LogStore: A Cloud-Native and Multi-Tenant Log Database

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Database services at Alibaba Cloud

Figure 1: Magic Quadrant for Cloud Database Management Systems

As of Nov 2020 ©Gantner,inc

Cloud Database Management Systems (DBMS) Leader

Database Products and Services:
26 Products or Services

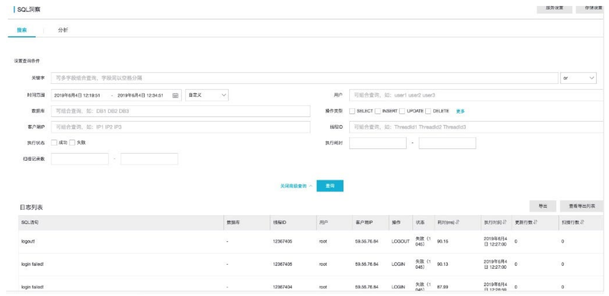
Enterprise Users:
100 thousands

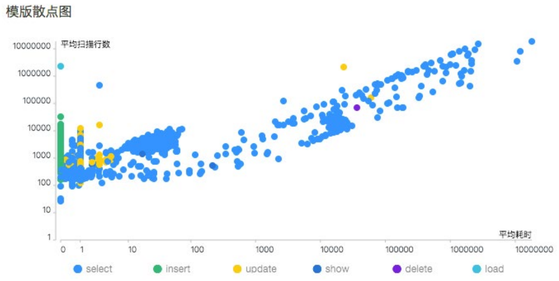
Databases Migrated:
400 thousands

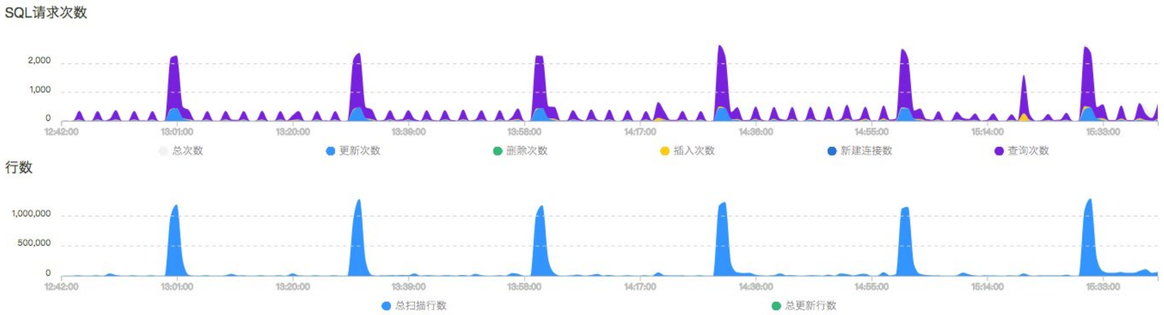
Expressway for running fully managed databases on Alibaba Cloud.
https://www.youtube.com/watch?v=5VkLDC_uIxM

The scenarios of using log data

SQL Explorer

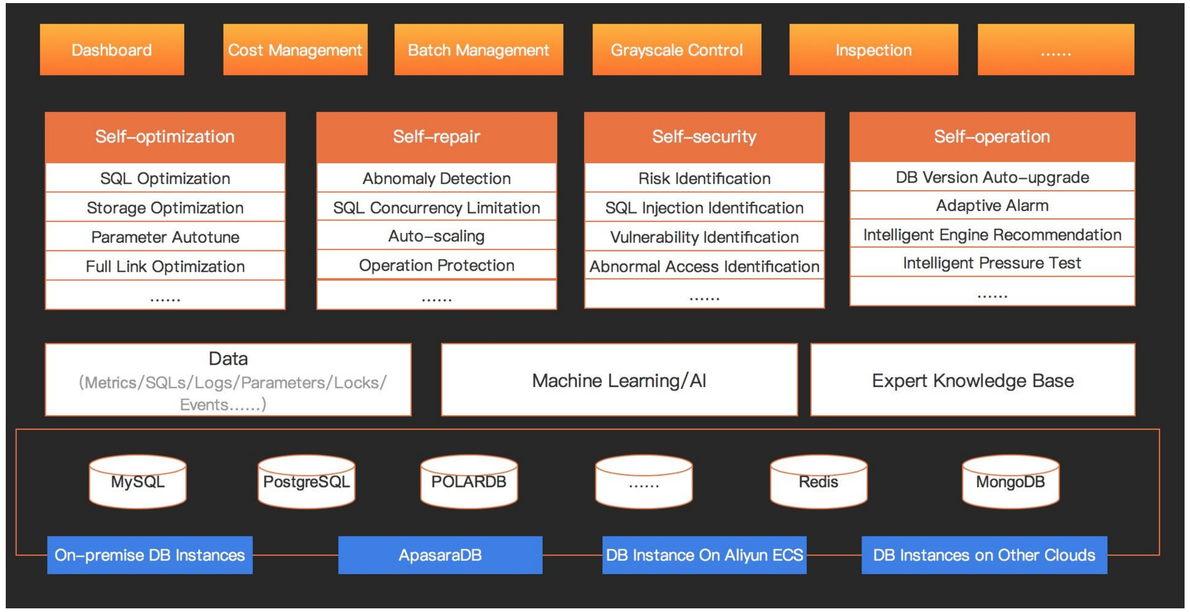






https://www.alibabacloud.com/help/doc-detail/96123.html?spm=a2c5t.11065259.1996646101.searchclickresult.44307061pHfASV

Database Autonomy Service (DAS)



