The eXpressive Internet Architecture: from Architecture to Network

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Outline

• XIA architecture concepts
  – Motivating example
• Building an XIA network
• Research directions

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!

• The Internet has been unbelievably 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
  – Five teams funded by NSF, including XIA
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: 
    hash(content) = 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?

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

Also keep many good features of Internet!
Interactions between Actors

Outline

- XIA architecture concepts
- Building an XIA network
  - Making it work
- Research directions

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
- Associated with different forwarding semantics
- Set of principal types can evolve over time

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

IP: Evolvability of:
  - Applications  
  - Link technologies

XIA adds evolvability at the waist:
  - Evolving set of principals  
  - Link technologies
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 informs network of 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
• Support for mobility, in-path services, ...
• Want to combine the above requirements

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 CID_5

Support for Fallbacks with DAG

• A node can have multiple outgoing edges
• Outgoing edges have priority among them
  – Forwarding to HID_5 is attempted if forwarding to CID_A is not possible – Realization of fallbacks
  – Helps routers deal with routing failures
**DAGs Support Scoping and Iterative Refinement**

- Client side
- Server-side domain hierarchy

raises many interesting questions!

**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

**Packet Processing Pipeline**

- Principle-independent processing defines how to interpret the DAG - core XIA architecture
- Principle-dependent processing realizes forwarding semantics for each XID type
- Implemented in Click – see NSDI 2012
- Optimizations possible: fast path processing, packet level and intra-packet parallelism

**Full XIA Prototype**

- Open source release: http://www.cs.cmu.edu/~xia
- Support for GENI and VM-based experiments
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
- Porting to XIA DP this summer

Outline

- XIA architecture concepts
- Building an XIA network
- Research directions
  - What is different?

Balance of Control between Network Core and Edge

- Internet places most control in the network
- XIA provides more control to the edge
  - Choice of principal, DAGs, Scion path selection
  - Also offers flexibility to service providers: control path properties, new services, ...
- Many research opportunities
  - Other mechanisms + other functions/layers
  - Customizing roles depending on context
  - How to manage the tradeoff at runtime

XIA Components and Interactions
Multiple Principal Types

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

Using DAGs

- DAG is “locator” that helps network reach “destination”
  - Provided by destination through a name service
  - Has the right incentive!
- DAG is created jointly by all parties involved
  - Source can modify destination DAG, pick from options, ...
  - DAG can be modified during session
  - Networks can limit what DAGs they accept
- Many other options exist
  - Path based options, locator services, different headers, ...

Example: Secure Mobile Service Access

Functionality in Network versus Edge

- Internet had notion that higher level functions were implemented at the edge
  - Currently lots of functionality in the network
- XIA addressing flexibility simplifies adding functions to the network
  - Services, new principal types
  - Does not require universal agreement (DAGs)
  - Example: supporting diversity at edge (Tapa)
- Many alternative solutions
  - Service-oriented architectures, active nets, ...
How Much and What Security in the Network

- XIA uses “intrinsic security” to guarantee some properties of communication operation
  - XIA: cryptographic identifiers, Scion paths
  - Several other projects are using cryptographic ids.
- Many alternatives to explore
  - Different types of cryptographic identifiers
  - Alternative approaches, evolving the mechanisms
  - Verifiability of network functions

What About the Users?

- Who are the users?
  - Human end-users, applications, or edge networks
- Trust management, naming
  - Hosts – DNS – nice and hierarchical
  - Services and content – different
    - Important: want to skip hosts
- User trust in network
  - Visibility + control
  - “Privacy button”

Conclusion

- XIA supports evolution, expressiveness, and trustworthy operation.
  - Multiple principal types, flexible addressing, and intrinsic security
  - More information (including on release)
    http://www.cs.cmu.edu/~xia
- Broad research agenda on key tradeoffs in network
  - Edge versus core, security in network, evolvability, ...
  - Affects all aspects of the network: transport protocols, trust management, applications, services, ...