CIS 551 / TCOM 401

Computer and Network Security

Spring 2008

Lecture 23

Announcements

- Project 4 is Due Friday May 2nd at 11:59 PM

- Final exam:
  - Friday, May 12th. Noon - 2:00pm DRLB A6

- Today:
  - Last details about voting
  - Secret sharing
  - Anonymity / Onion Routing / Crowds
    - Slides adapted from some by Levente Buttyán

Blind Signatures

- Digital signature scheme equipped with a commutative *blinding* operation
  - Signer never learns what they signed
  - Like signing an envelope with a window (or with carbon paper)
  - I.e.: unblind(sign(blind(m))) = sign(m)

- Voting scheme:
  - Voter prepares vote *v*, blinds, and authenticates to Authorization server, and sends vote. Server checks off voter, signs vote, and sends back to voter. Voter unblinds and now has sign(*v*).
  - Voter anonymously sends sign(*v*) to Tabulation server. Server checks signature, then counts vote.

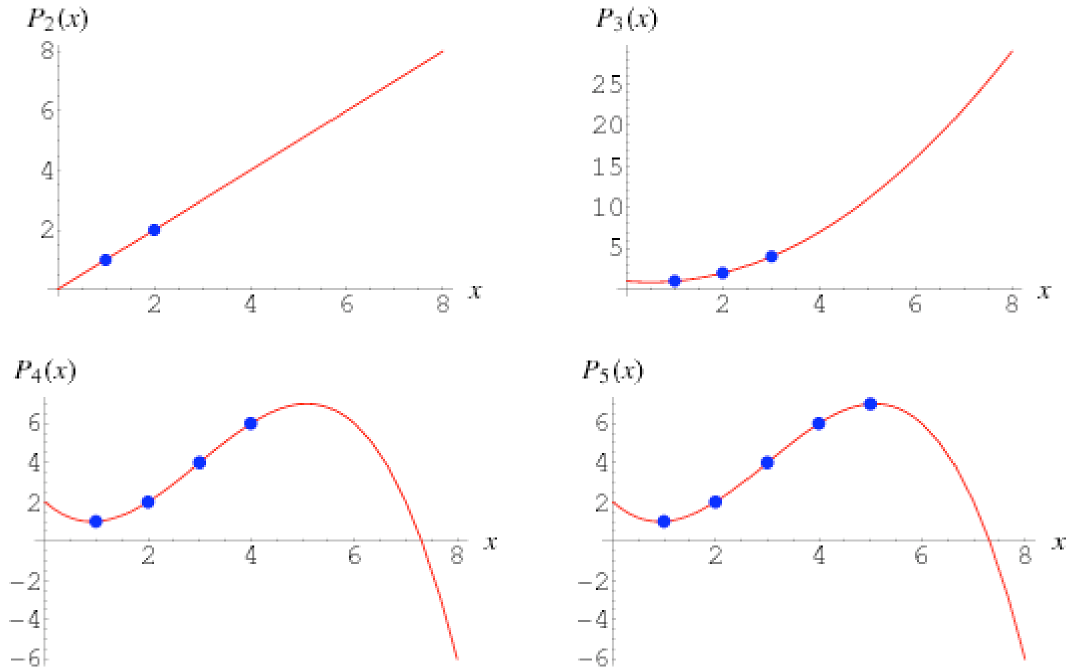
Homomorphic Encryption

- A *homomorphic* encryption scheme has an operator ★ such that Enc(m) ★ Enc(n) = Enc(m ★ n). ★ is usually either + or ×, never both.
  - E.g. both RSA and El Gamal have ×.
- Voting scheme:
  - Suppose scheme has + as homomorphism and votes are either 0 or 1.
  - Voter prepares Enc(0) or Enc(1) as vote, authenticates to Tabulation server, and submits vote.
  - Tabulation server sums all the votes, then decrypts result. Individual votes never decrypted.
- Need additional checks to ensure that the voters don't cheat by submitting Enc(2) or Enc(-17)
  - Civitas Solution: use a zero knowledge proof that shows the vote is a re-encryption of either 0 or 1.
  - Theory due to Hirt & Sako

Secret Sharing

- How to share a secret among N+1 players:
  - Owner of the secret generates N random bitstrings R1 … RN
  - Player 0 gets $S \oplus R1 \oplus \ldots \oplus RN$
  - Player j > 0 gets Rj
  - All N players can cooperate to recover S -- they just XOR their shares.
- *Threshold* schemes allow k-out-of-N players to recover the secret:
  - Owner of the secret picks a random polynomial f with degree (k-1) such that f(0) = S
  - Player j > 0 gets f(j)
  - If any k players get together, they can use Lagrange interpolation to calculate f(0)
  - If fewer than k players get together, there's no information about f(0).

Lagrange Interpolation



The Lagrange interpolating polynomial is P(x) that passes through n points: $(x_1, y_1 = f(x_1)), \ldots, (x_n, y_n = f(x_n))$

$$P(x) = \frac{(x-x_2)(x-x_3)\cdots(x-x_n)}{(x_1-x_2)(x_1-x_3)\cdots(x_1-x_n)}\,y_1 + \frac{(x-x_1)(x-x_3)\cdots(x-x_n)}{(x_2-x_1)(x_2-x_3)\cdots(x_2-x_n)}\,y_2 + \cdots + \frac{(x-x_1)(x-x_2)\cdots(x-x_{n-1})}{(x_n-x_1)(x_n-x_2)\cdots(x_n-x_{n-1})}\,y_n.$$

