SAND: A Fault-Tolerant Streaming Architecture for Network Traffic Analytics

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Introduction

Motivation

Network traffic arrives in a **streaming fashion**, and should be processed **in real-time**. For example,

1. Network traffic classification
2. Anomaly detection
3. Policy and charging control in cellular networks
4. Recommendations based on user behaviors

Challenges

1. A stream processing system must **sustain high-speed network traffic** in cellular core networks
   - existing systems: S4 [Neumeyer'10], Storm [1] ...
   - implemented in Java: heavy processing overheads
   - cannot sustain high-speed network traffic

[1] http://storm.incubator.apache.org/

Challenges

1. A stream processing system must **sustain high-speed network traffic** in cellular core networks
   - existing systems: S4 [Neumeyer'10], Storm [1] ...
   - implemented in Java: heavy processing overheads
   - cannot sustain high-speed network traffic
2. For critical applications, it is necessary to **provide correct results after failure recovery**
   - high hardware cost
   - cannot provide "correct results" after failure recovery
   - at-least-once vs. exactly-once

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[1] `http://storm.incubator.apache.org/`

Contributions

Design and implement SAND in C++:

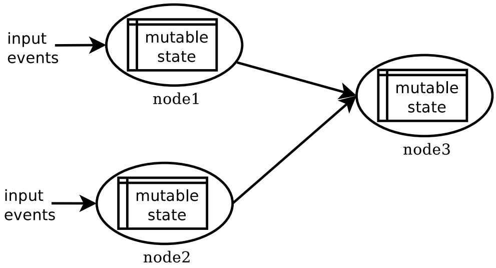
- high performance on network traffic
- a new fault tolerance scheme

Background

Background

Continuous operator model:

- Each node runs an operator with in-memory mutable state
- For each input event, state is updated and new events are sent out



Mutable state is lost if node fails.

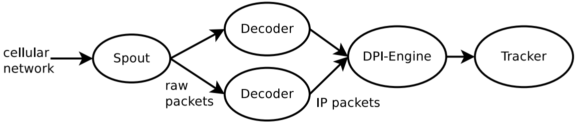
Example: `AppTracker`

- `AppTracker`: traffic classification for cellular network traffic
- Output traffic distribution in real-time:

Application	Distribution
HTTP	15.60%
Sina Weibo	4.13%
QQ	2.56%
DNS	2.34%
HTTP in QQ	2.17%

Example: `AppTracker`

Under the continuous operator model:

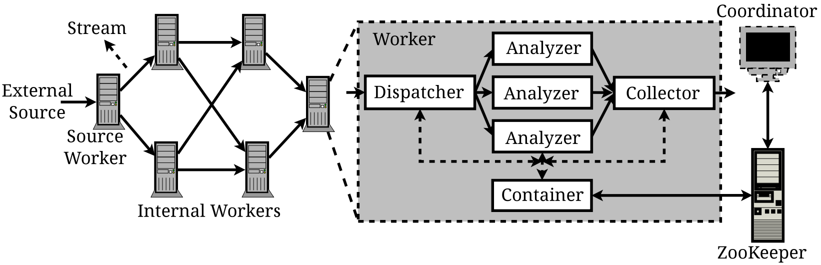


- Spout: capture packets from cellular network
- Decoder: extract IP packets from raw packets
- DPI-Engine: perform *deep packet inspection* on packets
- Tracker: track the distribution of application level protocols (HTTP, P2P, Skype ...)

System Design

Architecture of SAND

One *coordinator* and multiple *workers*.
Each worker can be seen as an operator.



Coordinator

Coordinator is responsible for

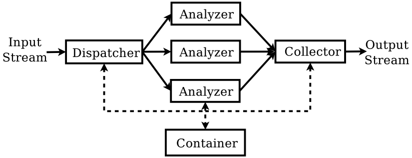
- managing worker executions
- detecting worker failures
- relaying control messages among workers
- monitoring performance statistics

Zookeeper cluster provides *fault tolerance* and *reliable coordination service*.

Worker

Contain 3 types of processes:

- The *dispatcher* decodes streams and distributes them to multiple analyzers
- Each *analyzer* independently processes the assigned streams
- The *collector* aggregates the intermediate results from all analyzers



The *container* daemon

- spawns or stops the processes
- communicates with the coordinator

Communication Channels

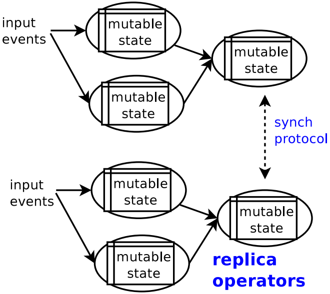
Efficient communication channels:

- Intra-worker: a lock-free shared memory ring buffer
- Inter-worker: ZeroMQ, a socket library optimized for clustered products

Fault-Tolerance

Previous Fault-Tolerance Schemes

1. *Replication*: each operator has a replica operator [Hwang'05,Shah'04,Balazinska'08]

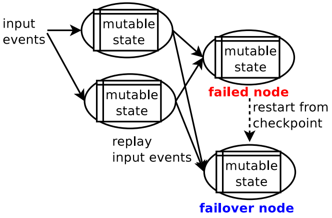


- Data streams are processed twice by two identical nodes
- Synchronization protocols ensures exact ordering of events in both nodes
- On failure, the system switches over to the replica nodes

2x hardware cost.