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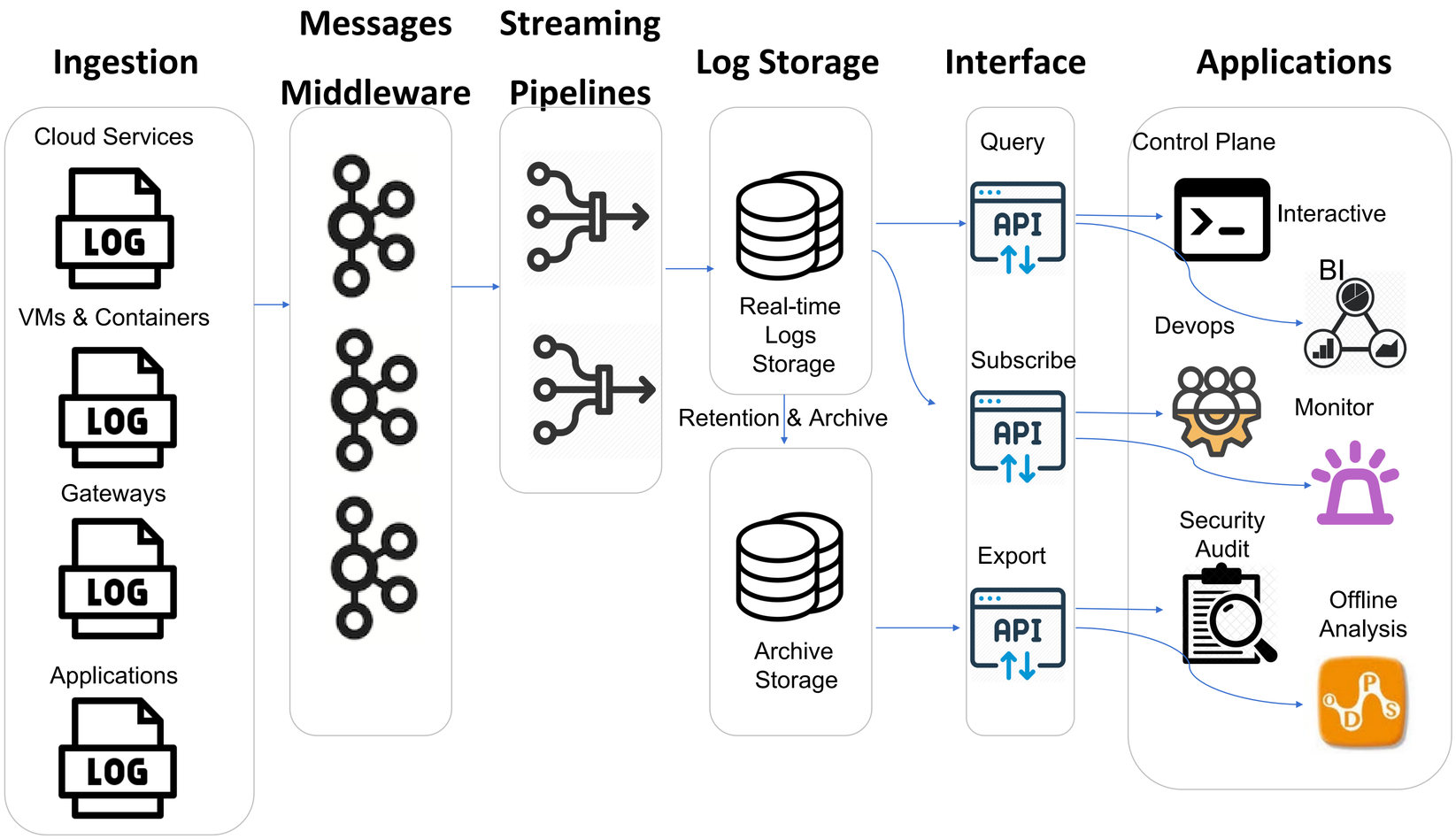
The log solution in Alibaba cloud



Problems & Challenges

- Extremely High Write Throughput
  - More than 50 millions logs per second.
- Huge Storage Volume
  - More than 10 PB.
  - Periodic retention and archive? Troublesome.

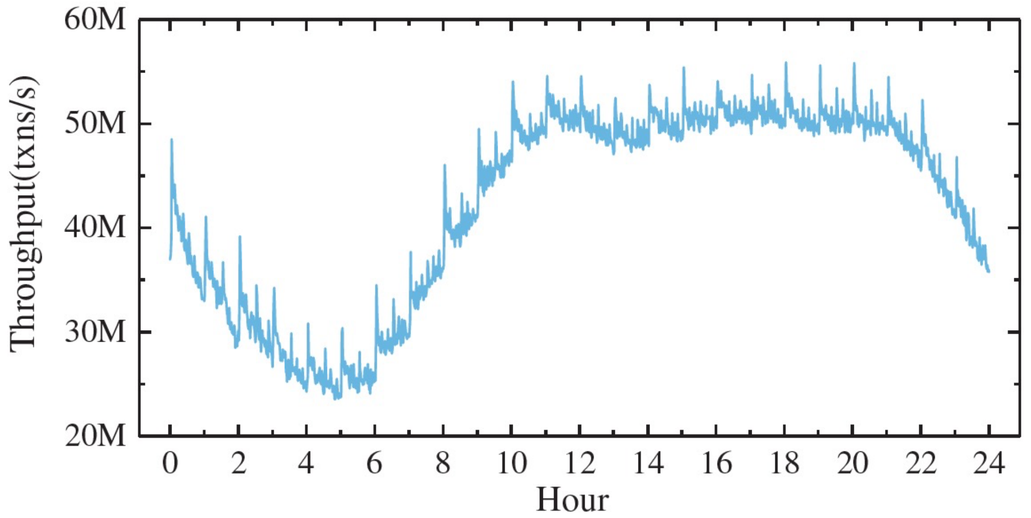


Figure 1: The total write throughput of Alibaba Cloud DBaaS audit logs in a day.

Problems & Challenges

- Large Number of Tenants and Highly Skew Workload
  - More than 100,000 tenants, different life cycle.
  - Workloads close to Zipfian distribution.
  - One tenant one store? Inefficient for most tiny tenants.

- Log Retrieval on Massive Data
  - Petabyte-sized historical logs.

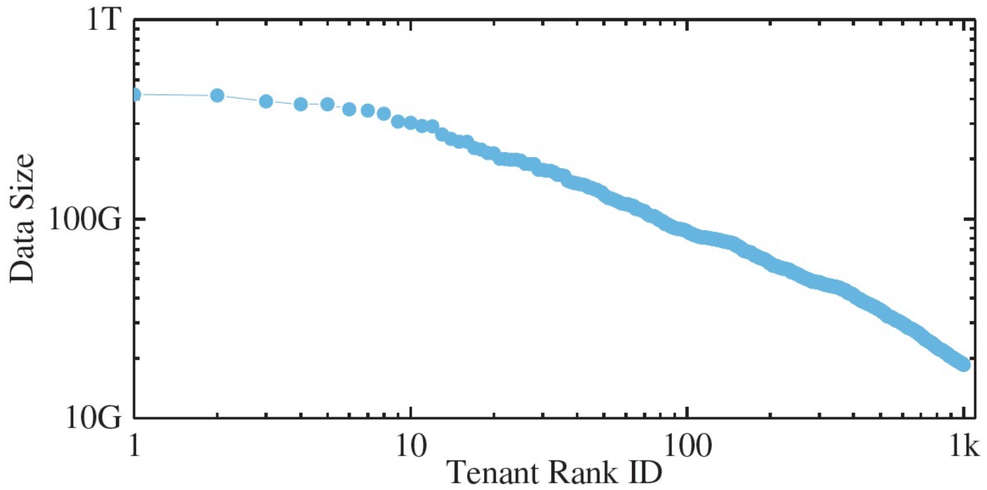


Figure 2: A statistics of tenants' daily data size in the *LogStore* production environment, which is highly skewed and close to the Zipfian Distribution.

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Designs & Contributions

✓ Cloud native architecture
- Combine shared-nothing and shared-data designs.
- Best practices to leverage object storage in database.

✓ Low-latency Writes
- Multi-replicas, WAL synchronization by Raft.
- Real-time data visibility.

✓ Query optimization for cloud storage
- LogBlock, column-oriented, full-column indexed, self-contained.
- Multi-level cache.
- Data skip and parallel pre-fetch.

