Usable Security of Named Data Networking

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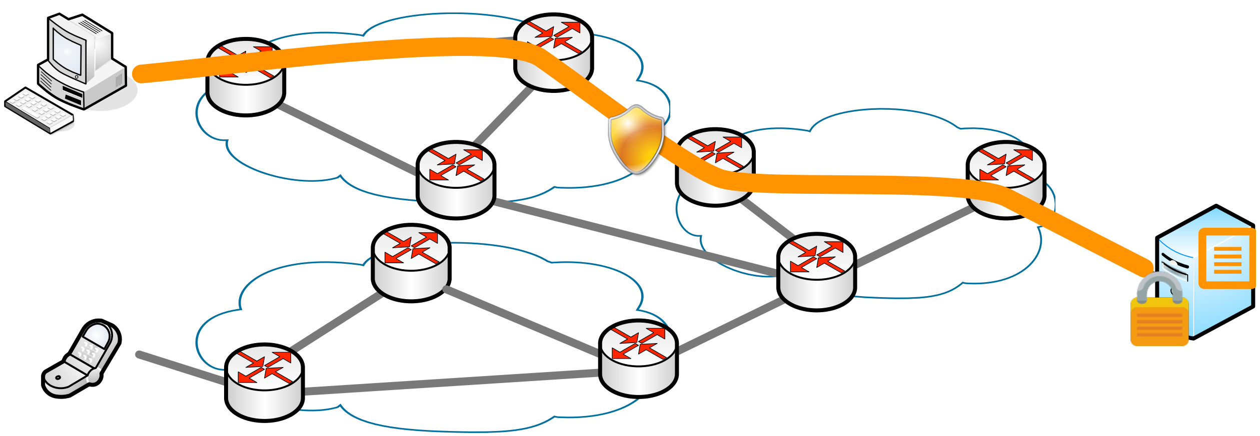
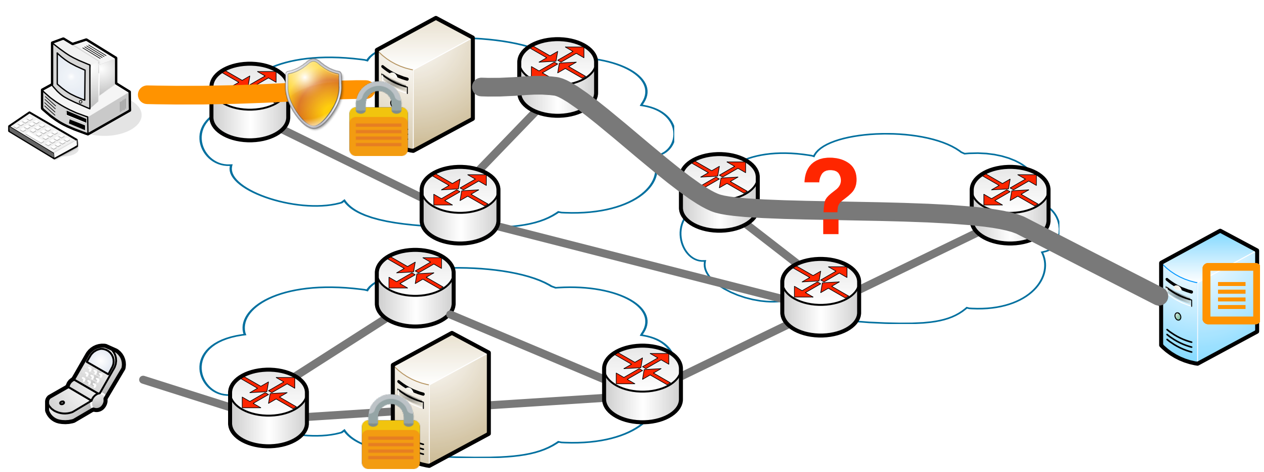
Traditional communication model of Internet

- Speaking to a host
  - end-to-end channel
- Communication security
  - container-based authenticity: X.509, Certificate Authority
  - channel-based confidentiality: IPSec, TLS/SSL



New communication vs. Old security

- Content Distribution Network (CDN)
  - multiple containers to secure
  - no end-to-end channel

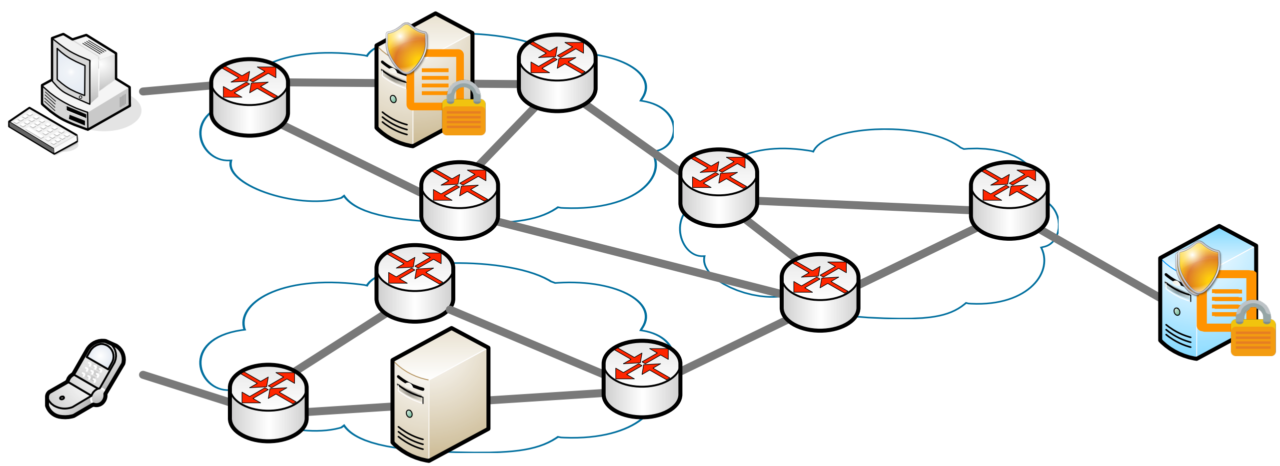


New communication vs. Old security

- Delay Tolerant Network (DTN)
    - temporary data container
    - no instantaneous end-to-end channel

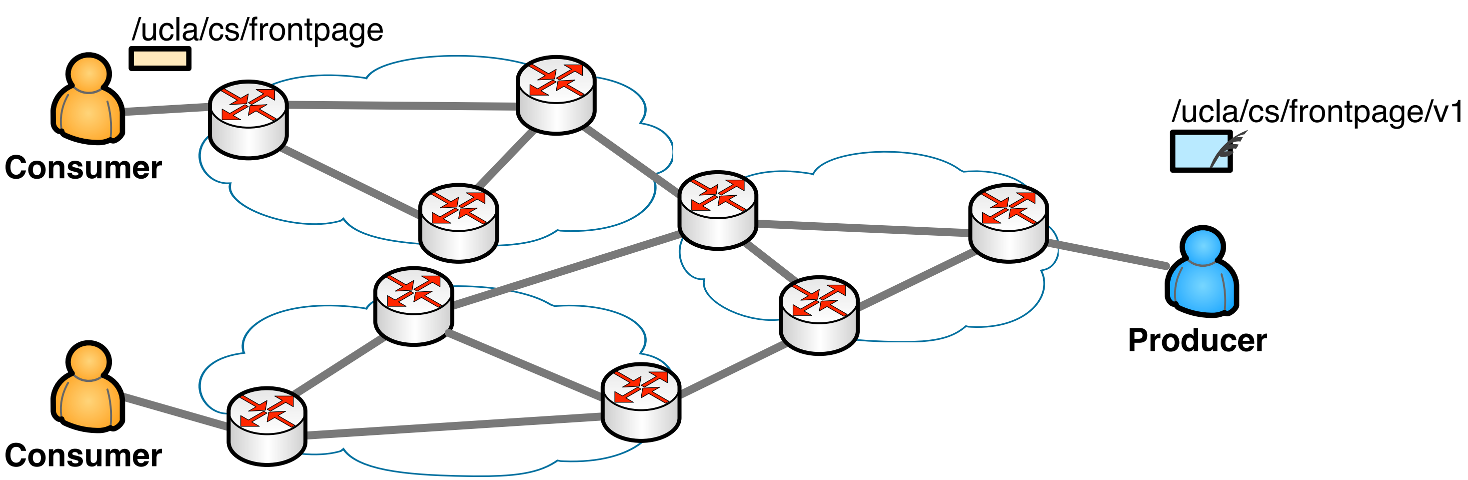
New security model is desired!

- No trustworthy container, no end-to-end encrypted channel
- Data-centric security: let's secure **data** directly!
  - authenticate data rather than container
  - encrypt data instead of channel



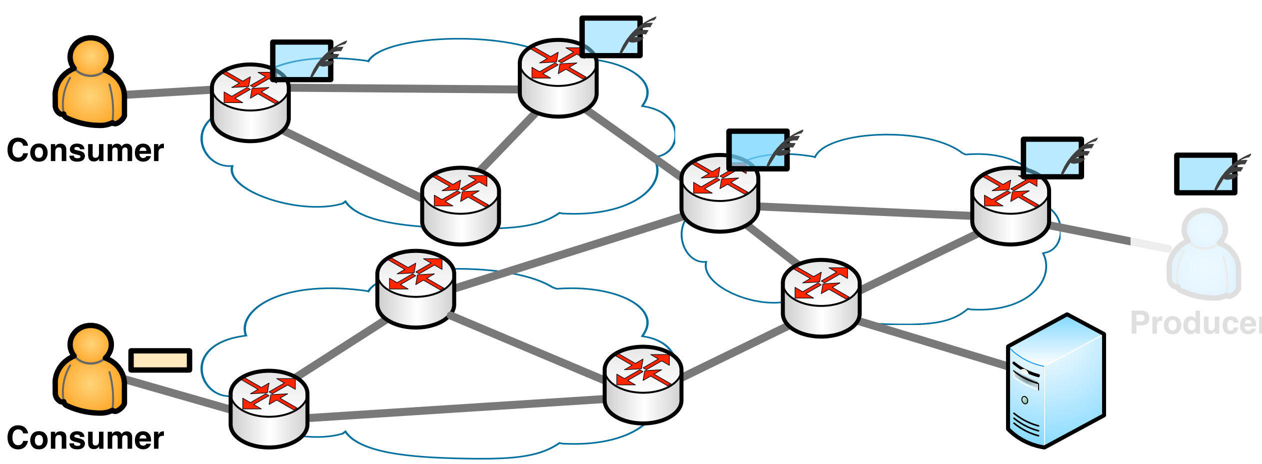
Named Data Networking

- Data-centric communication primitives
  - retrieve data by name rather by container address
  - **Interest Packet**: expressed by consumer, forwarded according to name
  - **Data Packet**: made by producer, forwarded along reverse path



Efficient & flexible data delivery

- Data can be picked anywhere
  - in-network caching
- Does not require instantaneous communication
  - producer can go offline
  - store pre-created data in third party storage



Built-in data authenticity

- Per packet signature
  - privilege separation: different data signed by different keys
- Retrieve public key as data
  - same authentication procedure
- Data carrying public key is a certificate
  - more powerful

NDN Data Packet

Name: /ucla/cs/alice/thesis/v_3/s_8

Content: ...

SignatureInfo:
KeyLocator: /ucla/cs/alice/KEY/2
ValidityPeriod: [2015/5/2, 2016/5/2)
...

Signature Bits: ...

NDN Certificate

Name: /ucla/cs/alice/KEY/2

Content:
6d:32:8d:23:a9:b0:89:...

SignatureInfo:
SignatureType: RSA-SHA256
KeyLocator: /ucla/cs/KEY/7
ValidityPeriod: [2015/1/1, 2017/1/1)
...

Signature Bits:
cd:ca:70:72:7b:ff:a8:...

X 509 Certificate

Subject Name

Subject Public Key Info

Certificate Signature Algorithm

Issuer Name

Validity Period

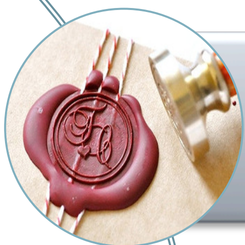
Certificate Signature

But how to utilize those features?

