The eXpressive Internet Architecture: From Architecture to Network

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Winlab FIA, May 14, 2012

How do you Improve on the Internet?

- The Internet has been tremendously successful
  - Has sustained tremendous growth
  - Supports very diverse set of applications and services
  - Integral part of our society and economy
- Lots of exciting research on how to improve Internet
  - Security, routing, wireless/mobile, management, ...
  - But Internet architecture constrains what can be modified
- Future Internet Architecture frees researchers to go beyond today’s IP architecture and infrastructure
  - Multi-phase, NSF-funded research program
  - Five teams building full scale networks

Predicting the Future is Hard!

- A lot of really smart people don’t agree:
  - Named Data Networking: content centric networking
    - data is a first class entity
  - Mobility First: mobility as the norm rather than the exception – generalizes delay tolerant networking
  - Nebula: Internet centered around cloud computing data centers that are well connected

We love all of them!

Outline

- Background
- XIA principles
- XIA architecture
- Building XIA
- Conclusion
XIA Vision

We envision a future Internet that:

- **Is trustworthy**
  - Security broadly defined is the biggest challenge
- **Supports long-term evolution of usage models**
  - Including host-host, content retrieval, services, ...
- **Supports long term technology evolution**
  - Not just for link technologies, but also for storage and computing capabilities in the network and end-points
- **Allows all actors to operate effectively**
  - Despite differences in roles, goals and incentives

Today’s Internet

- Client retrieves document from a specific web server
  - But client mostly cares about correctness of content, timeliness
  - Specific server, file name, etc. are not of interest
- **Transfer is between wrong principals**
  - What if the server fails?
  - Optimizing transfer using local caches is hard
    - Need to use application-specific overlay or transparent proxy – bad!

eXpressive Internet Architecture

- **Client expresses communication intent for content explicitly**
  - Network uses content identifier to retrieve content from appropriate location
- **How does client know the content is correct?**
  - Intrinsic security! Verify content using self-certifying id:
    - \( \text{hash(content)} = \text{content id} \)
- **How does source know it is talking to the right client?**
  - Intrinsic security! Self-certifying host identifiers

A Bit More Detail ...

- Flexible Trust Management
- Diverse Communicating Entities
- Intrinsic Security
- Hash( ) = CID?
Evolvable Set of Principals

- Identifying the intended communicating entities reduces complexity and overhead
  - No need to force all communication at a lower level (hosts), as in today’s Internet
- Allows the network to evolve

Security as Intrinsic as Possible

- Security properties are a direct result of the design of the system
  - Do not rely on correctness of external configurations, actions, data bases
  - Malicious actions can be easily identified

Other XIA Principles

- Narrow waist for all principals
  - Defines the API between the principals and the network protocol mechanisms
- Narrow waist for trust management
  - Ensure that the inputs to the intrinsically secure system match the trust assumptions and intentions of the user
  - Narrow waist allows leveraging diverse mechanisms for trust management: CAs, reputation, personal, ...
- All other network functions are explicit services
  - Keeps the architecture simple and easy to reason about
  - XIA provides a principal type for services (visible)

XIA: eXpressive Internet Architecture

- Each communication operation expresses the intent of the operation
  - Also: explicit trust management, APIs among actors
- XIA is a single inter-network in which all principals are connected
  - Not a collection of architectures implemented through, e.g., virtualization or overlays
  - Not based on a “preferred” principal (host or content), that has to support all communication

Look familiar?
What Applications Does XIA Support?

• Since XIA supports host-based communication, today’s applications continue to work
  – Will benefit from the intrinsic security properties
• New applications can express the right principal
  – Can also specify other principals (host based) as fallbacks
  – Content-centric applications
  – Explicit reliance on network services
  – Mobile users
  – As yet unknown usage models

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• Background
• XIA principles
• XIA architecture
  – Multiple principals
  – DAG-based addressing
  – Intrinsic security
• Building XIA
• Conclusion

What Do We Mean by Evolvability?

• Narrow waist of the Internet has allowed the network to evolve significantly
• But need to evolve the waist as well!
  – Can make the waist smarter

Multiple Principal Types

• Hosts XIDs support host-based communication similar to IP – who?
• Service XIDs allow the network to route to possibly replicated services – what does it do?
  – LAN services access, WAN replication, …
• Content XIDs allow network to retrieve content from “anywhere” – what is it?
  – Opportunistic caches, CDNs, …
• Autonomous domains allow scoping, hierarchy
• What are conditions for adding principal types?
Multiple Principal Types

Choice involves tradeoffs:
- Control
- Trust
- Efficiency
- Privacy

Supporting Evolvability

- Introduction of a new principal type will be incremental – no “flag day”!
  - Not all routers and ISPs will provide support from day one
- Creates chicken and egg problem - what comes first: network support or use in applications
- Solution is to provide an intent and fallback address
  - Intent address allows in-network optimizations based on user intent
  - Fallback address is guaranteed to be reachable

