Anonymity on the Internet

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Outline

- Introduction
  - What is anonymity and why should I care?
- High-latency Designs
  - e-mail
- Low-latency Designs
  - www, ssh, irc, *etc.*
- Research Problems
  - Hard problems that still need to be solved

What is Anonymity?

Definition

Anonymity is the state of being not identifiable within a set of subjects, the anonymity set. – Pfitzmann and Hansen

Who Needs Anonymity?

Political Dissidents

- Bloggers in China and Iran
- Critical ex-KGB agents in Russia

Intelligence Agencies

- Intelligence gathering
- Agents in hostile territory

Who Needs Anonymity?

Law Enforcement

- Tip lines
- Whistleblowers

Corporations

- Competitive analysis
- Protection for employees

Who Needs Anonymity?

You

- Private web browsing and e-mail

Criminals and Spammers

- They already have their anonymity!

Types of Anonymity

Channel Anonymity

Communicant identification should not be a property of the channel

Data Anonymity

Message contents shouldn't give away your identity

- Requires application-level scrubbing

Anonymous from Whom?

Outside observer/Network insider

Requires channel anonymity

Sender/Recipient Anonymity

Requires channel & data anonymity

Distributed Trust

"Anonymity Loves Company"

- You can't be anonymous by yourself
- You can't trust your anonymity to a single entity

Distributed trust

- Diversity and dispersal of security requirements
- Everyone whose anonymity is at stake should run a piece of the infrastructure.

Adversaries

Properties of Adversaries

- Internal or External
- Passive or Active
- Local or Global
- Static or Adaptive

High-latency Anonymity

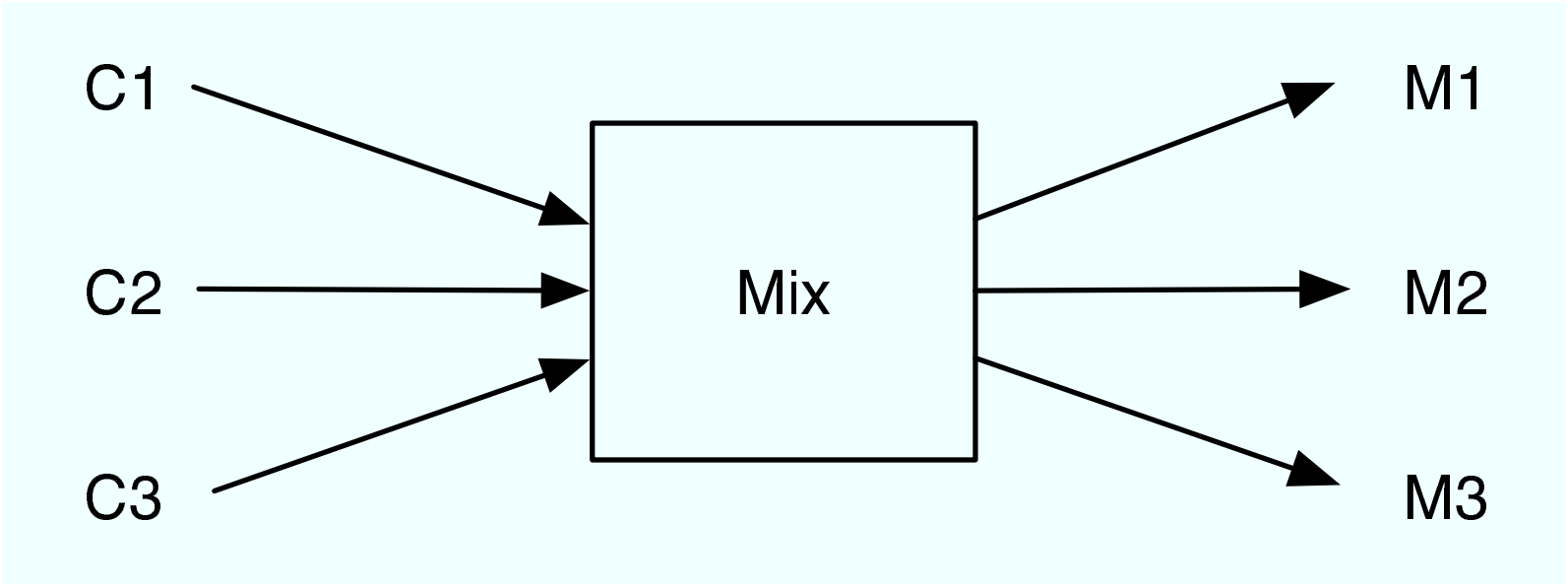
High-latency Anonymity

- "Message-based"
- Mainly used for e-mail
- Basic building block is a "mix" (Chaum '81)