✓ Dynamic Flow Scheduling on Heterogeneous Resources
- Global traffic control algorithm.
- Backpressure mechanism.

Architecture : Shared-Nothing VS. Shared-Data

- The most popular distributed architecture
- Data partitioned and stored on local disks
- Difficult to horizontal scaling, data repartition

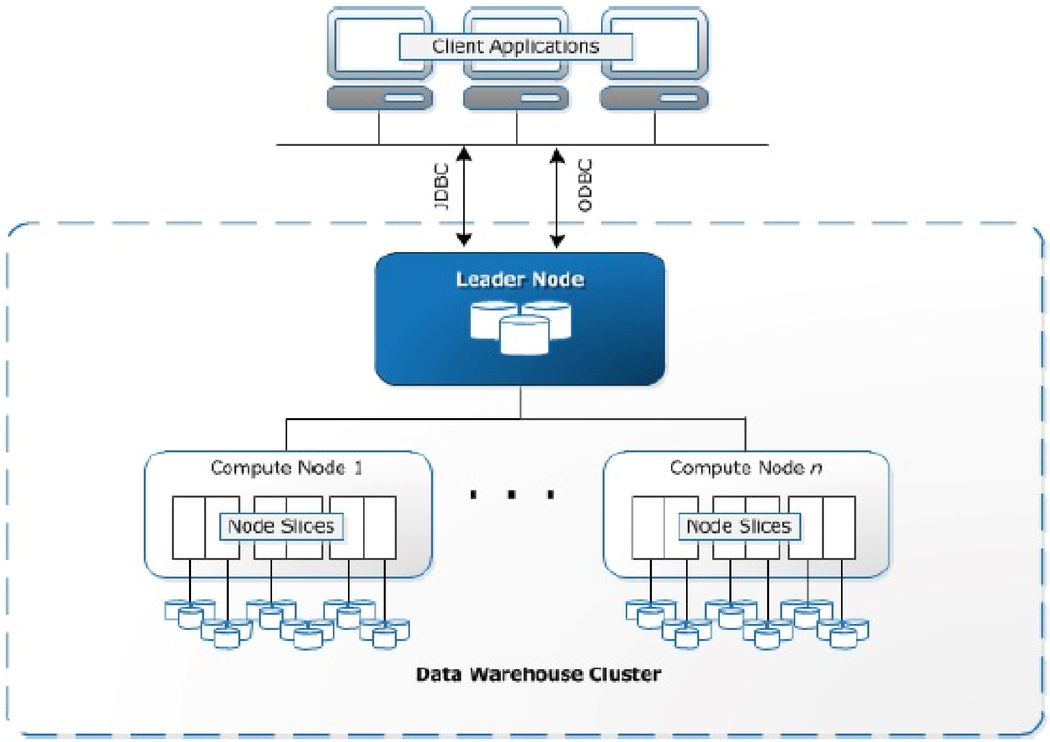


Figure 3: Amazon Redshift system architecture

SIGMOD'15 Amazon Redshift and the Case for Simpler Data Warehouses.

- Decouple computing and storage
- Leverage cloud storage, low costs
- Higher latency, depend on network