- Developers turn off security as the first step
  - fake signature
  - skip authentication
  - wish no one is eavesdropping

- Can we make security easier for developers?
  - automate data authentication
  - automate data encryption
  - minimize maintenance overhead

Outline

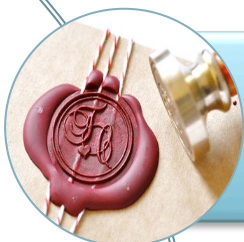


Automating Data-Centric Authenticity

Authenticating Long-Lived Data

Automating Data-Centric Confidentiality

Outline



Automating Data-Centric Authenticity

Authenticating Long-Lived Data

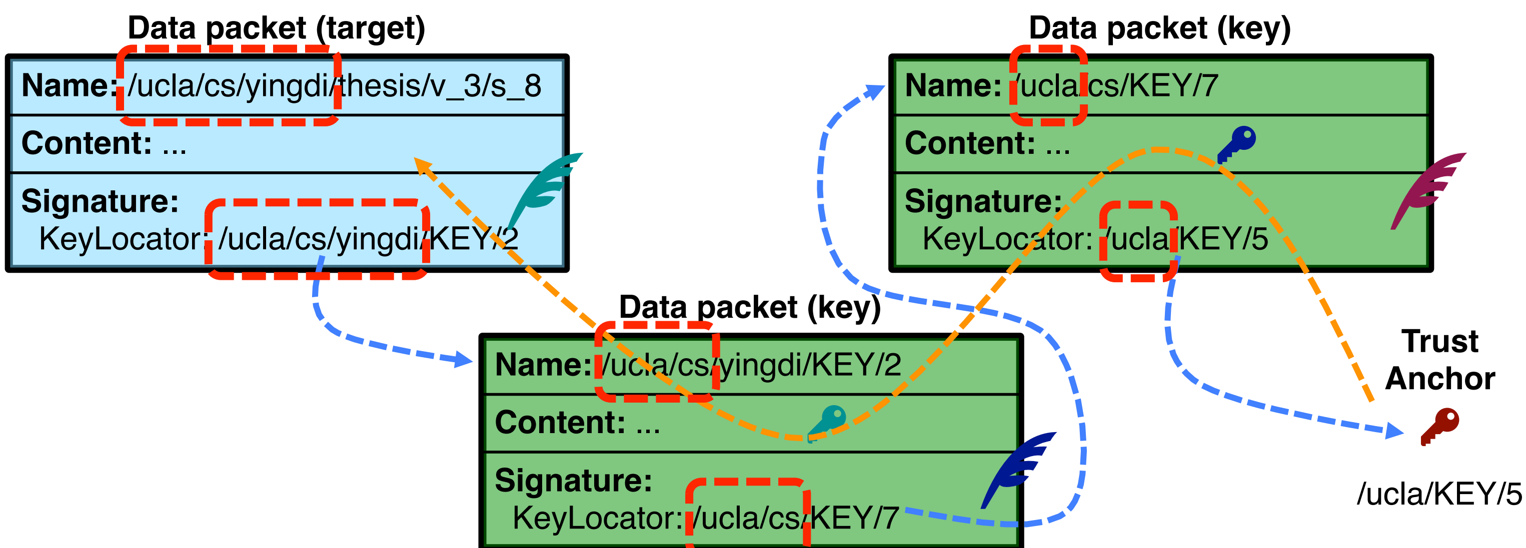
Automating Data-Centric Confidentiality

Trust chain

- Recursively retrieve key until reach a **trust anchor**
  - a pre-trusted key

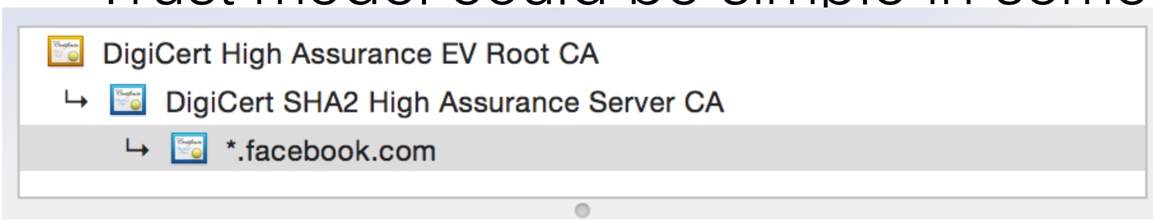
Trust Model

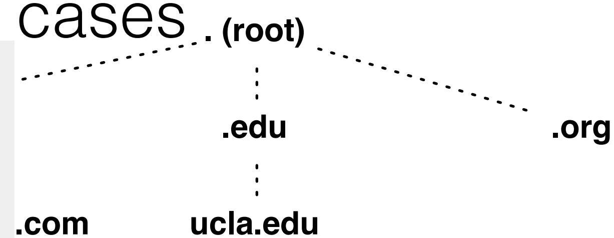
- Constrained by **trust derivation rules**
  - is data (or key) signed by a trusted producer (or issuer) ?
- Validate signature



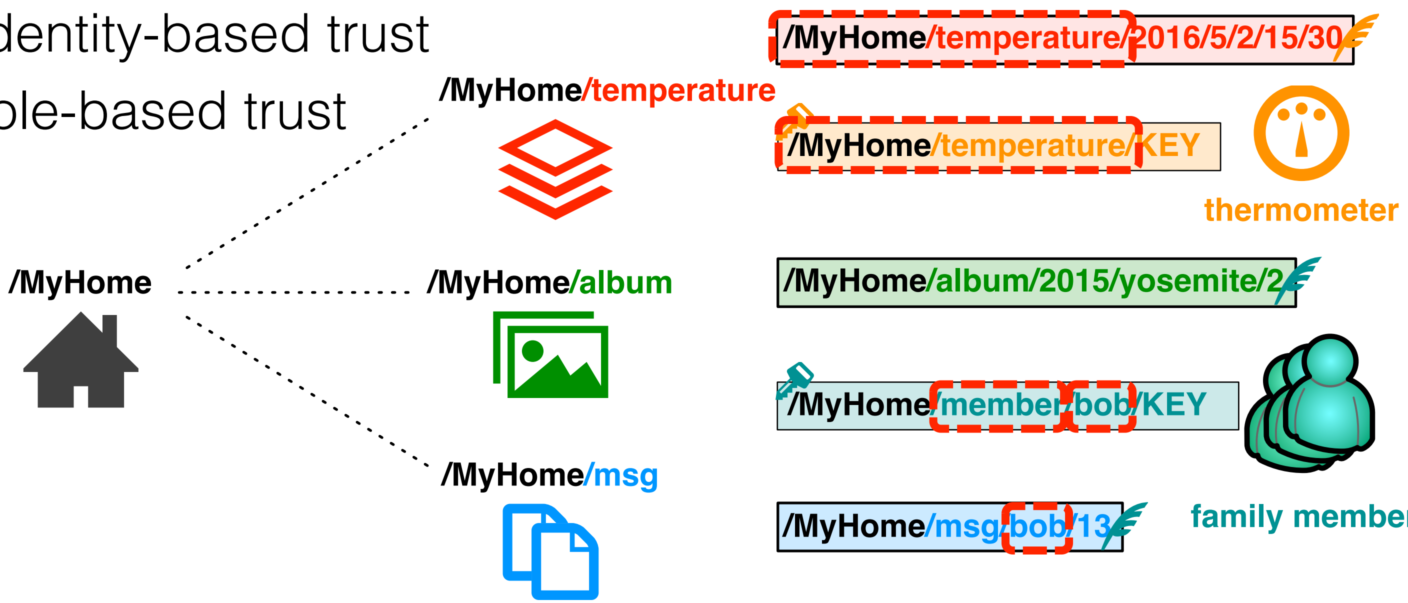
Diversity of trust models

- Trust model could be simple in some cases





- Application specific in general
  - capability-based trust
  - identity-based trust
  - role-based trust



NDN insight

- Name is a general expression
  - can refer to identity, capability, role, …
- Any trust model can be expressed as a list of relationship between data name and key name

Schematize the trust
Automate data authentication

- Data auth … easily if we have
  - a name-based policy language to express trust model
  - a library to perform authentication according to the policy

Describe trust relationship in name

- Relationship between data and key names

/My/home/msg/bob/13 ← /My/home/member/bob/KEY
/My/home/msg/alice/15 ← /My/home/member/alice/KEY

- Generalized as name pattern

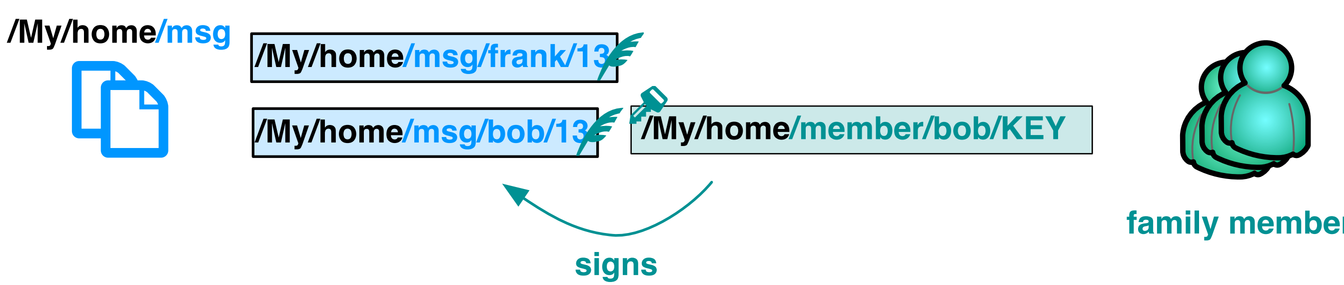
home_prefix + “home” + “msg” + user + msg_id
home_prefix + “home” + “member” + user + “KEY”

signs

- Regex-based syntax

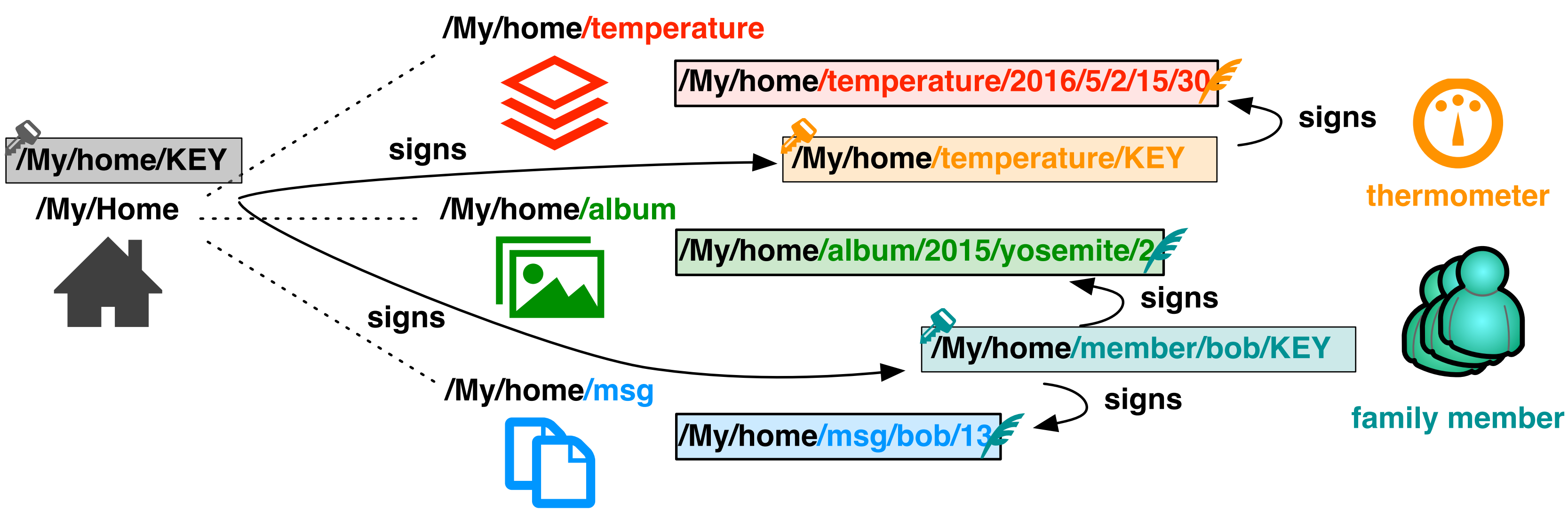
(<>*)<home><msg>([user_id])<>
\1<home><member>\2<KEY>

