Tor:
“Putting the P back in VPN”

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http://tor.eff.org/

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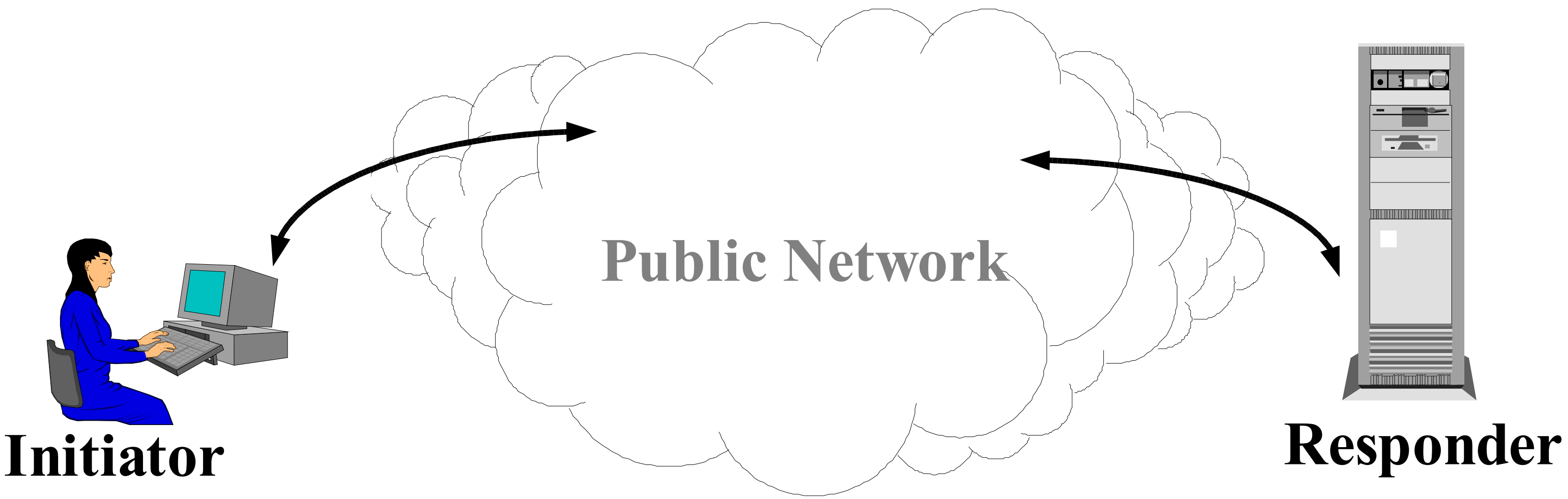
Talk Outline

- Motivation: Why anonymous communication?
  - Personal privacy
  - Corporate and governmental security
- Mixes and proxies: Anonymity building blocks
- Onion Routing: Lower latency, higher security
- Hidden servers and rendezvous points
- Open issues and hard problems

Public Networks are Vulnerable to Traffic Analysis

- In a Public Network (Internet):
- Packet (message) headers identify recipients
- Packet routes can be tracked



Encryption does *not* hide routing information.

Who Needs Anonymity?

- Journalists, Political Dissidents, Whistleblowers
- Censorship resistant publishers/readers
- Socially sensitive communicants:
  - Chat rooms and web forums for abuse survivors, people with illnesses
- Law Enforcement:
  - Anonymous tips or crime reporting
  - Surveillance and honeypots (sting operations)
- Corporations:
  - Who's talking to the company lawyers? Are your employees looking at monster.com?
  - Hiding procurement suppliers or patterns
  - Competitive analysis

Who Needs Anonymity?

- You:
  - Where are you sending email (who is emailing you)
  - What web sites are you browsing
  - Where do you work, where are you from
  - What do you buy, what kind of physicians do you visit, what books do you read, ...

Who Needs Anonymity?

- Government

Government Needs Anonymity? Yes, for...

- Open source intelligence gathering
  - Hiding individual analysts is not enough
  - That a query was from a govt. source may be sensitive
- Defense in depth on open and *classified* networks
  - Networks with only cleared users (but a million of them)
- Dynamic and semitrusted international coalitions
  - Network can be shared without revealing existence or amount of communication between all parties
- Elections and voting

Government Needs Anonymity? Yes, for...

- Networks partially under known hostile control
  - To attack comm. enemy must take down whole network
- Politically sensitive negotiations
- Road Warriors
- Protecting procurement patterns
- Anonymous tips (national security, congressional investigations, etc. in addition to law enforcement)

Anonymity Loves Company

- You can't be anonymous by yourself
  - *Can* have confidentiality by yourself

- A network that protects only DoD network users won't hide that connections from that network are from Defense Dept.

- You must carry traffic for others to protect yourself

- But those others don't want to trust their traffic to just one entity either. Network needs *distributed trust*.

- Security depends on diversity and dispersal of network.

Who Needs Anonymity?

- And yes criminals

Who Needs Anonymity?

- And yes criminals

  But they already have it.
  We need to protect everyone else.

Anonymous From Whom? Adversary Model

- Recipient of your message
- Sender of your message

=> Need Channel and Data Anonymity

- Observer of network from outside
- Network Infrastructure (Insider)

=> Need Channel Anonymity

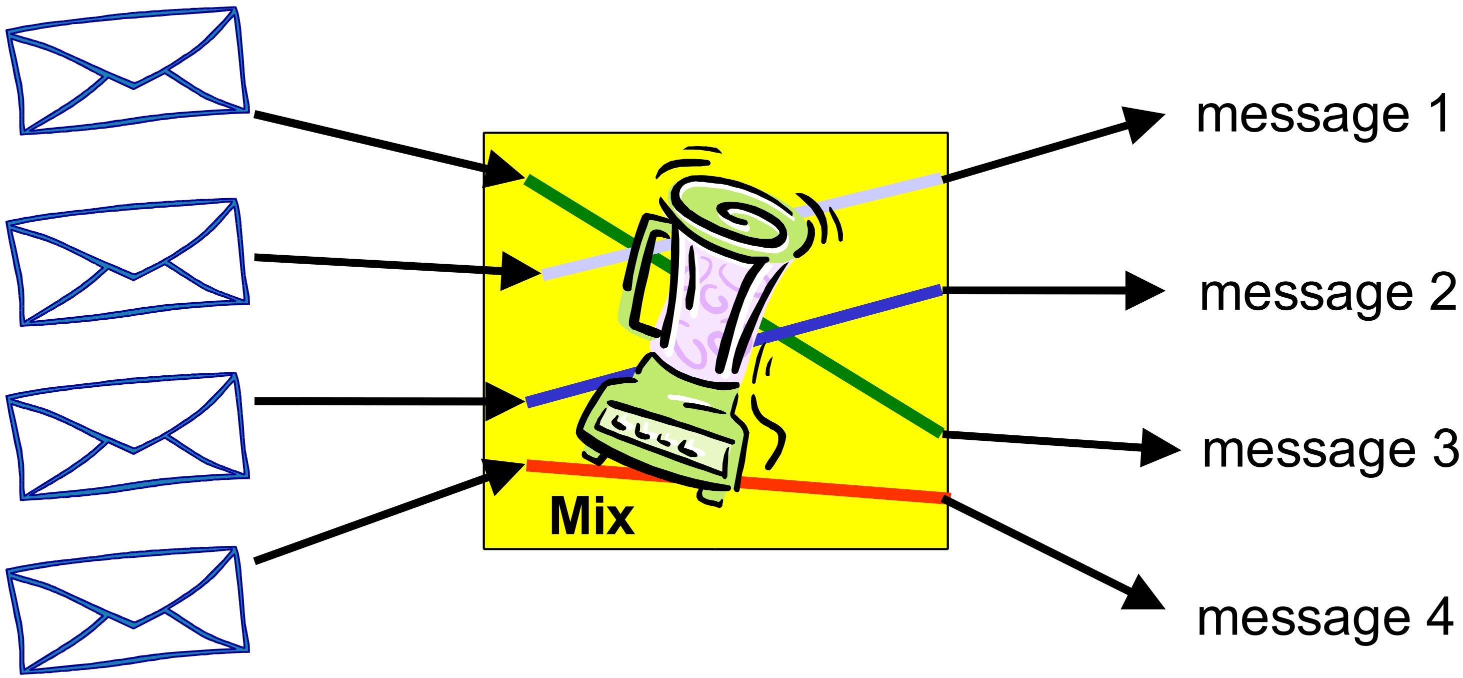
- Note: Anonymous authenticated communication makes perfect sense
- Communicant identification should be inside the basic channel, not a property of the channel

Focus of Tor is anonymity of the communication pipe,
not what goes through it

How Do You Get Communication Anonymity?

