Certificate Management for Cloud-Hosted Digital Twins

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https://mm.aueb.gr/projects/snds

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Motivation

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Why Certificates for DTs?

- What is a Digital Twin (DT)?
  - Virtual representation of physical IoT device
- How can we trust a cloud-hosted DT?
  - Is it authorized to represent the IoT device?
- Our scheme: short-lived certificates
  - Quick rotation of certificates
  - Resilience against malicious CAs
  - No IoT device secrets kept at the DTs
  - Low overhead and standards-based

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Design

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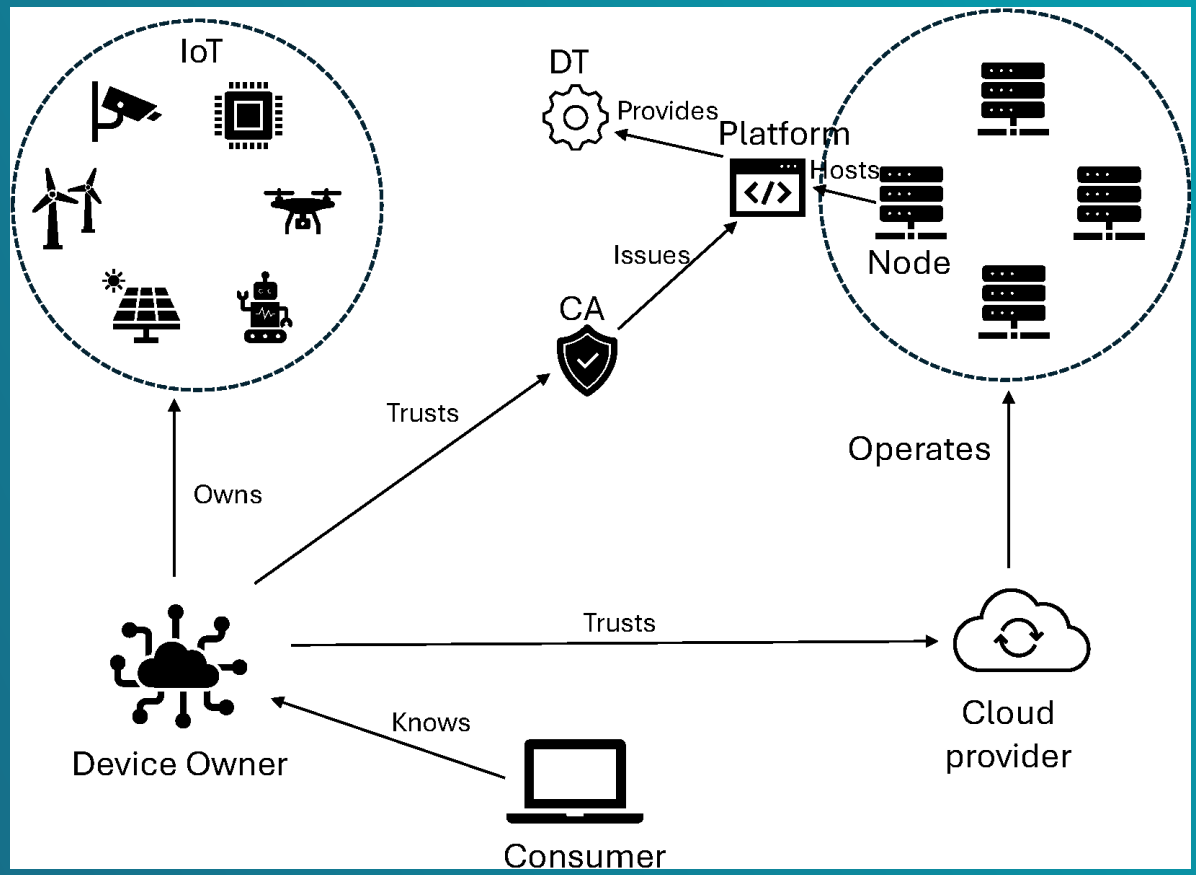
System Model

- (IoT) Device owner
  - Identified by $Owner_{URL}$
- Content consumer
- Cloud provider
- Certificate Authority
  - Identified by CA_{URL}
- DT platform
  - Offers DT instances
  - Identified by $Instance_{ID}$
  - Implementing API (NGSI-LD)



