Consumer - process „listening“ on an assigned tube, reserves and consumes jobs from the tube.

2.3.2 Job Lifecycle

Each job is uniquely assigned to one worker at a time. The client creates a job and inserts it to beanstalkd tube using „put“ command. While being in the tube, the job can be in next states[4]:

- **Ready** - the task is free and can be executed immediately by the consumer.
- **Delayed** - the task has assigned delay time that needs to expire before execution. After delay time expires, beanstalkd will automatically change its state to READY.
- **Reserved** - the task is reserved and is being executed by the consumer. Beanstalkd is responsible for checking whether the task is completed in time (TTR - Time to run).
- **Buried** - reserved task, the task will not be removed nor executed until the client decides. This state is often used for further inspection in debugging process when failure or undefined behavior occurs during task execution.
- **Deleted** - the task is deleted from the tube, beanstalkd no longer maintains these jobs.

Figure 4.1 describes the life cycle of a job in beanstalkd tube. Job is created by Producer using put command. Beanstalkd allows the Producer to add delay time before the task is ready for execution, setting the job state to DELAYED. After delay time expires, beanstalkd will automatically change job state to READY. The Producer can specify job priority and jobs with the READY state are stored in the priority queue. A job with the biggest

priority is reserved and executed by a Consumer. After successfully executing the task, the Consumer will delete the job from beanstalkd. If some error occurs, the Consumer can bury the task. The Consumer can decide that he is not interested in completing the reserved task. Using the release command (with optional delay) job state will be changed back to READY (or DELAY). Jobs with the BURIED state will not be touched by beanstalkd server until the client „kicks“ them to READY state.

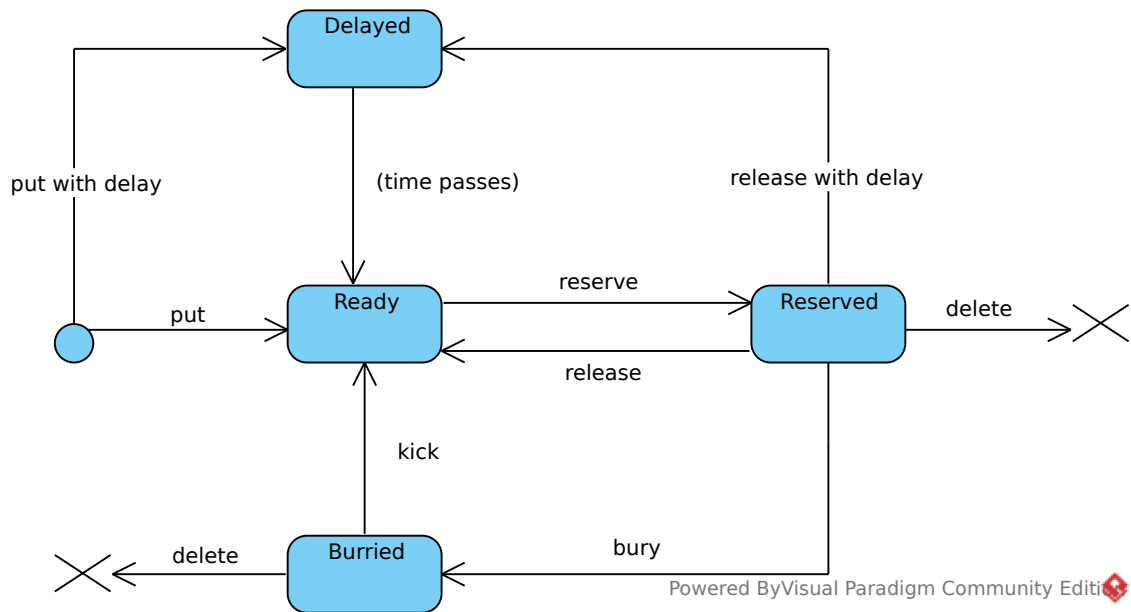


Figure 2.2: State machine diagram of job in Beanstalkd tube

2.3.3 Key characteristics

Key beanstalkd characteristics are:

Asynchronous - beanstalkd allows producers to put jobs in the queue, and workers can process them later.

Distributed - in the same way as Memcached, beanstalkd can be distributed, although this distribution is handled by clients. The beanstalkd server does not know anything about other beanstalkd running instances.

Persistent - beanstalkd offers support for persistent jobs during which all jobs are written to binlog. In case of a power outage, after restarting beanstalkd instance, it will recover jobs content from the logs.

Not secured - beanstalkd is designed to be run in a private/secure network. Therefore it does not support authentication or authorization.

Scalability - beanstalkd can be scaled horizontally, although it must be done on the client side, where each client would connect to multiple servers and then use specific algorithms(e.g., Round-robin) to switch between the different servers.

2.4 Event notifications

An *event* is a runtime operation executed by a software element, representing a significant change or occurrence in a system. Event is created in order to make some information available to other software elements not specified by the operation[37].

Event notification is a message created by a system in order to notify other parts of the system that an event has taken place[24]. Event notifications are usually used for monitoring and asynchronous job processing.

In object storage, event notifications are used to notify users or tenants about specific changes and occurrences in their bucket or account. Typical event notifications include creating new (or updating existing) objects in the bucket. In addition, most object vendors offer Publish/subscribe notifications, allowing users to subscribe to certain types of event notifications using predefined rules. Information about rules specifying event notifications is usually stored in the upper-level metadata (bucket or account).