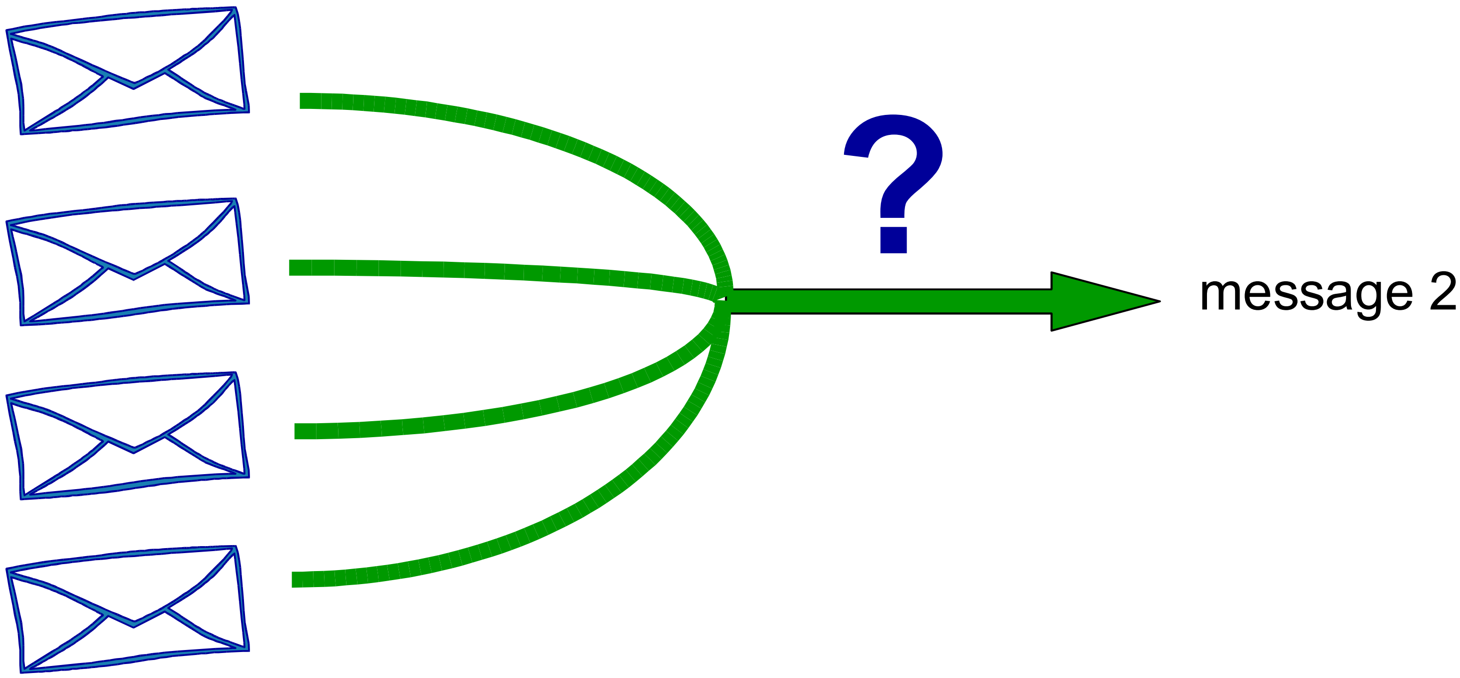
- Many technical approaches
- Overview of two extensively used approaches
  - Mixes
  - Proxies

What does a mix do?



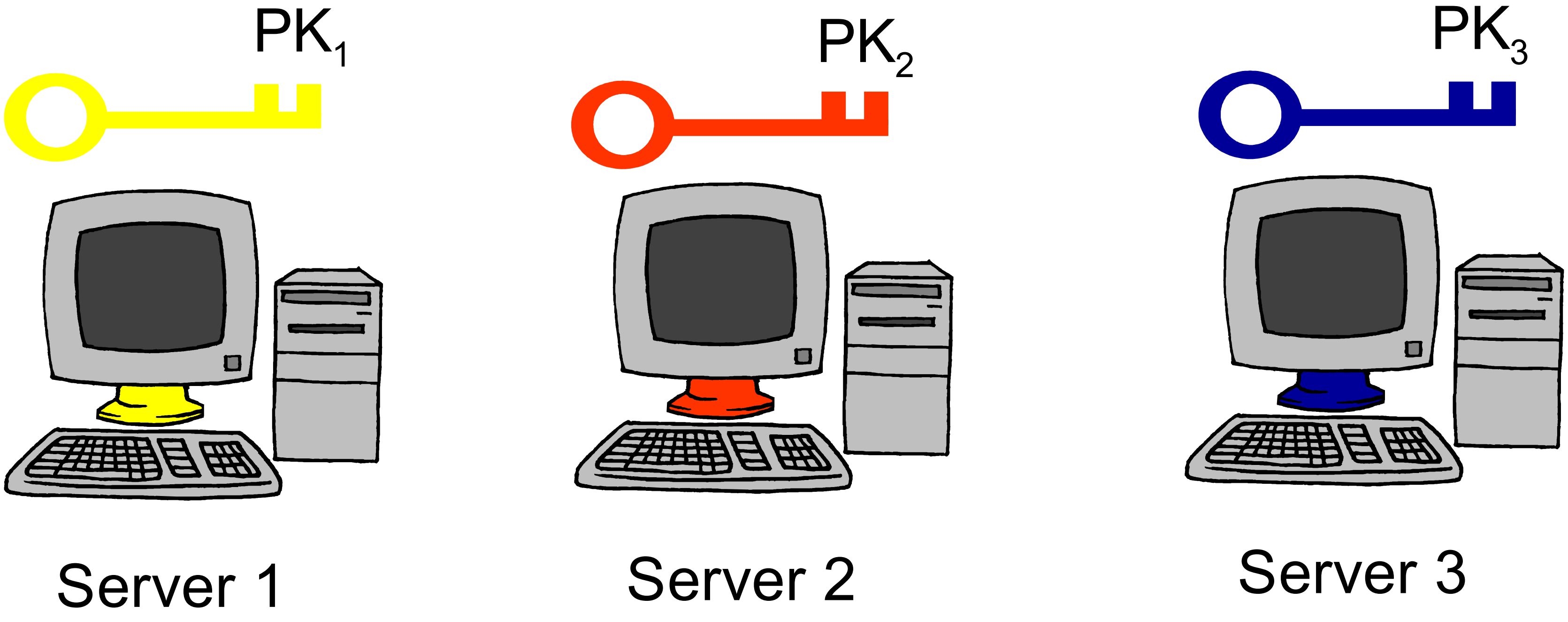
Randomly permutes and decrypts inputs

What does a mix do?

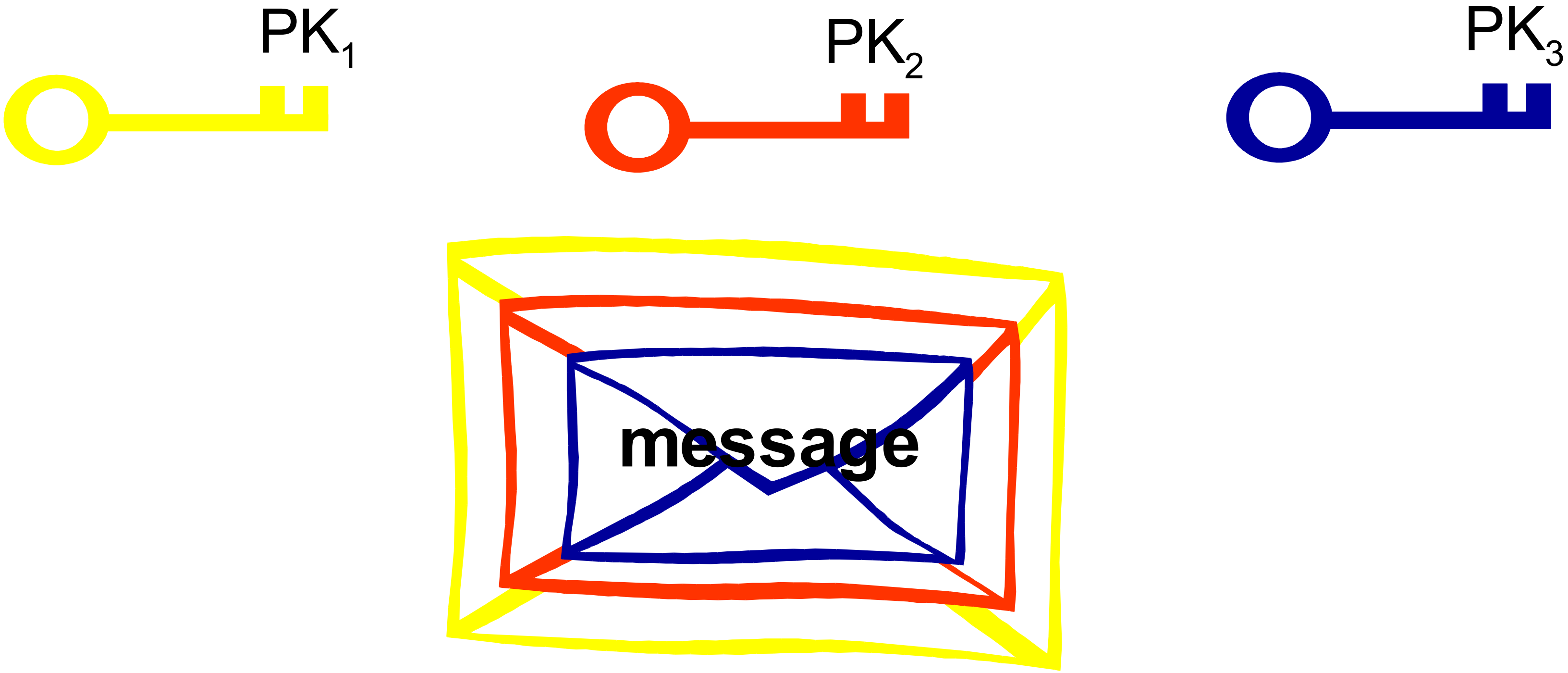


Key property: Adversary can't tell which ciphertext corresponds to a given message

Basic Mix (Chaum '81)