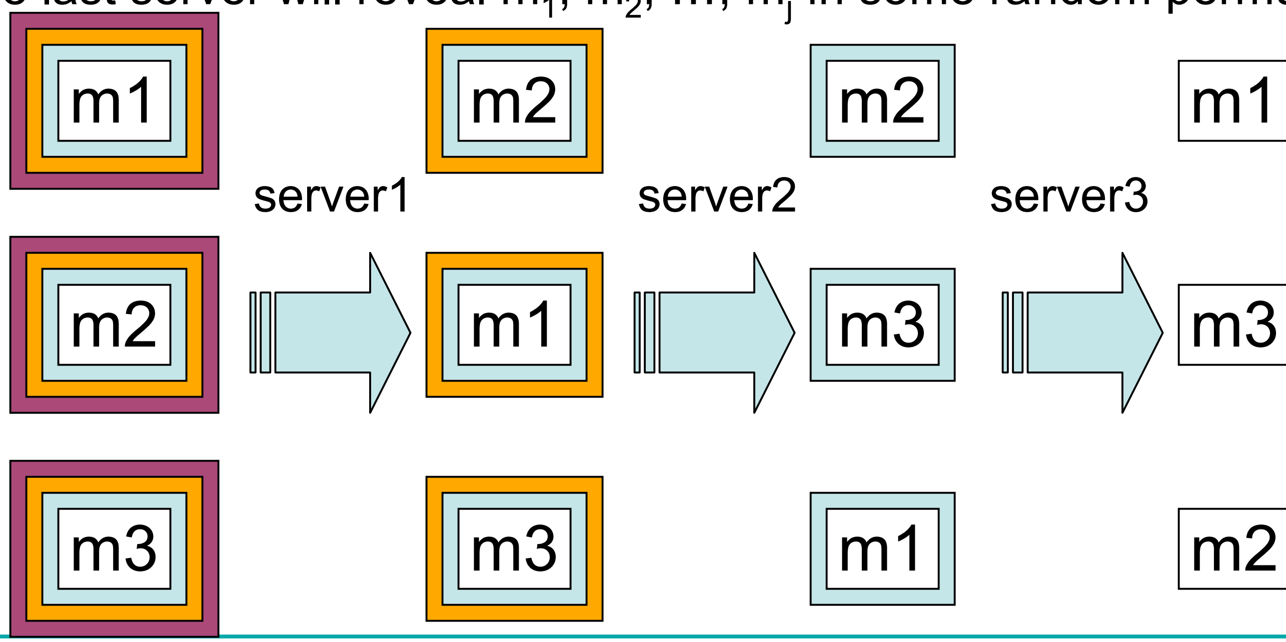
Example: 3-out-of-N Secret

- Suppose the secret is S = 7
- I generate (at random) $f(x) = 2x^2 - 3x + 7$
- Then S = f(0) = 7
  - Share s1 = f(1) = 6
  - Share s2 = f(2) = 9
  - Share s3 = f(3) = 16
  - Share s4 = f(4) = 27

- To recover secret and obtain 3 shares:
  - Example: given s2, s3, s4 = (2,9) (3,16) (4,27)
  - Calculate P(x) as on the previous slide [see blackboard]

Mix networks: Anonymity

- Chaum 1981: Basic Mix network
- Suppose that there are N servers with public keys $K_1 \ldots K_N$.
- A mix message M_a looks like: $K_1\{K_2\{\ldots K_N\{m_a\}\ldots\}\}$
- To anonymize a set of messages $M_1, M_2, \ldots, M_j$:
  - Server i decrypts the messages, permutes them, and forwards them to server i+1
  - The last server will reveal $m_1, m_2, \ldots, m_j$ in some random permutation:



Mix Networks

- Original Chaumian decryption mix:
  - Implemented with set of servers
  - Input: list of encrypted values
    - Enc(Enc(Enc(…c…)))
  - Output: same list, decrypted
    - But order of list permuted
  - Each server in mix permutes list and removes one layer of encryption
- Civitas based on a re-encyprtion mix network
  - Input: List of encrypted messages
  - Output: Permuted list of re-encrypted messages
  - Re-encryption in El Gamal requires only the public key

Mix Network Voting Schemes

- Voting scheme:
  - Voter encrypts vote, authenticates to Ballot Box server, submits vote.
  - Set of tabulation tellers run a mixnet over the encrypted votes, resulting in random permutation of votes.
  - Permuted list is decrypted and tallied.

Preserving web privacy

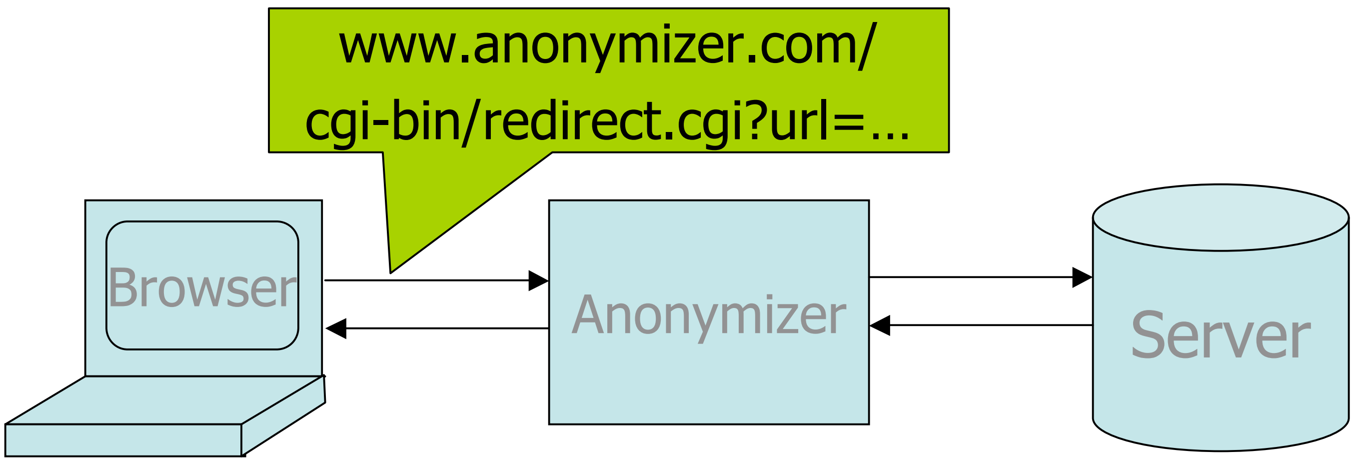
- Your IP address may be visible to web sites
  - This may reveal your employer, ISP, etc.
  - Can link activities on different sites, different times
- Can you prevent sites from learning about you?
  - Anonymizer
    - Single site that hides origin of web request
  - Crowds
    - Distributed solution
  - Onion Routing
    - Unlinkability of sender and receiver

Anonymity?

- Sender anonymity:
  - The identity of the sender is hidden, while the receiver (and message) might not be
- Receiver anonymity:
  - The identity of the receiver is hidden (message and sender might not be)
- Unlinkability of sender and receiver:
  - Although the sender and receiver can be identified as participating in communication, they cannot be identified as communicating *with each other*.