2.4.1 CloudEvents

Publishers tend to describe event data differently due to non-existing standards or formats. The lack of a common way to describe events means developers have to learn how to handle events for each event source. To solve this problem, CloudEvents was created.

CloudEvents is a specification for describing event data in common way[6] hosted by Cloud Native Computing Foundation (CNCF)[5]. CloudEvents goal is to dramatically simplify event specification and delivery across services, platforms and beyond. CloudEvents has been integrated by many popular object storage vendors, such as Oracle Cloud, IBM Cloud Code Engine, Azure, Google Cloud etc.

Attributes in CloudEvents specification can be divided into 3 categories:

Required attributes - set of attributes that are required to be included in all events[7]:

- id (string) - event identifier, must not be empty.
- source (URI-reference) - identifies context in which event occurred, must not be empty.
- specversion (string) - the version of CloudEvents specification, must not be empty.
- type (string) - value describing the type of occurred event. Often this attribute is used for policy enforcement, routing and monitoring.

Event data attributes - attributes containing and describing event data:

- datacontenttype (string) - content type of data value (allows data to carry any type of content).
- dataschema (URI) - identifies the schema that data adheres to.
- data - data payload

Optional attributes :

- time - timestamp
- subject (string) - the subject of the event in the context of the event producer.

- extension attributes - custom attributes allowing external systems to attach metadata to an event.

```
{
  "specversion" : "1.0",
  "type" : "com.github.pull_request.opened",
  "source" : "https://github.com/cloudevents/spec/pull",
  "subject" : "123",
  "id" : "A234-1234-1234",
  "time" : "2018-04-05T17:31:00Z",
  "comexampleextension1" : "value",
  "comexampleothervalue" : 5,
  "datacontenttype" : "text/xml",
  "data" : "<much wow=\"xml\"/>"
}
```

Listing 2.1: Example of event described using CloudEvents specification and JSON

2.4.2 Amazon S3 event notifications

Amazon Simple Storage Service (S3) is one of the most popular cloud object storages providing a REST web service interface. Amazon S3 is reliable, scalable, commercial and one of the most popular object storage that manages Web-Scale computing by itself[32]. As a result, Amazon S3 has a big impact on object storage and most other object storage vendors created compatible S3 API for their services.

One of the monitoring features that Amazon S3 provides is Event Notification, which offers users to receive notifications when certain events happen in their S3 bucket. To enable such notifications, users need to create a notification configuration that identifies which events Amazon S3 should publish[2]. Notifications are configured at the bucket level and then applied to each object in the bucket.

Amazon S3 provides limited event destinations to which event notification messages can be send[1]:

- Amazon Simple Notification Service (Amazon SNS) - flexible, fully managed push messaging service, can be used to send messages to mobile phones or distributed services.
- Amazon Simple Queue Service (Amazon SQS) queues - reliable and scalable hosted queues for storing messages as they travel between computers.
- AWS Lambda - serverless, event-driven compute service. Lambda can run custom code in response to the Amazon S3 bucket event (if the lambda function writes to the same bucket that triggers the notification, it can create an execution loop).
- Amazon EventBridge - serverless event bus service used to receive events from AWS. It allows users to define rules to match events and deliver them to defined targets.

By this date, Amazon S3 does not support CloudEvents specification and describes event data in its own way. Some of event types that Amazon S3 can publish are[1]:

Event type	Description
s3:TestEvent	after enabling the event notifications, Amazon S3 publishes a test notification to ensure that topic exist and bucket owner has permissions to publish specified topic.
s3:ObjectCreated:*	An object was created (regardless on operation).
s3:ObjectCreated:Put	An object was created by an HTTP PUT operation.
s3:ObjectCreated:Post	An object was created by HTTP POST operation.
s3:ObjectCreated:Copy	An object was created an S3 copy operation.
s3:ObjectCreated:CompleteMultipartUpload	An object was created by the completion of a S3 multi-part upload.
s3:ObjectRemoved:*	An object was removed (regardless on operation).
s3:ObjectRemoved>Delete	An object was deleted by HTTP DELETE operation.
s3:ObjectRemoved:DeleteMarkerCreated	An versioned object was marked for deletion.

Chapter 3

OpenIO SDS

OpenIO Software-defined storage is open source object storage that is perfectly capable of traditional use cases (such as archiving, big data, cloud). However, at the same time, combined with Grid for Apps (3.3.1), it opens the door for users to create an application that needs much more sophisticated back-end operations. These applications include industrial IoT, machine learning and artificial intelligence, as well as any other applications whose workflow can benefit from automated jobs or tasks[22]. In addition, OpenIO SDS is event-driven storage with the ability to intercept events seamlessly and transparently to the rest of the stack.

3.1 Key characteristics

Hardware agnostic

OpenIO SDS is fully software-defined storage capable of running on x86 or ARM hardware with minimal requirements. Cluster nodes can be different from each other, allowing different generations, types and capacities to be combined without affecting a performance or efficiency[10]. OpenIO has built-in support for heterogeneous hardware allowing every node to be used at its maximum performance.

No SPOF architecture

Every single service used to serve data is redundant from object chunks stored in a disc to the directory level, every information is duplicated. As a result, there is no single point of failure (SPOF) in the cluster and a node can be shutdown without affecting overall availability or integrity[18].