A Simple Mix

A Simple Mix

$C_i = E_{KU_{Mix}}[M_j]$ $M_j = D_{KR_{Mix}}[C_i]$

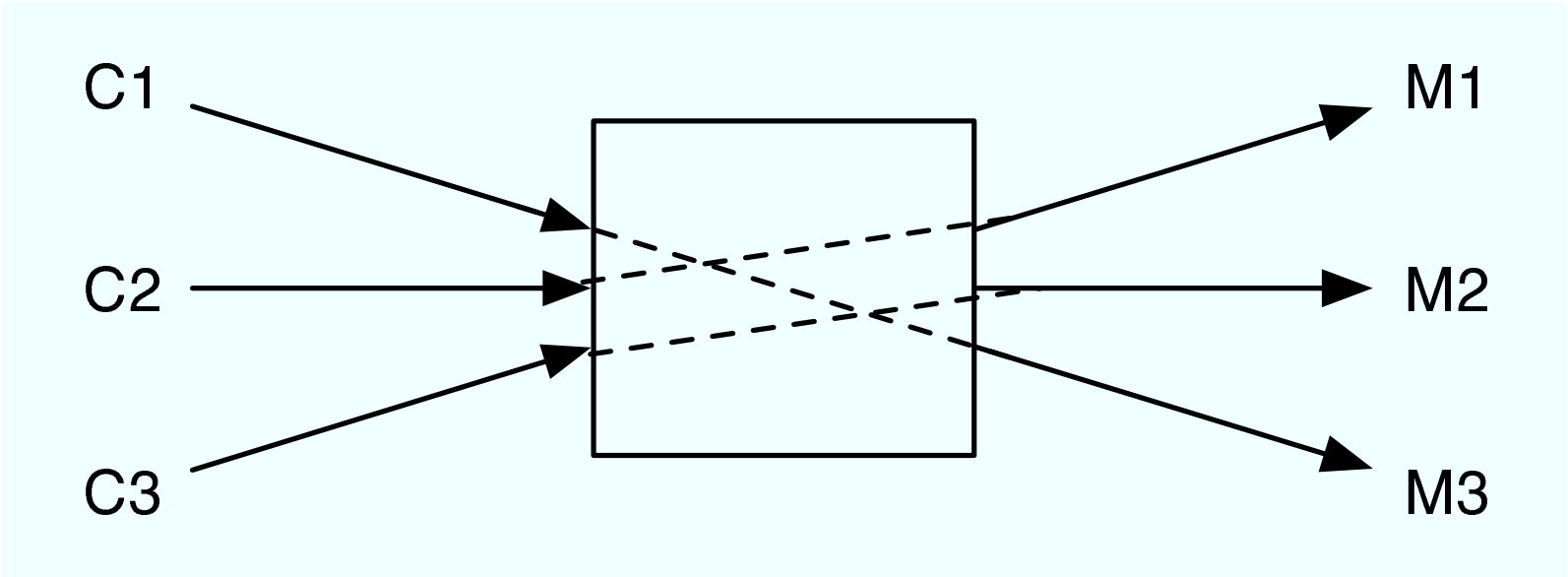


Mix decrypts and randomly permutes messages

A Simple Mix

A Simple Mix

$C_i = E_{KU_{Mix}}[M_j]$ $M_j = D_{KR_{Mix}}[C_i]$

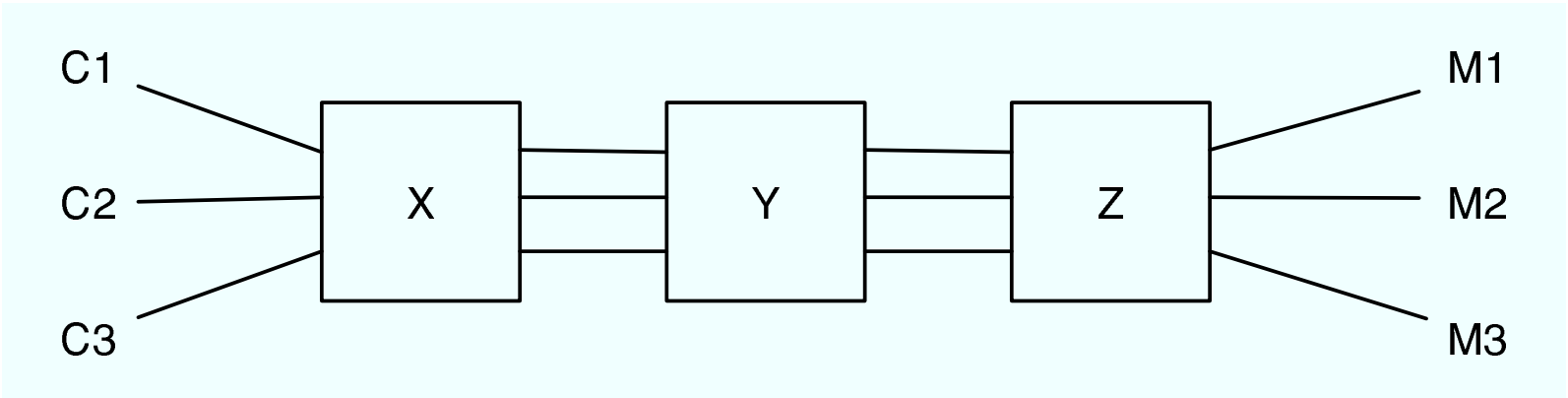


An observer does not know the true mapping of $C_i \rightarrow M_j$

Mix Networks

Cascade Topology

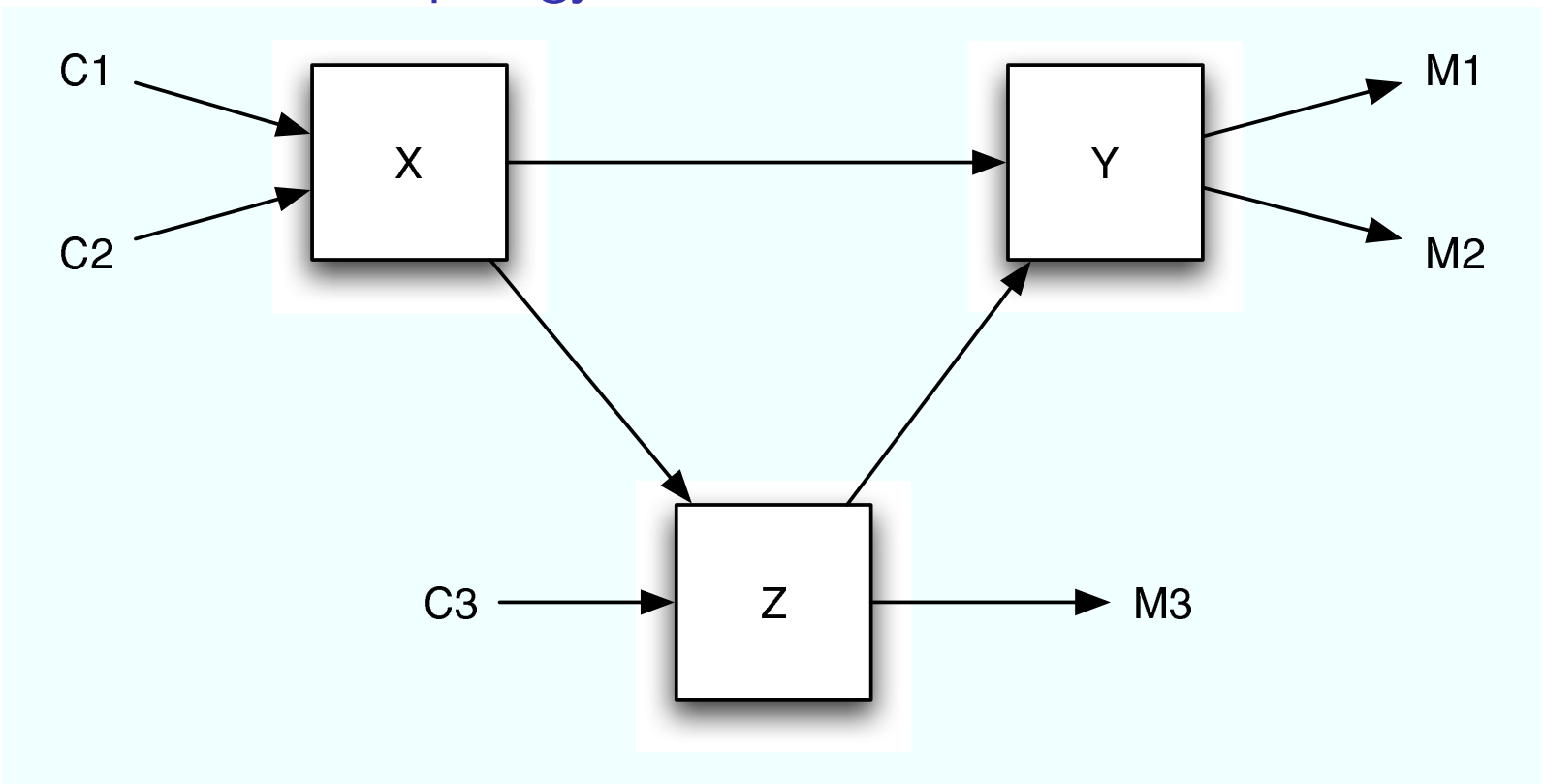
$$C_i = E_{KU_X}[E_{KU_Y}[E_{KU_Z}[M_j]]]$$



Only need 1 non-compromised/honest mix to be secure

Mix Networks

An Alternate Topology



Mixing Algorithms

Timed mix

Flush the mix every t seconds

Threshold mix

Flush the mix every n messages

Threshold or timed mix

Flush the mix every t seconds or when n messages accumulate in the mix

Threshold and timed mix

Flush the mix every t seconds but only when at least n messages have accumulated in the mix

Mixing Algorithms

Pool mix

Every time the mix fires, randomly select some messages to send and retain f_{min} in the mix

- Threshold pool mix
- Timed pool mix

Timed dynamic pool mix

Every time the mix fires, send $max(1, \lfloor m \times frac \rfloor)$ messages, where $0 \leq frac \leq 1$, and retain the rest in the mix

Active Attacks

Trickle attack (Threshold mixes)

"$n-1$ attack"

1. Block all incoming messages to a mix, including one particular message of interest, M
2. Send dummy messages into the mix until it fires
3. Allow M into the mix
4. Send dummy messages into the mix until it fires again
5. Observe the outputs to identify M

Active Attacks

Flooding attack (Timed mixes)

1. Block all incoming messages to a mix, including one particular message of interest, M
2. Wait until the mix fires
3. Allow M into the mix
4. Wait until the mix fires again
5. Observe the single output to identify M

Passive Attacks

Intersection Attack

Learn over time which Bobs are more likely to receive after certain Alices send

Partitioning Attack

Split large groups of Alices and Bobs into smaller groups (*i.e.*, reduce the size of the anonymity set)

Deployed Remailers

anon.penet.fi (Type 0)

- Mapped pseudonym to identity
- Legal attacks by the Church of Scientology (1995)

Cypherpunks remailer (Type I)

- Little or no delaying
- Doesn't hide message length
- Vulnerable to replay attacks

Deployed Remailers

Mixmaster (Type II)

- Added pools and message padding
- Keeps hashes of the headers for replay prevention

Mixminion (Type III)

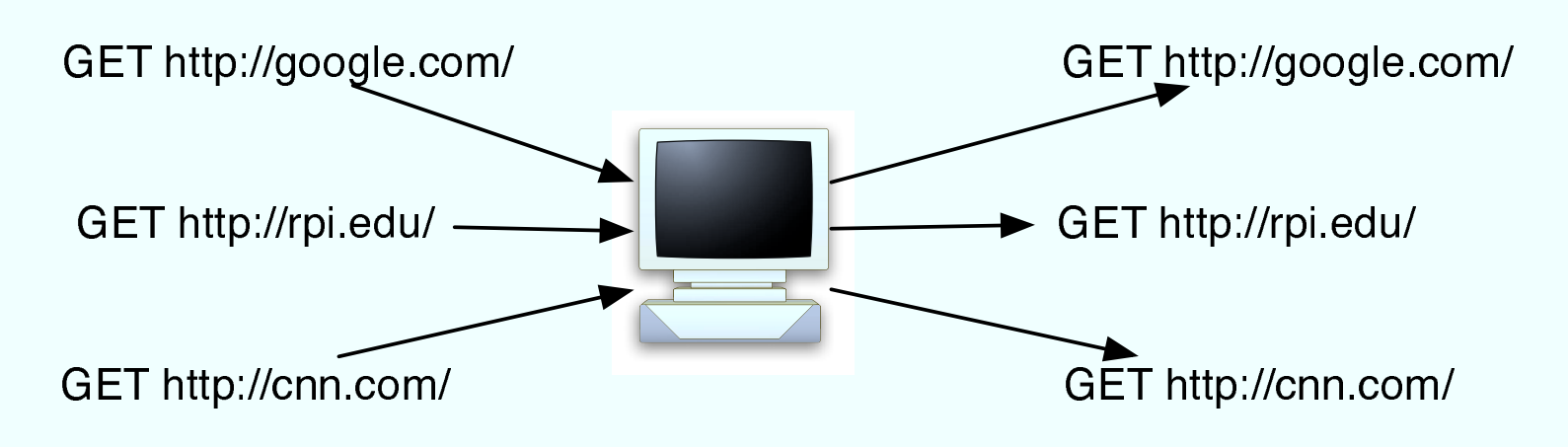
- Added reply blocks
- Key rotation to counter replay attacks

Low-latency Anonymity

Low-latency Anonymity

- Connection-oriented
- More suited for real-time applications (www, ssh, irc, etc.)
- Basic building block is a proxy

One-hop Proxies



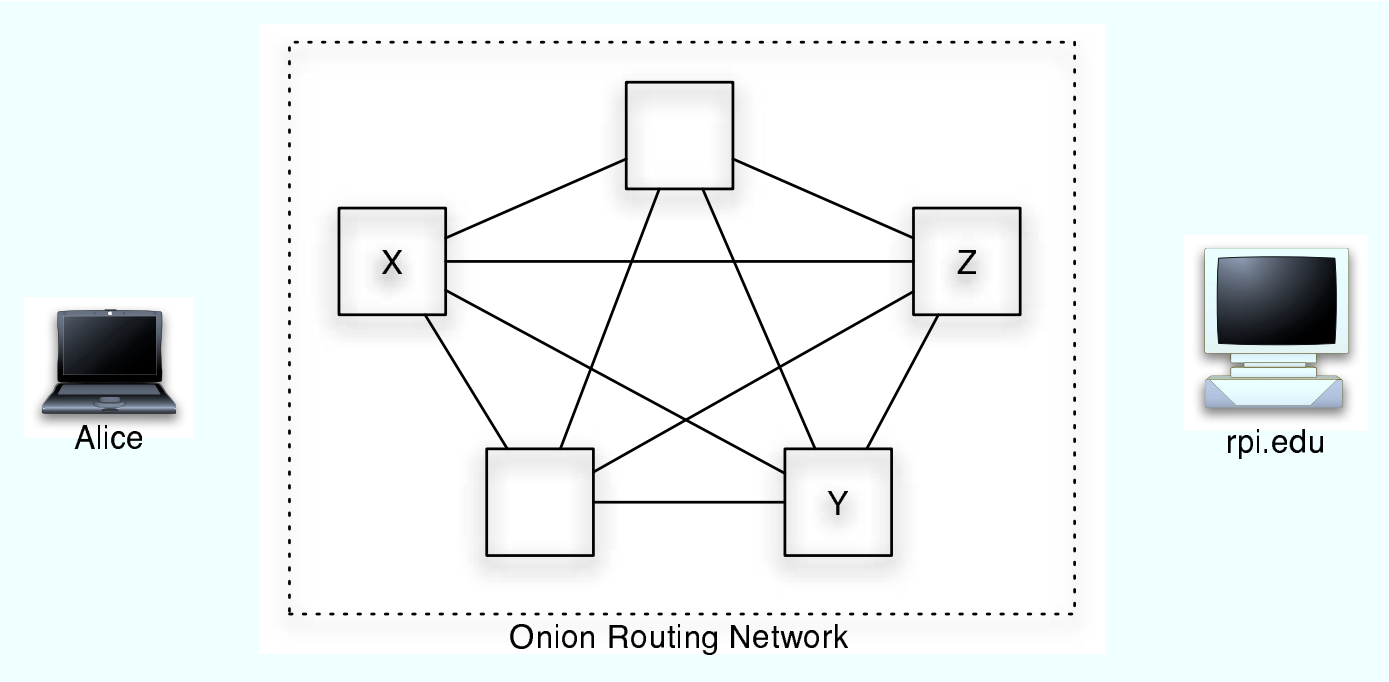
- Single point of failure and attack
- Single point of trust
- Example: anonymizer.com

