The eXpressive Internet Architecture: From Architecture to Network

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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

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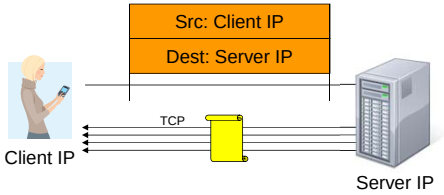
Today's Internet



- 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!

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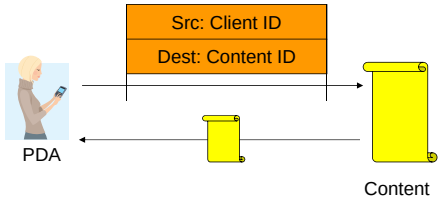
eXpressive Internet Architecture



- 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

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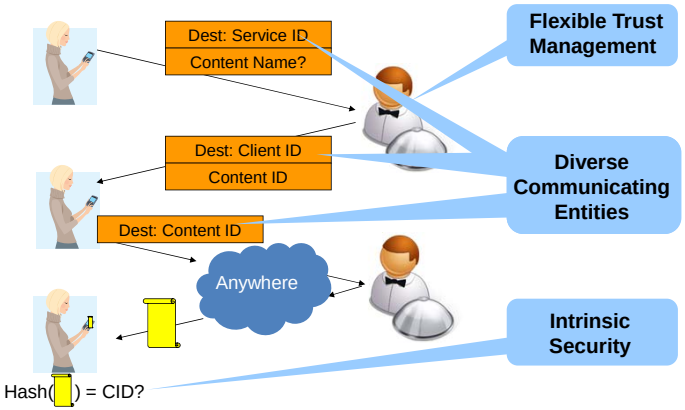
A Bit More Detail …



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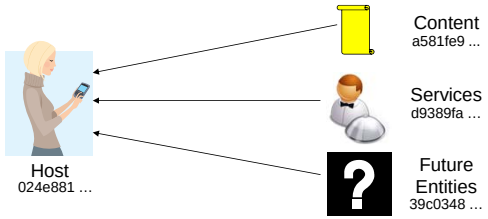
Evolvable Set of Principals

- 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*



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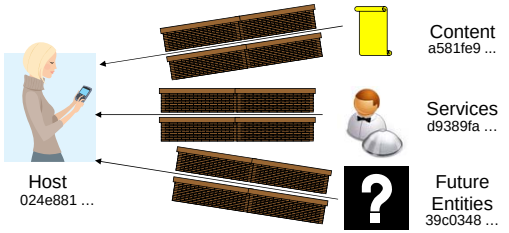
Security as Intrinsic as Possible

- 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



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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 intensions 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)

Look familiar?

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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

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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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Outline

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

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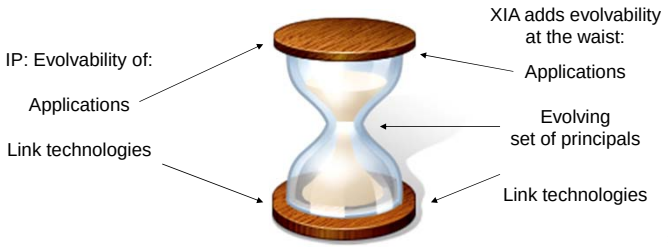
What Do We Mean by Evolvability?

- 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



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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?

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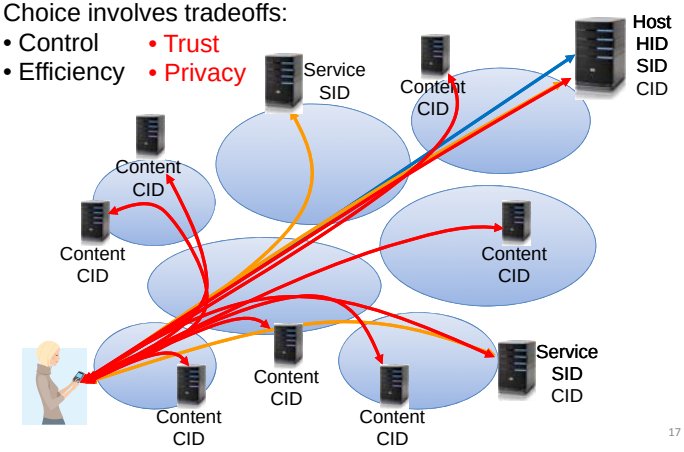
Multiple Principal Types

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



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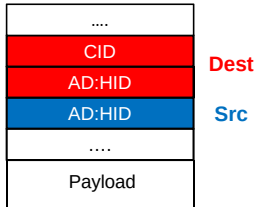
Supporting Evolvability

- 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



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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

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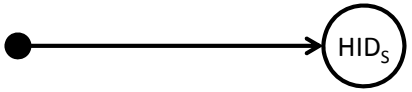
Our Solution: DAG-Based Addressing

- Uses direct acyclic graph (DAG)
  - Nodes: typed IDs (XID; expressive identifier)
  - Outgoing edges: possible routing choices
- Simple example: Sending a packet to HID_S