Cluster organization

Instead of a traditional cluster ring-like layout, OpenIO SDS is based on a grid of nodes 3.1. It is flexible and resource-conscious. Compared to other object storage solutions, cluster organization is not based on static data allocation that usually use Chord peer-to-peer distributed hash table algorithm. Instead, OpenIO SDS uses distributed directory for organizing data and metadata hash tables, which allows the software to attain the same level of scalability but with better and more consistent performance[10].

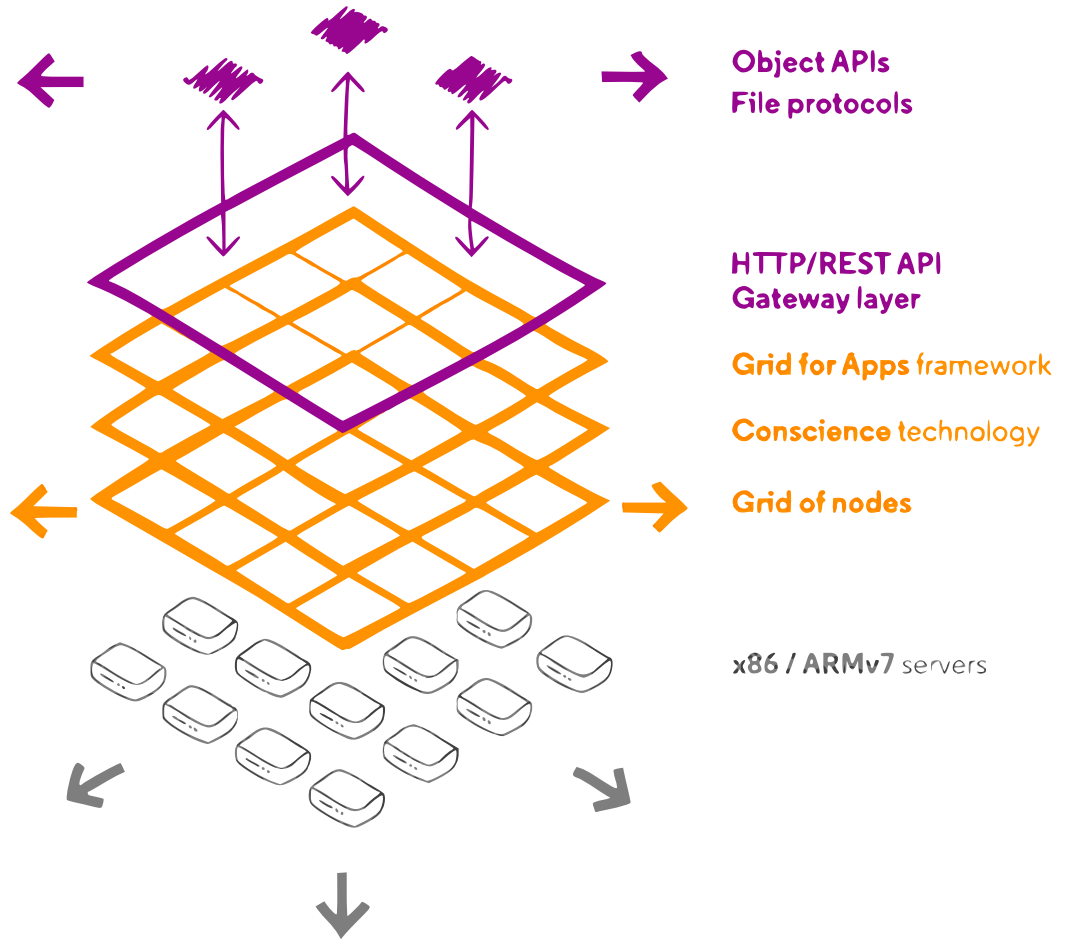


Figure 3.1: Layered view on OpenIO SDS architecture.[15]

Tiering

With tiering, OpenIO SDS offers users to configure a pool containing a group of hardware that can then be used to store specific types of objects. For example, users can create a pool of high-performance hard disks (e.g. SSDs) and use the pool to store objects that require low latency. This feature is realized by a mechanism called storage policies. Multiple storage policies can be defined in one particular namespace. Storage policies can also be used for specifying how many replicas should be created for a specific dataset[18].

3.2 Data organization

Multi-tenancy is one of the core concepts in OpenIO SDS. Data objects are stored within following hierarchy: Namespace/Account/Container/Object 3.2. Multiple namespaces can be configured in each cluster, providing multi-region/zone logical layouts for applications and segregated workloads depending on a tenant or geo-distribution need[11]. There is no classic subdirectory tree. Instead, objects are stored in a flat structure in the container level. However, like many other object storages, there is a way to emulate a filesystem.

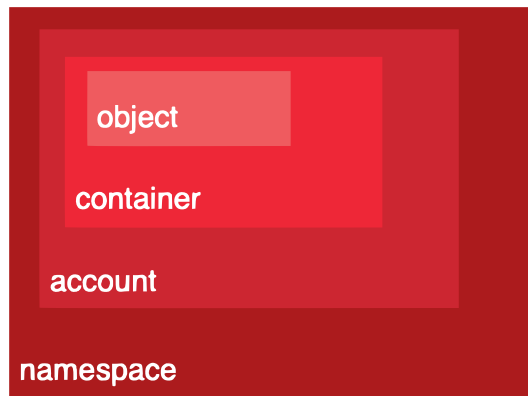


Figure 3.2: Object data organization in OpenIO SDS.[18]

3.2.1 Namespace

A coherent set of network services working together to run OpenIO's solutions. It hosts services and provides operations such as service configuration and monitoring.