Previous Fault-Tolerance Schemes

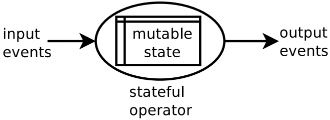
2. *Upstream backup with checkpoint* [Fernandez'03,Gu'09]:
   - Each node maintains backup of the forwarded events since last checkpoint
   - On failure, upstream nodes replay the backup events serially to the failover node to recreate the state



Less hardware cost. It's hard to provide **correct results** after recovery.

Why is it hard?

- Stateful continuous operators tightly integrate “computation” with “mutable state”
- Makes it harder to define clear boundaries when computation and state can be moved around



Checkpointing

- Need to coordinate checkpointing operation on each worker
- 1985: Chandy-Lamport invented an asynchronous snapshot algorithm for distributed systems
- A variant algorithm was implemented within SAND

Checkpointing Protocol

- Coordinator initiates a global checkpoint by sending markers to all source workers
- For each worker w,
  - on receiving a data event E from worker u
    - if marker from u has arrived, w buffers E
    - else w processes E normally
  - on receiving a marker from worker u
    - if all markers have arrived, w starts checkpointing operation

Checkpointing Operation

On each worker:

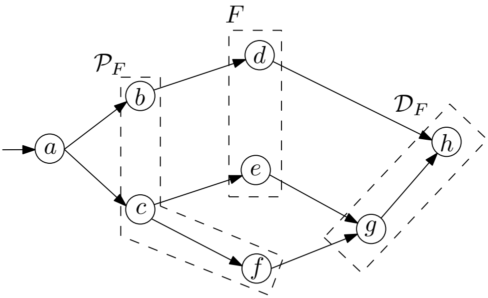
- When a checkpoint starts, the worker creates child processes using `fork`
- The parent processes then resume with the normal processing
- The child processes write the internal state to HDFS, which performs replication for data reliability

Output Buffer

Buffer output events for recovery:

- Each worker records output data events in its *output buffer*, so as to replay output events during failure recovery
- When global checkpoint c is finished, data in output buffers before checkpoint c can be deleted

Failure Recovery



- F: failed workers
- $\mathcal{D}_F$: downstream workers of F
- $F \cup \mathcal{D}_F$: rolled back to the most recent checkpoint c
- $\mathcal{P}_F$: the upstream workers of $F \cup \mathcal{D}_F$
- Workers in $\mathcal{P}_F$ replay output events after checkpoint c

Evaluation

Experiment 1

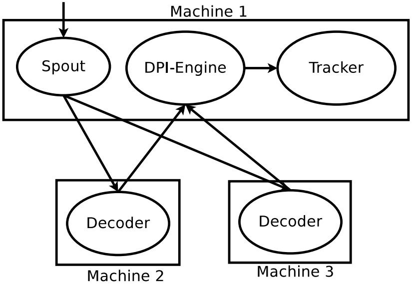
- Testbed: one quad-core machine with 4GB RAM
- Dataset: packet header trace; 331 million packets accounting for 143GB of traffic
- Application: packet counter

System	Packets/s	Payload Rate	Header Rate
Storm	260K	840Mb/s	81.15Mb/s
Blockmon	2.7M	8.4Gb/s	844.9Mb/s
SAND	9.6M	31.4Gb/s	3031.7Mb/s

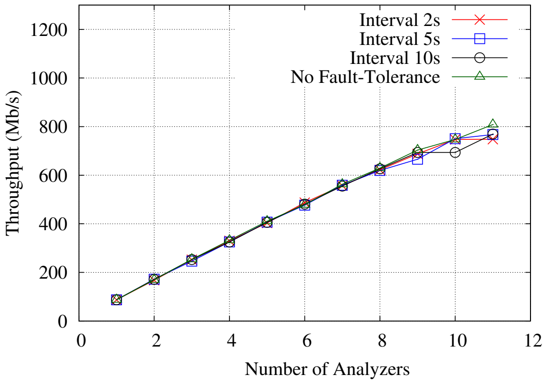
- 3.7X and 37.4X compared to Blockmon [Simoncelli'13] and Storm

Experiment 2

- Testbed: three 16-core machines with 94GB RAM
- Dataset: a 2-hour network trace (32GB) collected from a commercial GPRS core network in China in 2013
- Application: `AppTracker`

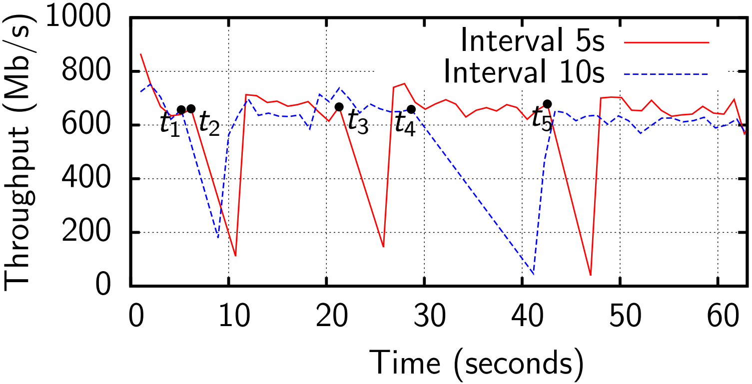


Experiment 2



- Scale out by running parallel workers on multiple servers
- Negligible overheads

Experiment 3



- Recover in order of seconds
- Recovery time is in proportion to checkpointing interval

Conclusion

- Present a new distributed stream processing system for network analytics
- Propose a novel checkpointing protocol that provides reliable fault tolerance for stream processing systems
- SAND can operate at core routers level and can recover from failure in order of seconds

Thank you!
Q & A