signs



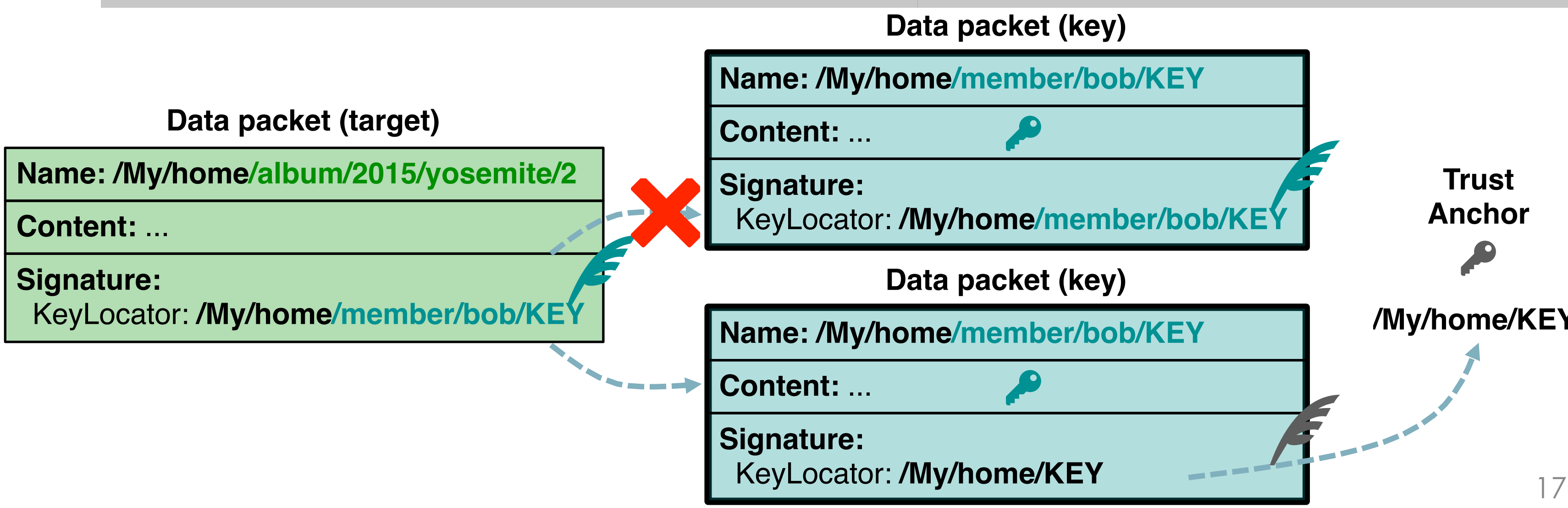
Trust schema

Rule ID	Data Name	Key Name
msg	(<>*)<home><msg>**([user])**<>	\1<home><member>\2<KEY>
album	(<>*)<home><album><><><>	\1<home><member>[user]<KEY>
temp	(<>*)<home><temperature><><><><><>	\1<home><temperature><KEY>
member	(<>*)<home><member>**([user])**<KEY>	\1<home><KEY>
therm	(<>*)<home><temperature><KEY>	\1<home><KEY>
root	(<>*)<home><KEY>	/My/home/KEY 30:b4:82:9c:45:…



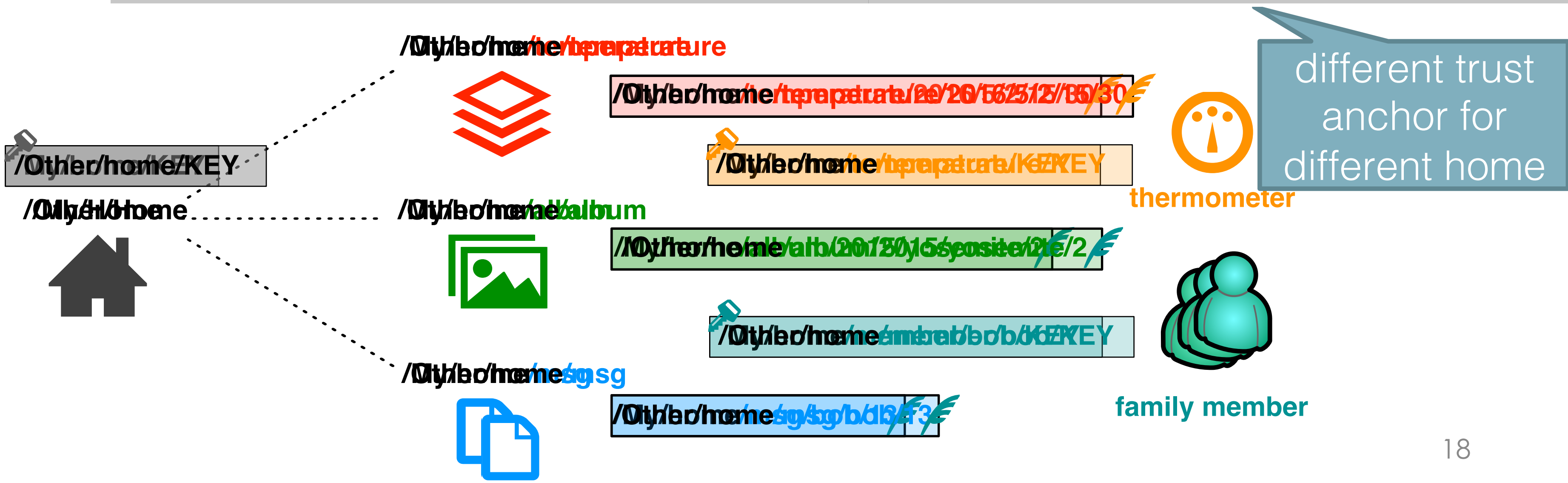
Trust chain construction

Rule ID	Data Name	Key Name
msg	(<>*)<home><msg>([user])<>	\1<home><member>\2<KEY>
album	(<>*)<home><album><><><>	\1<home><member>[user]<KEY>
temp	(<>*)<home><temperature><><><><><>	\1<home><temperature><KEY>
member	(<>*)<home><member>([user])<KEY>	\1<home><KEY>
therm	(<>*)<home><temperature><KEY>	\1<home><KEY>
root	(<>*)<home><KEY>	/My/home/KEY 30:b4:82:9c:45:…



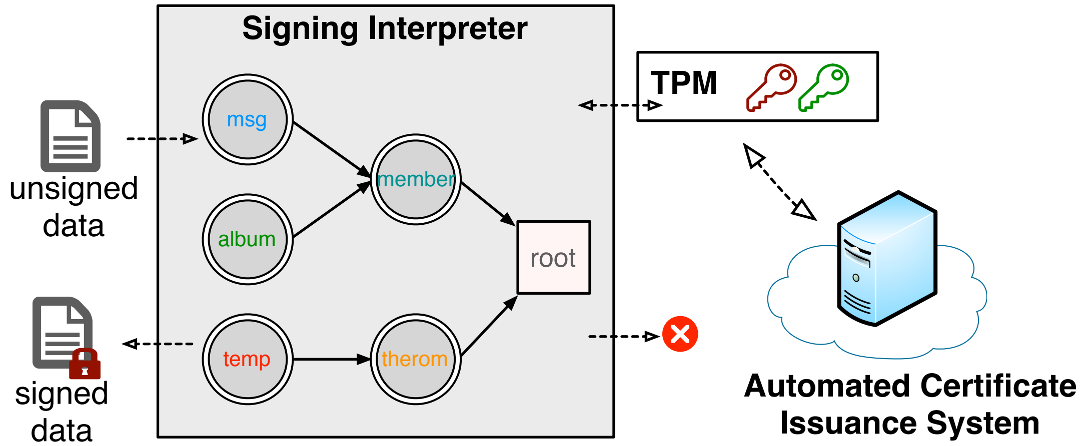
Re-usability

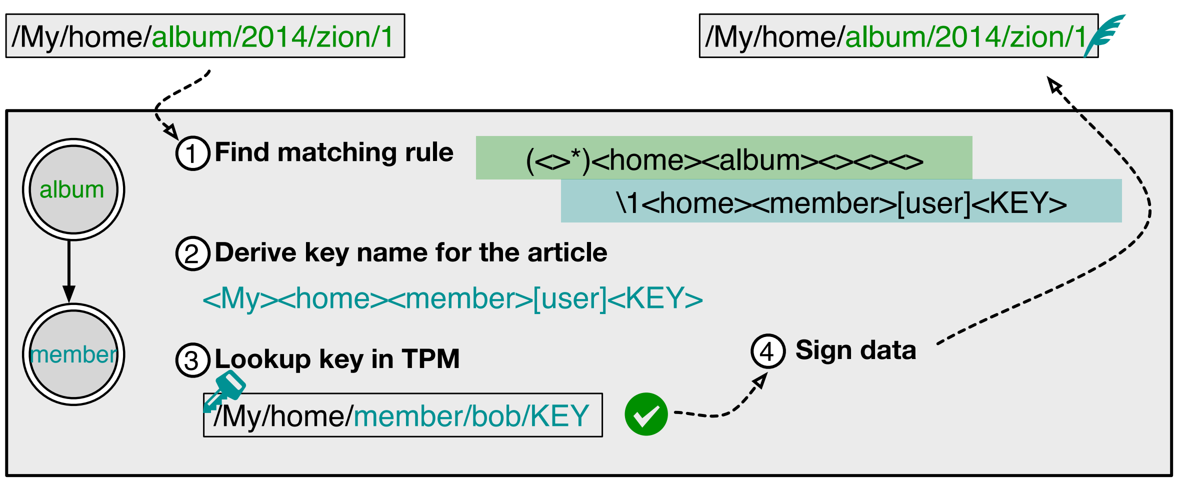
Rule ID	Data Name	Key Name
msg	(<>*)<home><msg>([user])<>	\1<home><member>\2<KEY>
album	(<>*)<home><album><><><>	\1<home><member>[user]<KEY>
temp	(<>*)<home><temperature><><><><><>	\1<home><temperature><KEY>
member	(<>*)<home><member>([user])<KEY>	\1<home><KEY>
therm	(<>*)<home><temperature><KEY>	\1<home><KEY>
root	(<>*)<home><KEY>	/Other/home/KEY 9c:45:30:b4:82:…



Automated Signing

- Signing Interpreter
- Determine signing key
- Request certificate if needed





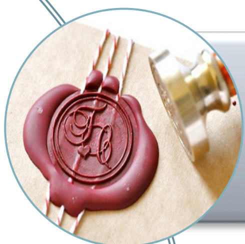
Implementation

- Available in all the NDN platform libraries
  - ndn-cxx: http://www.github.com/named-data/ndn-cxx
  - NDN-CCL: http://named-data.net/codebase/platform/ndn-ccl/
- Powers data and interest authentication in:
  - NFD: NDN Forwarding
  - NLSR: NDN Link State Routing Protocol
  - NDNS: NDN Domain Name System
  - Repo-ng: NDN Data Repository
  - ChronoChat: server-less multi-party chat application over NDN

Summary

- Trust schema is a **general expression** of NDN trust model
  - can be executed by any entity
- Trust schema is in **text format**
  - can be distributed as data packets
- A trust schema represents a **security design pattern**
  - regulate the behavior of applications
  - a set of common trust schemas

Outline



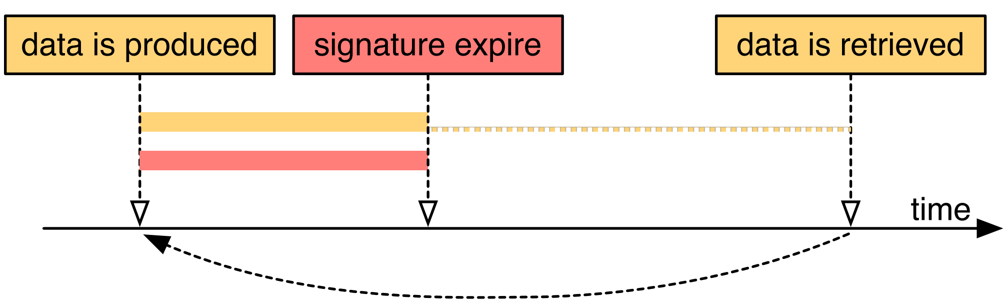
Automating Data-Centric Authenticity

Authenticating Long-Lived Data

Automating Data-Centric Confidentiality

Lifetime Mismatch

- Data lifetime is usually longer than its signature
  - crypto algorithm, key compromise, …
- Periodical re-signing is not the solution
  - will not scale in long term
  - data may outlive its producer
  - not a problem in channel based security
- After fact validation
  - verify signature validity at the time of production