Dummy source: special node indicating packet sender

Intent: final destination of packet with no outgoing edges

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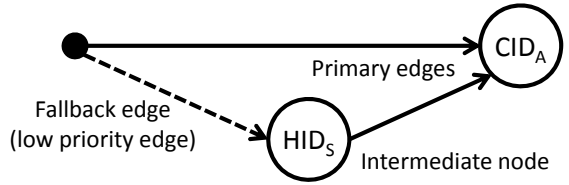
Support for Fallbacks with DAG

- A node can have multiple outgoing edges



- Outgoing edges have priority among them
  - Forwarding to HID$_S$ is attempted if forwarding to CID$_A$ is not possible – Realization of fallbacks

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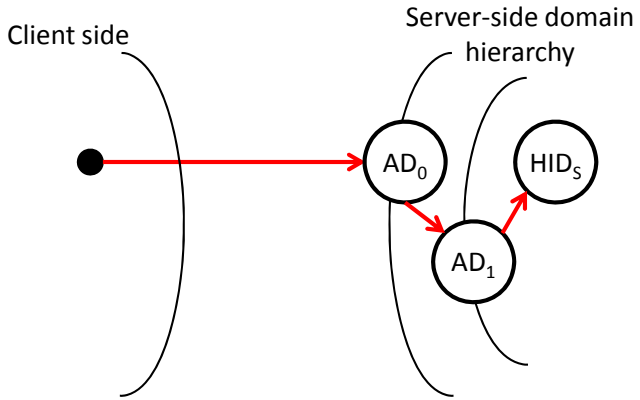
Support for Scoping with DAG



Support scalable routing, binding, migration, mobility, …

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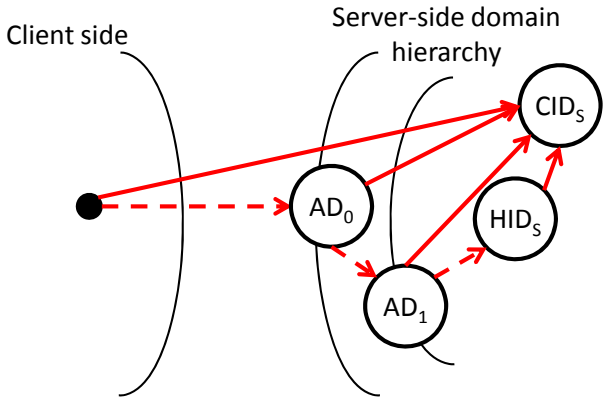
Iterative Refinement: Scoping while Maintaining Intent



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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?

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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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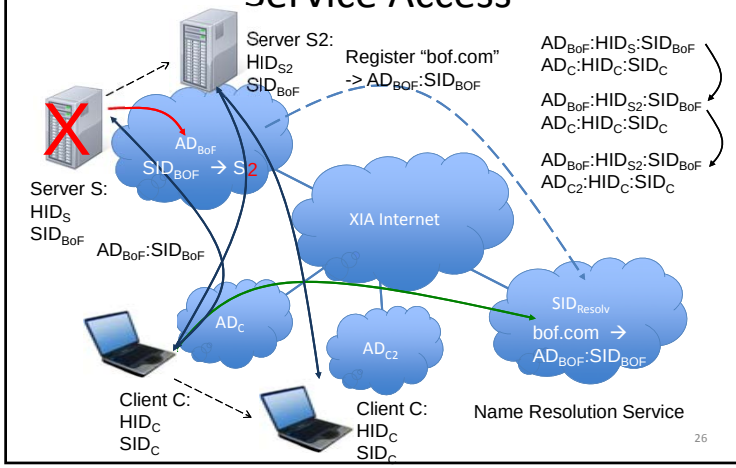
Example of Secure Mobile Service Access



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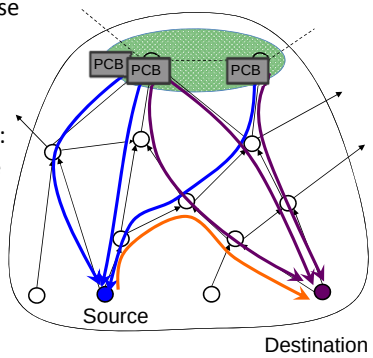
Path Selection in SCION Architecture Overview

- 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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Outline

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- XIA architecture
- Building XIA
  - Forwarding packets
  - Building a network
  - Prototype
- Conclusion

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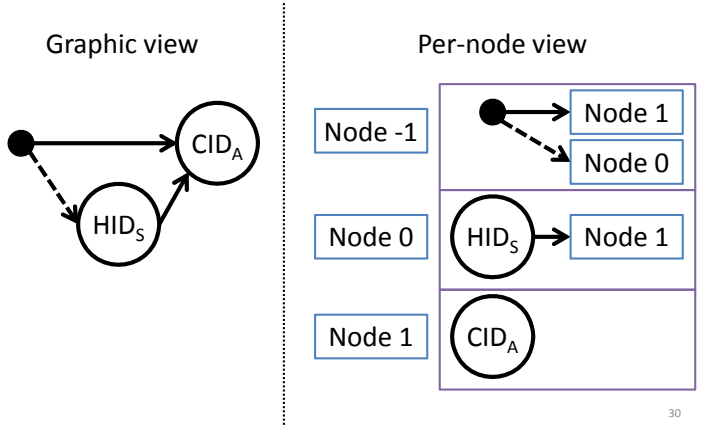
Putting Address into Packet Headers