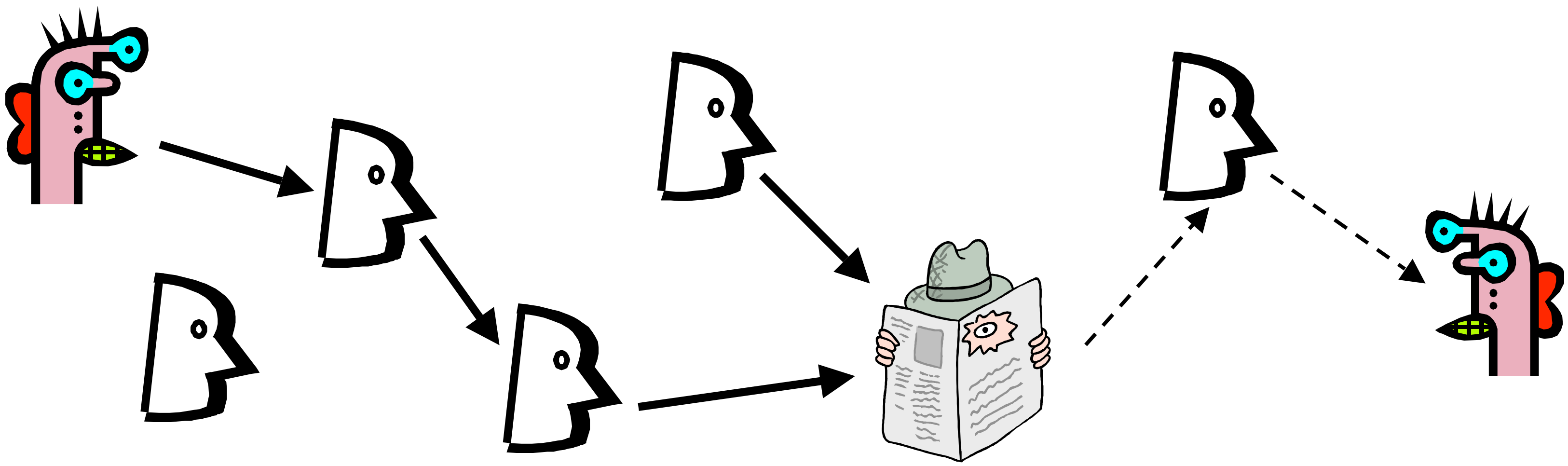
Browsing Anonymizers

- Anonymizer.com
- Web Anonymizer hides your IP address



- What does anonymizer.com know about you?

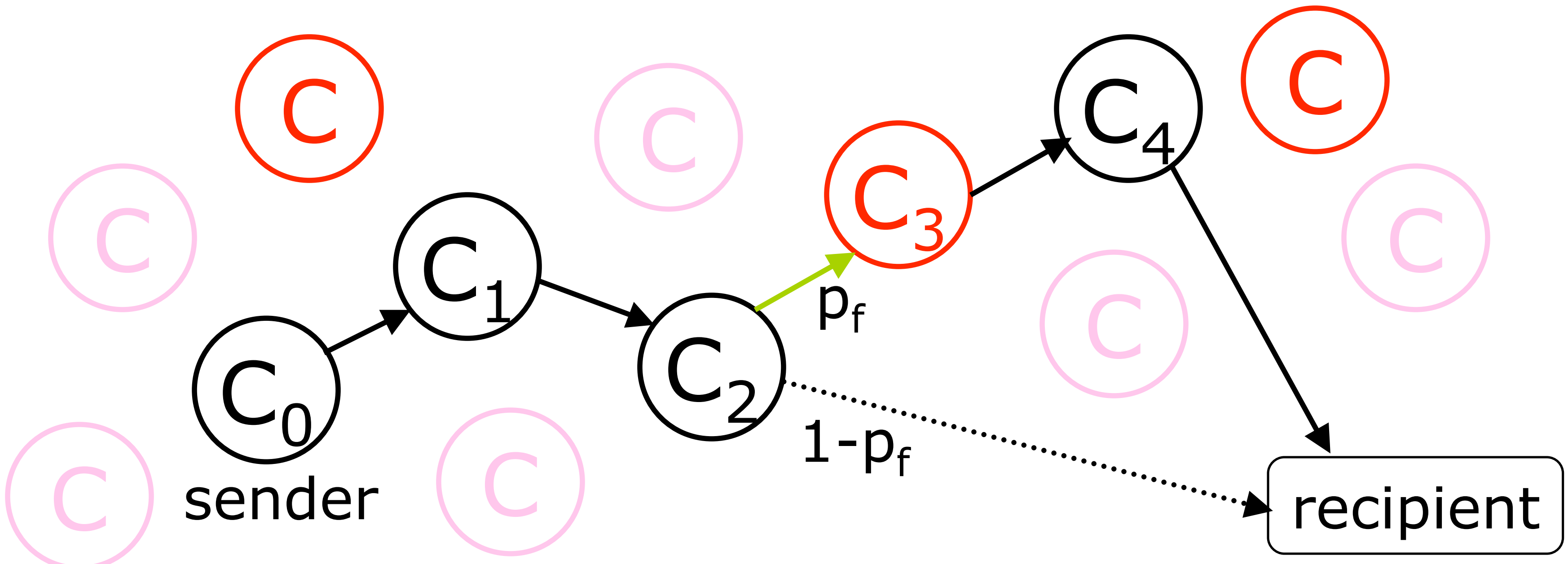
Related approach to anonymity



- Hide source of messages by routing them randomly
- Routers don't know for sure if the apparent source of the message is the actual sender or simply another router
  - Only secure against <u>local</u> attackers!
- Existing systems: Freenet, Crowds, etc.

Crowds

http://avirubin.com/crowds.pdf [Reiter,Rubin '98]



- Sender randomly chooses a path through the crowd
- Some routers are honest, some corrupt
- After receiving a message, honest router flips a coin
  - With probability P_f routes to the next member on the path
  - With probability 1- P_f sends directly to the recipient

What Does Anonymity Mean?

- Degree of anonymity:
  - Ranges from absolute privacy to provably exposed
- Beyond suspicion
  - The observed source of the message is no more likely to be the actual sender than anybody else
- Probable innocence
  - Probability <50% that the observed source of the message is the actual sender