3.2.2 Account

An account usually represents a tenant and is the top level of data organization. Each account owns and manages a collection of containers. In addition, the account keeps track of namespace usage for each customer (i.e. bytes occupied by all of a customer's objects)[18].

3.2.3 Container

Container represents an object bucket. Each container belongs to one (and only one) account and is identified by a unique name within the account. The container carries additional information specifying how to manage its objects (e.g. how to secure them)[18].

3.2.4 Object

Object is the smallest data unit visible by a customer and represents a named BLOB with metadata. OpenIO SDS allows several objects to be stored in a container and are considered as versions of the same object. Classic API operations (PUT/GET/DELETE) will be directed towards an object with the latest version. If the size of an object is larger than the specified limit at the namespace level, the object will be divided into chunks of data. This behavior allows capacity optimization as well as distributed reads that could be particularly useful for high-speed video streaming of large media[18].

3.3 Serverless computing

3.3.1 Grid For Apps

Like Amazon AWS Lambda, OpenIO offers an event-driven compute service called Grid for Apps that works on top of OpenIO.

Grid for Apps intercepts all the events that happen in the storage layer, and based on user configuration, triggers specific applications or scripts to act on data (metadata) stored in object storage[22]. The application is executed in cluster nodes and utilizes free unused resources available in the cluster. This improves efficiency (fewer data moving since object data are already available) and saves money (no need for external resources)[22].

Grid for Apps allows customers to perform operations such as metadata enrichment, data indexing and search (e.g. indexing metadata to Elasticsearch), pattern recognition, machine learning, data filtering, monitoring, etc[22].

Grid for Apps in OpenIO is realized using service event-agent and beanstalkd queue.

3.3.2 Event-agent

Event-agent is an OpenIO service responsible for handling asynchronous jobs. It relies on beanstalkd backend to manage jobs. Event-agent key characteristics are[12]:

- Stateless
- CPU intensive
- Must be deployed on every server of the cluster

Every event that occurs in OpenIO is inserted in beanstalkd tube. Event-agent is listening to the beanstalkd tube and consumes jobs from it. Consumers are produced using Eventlet Network Library [8]. The number of workers can be configured.

In event-agent, users can specify handlers for each type of event in event-handler.conf. Some of the event types in OpenIO are storage.content.new, storage.container.deleted, etc.

Events handler is defined as a pipeline containing applications that will react to the event. For example, deleting an object will invoke storage.content.deleted event. Event-agent will handle the event using content_cleaner application, which deletes objects chunks from object storage.

```
[handler:storage.content.deleted]
pipeline = content_cleaner

[handler:storage.content.new]
pipeline = notify

[filter:content_cleaner]
use = egg:oio#content_cleaner

[filter:notify]
use = egg:oio#notify
tube = oio-rebuild
queue_url = ${QUEUE_URL}
```

Listing 3.1: Example of event-agent handler configuration

OpenIO offers users to process events outside of the event-agent. In order to do that, users can use the application „notify“ which will send an event to a specified beanstalkd tube. Then a user can create a custom consumer process that will execute the job from beanstalkd tube. Example of such configuration is displayed in listing 3.1

Chapter 4

OpenStack Swift

This chapter introduces OpenStack object storage (code name Swift) and describes its key features. Furthermore, this chapter elaborates OpenStack Swift architecture, introduces its main services and interfaces for communication with object storage.

OpenStack Swift is an open source object storage developed by Rackspace, company that together with NASA created OpenStack project. After becoming an open source project, Swift became a leading open source object storage supported and developed by many popular IT companies, such as Red Hat, HP, Intel, IBM, and others.

OpenStack Swift is multi-tenant, scalable and durable object-storage capable of storing large amounts of unstructured data at low cost[29].

4.1 Key characteristics

Beside standard object storage characteristics (like scalability, durability, hardware agnostic, etc), some of the key OpenStack Swift characteristics:

Multi-regional capability OpenStack Swift has distributed architecture. Data can be distributed and replicated into multiple data centers, although negative effect could be higher latency between them. Distribution can provide high availability of data and recovery site[29].

No SPOF With all data being replicated and distributed, there is no single point of failure in OpenStack Swift architecture.

Developer-friendliness OpenStack Swift offers many built-in features that developers and users can use. Some of the most interesting built-in features are[29]:

- **Automatically expiring objects** - Objects can be given expiration time, after which objects become invalid and deleted from object storage.
- **Quotas** - Storage limits can be configured on container/account level.
- **Versioned objects** - User can store new version of object, while object storage keeps older versions.
- **Access control lists** - Users can configure access to their data to give or deny permission for reading or writing data to other users.

Middleware support - OpenStack Swift allows adding custom middlewares, which will be run directly on storage system[27]. This feature can be used for monitoring purposes, for example informing users or other applications about new objects in storage using Webhook middleware.

Large object support - By default, OpenStack Swift has a limit on single uploaded object which is 5GB. However, using segmentation, size of single object can be virtually unlimited. This option offers possible higher upload speed, in case of parallel upload[14].

Partial object retrieval User can retrieve part of object, for example just a portion of movie object file[26].

4.2 Data model

OpenStack Swift allows users to store unstructured data objects with a canonical name containing *account*, *container* and *object* in given order[29]. The account names must be unique in cluster, the container name must be unique in the account space and the object names must be unique in container. Other than that, if containers have same name but belong to different account, then they represent different storage locations. Same principle applies to objects, if objects have same name, but not same container and account name, then these objects are different.