Early Onion Routing

Onion Routing

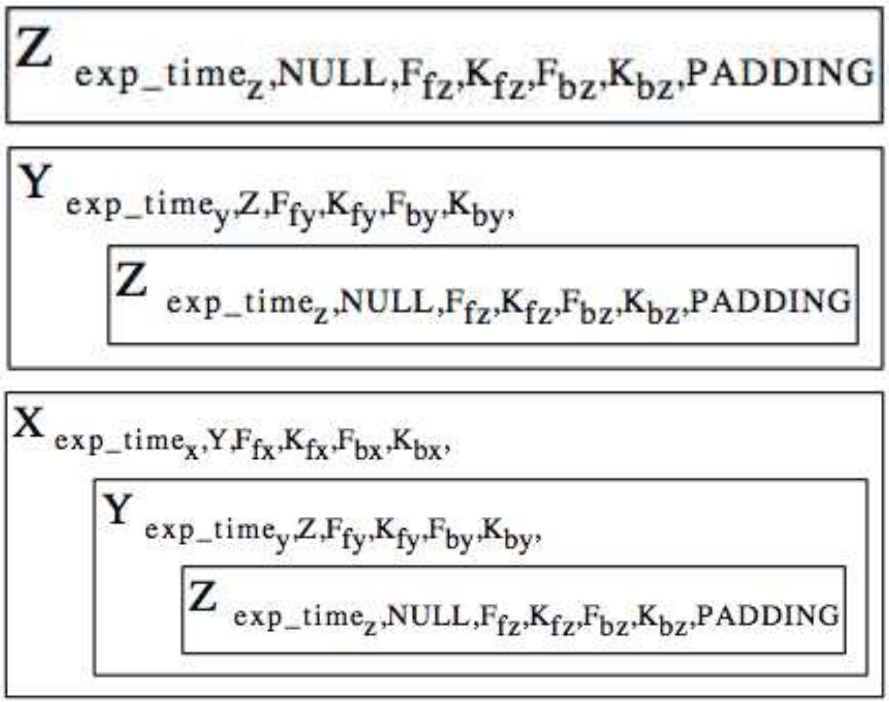
- Initially developed at NRL
- Uses slower asymmetric crypto to set up "circuits"
- Uses faster symmetric crypto for moving data

Building a Circuit



- Alice picks X, Y, Z nodes from the network

Building a Circuit

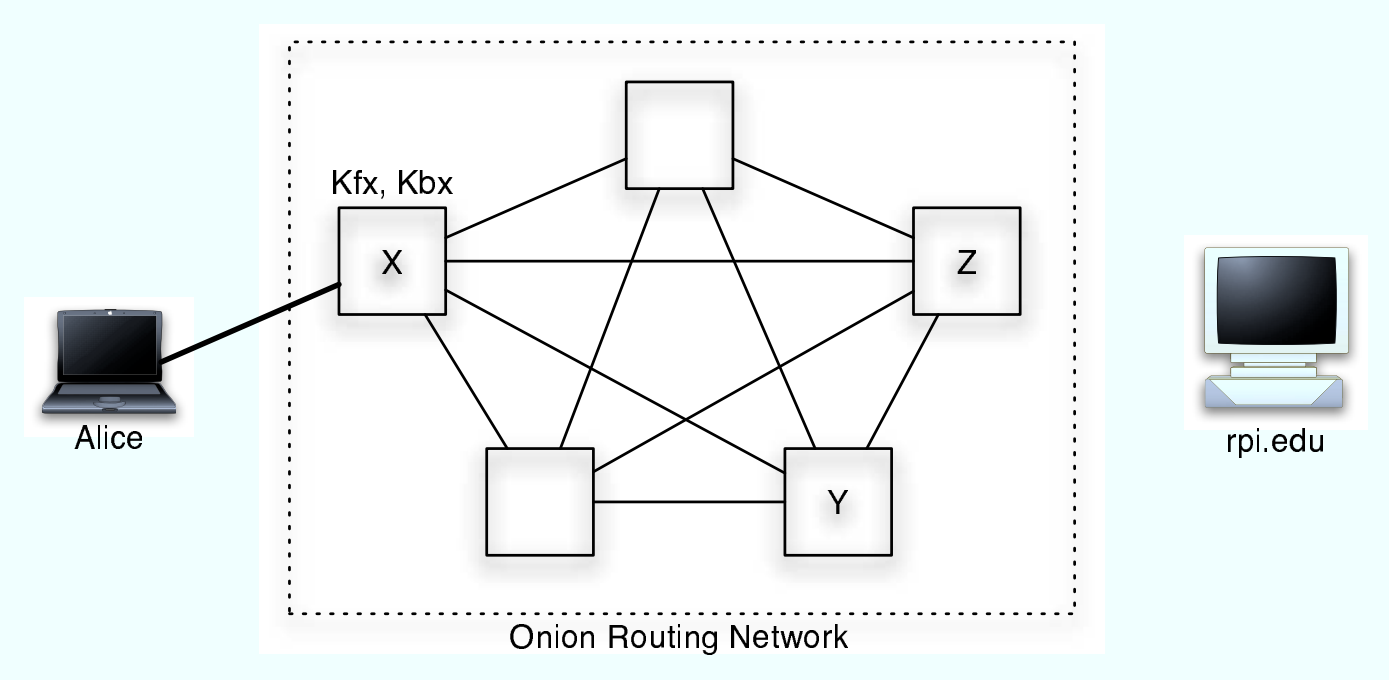


Construct an Onion

- Alice generates symmetric keys for each hop
- Each layer is encrypted with the node's public key

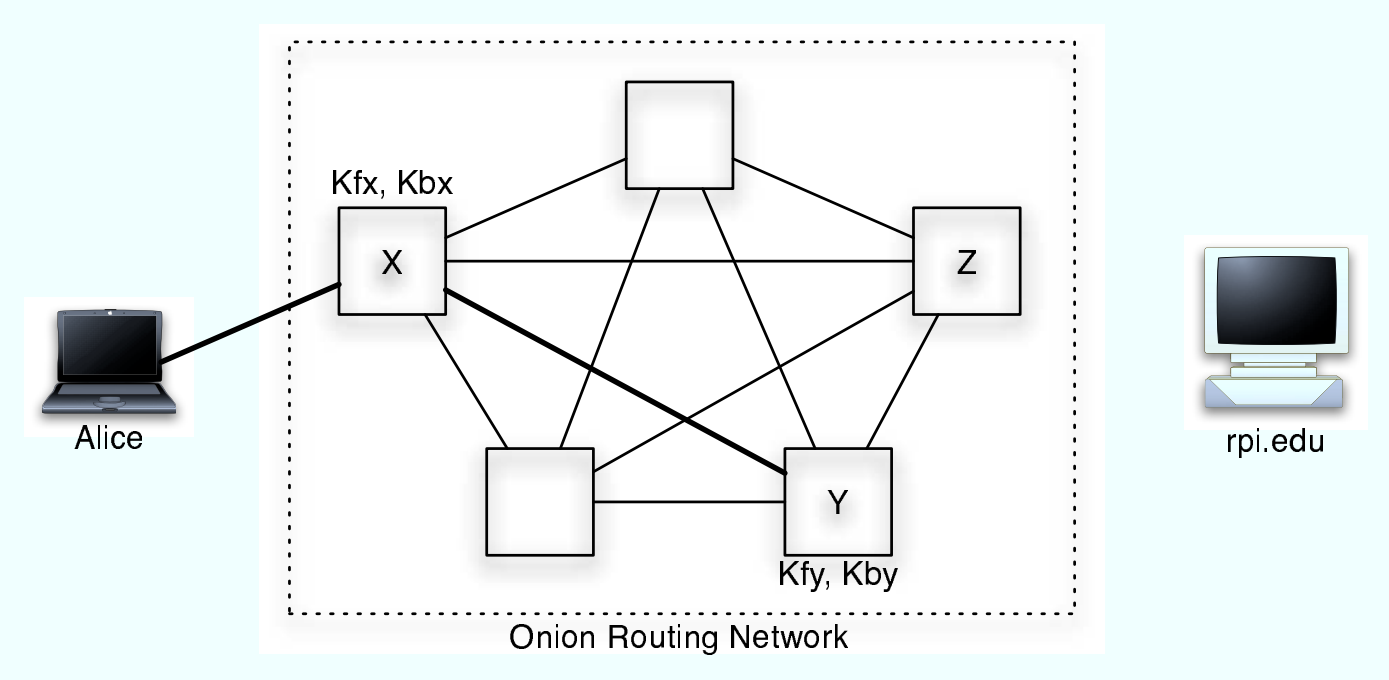
(D. Goldschlag *et al.*, "Hiding Routing Information", IH '96)

