SIGMOD
PODS
2024

Demystifying the QoS and QoE of Edge-hosted Video Streaming Applications in the Wild with SNESet

Yanan Li[1, 2], Guangqing Deng[2], Changming Bai[2], Jingyu Yang[2], Gang Wang[2], Hao Zhang[2], Jin Bai[2], Haitao Yuan[3], Mengwei Xu[1], Shangguang Wang[1]

[1] State Key Laboratory of Networking and Switching Technology

[2] Alibaba Group

[3] Nanyang Technological University

Background

- Video streaming applications (VSAs) are gaining momentum ☑.

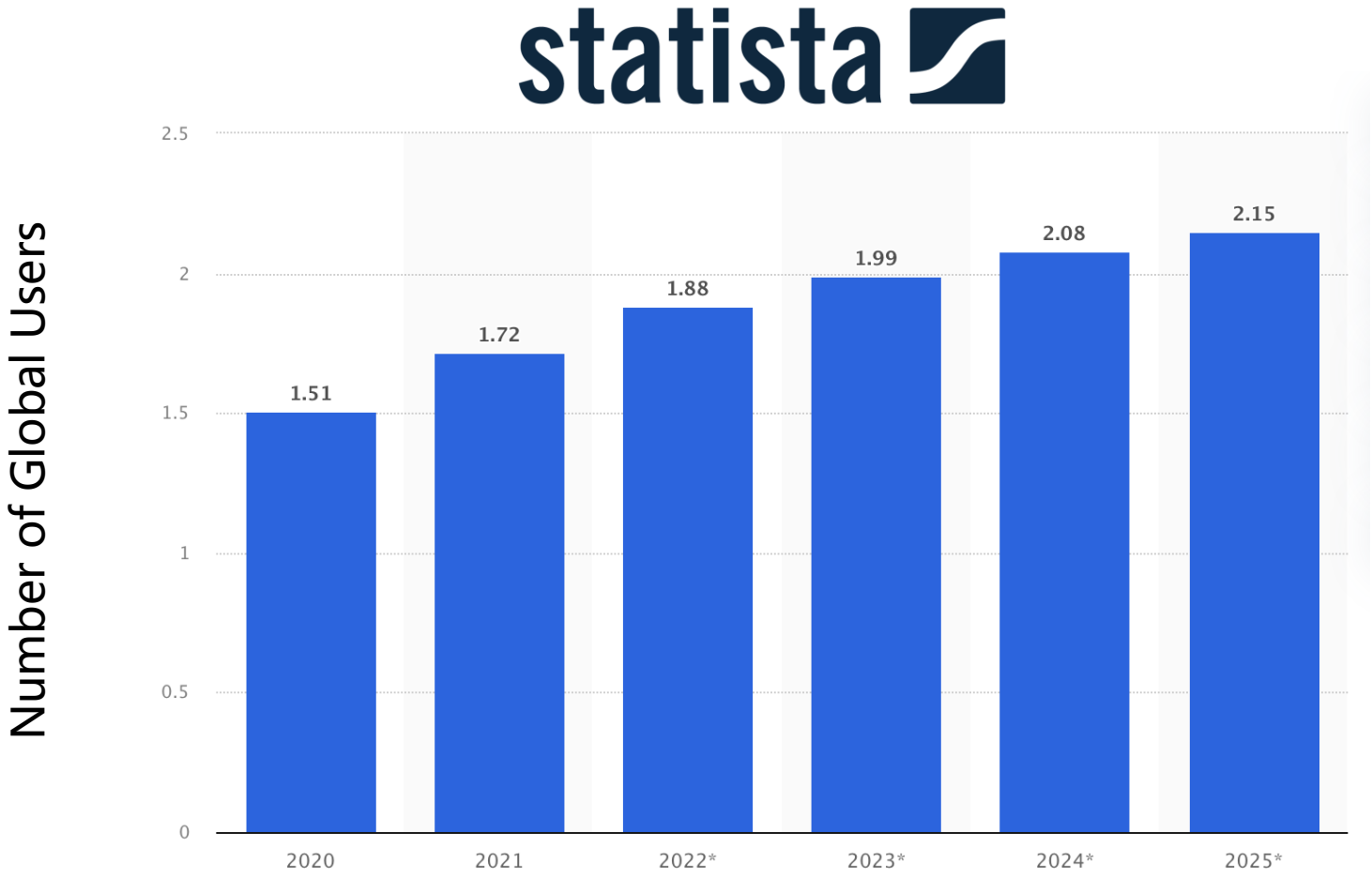
On-demand video

Video conferencing

Live streaming

Cloud gaming

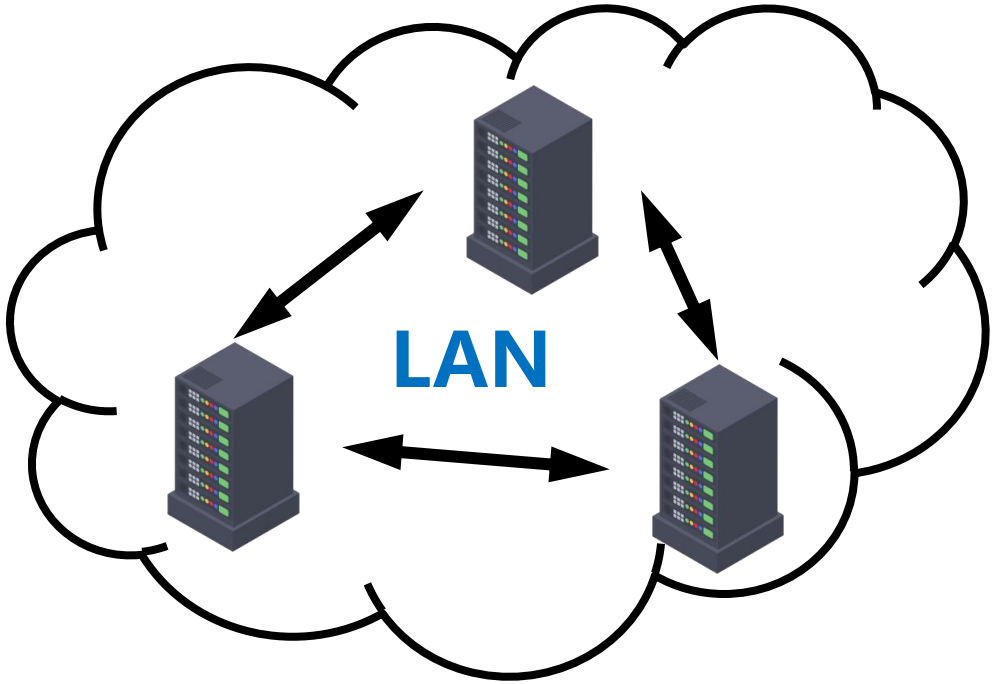
Background



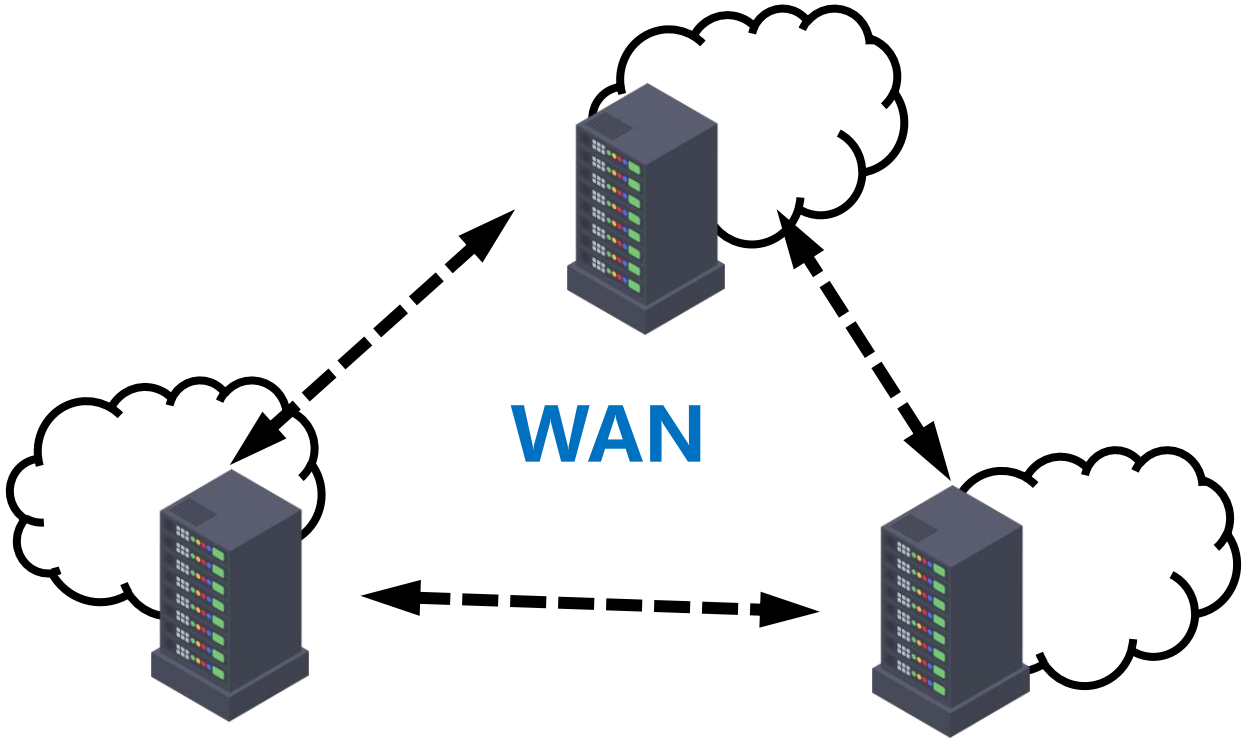
2 billion users worldwide

https://www.statista.com/outlook/dmo/digital-media/video-on-demand/video-streaming-svod/worldwide

Background



(a) Traditional centralized cloud



(b) Geo-distributed edge platform

What's Alibaba ENS?

- More geo-distributed micro-datacenters
  - Built atop Alibaba CDN
  - Cooperative third-party IDCs and network operators
  - Contain 2800+ edge sites in global

- Provide comprehensive services
  - FaaS, PaaS, IaaS, and heterogeneous computing (e.g., ARM SoC, FPGA)
  - 100 million peak query per seconds (QPS)

The Older Story – QoS

- QoS refers to the service quality of each component within end-to-end video delivery system.
  - Loss rate
  - Delay

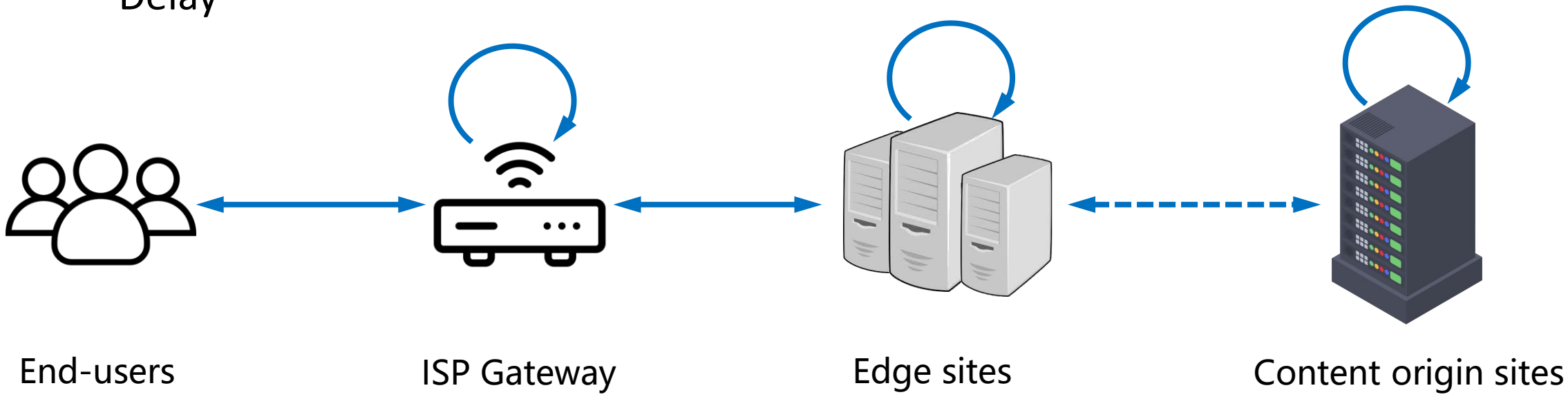


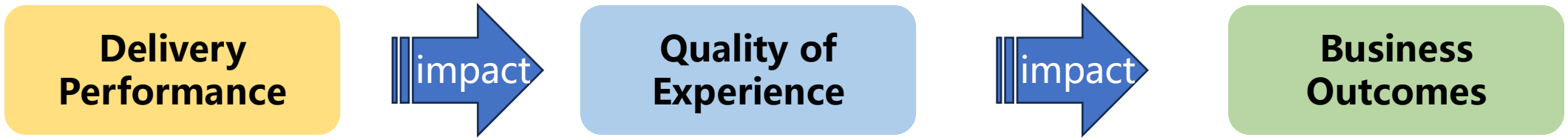
Fig 1. A example of end-to-end video delivery path.

The Newer Story – QoE

- ITU first defines QoE with Mean Opinion Score (MOS).