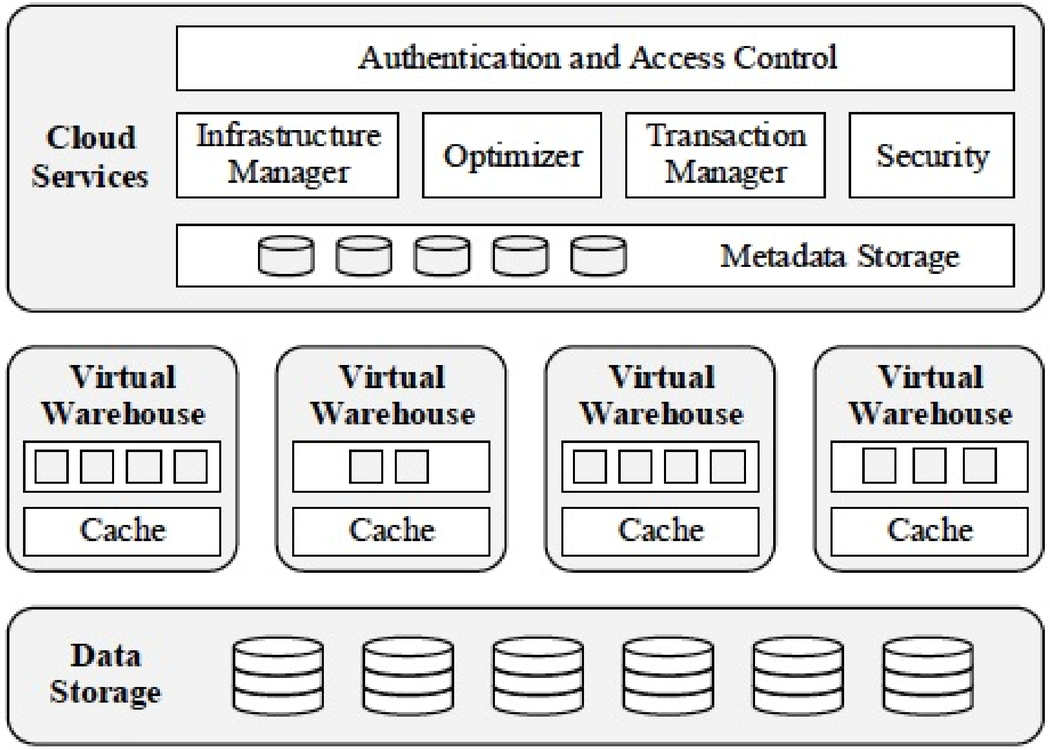


Figure 1: Multi-Cluster, Shared Data Architecture

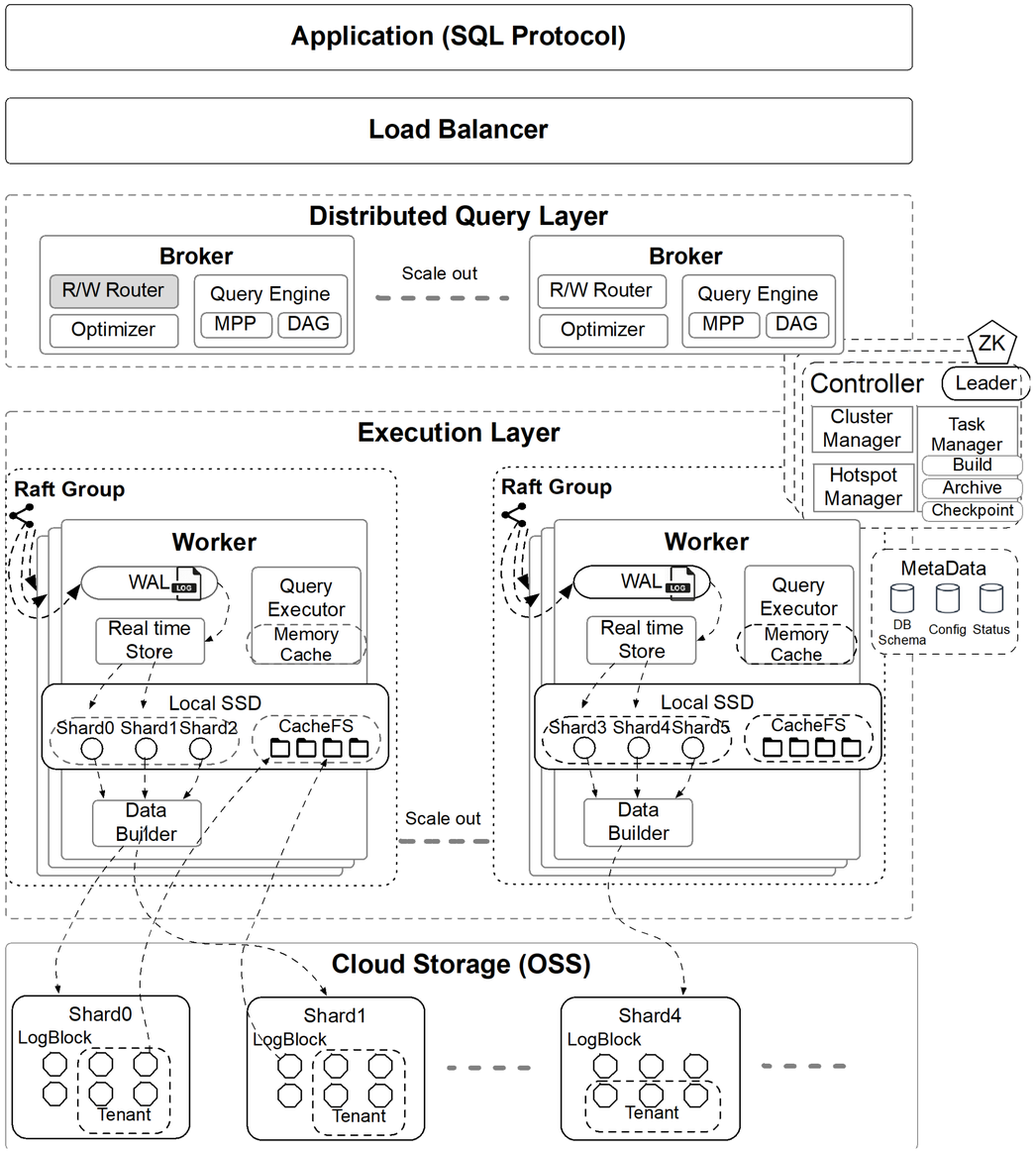
SIGMOD'16 The Snowflake Elastic Data Warehouse.

Architecture

- Controller
  - 3-nodes by ZK, one node is active
  - Metadata management
  - Cluster monitoring
  - Task scheduling, ex. checkpoints, archive, retention etc.

- Query Layer
  - Peer brokers, dispatched by SLB
  - Parsing, optimization
  - Parallel DAG execution

- Execution Layer
  - Work groups, synchronized by Raft
  - Real-time store, write-optimized
  - Data builder, transfer to read-optimized
  - File and Object Caches



Architecture – Storage Layer

- Alibaba Cloud OSS
  - A reliable and cost-effective object storage.
  - 99.9999999999% durability and 99.995% availability
  - Support HTTP(s) RESTful APIs or SDKs.

- Best practices
  - row-column hybrid storage
  - two-phase writing process
  - multi-Tenant storage
  - read-optimized LogBlock

Architecture – Log Block

- Self-contained
  - can rename or move
- Compressed
  - support Snappy, LZ4, ZSTD