Building a Circuit



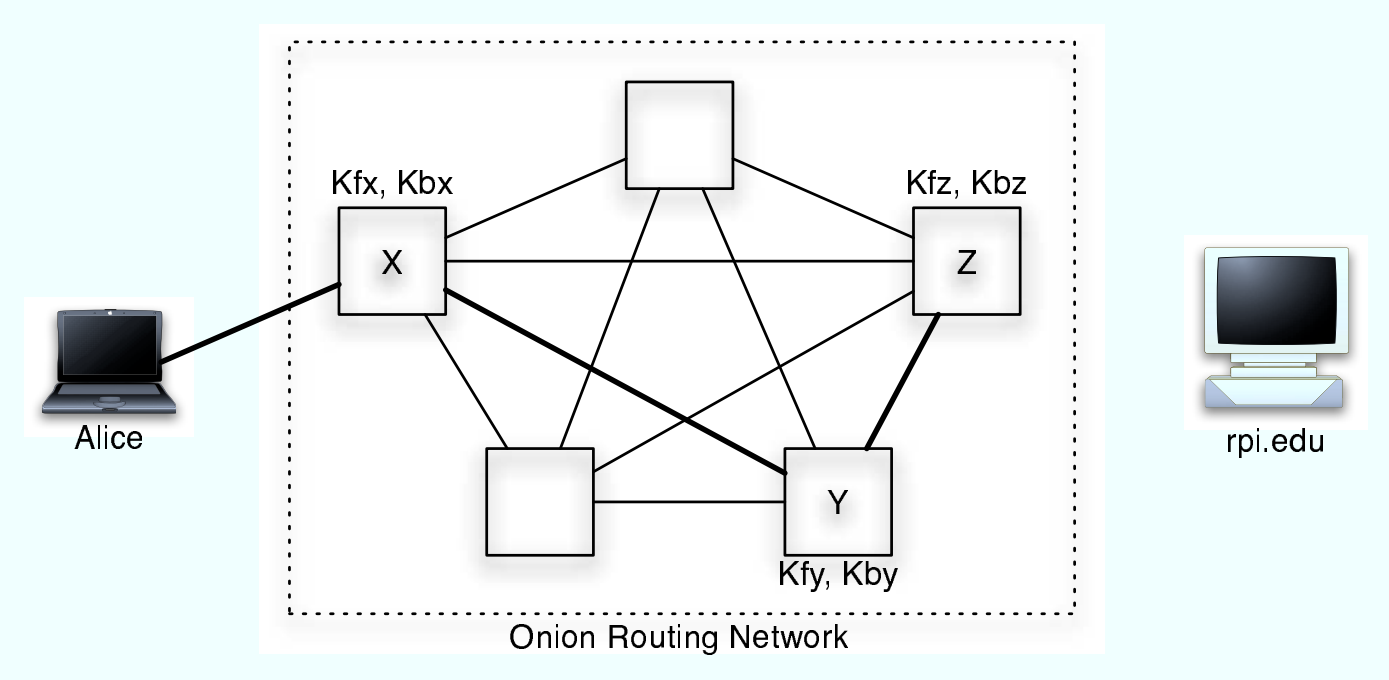
- Alice sends the onion to X
- X decrypts the outermost layer, learns its symmetric keys and the next hop

Building a Circuit



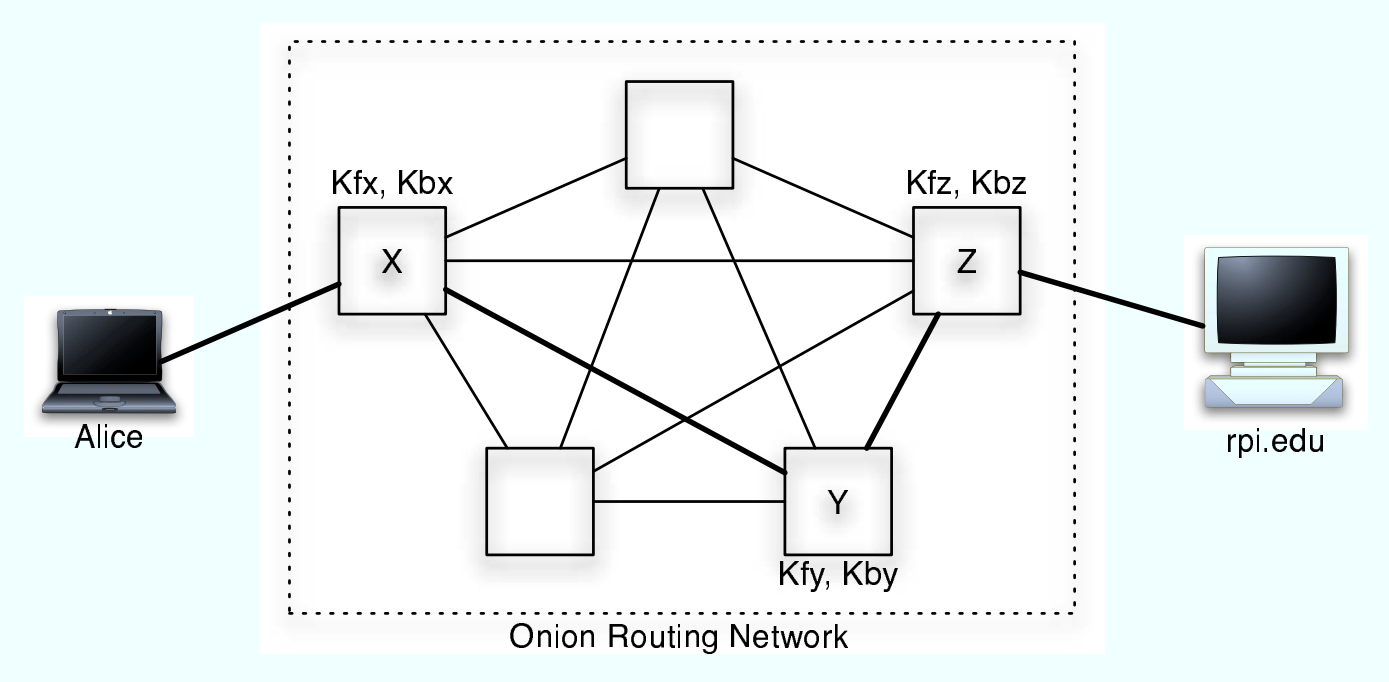
- X sends the onion to Y
- Y decrypts the outermost layer, learns its symmetric keys and the next hop

Building a Circuit



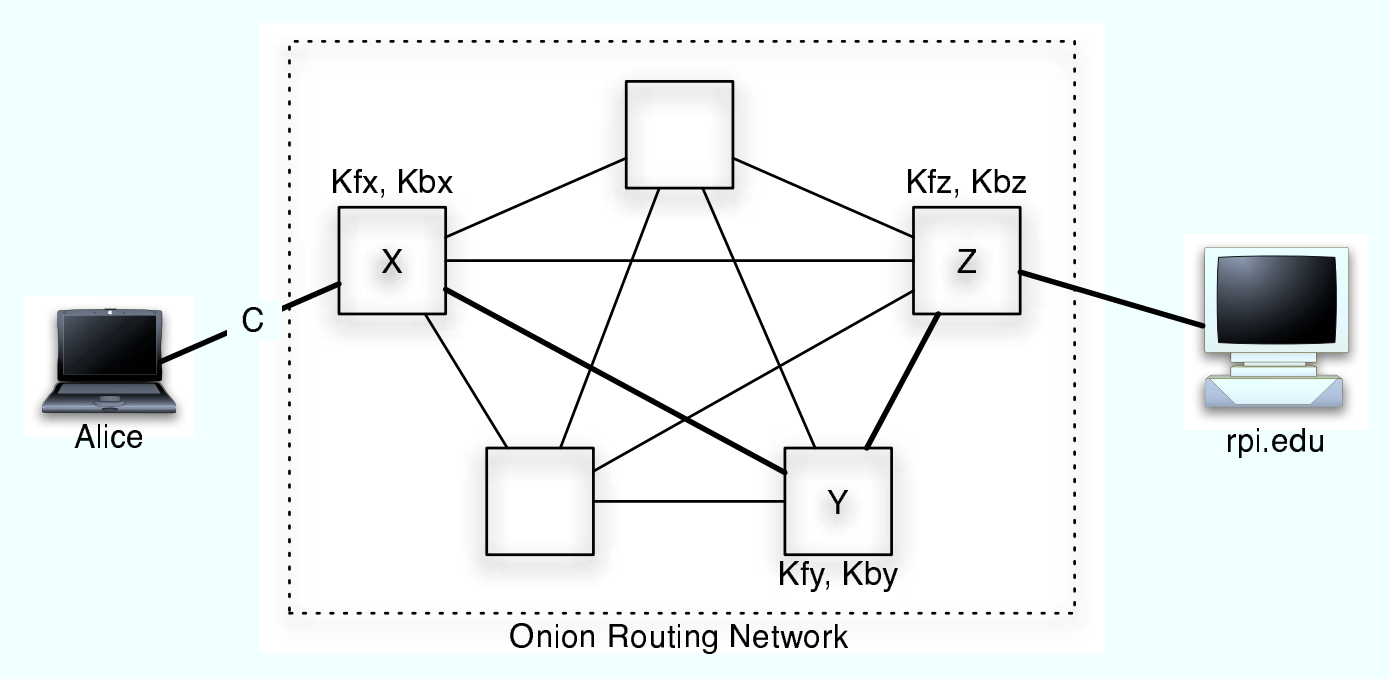
- Y sends the onion to Z
- Z decrypts the outermost layer, learns its symmetric keys and the next hop