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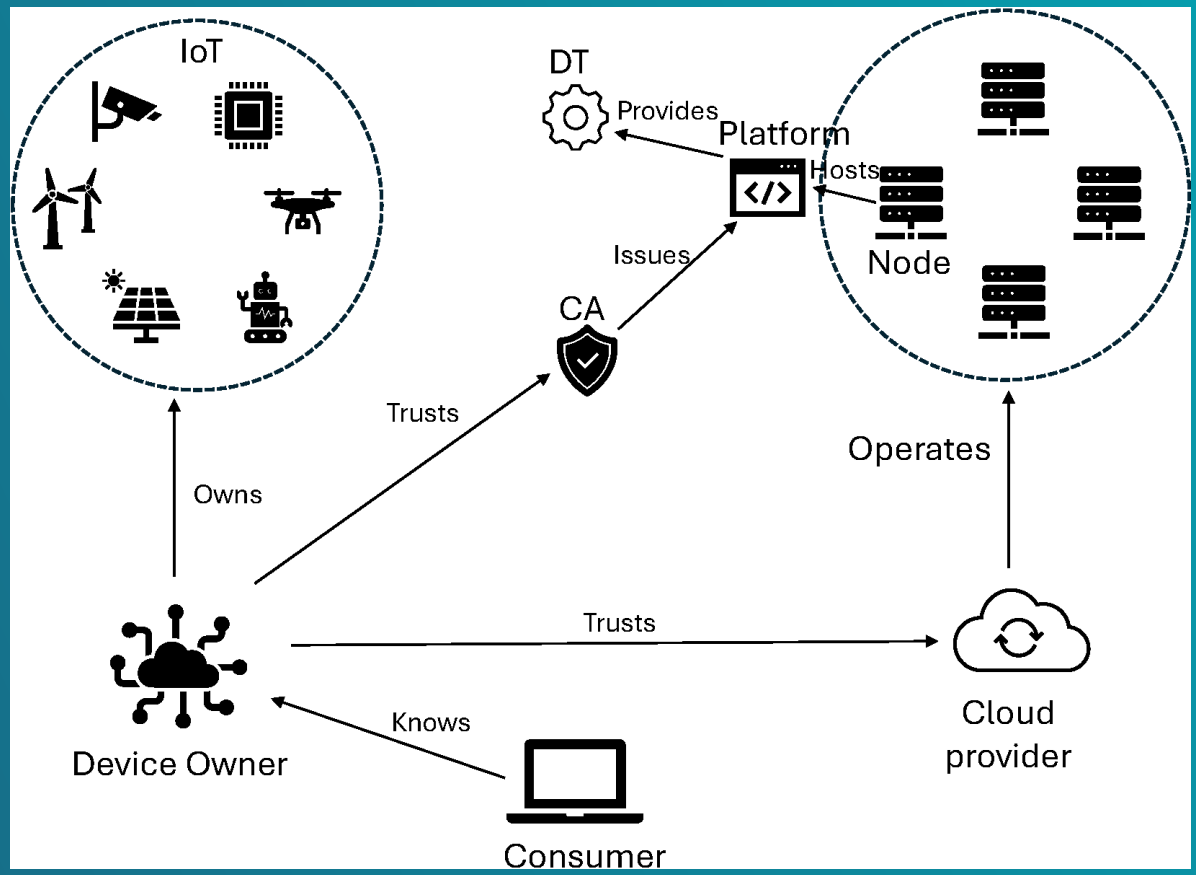
Trust Relationships

- Consumers know $Owner_{URL}$
- Owners know $Instance_{ID}$
  - Attested by cloud provider
  - Example: digest of binary
- Instances get certificates
  - From CA trusted by owner
  - Binding owner to instance
- Consumers will learn
  - The CAs trusted by owner
  - The instance's certificate