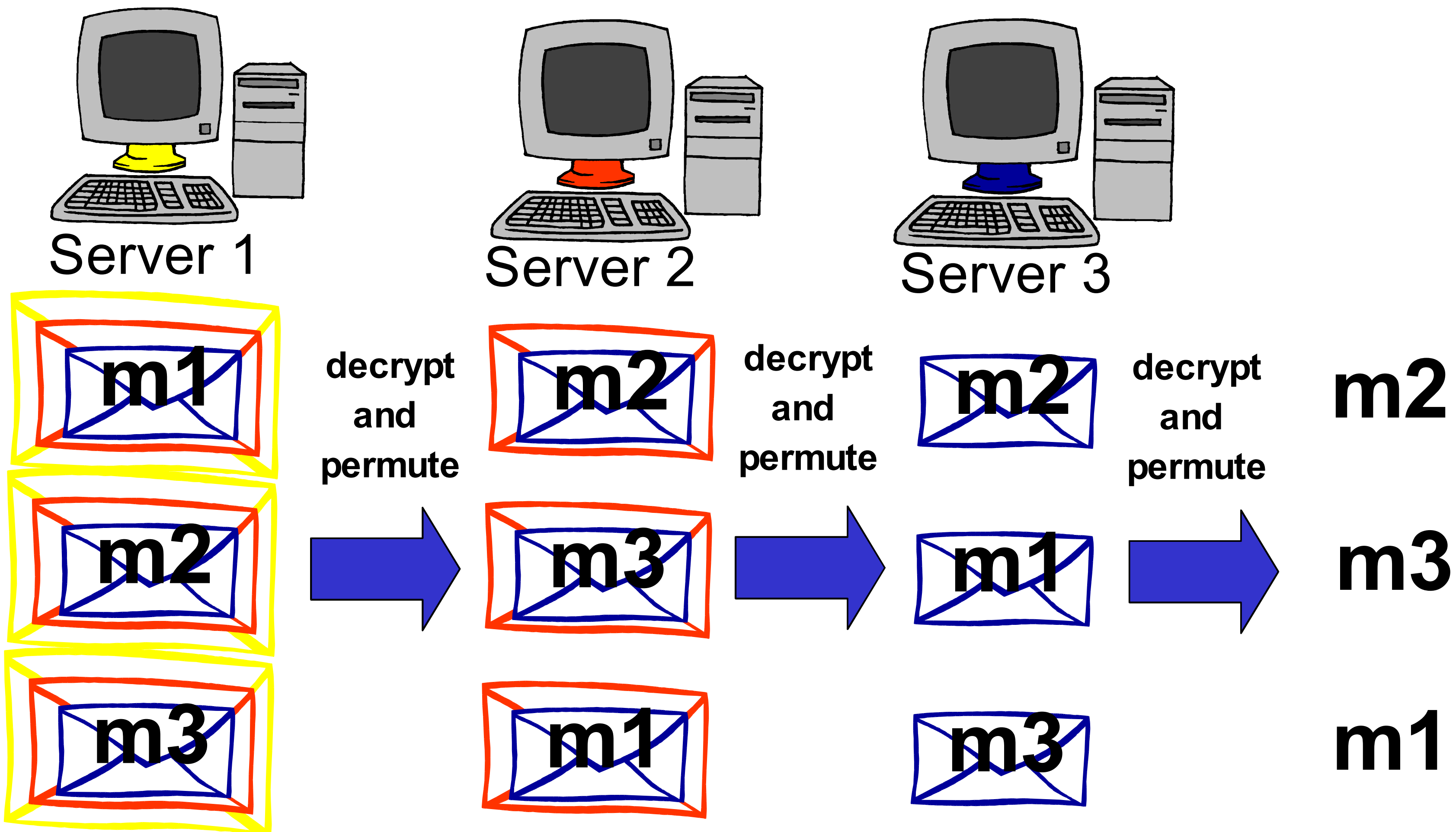


Encryption of Message

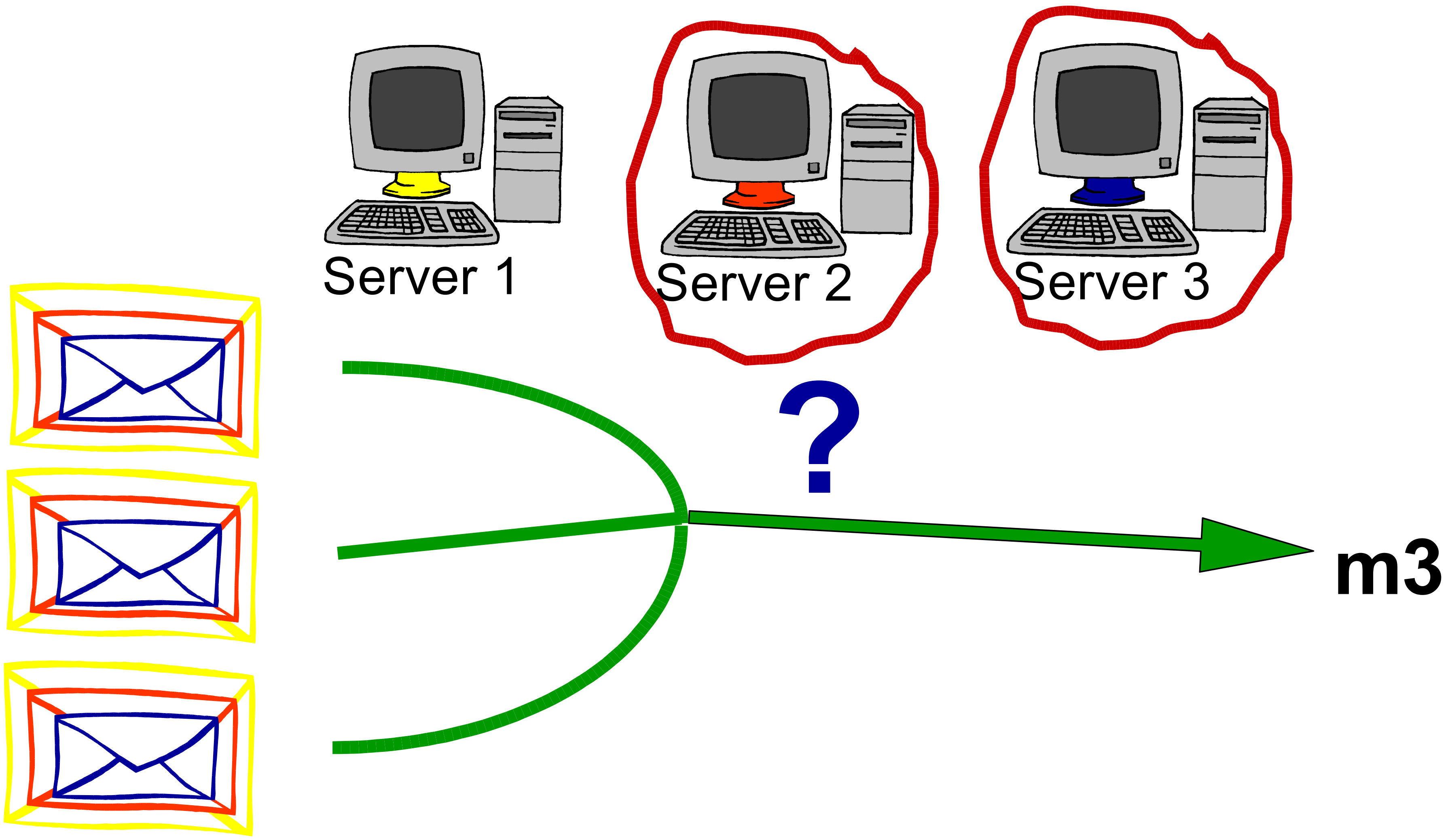


Ciphertext = $E_{PK1}[E_{PK2}[E_{PK3}[\text{message}]]]$

Basic Chaum-type Mix

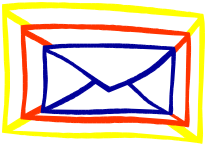


One honest server preserves privacy

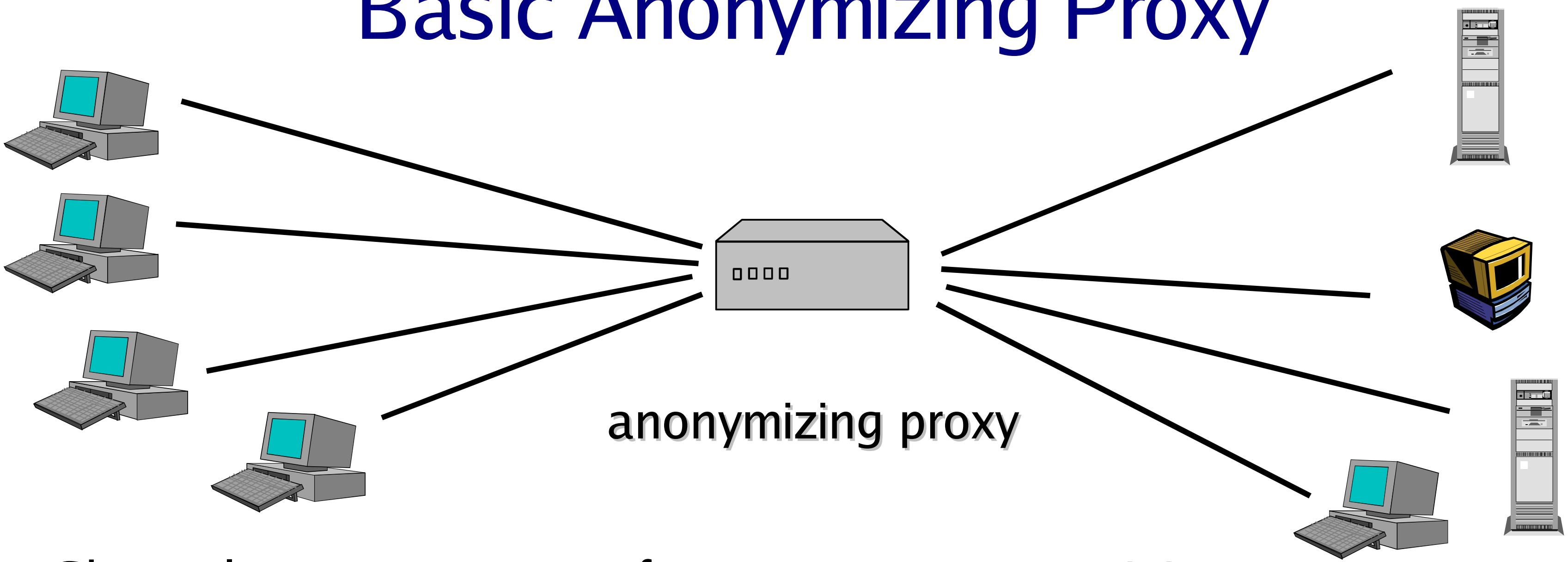


What if you need quick interaction?