  - A ***subjective*** metric ranging from 1 to 5.
  - Subjective metrics are **expensive/complicated** to collect and are **unreliable**.
- Similar to prior research, we primarily focus on ***objective*** QoE such as **stall/rebuffer ratio** and **startup delay**. [1]

[1] Xiaoqi Yin, Abhishek Jindal, Vyas Sekar, and Bruno Sinopoli. 2015. A control-theoretic approach for dynamic adaptive video streaming over HTTP. In Proceedings of the ACM SIGCOMM Conference. 325–338.

How QoS and QoE matter?



For example, a 100ms decrease in page load time can lead to an 8% better conversion rate for retail sites (around 4 billion dollars) [2].

[2] Deloitte Digital. 2020. Milliseconds make millions: A study on how improvements in mobile site speed positively affect a brand's bottom line. https://bit.ly/3rpm8WP.

Limitations of Existing Datasets

Table 1. Comparison with existing publicly available cloud/edge datasets.

Dataset	QoS (server-side)	QoE	Platform	Year	Duration	# of Sites	# of Network Protocol Stacks
Alibaba Dataset [38]	✓	✗	Alibaba ECS	2018	8 days	1	1
Google Dataset [100]	✓	✗	Google Borg	2019	1 month	1	1
Azure Dataset [27]	✓	✗	Azure Cloud	2019	30 days	1	1
Edge Dataset [112]	✓	✗	Alibaba ENS	2020	3 months	139	2
LiSSi lab Dataset [7]	✗	✓	Testbed	2015	1 week	1	1
Puffer [114]	✗	✓	Testbed*	Since Jan 2019	Keep updating	1	2
Huawei Dataset [102]	✓	✓	Testbed	2018	1 month	1	3
SNESet (Ours)	✓	✓	NEP	2022	4 months	789	4

* While we classify the Puffer [114] as a testbed, it falls somewhere between a traditional testbed and a real-world commercial system.