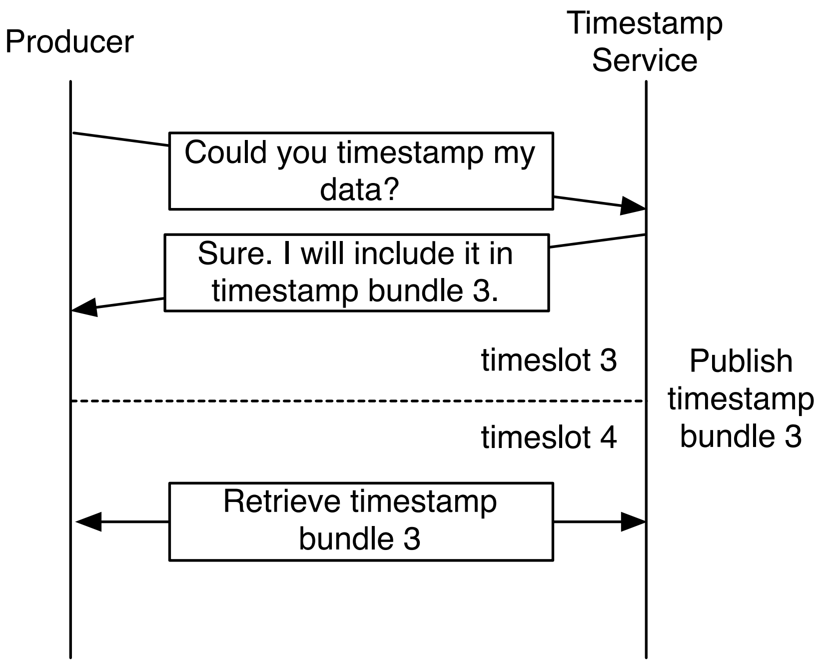


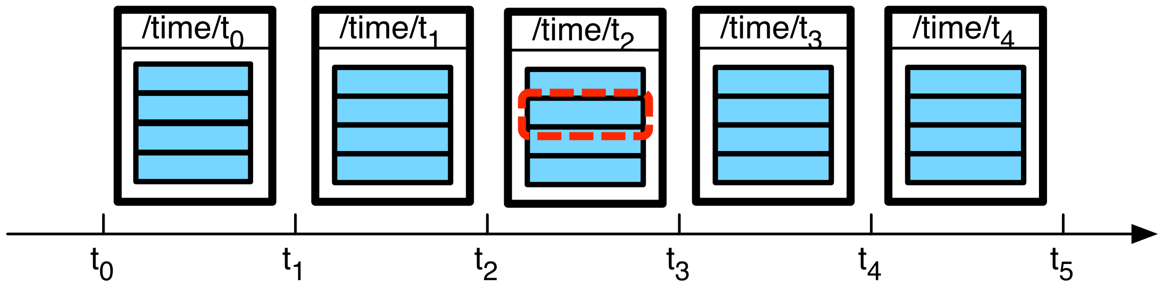
How to rollback the clock?

- Timestamp service
  - producer requests timestamp of data from the service
  - provide existence proof of data at a given time point
- Design challenges
  - how to tell the timestamp service is honest?
  - scale with the number of timestamp records

Verifiable timestamp

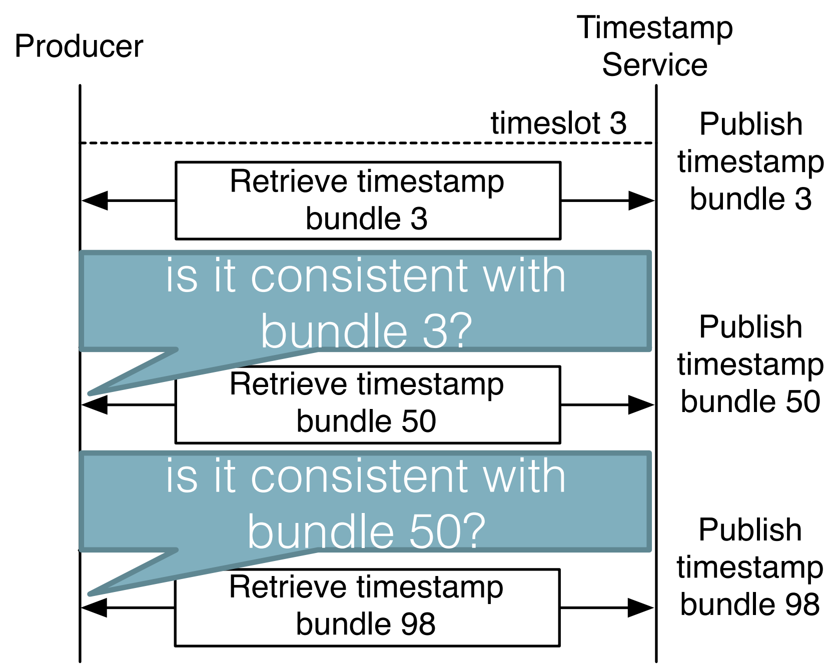
- Timestamp service periodically publishes a timestamp bundle
  - containing data received during the time period
- Producer requests including its data in a bundle
- Existence verification
  - check whether data is in the corresponding bundle

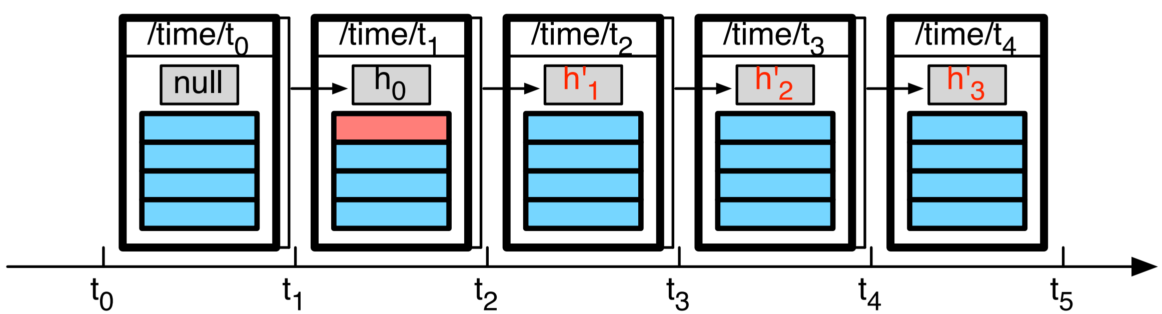




Consistent timestamp

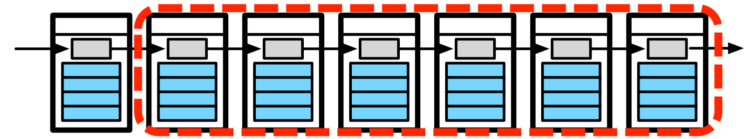
- Consistence verification
  - check whether the timestamp service modified the history
- A naïve solution: hash chain
  - each timestamp bundle fixes all the previous timestamp bundles
  - consumers and producers can verify consistency periodically





Reduce verification overhead

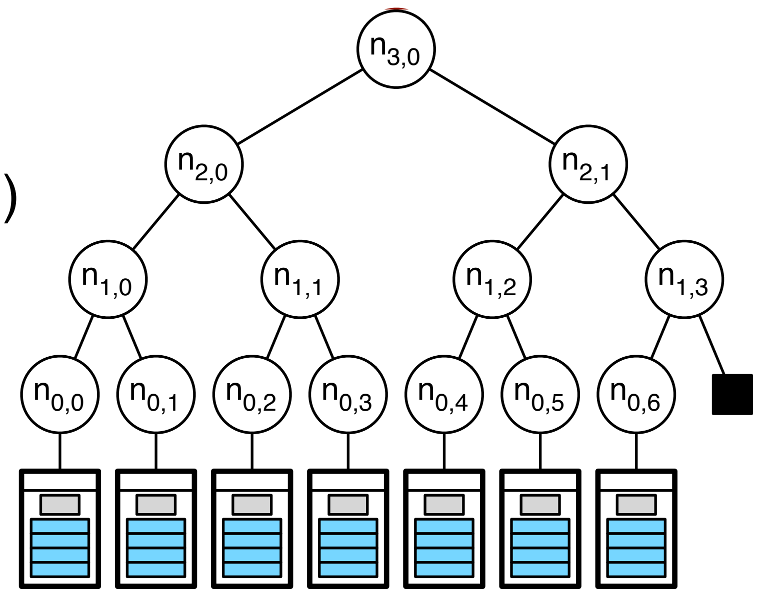
- Hash chain: O(m)
  - m: number of timeslots
  - 10-min timeslots for 20 years: 10^6



- k-ary Merkle tree:

  $$h_{i,n} = H(h_{i-1,nk^i} | h_{i-1,nk^i+1} | \ldots | h_{i-1,nk^i+k-1})$$

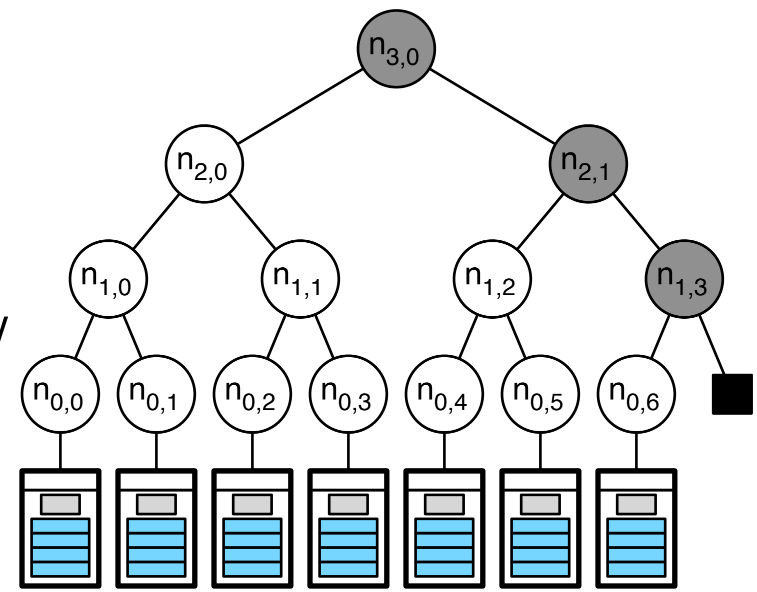
  - root hash as the state
  - existence verification:
    - $O(\log_k m)$
  - consistence verification:
    - $O(\log_k m)$
  - 20 years timestamps
    - 4 hash computations for 32-ary Merkle tree



Verification proof as data

- Proof is a pre-determined node set
  - simply publishes each node as data
  - consumer look up nodes necessary for verification

- Update nodes after adding a new timestamp bundle
  - complete nodes are not changed
  - at most one incomplete node at each layer



Node data

- Naming convention
  - uniquely identify a node in a particular state

/[tree_prefix]/[completeness]/[layer]/[index]/[hash]