- Web browsing, Remote login, Chat, etc.
- Mixnets introduced for email and other high latency apps
- Each layer of message requires expensive public-key crypto



Basic Anonymizing Proxy



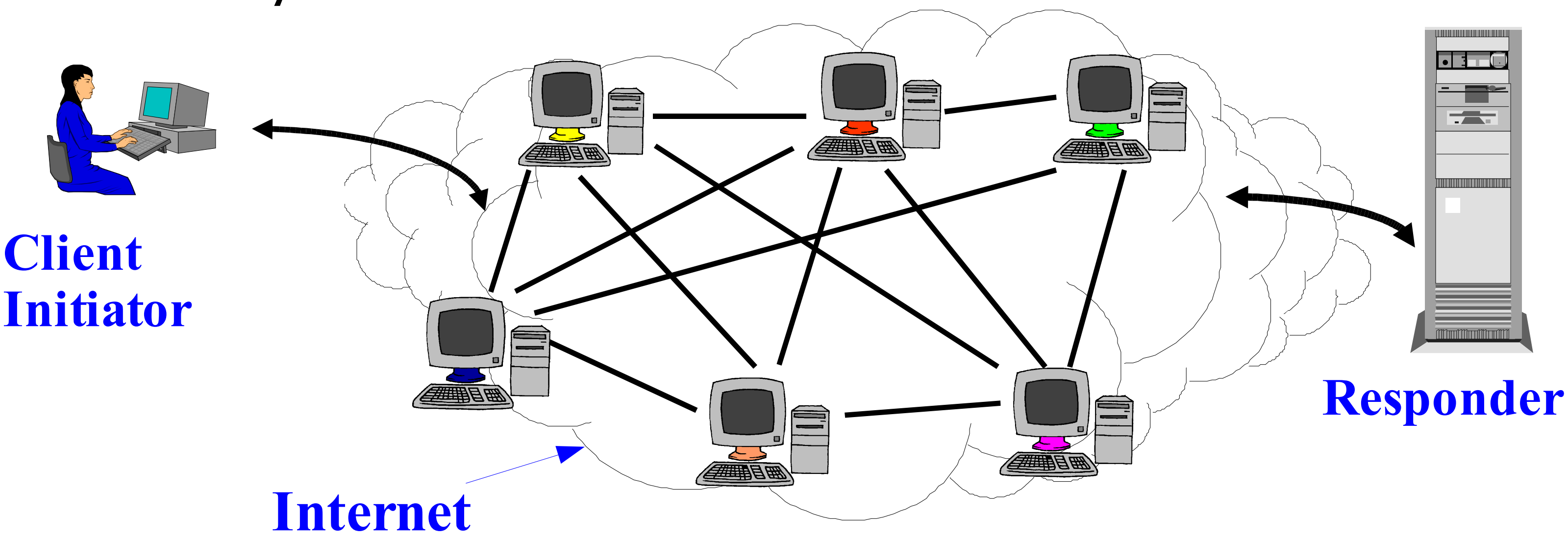
- Channels appear to come from proxy, not true originator
- Appropriate for Web connections, etc.:
  SSL, TLS, SSH (lower cost symmetric encryption)
- Examples: The Anonymizer
- Advantages: Simple, Focuses lots of traffic for more anonymity
- Main Disadvantage: Single point of failure, compromise, attack

Onion Routing
Traffic Analysis Resistant Infrastructure

- Main Idea: Combine Advantages of mixes and proxies
- Use (expensive) public-key crypto to establish circuits
- Use (cheaper) symmetric-key crypto to move data
  - Like SSL/TLS based proxies
- Distributed trust like mixes
- Related Work (some implemented, some just designs):
  - ISDN Mixes
  - Crowds, JAP Webmixes, Freedom Network
  - Tarzan, Morphmix

Network Structure

- Onion routers form an overlay network
  - Clique topology (for now)
  - TLS encrypted connections
- Proxy interfaces between client machine and onion routing overlay network



Tor

Tor

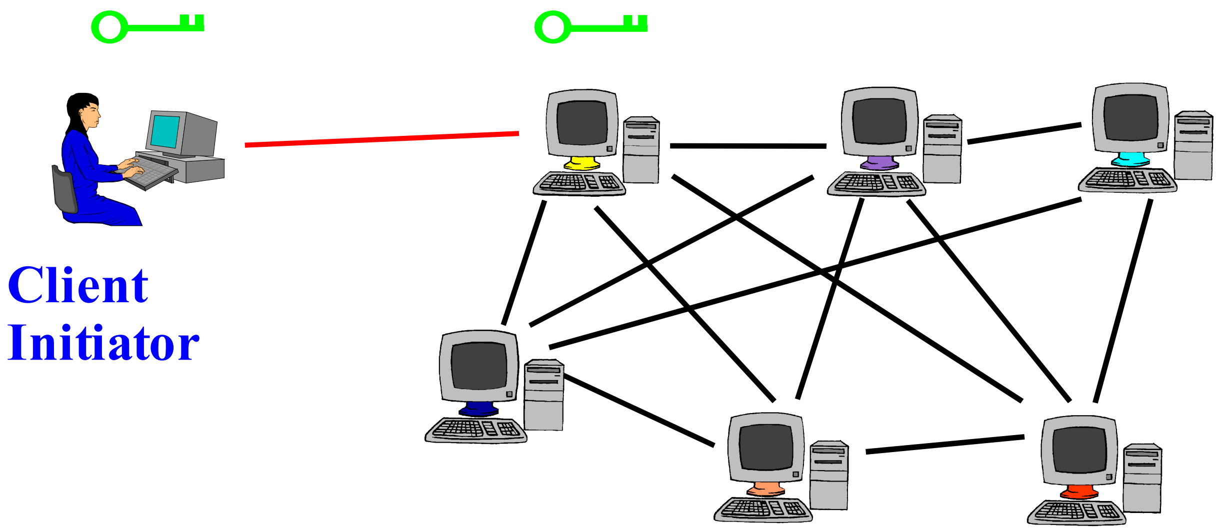
The Onion Routing

Tor

Tor's Onion Routing

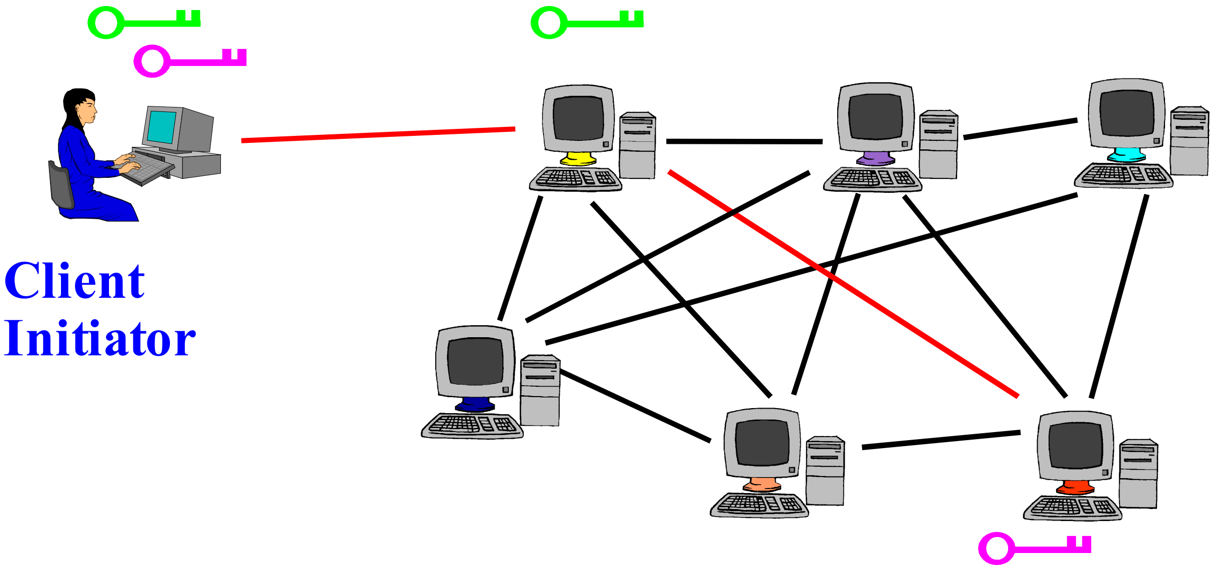
Tor Circuit Setup

- Client Proxy establishes session key + circuit w/ Onion Router 1



Tor Circuit Setup

- Client Proxy establishes session key + circuit w/ Onion Router 1
- Proxy tunnels through that circuit to extend to Onion Router 2



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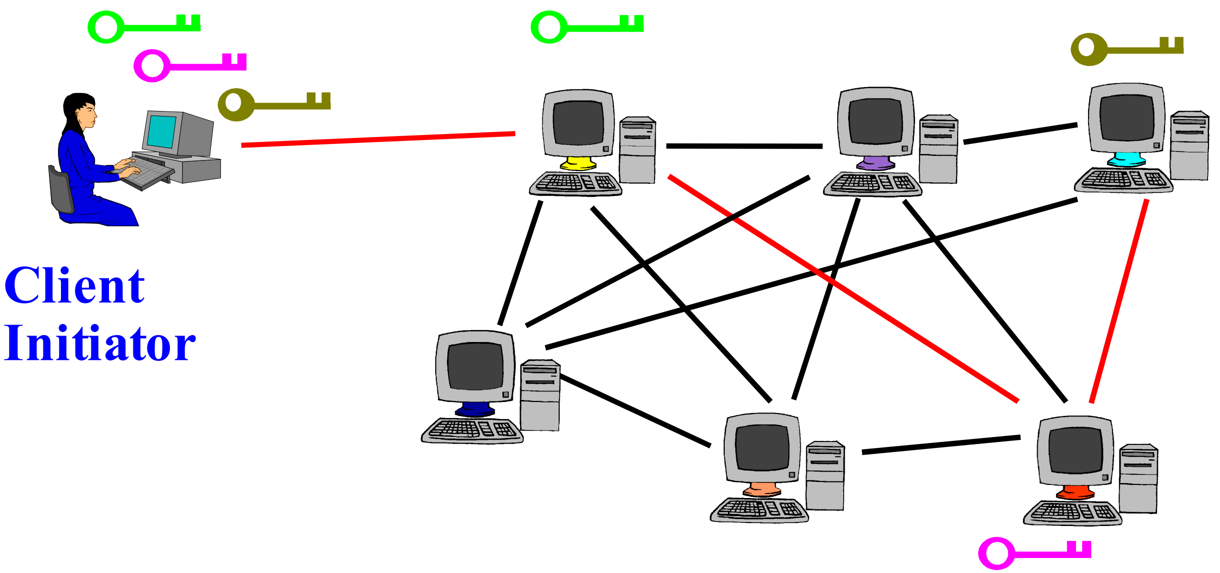