Building a Circuit



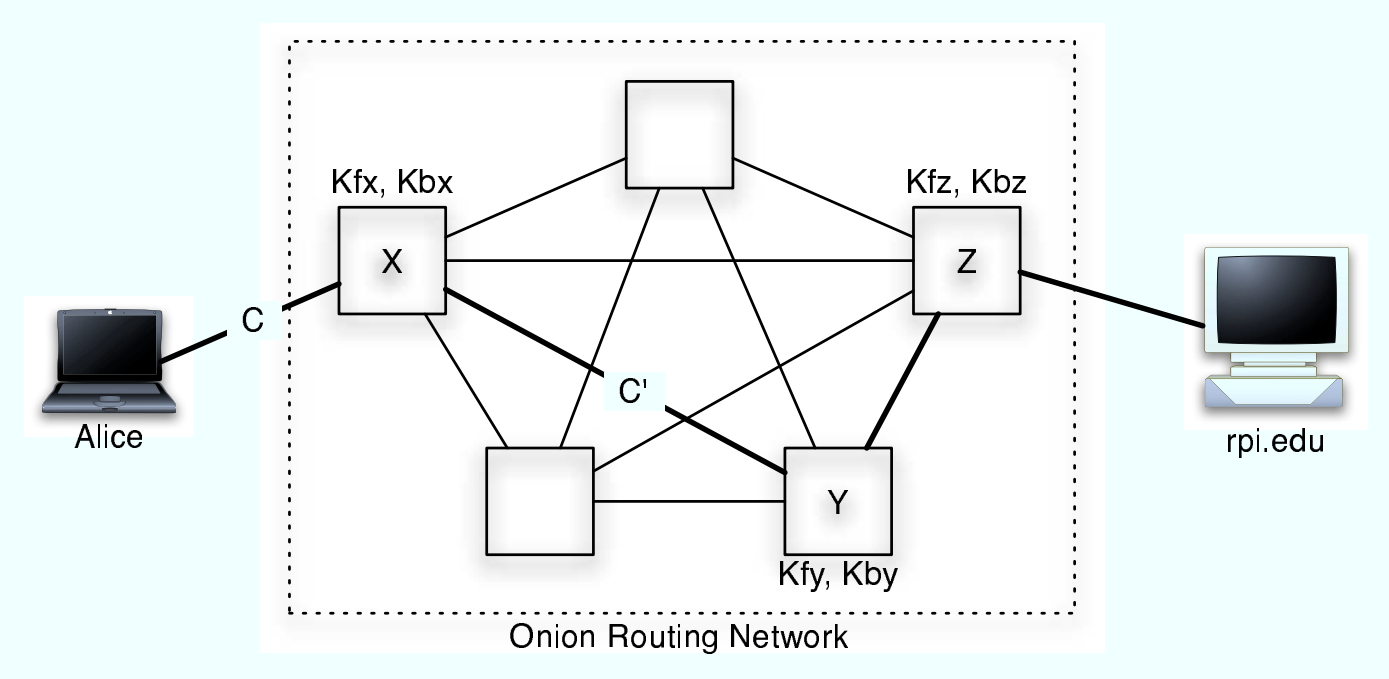
- Z establishes a connection to `rpi.edu`

Sending a Message



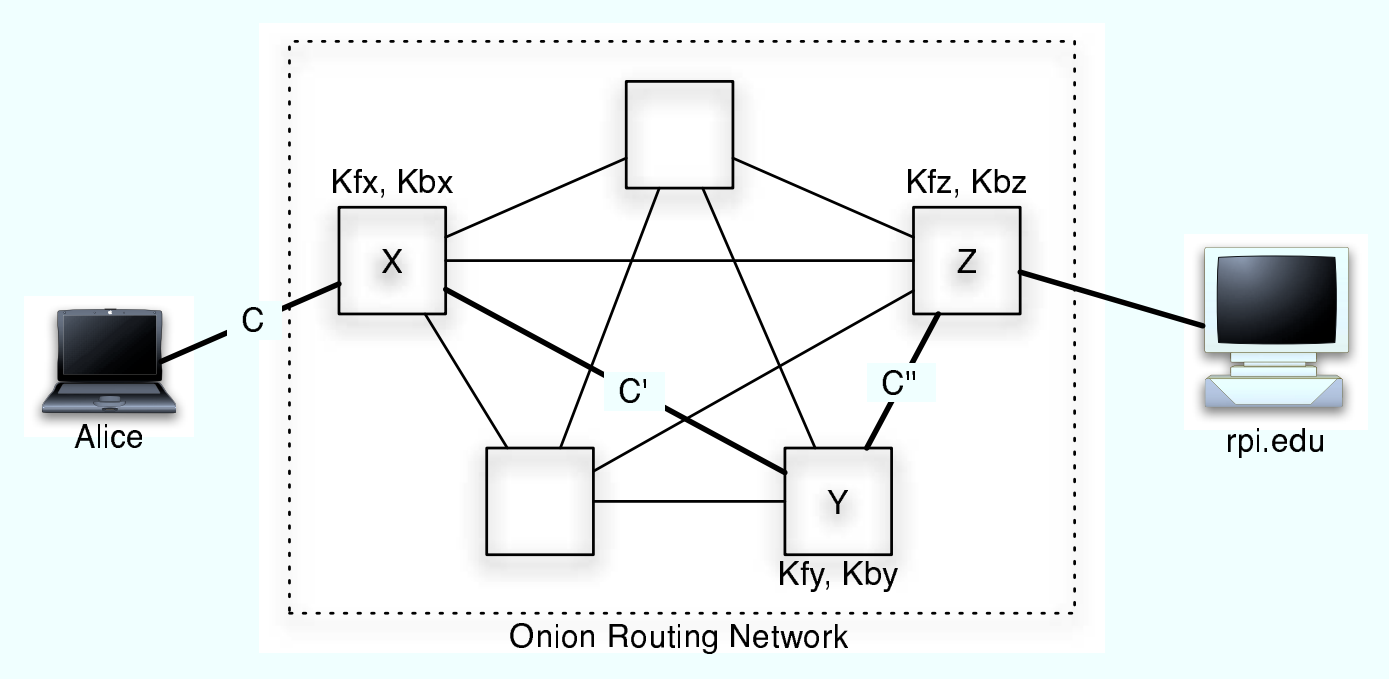
Alice sends $C = E_{K_{fx}}[E_{K_{fy}}[E_{K_{fz}}[M]]]$

Sending a Message



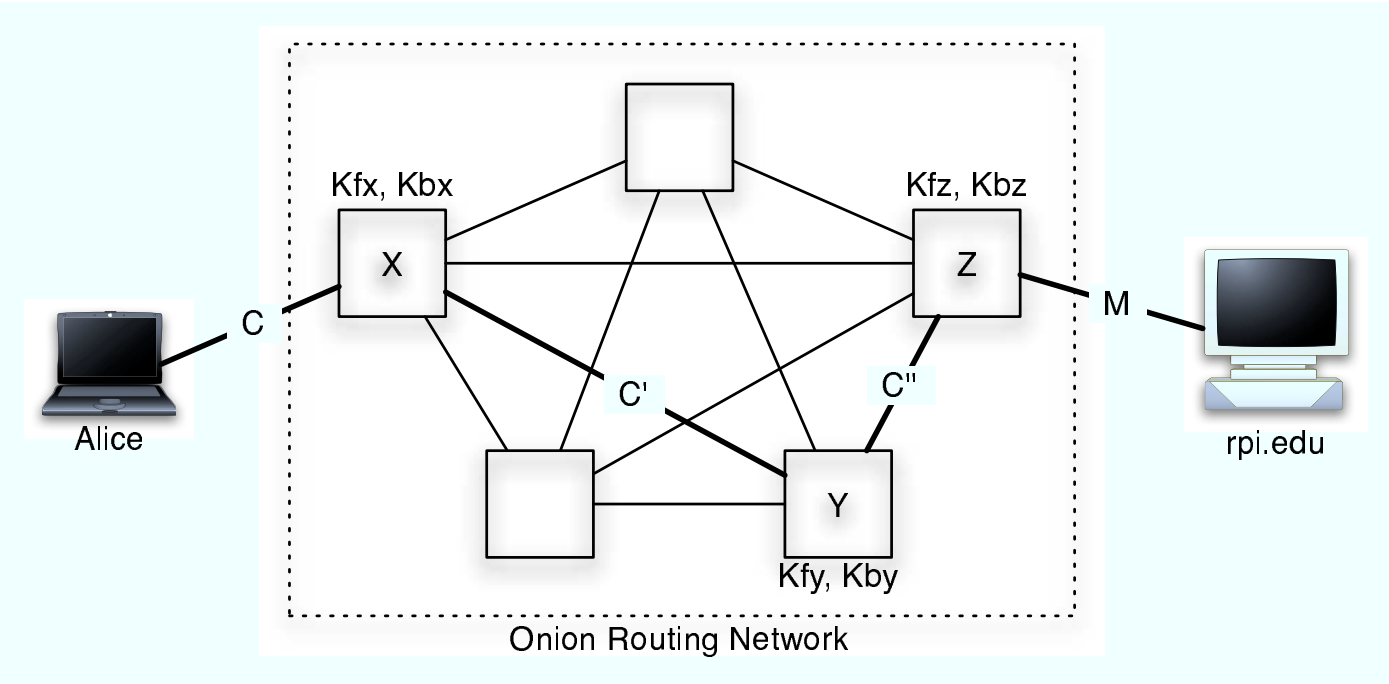
X sends $C' = D_{K_{fx}}[C] = E_{K_{fy}}[E_{K_{fz}}[M]]$

Sending a Message



Y sends $C'' = D_{K_{fy}}[C'] = E_{K_{fz}}[M]$

Sending a Message



Z sends $M = D_{K_{fz}}[C'']$

Problems

Problems

- Nodes have to remember what onions they have seen to prevent replay attacks
- Was never really widely used
- Patented

Tor (*not* TOR)

The Onion Router

- "Second Generation Onion Routing"
- Open source (3-clause BSD)
- Currently 800+ volunteer servers
- Tens/hundreds of thousands of users?