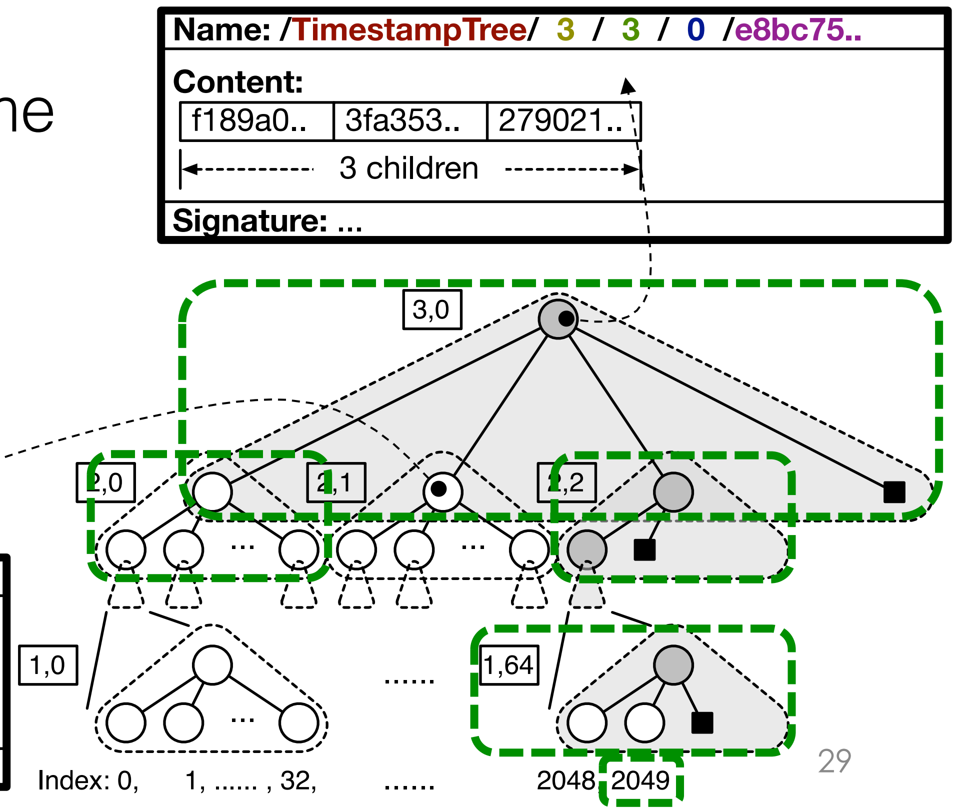
- Given a time point, the name of any node is determined

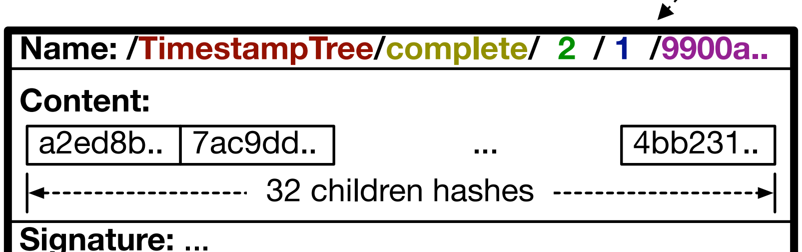
/TimestampTree/2050/1/64

/TimestampTree/complete/2/0

/TimestampTree/2050/2/2

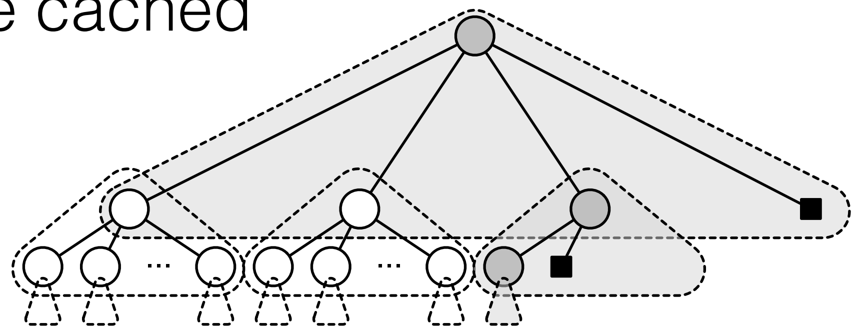
/TimestampTree/2050/3/0



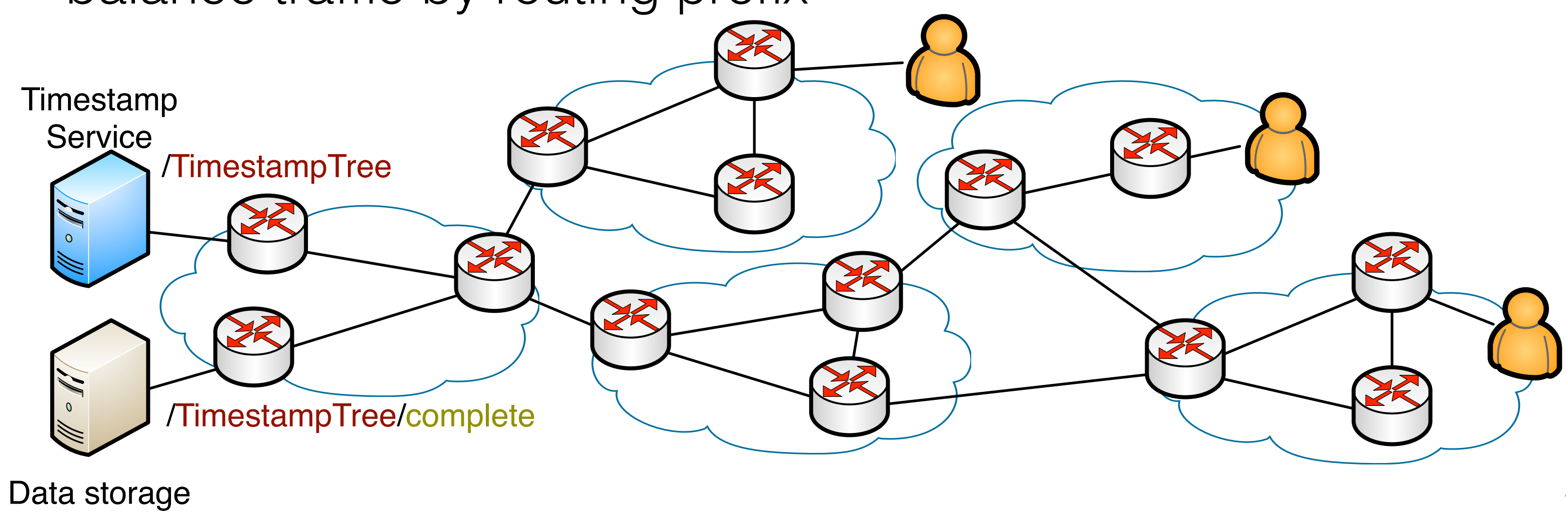


Node retrieval

- Nodes at higher layers are cached
  - more frequently retrieved
  - root node cached almost everywhere

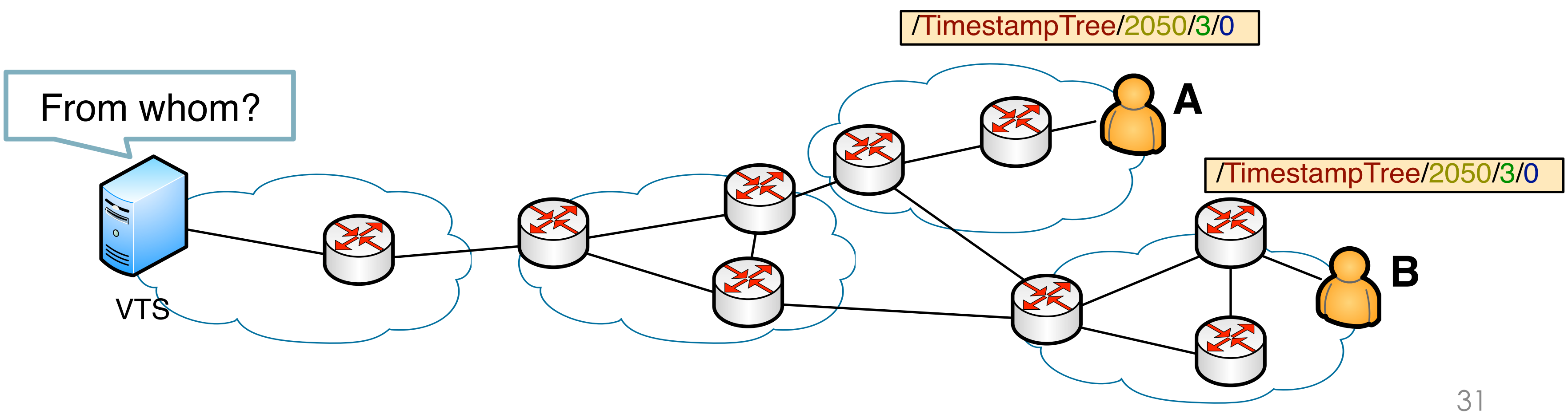


- Complete nodes can be served by dummy storage
  - balance traffic by routing prefix



Public auditing with Merkle tree

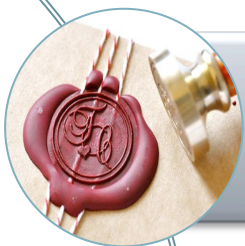
- All the users verify the consistence of timestamp service
  - occasionally retrieves the root
  - the more users, the more secure
    - single timestamp service for all the users
- Difficult to create double history
  - NDN interest does not carry sender address
  - Interest may not reach timestamp service (satisfied by cache)



Summary

- After fact validation is an authentication model for **non-instantaneous** communication
  - decouple the lifetime of data and signature
  - encourage the use of short-lived key
- **Untrustworthy** but **verifiable** timestamp service in NDN
  - borrow the concept public auditing concept from Certificate Transparency
  - publishing Merkle-tree as data simplifies verification query processing
  - absence of source address and efficient data distribution facilitates public auditing

Outline



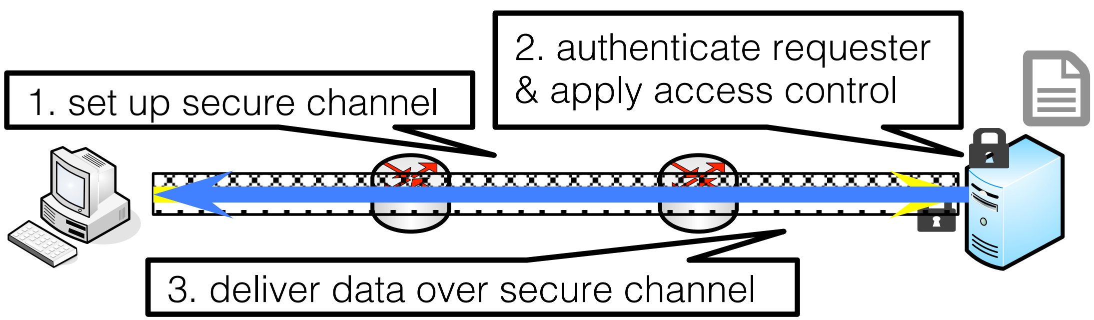
Automating Data-Centric Authenticity

Authenticating Long-Lived Data

Automating Data-Centric Confidentiality

Data confidentiality

- Current practice: perimeter-based security
  - data stays in trusted container
  - pass data to authorized users through an end-to-end secure channel
- Can we support data owner controlled confidentiality without trusted container and secured end-to-end channel?