Tor Circuit Usage

- Client Proxy establishes session key + circuit w/ Onion Router 1
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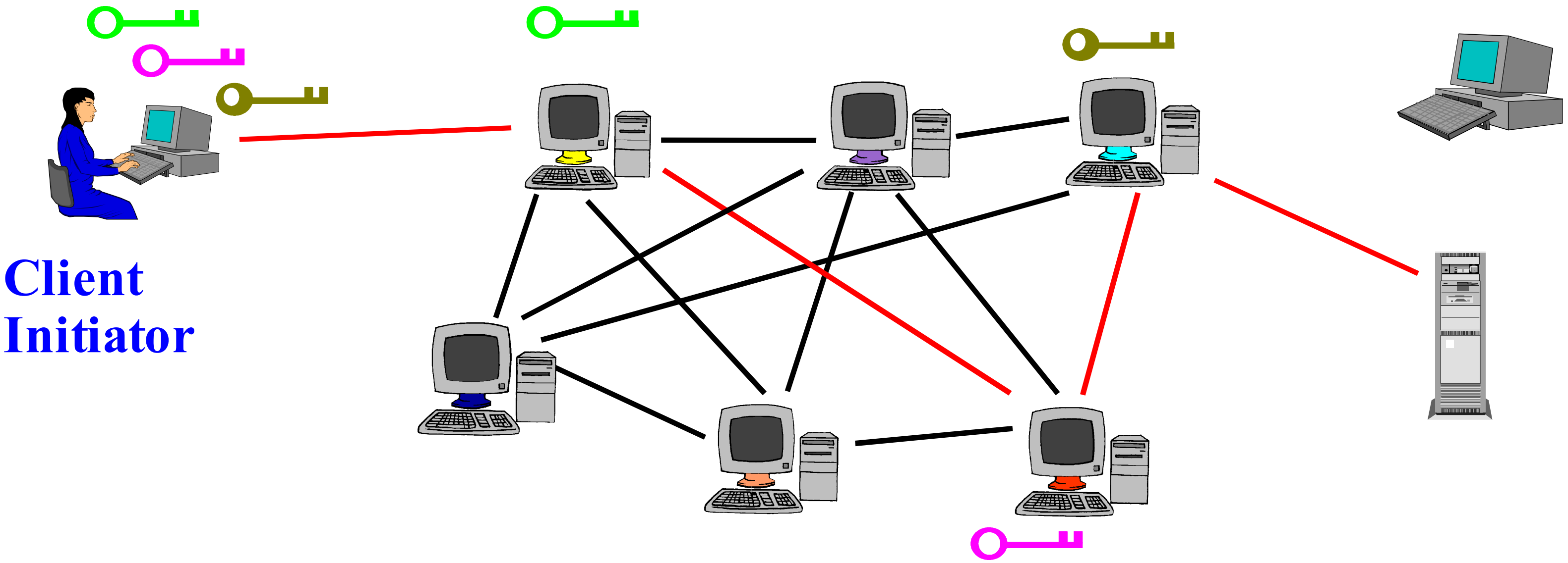
- Client applications connect and communicate over Tor circuit



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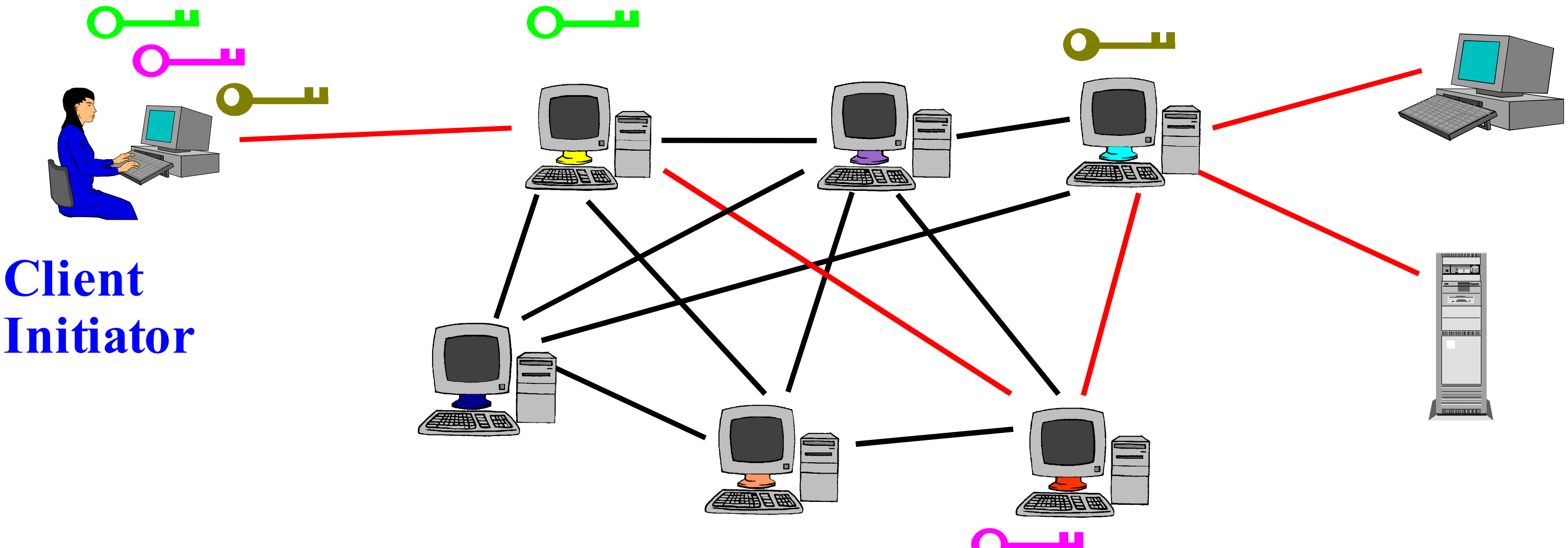

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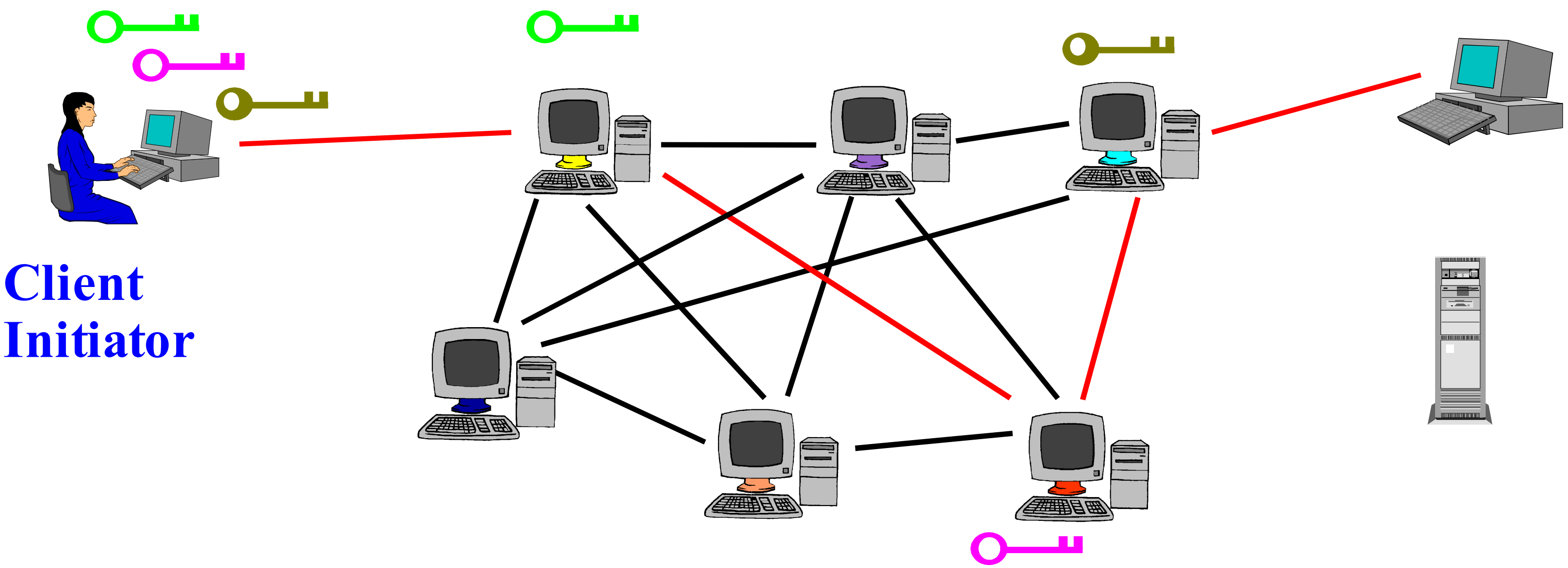


Where do I go to connect to the network?