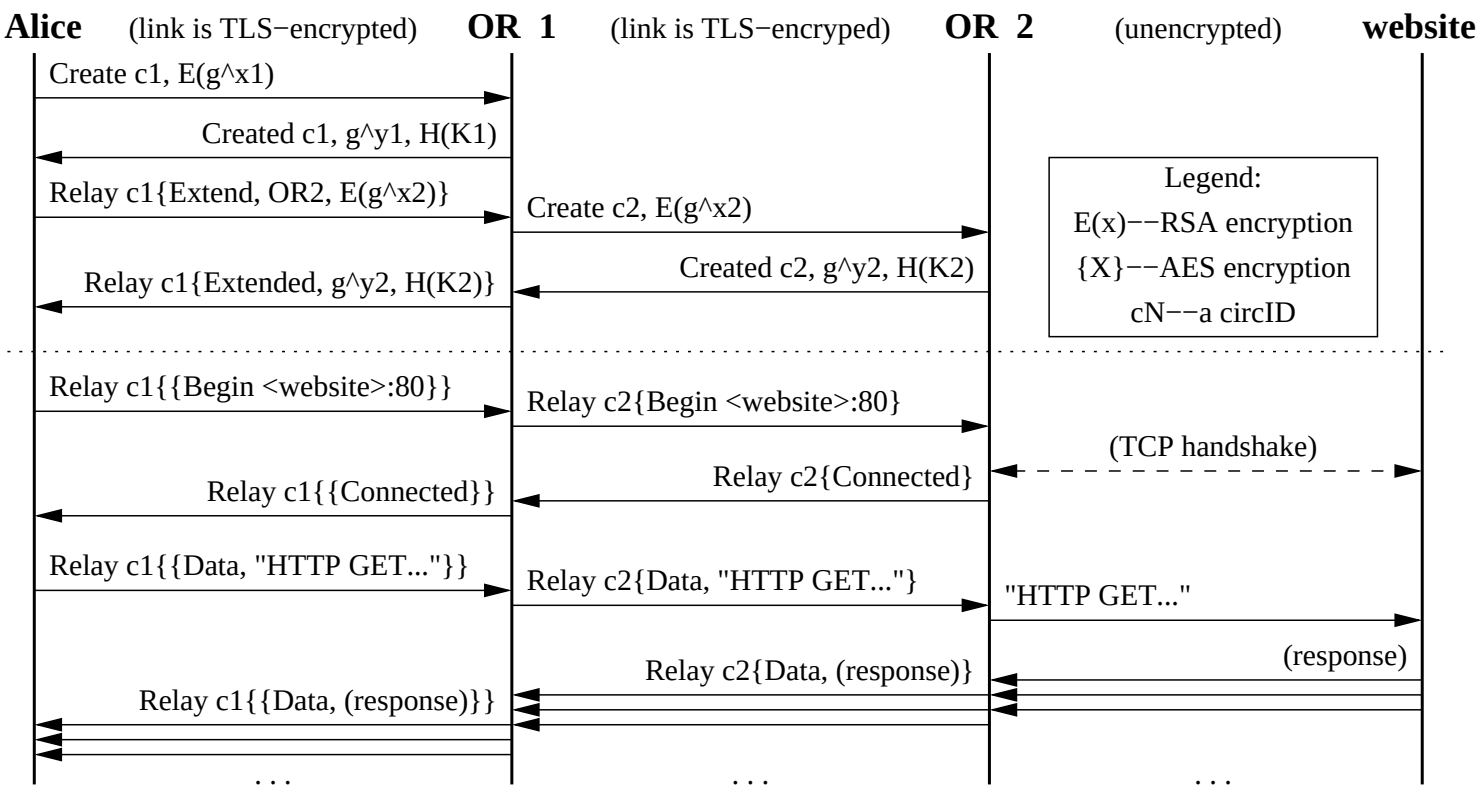
Threat Model

Threat Model

- Assume end-to-end attacks are trivial
  - No mixing, no padding
- Assume an adversary can monitor or manipulate traffic on part of the network
- Assume an adversary owns some of the nodes

Design and deploy for usability

Building a Circuit



Negotiate a session key at each hop, ephemeral Diffie-Hellman w/ RSA (Tor design, USENIX Security '04)

Directory Servers

Directory Servers

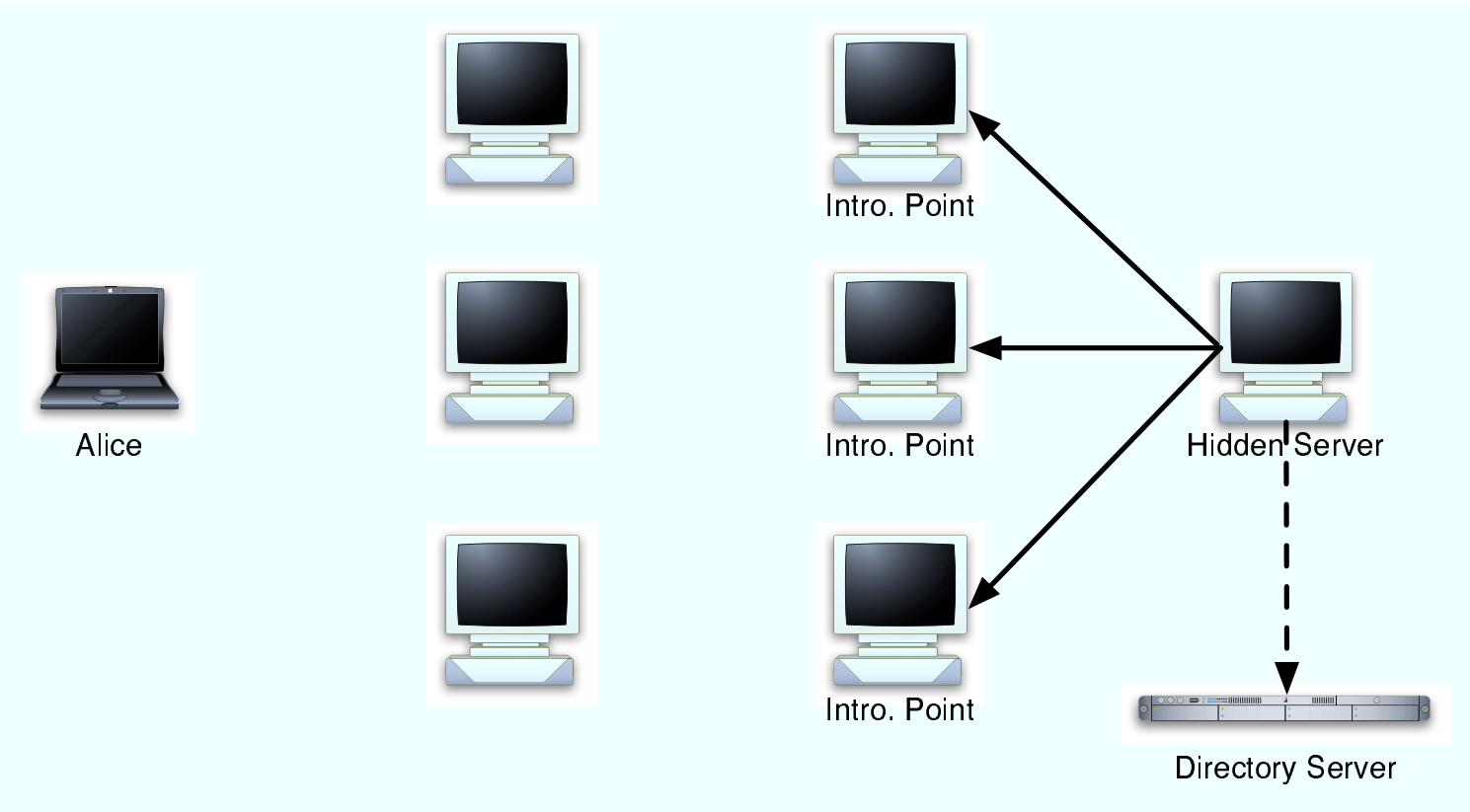
- Lets clients learn about servers
- Directories signed by authoritative directory servers, mirrored by other servers
- Fingerprints of authoritative dirserver public keys hard-coded into source
- Trust bottleneck

Hidden Services

Hidden Services

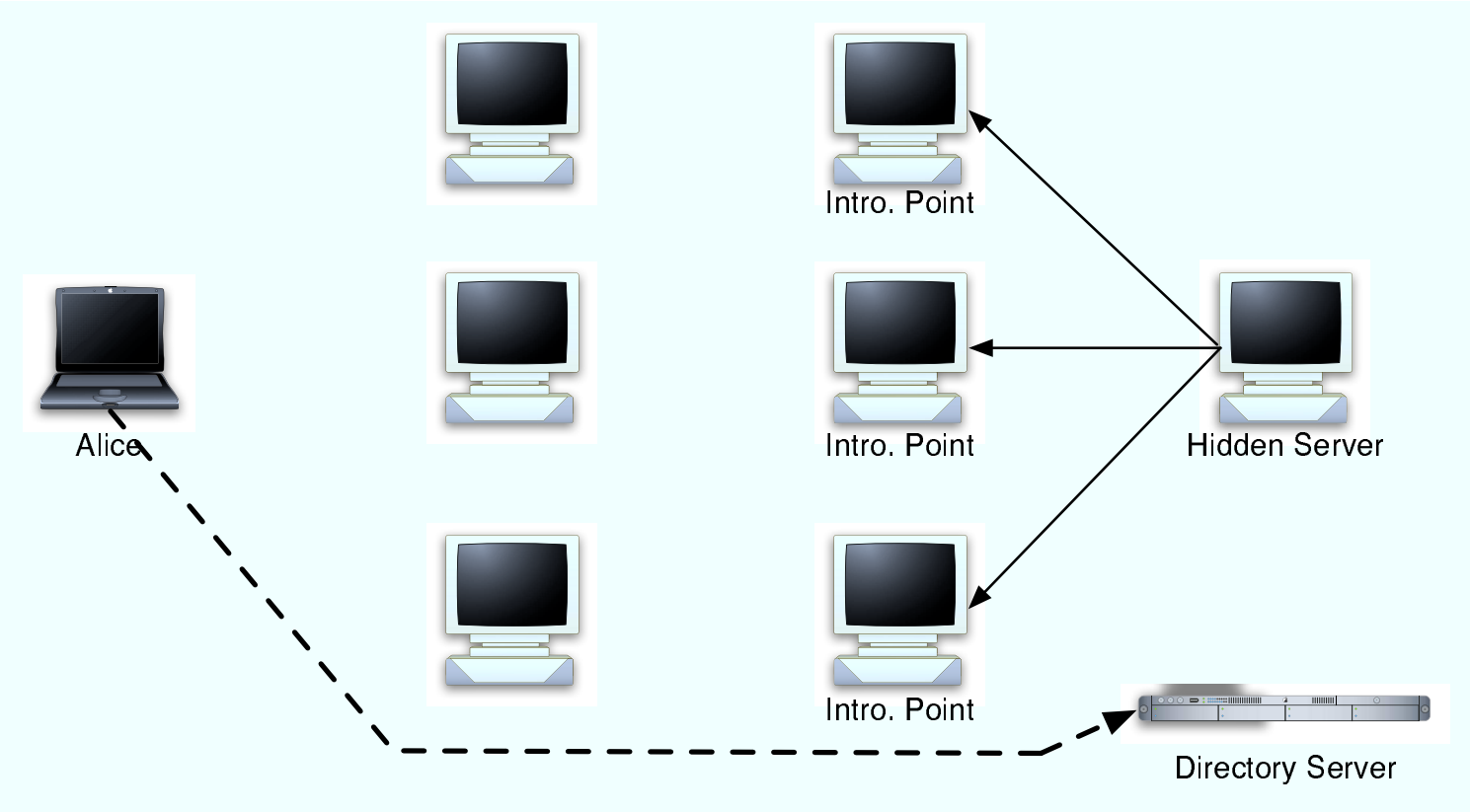
- Provides a service (e.g., web server) without revealing its IP address
- Uses a special `.onion` TLD, accessible only with a Tor client
- Addresses are based on a the hash of the hidden service's public key (*e.g.*, `6sxoyfb3h2nvok2d.onion`)
- Client (server) doesn't know who/where the server (client) is
- Allows you to offer a service behind a firewall with no open ports