(1) Comprehensive coverage

(2) Collected from large-scale platform in the wild

SNESet: The SOTA of QoS and QoE Datasets

Table 1. Comparison with existing publicly available cloud/edge datasets.

Dataset	QoS (server-side)	QoE	Platform	Year	Duration	# of Sites	# of Network Protocol Stacks
Alibaba Dataset [38]	✓	✗	Alibaba ECS	2018	8 days	1	1
Google Dataset [100]	✓	✗	Google Borg	2019	1 month	1	1
Azure Dataset [27]	✓	✗	Azure Cloud	2019	30 days	1	1
Edge Dataset [112]	✓	✗	Alibaba ENS	2020	3 months	139	2
LiSSi lab Dataset [7]	✗	✓	Testbed	2015	1 week	1	1
Puffer [114]	✗	✓	Testbed*	Since Jan 2019	Keep updating	1	2
Huawei Dataset [102]	✓	✓	Testbed	2018	1 month	1	3
SNESet (Ours)	✓	✓	NEP	2022	4 months	789	4

* While we classify the Puffer [114] as a testbed, it falls somewhere between a traditional testbed and a real-world commercial system.

SNESet, an active measurement of 8 VSAs spanning four months in 2022, covering end-users from 798 edge sites, 30 cities, and 3 ISPs in China.

Comprehensive Coverage of SNESet

Metrics	Taxonomy	Type	Net Stack	Description	Example
date_sequence	Context	BIGINT	-	The day of the month, which ranges from [1, 31].	21
hour_sequence	Context	BIGINT	-	The hour of the day, which ranges from [0, 23].	5
domain_name	Context	STRING	-	The domain name identifier, which represents different applications.	domain_18
city	Context	STRING	-	The city identifier.	city_14
isp	Context	STRING	-	The ISP identifier.	isp_10
node_name	Context	STRING	-	The edge site identifier.	node_12
avg_fbt_time	QoS (server-side)*	BIGINT	5	The average first-byte time represents the time from the edge site receiving the request to sending the first response packet (unit ms).	12
inner_net_droprate	QoS (server-side)	DOUBLE	3	Edge site internal network packet loss rate (%)	0.001
inner_net_rtt	QoS (server-side)	BIGINT	3	Edge site internal network round trip time (ms)	2
cpu_util	QoS (server-side)	DOUBLE	1	Edge site average CPU utilization	0.56
mem_util	QoS (server-side)	DOUBLE	1	Edge site average memory utilization	0.62
io_await_avg	QoS (server-side)	BIGINT	1	Edge site average I/O waiting time	31
io_await_max	QoS (server-side)	BIGINT	1	Edge site maximum I/O waiting time	34
io_util_avg	QoS (server-side)	DOUBLE	1	Edge site average I/O utlization	0.30
io_util_max	QoS (server-side)	DOUBLE	1	Edge site maximum I/O utilization	0.34
ng_traf_level	QoS (server-side)	DOUBLE	1	Edge site normalized bandwidth level in range [0, 1)	0.88
synack1_ratio	QoS (client-side)	DOUBLE	4	One-time success rate of establishing TCP connections.	0.86
tcp_conntime	QoS (client-side)*	BIGINT	4	The time from when the server receives a SYN packet to when it receives an ACK from the client (ms).	33
icmp_lossrate	QoS (client-side)	DOUBLE	3	The ICMP (Layer 3) packet loss rate	0.05
icmp_rtt	QoS (client-side)	DOUBLE	3	The ICMP (Layer 3) round trip time (ms)	21
499_5xx_ratio	QoS (client-side)	DOUBLE	5	The ratio of 499 and 5xx issued by Tengine	0.01
reset_ratio	QoS (client-side)	DOUBLE	5	Percentage of reset requests	0.22
buffer_rate	QoE	DOUBLE	5	The percentage of the video that experiences frozen or stalling events during the playback period.	0.04

* Moreover, the startup delay QoE metric can be approximated by $4 * \texttt{tcp\_conntime} + \texttt{avg\_fbt\_time}$.

Context Info

6/23

Comprehensive Coverage of SNESet

Metrics	Taxonomy	Type	Net Stack	Description	Example
date_sequence	Context	BIGINT	-	The day of the month, which ranges from [1, 31].	21
hour_sequence	Context	BIGINT	-	The hour of the day, which ranges from [0, 23].	5
domain_name	Context	STRING	-	The domain name identifier, which represents different applications.	domain_18
city	Context	STRING	-	The city identifier.	city_14
isp	Context	STRING	-	The ISP identifier.	isp_10
node_name	Context	STRING	-	The edge site identifier.	node_12
avg_fbt_time	QoS (server-side)*	BIGINT	5	The average first-byte time represents the time from the edge site receiving the request to sending the first response packet (unit ms).	12
inner_net_droprate	QoS (server-side)	DOUBLE	3	Edge site internal network packet loss rate (%)	0.001
inner_net_rtt	QoS (server-side)	BIGINT	3	Edge site internal network round trip time (ms)	2
cpu_util	QoS (server-side)	DOUBLE	1	Edge site average CPU utilization	0.56
mem_util	QoS (server-side)	DOUBLE	1	Edge site average memory utilization	0.62
io_await_avg	QoS (server-side)	BIGINT	1	Edge site average I/O waiting time	31
io_await_max	QoS (server-side)	BIGINT	1	Edge site maximum I/O waiting time	34
io_util_avg	QoS (server-side)	DOUBLE	1	Edge site average I/O utlization	0.30
io_util_max	QoS (server-side)	DOUBLE	1	Edge site maximum I/O utilization	0.34
ng_traf_level	QoS (server-side)	DOUBLE	1	Edge site normalized bandwidth level in range [0, 1)	0.88
synack1_ratio	QoS (client-side)	DOUBLE	4	One-time success rate of establishing TCP connections.	0.86
tcp_conntime	QoS (client-side)*	BIGINT	4	The time from when the server receives a SYN packet to when it receives an ACK from the client (ms).	33
icmp_lossrate	QoS (client-side)	DOUBLE	3	The ICMP (Layer 3) packet loss rate	0.05
icmp_rtt	QoS (client-side)	DOUBLE	3	The ICMP (Layer 3) round trip time (ms)	21
499_5xx_ratio	QoS (client-side)	DOUBLE	5	The ratio of 499 and 5xx issued by Tengine	0.01
reset_ratio	QoS (client-side)	DOUBLE	5	Percentage of reset requests	0.22
buffer_rate	QoE	DOUBLE	5	The percentage of the video that experiences frozen or stalling events during the playback period.	0.04

* Moreover, the startup delay QoE metric can be approximated by $4 * \texttt{tcp\_conntime} + \texttt{avg\_fbt\_time}$.