- Columnar-oriented
- Full-column indexed and Skippable
  - SMA
  - Inverted index
  - BKD tree index

schema information			
row count ①	column offset$_0$	…	column offset$_n$
compress type$_0$	SMA$_0$ ②	index offset$_0$	data offset$_0$
…	compress type$_n$	SMA$_n$	index offset$_n$
data offset$_n$	index type$_0$ ③	index data$_0$	…
index type$_n$	index data$_n$	column$_0$ block row count$_0$	column$_0$ block SMA$_0$
column$_0$ block data offset$_0$	column$_0$ block bitset offset$_0$	… ④	column$_0$ block row count$_n$
column$_0$ block SMA$_n$	column$_0$ block data offset$_n$	column$_0$ block bitset offset$_n$	…
column$_n$ block row count$_0$	column$_n$ block SMA$_0$	column$_n$ block data offset$_0$	column$_n$ block bitset offset$_0$
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column$_n$ block bitset offset$_n$	column$_0$ block data$_0$	column$_0$ block bitset$_0$	…
column$_0$ block data$_n$	column$_0$ block bitset$_n$ ⑤	…	column$_n$ block data$_0$
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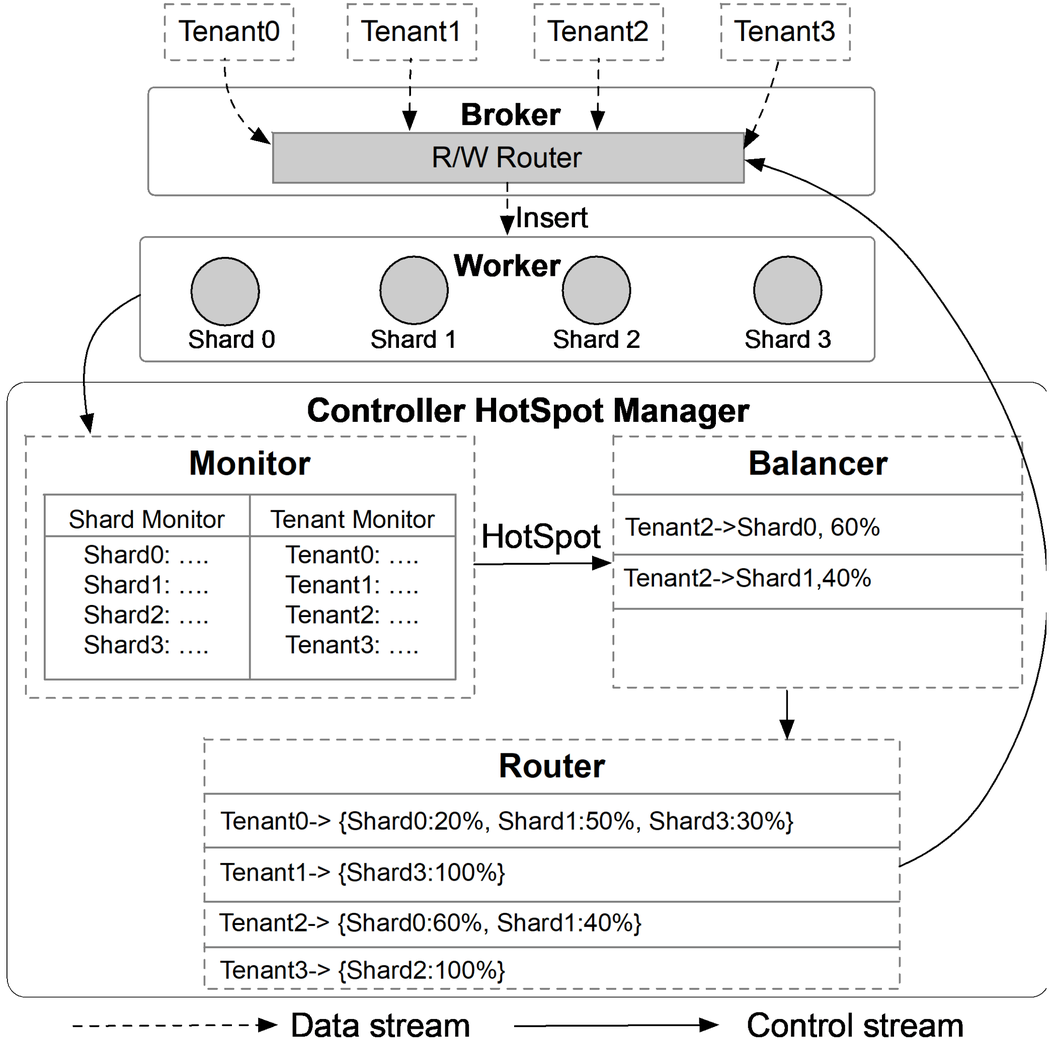
Load balancing