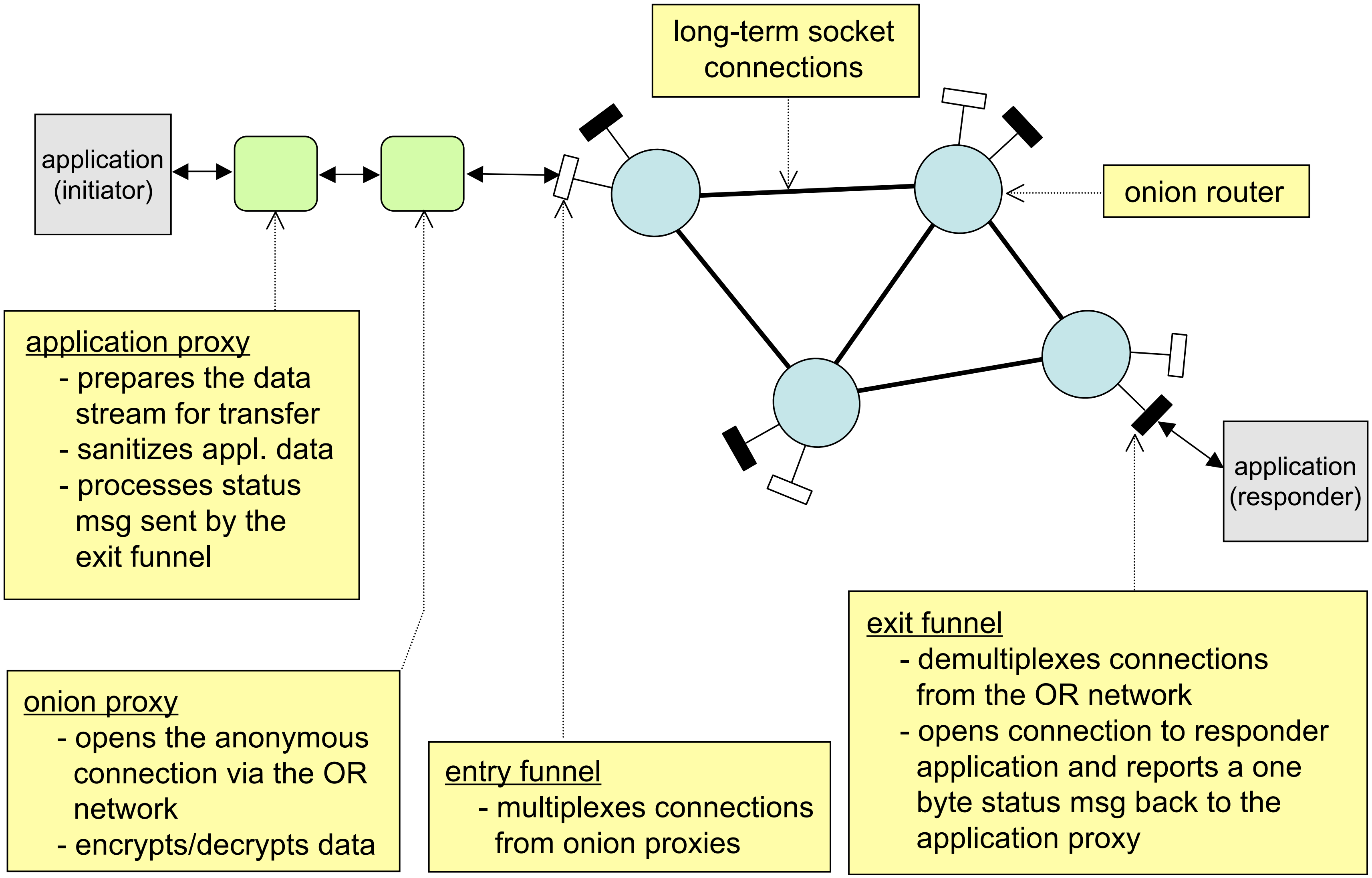
Guaranteed by Crowds if there are sufficiently few corrupt routers

- Possible innocence
  - Non-trivial probability that the observed source of the message is not the actual sender

A real-time MIX network – Onion routing

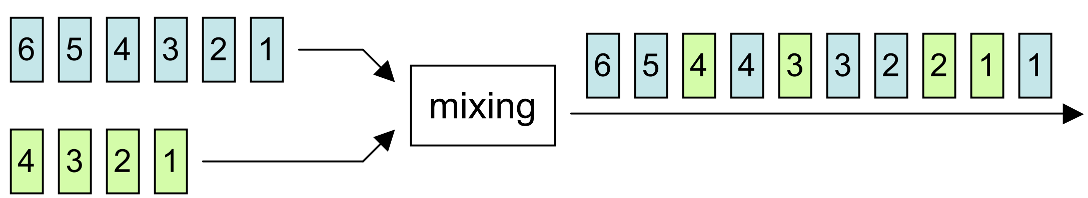
- general purpose infrastructure for anonymous communications over a public network (e.g., Internet)
- supports several types of applications (HTTP, FTP, SMTP, rlogin, telnet, …) through the use of application specific proxies
- operates over a (logical) network of onion routers
  - onion routers are real-time Chaum MIXes (messages are passed on nearly in real-time → this may limit mixing and weaken the protection!)
  - onion routers are under the control of different administrative domains → makes collusion less probable
- anonymous connections through onion routers are built dynamically to carry application data
- distributed, fault tolerant, and secure

Overview of OR architecture



OR network setup and operation

- long-term socket connections between “neighboring” onion routers are established → links
- neighbors on a link setup two DES keys using the Station-to-Station protocol (one key in each direction)
- several anonymous connections are multiplexed on a link
  - connections are identified by a connection ID (ACI)
  - an ACI is unique on a link, but not globally
- every message is fragmented into fixed size *cells* (48 bytes)
- cells are encrypted with DES in OFB mode (null IV)
  - optimization: if the payload of a cell is already encrypted (e.g., it carries (part of) an onion) then only the cell header is encrypted
- cells of different connections are mixed, but order of cells of each connection is preserved



Anonymous connection setup

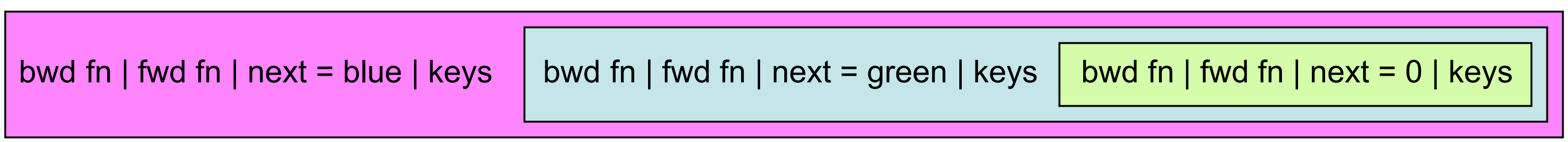
- the application is configured to connect to the application proxy instead of the real destination
- upon a new request, the application proxy
  - decides whether to accept the request
  - opens a socket connection to the onion proxy
  - passes a *standard structure* to the onion proxy
  - standard structure contains
    - application type (e.g., HTTP, FTP, SMTP, …)
    - retry count (number of times the exit funnel should retry connecting to the destination)
    - format of address that follows (e.g., NULL terminated ASCII string)
    - address of the destination (IP address and port number)
  - waits response from the exit funnel before sending application data

Anonymous connection setup (2)