Link & Physical Layer (Layer 1 & 2)

7/23

Comprehensive Coverage of SNESet

Metrics	Taxonomy	Type	Net Stack	Description	Example
date_sequence	Context	BIGINT	-	The day of the month, which ranges from [1, 31].	21
hour_sequence	Context	BIGINT	-	The hour of the day, which ranges from [0, 23].	5
domain_name	Context	STRING	-	The domain name identifier, which represents different applications.	domain_18
city	Context	STRING	-	The city identifier.	city_14
isp	Context	STRING	-	The ISP identifier.	isp_10
node_name	Context	STRING	-	The edge site identifier.	node_12
avg_fbt_time	QoS (server-side)*	BIGINT	5	The average first-byte time represents the time from the edge site receiving the request to sending the first response packet (unit ms).	12
inner_net_droprate	QoS (server-side)	DOUBLE	3	Edge site internal network packet loss rate (%)	0.001
inner_net_rtt	QoS (server-side)	BIGINT	3	Edge site internal network round trip time (ms)	2
cpu_util	QoS (server-side)	DOUBLE	1	Edge site average CPU utilization	0.56
mem_util	QoS (server-side)	DOUBLE	1	Edge site average memory utilization	0.62
io_await_avg	QoS (server-side)	BIGINT	1	Edge site average I/O waiting time	31
io_await_max	QoS (server-side)	BIGINT	1	Edge site maximum I/O waiting time	34
io_util_avg	QoS (server-side)	DOUBLE	1	Edge site average I/O utlization	0.30
io_util_max	QoS (server-side)	DOUBLE	1	Edge site maximum I/O utilization	0.34
ng_traf_level	QoS (server-side)	DOUBLE	1	Edge site normalized bandwidth level in range [0, 1)	0.88
synack1_ratio	QoS (client-side)	DOUBLE	4	One-time success rate of establishing TCP connections.	0.86
tcp_conntime	QoS (client-side)*	BIGINT	4	The time from when the server receives a SYN packet to when it receives an ACK from the client (ms).	33
icmp_lossrate	QoS (client-side)	DOUBLE	3	The ICMP (Layer 3) packet loss rate	0.05
icmp_rtt	QoS (client-side)	DOUBLE	3	The ICMP (Layer 3) round trip time (ms)	21
499_5xx_ratio	QoS (client-side)	DOUBLE	5	The ratio of 499 and 5xx issued by Tengine	0.01
reset_ratio	QoS (client-side)	DOUBLE	5	Percentage of reset requests	0.22
buffer_rate	QoE	DOUBLE	5	The percentage of the video that experiences frozen or stalling events during the playback period.	0.04

* Moreover, the startup delay QoE metric can be approximated by $4 * \texttt{tcp\_conntime} + \texttt{avg\_fbt\_time}$.

Network Layer (Layer 3)

4/23

Comprehensive Coverage of SNESet

Metrics	Taxonomy	Type	Net Stack	Description	Example
date_sequence	Context	BIGINT	-	The day of the month, which ranges from [1, 31].	21
hour_sequence	Context	BIGINT	-	The hour of the day, which ranges from [0, 23].	5
domain_name	Context	STRING	-	The domain name identifier, which represents different applications.	domain_18
city	Context	STRING	-	The city identifier.	city_14
isp	Context	STRING	-	The ISP identifier.	isp_10
node_name	Context	STRING	-	The edge site identifier.	node_12
avg_fbt_time	QoS (server-side)*	BIGINT	5	The average first-byte time represents the time from the edge site receiving the request to sending the first response packet (unit ms).	12
inner_net_droprate	QoS (server-side)	DOUBLE	3	Edge site internal network packet loss rate (%)	0.001
inner_net_rtt	QoS (server-side)	BIGINT	3	Edge site internal network round trip time (ms)	2
cpu_util	QoS (server-side)	DOUBLE	1	Edge site average CPU utilization	0.56
mem_util	QoS (server-side)	DOUBLE	1	Edge site average memory utilization	0.62
io_await_avg	QoS (server-side)	BIGINT	1	Edge site average I/O waiting time	31
io_await_max	QoS (server-side)	BIGINT	1	Edge site maximum I/O waiting time	34
io_util_avg	QoS (server-side)	DOUBLE	1	Edge site average I/O utlization	0.30
io_util_max	QoS (server-side)	DOUBLE	1	Edge site maximum I/O utilization	0.34
ng_traf_level	QoS (server-side)	DOUBLE	1	Edge site normalized bandwidth level in range [0, 1)	0.88
synack1_ratio	QoS (client-side)	DOUBLE	4	One-time success rate of establishing TCP connections.	0.86
tcp_conntime	QoS (client-side)*	BIGINT	4	The time from when the server receives a SYN packet to when it receives an ACK from the client (ms).	33
icmp_lossrate	QoS (client-side)	DOUBLE	3	The ICMP (Layer 3) packet loss rate	0.05
icmp_rtt	QoS (client-side)	DOUBLE	3	The ICMP (Layer 3) round trip time (ms)	21
499_5xx_ratio	QoS (client-side)	DOUBLE	5	The ratio of 499 and 5xx issued by Tengine	0.01
reset_ratio	QoS (client-side)	DOUBLE	5	Percentage of reset requests	0.22
buffer_rate	QoE	DOUBLE	5	The percentage of the video that experiences frozen or stalling events during the playback period.	0.04

* Moreover, the startup delay QoE metric can be approximated by $4 * \texttt{tcp\_conntime} + \texttt{avg\_fbt\_time}$.

Transport Layer (Layer 4)