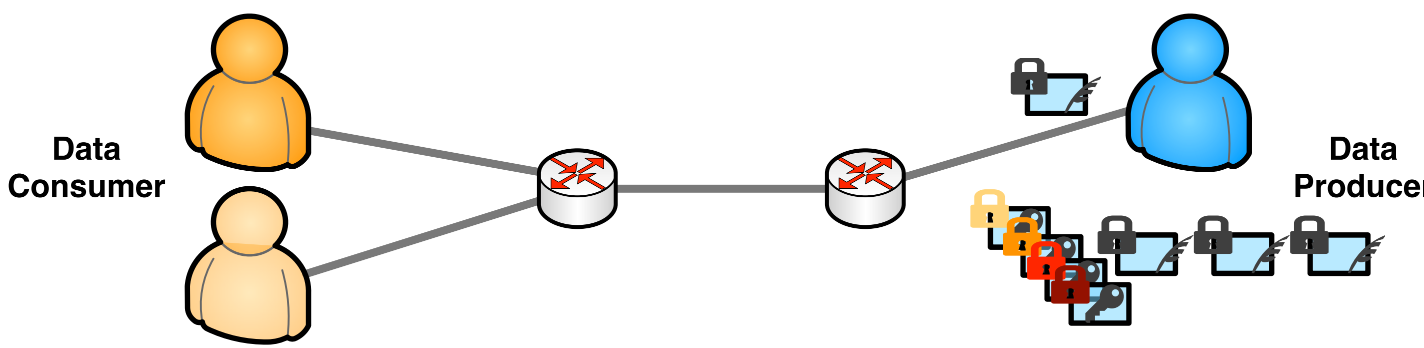


Data-centric confidentiality

- Encrypt data at the time of production
- Distribute decryption keys to authorized consumers
- Design challenges

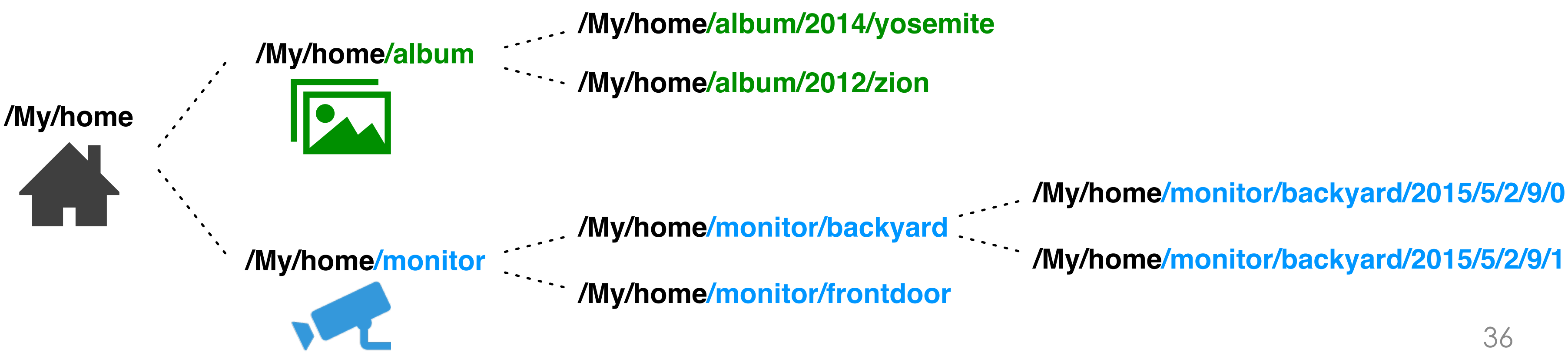
Specify privilege using hierarchical name
Publish encryption instruction as named keys

  - How to distribute decryption keys efficiently?



Distributed production & Dynamic sharing

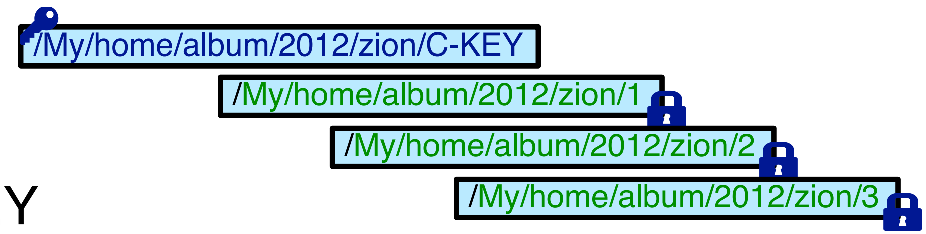
- Shared album in SmartHome
  - members produce photos at different sites in different years
  - shared with relatives later
    - no pre-knowledge about whom the photos will be shared with
- House surveillance video
  - produced by cameras in different rooms
  - allow security personel to watch the video when nobody at home
    - no pre-knowledge when family is out



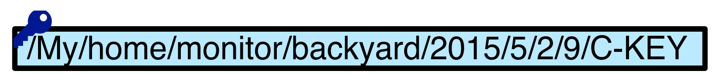
Content key

- Data is encrypted using a content key (C-KEY)
  - symmetric key
  - generated by producer

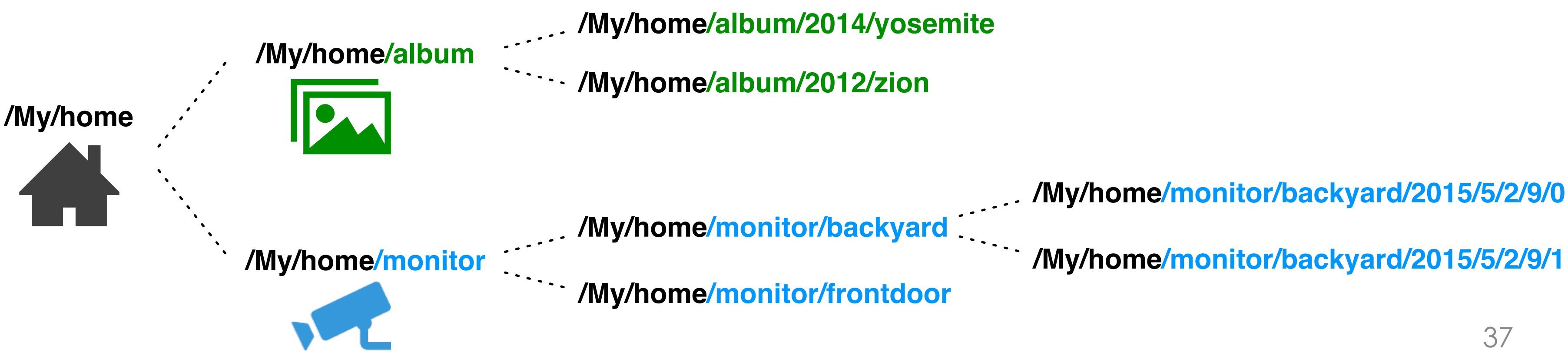
  /[content_namespace]/C-KEY



- Minimal access granularity
  - encrypt data under the namespace



- Distributed to authorized consumers eventually



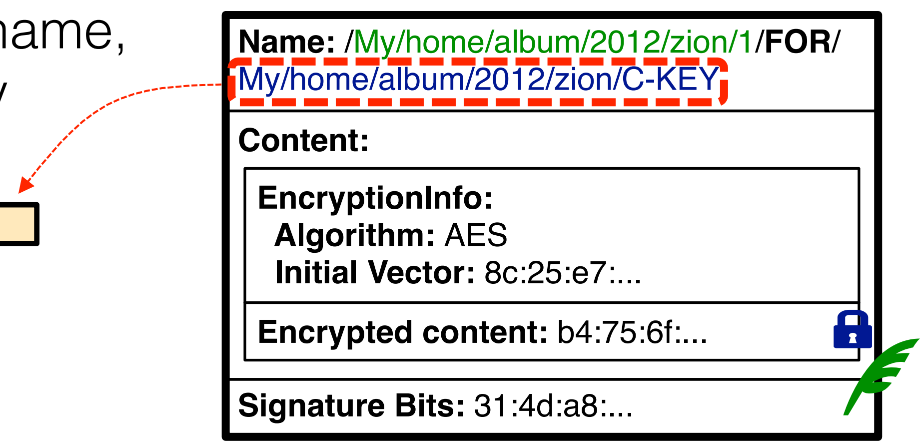
Encrypted data

- A data packet with encrypted content
  - encryption metadata
  - encrypted content

- Encryption key name is encoded in data name

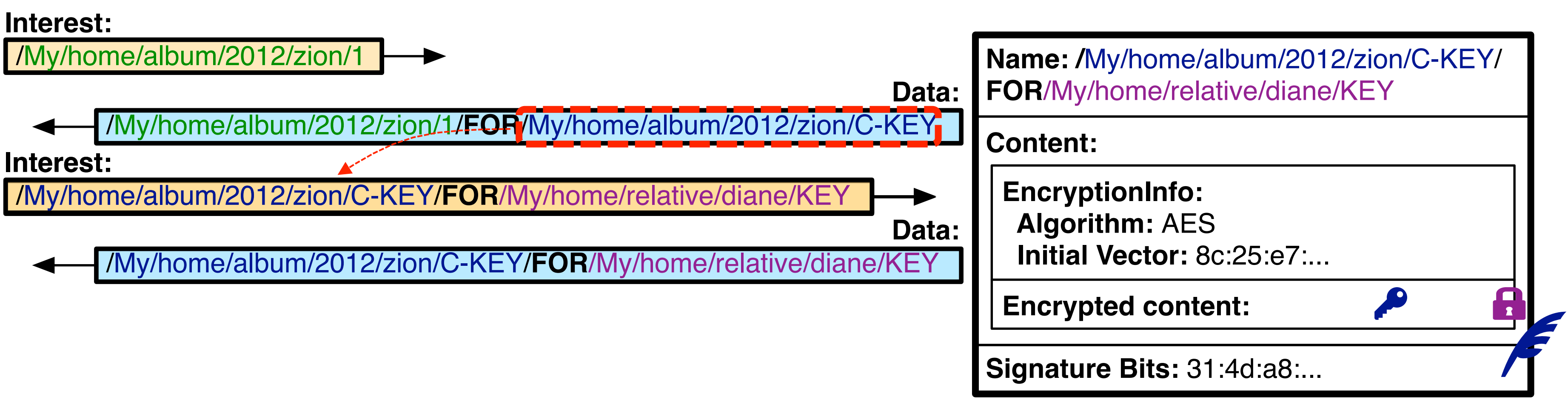
  /[content_name]/FOR/[encrypt_key_name]

  - different keys lead to different copies of encrypted data
  - follow encryption key name, retrieve decryption key



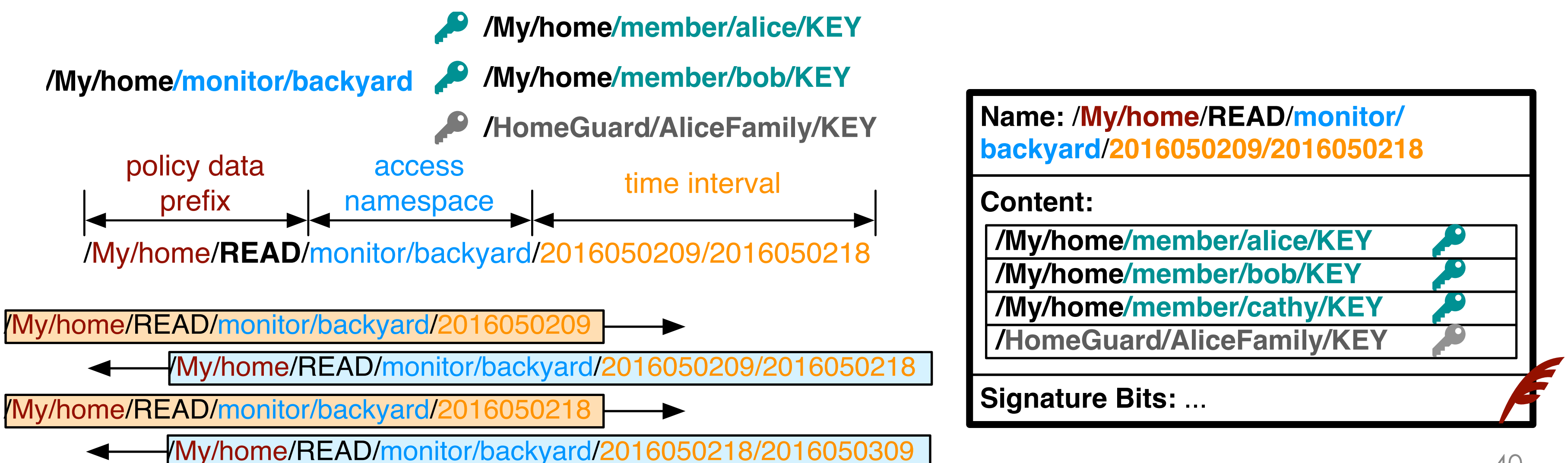
Content key distribution

- Distribute content key as encrypted data
  - encrypted using authorized consumer's public key
  - producer can publish the encrypted content key later
  - consumer can construct a decryption chain following the names