Addressing Requirements

- Fallback: intent that may not be globally understood must include a backwards compatible address
  - Incremental introduction of new XID types
- Scoping: support reachability for non-globally routable XID types or XIDs
  - Needed for scalability
  - Generalize scoping based on network identifiers
  - But we do not want to give up leveraging intent
- Iterative refinement: give each XID in the hierarchy option of using intent

Our Solution: DAG-Based Addressing

- Uses direct acyclic graph (DAG)
  - Nodes: typed IDs (XID; expressive identifier)
  - Outgoing edges: possible routing choices
- Simple example: Sending a packet to HID_5
  - Dummy source: special node indicating packet sender
  - Intent: final destination of packet with no outgoing edges
Support for Fallbacks with DAG

- A node can have **multiple outgoing edges**
- Outgoing edges have **priority** among them
  - Forwarding to HID is attempted if forwarding to CID is not possible
  - Realization of fallbacks

Support for Scoping with DAG

- Client side
- Server-side domain hierarchy

Iterative Refinement: Scoping while Maintaining Intent

- Client side
- Server-side domain hierarchy

DAG Addressing Research Questions

- DAG addressing supports is flexible ...
  - Fallback, binding, source routing, mobility, ..
- ... but many questions remain:
  - Is it expensive to process?
  - How big will the addresses be?
  - How do ISPs verify policy compliance?
  - Can they be used to attack network?
  - Can it be deployed incrementally?
**Intrinsic Security in XIA**

- XIA uses self-certifying identifiers that guarantee security properties for communication operation
  - Host ID is a hash of its public key – accountability (AIP)
  - Content ID is a hash of the content – correctness
  - Does not rely on external configurations
- Intrinsic security is specific to the principal type
- Example: retrieve content using ...
  - Content XID: content is correct
  - Service XID: the right service provided content
  - Host XID: content was delivered from right host

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**Example of Secure Mobile Service Access**

- Server S: HID$_{S}$ SID$_{buf}$
- Client C: HID$_{C}$ SID$_{C}$
- Name Resolution Service
- XIA Internet

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**Path Selection in SCION Architecture Overview**

- Source/destination can choose among up/down hill paths
- Path control shared between ISPs, receivers, senders
- Desirable security properties:
  - High availability, even in presence of malicious parties
  - Explicit trust for operations
  - Minimal TCB: limit number of entities that must be trusted
  - No single root of trust
  - Simplicity, efficiency, flexibility, and scalability

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**Distributed Control in XIA**

- Customers have more choices:
  - Choice of XID type, i.e. how is communication operation performed; involves different tradeoffs
  - DAGs add flexibility: fallback, services, ...
  - Scion offers some control over path selection
- Service providers have choices as well
  - Use of XID types to optimize new services
  - Scion allows new path optimization options
  - Use DAGs for binding, scoping, mobility, ...
- Provides opportunities for customizing interactions to context
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• Background
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  – Forwarding packets
  – Building a network
  – Prototype
• Conclusion

Putting Address into Packet Headers

XIP Packet Header

• DAGs represent source and destination addresses
• Array of nodes with pointers
• Maintains a LastNode field in the header
  – Routers to know where to begin forwarding lookups

Router’s View on Packet Forwarding

1. Forward to SID if possible
2. Otherwise, forward to AD
   • If router is AD itself, update last visited node to AD
Packet Processing Pipeline

- Principle-independent processing defines how to interpret the DAG
  - The core XIA architecture
- Principle-dependent processing realizes forwarding semantics for each XID type
- Optimizations possible: fast path processing, packet level and intra-packet parallelism

Evaluation Setup

- Router
- Packet generator

Software:
  - PacketShader I/O Engine
  - Click modular router – multithreaded (12 threads)

Hardware:
  - 10Gbit NIC: 4 ports (multi-queue support)
  - 2x 6 Core Intel Xeon @ 2.26GHz

Forwarding Performance Comparison

Fast Path Performance

XIP forwarding is fast!
@128 byte FB0 is 8% slower than IP
@192 byte FB3 is 26% slower than IP

Using fast-path processing, the gap between FB0 and FB3 is reduced significantly!
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XIP Protocol Stack

- Open source release of complete prototype this month
- Support for GENI and VM-based experiments

XIA Components and Interactions

Conclusion

- XIA supports evolution, expressiveness, and trustworthy operation.
  - Multiple principal types, flexible addressing, and intrinsic security
- But research has just started!
  - Transport protocols, applications, services, ...
  - Trustworthy protocols that fully utilizes intrinsic security of XIA
- More information on http://www.cs.cmu.edu/~xia