2/23

Comprehensive Coverage of SNESet

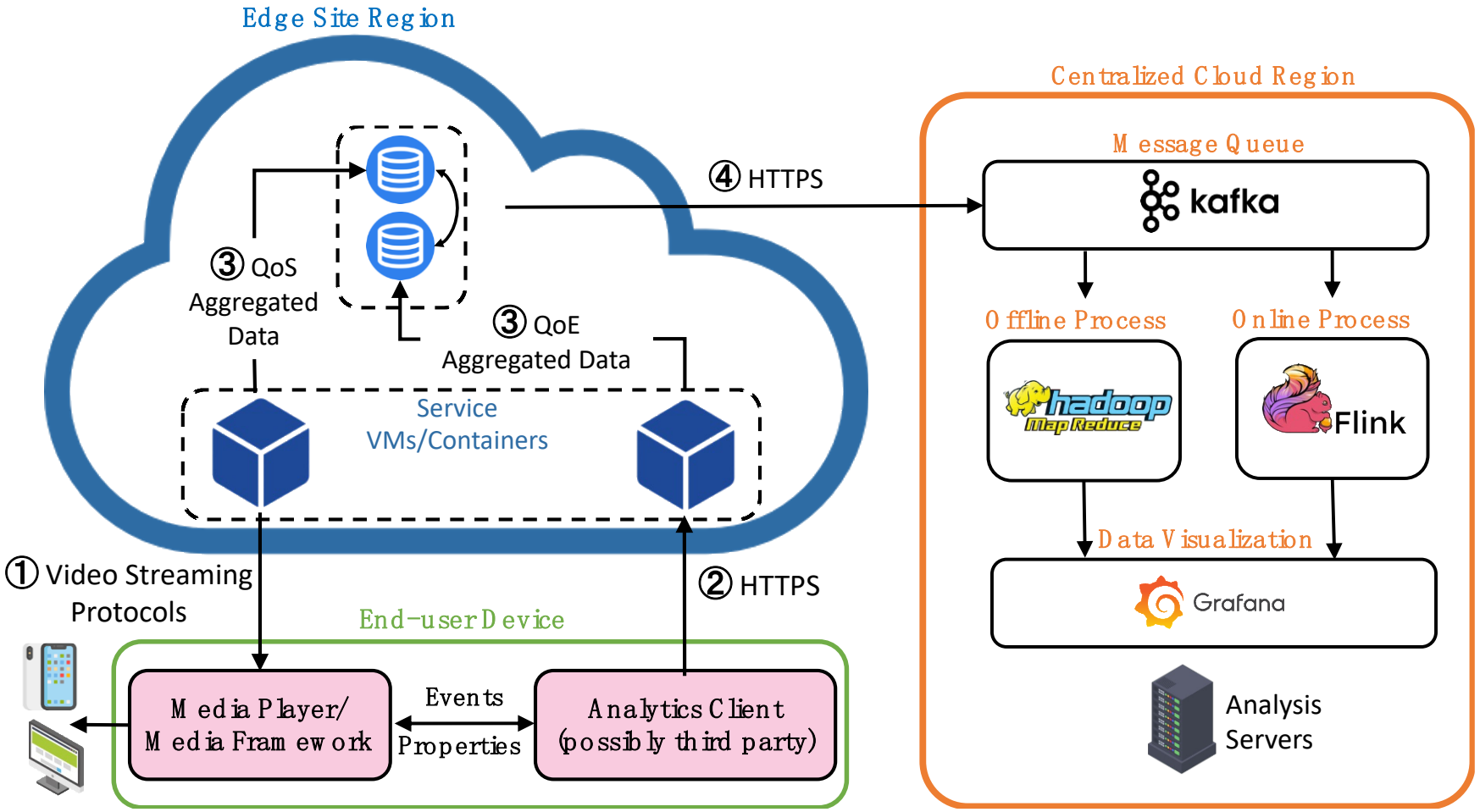
Metrics	Taxonomy	Type	Net Stack	Description	Example
date_sequence	Context	BIGINT	-	The day of the month, which ranges from [1, 31].	21
hour_sequence	Context	BIGINT	-	The hour of the day, which ranges from [0, 23].	5
domain_name	Context	STRING	-	The domain name identifier, which represents different applications.	domain_18
city	Context	STRING	-	The city identifier.	city_14
isp	Context	STRING	-	The ISP identifier.	isp_10
node_name	Context	STRING	-	The edge site identifier.	node_12
avg_fbt_time	QoS (server-side)*	BIGINT	5	The average first-byte time represents the time from the edge site receiving the request to sending the first response packet (unit ms).	12
inner_net_droprate	QoS (server-side)	DOUBLE	3	Edge site internal network packet loss rate (%)	0.001
inner_net_rtt	QoS (server-side)	BIGINT	3	Edge site internal network round trip time (ms)	2
cpu_util	QoS (server-side)	DOUBLE	1	Edge site average CPU utilization	0.56
mem_util	QoS (server-side)	DOUBLE	1	Edge site average memory utilization	0.62
io_await_avg	QoS (server-side)	BIGINT	1	Edge site average I/O waiting time	31
io_await_max	QoS (server-side)	BIGINT	1	Edge site maximum I/O waiting time	34
io_util_avg	QoS (server-side)	DOUBLE	1	Edge site average I/O utlization	0.30
io_util_max	QoS (server-side)	DOUBLE	1	Edge site maximum I/O utilization	0.34
ng_traf_level	QoS (server-side)	DOUBLE	1	Edge site normalized bandwidth level in range [0, 1)	0.88
synack1_ratio	QoS (client-side)	DOUBLE	4	One-time success rate of establishing TCP connections.	0.86
tcp_conntime	QoS (client-side)*	BIGINT	4	The time from when the server receives a SYN packet to when it receives an ACK from the client (ms).	33
icmp_lossrate	QoS (client-side)	DOUBLE	3	The ICMP (Layer 3) packet loss rate	0.05
icmp_rtt	QoS (client-side)	DOUBLE	3	The ICMP (Layer 3) round trip time (ms)	21
499_5xx_ratio	QoS (client-side)	DOUBLE	5	The ratio of 499 and 5xx issued by Tengine	0.01
reset_ratio	QoS (client-side)	DOUBLE	5	Percentage of reset requests	0.22
buffer_rate	QoE	DOUBLE	5	The percentage of the video that experiences frozen or stalling events during the playback period.	0.04

* Moreover, the startup delay QoE metric can be approximated by $4 * \texttt{tcp\_conntime} + \texttt{avg\_fbt\_time}$.

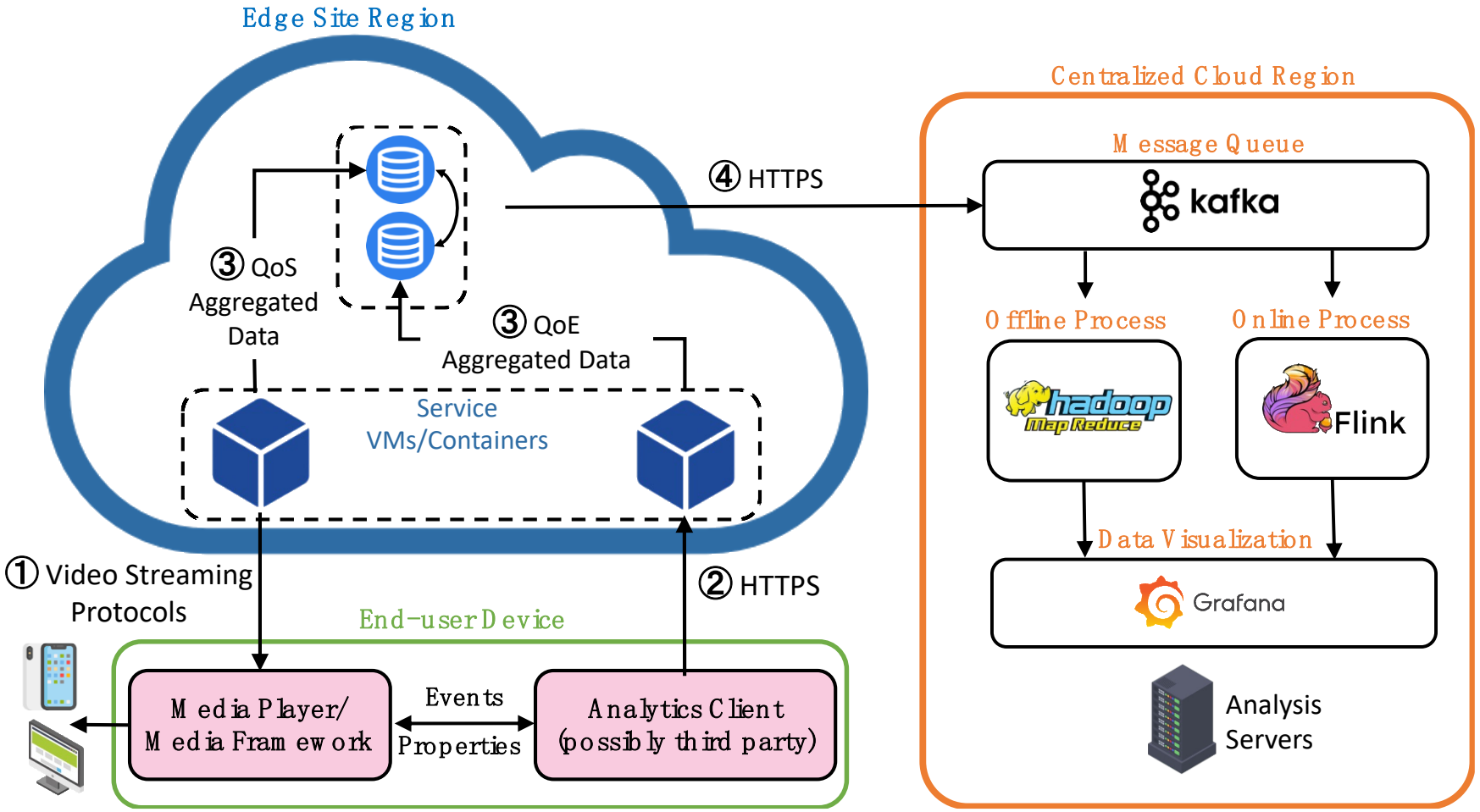
Application Layer (Layer 5)