4.2.1 Account

Accounts are root storage location for data. Each account contains list of containers within the account and metadata stored as key-value pairs. Accounts are stored in account database. In OpenStack Swift, account is **storage account** (more like storage location) and **do not represent a user identity**[29].

4.2.2 Container

Containers are user-defined storage location in account namespace where objects are stored. Containers are one level bellow accounts, therefore they are not unique in the cluster. Each container have a list of objects within the container and metadata stored as key-value pairs. Containers are stored in container database[29].

4.2.3 Object

Object represents data stored in OpenStack Swift. Each object belongs to one (and only one) container. Object can have metadata stored as key-value pairs. Swift stores multiple copies of object across the cluster to ensure durability and availability. Swift does this by assinging object to *partition*, which is mapped to multiple drives and each driver will contain object copy[29].

4.3 Server Processes

The path towards data in OpenStack Swift consists of four main software services: **Proxy server**, **Account server**, **Container server** and **Object server**. Typically Account, Container and Object server are located on same machine creating **Storage node**.

4.3.1 Proxy server

The proxy server is service responsible for communication with external clients. For each request, it will look up storage location(node) for account,container or object and route the request accordingly[13]. Proxy server is responsible for handling a lot of failures. For example, when a client send PUT request to OpenStack Swift, proxy server will determinate with nodes should store object. If some node fails, a proxy server will choose hand-off node to write data. When majority of nodes respond successfully, then the server proxy will return a success response code[29].

4.3.2 Account server

Account server stores informations about containers in a a particular account to SQL database. It is responsible for listing containers. It does not know where specific container are, just what containers are in an account[13].

4.3.3 Container server

Container server is similar to account server, execept it is responsible for listing objects and also does not know where specific objects are[13].

4.3.4 Object server

The Object Server is blob storage capable of storing, retriving and deleteing objects. Objects are stored as binary files to filesystem, where metadata are stored in file's extended attributes (xattrs). This requires filesystem with support of such attributes. Each object is stored using hash value of object path (account/container/object) and timestamp. This allows storing multiple versions of object. Since last write wins (due to timestamp), its ensured that correct object version is served[13].

4.4 Middlewares

Using Python WSGI middleware users can add functionalities and behaviors to OpenStack Swift. Most middlewares are added to the Proxy server, but can also be part of other servers (account server, container server or object server).

Middlewares are added by changing configuration of servers. In example ?? webhook middleware is added into proxy server by changing its pipeline (*pipeline:main*). Middlewares are executed in given order (first will be called webhook middleware then proxy-server middleware).

Some of the middlewares are required and will be automatically inserted by swift code[?].

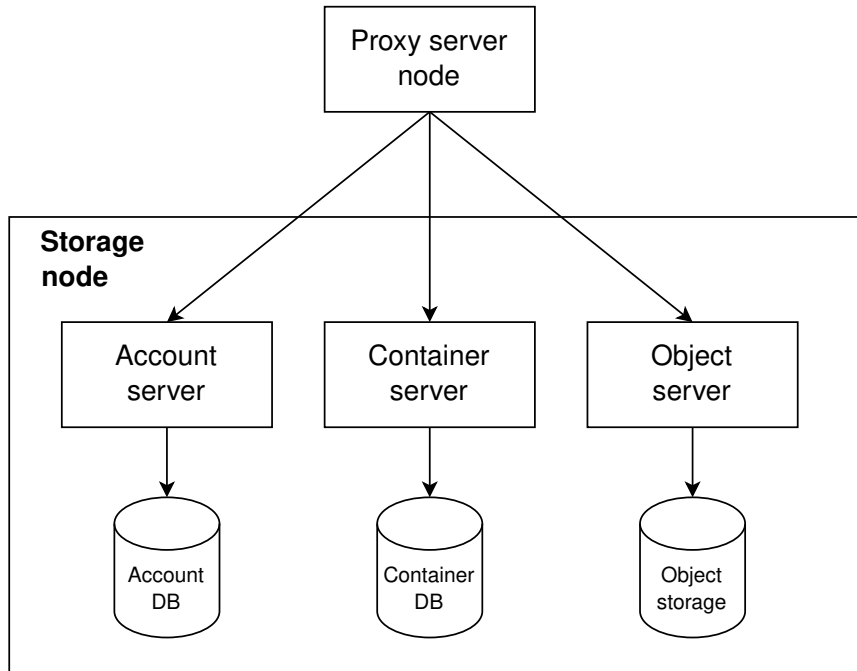


Figure 4.1: OpenStack Swift servers architecture.

4.4.1 Interface

OpenStack Swift servers are implemented using Python WSGI applications. Therefore only Python WSGI middlewares are accepted in OpenStack Swift.

In 4.1 is example of simplified healthcheck middleware. Constructor takes two arguments, first is WSGI application and second is configuration of middleware defined using Python Paste framework in proxy-server.conf. Middleware must have call method, containing the request environment informations and response from previous called middleware. Middleware can preform some operations and call next middleware in pipeline, or intercept a request. In healthcheck example, if path directs to /healthcheck , middleware will return HTTP Response and other middlewares in pipeline will not be called.