Hidden Services



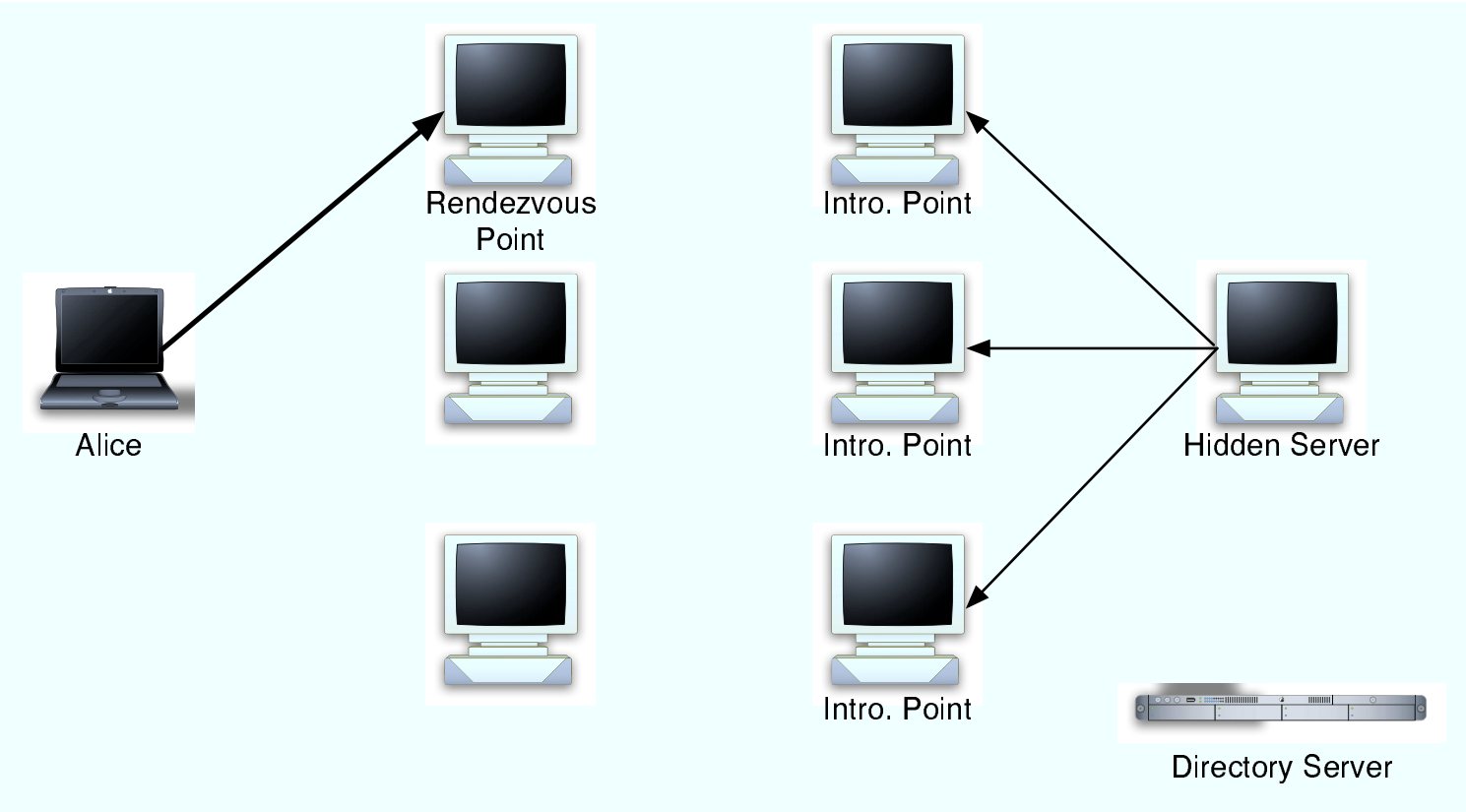
The hidden service picks *introduction points* and publishes them

Hidden Services



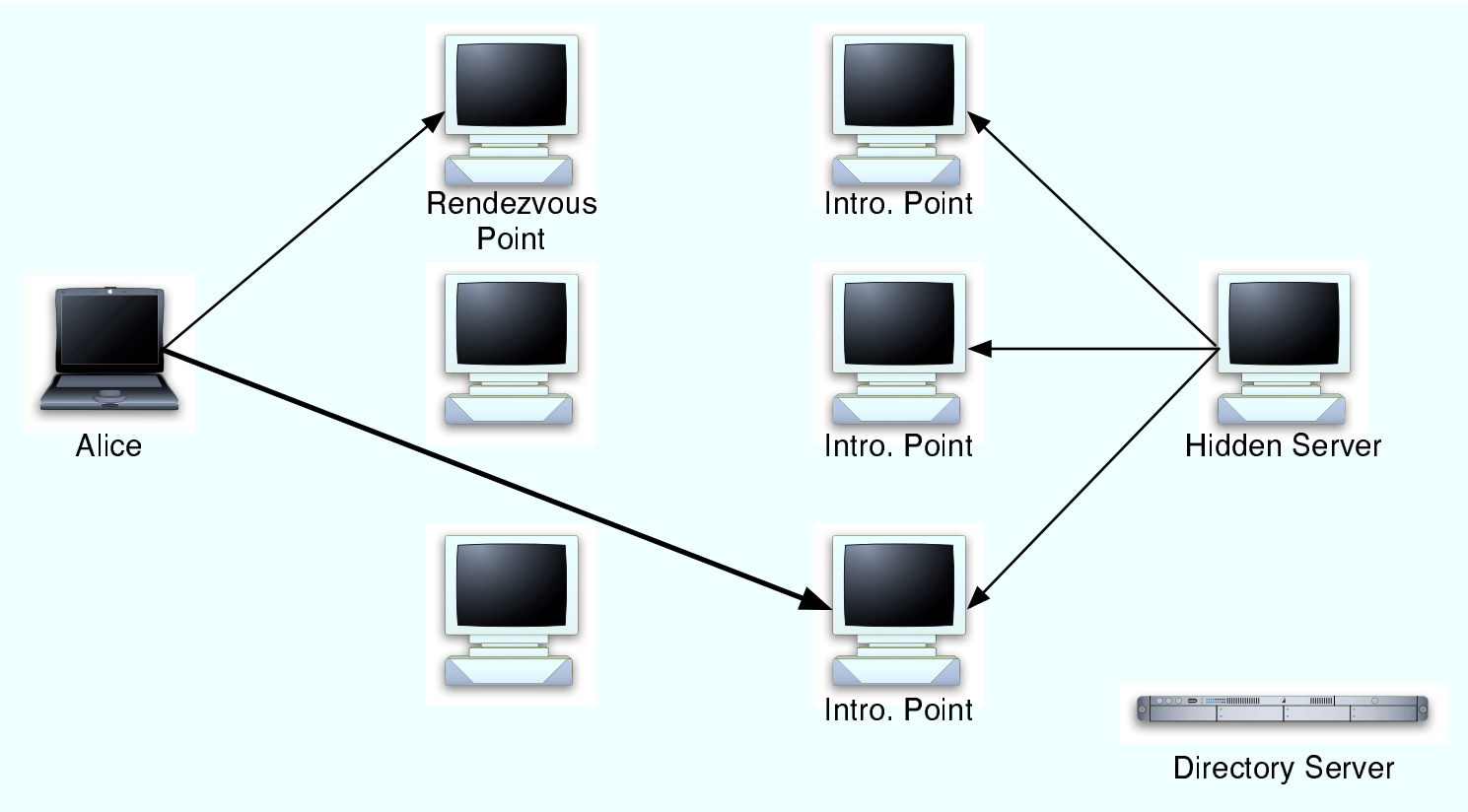
Alice learns about the hidden service's intro. points