- Directory Servers
  - Maintain list of which onion routers are up, their locations, current keys, exit policies, etc.
  - Directory server keys ship with the code
  - Control which nodes can join network
    - Important to guard against Sybil attack and related problems
  - These directories are cached and served by other servers, to reduce bottlenecks

Some Tor Properties

- Simple modular design, restricted ambitions.
  - ~30K lines of C code
  - Even servers run in user space, no need to be root
  - Just anonymize the pipe
    - Can use, e.g., privoxy as front end if desired to anonymize data
  - SOCKS compliant TCP: includes Web, remote login, mail, chat, more
    - No need to build proxies for every application
  - Flexible exit policies, each node chooses what applications/destinations can emerge from it

Some Tor Properties

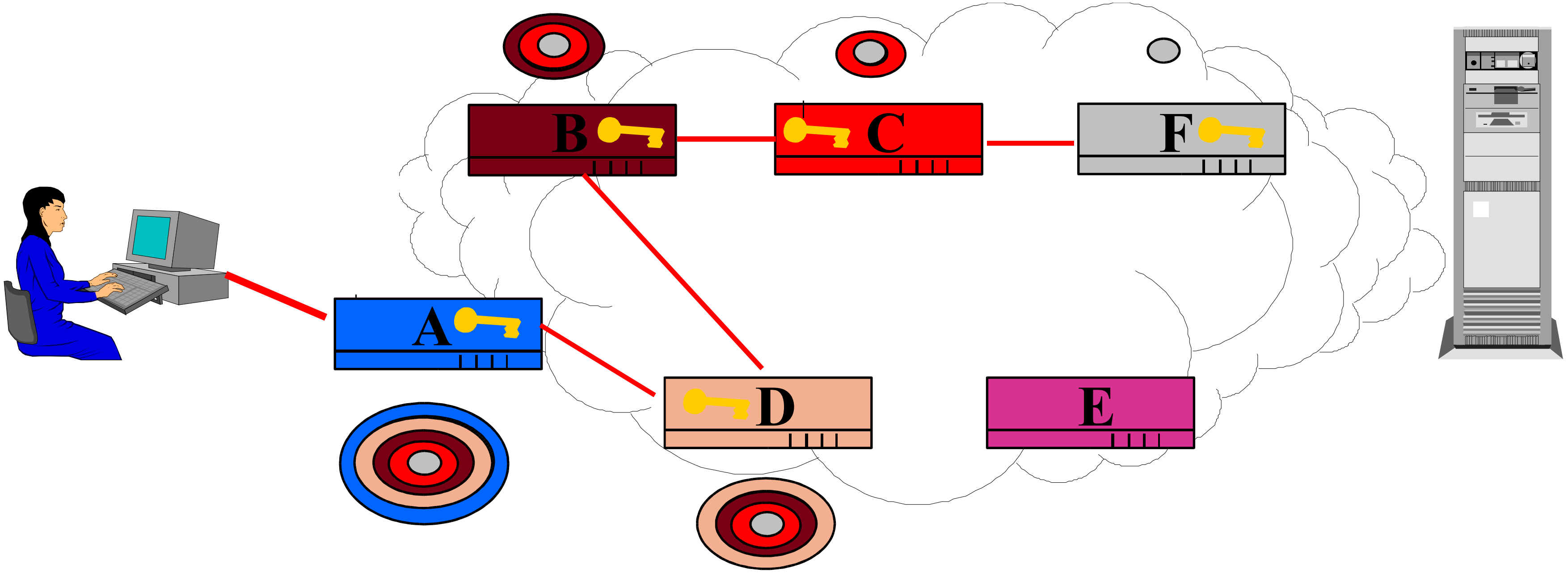
- Lots of supported platforms:
  Linux, BSD, MacOS X, Solaris, Windows, ...
- Many TCP streams (application connections) share one anonymous circuit
  - Less public-key encryption overhead than prior designs
  - Reduced anonymity danger from opening many circuits
  - (but we rotate away from used circuits after a while)

More Tor Properties

- Bandwidth rate limiting
  - Limits how much one OR can send to a neighbor
  - Token bucket approach limits average but permits bursts
- Circuit and stream level throttling
  - Controls congestion
  - Mitigates denial of service that a single circuit can do
- Stream integrity checks
  - Onion Routing uses stream ciphers
  - We must prevent, e.g., reasonable guess attack

    XOR out '`dir `' and XOR in '`rm *`'

Generations 0 and 1 Circuit Setup



- Each layer of the onion identifies the next hop in the route and contains the cryptographic keys to be used at that node.

More Tor Advantages

- No need to keep track of onions to prevent replay
  - There are no onions anymore
  - Even a replayed create cell will result in a new session key at an honest onion router
- Perfect Forward Secrecy
  - Storing all traffic sent to a node and later breaking its public key will not reveal encrypted content

Numbers and Performance

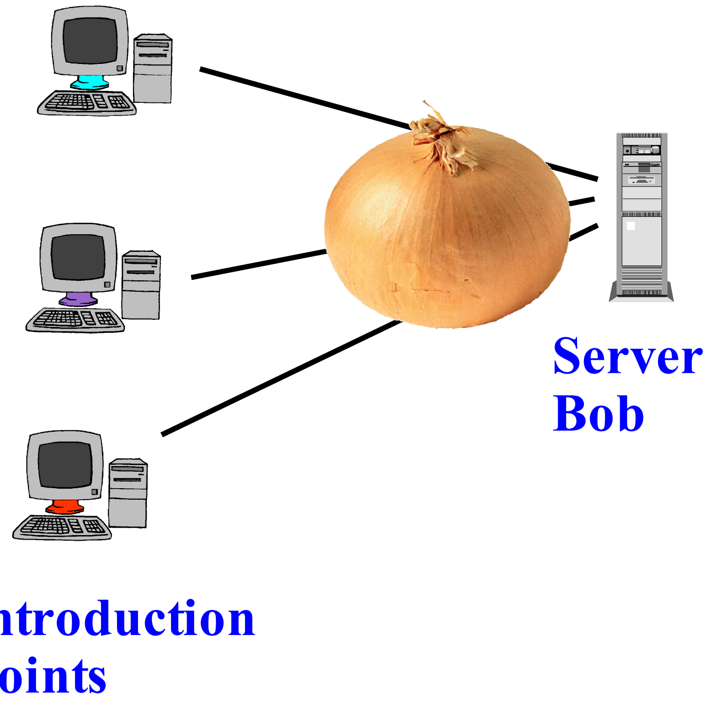
- Running since October 2003
- 150 nodes on five continents (North America, South America, Europe, Asia, Australia)
- Ten thousand(?) users
- Nodes process 1-90 GB / day application cells
- Network has never been down

Location Hidden Servers

- Alice can connect to Bob's server without knowing where it is or possibly who he is
- Can provide servers that
  - Are accessible from anywhere
  - Resist censorship
  - Require minimal redundancy for resilience in denial of service (DoS) attack
  - Can survive to provide selected service even during full blown distributed DoS attack
  - Resistant to physical attack (you can't find them)
- How is this possible?