Method filter_factory is used by Python Paste framework to instantiate middleware.

```

1 import os
2 from swift.common.swob import Request, Response
3
4 class HealthCheckMiddleware(object):
5     def __init__(self, app, conf):
6         self.app = app
7
8     def __call__(self, env, start_response):
9         req = Request(env)
10        if req.path == '/healthcheck':
11            return Response(request=req, body=b"OK", content_type="text/plain")(env,
12                                start_response)
13        return self.app(env, start_response)
14
15 def filter_factory(global_conf, **local_conf):
16     conf = global_conf.copy()
17     conf.update(local_conf)

```



```

18 def healthcheck_filter(app):
19     return HealthCheckMiddleware(app, conf)
20 return healthcheck_filter

```

Listing 4.1: Example of healthcheck middleware in OpenStack Swift

4.4.2 Metadata

OpenStack Swift separates metadata into 3 categories based on their use:

- **User Metadata** - User metadata takes form **X-`<type>`-Meta-`<key>`: `<value>`**, where **type** represent resource type(i.e. account, container, object), where **<key>** and **<value>** are set by user. User metadata remain persistent until are updated using new value or removed using header **X-`<type>`-Meta-`<key>`** with no value or a header **X-Remove-`<type>`-Meta-`<key>`: `<ignored-value>`**.

- **System Metadata** - System metadata takes the form of **X-`<type>`-Sysmeta-`<key>`: `<value>`**, where **type** represent resource type(i.e. account, container, object) and **<key>** and **<value>** are set by internal service in Swift WSGI Server. All headers containing system metadata are deleted from client request.

System metadata are visible only inside Swift provides mean to store potentially sensitive informations regarding Swift resources.

- **Object Transient-Sysmeta** - System metadata takes the form of **X-Object-Transient-Sysmeta-`<key>`: `<value>`**. Transient-sysmeta have similar behavior as system metadata, they can be access only within Swift and headers containing Transient-sysmeta are dropped. If middleware want to store object metadata, it should use transient-sysmeta[?].

Chapter 5

MinIO

This chapter introduces MinIO object storage, describes its key features, most important components and event notifications in MinIO.

5.1 Introduction

MinIO is a software-defined object storage that provides high performance and scalability. MinIO was designed to be the standard in private/hybrid cloud object storage. It runs on industry standard hardware and is 100% open source[9].

MinIO software-defined object storage suite consists of a MinIO server and optional components.

MinIO Server - MinIO Server is distributed object storage server.

MinIO Client - Service providing familiar UNIX commands like *ls*, *cat*, *cp*, *diff* in MinIO storage.

MinIO Console - Browser-based GUI offering all commands from MinIO Client in a design that feels more intuitive for DevOps and IT admins.

MinIO Kubernetes Operator - plugin allowing easy deployment and operation of MinIO object storage on Kubernetes.

5.2 Key features

MinIO was designed to provide multiple benefits to object storage:

Ease of use

MinIO can be installed simply by downloading a single binary file and executing it. Configuration setup has been kept to a bare minimum. Upgrading to a newer version is done with a single command, which is non-destructive and does not provoke any downtime[21].

Encryption and WORM

MinIO provides per-object encryption using unique object key which is protected by a master key managed key-management-system (KMS).

MinIO support object locking by enforcing Write-Once-Read-Many(WORM) immutability until lock is expired or lifted. This mode prevent tempering with data once written[25].

Metadata architecture

MinIO does not provide separate storage for metadata. All operations are preformed on object-level granularity. This approach isolates any failures and does not allow any spillover to larger system failures[21].

High availability

MinIO design allows server to lose up to half its drives and a cluster to lose up to half its servers and MinIO will still be able to successfully process requests and serve objects. This is achieved by erasure code that protects data with redundancy[21].

5.3 Event notifications

MinIO support event notification for event occuring to objects. MinIO provides Amazon S3 like events structure and API for defineing which events will be published. To set event configuration, users can use MinIO client or provided MinIO SDK API.

Supported event notification targets are: AMQP, Redis, MySQL, LMQTT, NATS, Apache Kafka, Elasticsearch, PostgreSQL, Webhooks and NSQ.

Chapter 6

Solution draft

This chapter describes current state of event notifications in OpenIO SDS, OpenStack Swift and MinIO. It describes proposed solutions for OpenIO SDS and OpenStack Swift in form of middleware.

6.1 Current state

6.1.1 OpenIO SDS

OpenIO Software-Defined storage has event-driven architecture, capable of publishing events to Beanstalkd using *event-agent service* and *Notify filter*. Main disadvantage of current event publishing state is that configuration describing what type of events should be published is applied to whole storage. Since OpenIO SDS is multi-tenant space, some tenants might be interested in different events inside storage. The best use-case solution would be to let tenants decide what kind of events should be published in storage assigned to them.

Second disadvantage is **lack of event filters**. Tenants might be interested in events involving specific objects or buckets that satisfy specific rules (for example object prefix, size, etc).

Third disadvantage is that events are published only to beanstalkd queue. OpenIO SDS does not support any other destinations for event publishing. Since events can be used for monitoring, there should be proper interface, allowing users to define destination for event publishing (i.e. Kafka, Prometheus, Grafana).

6.1.2 OpenStack Swift

Currently there is support for event publishing in OpenStack Swift. For example there is no way to detect changes in a given container except listing its content and comparing timestamps.

To partially solve this problem, OpenStack Swift created specification of middleware that would send out notifications to users if new object was created, metadata updated or or data has been deleted. There were two proposed solutions, both lacking common interface for event publishing (no support for either Amazon S3 or CloudEvents), which were not accepted and are outdated.