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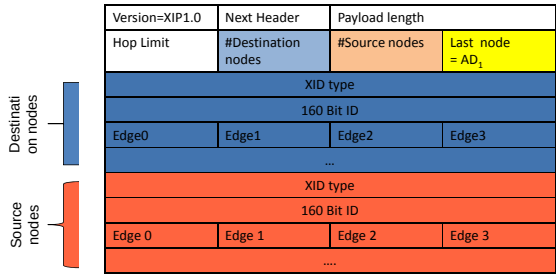
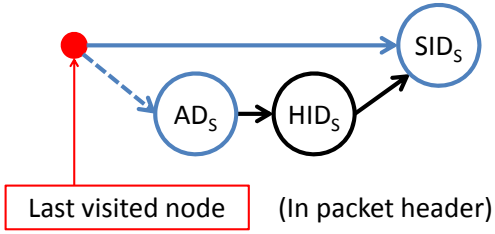
XIP Packet Header

- 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_S if possible
2. Otherwise, forward to AD_S
   - If router is AD_S itself, update last visited node to AD_S

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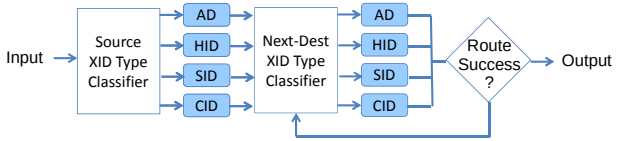
Packet Processing Pipeline



- 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

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Evaluation Setup

- Router
- Packet generator

Software:

PacketShader I/O Engine

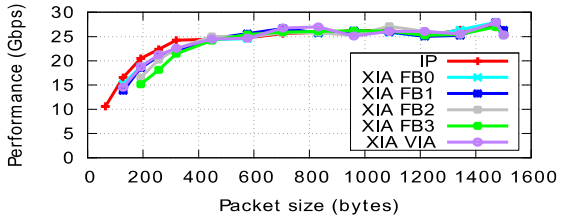
Click modular router – multithreaded(12 threads)

Hardware:

10Gbit NIC : 4 ports (multi-queue support)

2x 6 Core Intel Xeon @ 2.26GHz

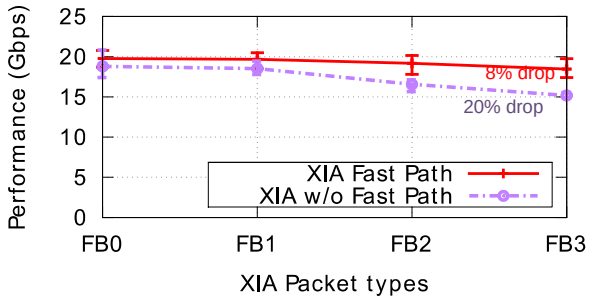
Forwarding Performance Comparison



351K FIB entries
Workload: Identifiers generated using Pareto distribution

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

Fast Path Performance



Look-aside cache of 1024 entries

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

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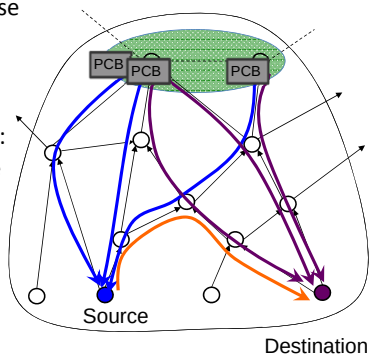

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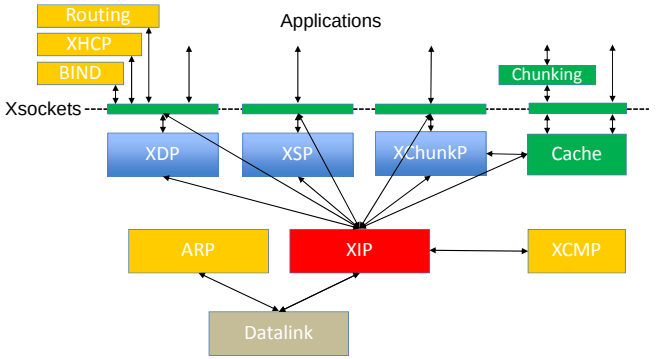
XIP Protocol Stack



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

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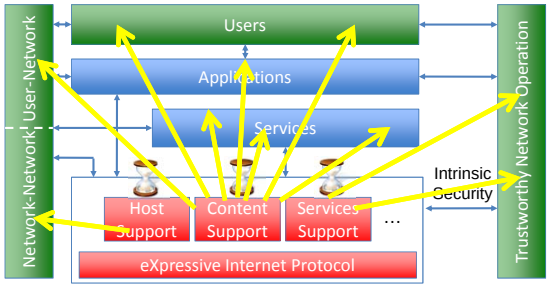
XIA Components and Interactions



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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