- ***Why Load imbalance?***
  - High Skewed Workload
    - close to Zipfian Distribution
  - Variations of Traffic
    - online promotions
    - business upgradation
  - Heterogeneity of ECS nodes
    - Various ECS node configuration

- ***State of Art***
  - Dynamic partition splitting
    - HBase
  - Rule-based/heuristic algorithms
    - Yak
  - Greedy algorithm
    - EStore

Global Traffic Control – modules

- Monitor
  - Collect tenant traffic, shard load and worker node load
  - Detect hot spots
- Balancer
  - Handle hot spots and imbalance
  - Scale out
- Router
  - Maintain routing tables on each broker



Global Traffic Control - modeling

Flow network G(V, E)

K_i: tenants; P_j: table shards

f(): the real flow (traffic)

c(): the capacity (max traffic)

X_{ij}: the proportion (weight) of the flow distributed to the shard P_j by the tenant K_i

- ***Constraints***

$$\forall P_j \in P, f(P_j) \leq c(P_j)$$

$$\forall D_k \in D, f(D_k) \leq \alpha \cdot c(D_k)$$

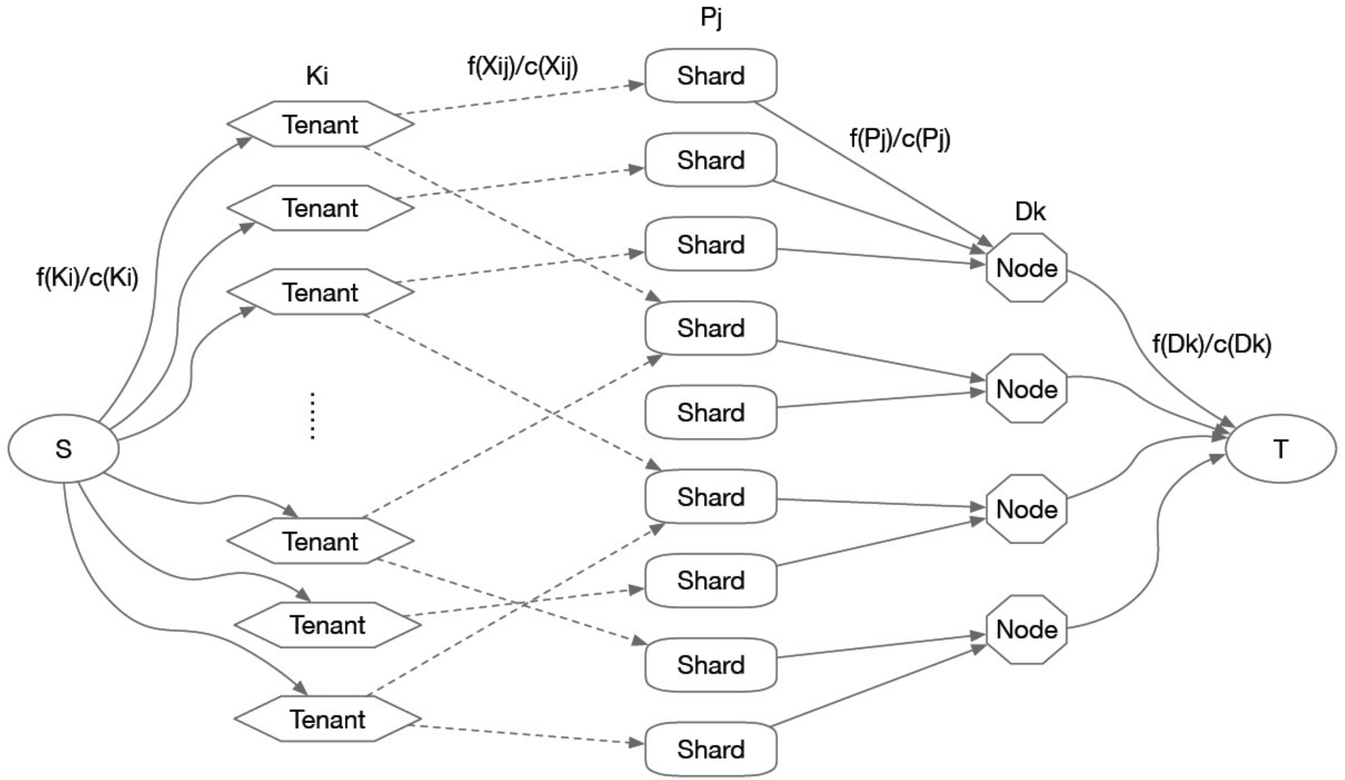
- ***Goals***

Maximum the traffic from S to T

$$\sum_{i=0}^{m} f(K_i)$$

- ***Algorithm***

- Greedy Algorithm
- Max-Flow Algorithm

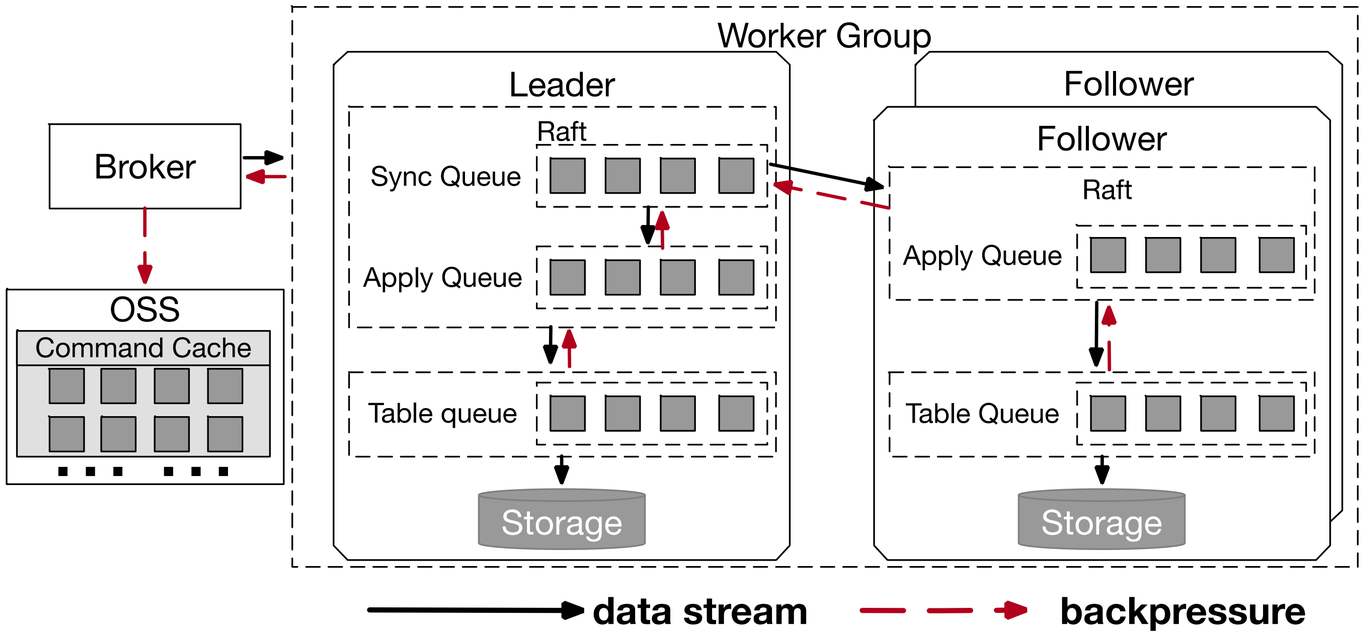


Global Traffic Control – backpressure

- ***Why?***
  - Extreme cases which rebalancing cannot respond in time
  - Inspired by streaming computing, Heron, Flink

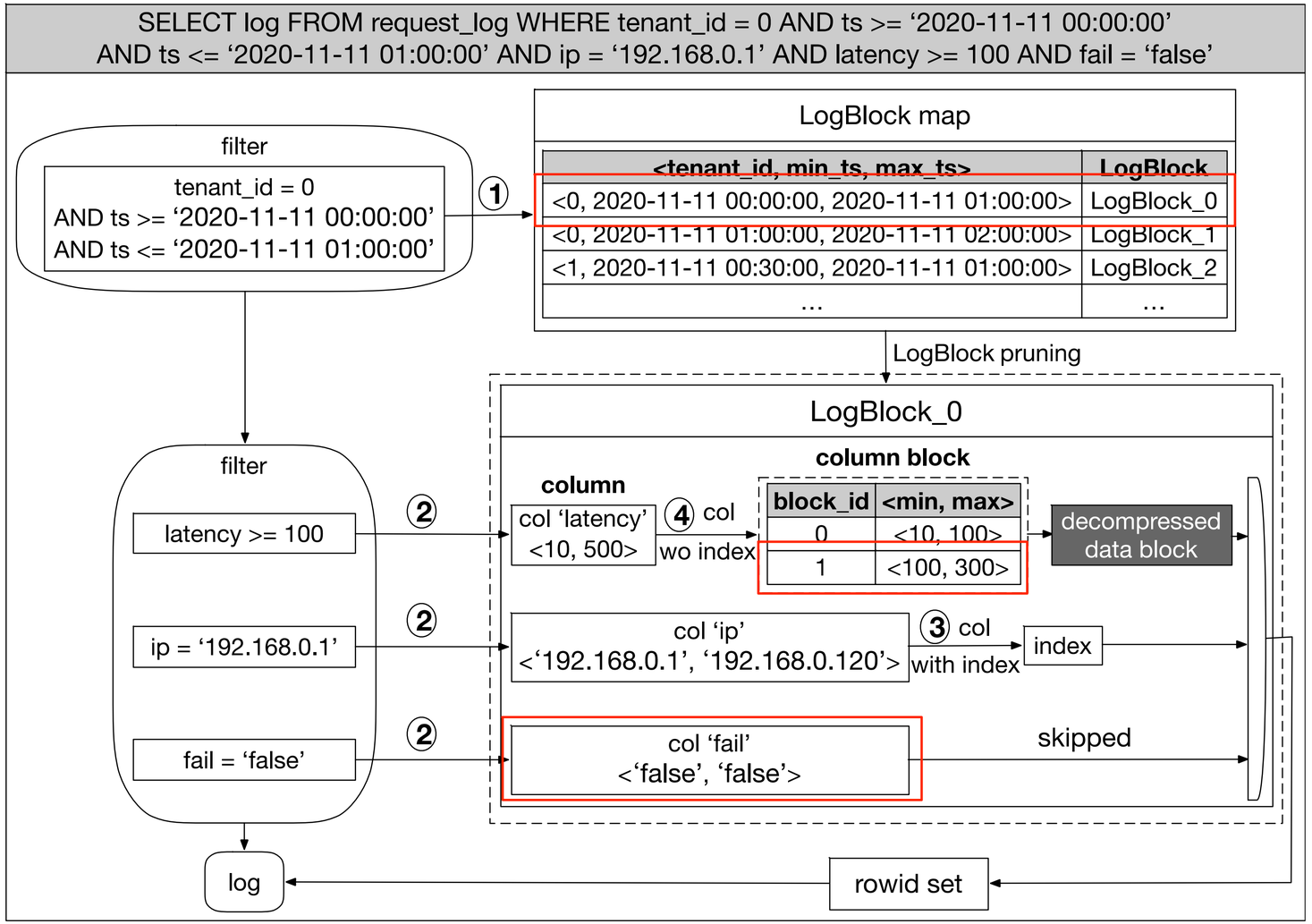
- ***Strategy***
  - Monitor the log number of queue
  - Monitor the total log size of queue
  - Threshold-based trigger
  - Reverse transfer to reject writing

- BP based Raft implementation
  - Synchronizing queue
  - Apply queue



Query Optimization – data skipping

- ***Less is More?***
- Skip on log block map
  - ‘tenant_id’, ‘ts’
- Skip on column
  - ‘fail’ column
- Column with index
  - Scan index directly, ‘ip’
- Column without index
  - Skip on column block, <min, max>
  - Scan related block