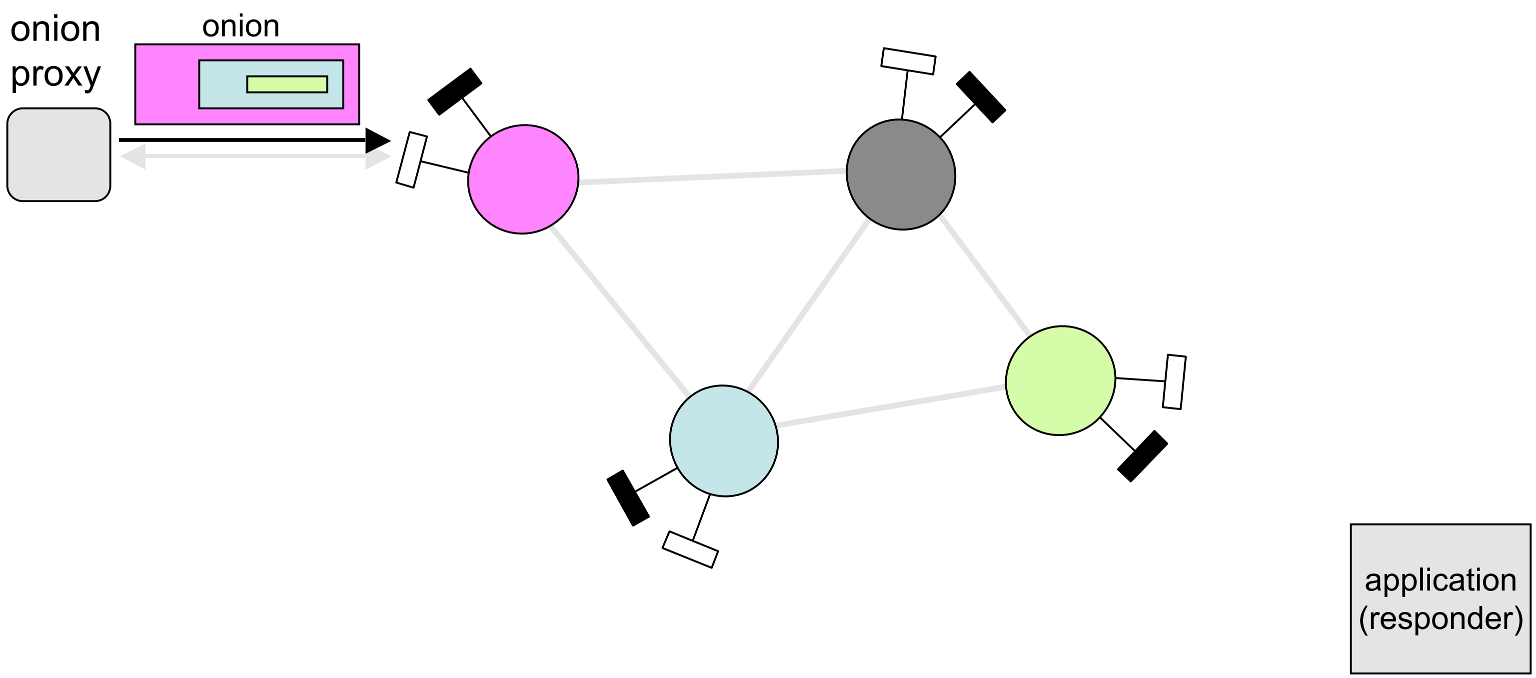
- upon reception of the standard structure, the onion proxy
  - decides whether to accept the request
  - establishes an anonymous connection through some randomly selected onion routers by constructing and passing along an *onion*
  - sends the standard structure to the exit funnel of the connection
  - after that, it relays data back and forth between the application proxy and the connection
- upon reception of the standard structure, the exit funnel
  - tries to open a socket connection to the destination
  - it sends back a one byte status message to the application proxy through the anonymous connection (in backward direction)
  - if the connection to the destination cannot be opened, then the anonymous connection is closed
  - otherwise, the application proxy starts sending application data through the onion proxy, entry funnel, anonymous connection, and exit funnel to the destination

Onions

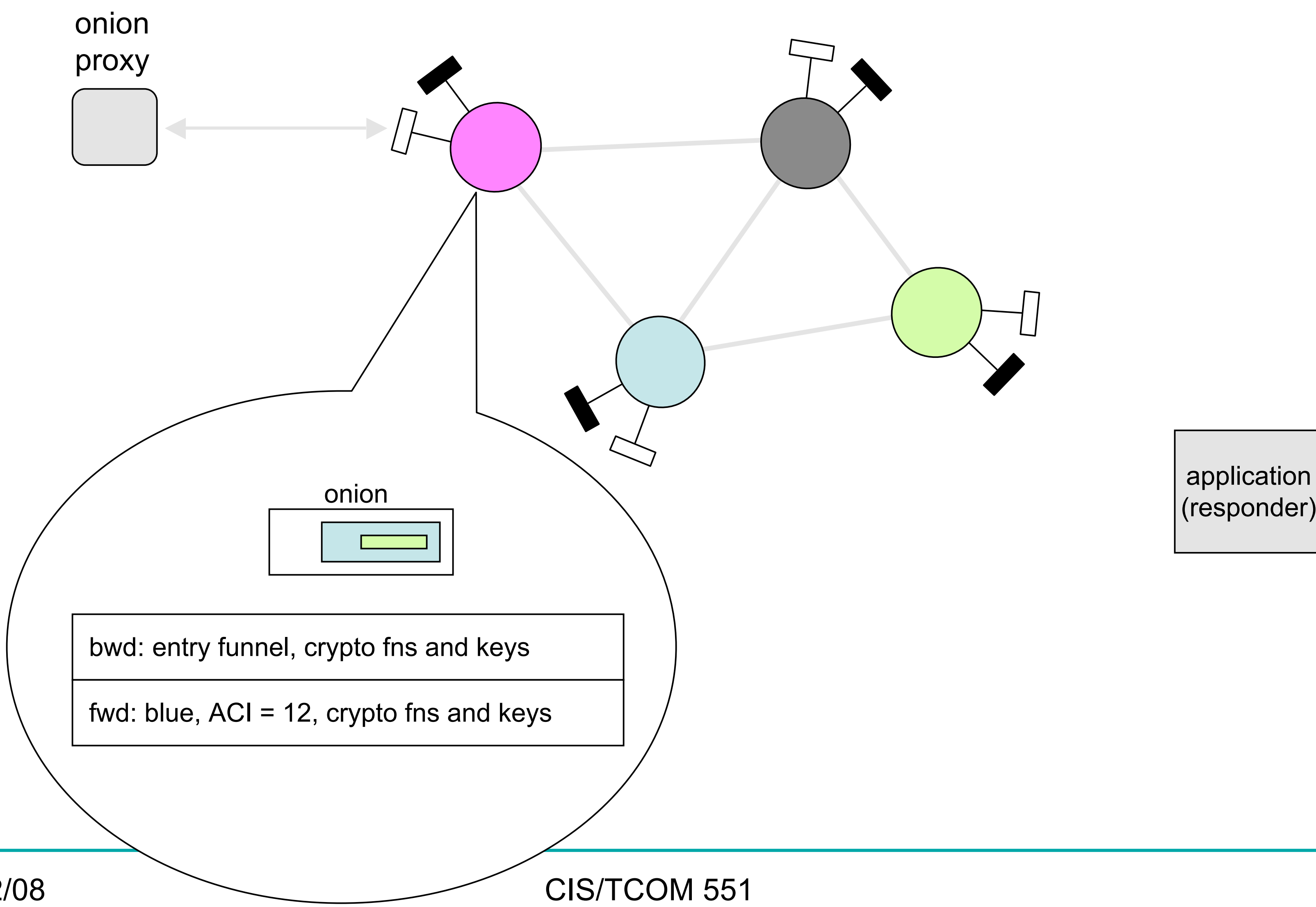
- an onion is a multi-layered data structure
- it encapsulates the route of the anonymous connection within the OR network
- each layer contains
  - backward crypto function (DES-OFB, RC4)
  - forward crypto function (DES-OFB, RC4)
  - IP address and port number of the next onion router
  - expiration time
  - key seed material
    - used to generate the keys for the backward and forward crypto functions
- each layer is encrypted with the public key of the onion router for which data in that layer is intended