5*/23

Data Collection System



Data Collection System

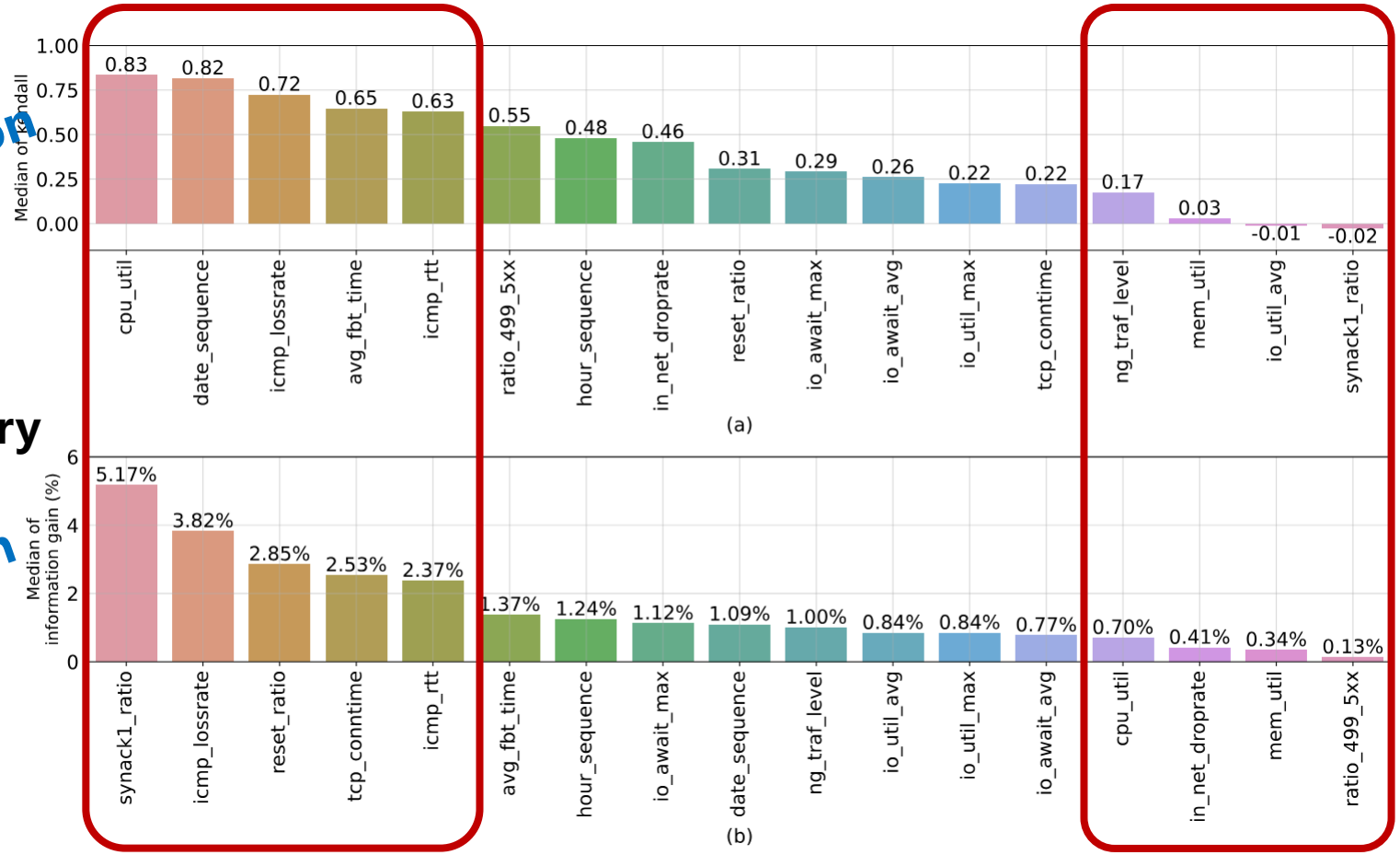


Qualitative Analytics

Kendall Correlation

Complementary

Information Gain



Implications

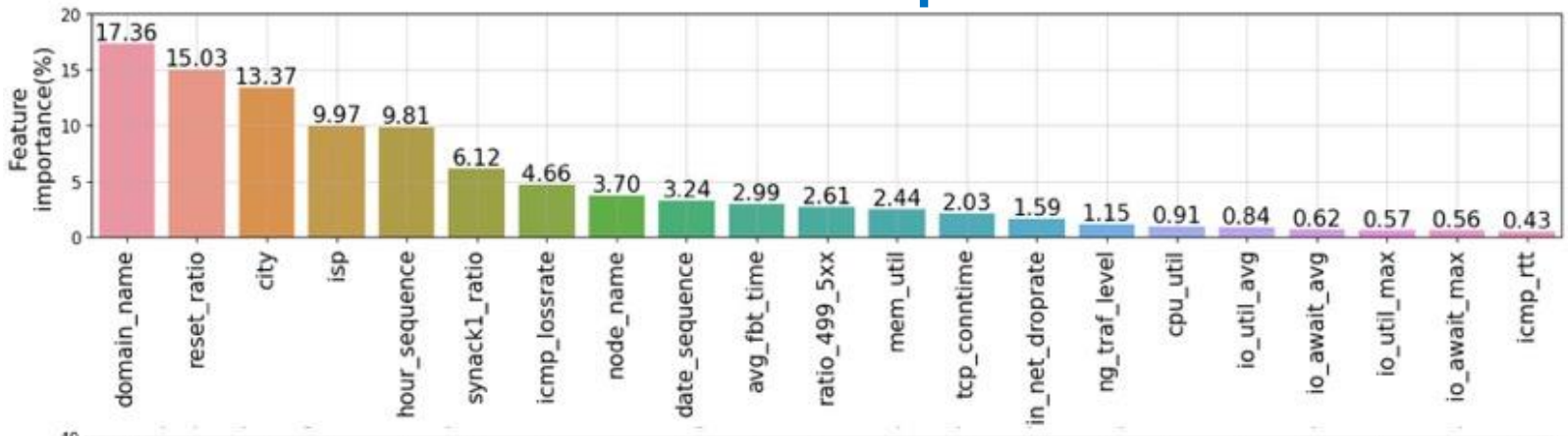
(1) End-to-end performance is critical.

(2) Co-locate with memory or I/O-intensive services.