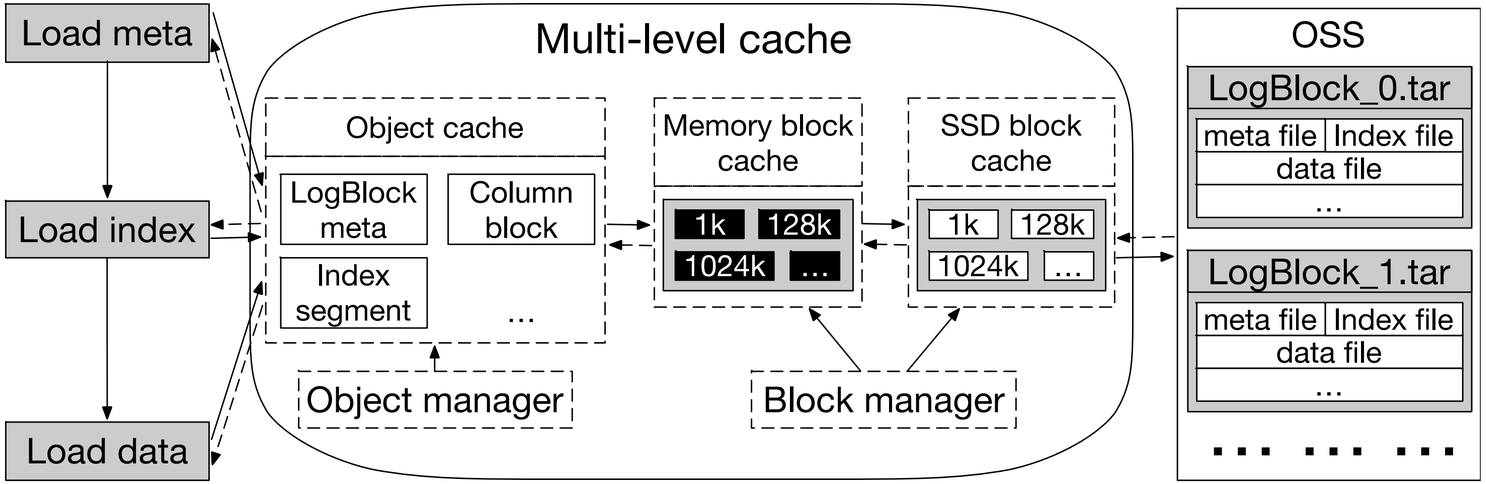


Query Optimization – multi-level cache

- ***How to bridge the gap between cloud storage and local storage?***

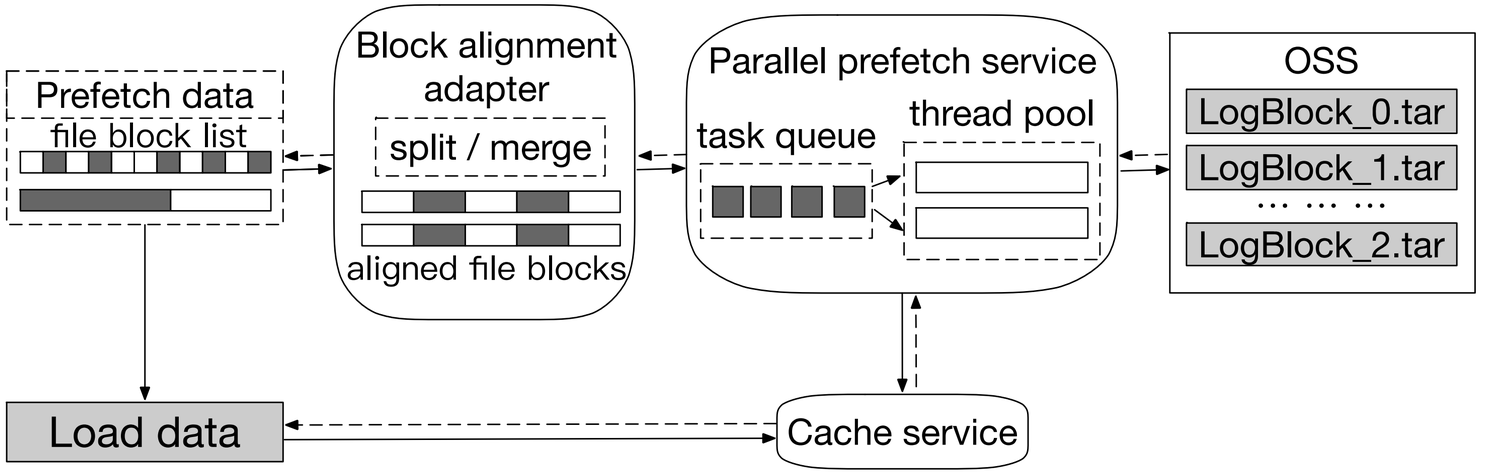
- Pass through whole query process
  - meta cache
  - indexes cache
  - data cache

- Multi-level
  - Memory block cache (8GB)
  - SSD block cache (200GB)
  - Memory object cache



Query Optimization – parallel prefetching

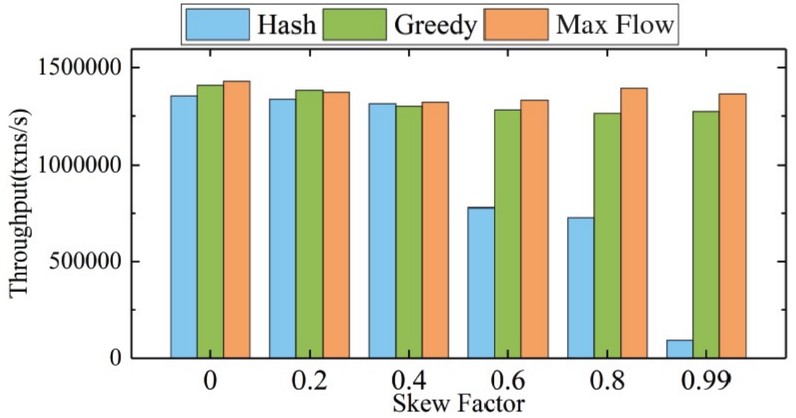
- Single thread per query?
- Multi-threads? Future direction
- Bottlenecks on query execution
  - Waiting IOs from cloud storage
  - Data computing
  - Vectorized execution
- Tradeoff
  - Parallel prefetching, then single thread execution
  - avoid IO blocking with cloud



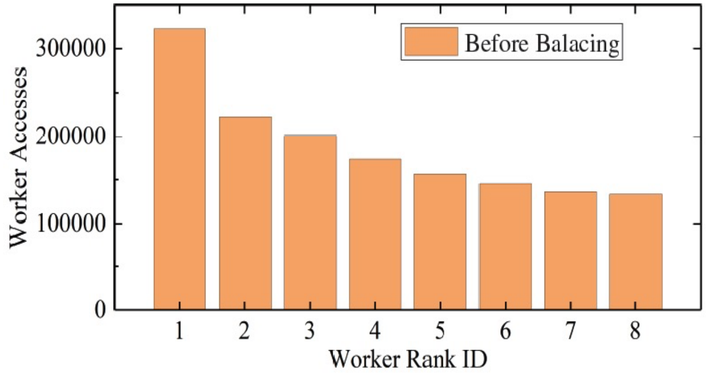
Benchmark – write throughput and traffic control