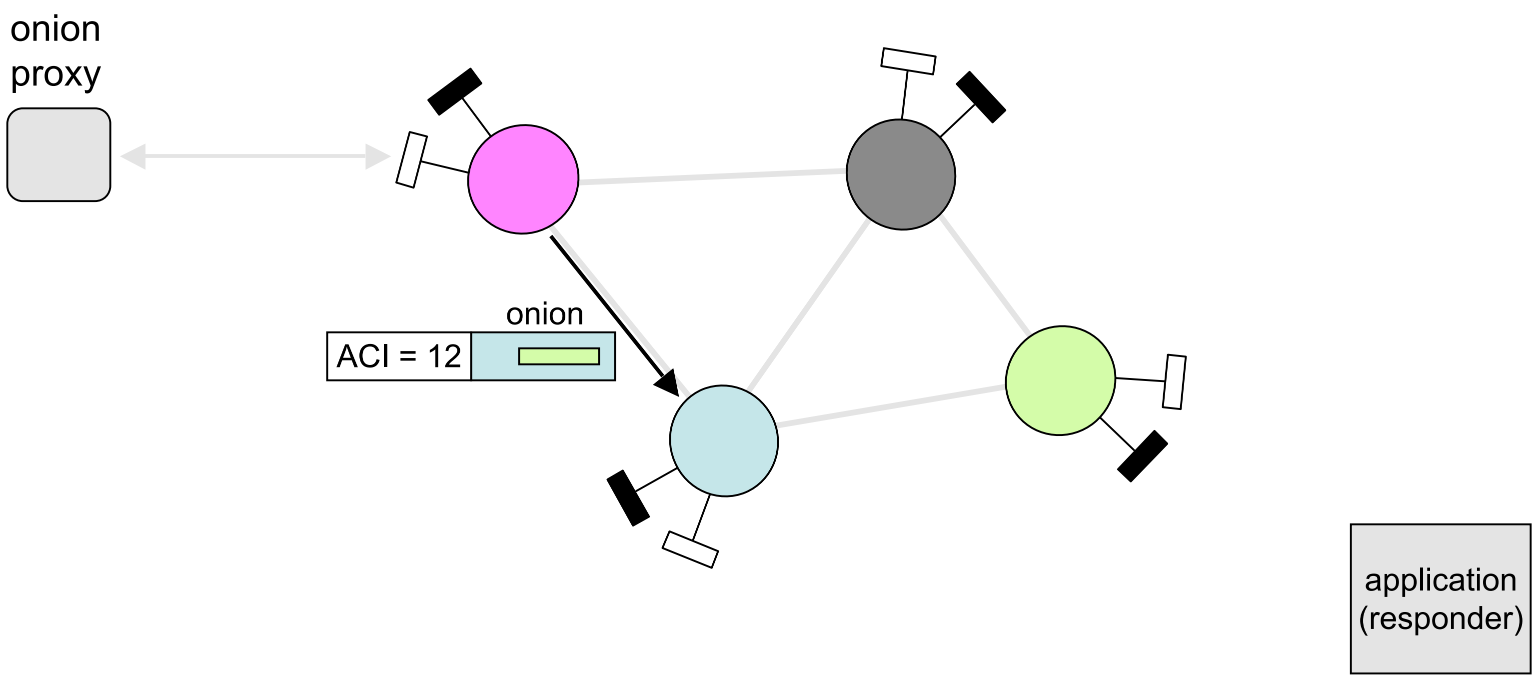
Anonymous connection setup



Anonymous connection setup



Anonymous connection setup