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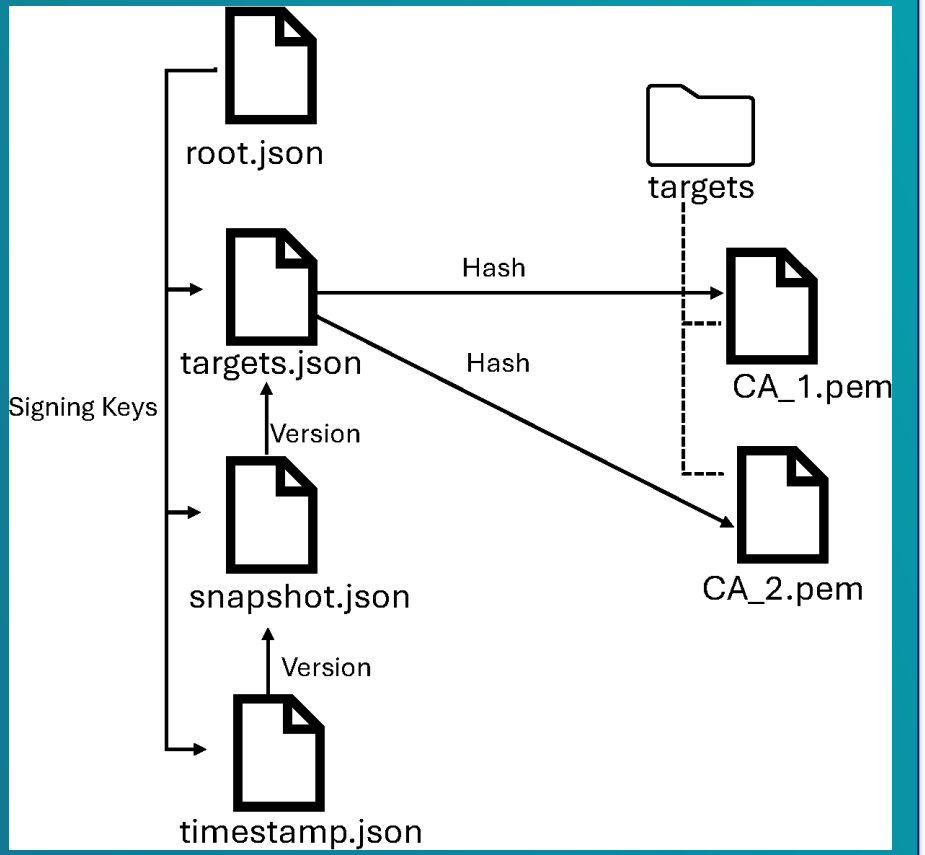
Trusted CA Management

- The Update Framework (TUF)
  - Disseminates PKs to consumers
  - PKs stored in target files
- Device owner defines four roles
  - Root: PKs for other roles
    - Its PKs transmitted out-of-band
  - Timestamp: hashes of snapshot
    - Periodically refreshed and signed
  - Snapshot: versions of root and targets
  - Targets: hashes of target files



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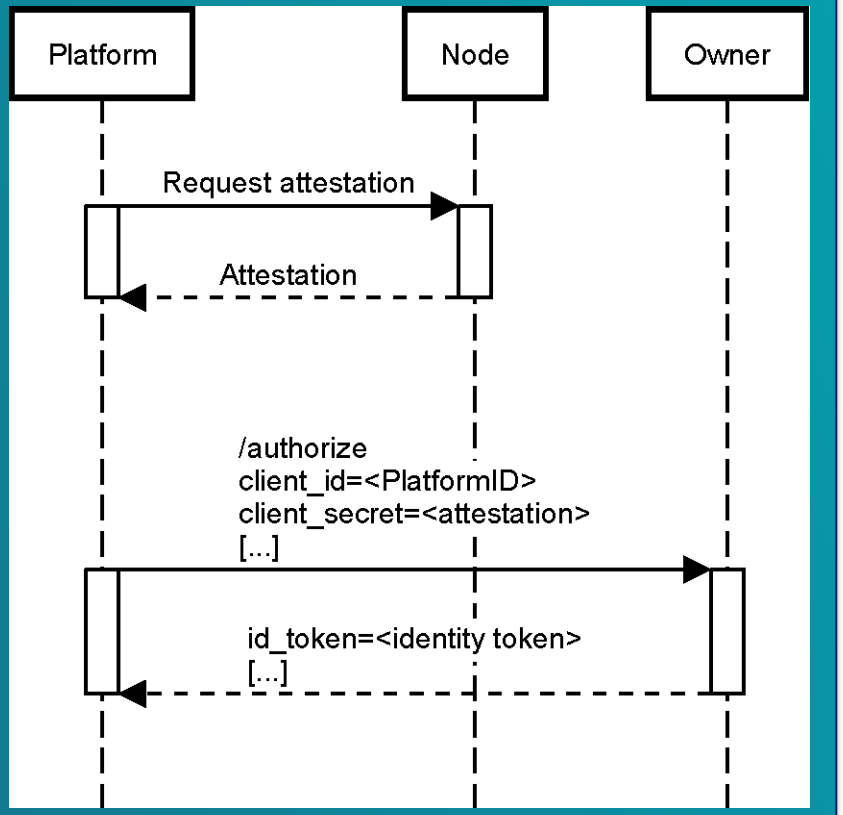
Platform Bootstrapping