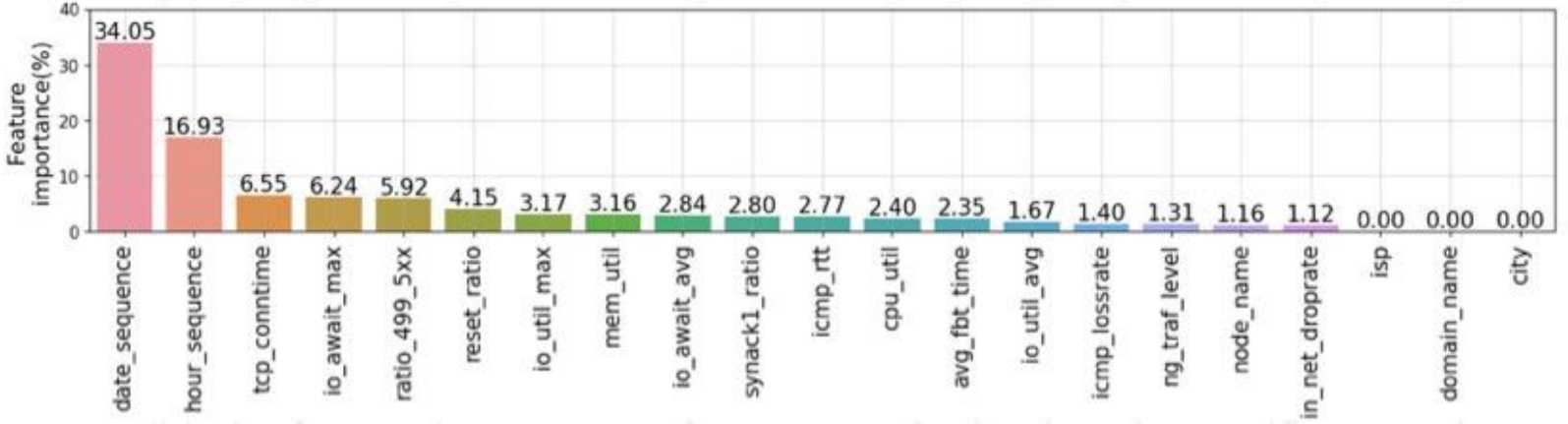
Quantitative Analytics

CatBoost feature importance score

Domain-agnostic

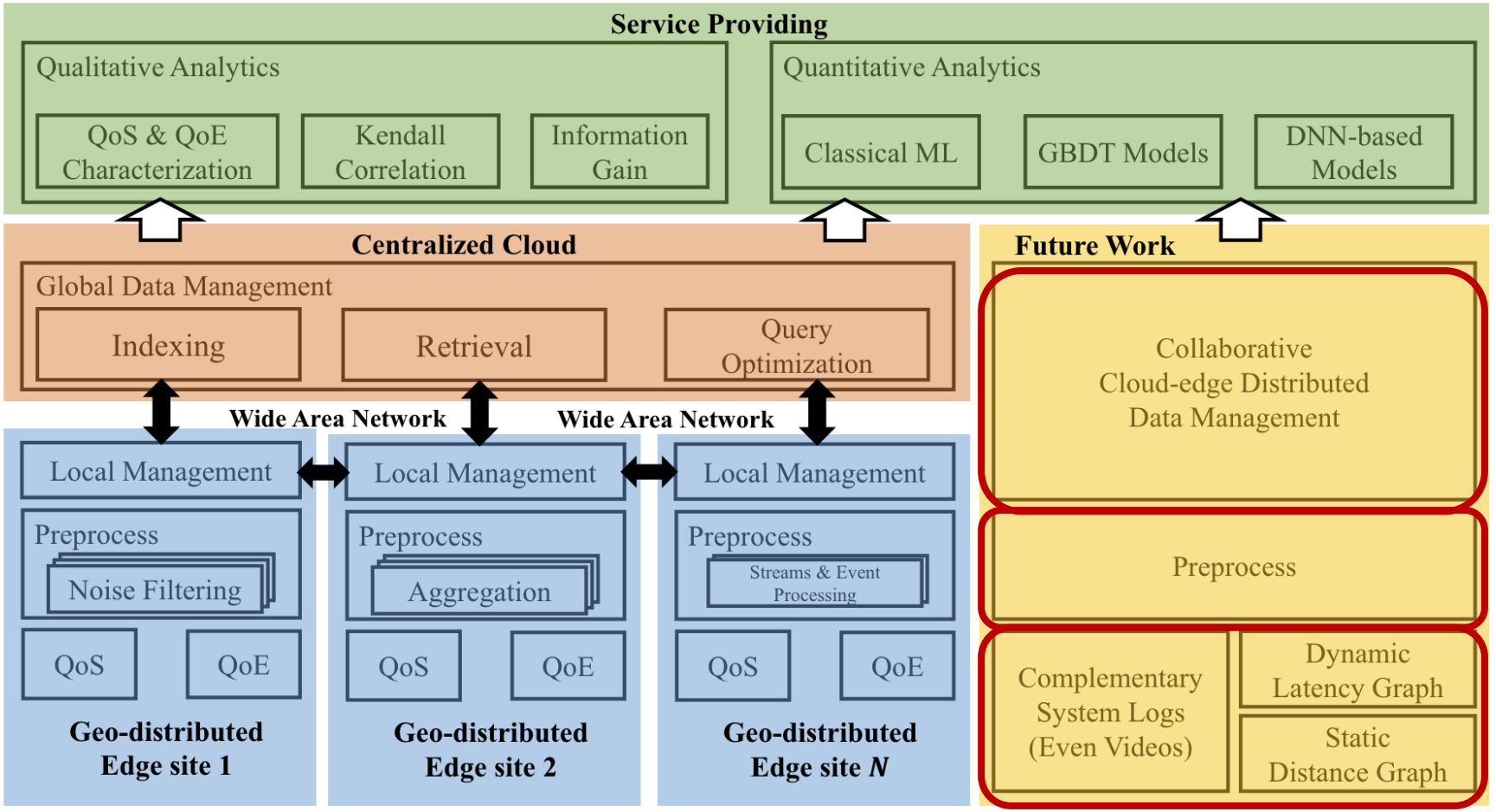


Domain-specific

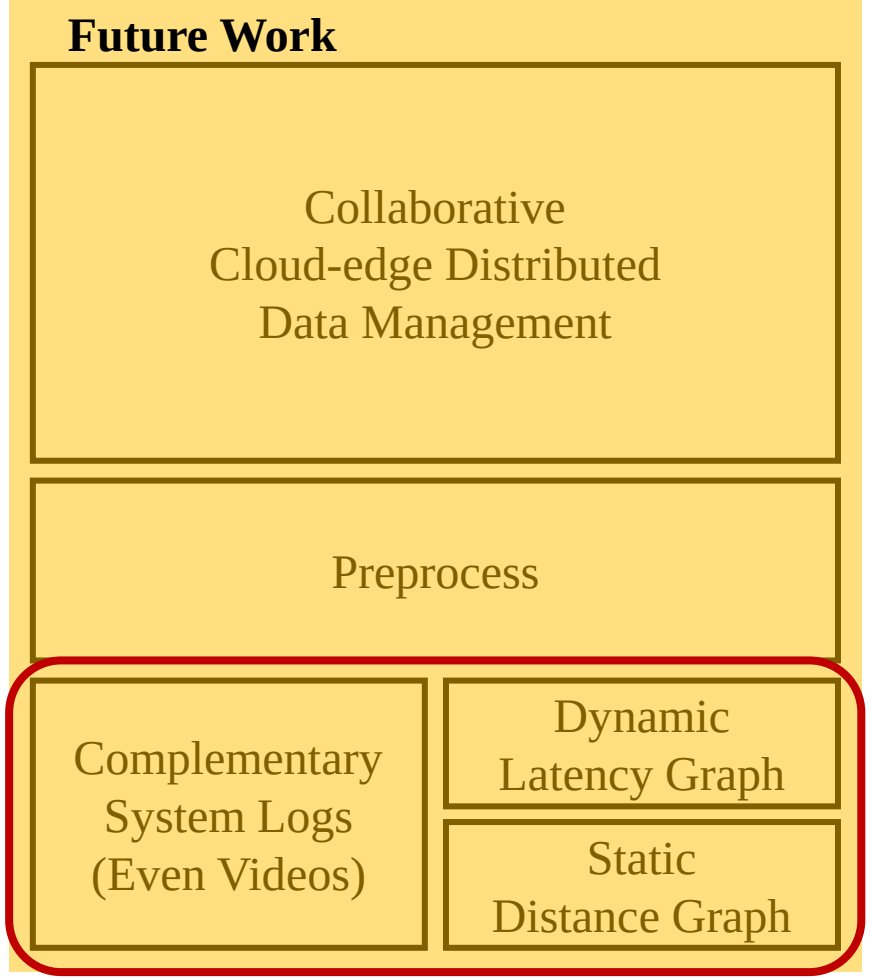


Implications:
One-size-fits-all QoS-based QoE prediction model aren’t appliable.