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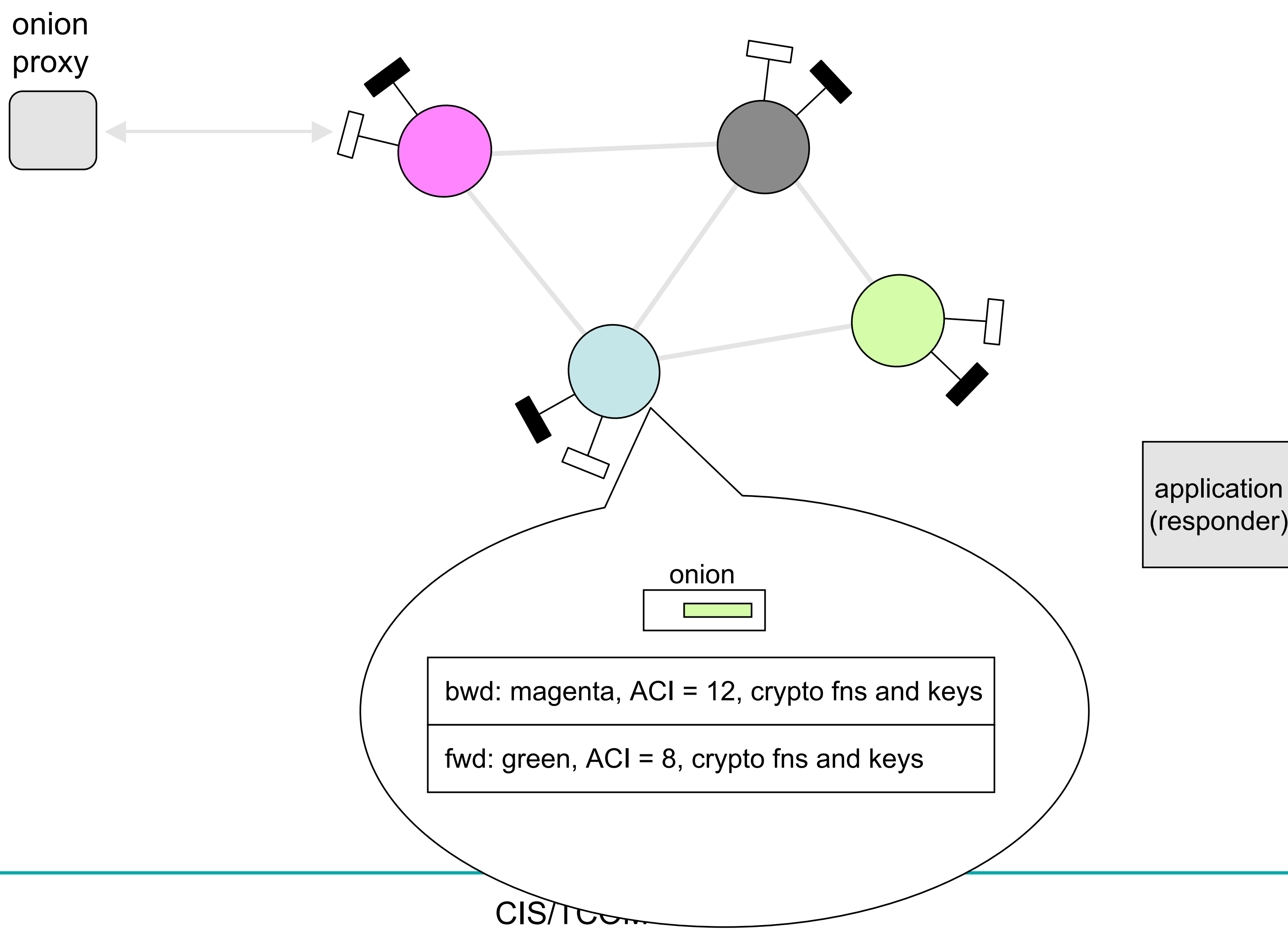
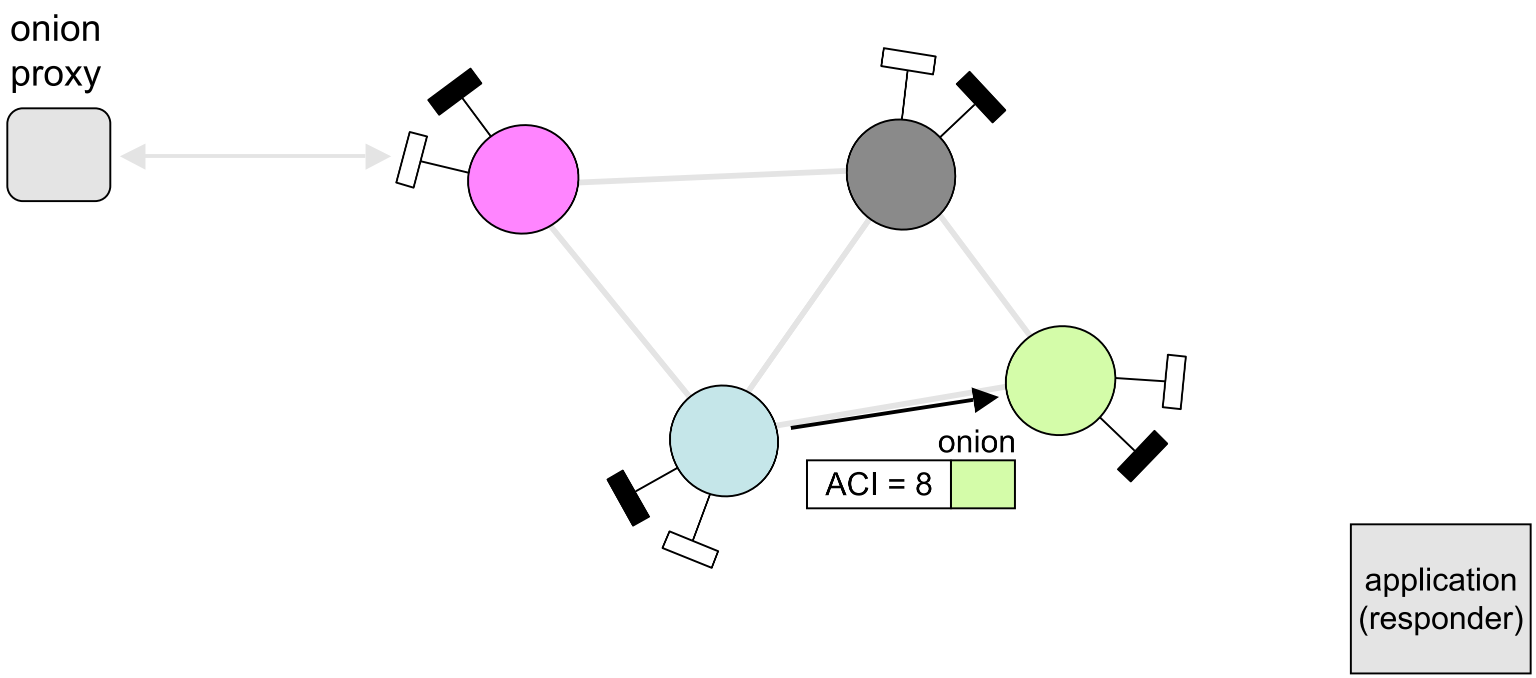
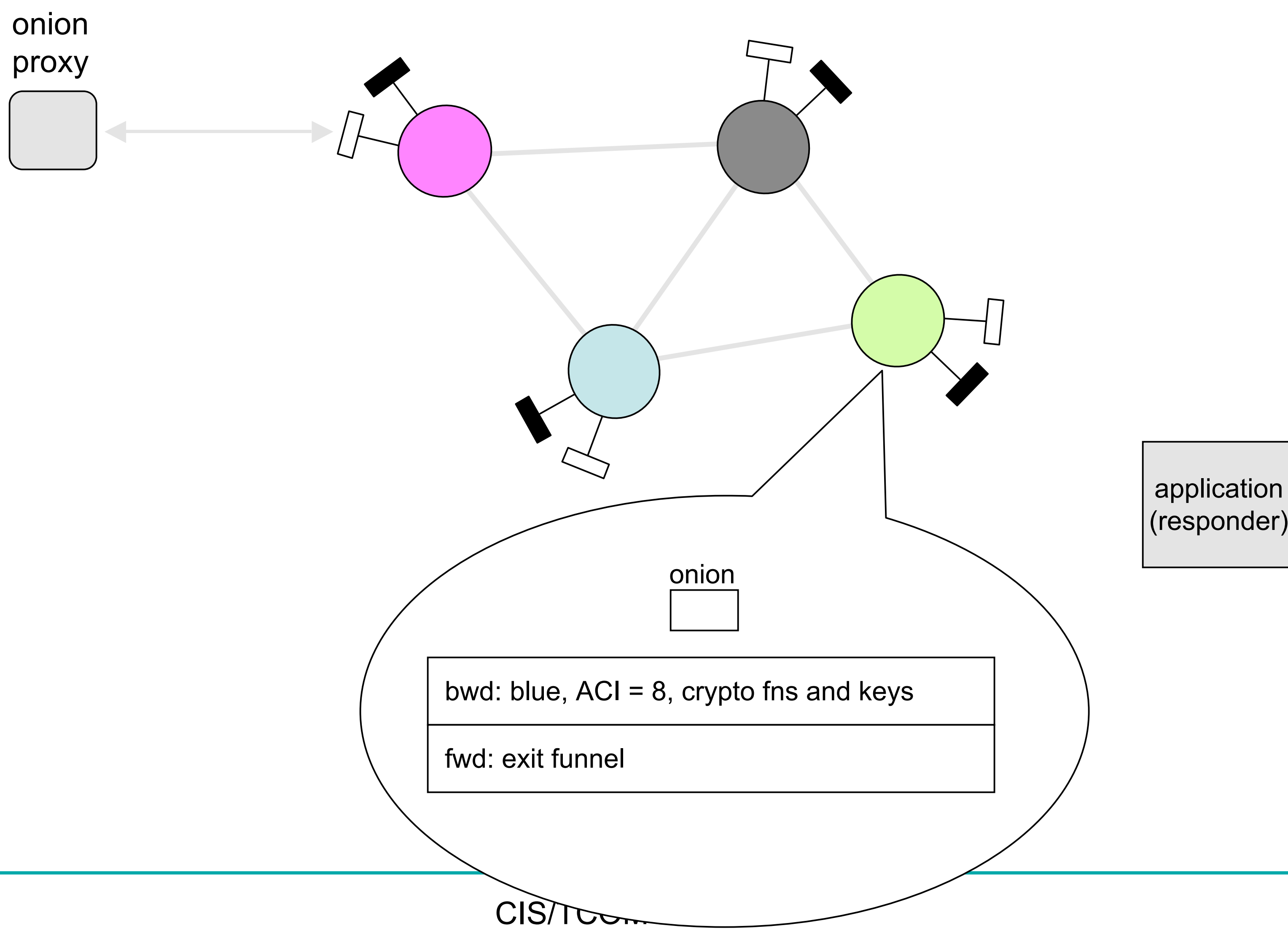


