Running ZooKeeper Coordination Services in Untrusted Clouds
HotDep’14

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Lack of Trust in Cloud Providers

- Privacy concerns slow down adoption of cloud technology
  - No trust in providers (especially sensitive applications)

  “Snowden leaks aren’t driving companies away from the cloud; but [...] made them a lot more careful” ¹

  “Most IT pros do not trust cloud services with sensitive data” ²

- Challenge: Privacy in cloud computing
  - Encryption of sensitive data
  - Trusted execution
  - Verification of software stack

¹ http://www.computerworld.com/article/2487123
Trusted Cloud

Establish Trust in the Cloud
- Homomorphic encryption
- TPM-based trusted software stack
- Hardware-isolated environments

Trusted Execution Environment (TEE)
- Isolation enforced by hardware
  - Intel SGX, ARM TrustZone
- Application logic split into trusted and untrusted part
  - Process sensitive data only in TEEs
  - Verification of trusted software stack
  - Minimizing trusted codebase
    - Fewer bugs reduce attack surface
Trusted Coordination

- TEEs coming to cloud environments
  - Trusted distributed applications in the cloud
    → Trusted coordination
Trusted Coordination

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- Apache ZooKeeper – coord. service
  - Configuration management for distr. app.
  - Leader election
Trusted Coordination

• TEEs coming to cloud environments
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• Apache ZooKeeper – coord. service
  • Configuration management for distr. app.
  • Leader election

• Trusted ZooKeeper
  • Transparent encryption layer to ZooKeeper
  • All functionality of ZooKeeper preserved
ZooKeeper Privacy Proxy

System Architecture

ZooKeeper

- Data items: *znode*
- Callback mechanism
  - Update notification
- “Sequential znodes”
  - Leader election
  - Fairness for distr. lock
ZooKeeper Privacy Proxy

System Architecture

Threat

- Provider/Attacker can eavesdrop all storage and transmitted messages
ZooKeeper Privacy Proxy

System Architecture

Threat
- Provider/Attacker can eavesdrop all storage and transmitted messages
- Provider/Attacker can **not** look inside TEEs
Our approach:

- ZooKeeper Privacy Proxy (ZPP)
- Running inside a TEE
- Encryption of:
  - Payload of znodes
  - Names of znodes
ZooKeeper Privacy Proxy

Link Encryption

- Client to ZPP
  - SSL-encrypted transport between Client and ZPP
- ZPP to ZooKeeper
  - Shared key-encrypted payload and node names between ZPP and ZooKeeper
ZooKeeper Privacy Proxy

znode Name Encryption

• Encryption of znode names
  • Encryption of individual parts of paths
  • Hierarchy of znodes preserved

⇒ Works for most operations
ZooKeeper Privacy Proxy

Name Clash Sequence Numbers

: Client$_i$

create(/foo, sequent.)

/foo001

: ZPP$_j$

create(ciph(/foo), sequent.)

ciph(/foo) + 001

: ZooKeeper$_k$
ZooKeeper Privacy Proxy

Name Clash Sequence Numbers

: Client<sub>i</sub>  
create(/foo, sequent.)

: ZPP<sub>j</sub>  
create(ciph(/foo), sequent.)

: ZooKeeper<sub>k</sub>  
ciph(/foo) + 001

ciph(/foo001)

/boo001
create(/foo001, regular)

/boo001?
ZooKeeper Privacy Proxy
Supporting Sequential znodes

- “Dictionaries” (Helper znodes)
  - Additional ZPP-maintained data
  - Encrypted payload of helper znode
  - Stored inside ZooKeeper
  - Hidden from clients

- Sequence numbers
  - Mapping of znode name to next free sequence number
  - Example: Payload of /dict/seqno:
    ```
    { "dict": { "/foo": 3, "/bar": 2 } }
    ```
ZooKeeper Privacy Proxy

Dictionary Nodes

Dictionary Maintenance

- Dictionary in-memory at all ZPPs
- Monitoring dictionary causes callback on change

**Example:** `create()` sequential node

1. Sequence number appended to znode name
2. Sequence number of parent znode incremented
3. Atomically create znode and update the dictionary
ZooKeeper Privacy Proxy

Dictionary Nodes (Overview)

: **Client$_i$**

: **ZPP$_j$**

: **ZooKeeper$_k$**

get("/dict", watch)

payload
ZooKeeper Privacy Proxy

Dictionary Nodes (Overview)

: Client<sub>i</sub> -> create("/foo", sequent.)

: ZPP<sub>j</sub> -> get("/dict", watch)

: ZooKeeper<sub>k</sub> -> performCreate()

"/foo" + SqN

get("/dict", watch)

payload

callback

get("/dict", watch)

payload
ZooKeeper Privacy Proxy

Dictionary Nodes (create() detailed)

: Client_i

create("/foo", sequent.)

: ZPP_j

atomic: performCreate()

\[
\text{set(}/dict\text{, } SqN+1, \text{ version)}
\]
\[
\text{create(ciph(}/foo\text{+SqN), regular)}
\]

\[
\text{call results}
\]

: ZooKeeper_k

"/foo" + SqN
Related Work

Untrusted storage

- Venus: Verification for untrusted cloud storage (CCSW’10)
- Fail-aware untrusted storage (DSN’09)

Full SQL interface

- TrustedDB: A Trusted Hardware Based Database with Privacy and Data Confidentiality. (TKDE’13)
- The Blind Stone Tablet: Outsourcing Durability to Untrusted Parties. (NDSS’09)
Evaluation

Experimental Setup

- OpenStack virtual machines
- 5 ZooKeeper replicas
- 1 ZooKeeper Privacy Proxy
- 1 Client VM

Experiments

- Batch of 500+ operations
- Various payload sizes
  ⇒ moderate throughput impact
Summary

• No trust in cloud providers
  • Sensitive applications conflict untrusted providers

• ZooKeeper deployment in untrusted clouds
  • ZooKeeper Privacy Proxy
  • Application logic split in trusted and untrusted part
  • Encryption of all data stored inside ZooKeeper
  • All ZooKeeper functionality and semantics preserved

• SERECA: Upcoming EU project
  • Trusted execution of distributed applications in the cloud
  • TEEs: ARM TrustZone and Intel SGX