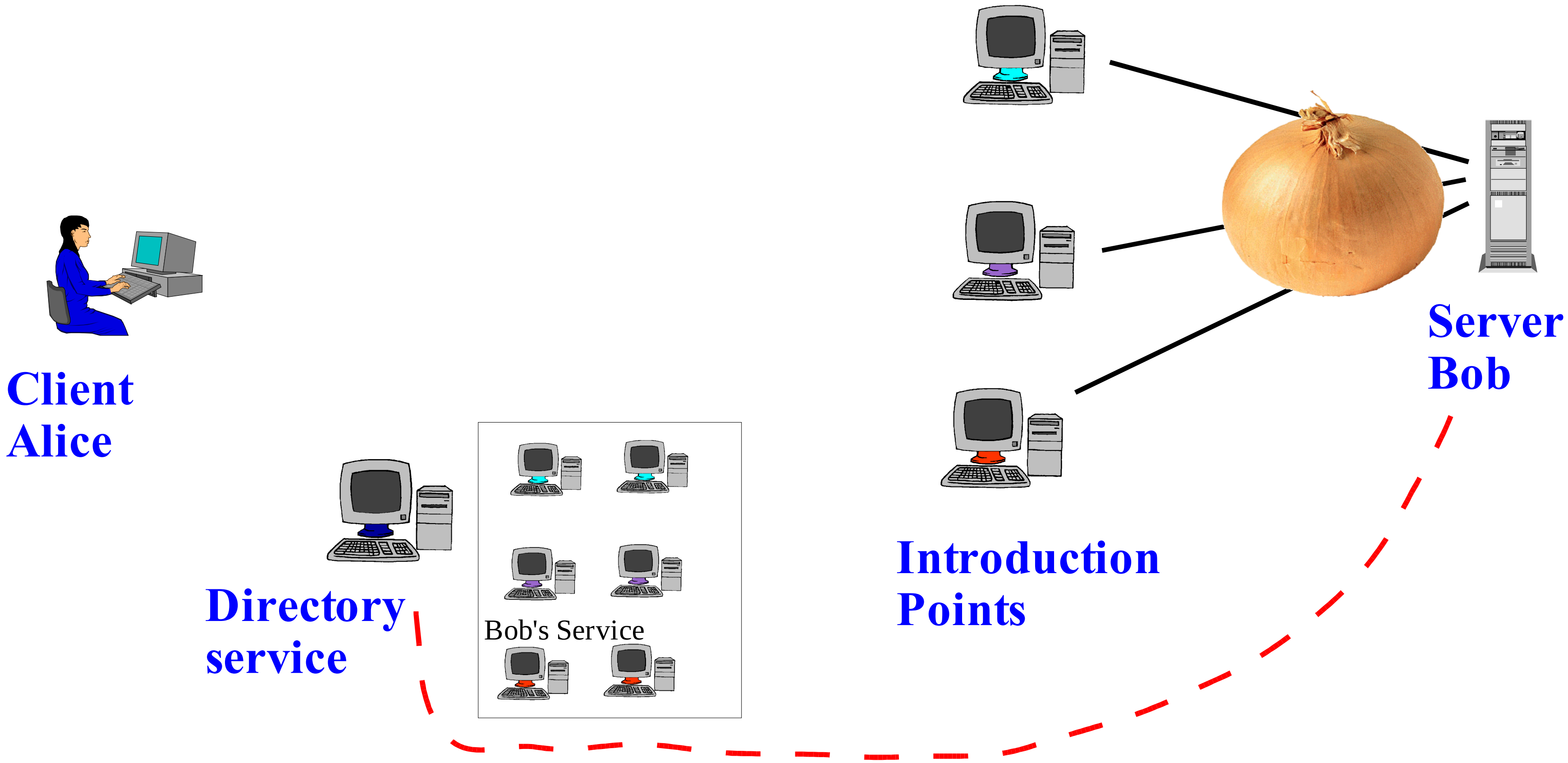
Location Hidden Servers

1. Server Bob creates onion routes to Introduction Points (IP)



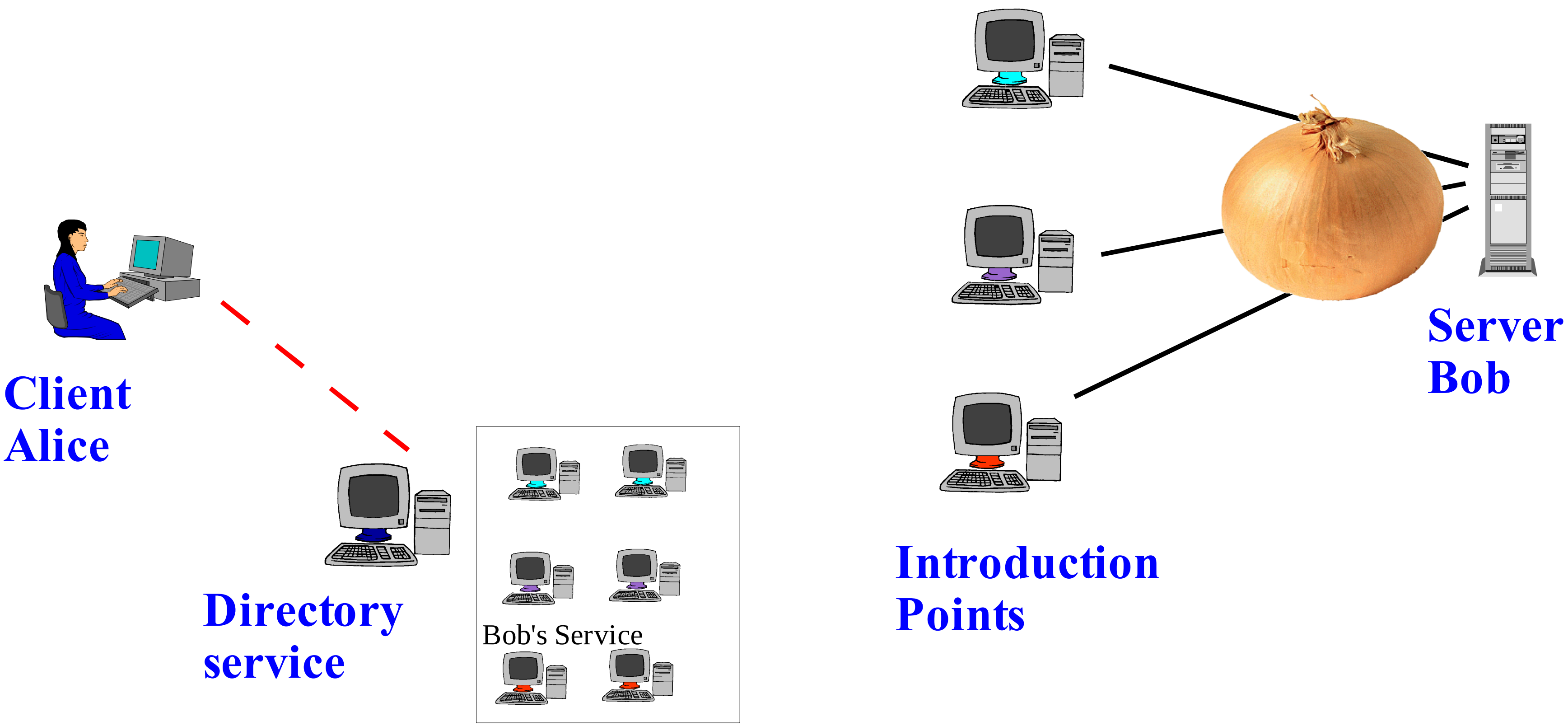
Location Hidden Servers

1. Server Bob creates onion routes to Introduction Points (IP)
2. Bob gets Service Descriptor incl. Intro Pt. addresses to Alice
   - In this example gives them to Service Lookup Server



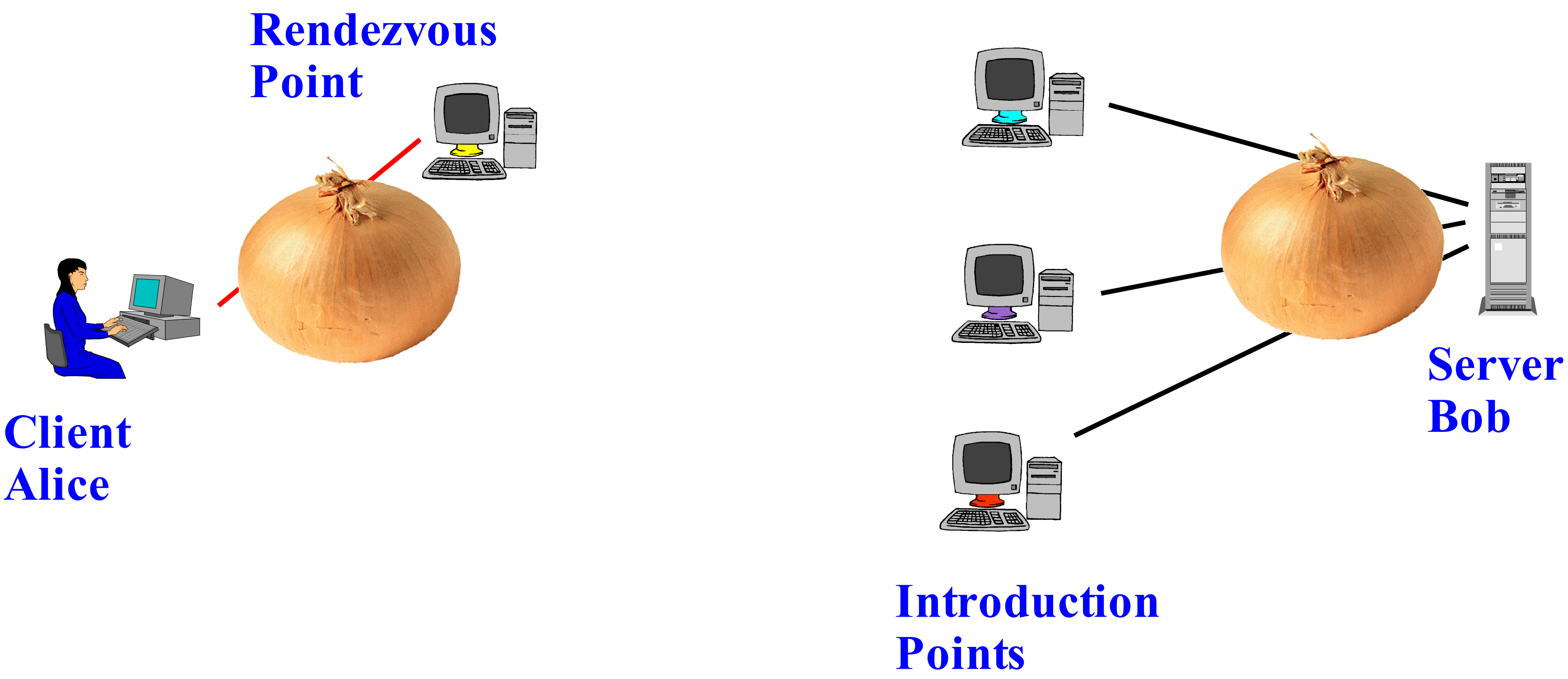
Location Hidden Servers

2'. Alice obtains Service Descriptor (including Intro Pt. address) at Lookup Server