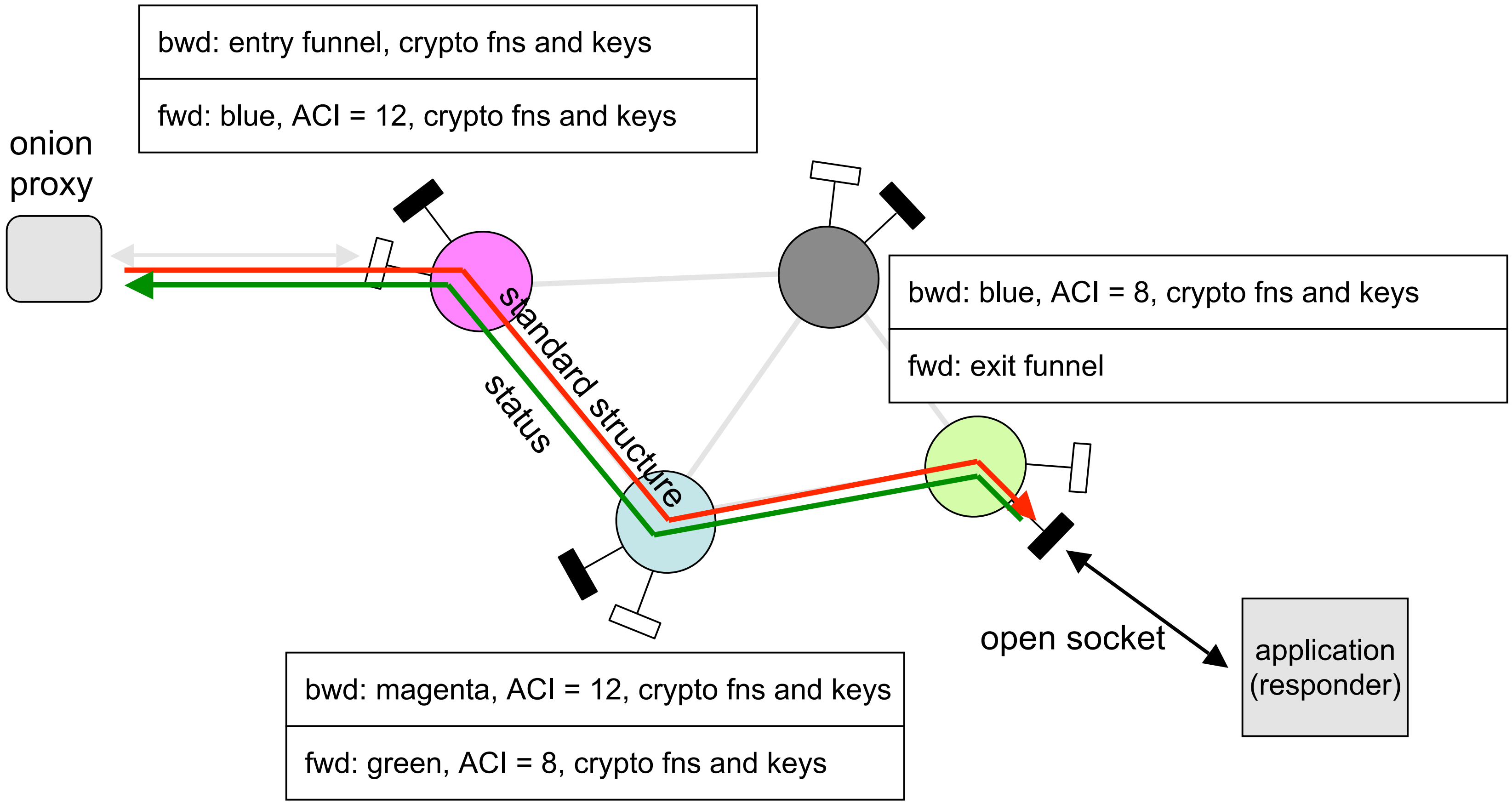
Anonymous connection setup



Anonymous connection setup



Anonymous connection setup



Data movement

- forward direction
  - the onion proxy adds all layers of encryption as defined by the anonymous connection
  - each onion router on the route removes one layer of encryption
  - responder application receives plaintext data
- backward direction
  - the responder application sends plaintext data to the last onion router of the connection (due to sender anonymity it doesn't even know who is the real initiator application)
  - each onion router adds one layer of encryption
  - the onion proxy removes all layers of encryption