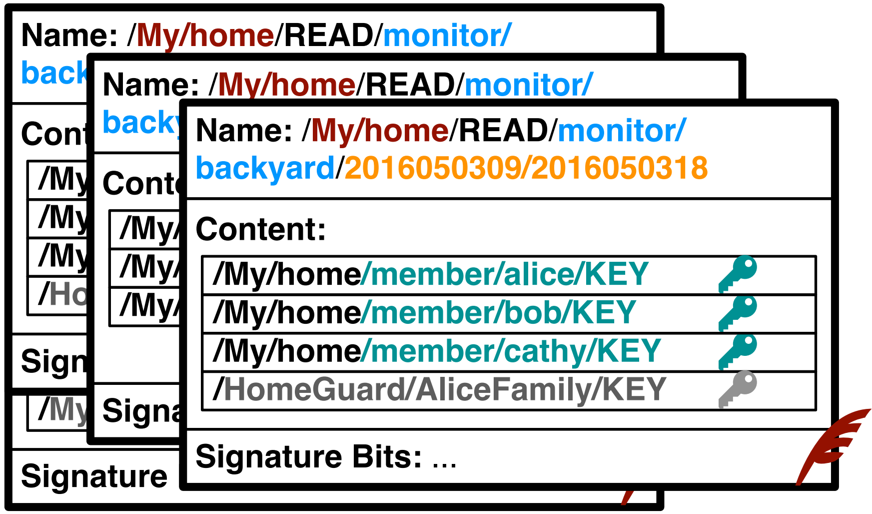
Access control policy distribution

- Some producers require updated access control policy
  - surveillance camera
- Access control policy
  - a list of (namespace, authorized consumer key set)
- Namespace owner publishes access control policy
  - producer retrieves the latest policy

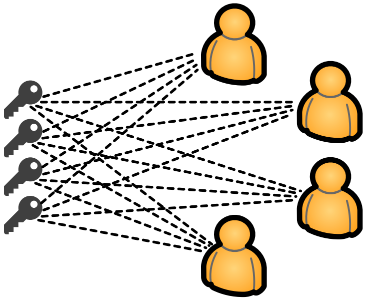


Scalability issues

- Policy retrieval overhead
  - large data packet for popular namespace
  - redundant key retrieval



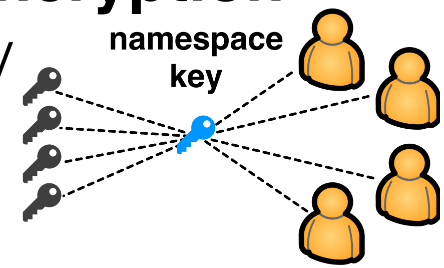
- Key encryption overhead
  - a large number of content key
  - an encrypted copy of content key for each authorized consumer
  - numbers of encrypted copies of content keys: O(mn)
    - m: number of authorized consumers
    - n: number of content keys

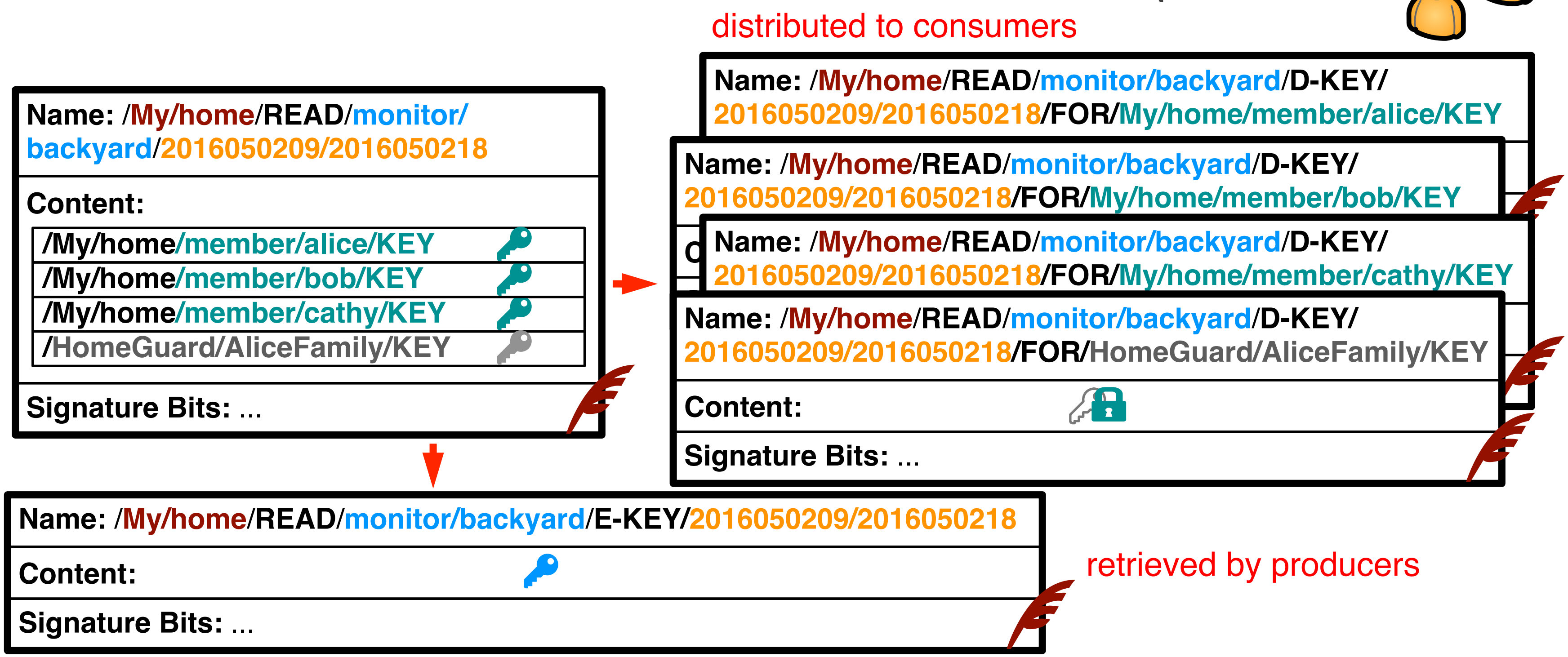


Does a producer have to know all the authorized consumers?

Namespace encryption key

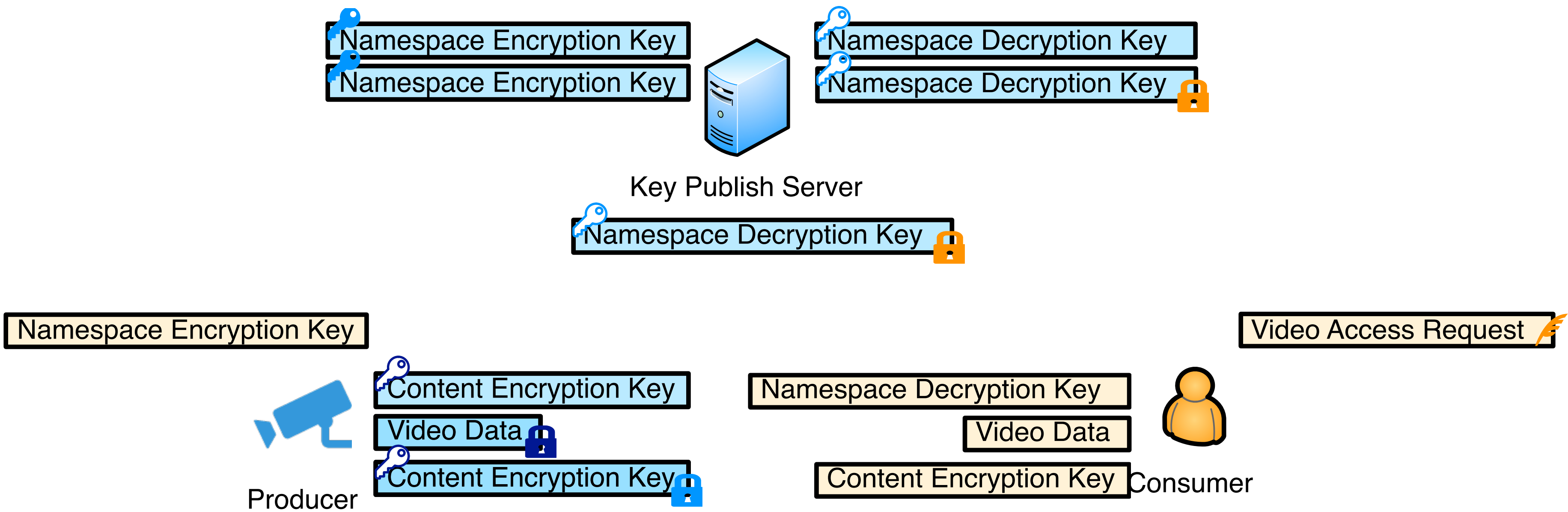
- Namespace owner publish **namespace encryption keys** instead of namespace access policy
- Number of encrypted copies: O(m+n)





Automate granting access

- Namespace owner can run a key publishing server to automate data encryption
  - validate consumer's access request using trust schema
  - generate namespace decryption key for requesting consumer



Implementation

- Available in all the NDN platform libraries
  - ndn-group-encrypt:
    - http://github.com/named-data/ndn-group-encrypt/
  - NDN-CCL
    - http://named-data.net/codebase/platform/ndn-ccl/
- Powers data access control in:
  - NDNfit: health data sharing over NDN
  - EBAMS: building management system over NDN

Summary

- Data-centric confidentiality is a **decryption key distribution** problem
  - control access by publishing encryption/decryption keys
- Key name specifies access at **fine granularity**
  - automate data encryption
- Indirected encryption enables **scalable** key distribution

Conclusion

- Data-centric security model enables flexible data communication model
  - reduced dependency on the data containers and channels
- Usability is critical to any security solution
  - developers need high-level abstraction
  - automation minimizes developer's workload
- Expressive names enables usable security in NDN
  - provide sufficient context and fine granularity for least privilege
  - naming pattern can represent flexible trust models and automate authentication & encryption

Future work

- Trust schema bootstrapping
- Robust timestamp service
  - multiple instances
  - failure recovery
- Enable name confidentiality

List of publications

- Journal and conference papers
    - Y. Yu, A. Afanasyev, D. Clark, kc claffy, V. Jacobson, and L. Zhang, "Schematizing Trust in Named Data Networking," Proc. of ACM ICN, 2015.
    - A. Afanasyev, Z. Zhu, Y. Yu, L. Wang, and L. Zhang, "The Story of ChronoShare, or How NDN Brought Distributed Secure File Sharing Back," in Proc. of IEEE MASS, 2015.
    - Y. Yu, D. Wessels, M. Larson, and L. Zhang, "Check-R: A New Method of Measuring DNSSEC Validating Resolvers," in Proc. of IEEE TMA Workshop, 2013.
    - Y. Yu, D. Wessels, M. Larson, and L. Zhang, "Authoritative Name Server Selection of DNS Caching Resolvers," in ACM Computer Communication Reviews, 2012.
- Technical reports
    - W. Shang, Y. Yu, R. Droms, and L. Zhang, "Challenges in IoT Networking via TCP/IP Architecture," Technical Report NDN-0038, 2016.
    - V. Lehman, A. Hoque, Y. Yu, L. Wang, B. Zhang, and L. Zhang, "A Secure Link State Routing Protocol for NDN", Technical Report NDN-0037, 2016.
    - W. Shang, Y. Yu, T. Liang, B. Zhang, and L. Zhang "NDN-ACE: Access Control for Constrained Environments over Named Data Networking", NDN, Technical Report NDN-0036, 2015
    - Y. Yu, A. Afanasyev, and L. Zhang "Name-Based Access Control", Technical Report NDN-0034, 2015
    - Y. Yu "Public Key Management in Named Data Networking", Technical Report NDN-0029, 2015
    - Y. Yu, A. Afanasyev, Z. Zhu, and L. Zhang "An Endorsement-based Key Management System for Decentralized NDN Chat Application", Technical Report NDN- 0023, 2014
    - Y. Yu, J. Cai, E. Osterweil, and L. Zhang "Measuring the Placement of DNS Servers in Top-Level-Domain" Technical Report, May. 2011

Special Thanks To Collaborators


Lixia Zhang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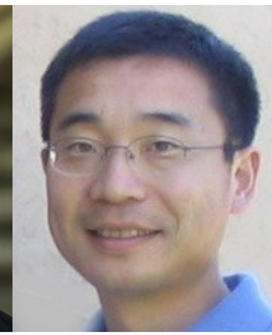
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Lan Wang