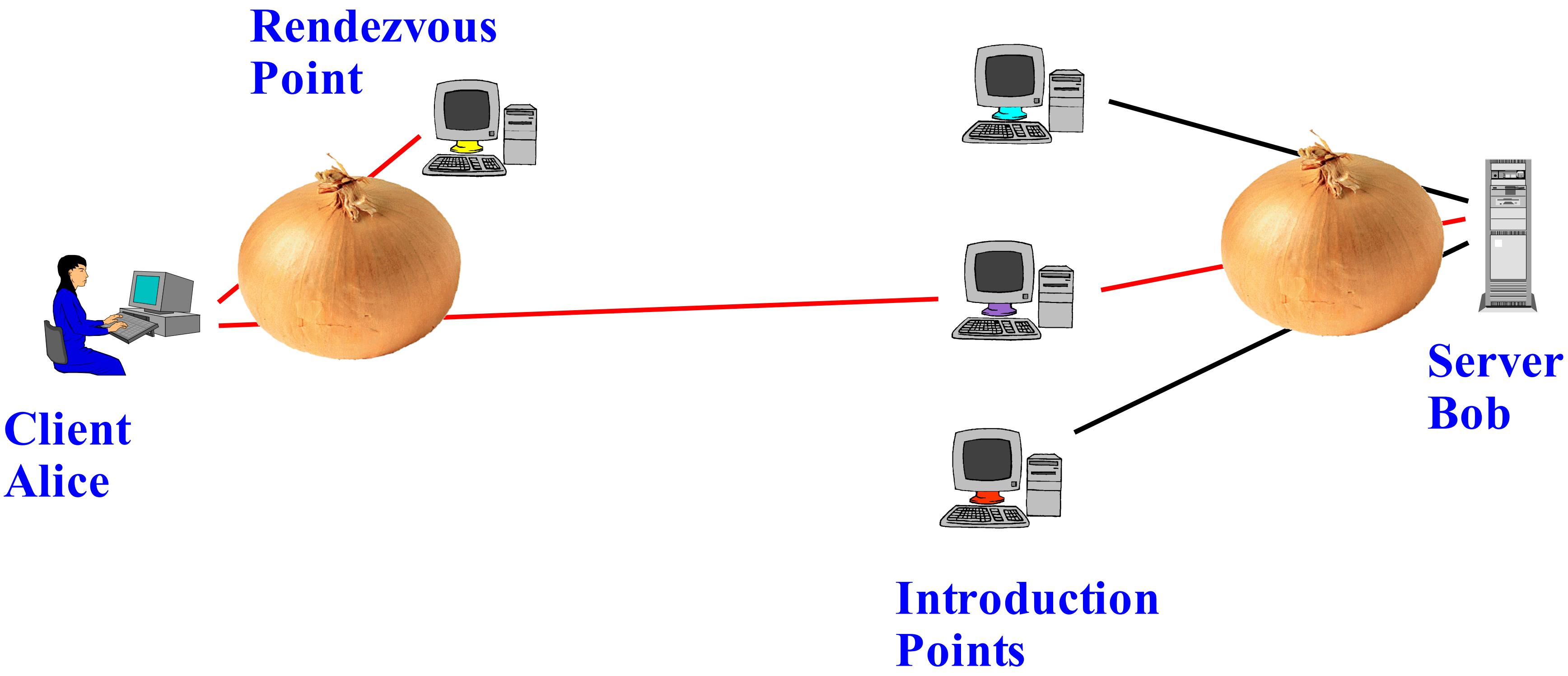
Location Hidden Servers

3. Client Alice creates onion route to Rendezvous Point (RP)



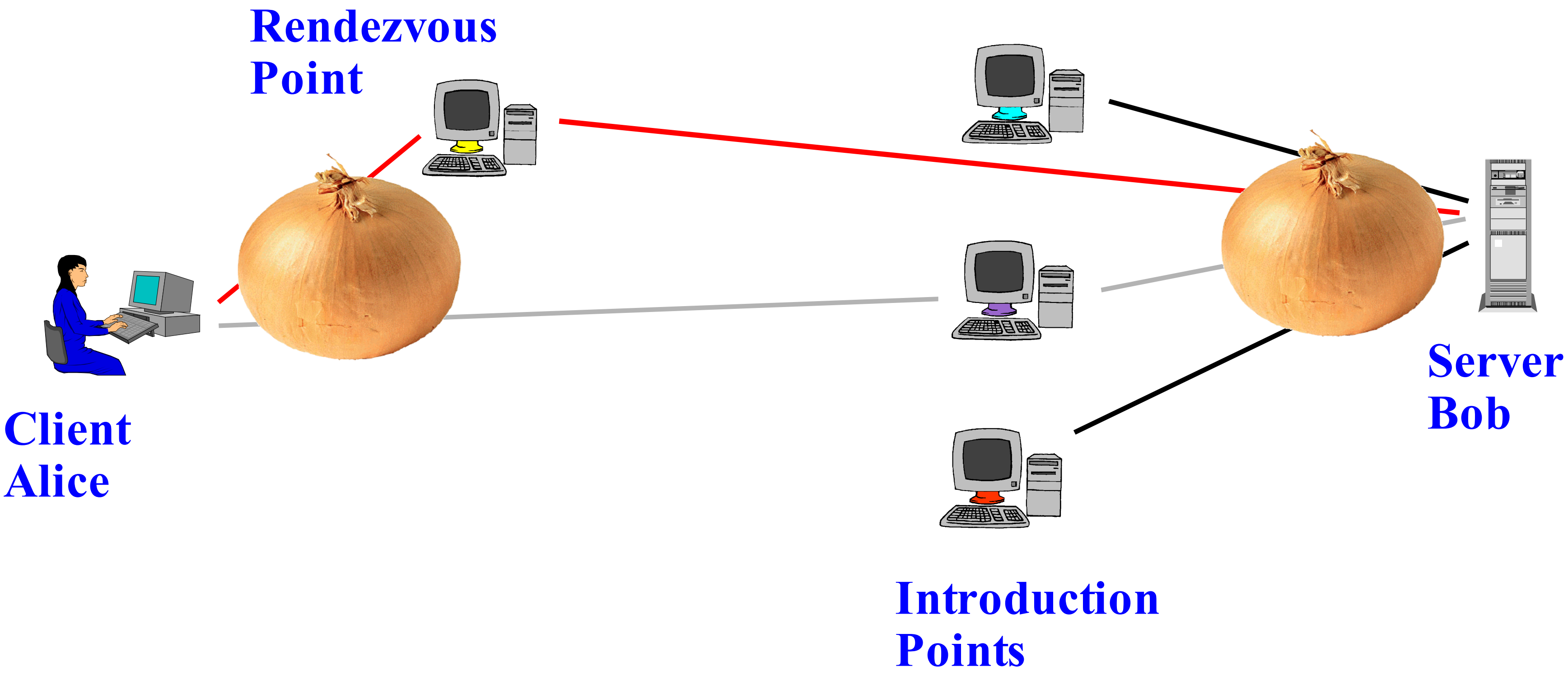
Location Hidden Servers

3. Client Alice creates onion route to Rendezvous Point (RP)
4. Alice sends RP addr. and any authorization through IP to Bob



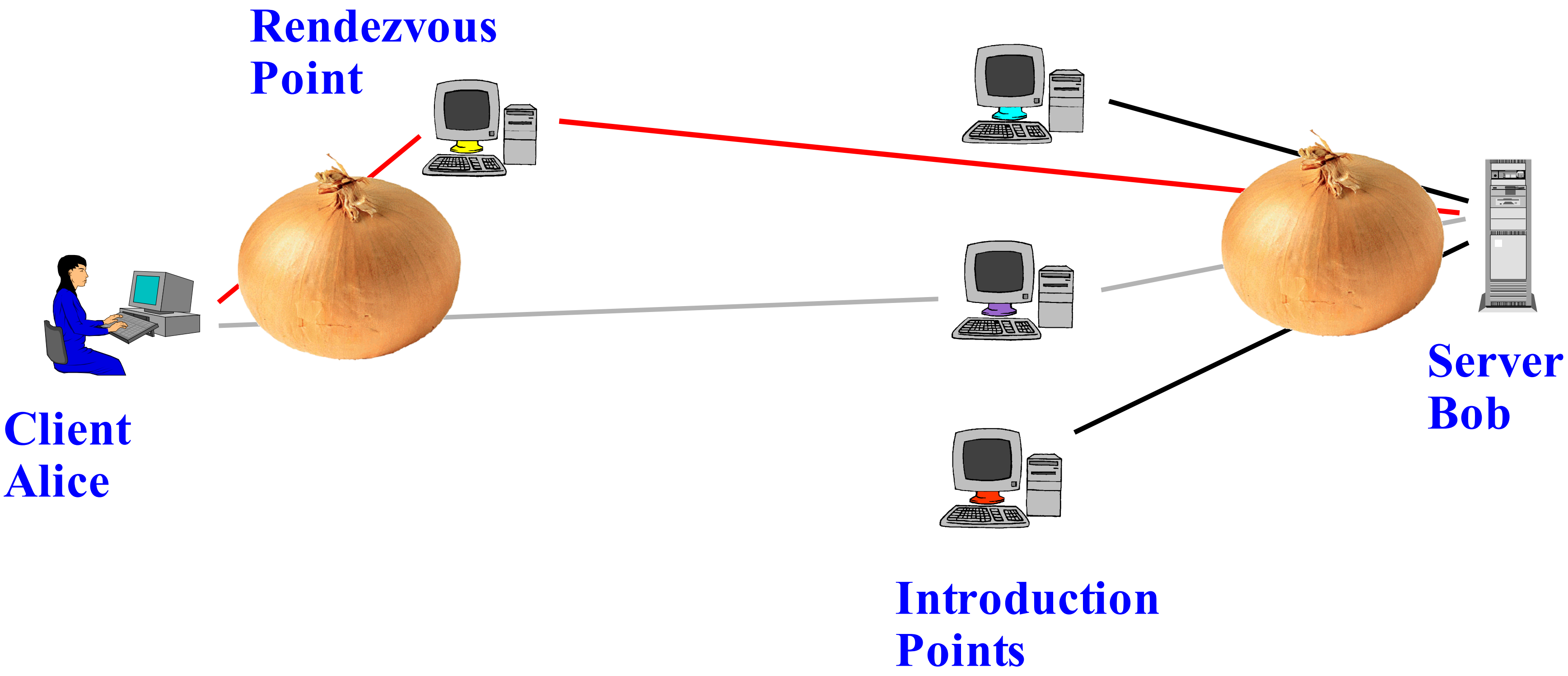
Location Hidden Servers

5. If Bob chooses to talk to Alice, connects to Rendezvous Point



Location Hidden Servers

5. If Bob chooses to talk to Alice, connects to Rendezvous Point
6. Rendezvous point mates the circuits from Alice and Bob



How do we compare Tor's security?

Assume the adversary owns c of the n nodes.

(he can choose which)

What's the chance for a random Alice talking to a random Bob that the adversary learns they are linked?

- Freedom, Tor: c^2/n^2 (10 of 100 => 1%)
- Peekabooty, six-four, freenet: c/n (10 of 100 => 10%)
- JAP: c^2/(n/2)^2 (10 of 100 => 4%)
- Anonymizer: 1 if c>0

Get the Code, Run a Node!
(or just surf the web anonymously)

- Current code freely available (3-clause BSD license)
- Comes with a specification – the JAP team in Dresden implemented a compatible Tor client in Java
- Design paper, system spec, code, see the list of current nodes, etc.
- http://tor.eff.org/

Packet-level vs. Stream-level

- IP packets reveal OS characteristics
- Need kernel hooks to grab / push packets
- TLS for UDP is hard
- Tagging / malleability attacks still a problem
- Still need sequence numbers, etc for crypto and for detecting duplicate frames.
- Need application-level scrubbing; and DNS requests to your local DNS server leak info.
- Exit policies turn into IDS policies?!
- But, solves DNS problem, and do more protocols.

Tradeoffs

- Low-latency (Tor) vs. high-latency (Mixminion)
- Packet-level vs stream-level capture
- Padding vs. no padding (mixing, traffic shaping)
- UI vs. no UI
- AS-level paths and proximity issues
- Incentives to run servers / allow exits
- Enclave-level onion routers / proxies / helper nodes
- Path length? (3 hops, don't reuse nodes)
- Abuse?
- China?
- P2P network vs. static network