Usable Security of Named Data Networking

Yingdi Yu
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
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
- Constrained by trust derivation rules
  - Is data (or key) signed by a trusted producer (or issuer)?
- Validate signature

Trust Model

Data packet (target)
- Name: /ucla/cs/yingdi/thesis/v_3/s_8
- Content: ...
- Signature: KeyLocator: /ucla/cs/yingdi/KEY/2

Data packet (key)
- Name: /ucla/cs/KEY/7
- Content: ...
- Signature: KeyLocator: /ucla/KEY/5

Trust Anchor
- /ucla/KEY/5

Data packet (key)
- Name: /ucla/cs/yingdi/KEY/2
- Content: ...
- Signature: KeyLocator: /ucla/cs/KEY/7
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

• Data authentication can be done correctly and easily if we have
  • a name-based policy language to express trust model
  • a library to perform authentication according to the policy

Schematize the trust
Automate data authentication
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”

• Regex-based syntax

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

/My/home/msg/frank/13
/My/home/msg/bob/13
/My/home/member/bob/KEY

family member
Trust schema

<table>
<thead>
<tr>
<th>Rule ID</th>
<th>Data Name</th>
<th>Key Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>msg</td>
<td>(&lt;&gt;*)(home&gt;&lt;msg&gt;([user])&lt;&gt;</td>
<td>\1&lt;home&gt;&lt;member&gt;\2&lt;KEY&gt;</td>
</tr>
<tr>
<td>album</td>
<td>(&lt;&gt;*)(home&gt;&lt;album&gt;&lt;&gt;&lt;&gt;&lt;&gt;</td>
<td>\1&lt;home&gt;&lt;member&gt;[user]&lt;KEY&gt;</td>
</tr>
<tr>
<td>temp</td>
<td>(&lt;&gt;*)(home&gt;&lt;temperature&gt;&lt;&gt;&lt;&gt;&lt;&gt;&lt;&gt;</td>
<td>\1&lt;home&gt;&lt;temperature&gt;&lt;KEY&gt;</td>
</tr>
<tr>
<td>member</td>
<td>(&lt;&gt;*)(home&gt;&lt;member&gt;([user])&lt;&gt;</td>
<td>\1&lt;home&gt;&lt;KEY&gt;</td>
</tr>
<tr>
<td>therm</td>
<td>(&lt;&gt;*)(home&gt;&lt;temperature&gt;&lt;KEY&gt;</td>
<td>\1&lt;home&gt;&lt;KEY&gt;</td>
</tr>
<tr>
<td>root</td>
<td>(&lt;&gt;*)(home&gt;&lt;KEY&gt;</td>
<td>/My/home/KEY 30:b4:82:9c:45:…</td>
</tr>
</tbody>
</table>

Diagram:
- /My/Home
- /My/home/temperature
- /My/home/temperature/2016/5/2/15/30
- /My/home/temperature/KEY
- /My/home/album
- /My/home/album/2015/yosemite/2
- /My/home/album/2015/yosemite/2
- /My/home/member/bob/KEY
- /My/home/msg
- /My/home/msg/bob/13

Icons:
- signs
- thermometer
- family member
## Trust chain construction

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<td>&lt;KEY&gt;</td>
<td>/My/home/KEY 30:b4:82:9c:45:…</td>
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</table>

### Data packet (target)
- **Name**: /My/home/album/2015/yosemite/2
- **Content**: ...
- **Signature**: KeyLocator: /My/home/member/bob/KEY

### Data packet (key)
- **Name**: /My/home/member/bob/KEY
- **Content**: ...
- **Signature**: KeyLocator: /My/home/member/bob/KEY

### Data packet (key)
- **Name**: /My/home/member/bob/KEY
- **Content**: ...
- **Signature**: KeyLocator: /My/home/KEY

---

Trust Anchor: /My/home/KEY
## Re-usability

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</tr>
<tr>
<td>root</td>
<td>(&lt;&gt;*&lt;home&gt;&lt;KEY&gt;</td>
<td>/Other/home/KEY 9c:45:30:b4:82:</td>
</tr>
</tbody>
</table>
Automated Signing

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

Automated Certificate Issuance System

1. Find matching rule: 
   (*)<home><album>-----
   \1<home><member>[user]<KEY>

2. Derive key name for the article:
   <My><home><member>[user]<KEY>

3. Lookup key in TPM:
   /My/home/member/bob/KEY

4. Sign data:
   /My/home/album/2014/zion/1
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
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

![Diagram showing timestamp retrieval and verification process]
Reduce verification overhead

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

- **k-ary Merkle tree:**
  $h_{i,n} = \text{H}(h_{i-1,n,k^i}, h_{i-1,n,k^i+1}, \ldots, h_{i-1,n,k^i+k-1})$
  - 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

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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?

1. set up secure channel
2. authenticate requester & apply access control
3. deliver data over secure channel

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Data-centric confidentiality

- Encrypt data at the time of production
- Distribute decryption keys to authorized consumers
- Design challenges
  - How does a producer learn the authorized consumers?
  - Changing authorized consumers
  - Distributed production
- How to distribute decryption keys efficiently?

Specify privilege using hierarchical name
Publish encryption instruction as named keys
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 personnel 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

**Interest:**
```
My/home/album/2012/zion/C-KEY/...
```

**Content:**
```
Name: /My/home/album/2012/zion/1/FOR/
My/home/album/2012/zion/C-KEY/

EncryptionInfo:
Algorithm: AES
Initial Vector: 8c:25:e7:...

Encrypted content: b4:75:6f:...

Signature Bits: 31:4d:a8:...
```
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

• Technical reports
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Alexander Afanasyev  Zhenkai Zhu  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 consistency 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 timestamped
  - distribute data with keys and timestamps
- Bob verifies the existence of keys using timestamp
  - verifies data using keys