- DT instance requests attestation
  - Proves $Instance_{ID}$ is legit software
  - Signed by cloud provider
- DT instance asks for identity token
  - Uses OpenID connect with owner
  - Sends its attestation as proof
- Owner generates OpenID token
  - Binds $Instance_{ID}$ to owner and CA
  - Token can be used to get certificates



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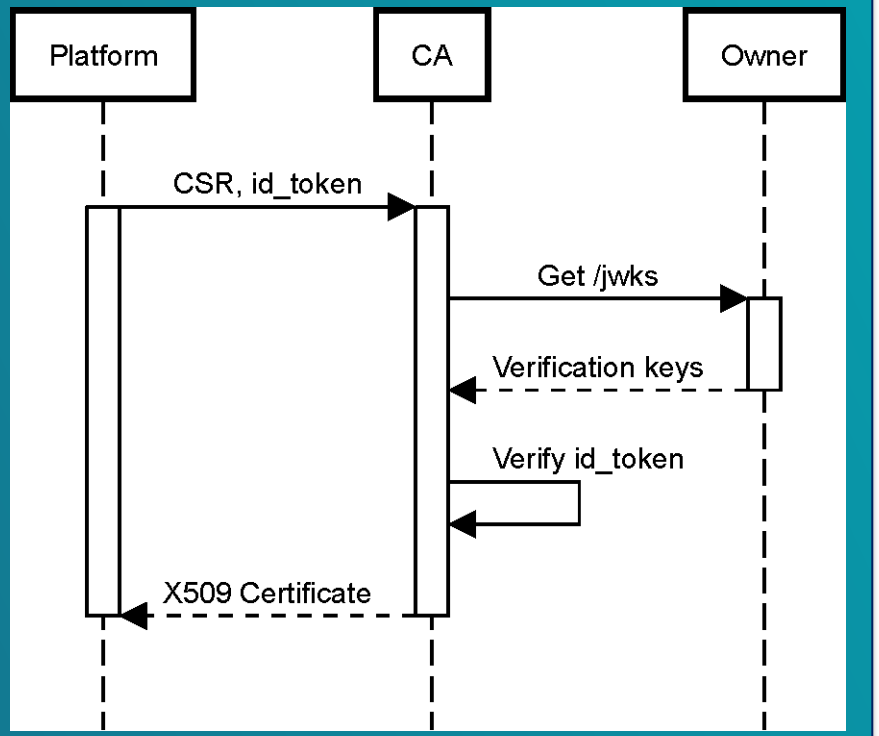
Certificate Issuance

- DT instance asks for certificate
  - Using its OpenID token
  - Creates new key pair and CSR
  - CA uses OpenID to get owner keys
  - Checks token is signed by owner
  - Checks token is new and not expired
- CA issues certificate
  - Indicates $Instance_{ID}$ and $Owner_{URL}$
  - Certificate is short-lived (10 min)



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Signing and Verification

- Consumers ask DT instance for data
  - DT responds with IoT device's state
  - Responses are signed with key corresponding to certificate
- Consumer uses owner as root of trust
  - Uses TUF to get PKs of CAs trusted by owner
  - Uses CA PKs to verify DT instance's certificate
  - Uses DT's PK to verify responses
- The process is completely automated
  - New certificates issued every few minutes

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Evaluation

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Implementation & Performance

- Publicly available prototype in github
  - https://github.com/mmlab-aueb/certificate-management
  - DT instance implements NGSI-LD API
  - Platform identified via SPIFFE
  - Attestations use SPIRE
  - Custom OpenID provider for owners
- Performance evaluation
  - Owner and DT in same cloud provider
  - Public instance of Fulcio as CA
  - Measurements on i5 CPU in Ubuntu 22.04

Process	Time (ms)
Attestation issuance	1
Identity token issuance	4
Certificate issuance	390

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Security Evaluation

- Man-in-the-Middle attacks
  - DT – consumer: cannot create valid signature
  - DT – owner: use nonces to avoid CSR replay attacks
- DT platform compromise
  - Only already verified instance are susceptible
- OpenID provider compromise
  - Certificate Transparency to detect third party certificates
- Malicious CA
  - TUF only allows trusted CAs, multiple root keys used

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Conclusions

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Summary

- Certificate management solution for DTs
  - Automated certificate issuance
  - Securely binds DTs to IoT devices
  - Frequent certificate issuance
  - No IoT device secrets maintained at DT
  - Uses existing protocols and mechanisms
- Future work: integrate transparency services
  - Prevent fake certificates or attestations
  - Enable certificate verification after keys expire

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Thank you

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