6.1.3 MinIO

MinIO supports event publishing in form of Bucket notifications. It can inform user when a object is created, updated or deleted. MinIO offers various notification targets (i.e. MySQL, Redis, Elasticsearch) but does not offer Beanstalkd as notification target.

MinIO provides only event publishing for buckets. There is no support for any events in account level (i.e. creating a new bucket, updating buckets metadata).

Minio is open-source object storage but does not provide custom middlewares. Since MinIO is implemented in Go programming language, any custom changes (tweaks) in MinIO source code means that whole project needs to be compiled, which can result in incompatibility in future versions of MinIO.

6.2 Middleware for OpenStack Swift and OpenIO SDS

The goal is to create common middleware that is capable of running within OpenStack Swift as well as OpenIO SDS. The middleware will allow user to configure: which types of events will be published and destination where given events will be published.

6.2.1 Location

For OpenIO SDS ideal place to run new middleware is inside pipeline of event-agent. The main reason is that event-agent has access to every event that occurs in OpenIO SDS and process jobs in asynchronous mode, which means it will not have impact on latency of clients requests.

Most of middlewares within OpenStack Swift are placed in Proxy server, since they can react to every client request. Therefore, new proposed middleware will be placed inside proxy server pipeline.

6.2.2 Design

Middleware heavily utilizes containers/buckets and accounts metadata. Information about which event should be published and where, will be stored in metadata of upper level. For publishing events regarding objects, configuration will be stored in a container/bucket metadata (for container/bucket events configuration will be stored in account level).

Compared to Amazon S3 Notifications, EventNotification middleware will be capable of publishing events regarding containers/buckets. Furthermore, EventNotification middleware will be able to publish events regarding reading content from object storage (HTTP GET/HEAD), where Amazon S3 only offers notifications about changes (PUT/POST) in bucket.

EventNotification middleware can be configured so that specific event types will be forbidden for publishing in whole object storage. In use case where there could be a lot of reads from object storage, and publishing those events could have big impact on object storage performance. Therefore such event types can be disabled for whole object storage.

Activity diagram of EventNotification middleware in container level is shown in figure 6.1. Container metadata contains event notification configuration for publishing objects in given container. Therefore first step is to parse and validate such metadata. If the event notification configuration is not valid, then it is removed from metadata.

Next step is deciding if event should be published. Since metadata about event publishing are stored in upper level, EventNotification needs to read account metadata from storage. After reading and parsing account metadata, EventNotification middleware checks if event satisfies rule in configuration retrieved from account metadata. If yes, then event will be published to specified destination in account metadata.

6.2.3 Structure of published event

EventNotification can publish event notification in Amazon S3 like structure and in structure following CloudEvents standard. Listing 6.1 and 6.3 describes event notification structure in JSON format.

```

1  {
2      "specversion" : "1.0",
3      "type" : "event type",
4      "objectstorage" : "name of object storage (swift, openiosds)",
5      "source" : "URI-reference where an event occurred",
6      "id" : "request id",
7      "time" : "the time, in ISO-8601 format when event occurred",
8      "datacontenttype" : "application/json",
9      "data": {
10         "userid": "id of user that created event",
11         "useripaddress": "ip address of user that created event",
12         "requestid": "request id",
13         "transactionid": "transaction id",
14         "configurationid": "id configuration that triggered notification",
15         "resource": {
16             "name": "name of resource that triggered event (name of object, container
or account)",
17             "hash": "hash value / internal id of resource",
18             "metadata": "user metadata"
19         }
20     }
21 }
22

```

Listing 6.1: CloudEvents structure of event notification published by EventNotification middleware.

```

1  {
2      "Records": [
3          {
4              "eventVersion": "2.2",
5              "eventSource": "aws:s3",
6              "eventTime": "The time, in ISO-8601 format, for example, 1970-01-01T00
:00:00.000Z, when Amazon S3 finished processing the request",
7              "eventName": "event-type",
8              "userIdentity": {
9                  "principalId": "id of user who caused the event"
10             },
11             "requestParameters": {
12                 "sourceIPAddress": "ip address where request came from"
13             },
14             "responseElements": {
15                 "x-amz-request-id": "request ID"
16             },
17             "s3": {
18                 "s3SchemaVersion": "1.0",

```

```

19         "configurationId": "ID found in the bucket notification configuration",
20         "bucket": {
21             "name": "bucket-name",
22             "ownerIdentity": {
23                 "principalId": "if od bucket owner"
24             },
25             "arn": "bucket-ARN in format arn:aws:s3:::<bucket-name>"
26         },
27         "object": {
28             "key": "object key/name",
29             "size": "object-size in bytes",
30             "eTag": "object eTag/hash",
31             "versionId": "object version if bucket is versioning-enabled, otherwise
32 null",
33             "sequencer": "a string representation of a hexadecimal value used to
34 determine event sequence, only used with PUTs and DELETes"
35         }
36     }
37 }
38

```

Listing 6.2: Amazon S3 structure of event notification published by EventNotification middleware.

6.2.4 Event Notification configuration

User can store event notification configuration using metadata with key **EventNotificationConfiguration** where value is configuration. EventNotification middleware offers Amazon S3 like structure for configuring event notifications. Listing ?? describes event notification configuration.

<Target> represent targeted destination where event notifications will be sent (e.g. Beanstalkd, Elasticsearch).