Potential Data-centric Problems

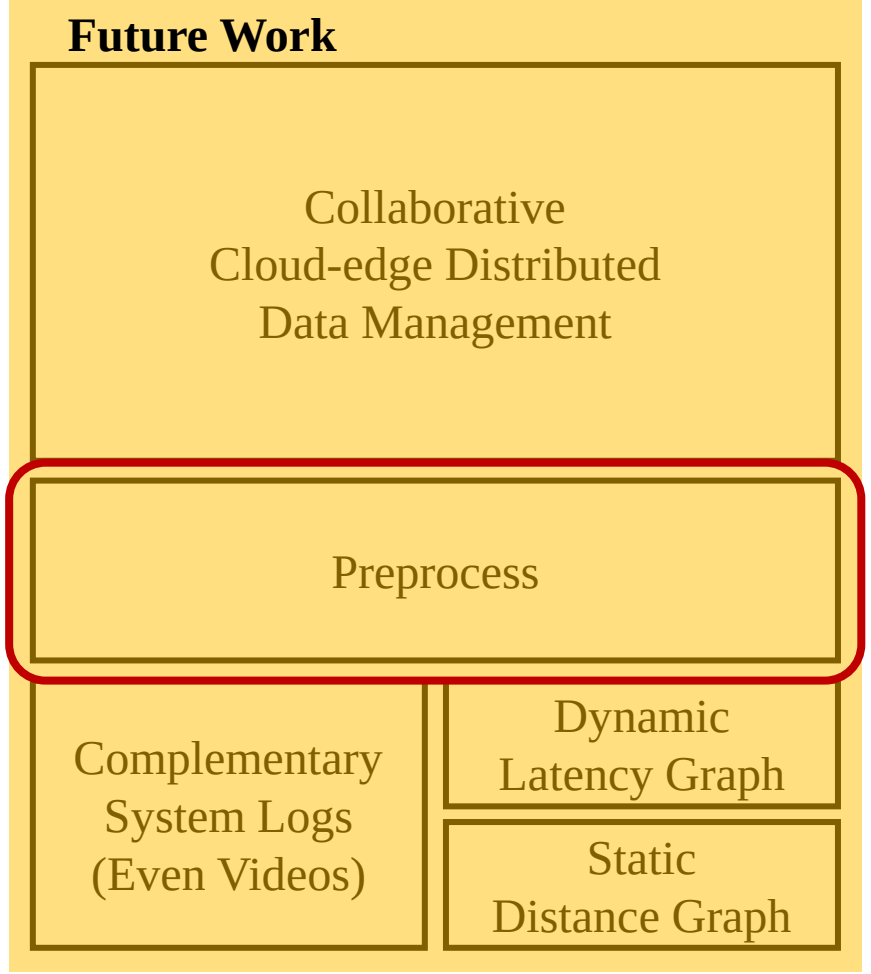


Data Collection Challenges



- **Objectives**: Accurately reflects end users' QoE while minimizing the costs.
  - Lightweight implementations;
  - Low runtime costs;
  - Efficient integration with both the internal and external datasets.

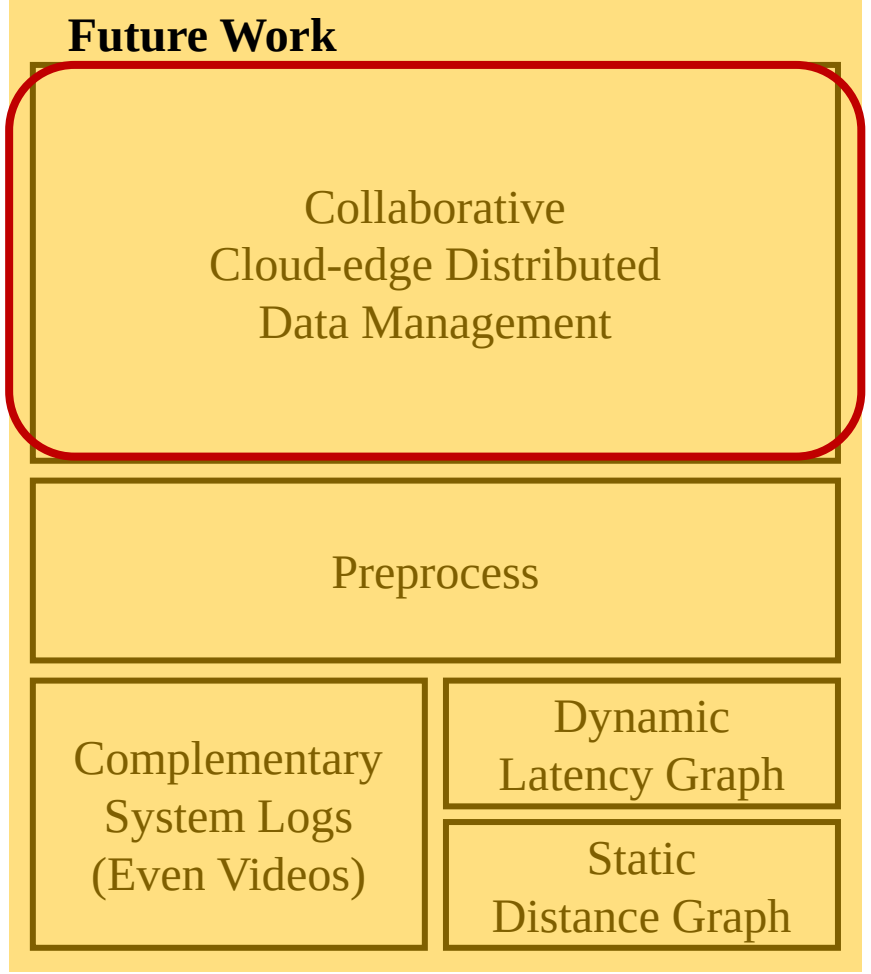
Data Preparation Challenges



The daily data volumes of each edge sites is about terabytes (TB, 10^{12}).

- Filtering redundant information for resource-constrained edge sites
- Data augmentation for class imbalance issue

Data Management Challenges



- Limitations of the existing centralized data management:
  - Network bandwidth overhead
  - Transmission time consumption.
- Key considerations:
  - Diverse data type: structured QoS, semi-structured QoE/system logs, graph data, and even videos.
  - Large-scale geo-distributed sites connected through WAN.
  - Automated materialized views

Conclusions

- We have collected **SNESet**, which contains both QoS and QoE metrics for eight VSAs on a large-scale edge platform using active measurements.
- **Qualitatively** and **quantitatively** analyze the impact of different QoS metrics on QoE in both **domain-agnostic** and **domain-specific** scenarios.
- Potential data-centric problems.

Thanks for listening!

Paper: Demystifying the QoS and QoE of Edge-hosted Video Streaming Applications in the Wild with SNESet

Dataset & Code: https://github.com/YananLi18/SNESet

Acknowledgments:
Special thanks to Alibaba Group

Mail to: YaNanLi@bupt.edu.cn