- Greedy vs. Max Flow
  - write throughput
  - routes of tenants

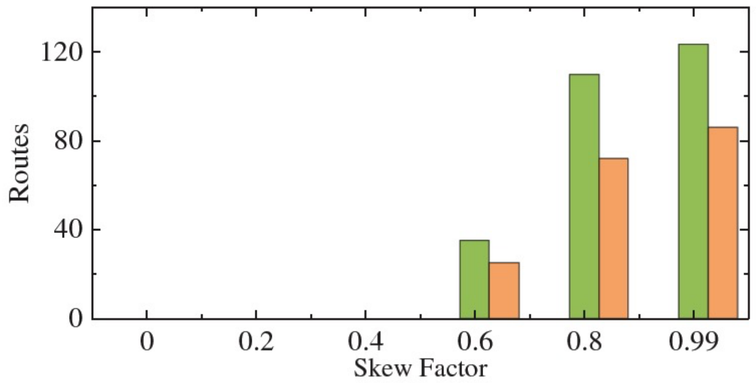
- Before vs. After Balancing
  - Worker accesses distribution
  - CPU utilization



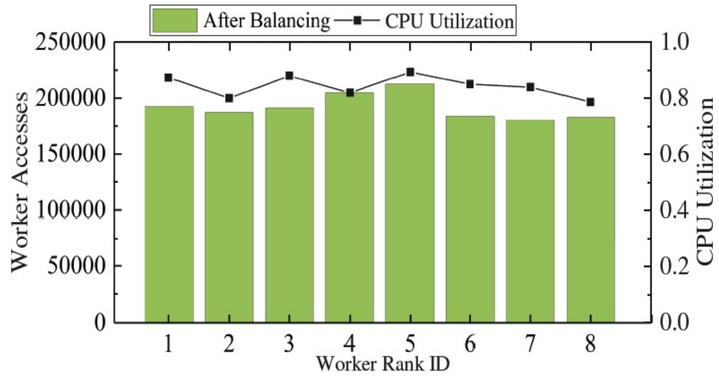
(a) Throughput as skew factor grow



(b) Worker accesses per second before Max Flow algorithm balancing when $\theta = 0.99$.



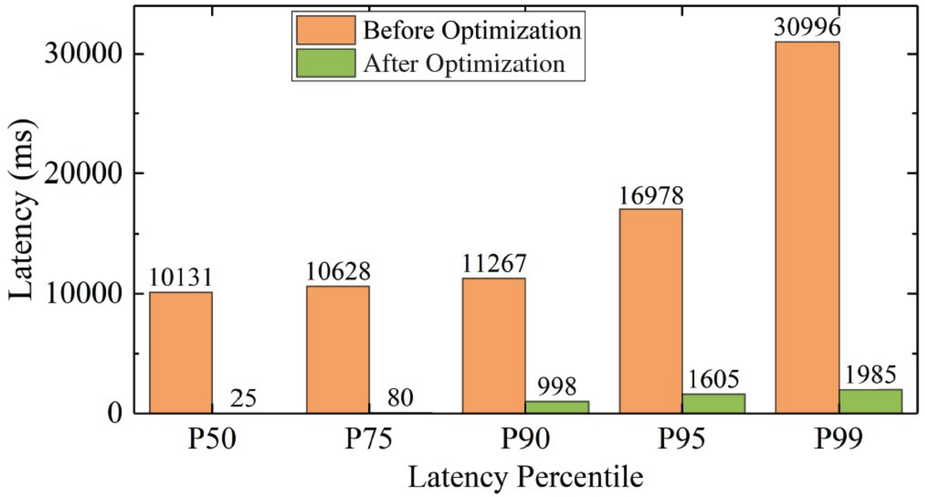
(c) Routes as skew factor grow



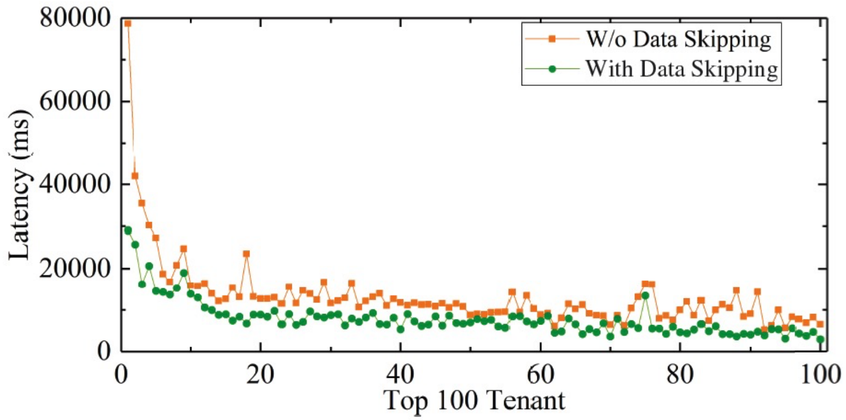
(c) Worker accesses per second balanced by Max Flow algorithm when $\theta = 0.99$.

Benchmark – query optimization

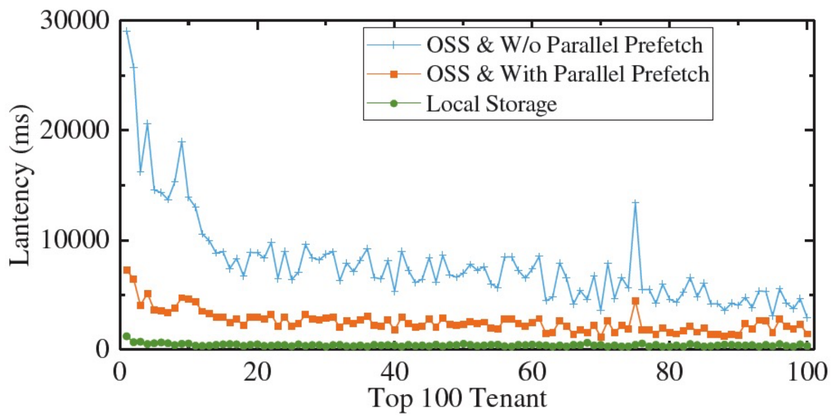
- Overall Performance
  - P99 within 2 sec， P90 within 1 sec.
  - About 10 times improvement.



- Data Skipping
  - Average query latency improved 1.7. times
  - More obvious to large tenant.
  - About 2.7 times improvement for large tenants.



- Parallel Prefetch from Oss
  - Without
    - 18.5 times slower than local
  - With
    - 6 times slower than local



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Conclusion and Future

- LogStore has been deployed in Alibaba Cloud,
  - More than 500 machines.
  - Process more than 100GB logs per second.
  - Run stably for more than two years.

- Future works
  - Read/Write Splitting
  - Parallel query based on cloud storage
  - Add light-weight index structures on real-time store
  - Vectorized execution and JIT compilation

Alibaba Cloud

PolarDB

Thanks