<FilterKey> is unique name of filter containing rules that must be satisfied in order to publish events.

Event types are described in pseudo Amazon S3 way. Even type takes form **s3:<Type><Action>:<Method>** where type represents resource type (object, bucket), action represent action preformed by user and can have values: **Created, Deleted, Accessed**. Method represent REST API method preformed by user: **Get, Put, Post, Delete, Copy, Head**. For example, if new object was created, even type would be described as **s3:ObjectCreated:Put**. To match event type regardless of API method assign value ***** to **<Method>**.

```

1  {
2      "<Target>Configurations": [
3          {
4              "Id": "configuration id",
5              "TargetParams": "set of key-value pairs, used specify dynamic parameters of
6 targeted destination (e.g. name of beanstalkd tube or name of index in Elasticsearch)",
7              "Events": "array of event types that will be published",
8              "StructureType": "type of event notification structure: S3 or CloudEvents (
9 default value S3)",
10             "Filter": {
11                 "<FilterKey>": {
12                     "FilterRules": [
13

```

```

12         "Name": "filter operations (i.e. prefix, suffix, size)",
13         "Value": "filter value"
14     }
15     ...
16 ]
17 }
18 }
19 }
20 ...
21 ]
22 }
23

```

Listing 6.3: Structure of event notification configuration label

6.3 Adapter for MinIO

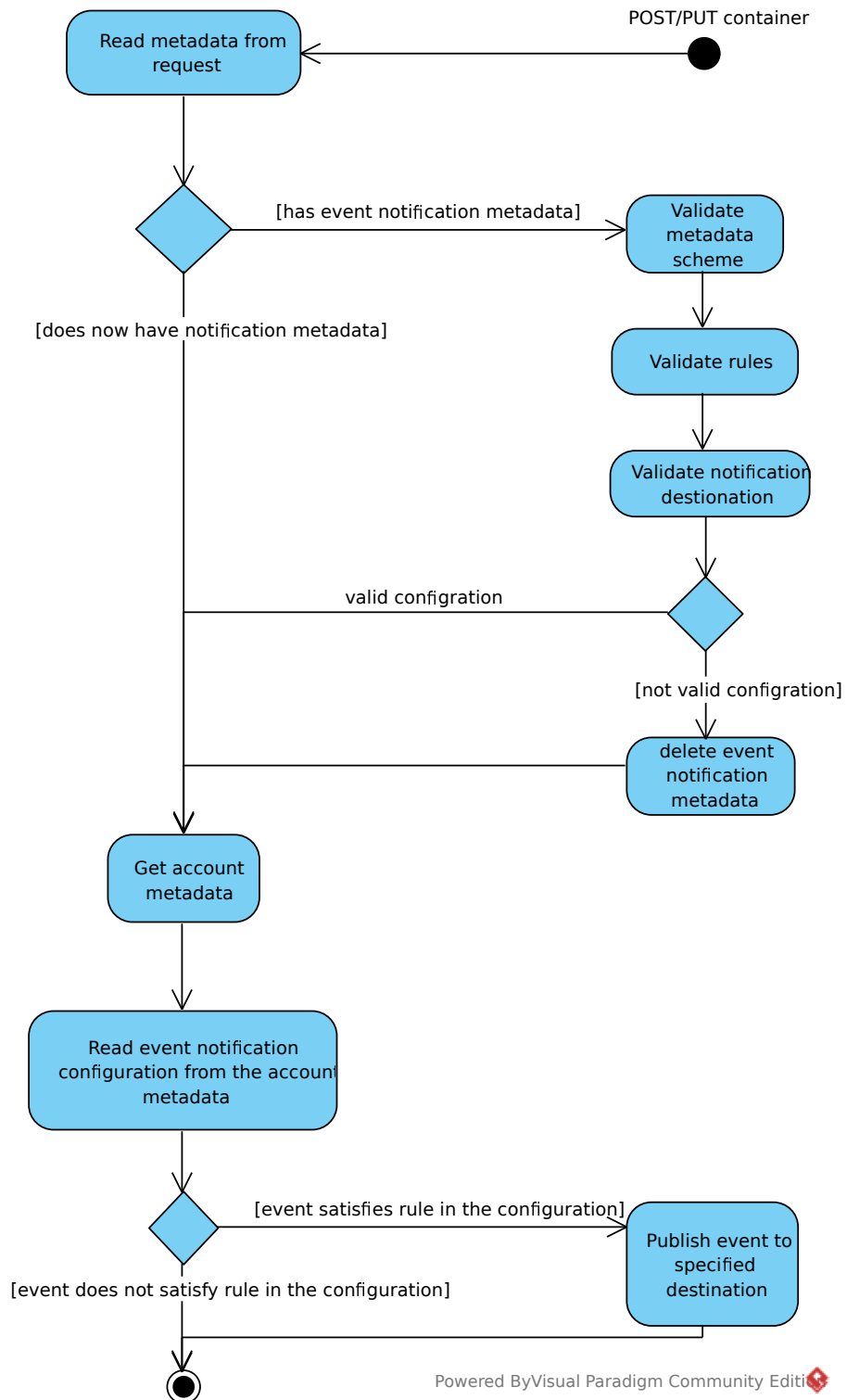


Figure 6.1: Activity diagram of EventNotification middleware.

Chapter 7

Implementation, experiments and assessment

Chapter 8

Conclusion

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