David Clark


kc claffy


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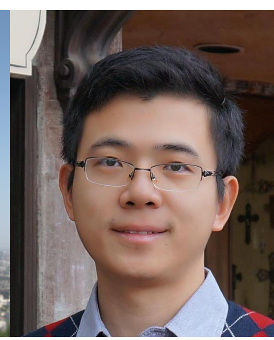
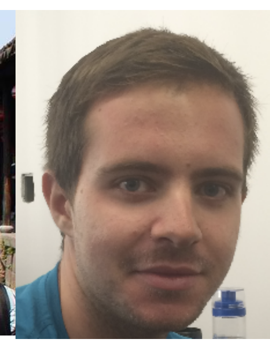

Wentao Shang


Haitao Zhang


Spyridon Mastorakis

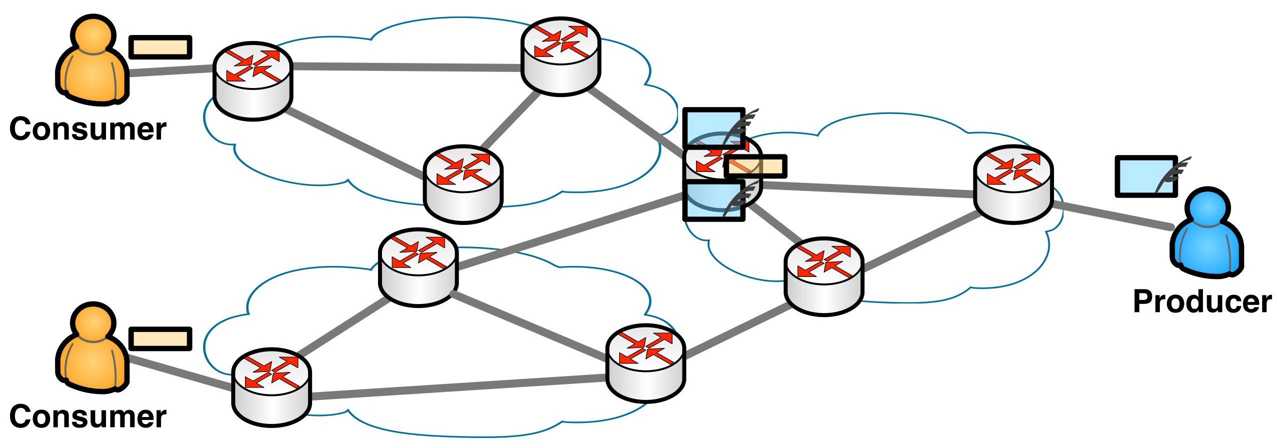

Qiuhan Ding


Prashanth Swami

End

NDN Overview

- Native multicast
  - Interest for the same data can be merged



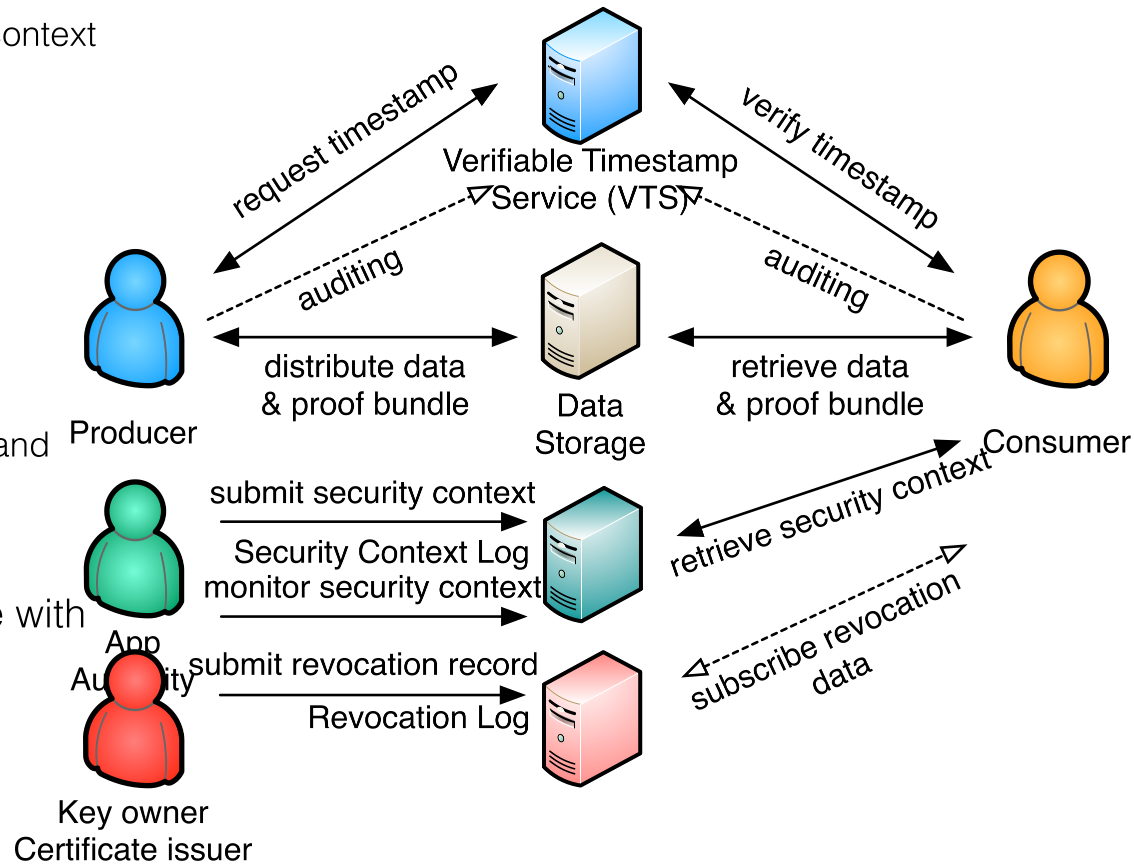
Data-centric security & NDN

- Named Data Networking (NDN)
  - data-centric communication primitives
  - retrieve data by name rather by host

- NDN enables data-centric security
  - per-packet signature
  - hierarchical naming
    - security context
    - least privilege
  - efficient key distribution

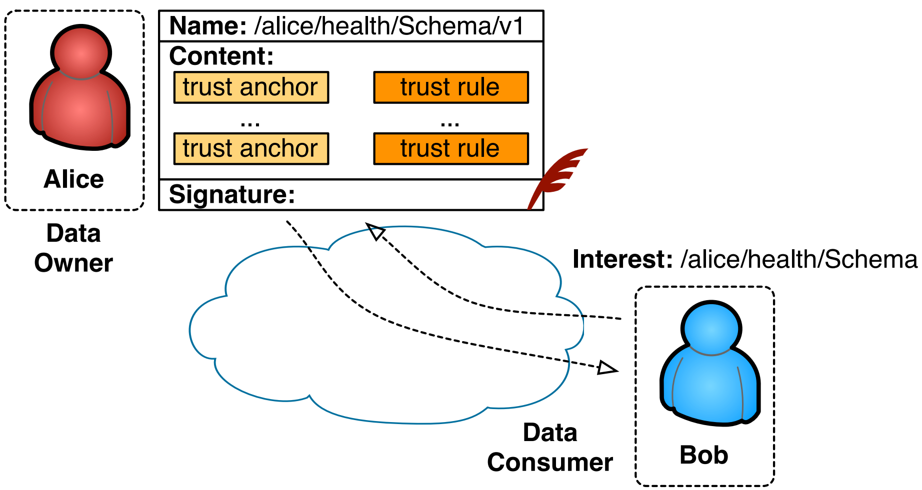
SigLogger Overview

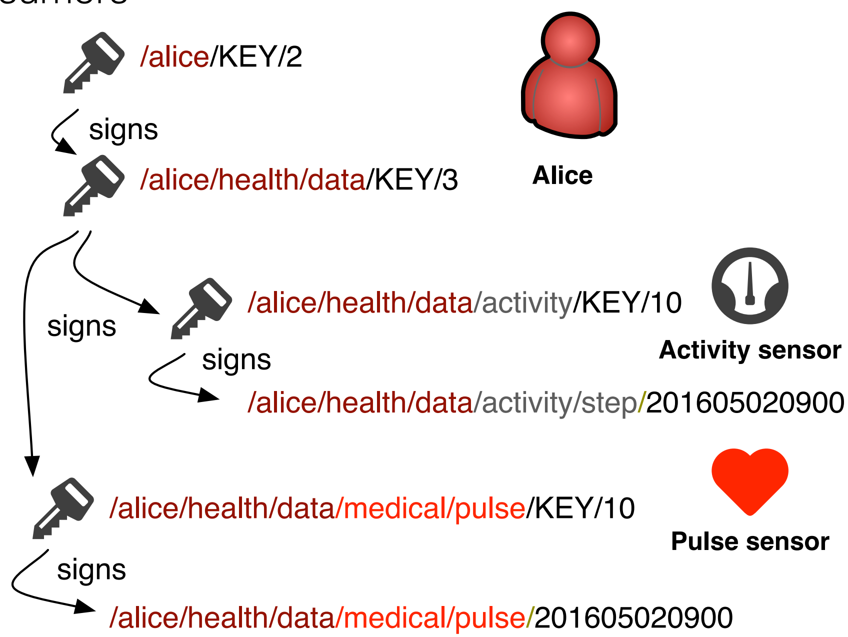
- Security Context Log
  - record security context over the time
    - trust schema
  - assure only one valid version of context at any time point
  - secure through publicity
- Revocation Log
  - record revocation over the time
  - promptly distribute revocation information to consumers
- Verifiable Timestamp Service
  - provide existence proof of data (and keys)
  - untrustworthy but auditable
- Producer distributes proof bundle with data
  - timestamp of data
  - intermediate keys
  - timestamp of keys



Signing-based write access

- Key name represents capability
  - capable of producing data under a namespace
  - capable of delegating the write access of a sub-namespace to others
  - signing key hierarchy
- Express write access control policy as trust schema
- Distribute trust schema as data
  - published by data owner retrieved by consumers





Append-only timestamp service

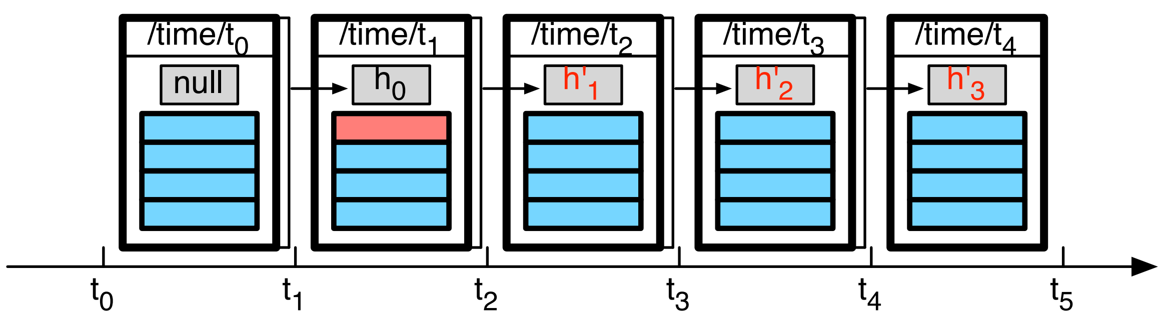
- Chaining timestamp data by hash
  - each timestamp data fixes all the previous timestamp bundle

$$h_k = H(TB_k|h_{k-1})$$

- Consistence verification

No way to know whether the timestamp service is honest about $[t_i,t_j)$

  - any modification before t_i will be detected

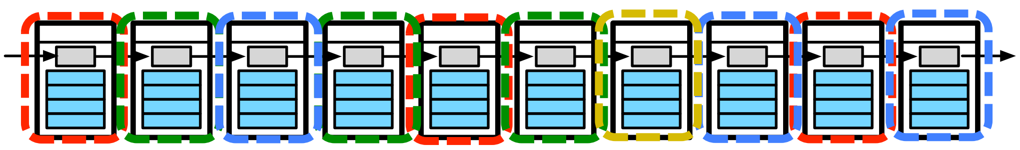


Public auditing

- Easy to catch misbehavior if
  - the consistency of each timestamp bundle is checked by at least one consumer

- Each consumer verifies consistence occasionally
- A lot of consumers collectively audit the single timestamp service

- How to minimize verification overhead



Use Case Example

- Alice obtains a timestamp for her thesis
  - also for keys if not timestampped
  - distribute data with keys and timestamps
- Bob verifies the existence of keys using timestamp
  - verifies data using keys