Hidden Services



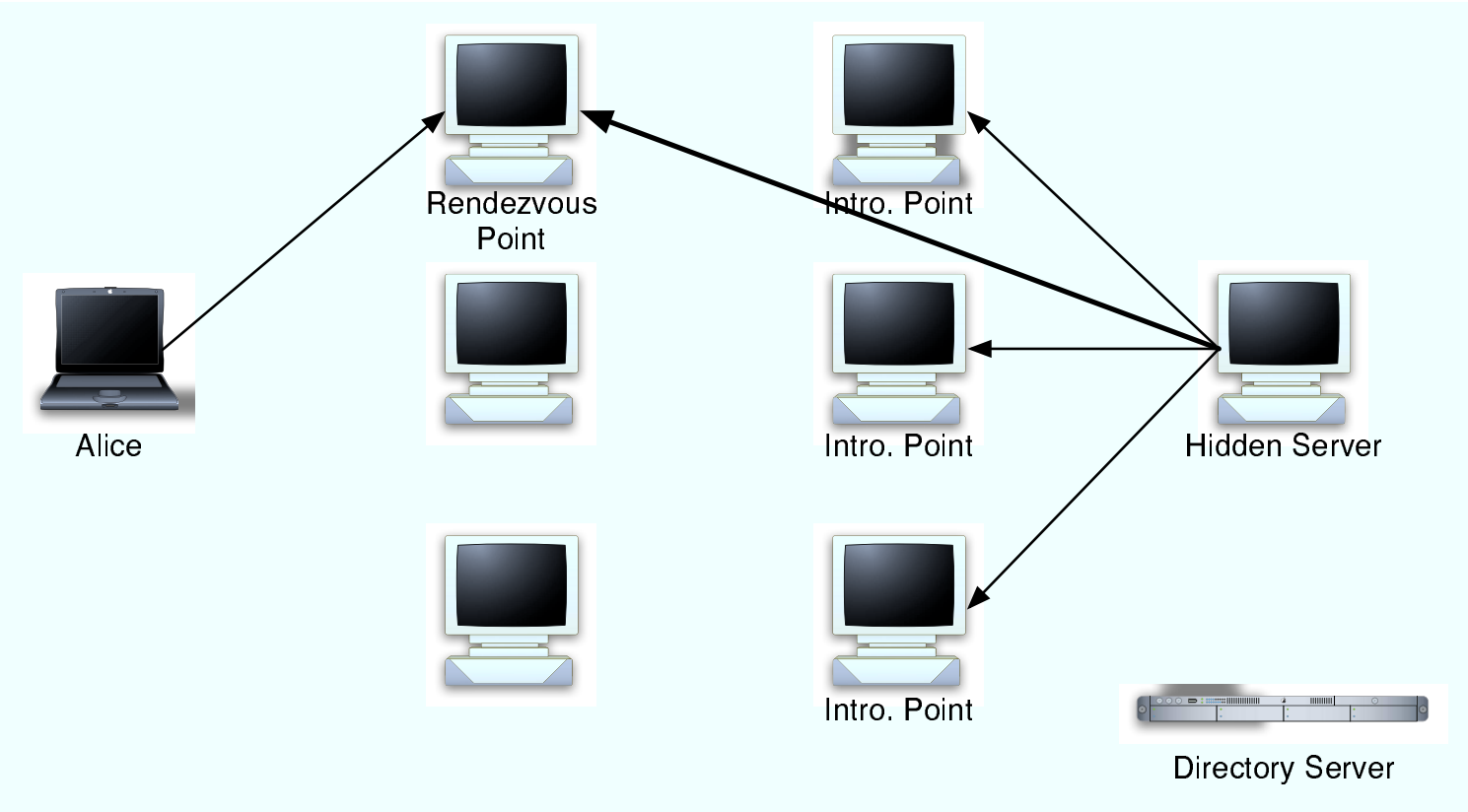
Alice randomly chooses a *rendezvous point*, *RP*, and gives it a "rendezvous cookie", *RC*

Hidden Services



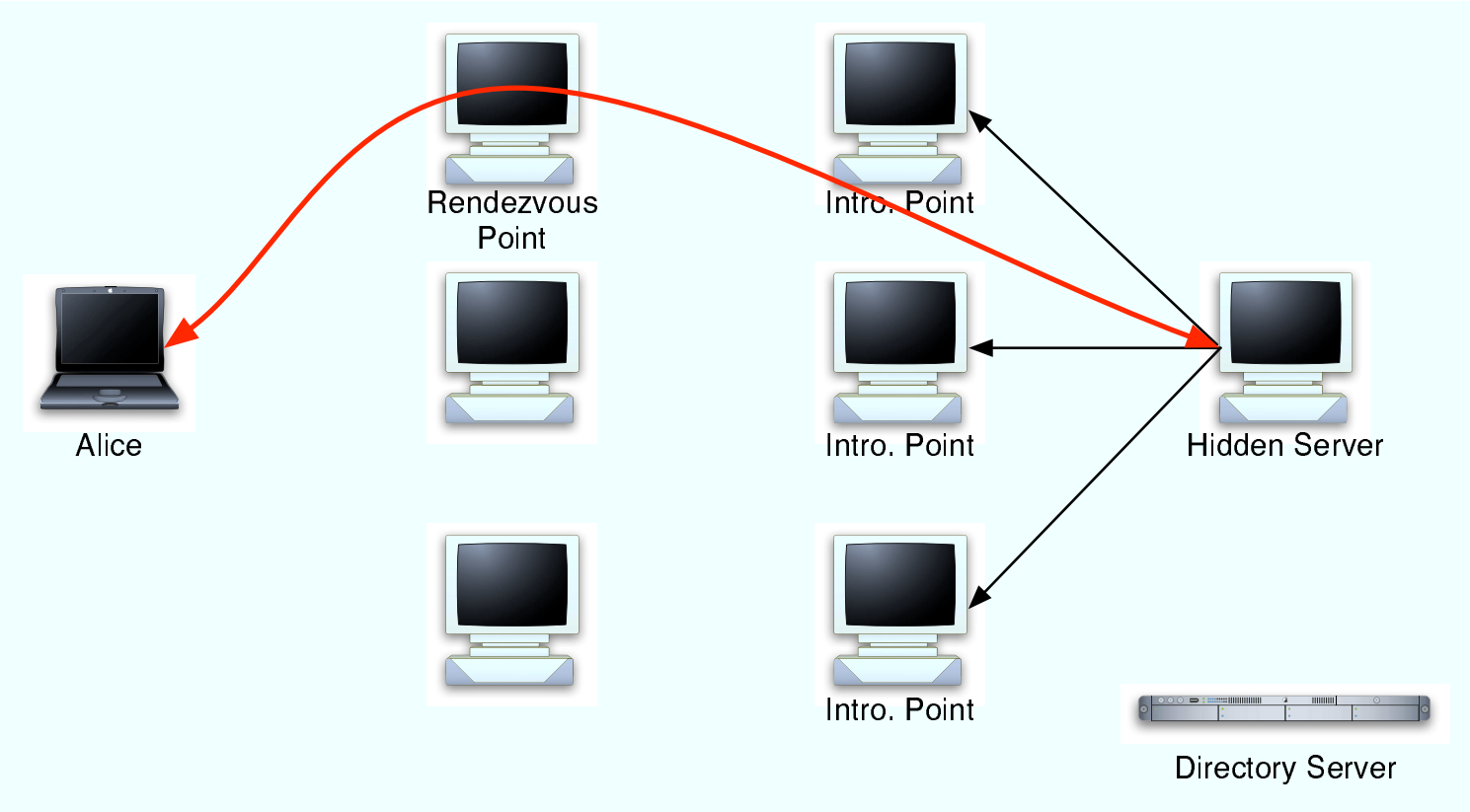
Alice connects to one of the hidden service's intro. points and gives it $E_{KU_{HS}}[RP|RC|g^x]$

Hidden Services



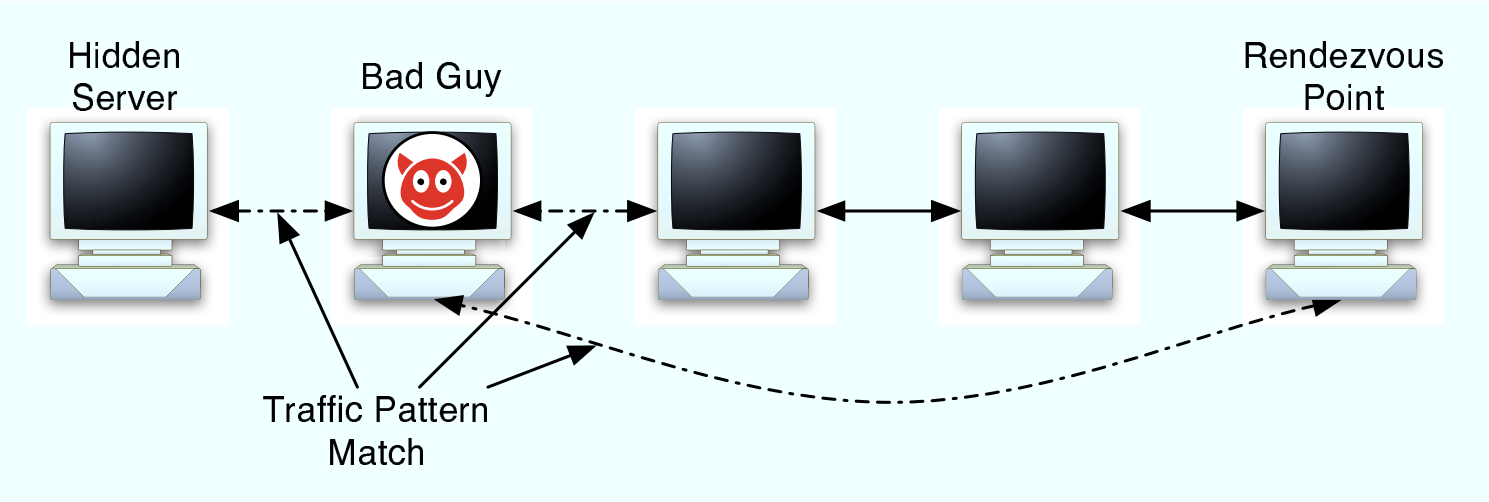
The hidden service connects to RP, presents RC, RP pairs up the circuits, gives Alice g^y and $SHA1[g^{xy}]$

Hidden Services



Alice and the hidden service now share an encrypted tunnel

An Attack on Hidden Services



(L. Øverlier and P. Syverson, "Locating Hidden Servers", IEEE Symposium on Security and Privacy '06)

Other Designs

Tarzan/Morphmix

- Fully p2p
- You lose if you pick a bad first node
- Morphmix added "collusion resistance"

JAP

- Java Anonymous Proxy
- Uses cascades instead of free-routes
- Backdoored by court order (2003)
  - Successfully fought in court

Other Designs

Freedom Network

- Zero-Knowledge Systems
- Commercial attempt at an anonymity network
- Similar to onion routing
- Bankrupt

Attacks on Low-Latency Anonymity

Packet counting/timing attacks

Watch inputs to and outputs from the network, looking for timing and volume correlations between inputs and outputs

Website fingerprinting

Build "fingerprints" of target websites through the anonymity system and compare to observed client traffic

Research Problems

Scalability

- Non-clique network topology
- De-centralized directory
- Avoiding a bad person running 10,000 servers (Sybil attack) without a human

Research Problems

End-to-end Attacks

- Avoiding some end-to-end attackers (*e.g.*, ISP-level adversaries)
- How much mixing or padding do we need for it to be useful without killing performance? (Mid-latency?)
- Blending high-latency traffic with low-latency traffic

Research Problems

Blocking Resistance

- "The China Problem"
- Let the good guys know about nodes in the network without the bad guys finding out too
- Hide the fact that we're speaking some anonymity network's protocol

Usability and Incentives

- Make the software easier to use (securely)
- Convince people to run useful servers

Questions

Questions?

See `http://freehaven.net/anonbib/` for lots of neat papers